Digital Video Broadcasting (DVB);
Next Generation broadcasting system to Handheld, physical layer specification (DVB-NGH)

DVB Document A160

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DVB®
Digital Video
Broadcasting

Contents

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Foreword

This final draft European Standard (EN) has been produced by Joint Technical Committee (JTC) Broadcast of the European Broadcasting Union (EBU), Comité Européen de Normalisation ELECtrotechnique (CENELEC) and the European Telecommunications Standards Institute (ETSI), and is now submitted for the ETSI standards One-step Approval Procedure.

NOTE: The EBU/ETSI JTC Broadcast was established in 1990 to co-ordinate the drafting of standards in the specific field of broadcasting and related fields. Since 1995 the JTC Broadcast became a tripartite body by including in the Memorandum of Understanding also CENELEC, which is responsible for the standardization of radio and television receivers. The EBU is a professional association of broadcasting organizations whose work includes the co-ordination of its members' activities in the technical, legal, programme-making and programme-exchange domains. The EBU has active members in about 60 countries in the European broadcasting area; its headquarters is in Geneva.

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The Digital Video Broadcasting Project (DVB) is an industry-led consortium of broadcasters, manufacturers, network operators, software developers, regulatory bodies, content owners and others committed to designing global standards for the delivery of digital television and data services. DVB fosters market driven solutions that meet the needs and economic circumstances of broadcast industry stakeholders and consumers. DVB standards cover all aspects of digital television from transmission through interfacing, conditional access and interactivity for digital video, audio and data. The consortium came together in 1993 to provide global standardisation, interoperability and future proof specifications.

Proposed national transposition dates	
Date of latest announcement of this EN (doa):	3 months after ETSI publication
Date of latest publication of new National Standard or endorsement of this EN (dop/e):	6 months after doa
Date of withdrawal of any conflicting National Standard (dow):	6 months after doa

1 Scope

The present document describes the next generation transmission system for digital terrestrial and hybrid (combination of terrestrial with satellite transmissions) broadcasting to handheld terminals. It specifies the entire physical layer part from the input streams to the transmitted signal. This transmission system is intended for carrying Transport Streams or generic data streams feeding linear and non-linear applications like television, radio and data services.

The scope is as follows:

- it gives a general description of the transmission system for digital terrestrial and hybrid broadcasting to handheld terminals;
- it specifies the digitally modulated signal in order to allow compatibility between pieces of equipment developed by different manufacturers. This is achieved by describing in detail the signal processing at the modulator side, while the processing at the receiver side is left open to different implementation solutions. However, it is necessary in this text to refer to certain aspects of reception.

The standard consists of four parts each covering a different structure of the transmitter network:

• Base profile (profile I):	Covers sheer terrestrial transmission with single and multi-aerial structures that require only a single aerial and tuner on the receiver side
• MIMO profile (profile II):	Covers sheer terrestrial transmission with multi-aerial structures on both ends. Terminals suitable for this profile need to employ two tuners as well.
• Hybrid profile (profile III):	Covers a combination of terrestrial and satellite transmissions that requires only a single tuner on receiver side.

Hybrid MIMO profile (profile IV): Covers a combination of terrestrial and satellite transmission requiring a double aerial and tuner set-up on receiver side. Once again, a part of the configurations can be handled by profile II receivers, other configurations require a special hybrid MIMO receiver.The present document describes the base profile in full detail. For the MIMO and hybrid profiles only the differences between those and the base profile are described, i.e. additional functional blocks and parameter settings and those that are permitted in the MIMO or hybrid profile. The hybrid MIMO profile is not formulated solely as a list of differences to the other three profiles. Instead it defines how previously-described elements are to be combined to provide hybrid MIMO transmission, as well as introducing profile-specific information. Functional blocks and settings that are the same as in the base profile are not described again, but can be derived from the base profile.

2 References

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the reference document (including any amendments) applies.

Referenced documents which are not found to be publicly available in the expected location might be found at http://docbox.etsi.org/Reference.

NOTE: While any hyperlinks included in this clause were valid at the time of publication ETSI cannot guarantee their long term validity.

2.1 Normative references

The following referenced documents are necessary for the application of the present document.

[1]	ISO/IEC 13818-1: "Information technology - Generic coding of moving pictures and associated audio information: Systems".
[2]	ETSI EN 300 468: "Digital Video Broadcasting (DVB); Specification for Service Information (SI) in DVB systems".
[3]	ETSI TS 102 606-1 and -2: "Digital Video Broadcasting (DVB); Generic Stream Encapsulation (GSE) Protocol".
[4]	ETSI TS 102 992: "Digital Video Broadcasting (DVB); Structure and modulation of optional transmitter signatures (T2-TX-SIG) for use with the DVB-T2 second generation digital terrestrial television broadcasting system".

2.2 Informative references

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1]	ETSI EN 302 755: "Digital Video Broadcasting (DVB); Frame structure channel coding and modulation for a second generation digital terrestrial television broadcasting system (DVB-T2)"
[i.2]	ETSI EN 102 831: "Digital Video Broadcasting (DVB); Implementation guidelines for a second generation digital terrestrial television broadcasting system (DVB-T2)"
[i.3]	ETSI EN 102 773: " Digital Video Broadcasting (DVB); Modulator Interface (T2-MI) for a second generation digital terrestrial television broadcasting system (DVB-T2)"
[i.4]	NGH System Specification

3 Definitions, symbols and abbreviations

3.1 Definitions

In this entire specification, the following terms and definitions apply:

0xkk: digits 'kk' should be interpreted as a hexadecimal number

active cell: OFDM cell carrying a constellation point for L1 signalling or a PLP

anchor PLP: An anchor PLP is the PLP of a PLP cluster which shall be always decoded in order for the receiver to play-out the service partially or fully, i.e. with part or all of the service components respectively. The anchor PLP carries the in-band signalling for all PLPs (anchor and associated PLPs) in the given PLP cluster.

aP1 symbol: additional P1 symbol that carries S3 and S4 signalling fields and is located right after the P1 symbol

associated PLP: An associated PLP is a PLP associated with an anchor PLP in a given PLP cluster. The associated PLP carries a service component of the full service carried by the given PLP cluster. An associated PLP does not carry in-band signalling, which in turn is carried by the anchor PLP of the given PLP cluster.

auxiliary stream: sequence of cells carrying data of as yet undefined modulation and coding, which may be used for future extensions or as required by broadcasters or network operators

baseband frame: set of K_{bch} bits which form the input to one FEC encoding process (BCH and LDPC encoding)

common PLP: PLP having one slice per logical frame, transmitted after the L1-POST signalling, which may contain data shared by multiple PLPs

data PLP: PLP of type 1, type 2, type 3 or type 4

data cell: OFDM cell which is not a pilot or tone reservation cell (may be an unmodulated cell in the frame closing symbol)

data symbol: OFDM symbol in an NGH frame which is not a P1 or P2 symbol

div: integer division operator, defined as:

$$x \text{ div } y = \left\lfloor \frac{x}{y} \right\rfloor$$

dummy cell: OFDM cell carrying a pseudo-random value used to fill the remaining capacity not used for L1 signalling, PLPs or Auxiliary Streams

elementary block of frames: block of not more than four NGH frames belonging to the same NGH profile and building an instance of the frame type sequence of the related NGH system (e.g. SISO/SISO/SISO/MIMO)

elementary period: time period which depends on the system bandwidth and is used to define the other time periods in the NGH system

FEC block: set of N_{cells} OFDM cells carrying all the bits of one LDPC FECFRAME

FEC chain: The part of the BICM block reaching from the FEC encoder to the I/Q component interleaver (if present, otherwise to the cell interleaver) for PLPs and the cell mapper for L1 signalling

FECFRAME: set of N_{ldpc} (16 200 or 4 320) bits from one LDPC encoding operation

FEF interval:

FEF part: part of the super-frame between two NGH frames which contains FEFs

NOTE: A FEF part always starts with a P1 symbol. The remaining contents of the FEF part should be ignored by a DVB-NGH receiver and may contain further P1 symbols.

FFT size: nominal FFT size used for a particular mode, equal to the active symbol period T_s expressed in cycles of the elementary period T

for i=0..xxx-1: the corresponding signalling loop is repeated as many times as there are elements of the loop

NOTE: If there are no elements, the whole loop is omitted.

frame closing symbol: OFDM symbol with higher pilot density used at the end of an NGH frame in certain combinations of FFT size, guard interval and scattered pilot pattern

hybrid combining:

Im(x): imaginary part of x

input stream: A stream of data for an ensemble of services delivered to the end users by the NGH system. An input stream may be structured into a number of logical channel groups defined in accordance with the service requirements.

interleaving frame: unit over which dynamic capacity allocation for a particular PLP is carried out, made up of an integer, dynamically varying number of FEC blocks and having a fixed relationship to the logical frames

NOTE: The interleaving frame may be mapped directly to one logical frame or may be mapped to multiple logical frames. It may contain one or more TI blocks.

L1-POST signalling: signalling carried in the beginning of a logical frame providing more detailed L1 information about the NGH system and the PLPs, L1-POST signalling consists of a configurable and a dynamic part

L1-POST configurable signalling: L1 signalling consisting of parameters which remain the same for the duration of one logical super-frame

L1-POST dynamic signalling: L1 signalling consisting of parameters which may change from logical frame to logical frame within the same logical super-frame

L1-PRE signalling: signalling carried in the P2 symbols having a fixed size, coding and modulation, including basic information about the NGH system as well as information needed to decode the L1-POST signalling

NOTE: Some fields of the L1-PRE signalling may change from one NGH frame to another within the same NGH super-frame, for example, L1_POST_DELTA for logical channel types B and C.

logical channel: A flow of logical super-frames for the transport of data over a given repeating pattern of RF channels in the NGH system.

logical channel group: A group of logical channels such that the NGH frames which carry the logical frames of one logical channel in the group are separable in time from the NGH frames which carry the logical frames of another logical channel in the same group.

logical frame: A container with a fixed number of QAM cells and a given structure for the carriage of data into the NGH frames.

logical super-frame: An entity composed of a number of logical frames. The logical configurable signalling information may only change at the boundaries of two logical super-frames.

MIXO: either MISO or MIMO

MIXO group: group (1 or 2) to which a particular transmitter in a MIXO network belongs, determining the type of processing which is performed to the data cells and the pilots

NOTE: Signals from transmitters in different groups will combine in an optimal manner at the receiver.

mod: modulo operator, defined as:

$$x \bmod y = x - y \left\lfloor \frac{x}{y} \right\rfloor$$

NGH frame: fixed physical layer TDM frame that is further divided into variable size sub-slices. An NGH frame starts with one P1 symbol, followed for a part of the frame types by an additional P1 (aP1) symbol and always one or multiple P2 symbols carrying the L1-PRE information

NGH profile: subset of all configurations allowed by the related part of the present document

NOTE:The present document defines a base profile, a MIMO profile, a hybrid profile and a hybrid MIMO profile.

NGH system: second generation terrestrial broadcast system whose input is one or more TS, GCS or GSE streams and whose output is an RF signal

NOTE: The NGH system:

- means an entity where one or more PLPs are carried, in a particular way, within a DVB-T2 signal on one or more frequencies;
- is unique within the NGHnetwork and it is identified with NGH_system_id. Two NGH systems with the same NGH_system_id and network_id have identical physical layer structure and configuration, except for the cell_id which may differ;
- is transparent to the data that it carries (including Transport Streams and services).

NGH_SYSTEM_ID: this 16-bit field identifies uniquely the NGH system within the DVB network (identified by NETWORK_ID)

NGH super-frame: set of NGH frames consisting of a particular number of consecutive NGH frames

NOTE: A super-frame may in addition include FEF parts.

NGH signal: signal belonging to a particular profile of the present document (NGH base profile, NGH MIMO profile, NGH hybrid profile or NGH hybrid MIMO profile profile) and consisting of the related NGH frame types, including any FEF parts

NOTE: A composite RF signal may be formed comprising two or more NGH signals, where each NGH signal has the others in its FEF parts

nn_D: digits 'nn' should be interpreted as a decimal number

normal symbol: OFDM symbol in an NGH frame which is not a P1, an aP1, a P2 or a frame closing symbol

OFDM cell: modulation value for one OFDM carrier during one OFDM symbol, e.g. a single constellation point

OFDM symbol: waveform Ts in duration comprising all the active carriers modulated with their corresponding modulation values and including the guard interval

P1/aP1 signalling: signalling carried by the P1/aP1 symbol(s) and used to identify the basic mode of the NGH frame, the aP1 symbol is present only in a part of the defined frame types

P1 symbol: fixed pilot symbol that carries S1 and S2 signalling fields and is located in the beginning of the frame within each RF-channel

NOTE: The P1 symbol is mainly used for fast initial band scan to detect the NGH signal, its timing, frequency offset and FFT-size.

P2 symbol: pilot symbol located right after P1 (aP1 if present) with the same FFT size and guard interval as the data symbols

NOTE: The number of P2 symbols depends on the FFT-size. The P2 symbols are used for fine frequency and timing synchronization as well as for initial channel estimate. P2 symbols carry L1-PRE signalling information and may also carry data.

PLP_ID: this 8-bit field identifies uniquely a PLP within the NGH system, identified with the NGH_system_id

NOTE: The same PLP_ID may occur in one or more logical frames of the logical super-frame.

PLP cluster: A PLP cluster is the set of up to 4 PLPs that carry a particular TS input stream or a collection of GS input streams with the same STREAM_GROUP_ID

physical layer pipe: physical layer TDM channel that is carried by the specified sub-slices

NOTE: A PLP may carry one or multiple services.

Re(x): real part of x

reserved for future use: not defined by the present document but may be defined in future revisions of the present document

NOTE: Further requirements concerning the use of fields indicated as "reserved for future use" are given in clause **Error! Reference source not found.**.

slice: set of all cells of a PLP which are mapped to a particular NGH frame

NOTE: A slice may be divided into sub-slices.

sub-slice: group of cells from a single PLP, which before frequency interleaving, are allocated to active OFDM cells with consecutive addresses over a single RF channel

time interleaving block (TI-block): set of cells within which time interleaving is carried out, corresponding to one use of the time interleaver memory

type 1 PLP: PLP having one slice per logical frame, transmitted before any type 2 PLPs

type 2 PLP: PLP having two or more sub-slices per logical frame, transmitted after any type 1 PLPs

type 3 PLP: PLP carrying O-LSI data and being located at the end of the logical frame

type 4 PLP: PLP carrying H-LSI data and being transmitted via hierarchical modulation over a dedicated type 1 PLP

uninterleaved logical frame: Collection of all PLPs whose cells are transmitted in a sequence of interleaved logical frames

3.2 Symbols

For the purposes of the present document, the following symbols apply:

$\oplus$	Exclusive OR / modulo-2 addition operation
Δ	Guard interval duration
λ_i	LDPC codeword bits
η_{MOD}, $\eta_{\mathrm{MOD}}(i)$	number of transmitted bits per constellation symbol (for PLP *i*)
$\mathbf{1}_{TR}$	Vector containing ones at positions corresponding to reserved carriers and zeros elsewhere

$a_{m,l,p}$	Frequency-Interleaved cell value, cell index *p* of symbol *l* of NGH frame *m*
A_{CP}	Amplitude of the continual pilot cells
A_{P2}	Amplitude of the P2 pilot cells
A_{SP}	Amplitude of the scattered pilot cells
ß	Power imbalance parameter for two antennas transmission
b_i	
$b_{BS,j}$	Bit j of the BB scrambling sequence
$b_{e,do}$	Output bit of index *do* from substream *e* from the bit-to-sub-stream demultiplexer
$c(x)$	BCH codeword polynomial
C/N	Carrier-to-noise power ratio
C/N+I	Carrier-to-(Noise+Interference) ratio
$C_{bal}(m)$	Value to which bias balancing cells are set for NGH frame *m*
$C'_{bal}(m)$	Desired value for the bias balancing cells in NGH frame *m* to approximately balance the bias
$C_{bias}(m)$	Bias in coded and modulated L1 signalling for NGH frame *m* before applying the L1-ACE algorithm
$C_{bias\_L1\_ACE}(m)$	Value of $C_{bias}(m)$ after being reduced by the correction to be applied by the bias balancing cells
$C'_{bias}(m)$	Residual bias in the modulated cells of the L1 signalling for NGH frame *m* after correction by the L1-ACE algorithm
C_{data}	Number of active cells in one normal symbol
C_{FC}	Number of active cells in one frame closing symbol
$C_{im}(m)$	Imaginary part of $C_{bias}(m)$
$C_{L1\_ACE\_MAX}$	Maximum correction applied by L1-ACE algorithm
C_{LSI}	Number of local service cells
$c_{m,l,k}$	Cell value for carrier *k* of symbol *l* of NGH frame *m*
C_{P2}	Number of active cells in one P2 symbol
$c\_post_{m,i}$	Correction applied to cell *i* of coded and modulated L1-post signalling in NGH frame *m* by L1-ACE algorithm
$c\_pre_{m,i}$	Correction applied to cell *i* of coded and modulated L1-pre signalling in NGH frame *m* by L1-ACE algorithm
$C_{re}(m)$	Real part of $C_{bias}(m)$
$CSS_{S1,i}$	Bit *i* of the S1 modulation sequence
$CSS_{S2,i}$	Bit *i* of the S2 modulation sequence
C_{tot}	Number of active cells in one NGH frame
D_{BC}	Number of cells occupied by the bias balancing cells and the associated dummy cells
D_i	Number of cells mapped to each NGH frame of the Interleaving Frame for PLP *i*
$D_{i,aux}$	Number of cells carrying auxiliary stream i in the NGH frame
$D_{i,common}$	Number of cells mapped to each NGH frame for common PLP *i*
$D_{i,j}$	Number of cells mapped to each NGH frame for PLP *i* of type *j*
$D(k)$	Delay as an integer multiple of logical frames for reading k-th IU in each TI-block
D_{L1}	Number of OFDM cells in each NGH frame carrying L1 signalling
D_{L1post}	Number of OFDM cells in each NGH frame carrying L1-post signalling

D_{L1pre}	Number of OFDM cells in each NGH frame carrying L1-pre signalling
$d_{n,s,r,\mathrm{q}}$	Time Interleaver input / cell interleaver output for cell *q* of FEC block *r* of TI-block *s* of Interleaving Frame *n*
D_{PLP}	Number of OFDM cells in each NGH frame available to carry PLPs
$d_{r,\mathrm{q}}$	Cell interleaver output for cell *q* of FEC block *r*
D_{x}	Difference in carrier index between adjacent scattered-pilot-bearing carriers
D_{y}	Difference in symbol number between successive scattered pilots on a given carrier
$e_{m,l,p}$	Cell value for cell index *p* of symbol *l* of NGH frame *m* following MISO processing
f_{c}	Centre frequency of the RF signal
$f\_post_{m,i}$	Cell *i* of coded and modulated L1-post signalling for NGH frame *m*
$f'\_post_{m,i}$	Cell *i* of L1-post signalling for NGH frame *m* after modification by the L1-ACE algorithm
$f\_pre_{m,i}$	Cell *i* of coded and modulated L1-pre signalling for NGH frame *m*
$f'\_pre_{m,i}$	Cell *i* of L1-post signalling for NGH frame *m* after modification by the L1-ACE algorithm
f_{q}	Constellation point normalized to mean energy of 1
$fq_{r,q}$	Data cell input to the cell interleaver from the FEC block of incremental index r within each TI-block
f_{Sh}	Frequency shift for parts 'B' and 'C' applied to the P1 and aP1 symbols
Φ_{k}	eSFN predistortion term
$g(x)$	BCH generator polynomial
$g_1(x), g_2(x), \ldots, g_{12}(x)$	polynomials to obtain BCH code generator polynomial
g_{q}	OFDM cell value after constellation rotation and I/Q component interleaving
$H(p)$	Frequency interleaver permutation function, element *p*
$H_0(p)$	Frequency interleaver permutation function, element *p*, for even symbols
$H_1(p)$	Frequency interleaver permutation function, element *p,* for odd symbols
I_{JUMP}, $I_{\mathrm{JUMP}}(i)$	Frame interval: difference in frame index between successive NGH frames to which a particular PLP is mapped (for PLP *i*)
i_j	BCH codeword bits which form the LDPC information bits
j	$\sqrt{-1}$
k'	Carrier index relative to the centre frequency
k	OFDM carrier index
K_{bch}	number of bits of BCH uncoded Block
Kbit	1 024 bits
K_{ext}	Number of carriers added on each side of the spectrum in extended carrier mode
$K_{L1\_PADDING}$	Length of L1_PADDING field
K_{ldpc}	number of bits of LDPC uncoded Block
K_{max}	Carrier index of last (highest frequency) active carrier
K_{min}	Carrier index of first (lowest frequency) active carrier
K_{mod}	Modulo value used to calculate continual pilot locations
$k_{\mathrm{p1}}(i)$	Carrier index *k* for active carrier *i* of the P1 symbol

K_{post}	Length of L1-post signalling field including the padding field
$K_{post\_ex\_pad}$	Number of information bits in L1-post signalling excluding the padding field
K_{pre}	Information length of the L1-pre signalling
K_{sig}	Number of signalling bits per FEC block for L1-pre- or L1-post signalling
K_{total}	Number of OFDM carriers
l	Index of OFDM symbol within the NGH frame
L	Maximum value of real or imaginary part of the L1-post constellation
L_{data}	Number of data symbols per NGH frame including any frame closing symbol but excluding P1 and P2
L_{F}	Number of OFDM symbols per NGH frame excluding P1
$L(i)$	Number of cells for the common or type 1 PLP i in the logical frame
$L_{\mathrm{im}}(m)$	Correction level for the imaginary part of the L1-post used in the L1-ACE algorithm
L_{normal}	Number of normal symbols in a NGH frame, i.e. not including P1, P2 or any frame closing symbol
$L_{\mathrm{pre}}(m)$	Correction level for the L1-pre used in the L1-ACE algorithm
$L_r(q)$	Cell interleaver permutation function for FEC block *r* of the TI-block
$L_{\mathrm{re\_post}}(m)$	Correction level for the real part of the L1-post used in the L1-ACE algorithm
L_{TI}	
m	NGH frame number
M_{aux}	Number of auxiliary streams in the NGH system
Mbit	2^{20} bits
Mbit/s	Data rate corresponding to 10^6 bits per second
M_{common}	Number of common PLPs in the NGH system
m_i	BCH message bits
M_{IR}	Number of incremental redundancy parity bits
M_j	Number of PLPs of type *j* in the NGH system
M_{large}	
M_{max}	Sequence length for the frequency interleaver
M_{small}	
MSS_DIFF_i	Bit *i* of the differentially modulated P1 sequence
MSS_SCR_i	Bit *i* of the scrambled P1 modulation sequence
MSS_SEQ_i	Bit *i* of the overall P1 modulation sequence
M_{TI}	Maximum number of cells required in the TI memory
n	Interleaving Frame index within the super-frame
N_{bch}	number of bits of BCH coded Block
N_{bch_parity}	Number of BCH parity bits
$N_{BLOCKS\_IF}(n)$, $N_{BLOCKS\_IF}(i,n)$	Number of FEC blocks in Interleaving Frame *n* (for PLP *i*)
$N_{BLOCKS\_IF\_MAX}$	Maximum value of $N_{BLOCKS\_IF}(n)$
N_{cells}, $N_{\mathrm{cells}}(i)$	Number of QAM cells per FEC Block (for PLP *i*)
N_D	Number of rotation dimensions
N_{data}	Number of data cells in an OFDM symbol (including any unmodulated data cells in the frame closing symbol)
N_{dummy}	Number of dummy cells in the NGH frame
N_{EBF}	Number of EBFs in a super-frame
N_F	Number of NGH frames in an EBF

$N_{FEC\_TI}\,(n,s)$	Number of FEC blocks in TI-block s of Interleaving Frame n
$N_{\mathrm{FEC\_TI\_MAX}}$	
N_{FEF}	Number of FEF parts in one super-frame
N_{FFT}	FFT size
N_{group}	Number of bit-groups for BCH shortening
$N_{\mathrm{im}}(m)$	Number of L1-post cells available for correction by the imaginary part of the L1-ACE algorithm
N_{IU}	Number of interleaver units, into which each FEC block is partitioned
N_{K}	Number of TFS cycles, over which a FEC block is time-interleaved
N_{L1}	Total number of bits of L1 signalling
N_{L1_mult}	Number of bits that is a guaranteed factor of N_{post}
N_{large}	
N_{ldpc}	number of bits of LDPC-coded block
N_{ldpc2}	Number of bits of extended 4k LDPC-coded block
$N_{\mathrm{ldpc\_parity\_ext\_4k}}$	Number of parity bits of the extended 4k LDPC code
$N_{MOD\_per\_Block}$	Number of modulated cells per FEC block for the L1-post signalling
N_{MOD_Total}	Total number of modulated cells for the L1-post signalling
$N_{\mathrm{MUs,PLP}}$	Required number of memory units in TI for one PLP
N_{P2}	Number of P2 symbols per NGH frame
N_{pad}	Number of BCH bit-groups in which all bits will be padded for L1 signalling
N_{PN}	Length of the frame-level PN sequence
N_{post}	Length of punctured and shortened LDPC codeword for L1-post signalling
$N_{post\_FEC\_Block}$	Number of FEC blocks for the L1-post signalling
N_{post_temp}	Intermediate value used in L1 puncturing calculation
$N_{\mathrm{pre}}(m)$	Number of L1-PRE cells available for correction by the L1-ACE algorithm
n_{pre}	Number of L1-PRE sub-blocks, which are carried by consecutive NGH frames
N_{punc}	Number of LDPC parity bits to be punctured
N_{punc_groups}	Number of parity groups in which all parity bits are punctured for L1 signalling
N_{punc_temp}	Intermediate value used in L1 puncturing calculation
N_{r}	Number of bits in Frequency Interleaver sequence
N_{R}	Number of rows of I/Q component interleaving matrix
$N_{\mathrm{re}}(m)$	Total number of L1 cells available for correction by the real part of the L1-ACE algorithm
$N_{\mathrm{re\_post}}(m)$	Number of L1-post cells available for correction by the real part of the L1-ACE algorithm
N_{res}	Total number of reserved bits of L1 signalling to be used for bias balancing
N_{RF}	Number of RF channels used in a TFS system
$N_{\mathrm{sub\text{-}slices}}$	Number of sub-slices per NGH frame on each RF channel
$N_{\mathrm{sub\text{-}slices\_total}}$	Number of sub-slices per NGH frame across all RF channels
$N_{sub\text{-}streams}$	Number of sub-streams produced by the bit-to-sub-stream demultiplexer
N_{NGH}	Number of NGH frames in a super-frame

N_{TI}	Number of TI-blocks in an Interleaving Frame
p	Data cell index within the OFDM symbol in the stages prior to insertion of pilots and dummy tone reservation cells
p^1_j	j-th parity bit group in the first parity part for additional parity generation of L1-POST
p^2_j	j-th parity bit group in the second parity part for additional parity generation of L1-POST
$P(r)$	Cyclic shift value for cell interleaver in FEC block *r* of the TI-block
$p_1(t)$	Time-domain complex baseband waveform for the P1 signal
$p_{1A}(t)$	Time-domain complex baseband waveform for part 'A' of the P1 signal
P_I, $P_I(i)$	Number of NGH frames to which each Interleaving Frame is mapped (for PLP *i*)
p_i	LDPC parity bits
pn_l	Frame level PN sequence value for symbol *l*
q	Index of cell within coded and modulated LDPC codeword
Q_{ldpc}	Code-rate dependent LDPC constant
Q_{ldpc1}	Number of parity bit groups in the first parity part for additional parity generation
Q_{ldpc2}	Number of parity bit groups in the second parity part for additional parity generation
r	FEC block index within the TI-block
$R_{eff\_ext\_4k\_LDPC\_1\_2}$	Effective code rate of 4k LDPC with nominal rate 1/2
R_{eff_post}	Effective code rate of L1-post signalling
r_i	BCH remainder bits
r_i	QPSK output symbols of L1-PRE
R'_i	Value of element *i* of the frequency interleaver sequence following bit permutations
R'_i	Value of element i of the frequency interleaver sequence prior to bit permutations
$r_{l,k}$	Pilot reference sequence value for carrier *k* in symbol *l*
R_{RQD}	Complex phasor representing constellation rotation angle
s	Index of TI-block within the Interleaving Frame
S_{CHE}	Number of additional symbols needed for channel estimation when hopping between RF signals
S_i	Element i of cell interleaver PRBS sequence
S_{tuning}	Number of symbols needed for tuning when hopping between RF signals
T	Elementary time period for the bandwidth in use
t_c	Column-twist value for column *c*
T_{EBF}	Duration of one EBF
T_F	Duration of one NGH frame
T_{FEF}	Duration of one FEF part
T_P	Time interleaving period
T_{P1}	Duration of the P1 symbol
T_{P1A}	Duration of part 'A' of the P1 signal
T_{P1B}	Duration of part 'B' of the P1 signal
T_{P1C}	Duration of part 'C' of the P1 signal
T_S	Total OFDM symbol duration
T_{SF}	Duration of one super-frame

T_U	Active OFDM symbol duration
u_i	Parity-interleaver output bits
v_i	column-twist-interleaver output bits
w_i	Bit *i* of the symbol-level reference PRBS
$\lfloor x \rfloor$	Round towards minus infinity: the most positive integer less than or equal to x
$\lceil x \rceil$	Round towards plus infinity: the most negative integer greater than or equal to x
x^*	Complex conjugate of x
X_j	The set of bits in group *j* of BCH information bits for L1 shortening
$x_{m,l,p}$	Complex cell modulation value for cell index *p* of OFDM symbol *l* of NGH frame *m*
$y_{i,q}$	Bit *i* of cell word *q* from the bit-to-cell-word demultiplexer
z_q	Constellation point prior to normalization
π_p	Permutation operator defining parity bit groups to be punctured for L1 signalling
$\pi^1{}_p$	Puncturing pattern order of first parity bit grou
$\pi^2{}_p$	Puncturing pattern order of second parity bit group
π_s	Permutation operator defining bit-groups to be padded for L1 signalling

The symbols *s*, *t*, *i*, *j, k* are also used as dummy variables and indices within the context of some clauses or equations.

In general, parameters which have a fixed value for a particular PLP for one processing block (e.g. NGH frame, Interleaving Frame, TI-block as appropriate) are denoted by an upper case letter. Simple lower-case letters are used for indices and dummy variables. The individual bits, cells or words processed by the various stages of the system are denoted by lower case letters with one or more subscripts indicating the relevant indices.

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

16-QAM	Uniform 16-ary Quadrature Amplitude Modulation
256-QAM	Uniform 256-ary Quadrature Amplitude Modulation
64-QAM	Uniform 64-ary Quadrature Amplitude Modulation
ACM	Adaptive Coding and Modulation
BB	BaseBand
BBF	BaseBand Frame
BCH	Bose-Chaudhuri-Hocquenghem multiple error correction binary block code
BICM	Bit Interleaved Coding and Modulation
BPSK	Binary Phase Shift Keying
CBR	Constant Bit Rate
CCM	Constant Coding and Modulation
CI	Cell Interleaver
CRC	Cyclic Redundancy Check
D	Decimal notation

DAC	Digital to Analogue Conversion
DBPSK	Differential Binary Phase Shift Keying
DFL	Data Field Length
DNP	Deleted Null Packets
DVB	Digital Video Broadcasting project
DVB-NGH	DVB-NGH System

NOTE: Specified in EN 303 105

EBF	Elementary Block of NGH Frames
EBU	European Broadcasting Union
EIT	Event Information Table
eSFN	Enhanced Single Frequency Network
eSM	Enhanced Spatial Multiplexing
FEC	Forward Error Correction
FEF	Future Extension Frame
FFT	Fast Fourier Transform
FIFO	First In First Out
GCS	Generic Continuous Stream
GF	Galois Field
GS	Generic Stream
GSE	Generic Stream EncapsulationHEX Hexadecimal notation
H-LSI	Hierarchical modulation Local Service Insertion
IF	Intermediate Frequency
IFFT	Inverse Fast Fourier Transform
IS	Interactive Services
ISCR	Input Stream Clock Reference
ISI	Input Stream Identifier
ISSY	Input Stream SYnchronizer
ISSYI	Input Stream SYnchronizer Indicator
IU	Interleaving Unit
L-PLP	Local service PLP
LC	Logical Channel
LDPC	Low Density Parity Check (codes)
LF	Logical Frame
LS	Local Service
LSB	Least Significant Bit
LSI	Local Service Insertion
MFN	Multi-Frequency Network
MIMO	Multiple Input Multiple Output

NOTE: Meaning multiple transmitting and multiple receiving antennas.

MIS	Multiple Input Stream
MISO	Multiple Input, Single Output

NOTE: Meaning multiple transmitting antennas but one receiving antenna.

MODCOD	MODulation and CODing
MODCODTID	MODulation, CODing and Time Interleaving Depth
MPEG	Moving Pictures Experts Group
MSB	Most Significant Bit

NOTE: In DVB-NGH the MSB is always transmitted first.

MSS	Modulation Signalling Sequences
MU	Memory Unit
NA	Not Applicable
NPD	Null-Packet Deletion
NU-64-QAM	Non-uniform 64-ary Quadrature Amplitude Modulation
NU-256-QAM	Non-uniform 256-ary Quadrature Amplitude Modulation
OFDM	Orthogonal Frequency Division Multiplex
O-LSI	Orthogonal Local Service Insertion
O-UPL	Original User Packet Length
PAPR	Peak to Average Power Ratio
PCR	Programme Clock Reference
PER	(MPEG TS) Packet Error Rate
PH	Phase Hopping
PID	Packet IDentifier
PLL	Phase Locked Loop
PLP	Physical Layer Pipe
PRBS	Pseudo Random Binary Sequence
QEF	Quasi Error Free
QPSK	Quaternary Phase Shift Keying
RF	Radio Frequency
R-PLP	Regional service PLP
SDT	Service Description Table
SFN	Single Frequency Network
SIS	Single Input Stream
SISO	Single Input Single Output

NOTE: Meaning one transmitting and one receiving antenna.

SM	Spatial Multiplexing
SoAC	Sum of AutoCorrelation
TDI	Time De-Interleaving
TDM	Time Division Multiplex
TF	Time/Frequency
TFS	Time-Frequency Slicing
TS	Transport Stream
TSPS	Transport Stream Partial Stream
TSPSC	Transport Stream Partial Stream Common
TTO	Time To Output
TV	TeleVision
UP	User Packet
UPL	User Packet Length
VCM	Variable Coding and Modulation
VMIMO	Virtual MIMO

Part I: Base profile

4 System overview and architecture

The top level NGH system architecture is represented in figure 1. Services or service components are embedded into Transport Streams (TS) [1] or Generic Streams [3] which are then carried in individual Physical Layer Pipes (PLPs). The PLPs are mapped onto logical channels (LC), which are then transmitted in NGH physical frames according to a fixed schedule. The sequence of NGH frames carrying a logical channel may be transmitted over a single or multiple RF frequencies.

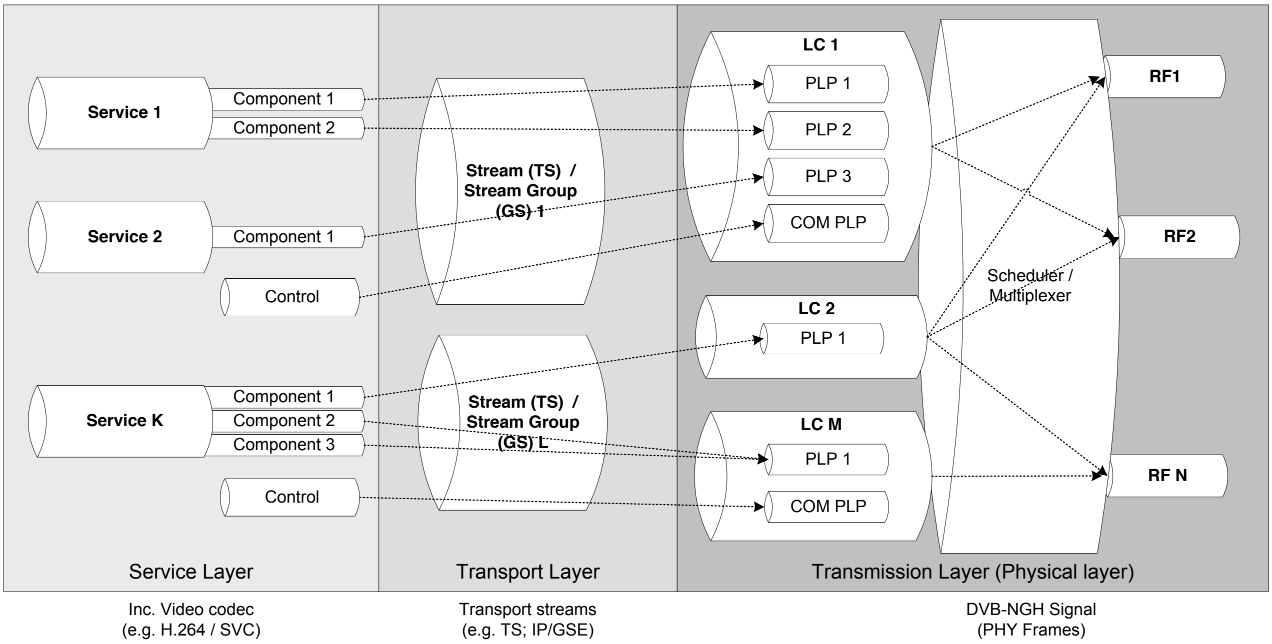


Figure 1: Top level NGH system architecture

This specification is restricted to the physical layer. The overall system specification is described in [i.4].

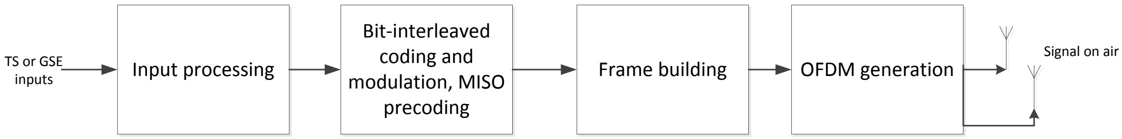


Figure 2: High level NGH phy layer block diagram

Figure 2 shows the NGH physical layer block diagram which comprises four main building blocks. The input to the NGH system shall consist of one or more logical data streams. One logical data stream is carried by one Physical Layer Pipe (PLP). The PLP specific input processing stage (see also figures 3-5) comprises the mode adaptation as well as the encapsulation into baseband frames (BBFs). BBFs are then FEC encoded and interleaved at FEC frame level as well as - after being modulated onto a QAM constellation – interleaved on component, time and frequency level (figure 6). The frame building block (figure 7) comprises the generation of the NGH logical and physical frames which are finally OFDM modulated and transmitted on a single or multiple (in case of TFS usage) RF frequencies (figure 9). In the latter case the system is designed to allow continuous reception of a service with a single tuner.

4.1 Input processing

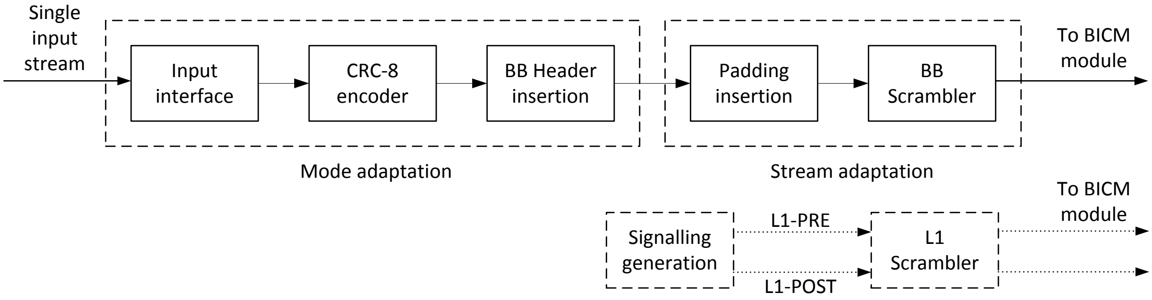


Figure 3: System block diagram, input processing module for input mode 'A' (single PLP)

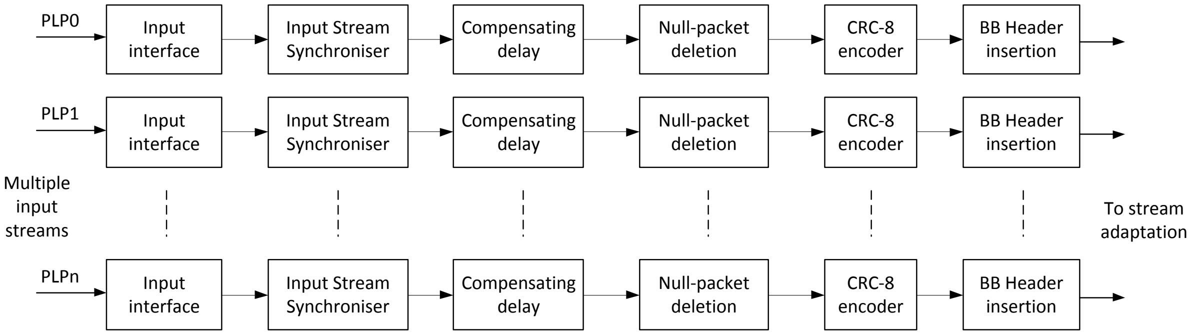


Figure 4: Mode adaptation for input mode 'B' (multiple PLP)

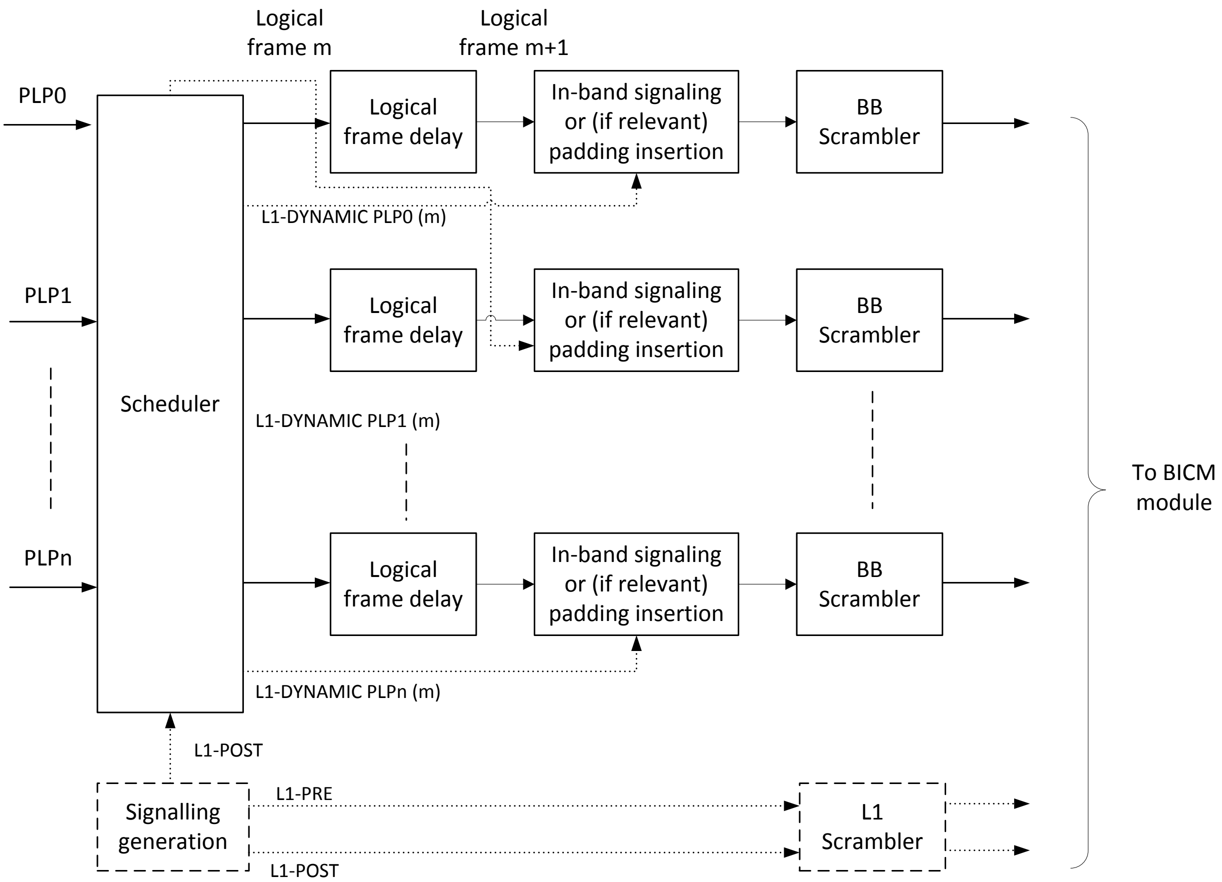


Figure 5: Stream adaptation for input mode 'B' (multiple PLP)

4.1.1 Mapping of input streams onto PLPs

Input data in the form of TS packets or GS data (e.g. GSE packets) enter the NGH system in parallel with one input stream per PLP branch. For input streams that are Transport Streams TS data that is common to all TSs and time synchronized are extracted (and replaced by null packets in the original stream) and put into a dedicated partial transport for common data (TSPSC) stream that is transmitted in a common PLP. Each input TS may also be split into several partial transport streams (TSPS), which are transmitted in dedicated data PLPs. This may be used to send e.g. service components in different PLPs, with potentially a different robustness using e.g. a different MODCODTID per service component.

The sum of the coded bit rates (i.e. bit rates at the output of the LDPC encoder) of a PLP cluster shall not exceed 12 Mbit/s. A PLP cluster is the set of up to 4 PLPs that carry a particular TS input stream or a collection of GS input streams with the same stream group id.

4.1.2 Encapsulation into baseband frames

The input data is put into the payload of baseband frames (BBFs), which also have a header with a fixed size for a given mode. The BBFs may also have some padding in the end. The first BBF in each *interleaving frame* (see below) may carry some in-band signaling (IBS) of type A (dynamic info used to find PLPs) and type B (ISSY and other info to help the receiver with e.g. buffer management).

4.2 Bit-interleaved coding and modulation, MISO precoding

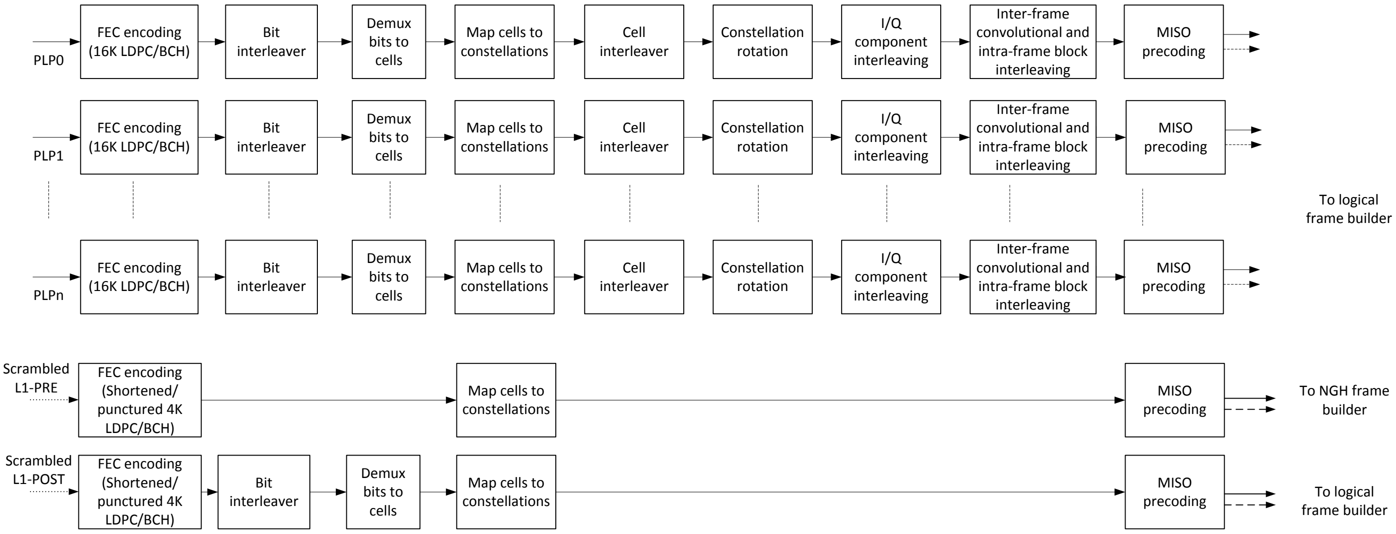


Figure 6: Bit interleaved coding and modulation (BICM), MISO precoding

4.2.1 FEC encoding and interleaving inside a FEC block

The BBFs are FEC-encoded using a BCH code followed by a 16200 bit (16K) LDPC code (4K for L1-PRE and L1-POST). Bit interleaving is applied within the FEC block. Bit interleaved FEC block bits are demultiplexed to cell words and mapped to constellations points (cells). Cell interleaving is then applied within each FEC block.

4.2.2 Modulation and component interleaving

The constellation is either non-rotated (QPSK, 16-QAM, 64-QAM or 256-QAM), 2D-rotated (QPSK, 16-QAM, 64-QAM) or 4D-rotated (QPSK). For QPSK, 2D- and 4D-rotations are only specified for a subset of the code rates. In addition there are non-uniform constellations (NU-64-QAM and NU-256-QAM). NU-64-QAM is either non-rotated or 2D-rotated. NU-256-QAM is never rotated. When constellation rotation is used, an I/Q component interleaver is applied to the rotated real and imaginary constellation components (two components with 2D rotation and four components with 4D rotation) whereby the components become separated over the time interleaving depth, increasing the time diversity. When TFS is used, these components also appear on different RF channels, in order to increase frequency diversity.

4.2.3 Formation of interleaving frames for each PLP

An integer number of FEC blocks from each PLP are collected into an interleaving frame. This number of FEC blocks in one interleaving frame can be different from PLP to PLP and over time and so is signaled for each PLP. An interleaving frame is either transmitted in one logical frame or is spread across more than one logical frame thereby providing more time diversity for the FEC blocks of the PLP.

4.2.4 Time interleaving (inter-frame convolutional interleaving plus intra-frame block interleaving)

The time interleaver block spreads the cells of the FEC blocks for each interleaving frame over one or multiple logical frames (LFs). Interleaving over multiple LFs is achieved by convolutional interleaving referred to as inter-frame interleaving. With or without inter-frame interleaving, the FEC block cells are shuffled within each logical frame by block interleaving, which is referred to as intra-frame interleaving. Both convolutional and block interleaving together constitute the time interleaving. Its configuration is PLP-specific. If the time interleaver is configured to carry out exclusively intra-frame interleaving and no inter-frame interleaving, then the time interleaving becomes a sheer block interleaving.

4.3 Frame building, frequency interleaving

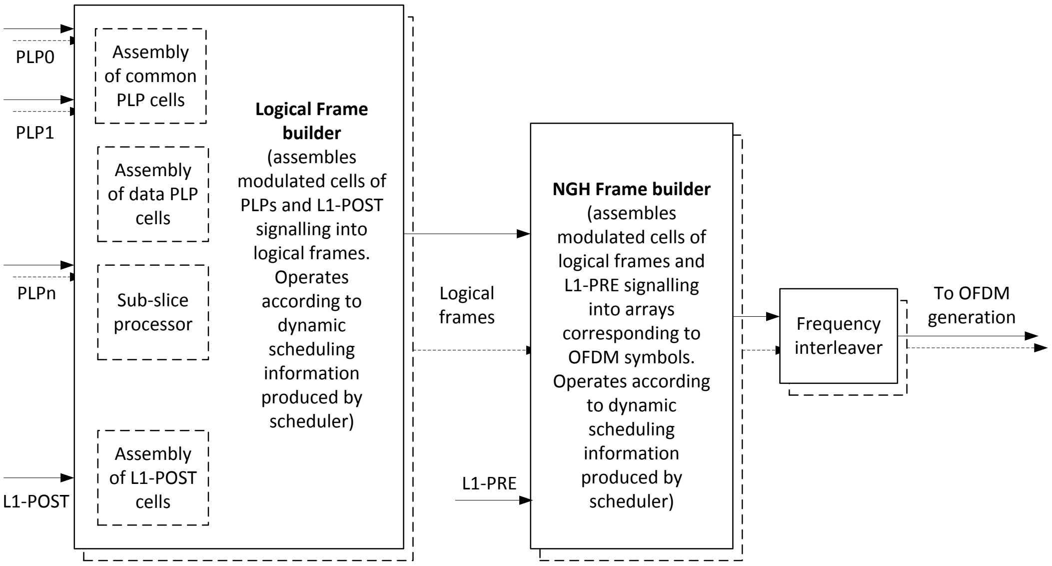


Figure 7: Frame builder

4.3.1 Formation of logical frames

The collection of time interleaving blocks that are simultaneously output are assembled in a logical frame. The result of the time interleaving process is a sequence of cells for each PLP in each logical frame. The cell sequences of the different PLPs in the logical frame are then combined in such a way that the cells of one PLP are followed by the cells of the second PLP etc. With M PLPs we obtain therefore a vector with cells arranged in M slices (“bursts”), i.e. with one slice per PLP. In addition subslicing may be performed, by which each slice is divided into L smaller parts or sub-slices which are then distributed in time over the logical frame duration. A logical channel (see clause 4.1.9) is derived from a sequence of logical frames. With logical channel type D each slice is divided into the same number (one or more) of sub-slices per RF channel used by the logical channel. In this case we have a matrix with one column per RF channel containg the logical frame cells of that RF channel.

A logical frame consists of the following elements (in order):

- L1-POST signalling
- Common PLPs
- Type 1 PLPs (optionally with type 4 H-LSI PLPs hierarchically modulated on top of type 1 PLPs)
- Type 2 PLPs
- Auxiliary streams
- Dummy cells
- Type 3 PLPs (O-LSI)

The L1-POST is mandatory. All of the other elements of the logical frame are optional, except that at least one of the PLP types 1, 2 and 3 must appear in each LF. For LC type D the L1-POST is put in the beginning of all the columns of the above-mentioned matrix. PLP type 4 only occurs in the presence of PLP type 1 which it hierarchically modulates.

Each LF in a logical super-frame of a given logical channel has a constant number of cells. The number of logical frames in a logical super-frame of a given logical channel is signalled in L1-POST. Because of bit rate variations of the incoming streams the resulting number of FEC block cells may vary somewhat across logical frames. The statistical multiplexing of video streams can (and should) be organized in a way that the total number of cells remains constant rather than the total bit rate. However, this process is not perfect and it is in general impossible to guarantee a constant number of FEC block cells per collection window. After cell interleaving this means that there will also be some variations in the number of cells per LF. In order to compensate for this a number of auxiliary stream cells and/or dummy cells are added each LF just before the occurrence of any PLPs of Type 3 (or in the end of the LF when there are no Type 3 PLPs). The number of auxiliary stream cells and/or dummy cells is signalled in the L1-POST dynamic signalling.

At this point of the chain we have thus a sequence of logical frames, each containing a vector (matrix instead of a vector in the case of logical channel type D) of cells. There is not yet any organization into OFDM symbols and carriers applied and the logical frame/logical channel concept does not require this – each logical frame is just a vector of cells (matrix with logical channel type D). Each logical frame within the current logical super-frame has the same size and the sequence of such logical frames and logical super-frames constitutes a logical channel (LC). For LCs of types A, B and C this is fully valid - in this case the receiver is able to receive and demodulate all cells of a logical channel (in LC type C using TFS/frequency hopping) since all cells of the LC always appear sequentially. However, for LC type D the LF is composed of N parallel vectors, when TFS is performed over N RF channels, which means that the logical channel in this case exists simultaneously on multiple RF channels. The L1-POST signalling also appears for each of the parallel vectors.

In this case (LC type D) the N vectors of the matrix are processed via a “shift-and-fold procedure”, which ensures that the sub-slices of each PLP are spread in time in a way which allows a single tuner to receive the relevant PLP (or PLPs) via frequency hopping.

4.3.2 Mapping of logical frames onto NGH frames

The way the logical channel cells are transmitted is that they use cell capacity in one or more RF channels, each having an OFDM-modulated NGH signal. The NGH signal is composed of NGH frames, potentially with FEF gaps between them, divided into OFDM symbols and OFDM cells. See also figure 8.

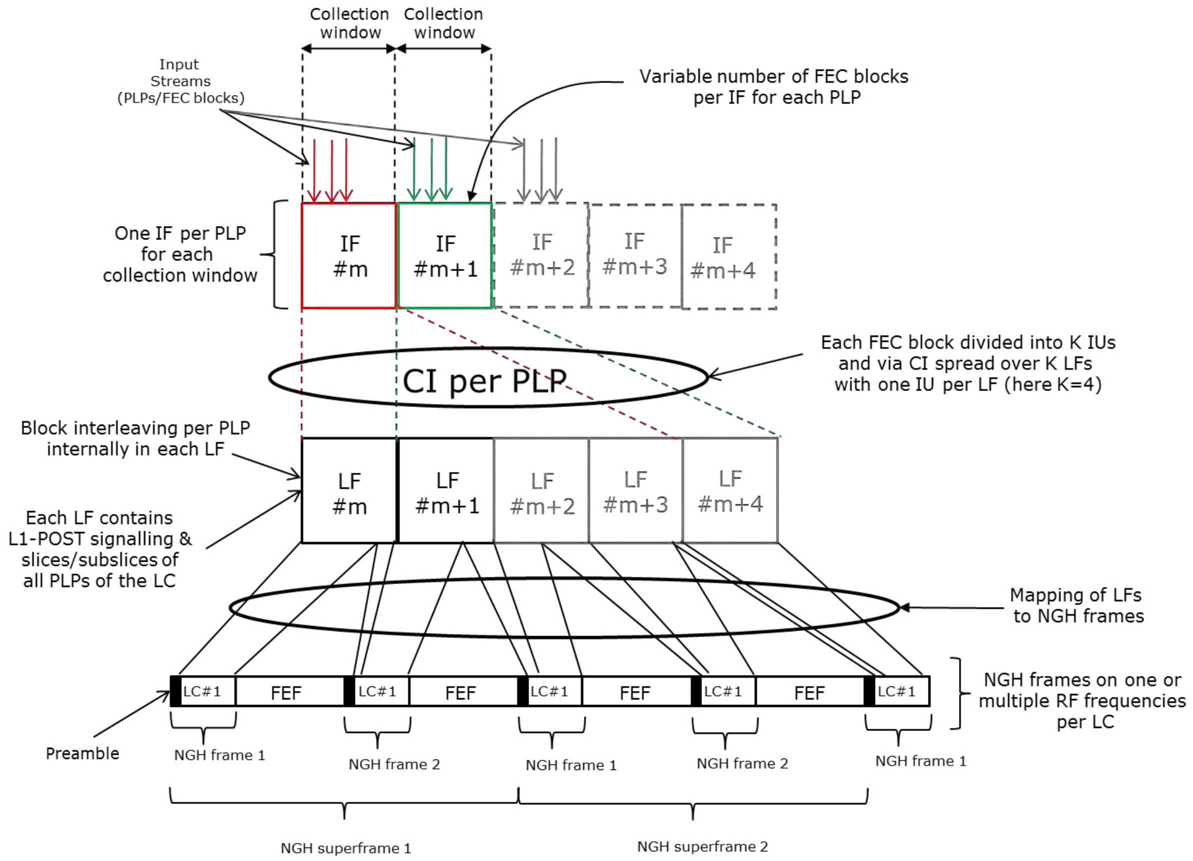


Figure 8: Mapping of input stream FEC blocks to interleaving frames, logical frames and NGH frames

Each physical layer frame begins with a P1 symbol (accompanied in some cases by an additional P1 symbol (aP1)), followed by a number of P2 symbols, depending on the applied FFT size In certain combinations of FFT size, guard interval and pilot patterns, the frame shall end with a frame closing symbol. In addition to this, the physical frame incorporates scattered pilots and continual pilots amongst the data cells, which are the capacity units or the “payload” of the NGH frames used to carry the logical channel cells. Data cells are those cells in the NGH frame that are not occupied by any of the other components (P1/aP1, P2 pilots, frame closing pilots, scattered pilots, continual pilots, reserved tones) and therefore are available for transport of logical channel cells.

A set of NGH frames constitutes a super-frame. In a super-frame the NGH frames may be allocated to different logical frames and may also use different frame types (SISO, MISO), as indicated by the L1-PRE signalling of the NGH frame, which signals the composition of the NGH frame.

The RF bandwidth, FFT size, guard interval (GI) and pilot pattern (PPx) may be different on different RF channels. In addition, on a given RF channel the pilot pattern may be unique for all frames carrying a particular logical channel. For a given PLP the MODCODTID (modulation/constellation, channel coding and time interleaving depth) is however given by the logical channel and not by the RF channel. Please note again that the logical frames do not have anything to do with OFDM – they are just fixed-length (potentially parallel in case of LC type D) sequences of cells with no OFDM symbols or carriers involved!

A given RF channel has a fixed, well-determined cell capacity (cells per second) to carry LC cells. When more than one logical channel is used, the NGH frames used to carry a particular logical channel also have a fixed, well-determined capacity. A set of RF channels has a total cell capacity that is the sum of the cell capacities of the individual RF channels. This total cell capacity may be used by any number of logical channels and the cell rate of each logical channel must exactly match the available cell rate capacity of the NGH frames allocated to carry this logical channel.

A constant cell capacity is allocated to each LC, which may be distributed in any way among the RF channels, as long as continuous reception is possible with a single tuner. Reception with a single tuner is enabled through a particular minimum distance in time of the relevant symbols on the different RF channels. This distance shall be equal or larger than 5 ms (rounded up to the nearest number of OFDM symbols) plus additional time for channel estimation to finalise and restart (additional $2(D_Y-1)$ symbols) where D_y is a parameter of the scattered pilot pattern in use.

When the bit rates of the input streams are appropriately selected, the corresponding cell rate may approach the logical channel capacity of the NGH frames, but normally not match it exactly. The logical frames are defined to always exactly fill the data cell capacity of the corresponding NGH frames, but to adjust for the mismatch between required cell rate of input streams and available capacity auxiliary stream cells and/or dummy cells are added in the logical frame so that each logical frame of a particular logical channel gets the same size in cells during one logical super-frame.

A set of NGH physical layer frames forms a super-frame. Changes of physical layer parameters can only be done at super-frame boundaries. A super-frame may contain FEFs at regular intervals (e.g. after every N^{th} frame). A particular frame only carries cells from one logical channel. In a super-frame there may be any allocation of logical channels to NGH frames, but this allocation may not change across super-frames, unless there is a reconfiguration, which in general is not seamless.

4.3.3 Logical channel types

As can be seen from the above, the logical frames and the NGH frames can be seen as two different protocol layers, which are largely independent. The logical frames have their own L1 signaling (L1-POST) and are carried as the payload of the available capacity in the NGH frames. The NGH frames also have their own signalling (L1-PRE) and offer a data cell capacity to the logical frames.

Similar to other protocols, the “packet size” of the higher protocol layer does not need to perfectly match the capacity of the lower layer. With LC type A there is a match in so far as each NGH frame carries exactly one logical frame. This also applies to LC type D, albeit with multiple RF frequencies.

However, with LC types B and C the logical frames are completely decoupled (unsynchronized) from the NGH frames. With LC type B this is done using one RF channel and with LC Type C using multiple RF channels. LC type A can be seen as a special case of LC type B (both use a single RF channel, but with LC type A the logical frame is synchronized with the NGH frames). Similarly, LC type B can be seen as a special case of LC type C (both use logical frames that are unsynchronized with the NGH frames, but with LC type C the NGH frames may use different RF frequencies). In all cases reception is possible using a single tuner.

4.3.4 Single tuner reception for frequency hopping

For LC type C, where there is no frequency hopping internally in an NGH frame, a sufficient requirement is that the time separation between NGH frames on different RF channels, carrying the same logical channel, fulfills the minimum tuning time requirement, as explained above.

For LC type D the subslicing internally within one NGH frame is specified to ensure that this tuning time condition is fulfilled. However, since a PLP may end on one RF channel in one NGH frame and may continue early in the following NGH frame on another RF channel, there must be some means to ensure, for every PLP, that the receiver has enough time to jump between the two RF frequencies also in this case.

One way of achieving this is to use of a FEF part between the NGH frames. In the FEF part there may e.g. a DVB-T2 signal, during which the NGH receiver may jump to the next frequency without losing the service.

Another way is to ensure that one or more *other* PLP types are used (for other services) between the occurrences of the current PLP type. One application is when the desired service is carried on a type 2 PLPs one may e.g. use a sufficient number of symbols with type 1 PLPs in the beginning of the logical frame/NGH frame (these two are synchronized for LC type D) to allow time for frequency hopping. When a service is carried on several PLPs these are co-scheduled in the NGH frame so that it makes no difference for the receiver from the frequency hopping point of view.

4.4 OFDM generation

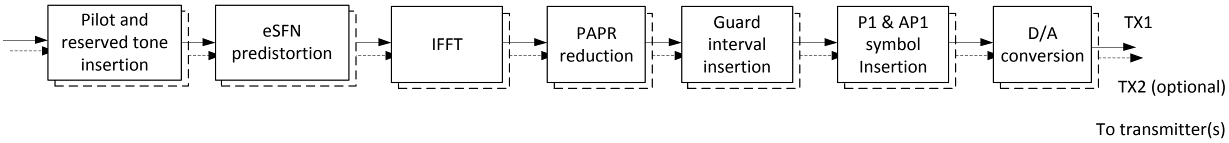


Figure 9: OFDM generation

The input to the OFDM generation part is a sequence of QAM cells grouped in OFDM symbols each of which is comprised of a fixed number of QAM cells. The pilot and reserved tone insertion block inserts scattered, continuous, and edge pilot cells as well as leaves space amongst the QAM cells for later insertion of PAPR reduction tones by the PAPR reduction block if necessary. P2 pilots are also inserted for P2 OFDM symbols. The eSFN block pre-distorts the cells of each OFDM symbol to impose some time diversity at the receiver. The IFFT transforms the sequence of QAM cells of each OFDM symbol into the time domain via an inverse Fourier transform. The output of the IFFT is a time domain OFDM symbol whose crest factor may be reduced by the PAPR reduction. PAPR reduction can use one or both of tone reservation and/or active constellation extension. The guard interval insertion adds a cyclic prefix of the current time domain OFDM symbol to the beginning of the OFDM symbol. A number of these cyclically extended symbols form an NGH frame which is delimited by the insertion of a first preamble (P1) symbol which in the MIMO, the hybrid and the hybrid MIMO profiles is followed by an additional first preamble (aP1) symbol. The P1 (and aP1) symbols are special non-OFDM symbols which are modulated with information that describes how the following second preamble (P2) symbol is composed. The last block in OFDM generation is the conversion of the stream of time discrete signal samples into an analogue signal ready for up conversion into the RF transmit frequency and amplification.

NOTE: The term "modulator" is used throughout the present document to refer to equipment carrying out the complete modulation process starting from input streams and finishing with the signal ready to be upconverted and transmitted, and including the input interface, formation of BBFRAMES, etc. (i.e. mode adaptation). However other documents may sometimes refer to the mode adaptation being carried out within a T2-gateway, and in this context the term "modulator" refers to equipment accepting BBFRAMES at its input, and applying processing from the stream adaptation module onwards.

Care should be taken to ensure these two usages are not confused.

5 Input processing

5.1 Mode adaptation

The input to the NGH system shall consist of one or more logical data streams. One logical data stream is carried by one Physical Layer Pipe (PLP). The mode adaptation modules, which operate separately on the contents of each PLP, slice the input data stream into data fields which, after stream adaptation, will form baseband frames (BBFs). The mode adaptation module comprises the input interface, followed by two sub-systems (the input stream synchronizer and the null packet deletion (the latter is optional for TSs)) and then finishes by slicing the incoming data stream into data fields and appending the baseband frame header (BBF-HDR) in front of each data field. Each of these sub-systems is described in the following clauses.

Each input PLP may have one of the formats specified in clause 5.1.1. The mode adaptation module can process input data for a PLP in one of three modes, the ISSY-IBS mode (one ISSY field per Logical Frame (LF) carried as part of the mandatory in-band signalling type B), the ISSY-BBF mode (one ISSY field per baseband frame carried in the baseband frame header) or the ISSY-UP mode (one ISSY field attached to each user packet), which are described in clause 5.1.7. The PLP mode – ISSY-IBS, ISSY-BBF or ISSY-UP - is indicated with the L1-POST configurable parameter PLP_ISSY_MODE (see clause 8.1.3.1).

Each TS input stream may be carried by a PLP cluster, i.e. a maximum of four PLPs, including any common PLP. Each GS input stream is carried by only one PLP (data PLP or common PLP) and each PLP may carry only one input GS. A PLP cluster, that is carrying GS input streams associated with the same stream group id, see L1 signalling, may carry a maximum of four GS input streams.

The bit rates of any TS or GS input streams shall be such that the sum of the coded bit rates (after BCH and LDPC encoding) of a PLP cluster, i.e. the PLPs carrying a particular TS, or a particular group of GS input streams, does not exceed 12 Mbit/s.

5.1.1 Input formats

The input pre-processor/service splitter shall supply to the mode adaptation module(s) a single or multiple streams (one for each mode adaptation module). In the case of a TS, the packet rate will be a constant value, although only a proportion of the packets may correspond to service data and the remainder may be null packets.

Each input stream (PLP) of the NGH system shall be associated with a modulation, a FEC protection mode and a particular time interleaving depth. All three parameters are statically configurable and are indicated with the L1-POST configurable parameters PLP_MOD/PLP_ROTATION, PLP_COD and FRAME_INTERVAL/TIME_IL_LENGTH/TIME_IL_TYPE respectively.

Each input PLP may take one of the following formats:

- Transport Stream (TS) [1]:

  A Transport Stream is characterized by packets of a fixed length of originally 188 bytes. Since the sync byte in the beginning (47_{HEX}) is known a priori and is hence not transmitted (but can be attached again by the receivers if necessary), the basic length of the transmitted UPs is 187 bytes. When a PLP carries TS packets from different original TSs (e.g. to carry audio service(s) (components) of several TSs in a dedicated PLP) the ngh_stream_id is placed in the former sync byte position of each TS packet. So the resulting TS packets are 188 bytes long. The ngh_stream_id allows the receiver to identify the correct TS for the reassembly operation in the receiver.

If Null Packet Deletion is used, a DNP field is attached (1 byte) to each user packet. The application of Null Packet Deletion is indicated by the L1-POST configurable parameter PLP_NPDI, see clause 7.2.

When only a single service (sub-)component is transported with a (partial) TS by the related PLP, TS header compression can be used leading to a 2 bytes shorter user packet length. TS packet header compression is described in clause 5.1.1.1 below. The different combinations of attributes are explained in detail in clause 5.1.7, which distinguishes between the ISSY-LF mode, the ISSY-BBF mode and the ISSY-UP mode.

- Generic Stream Encapsulation (GSE) [3]:

  A GSE is characterised by variable or constant length packets, as signalled by the GSE packet headers.

- Generic Continuous Stream (GCS) [?]:

  A GCS is characterised by a continuous bit-stream or a variable length packet stream where the modulator is not aware of the packet boundaries.

The L1-POST configurable parameter PLP_PAYLOAD_TYPE indicates, if the related PLP carries either a GCS, GSE, TS or a TS with header compression. The L1-PRE parameter TYPE provides an overview over the stream types carried within the NGH super-frame it belongs to.

5.1.1.1 Transport Stream packet header compression

TS packet header compression can optionally be applied to Transport Streams or partial Transport Streams, if they carry content belonging to one single PID, i.e. for one service component (video, audio, …) or service sub-component (SVC base layer, SVC enhancement layer, MVC base view or MVC dependent view). Null packets (PID 8191_D) can still be part of that (partial) TS, i.e. a distinction between the service (sub-)component PID and the null packet PID is enabled.

Also under the aforementioned circumstances TS packet header compression is an optional feature and its use is up to the provider. The compression and decompression process is fully transparent.

The signal flow consists of a direct path where TS packet header compression is applied and a path where it is not applied. The feature is applicable to an entire Physical Layer Pipe (PLP), i.e. a PLP carrying a (partial) TS can use one of the two paths sketched below, if the aforementioned conditions are fulfilled. The use of TS packet header compression is signalled with L1-POST configurable parameter PLP_PAYLOAD_TYPE.

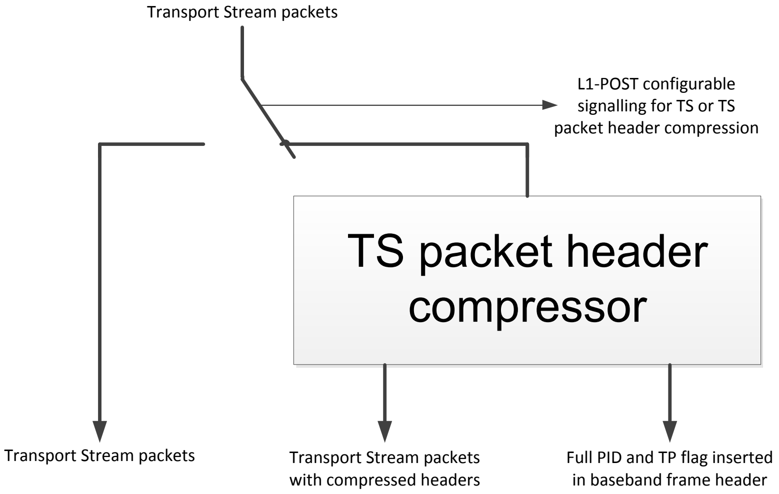


Figure 10: TS packet header compression on transmitter side

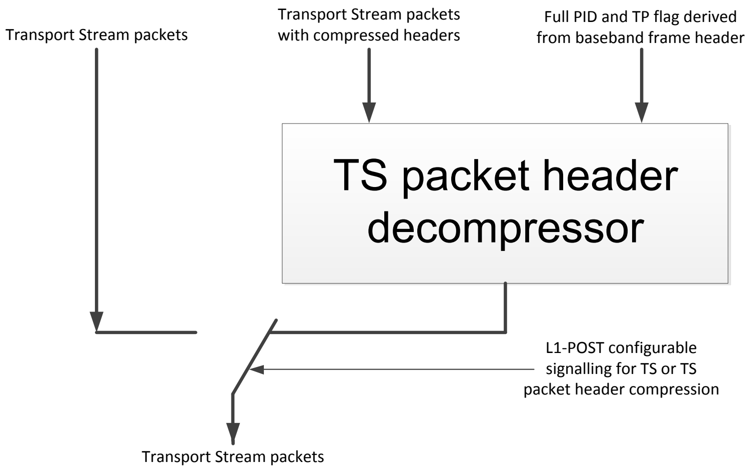


Figure 11: TS packet header decompression on receiver side

The packet header compression is defined as outlined below.

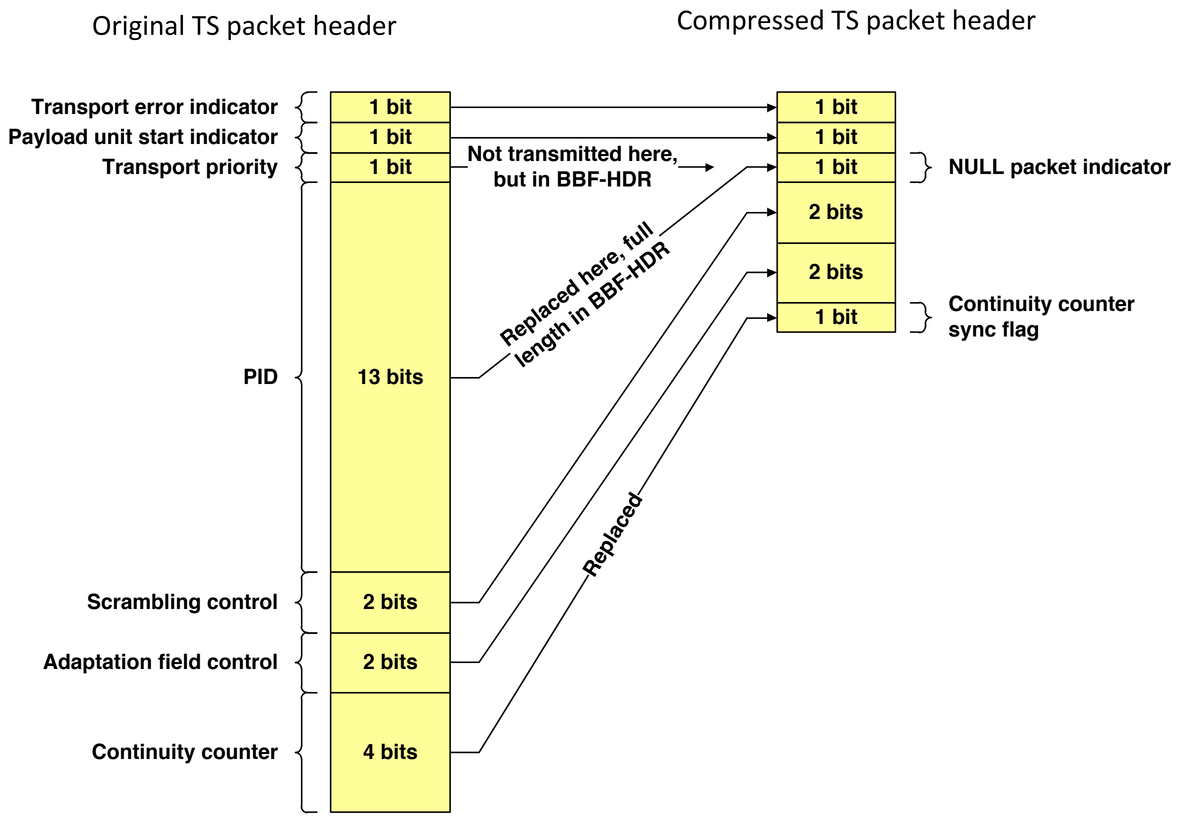


Figure 12: Relationship between original and compressed TS packet headers (without sync byte)

The following parameters of the original TS packet header are compressed for transmission and decompressed on receiver side (if needed) as follows:

Transport priority (TP): Not transmitted as part of the compressed TS packet header, but as part of the baseband frame header

PID: Replaced for compressed TS packet header by a single bit null packet indicator that distinguishes between useful packets and null packets, the full 13 bit PID is transmitted as part of the extended baseband frame header and can be re-inserted by the TS packet header decompressor on receiver side

Continuity counter: Reduced from 4 to 1 bit (continuity counter sync flag), provides synchronisation of the receiver side 4-bit counter by the following conversion rule:

Continuity counter sync flag	Continuity counter
1	0000
0	0001 to 1111

The original 4-bit count can be reconstructed on the receiver side for the error-free cases.

5.1.2 Input interface

The input interface subsystem shall map the input into internal logical-bit format. The first received bit will be indicated as the most significant bit (msb). Input interfacing is applied separately for each single physical layer pipe (PLP), see figure 4.

The Input Interface shall read a data field, composed of DFL bytes (Data Field Length), where:

- $0 \le DFL*8 \le (K_{bch} - 64)$ for TS packet header compression, ISSY-BBF mode
- $0 < DFL*8 < (K_{bch} - 48)$ for TS, GCS, GSE, ISSY-BBF mode
- $0 < DFL*8 < (K_{bch} – 40)$ for TS packet header compression, ISSY-LF or ISSY-UP mode
- $0 < DFL*8 < (K_{bch} – 24)$ for TS, GCS, GSE, ISSY-IBS or ISSY-UP mode

where K_{bch} is the number of bits protected by the BCH and LDPC codes (see clause 6.1).

The maximum value of DFL depends on the chosen LDPC code, carrying a protected payload of K_{bch} bits. The 3-, 5-, 6- or 8-byte BBF-HDR is appended to the front of the data field, and is also protected by the BCH and LDPC codes.

The input interface shall either allocate a number of input bits equal to the available data field capacity, thus breaking UPs in subsequent data fields (this operation being called "fragmentation"), or shall allocate an integer number of UPs within the data field (no fragmentation). The available data field capacity is equal to the maximum values being listed with the bullet points above for the different ISSY modes and input formats, i.e. K_{bch}-64, K_{bch}-48, K_{bch}-40 or K_{bch}-24, when in-band signalling is not used (see clause 5.2.3), but less when in-band signalling is used. When the value of DFL*8 is smaller than the aforementioned maximum values, a padding field shall be inserted by the stream adapter (see clause 5.2) to complete the LDPC/BCH code block capacity. A padding field shall also be allocated in the first BBF of an interleaving frame, to transmit in-band signalling (whether fragmentation is used or not), if this is used. See clause 5.2.3 for the different types of in-band signalling.

5.1.3 Input stream synchronization (optional)

Data processing in the DVB-NGH modulator may produce variable transmission delay on the user information. The Input Stream Synchronizer subsystem shall provide suitable means to guarantee Constant Bit Rate (CBR) and constant end-to-end transmission delay for any input data format. The use of the Input Stream Synchronizer subsystem is optional for PLPs carrying GSE or GCS streams. In the case of PLPs carrying transport streams (TS), it shall always be used.

Input stream synchronization shall follow the specification given in annex C.1. This process will also allow synchronization of multiple input streams travelling in independent PLPs, since the reference clock and the counter of the input stream synchronizers shall be the same.

The ISSY field (Input Stream Synchronization, 3 bytes) carries the value of a counter clocked at the modulator clock rate $1/T$ (where T is defined in clause 11.4) and can be used by the receiver to regenerate the correct timing of the regenerated output stream. The ISSY field carriage shall depend on the input stream format and on the PLP mode, as defined in clauses ??? and figures 18 to 19. In ISSY-UP mode the ISSY field is appended to UPs for packetized streams. In ISSY-IBS mode a single ISSY field is transmitted per interleaving frame in the in-band signalling type B, taking advantage of the fact that UPs of an interleaving frame experience similar delay/jitter.

When the ISSY mechanism is not being used, the corresponding fields of the in-band signalling type B, if any, shall be set to '0'.

A full description of the format of the ISSY field is given in annex C.1.

5.1.4 Compensating delay

The interleaving parameters P_I and N_{TI} (see clause 6.6), and the frame interval I_{JUMP} (see clause 6.6) may be different for the data PLPs in a group and the corresponding common PLP. In order to allow the re-assembly of a service from the PLPs in its PLP cluster (for Transport Streams, the recombining mechanism described in annex A is used) without requiring additional memory in the receiver, the input streams (PLPs) shall be delayed in the modulator following the insertion of Input Stream Synchronization Information. The delay (and the indicated value of TTO - see annex C.1) shall be such that, for a receiver implementing the buffer strategy defined in clause C.1.1, the partial transport streams at the output of the de-jitter buffers for the data and common PLPs would be essentially co-timed, i.e. packets with corresponding ISCR values on the two streams shall be output within 1 ms of one another.

The compensating delay shall also be used, when the input stream is additionally transmitted from a second modulator with different PLP parameters (e.g., time interleaver duration), and if it is intended for a receiver to hand over from one signal to the other or to combine both received signals.

5.1.5 Null Packet Deletion (optional, for TS only, ISSY-IBS, ISSY-BBF and ISSY-UP modes)

Transport Stream rules require that bit rates at the output of the transmitter's multiplexer and at the input of the receiver's demultiplexer are constant in time and the end-to-end delay is also constant. For some Transport Stream input signals, a large percentage of null packets may be present in order to accommodate variable bit rate services in a constant bit rate TS. In this case, in order to avoid unnecessary transmission overhead, TS null packets shall be identified (PID = 8191_D) and removed. The process is carried out in a way that the removed null packets can be re-inserted in the receiver in the exact place where they were originally, thus guaranteeing constant bit-rate and avoiding the need for time-stamp (PCR) updating.

When Null Packet Deletion is used, useful packets (i.e. TS packets with PID $\neq 8\,191_D$), including the optionally appended ISSY field (ISSY-UP mode), shall be transmitted while null packets (i.e. TS packets with PID = $8\,191_D$), including the optionally appended ISSY field, may be removed, see figure 13.

After transmission of a UP, a counter called DNP (deleted null packets, 1 byte) shall be first reset and then incremented at each deleted null packet. When DNP reaches the maximum allowed value DNP = 255_D, then if the following packet is again a null packet this null packet is kept as a useful packet and transmitted.

Insertion of the DNP field (1 byte) shall be after each transmitted UP according to clause 5.1.7 and figures 18 and 19.

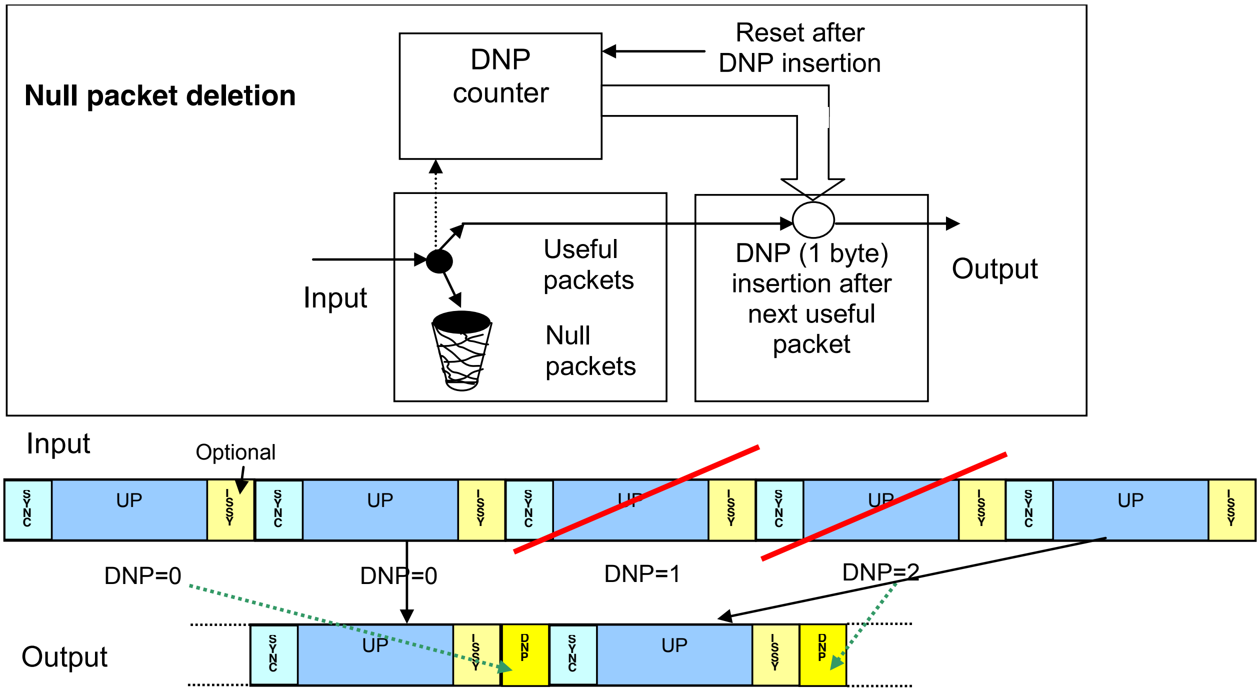
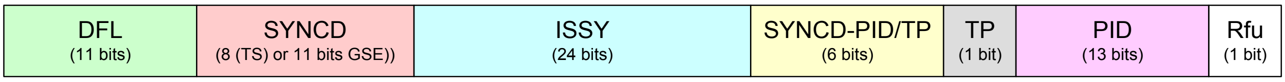


Figure 13: Null packet deletion scheme

5.1.6 Baseband frame header (BBFHDR) insertion

A BBFHDR of a fixed length of either 8 (TS packet header compression applied in ISSY-BBF mode), 6 (all remaining input stream formats in ISSY-BBF mode), 5 (TS packet header compression applied in ISSY-IBS or ISSY-UP mode) or 3 bytes (all remaining input stream formats in ISSY-IBS or ISSY-UP mode) shall be inserted in front of the baseband data field in order to describe the format of the data field. The BBFHDR shall take one of four forms as shown in figures 14 to 17:

- Input stream format TS packet header compression (PLP_PAYLOAD_TYPE ≠ “xxxxx”), ISSY-BBF mode (figure 14 below)
- Input stream format other than TS packet header compression (PLP_PAYLOAD_TYPEs), ISSY-BBF mode (figure 15 below)
- Input stream format TS packet header compression (PLP_PAYLOAD_TYPE =), ISSY-LF or ISSY-UP mode (figure 16 below)
- Input stream format other than TS packet header compression (PLP_PAYLOAD_Types), ISSY-LF or ISSY-UP mode (figure 17 below)



DFL	SYNCD	ISSY	SYNCD-PID/TP	TP	PID	Rfu
(11 bits)	(8 (TS) or 11 bits GSE))	(24 bits)	(6 bits)	(1 bit)	(13 bits)	(1 bit)

Figure 14: BBF-HDR format for TS packet header compression, ISSY-BBF mode

DFL (11 bits)	SYNCD (8 (TS) or 11 bits (GSE))	ISSY (24 bits)	Rfu (5 bits (TS) or 2 bits (GSE))

Figure 15: BBF-HDR format for TS, GCS, GSE, ISSY-BBF mode

DFL (11 bits)	SYNCD (8 (TS) or 11 bits (GSE))	SYNCD-PID/TP (6 bits)	TP (1 bit)	PID (13 bits)	Rfu (1 bit)

Figure 16: BBF-HDR format for TS packet header compression, ISSY-IBS or ISSY-UP mode

DFL (11 bits)	SYNCD (8 (TS) or 11 bits (GSE))	Rfu (5 bits (TS) or 2 bits (GSE))

Figure 17: BBF-HDR format for TS, GCS and GSE, ISSY-IBS or ISSY-UP mode

DFL (11 bits):	Data Field Length in bytes, in the range [0, 1461]
SYNCD (8 bits (TS) or 11 bits (GSE)):	The distance in bytes from the beginning of the data field to the beginning of the first transmitted UP, which starts in the data field. SYNCD = 0_D means that the first UP is aligned to the beginning of the Data Field. SYNCD = 255_D (TS) or SYNC = 2047_D (GSE) means that no UP starts in the data field; for GCS , SYNCD is reserved for future use and shall be set to 0_D.
SYNCD-PID/TP (6 bits):	The four most significant bits indicate the distance in number of TS packets from the SYNCD position to the first TS packet belonging to a new PID after PID change and/or to a new transport priority (TP) setting after change, the two least significant bits indicate if the distance indication applies to a PID change (“10”), a TP change (“01”) or a change of both parameters at the same time (“11”), set to “111100” if no PID or TP change in this BBF
TP (1 bit):	Transport priority as originally indicated in the uncompressed TS packet headers
PID (13 bits):	The content of this parameter replaces the NPD indicator being part of the compressed TS Headers. It signals the PID continuously, only in the case of a PID change within the related baseband frame it signals the new PID exclusively
Rfu (1 (TS-PHC), 2 (GSE) or 5 bits (TS)):	Reserved for future use

5.1.7 Mode adaptation sub-system output stream formats

This clause describes the mode adaptation processing and fragmentation for the various modes and input stream formats, as well as illustrating the output stream format. Three modes are available, one comes with a single ISSY field per Logical Frame being located in the in-band signalling type B (ISSY-LF), the second with a single ISSY field per baseband frame (ISSY-BBF) and the third one with a single ISSY field being attached to each user packet (ISSY-UP).

5.1.7.1 ISSY-IBS mode, TS, GSE and GCS

Transport Stream packets are carried without the sync-byte (47_{HEX}) that is known a priori. Hence for the signal on air these packets are 187 bytes long (with appended DNP field 188 bytes). The sync-byte can be appended again by the receivers in front of the received packet, if needed. Furthermore the TS packet headers can be compressed, if only a single service (sub-)component (SVC base or enhancement layer or MVC base and dependent view(s)) is transported with the related TS. With this header compression the UP becomes 2 bytes shorter.

The mode adaptation unit shall perform the following sequence of operations (see figure 18):

- Optional input stream synchronization (see clause 5.1.3). ISSY field appended after each Logical NGH Frame.
- Compensating delay (see clause 5.1.4)
- For TS only, optional null-packet deletion (see clause 5.1.5); DNP computation and storage after the next transmitted UP. The use of DNP is indicated by the L1-POST configurable signalling parameter NPDI. The packet length increases with the use of DNP by a single byte.
- SYNCD computation (pointing at the first bit of the first transmitted UP which starts in the data field) and storage in BBF-HDR. The bits of the transmitted UP finish with the DNP field, if used.

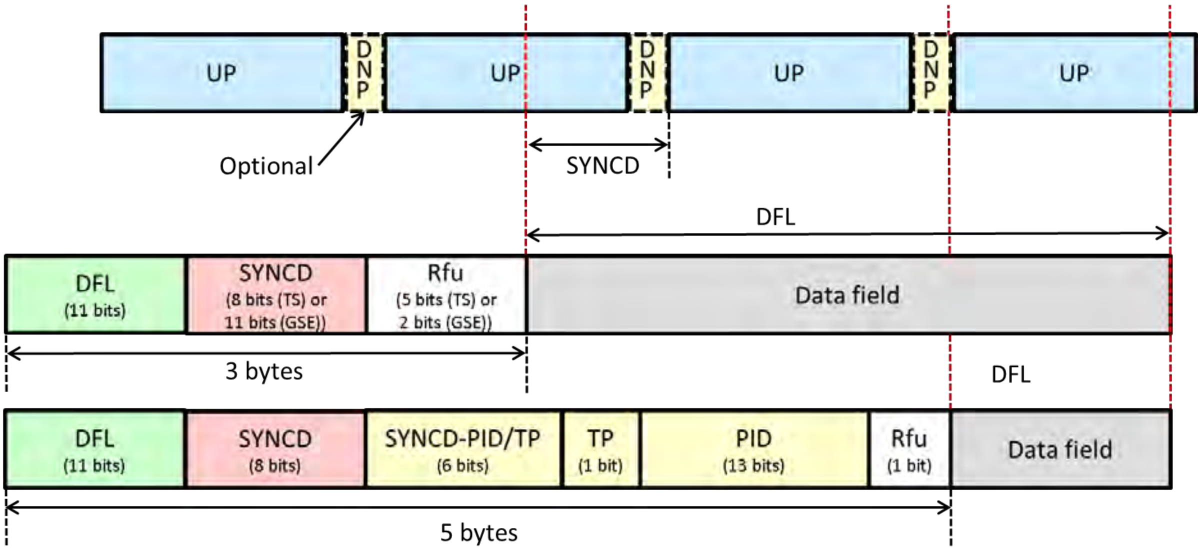


Figure 18: Stream format at the output of the mode adapter, ISSY-IBS mode, with TS header compression (bottom) and remaining input stream formats (above)

5.1.7.2 ISSY-UP mode, TS and GSE

This mode differs from the ISSY-LF mode only in so far as a 3-byte long ISSY field is attached to each UP, i.e. the length of the user packets becomes three bytes longer.

The mode adaptation unit performs the same steps as for the ISSY-LF mode – apart from the fact that in the first step an ISSY field is appended to each user packet (instead of being appended to each logical frame).

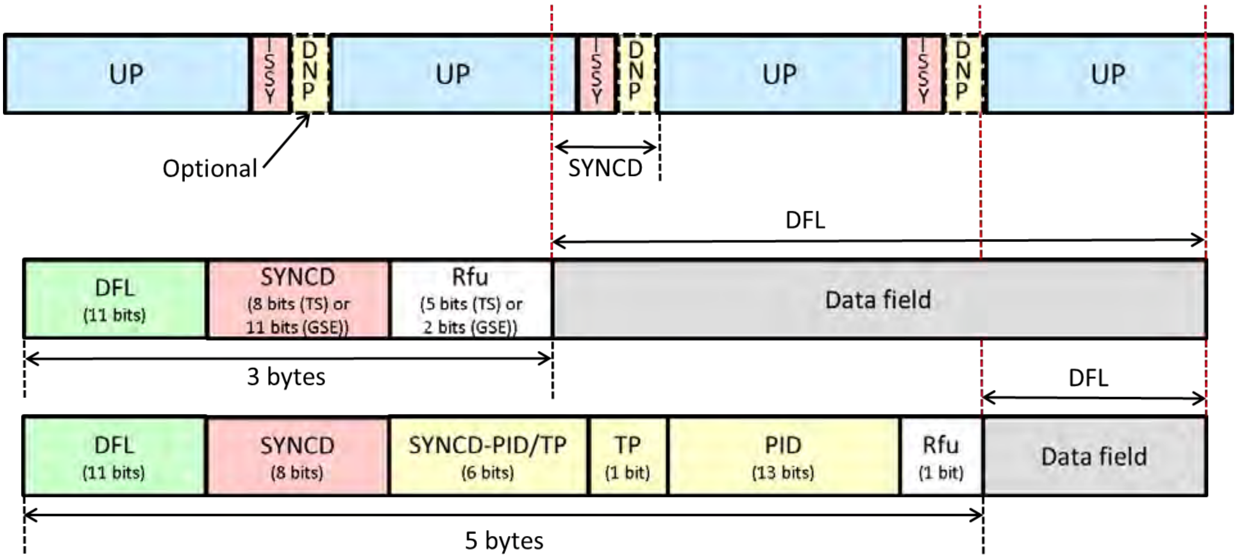


Figure 19: Stream format at the output of the mode adapter, ISSY-UP mode (DNP optionally attached to each UP)

5.2 Stream adaptation

Stream adaptation (see figure 20 and also clause 4.1) provides:

a) Scheduling (for input mode 'B'), see clause 5.2.1;

b) Padding (see clause 5.2.2) to complete a constant length (K_{bch} bits) BBF and/or to carry in-band signalling according to clause 5.2.3;

c) Scrambling (see clause 5.2.4) for energy dispersal.

The input stream to the stream adaptation module shall be a BBF-HDR followed by a data field. The output stream shall be a baseband frame as shown in figure 20.

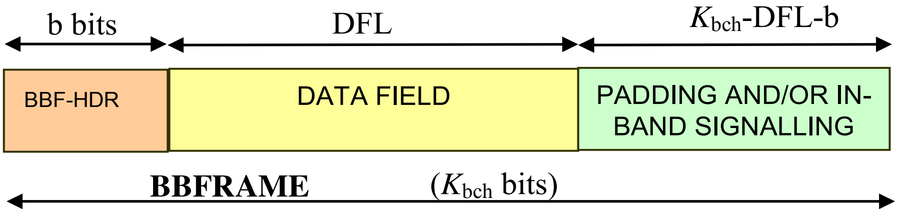


Figure 20: Baseband frame format at the output of the STREAM ADAPTER

5.2.1 Scheduler

In order to generate the required L1-POST dynamic signalling information, the scheduler must decide exactly which cells of the final NGH signal will carry data belonging to which PLPs, as shown in figure 5. Although this operation has no effect on the data stream itself at this stage, the scheduler shall define the exact composition of the frame structure, as described in clause 9.

The scheduler works by counting the FEC blocks from each of the PLPs. Starting from the beginning of the interleaving frame (which corresponds to either one or more NGH frames - see clause 9), the scheduler counts separately the start of each FEC block received from each PLP. The scheduler then calculates the values of the dynamic parameters for each PLP for each NGH frame. This is described in more detail in clause 9. The scheduler then forwards the calculated values for insertion as in-band signalling data, and to the L1 signalling generator.

The scheduler does not change the data in the PLPs whilst it is operating. Instead, the data will be buffered in preparation for frame building, typically in the time interleaver memories as described in clause 6.6.

5.2.2 Padding

K_{bch} depends on the FEC rate, as reported in table 4. Padding may be applied in circumstances when the user data available for transmission is not sufficient to completely fill a BBF or when an integer number of UPs has to be allocated in a BBF.

(K_{bch}-DFL-64) or (K_{bch}-DFL-48) or (K_{bch}-DFL-40) or (K_{bch}-DFL-24) (the exact value depends on the BBF configuration applied) zero bits shall be appended after the DATA FIELD. The resulting BBF shall have a constant length of K_{bch} bits.

5.2.3 Use of the padding field for in-band signalling

In input mode 'B', the PADDING field may also be used to carry in-band signalling.

Two types of in-band signalling are defined: Type A and type B. Future versions of the present document may define other types of in-band signalling. The PADDING field may contain an in-band signalling block of type A only or of type B only or a block of type A followed by a block of type B.

Type A signalling shall only be carried in the first BBF of an interleaving frame and its presence shall be indicated by setting IN-BAND_A_FLAG field in L1-POST signalling, defined in clause 8.1.3, to '1'. If IN-BAND_A_FLAG is set to '1', the in-band signalling block of type A shall immediately follow the data field of the relevant BBF.

Type B signalling shall only be carried in the first BBF of an interleaving frame and its presence shall be indicated by setting IN-BAND_B_FLAG field in L1-POST signalling, defined in clause 8.1.3, to '1'.

If a BBF carries type B signalling but not type A, the in-band type B signalling shall immediately follow the data field of the relevant BBF.

If a BBF carries both, type A and type B signalling, the type A block be followed immediately by the type B block.

Any remaining bits of the BBF following the last in-band signalling block are reserved.

Figure 21 illustrates the signalling format of the PADDING field when in-band signalling is delivered.

The first two bits of each in-band signalling block shall indicate the PADDING_TYPE as given in table 1.

Table 1: The mapping of padding types

Value	Input stream format	Type
00	Any	In-band type A
01	TS	In-band type B
01	GSE or GCS	Reserved for future use
10	Any	Reserved for future use
11	Any	Reserved for future use

The format of an in-band type A block is given in clause 5.2.3.1. The format of an in-band type B block is given in clause 5.2.3.2.

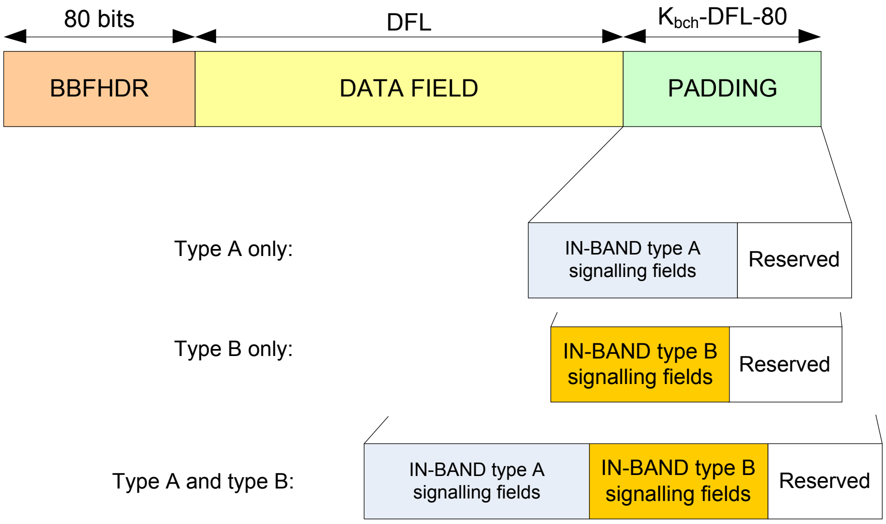


Figure 21: Padding format at the output of the stream adapter for in-band type A, B, or both

5.2.3.1 In-band type A

An in-band signalling block carrying L1/L2 update information and co-scheduled information is defined as in-band type A. When PLP_IN_BAND_A_FLAG field in L1-POST configurable signalling, defined in clause 8.1.3.1, is set to '0', the in-band type A is not carried in the PADDING field. The use of in-band type A is mandatory for anchor PLPs that appear in every logical frame (i.e. the values for P_I and I_{JUMP} for the current PLP are both equal to 1; see clauses 9.2.2 and 9.3).

The in-band type A block carrying dynamic signalling for logical frame *n*+1 (with the exception of the parameter PLP_RF_IDX that refers to logical frame n+2 in the case of logical channel type D, see clause ???) of a PLP or multiple PLPs is inserted in the PADDING field of the first BBF of logical frame *n* of each PLP. If NUM_OTHER_PLP_IN_BAND = 0 (see below), the relevant PLP carries only its own in-band dynamic information. If NUM_OTHER_PLP_IN_BAND > 0, it carries dynamic information of other PLPs as well as its own information, for shorter channel switching time.

Table 2 indicates the detailed use of fields for in-band type A signalling.

Table 2: Padding field mapping for in-band type A

Field	Size
PADDING_TYPE ('00')	2 bits
PLP_L1_CHANGE_COUNTER	8 bits
RESERVED_1	8 bits
L1_POST_DELTA	24 bits
LC_NEXT_FRAME_DELTA	24 bits
CURRENT_PLP_SUB_SLICE_INTERVAL	22 bits
START_RF_IDX	3 bits
CURRENT_PLP_START	22 bits
CURRENT_PLP_NUM_BLOCKS	10 bits
NUM_ASSOC_PLP	2 bits
For i=0..NUM_ASSOC_PLP-1 {	
PLP_ID	8 bits
PLP_START	22 bits
PLP_NUM_BLOCKS	10 bits
RESERVED_2	8 bits
}	
IF LC_TYPE = ‟011”{	
For j=0..NUM_PLP_PER_LF-1 {	
PLP_RF_IDX_NEXT	3 bits
}	
}	
NUM_OTHER_PLP_IN_BAND	8 bits
For i=0..NUM_OTHER_PLP_IN_BAND-1 {	
PLP_SUB_SLICE_INTERVAL	22 bits
START_RF_IDX	3 bits
For j=0..MAX_TIME_IL_LENGTH-1 {	
PLP_ID	8 bits
PLP_START	22 bits
PLP_NUM_BLOCKS	10 bits
PLP_ANCHOR_FLAG	1 bit
}	
RESERVED_3	8 bits
}	
For j=0..MAX_TIME_IL_LENGTH-1 {	
TYPE_2_START	22 bits
}	

PADDING_TYPE: This 2-bit field indicates the type of the in-band signalling block and shall be set to '00' for type A.

PLP_L1_CHANGE_COUNTER: This 8-bit field indicates the number of logical super-frames (LSFs) ahead where the configuration (i.e. the contents of the fields in the L1-PRE signalling or the configurable part of the L1-POST signalling) will change in a way that affects the PLPs referred to by this in-band signalling field. The next LSF with changes in the configuration is indicated by the value signalled within this field. If this field is set to the value '0', it means that no scheduled change is foreseen.
E.g. value '1' indicates that there is change in the next LSF. This counter shall always start counting down from a minimum value of 2.

RESERVED_1: This 8-bit field is reserved for future use.

L1_POST_DELTA: This 24-bit field indicates the gap, in QAM cells, between the last cell carrying L1-PRE signalling and the first cell of the first logical frame starting in the current NGH frame. The value (HEX) FFFFFF means that no new logical frame starts in the current NGH frame.

LC_NEXT_FRAME_DELTA: This 24-bit field indicates the relative timing in T periods between the current NGH frame and the next NGH frame which carries the current logical channel.

CURRENT_PLP_SUB_SLICE_INTERVAL: This 22-bit field indicates the number of cells from the start of one sub-slice of one PLP to the start of the next sub-slice of the same PLP on the same RF channel for the relevant logical frame. If the number of sub-slices per logical frame equals the number of RF channels, then the value of this field indicates the number of cells on one RF channel for the type 2 data PLPs. If there are no type 2 PLPs in the relevant logical frame, this field shall be set to '0'.

START_RF_IDX: This 3-bit field indicates the ID of the starting frequency of the logical channel typ D frame, for the relevant NGH frame, as described in clause 9.4.4. The starting frequency within the frame of logical channel type D may change dynamically. When logical channel type D is not used, the value of this field shall be set to '0'.

CURRENT_PLP_START: This 22-bit field signals the start position of the current PLP in the relevant logical frame. The start position is specified using the addressing scheme described in clause 9.9.3.1.

CURRENT_PLP_NUM_BLOCKS: This 10-bit field indicates the number of FEC blocks used for the current PLP within the Interleaving Frame which is mapped to the next logical frame.

NUM_ASSOC_PLP: This 3-bit field indicates the number of PLPs associated with the current anchor PLP, and for which dynamic information is provided by the current anchor PLP in-band signalling.

The following fields appear in the NUM_ASSOC_PLP loop:

> **PLP_ID:** This 8-bit field identifies uniquely a PLP. If the PLP_ID corresponds to a PLP whose PLP_TYPE (see 8.1.3.1) is one of the values reserved for future use, the remaining bits of this other PLP loop shall still be carried, and they too shall be reserved for future use and shall be ignored.
>
> **PLP_START:** This 22-bit field signals the start position of PLP_ID in the next logical frame . When PLP_ID is not mapped to the relevant logical frame, this field shall be set to '0'. The start position is specified using the addressing scheme described in clause 9.9.3.1.
>
> **PLP_NUM_BLOCKS:** This 10-bit field indicates the number of FEC blocks for PLP_ID contained in the interleaving frame which is mapped to the next logical frame. It shall have the same value for every logical frame to which the interleaving frame is mapped. When PLP_ID is not mapped to the next logical frame, this field shall be set to '0'.
>
> **RESERVED_2:** This 8-bit field is reserved for future use.

The following field appears in the NUM_PLP_PER_LF loop if LC_TYPE = “011” (i.e. LC Type D):

> **PLP_RF_IDX_NEXT:** For LC type D PLPs this 3-bit field indicates the RF frequency of the current PLP in the one after the next logical frame (n+2) where the PLP occurs. The value shall be interpreted according to the LC_CURRENT_FRAME_RF_IDX of L1-PRE. For LC types A, B and C this field shall be reserved for future use.

NUM_OTHER_PLP_IN_BAND: This 8-bit field indicates the number of other PLPs excluding the current PLP for which L1-POST dynamic information is delivered via the current in-band signalling. This mechanism shall only be used when the values for P_I and I_{JUMP} for the current PLP are both equal to 1 (otherwise NUM_OTHER_PLP_IN_BAND shall be set to ”0” and the loop will be empty).

The following fields appear in the NUM_OTHER_PLP_IN_BAND loop:

> **PLP_SUB_SLICE_INTERVAL:** This 22-bit field indicates the number of cells from the start of one sub-slice of one PLP to the start of the next sub-slice of the same PLP on the same RF channel for the relevant logical frame. If the number of sub-slices per logical frame equals the number of RF

channels, then the value of this field indicates the number of cells on one RF channel for the type 2 data PLPs. If there are no type 2 PLPs in the relevant logical frame, this field shall be set to '0'.

START_RF_IDX: This 3-bit field indicates the ID of the starting frequency of the logical channel type D frame, for the relevant NGH frame, as described in clause 9.4.4. The starting frequency within the frame of logical channel type D may change dynamically. When logical channel type D is not used, the value of this field shall be set to '0'.

The following fields appear in the MAX_TIME_IL_LENGTH loop:

PLP_ID: This 8-bit field identifies uniquely a PLP. If the PLP_ID corresponds to a PLP whose PLP_TYPE (see clause 8.1.3.1) is one of the values reserved for future use, the remaining bits of this other PLP loop shall still be carried, and they too shall be reserved for future use and shall be ignored.

PLP_START: This 22-bit field signals the start position of PLP_ID in the next logical frame. When PLP_ID is not mapped to the relevant logical frame, this field shall be set to '0'. The start position is specified using the addressing scheme described in clause 9.9.3.1.

PLP_NUM_BLOCKS: This 10-bit field indicates the number of FEC blocks for PLP_ID contained in the interleaving frame which is mapped to the next logical frame. It shall have the same value for every logical frame to which the Interleaving Frame is mapped. When PLP_ID is not mapped to the next logical frame, this field shall be set to '0'.

PLP_ANCHOR_FLAG: This 1-bit field indicates if the PLP identified by PLP_ID is an anchor PLP for all its associated PLPs. The value “1” indicates an anchor PLP.

RESERVED_3: This 8-bit field is reserved for future use.

The following fields appear in the MAX_TIME_IL_LENGTH loop:

TYPE_2_START: This 22-bit field indicates the start position of the first of the type 2 PLPs using the cell addressing scheme defined in clause 9.9.3.1. If there are no type 2 PLPs, this field shall be set to '0'. For LC type D it has the same value on every RF channel, and can be used to calculate when the sub-slices of a PLP are 'folded' (see clause 9.2.2.2.2). The value of TYPE_2_START shall be signalled for each of the P_I logical frames.

If there is no user data for a PLP in a given logical frame, the scheduler shall either:

- allocate no blocks (previously indicated by PLP_NUM_BLOCKS equal to 0); or
- allocate one block (previously indicated by PLP_NUM_BLOCKS equal to 1), with DFL=0, to carry the in-band type A signalling (and the remainder of the BBFRAME will be filled with padding by the input processor).

NOTE 1: In the case when the value of PLP_NUM_BLOCKS referring to the current Interleaving Frame equals 0 (as signalled in a previous Interleaving Frame), the dynamic signalling normally carried in the in-band signalling for the relevant PLP will still be present in the L1-POST signalling (see clause 8.1.3.3), and may also be carried in the in-band signalling of another PLP.

NOTE 2: In order to allow in-band signalling to be used together with GSE [3] it is assumed that, for baseband frames containing in-band signalling, the data field, containing the GSE packets, does not fill the entire baseband frame capacity, but leaves space for a padding field including in-band signalling at the end of the BBF.

5.2.3.2 In-band type B

For a PLP carrying TS, an in-band type B block shall carry additional information related to the input processing for the PLP containing the type B block. In particular it shall contain extra ISSY information, to enable faster initial acquisition, related to the BBF carrying the type B block. The use of in-band type B signalling is optional.

Table **Error! Bookmark not defined.** shows the detailed use of fields for in-band type B signalling for TS.

Table 3: Padding field mapping for in-band type B

Field	Size
`PADDING_TYPE ('01')`	2 bits
`TTO`	31 bits
`FIRST_ISCR`	22 bits
`BUFS_UNIT`	2 bits
`BUFS`	10 bits
`TS_RATE`	27 bits
`RESERVED_B`	8 bits

PADDING_TYPE: This 2-bit field indicates the type of the in-band signalling block and shall be set to '01' for type B.

TTO: This 31-bit field shall signal directly the value of TTO (as defined in annex C.1) for the first UP that begins in the data field of the BBF containing the type B block. If ISSY is not used for the PLP containing this block, this field shall be set to '0'.

FIRST_ISCR: This 22-bit field shall give the $\text{ISCR}_{\text{long}}$ value (see annex C.1) for the first UP that begins in the data field. If ISSY is not used for the PLP containing this block, this field shall be set to '0'.

BUFS_UNIT: This 2-bit field shall indicate the unit used for the following BUFS field, as defined for the BUFS_UNIT field in annex C.1. If ISSY is not used for the PLP containing this block, this field shall be set to '0'.

BUFS: This 10-bit field shall indicate the size of the receiver buffer assumed by the modulator for the relevant PLP, as defined for the BUFS field in annex C.1. If ISSY is not used for the PLP containing this block, this field shall be set to '0'.

TS_RATE: This 27-bit field shall indicate the clock rate of the transport stream being carried by the relevant PLP, in bits per second. If the actual clock rate is not an integer number of bits/s the value of TS_RATE shall be rounded to the nearest integer.

NOTE: This value is not necessarily exact and receivers should make use of ISCR (as described in annex C.1) to maintain the correct output clock rate.

RESERVED_B: This 8-bit field is reserved for future use.

For PLPs carrying GCS or GSE, the PADDING_TYPE '01' is reserved for future use.

5.2.4 Baseband frame scrambling

The complete baseband frame shall be randomized. The randomization seq

uence shall be synchronous with the BBF, starting from the MSB and ending after K_{bch} bits.

The scrambling sequence shall be generated by the feed-back shift register of figure 22. The polynomial for the Pseudo Random Binary Sequence (PRBS) generator shall be:

$$1 + X^{14} + X^{15}$$

Loading of the sequence (100101010000000) into the PRBS register, as indicated in figure 22, shall be initiated at the start of every BBF.

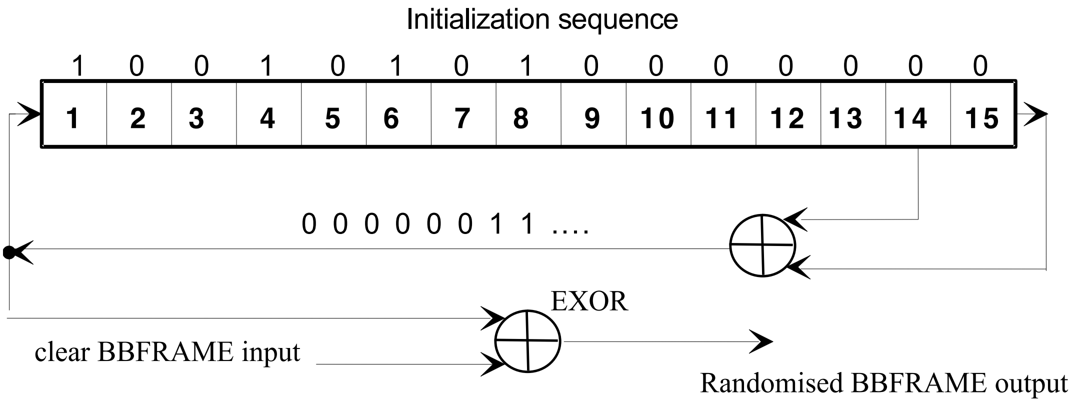


Figure 22: Possible implementation of the PRBS encoder

The L1-PRE and L1-POST signalling blocks are also scrambled using the same scrambling sequence. The details of this are given in clause 8.2.2.1.

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6 Bit-interleaved coding and modulation

6.1 FEC encoding

This sub-system shall perform outer coding (BCH), inner coding (LDPC) and bit interleaving. The input stream shall be composed of BBFs and the output stream of FECFRAMEs.

Each BBF (K_{bch} bits) shall be processed by the FEC coding subsystem, to generate a FECFRAME (N_{ldpc} bits). The parity check bits (BCHFEC) of the systematic BCH outer code shall be appended after the BBF, and the parity check bits (LDPCFEC) of the inner LDPC encoder shall be appended after the BCHFEC field, as shown in figure 23.

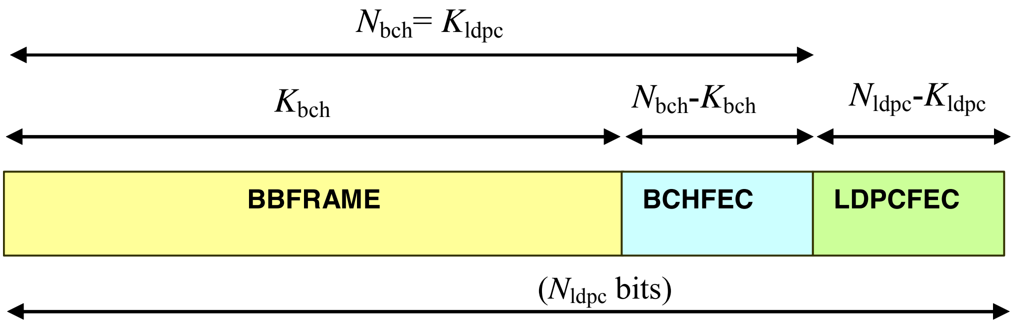


Figure 23: Format of data before bit interleaving

Table 4 gives the FEC coding parameters.

Table 4: Coding parameters

LDPC code	BCH uncoded block K_{bch}	BCH coded block N_{bch} LDPC uncoded block K_{ldpc}	BCH t-error correction	N_{bch}-K_{bch}	LDPC coded block N_{ldpc}
3/15	3 072	3 240	12	168	16 200
4/15	4 152	4 320	12	168	16 200
5/15	5 232	5 400	12	168	16 200
6/15	6 312	6 480	12	168	16 200
7/15	7 392	7 560	12	168	16 200
8/15	8 472	8 640	12	168	16 200
9/15	9 552	9 720	12	168	16 200
10/15	10 632	10 800	12	168	16 200
11/15	11 712	11 880	12	168	16 200

6.1.1 Outer encoding (BCH)

A t-error correcting BCH (N_{bch}, K_{bch}) code shall be applied to each BBF to generate an error protected packet. The BCH code parameters are given in table 4.

The generator polynomial of the *t* error correcting BCH encoder is obtained by multiplying the first *t* polynomials in table 5.

Table 5: BCH polynomials

$g_1(x)$	$1+x+x^3+x^5+x^{14}$
$g_2(x)$	$1+x^6+x^8+x^{11}+x^{14}$
$g_3(x)$	$1+x+x^2+x^6+x^9+x^{10}+x^{14}$
$g_4(x)$	$1+x^4+x^7+x^8+x^{10}+x^{12}+x^{14}$
$g_5(x)$	$1+x^2+x^4+x^6+x^8+x^9+x^{11}+x^{13}+x^{14}$
$g_6(x)$	$1+x^3+x^7+x^8+x^9+x^{13}+x^{14}$
$g_7(x)$	$1+x^2+x^5+x^6+x^7+x^{10}+x^{11}+x^{13}+x^{14}$
$g_8(x)$	$1+x^5+x^8+x^9+x^{10}+x^{11}+x^{14}$
$g_9(x)$	$1+x+x^2+x^3+x^9+x^{10}+x^{14}$
$g_{10}(x)$	$1+x^3+x^6+x^9+x^{11}+x^{12}+x^{14}$
$g_{11}(x)$	$1+x^4+x^{11}+x^{12}+x^{14}$
$g_{12}(x)$	$1+x+x^2+x^3+x^5+x^6+x^7+x^8+x^{10}+x^{13}+x^{14}$

The bits of the baseband frame form the message bits $M = (m_{K_{bch}-1}, m_{K_{bch}-2}, \ldots, m_1, m_0)$ for BCH encoding, where $m_{K_{bch}-1}$ is the first bit of the BBF-HDR and m_0 is the last bit of the BBF (or padding field if present). BCH encoding of information bits $M = (m_{K_{bch}-1}, m_{K_{bch}-2}, \ldots, m_1, m_0)$ onto a codeword is achieved as follows:

- Multiply the message polynomial $m(x)$ = $m_{K_{bch}-1} x^{k_{bch}-1} + m_{K_{bch}-2} x^{k_{bch}-2} + \ldots + m_1 x + m_0$ by $x^{N_{bch}-K_{bch}}$.
- Divide $x^{N_{bch}-K_{bch}}$ $m(x)$ by $g(x)$, the generator polynomial. Let $d(x) = d_{N_{bch}-K_{bch}-1} x^{N_{bch}-K_{bch}-1} + \ldots + d_1 x + d_0$ be the remainder.
- Construct the output codeword *I*, which forms the information word *I* for the LDPC coding, as follows:

$$I = (i_0, i_1, \ldots, i_{N_{bch}-1}) = (m_{K_{bch}-1}, m_{K_{bch}-2}, \ldots, m_1, m_0, d_{N_{bch}-K_{bch}-1}, d_{N_{bch}-K_{bch}-2}, \ldots, d_1, d_0)$$

NOTE: The equivalent codeword polynomial is $c(x) = x^{N_{bch}-K_{bch}} m(x) + d(x)$.

6.1.2 Inner encoding (LDPC)

The LDPC encoder treats the output of the outer encoding, $I = (i_0, i_1, \ldots i_{K_{ldpc}-1})$, as an information block of size $K_{ldpc} = N_{BCH}$, and systematically encodes it onto a codeword **Λ** of size N_{ldpc}, where:

$$\Lambda = (\lambda_0, \lambda_1, \lambda_2, \ldots \lambda_{N_{LDPC-1}}) = (i_0, i_1, \ldots i_{K_{ldpc}-1}, p_0, p_1, \ldots p_{N_{ldpc}-K_{ldpc}-1}).$$

The LDPC code parameters (N_{ldpc}, K_{ldpc}) are given in table 4.

The task of the encoder is to determine $N_{ldpc} - K_{ldpc}$ parity bits $(p_0, p_1, \ldots, p_{n_{ldpc}-k_{ldpc}-1})$ for every block of k_{ldpc} information bits, $(i_0, i_1, \ldots i_{K_{ldpc}-1})$. The procedure is as follows:

- Initialize $p_0 = p_1 = p_2 = \ldots = p_{N_{ldpc}-K_{ldpc}-1} = 0$
- Accumulate the first information bit, i_0, at parity bit addresses specified in the first row of tables E.3 through E.9. For example, for rate 10/15 (see table E.8), (all additions are in GF(2)):

$p_0 = p_0 \oplus i_0$ $p_{4297} = p_{4297} \oplus i_0$

$p_{2084} = p_{2084} \oplus i_0$ $p_{2481} = p_{2481} \oplus i_0$

$p_{1613} = p_{1613} \oplus i_0$ $p_{3369} = p_{3369} \oplus i_0$

$p_{1548} = p_{1548} \oplus i_0$ $p_{3451} = p_{3451} \oplus i_0$

$p_{1286} = p_{1286} \oplus i_0$ $p_{4620} = p_{4620} \oplus i_0$

$p_{1460} = p_{1460} \oplus i_0$ $p_{2622} = p_{2622} \oplus i_0$

$p_{3196} = p_{3196} \oplus i_0$

- For the next 359 information bits, $i_m, m = 1, 2, \ldots, 359$ accumulate i_m at parity bit addresses $\{x + m \bmod 360 \times Q_{ldpc}\} \bmod (N_{ldpc} - K_{ldpc})$ where x denotes the address of the parity bit accumulator corresponding to the first bit i_0, and Q_{ldpc} is a code rate dependent constant specified in table 6. Continuing with the example, $Q_{ldpc} = 15$ for rate 10/15. So for example for information bit i_1, the following operations are performed:

$p_{15} = p_{15} \oplus i_1$ $p_{4312} = p_{4312} \oplus i_1$

$p_{2099} = p_{2099} \oplus i_1$ $p_{2496} = p_{2496} \oplus i_1$

$p_{1628} = p_{1628} \oplus i_1$ $p_{3384} = p_{3384} \oplus i_1$

$p_{1563} = p_{1563} \oplus i_1$ $p_{3466} = p_{3466} \oplus i_1$

$p_{1301} = p_{1301} \oplus i_1$ $p_{4635} = p_{4635} \oplus i_1$

$p_{1475} = p_{1475} \oplus i_1$ $p_{2637} = p_{2637} \oplus i_1$

$p_{3211} = p_{3211} \oplus i_1$

- For the 361st information bit i_{360}, the addresses of the parity bit accumulators are given in the second row of the tables E.3 through E.9. In a similar manner the addresses of the parity bit accumulators for the following 359 information bits $i_m, m = 361, 362, \ldots, 719$ are obtained using the formula $\{x + (m \bmod 360) \times Q_{ldpc}\} \bmod (N_{ldpc} - K_{ldpc})$ where x denotes the address of the parity bit accumulator corresponding to the information bit i_{360}, i.e. the entries in the second row of the tables E.3 through E.9.
- In a similar manner, for every group of 360 new information bits, a new row from tables E.3 through E.9 are used to find the addresses of the parity bit accumulators.

After all of the information bits are exhausted, the final parity bits are obtained as follows:

- Sequentially perform the following operations starting with $i = 1$.

$$p_i = p_i \oplus p_{i-1}, \quad i = 1,2,\ldots,N_{ldpc} - K_{ldpc} - 1$$

- Final content of p_i, $i = 0,1,..,N_{ldpc} - K_{ldpc} - 1$ is equal to the parity bit p_i.

Table 6: Q_{ldpc} values

Code Rate	Q_{ldpc}
3/15	36
4/15	33
5/15	30
6/15	27
7/15	24
8/15	21
9/15	18
10/15	15
11/15	12

6.1.3 Bit Interleaver

The output *Λ* of the LDPC encoder shall be bit interleaved, which consists of parity interleaving followed by column twist interleaving. The parity interleaver output is denoted by *U* and the column twist interleaver output by *V*.

In the parity interleaving part, parity bits are interleaved by:

$$\begin{aligned} &u_i = \lambda_i \text{ for } 0 \le i < K_{ldpc} \text{ (information bits are not interleaved.)} \\ &u_{K_{ldpc}+360t+s} = \lambda_{K_{ldpc}+Q_{ldpc}\cdot s+t} \text{ for } 0 \le s < 360,\ 0 \le t < Q_{ldpc} \end{aligned};$$

where Q_{ldpc} is defined in table 6.

NOTE: Only parity interleaving is applied to QPSK modulation.

The configuration of the column twist interleaving for each modulation format is specified in table 7.

Table 7: Bit interleaver structure

Modulation	Rows N_r	Columns N_c
16-QAM	2 025	8
64-QAM or NU-64-QAM	1 350	12
256-QAM or NU-256-QAM	2 025	8

In the column twist interleaving part, the data bits u_i from the parity interleaver are serially written into the column-twist interleaver column-wise, and serially read out row-wise (the MSB of the BBF-HDR is read out first) as shown in figure 24, where the write start position of each column is twisted by t_c according to table 8. This interleaver is described by the following:

The input bit u_i with index i, for $0 \leq i < N_{ldpc}$, is written to column c_i, row r_i of the interleaver, where:

$$c_i = i \operatorname{div} N_r$$
$$r_i = (i + t_{c_i}) \bmod N_r$$

The output bit v_j with index j, for $0 \leq j < N_{ldpc}$, is read from row r_j, column c_j, where:

$$r_j = j \operatorname{div} N_c$$
$$c_j = j \bmod N_c$$

So for 16-QAM and N_{ldpc} = 16 200, the output bit order of column twist interleaving would be:

$$(v_0, v_1, v_2, \ldots v_{16199}) = (u_0, u_{4049}, u_{4050}, \ldots, u_{12149}, u_{14173}, u_{16194}).$$

A longer list of the indices on the right hand side, illustrating all 8 columns, is: 0, 4 049, 4 050, 8 092, 10 123, 10 125, 14 174, 16 195, …… , 2 024, 4 048, 6 074, 8 091, 10 122, 12 149, 14 173, 16 194.

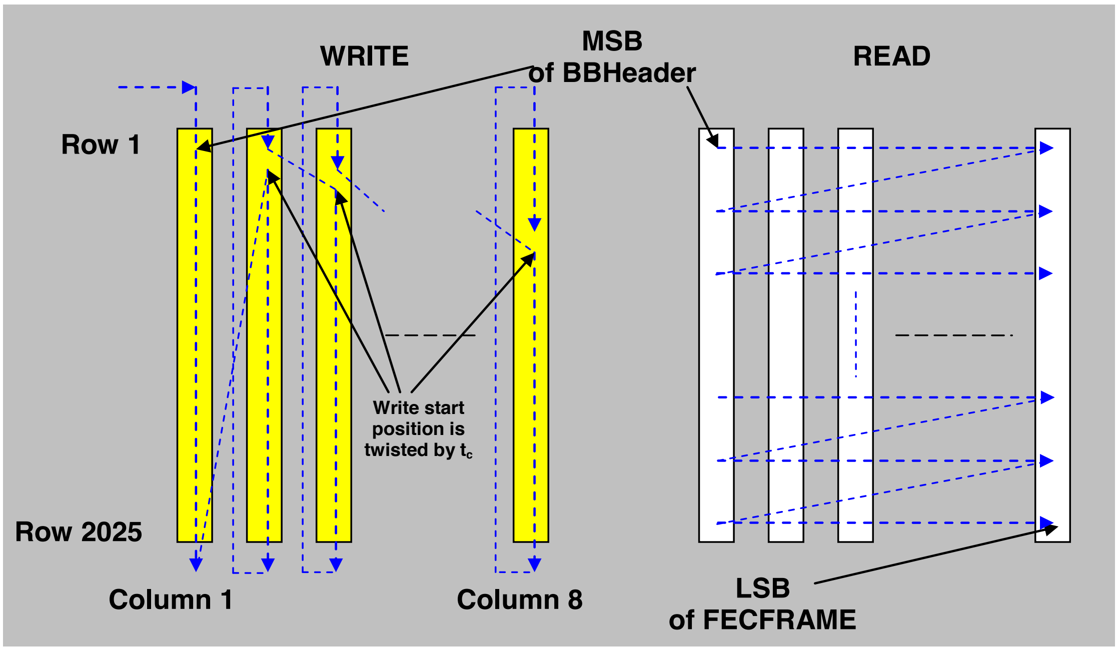


Figure 24: Bit interleaving scheme for normal FECFRAME length and 16-QAM

Table 8: Column twisting parameter t_c

Modulation	Columns N_c	N_{ldpc}	Twisting parameter t_c											
			Col. 0	1	2	3	4	5	6	7	8	9	10	11
16-QAM	8	16 200	0	1	0	8	2	0	1	5	-	-	-	-
64-QAM or NU-64-QAM	12	16 200	0	12	7	1	3	1	8	7	1	0	3	9
256-QAM or NU-256-QAM	8	16 200	0	1	0	8	2	0	1	5	-	-	-	-

6.2 Mapping bits onto constellations

Each FECFRAME (which is a sequence of 16 200 bits), shall be mapped to a coded and modulated FEC block by first de-multiplexing the input bits into parallel cell words and then mapping these cell words into constellation values. The number of output data cells and the effective number of bits per cell η_{MOD} is defined by table 9. De-multiplexing is performed according to clause 6.2.1 and constellation mapping is performed according to clause 6.2.2.

Table 9: Parameters for bit-mapping into constellations

LDPC block length (N_{ldpc})	Modulation mode	η_{MOD}	Number of output data cells (N_{cells})
16 200	256-QAM or NU-256-QAM	8	2 025
	64-QAM or NU-64-QAM	6	2 700
	16-QAM	4	4 050
	QPSK	2	8 100

6.2.1 Bit to cell word de-multiplexer

The bit-stream v_{di} from the bit interleaver is de-multiplexed into $N_{substreams}$ sub-streams, as shown in figure 25. The value of $N_{substreams}$ is defined in table 10.

Table 10: Number of sub-streams in de-multiplexer

Modulation	Number of sub-streams, $N_{substreams}$
QPSK	2
16-QAM	8
64-QAM or NU-64-QAM	12
256-QAM or NU-256-QAM	8

The de-multiplexing is defined as a mapping of the bit-interleaved input bits, v_{di} onto the output bits $b_{e,do}$, where:

do = di div $N_{substreams}$;

e is the de-multiplexed bit substream number ($0 \le e < N_{substreams}$), which depends on di as defined in tables 12 to 17;

v_{di} is the input to the de-multiplexer;

di is the input bit number;

$b_{e,do}$ is the output from the de-multiplexer;

do is the bit number of a given stream at the output of the de-multiplexer.

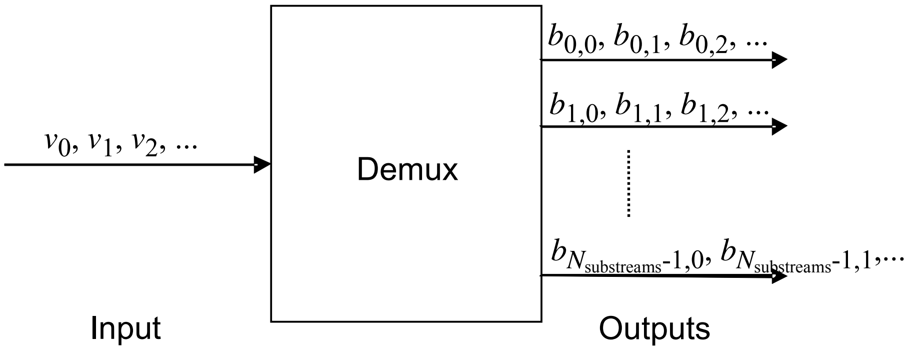


Figure 25: De-multiplexing of bits into sub-streams

Table 11: Parameters for de-multiplexing of bits to sub-streams for code rates 3/15 and 4/15

Modulation format	**QPSK**							
Input bit-number, *di* mod $N_{substreams}$	0	1						
Output bit-number, *e*	0	1						
Modulation format	**16-QAM**							
Input bit-number, *di* mod $N_{substreams}$	0	1	2	3	4	5	6	7
Output bit-number, *e*	4	3	2	1	6	5	7	0

Table 12: Parameters for de-multiplexing of bits to sub-streams for code rates 5/15

Modulation format	**QPSK**											
Input bit-number, *di* mod $N_{substreams}$	0	1										
Output bit-number, *e*	0	1										
Modulation format	**16-QAM**											
Input bit-number, *di* mod $N_{substreams}$	0	1	2	3	4	5	6	7				
Output bit-number, *e*	6	0	3	4	5	2	1	7				
Modulation format	**64-QAM or NU-64-QAM**											
Input bit-number, *di* mod $N_{substreams}$	0	1	2	3	4	5	6	7	8	9	10	11
Output bit-number, *e*	4	2	0	5	6	1	3	7	8	9	10	11
Modulation format	**256-QAM or NU-256-QAM**											
Input bit-number, *di* mod $N_{substreams}$	0	1	2	3	4	5	6	7				
Output bit-number, *e*	4	0	1	2	5	3	6	7				

Table 13: Parameters for de-multiplexing of bits to sub-streams for code rates 6/15

Modulation format	**QPSK**	
Input bit-number, *di* mod $N_{substreams}$	0	1
Output bit-number, *e*	0	1

Modulation format	**16-QAM**							
Input bit-number, *di* mod $N_{substreams}$	0	1	2	3	4	5	6	7
Output bit-number, *e*	7	5	4	0	3	1	2	6

Modulation format	**64-QAM or NU-64-QAM**											
Input bit-number, *di* mod $N_{substreams}$	0	1	2	3	4	5	6	7	8	9	10	11
Output bit-number, *e*	4	0	1	6	2	3	5	8	7	10	9	11

Modulation format	**256-QAM or NU-256-QAM**							
Input bit-number, *di* mod $N_{substreams}$	0	1	2	3	4	5	6	7
Output bit-number, *e*	4	0	5	1	2	3	6	7

Table 14: Parameters for de-multiplexing of bits to sub-streams for code rate 7/15

Modulation format	QPSK	
Input bit-number, $d_i \bmod N_{substreams}$	0	1
Output bit-number, e	0	1

Modulation format	16-QAM							
Input bit-number, $d_i \bmod N_{substreams}$	0	1	2	3	4	5	6	7
Output bit-number, e	0	2	6	3	4	1	5	7

Modulation format	64-QAM or NU-64-QAM											
Input bit-number, $d_i \bmod N_{substreams}$	0	1	2	3	4	5	6	7	8	9	10	11
Output bit-number, e	2	0	8	7	1	6	4	3	10	9	5	11

Modulation format	256-QAM or NU-256-QAM							
Input bit-number, $d_i \bmod N_{substreams}$	0	1	2	3	4	5	6	7
Output bit-number, e	2	6	0	1	4	5	3	7

Table 15: Parameters for de-multiplexing of bits to sub-streams for code rate 8/15

Modulation format	QPSK	
Input bit-number, $d_i \bmod N_{substreams}$	0	1
Output bit-number, e	0	1

Modulation format	16-QAM							
Input bit-number, $d_i \bmod N_{substreams}$	0	1	2	3	4	5	6	7
Output bit-number, e	0	4	3	1	2	5	6	7

Modulation format	64-QAM or NU-64-QAM											
Input bit-number, $d_i \bmod N_{substreams}$	0	1	2	3	4	5	6	7	8	9	10	11
Output bit-number, e	2	0	4	1	6	7	8	5	10	3	9	11

Modulation format	256-QAM or NU-256-QAM							
Input bit-number, $d_i \bmod N_{substreams}$	0	1	2	3	4	5	6	7
Output bit-number, e	2	6	1	0	7	5	3	4

Table 16: Parameters for de-multiplexing of bits to sub-streams for code rate 9/15

Modulation format	QPSK	
Input bit-number, di mod $N_{substreams}$	0	1
Output bit-number, e	0	1

Modulation format	16-QAM							
Input bit-number, di mod $N_{substreams}$	0	1	2	3	4	5	6	7
Output bit-number, e	7	1	4	2	5	3	6	0

Modulation format	64-QAM or NU-64-QAM											
Input bit-number, di mod $N_{substreams}$	0	1	2	3	4	5	6	7	8	9	10	11
Output bit-number, e	11	7	3	10	6	2	9	5	1	8	4	0

Modulation format	256-QAM or NU-256-QAM							
Input bit-number, di mod $N_{substreams}$	0	1	2	3	4	5	6	7
Output bit-number, e	7	3	1	5	2	6	4	0

Table 17: Parameters for de-multiplexing of bits to sub-streams for code rates 10/15 and 11/15

Modulation format	QPSK	
Input bit-number, di mod $N_{substreams}$	0	1
Output bit-number, e	0	1

Modulation format	16-QAM							
Input bit-number, di mod $N_{substreams}$	0	1	2	3	4	5	6	7
Output bit-number, e	7	1	4	2	5	3	6	0

Modulation format	64-QAM or NU-64-QAM											
Input bit-number, di mod $N_{substreams}$	0	1	2	3	4	5	6	7	8	9	10	11
Output bit-number, e	11	7	3	10	6	2	9	5	1	8	4	0

Modulation format	256-QAM or NU-256-QAM							
Input bit-number, di mod $N_{substreams}$	0	1	2	3	4	5	6	7
Output bit-number, e	7	3	1	5	2	6	4	0

For 16-QAM, 64-QAM and NU-64-QAM, the words of width $N_{substreams}$ are split into two cell words of width $\eta MOD = N_{substreams}/2$ at the output of the demultiplexer. The first $\eta_{mod} = N_{substreams}/2$ bits $[b_{0,do}..b_{Nsubstreams/2-1,do}]$ form the first of a pair of output cell words $[y_{0,2do}..\, y_{\eta mod-1,\, 2do}]$ and the remaining output bits $[b_{Nsubstreams/2,\, do}..b_{Nsubstreams-1,do}]$ form the second output cell word $[y_{0,\, 2do+1}..y_{\eta mod-1,2do+1}]$ fed to the constellation mapper. In the case of QPSK, 256-QAM and NU-256-QAM, the words of width $N_{substreams}$ from the demultiplexer form the output cell words and are fed directly to the constellation mapper, so:

$$[y_{0,do}..y_{\eta mod-1,do}] = [b_{0,do}..b_{Nsubstreams-1,do}]$$

6.2.2 Cell word mapping into I/Q constellations

Each cell word ($y_{0,q}..y_{\eta mod-1,q}$) from the demultiplexer in clause 6.2.1 shall be modulated using either QPSK, 16-QAM, 64-QAM, NU-64-QAM, 256-QAM or NU-256-QAM constellations to give a constellation point z_q prior to normalization.

BPSK is only used for the L1 signalling (see clause 8.2.3) but the constellation mapping is specified here.

The exact values of the real and imaginary components Re(z_q) and Im(z_q) for each combination of the relevant input bits $y_{e,q}$ are given in tables 18 to **Error! Reference source not found.** for the various constellations.

Observe that non-uniform constellations are specific for each code rate, while uniform constellations apply to all code rates. The choice between the use of uniform and non-uniform constellations is signalled by the parameter PLP_MOD, which has one entry each for 64-QAM, 256-QAM, NU-64-QAM and NU-256-QAM (see clause 8.1.3.1).

Table 18: Constellation mapping for BPSK

$y_{0,q}$	1	0
Re(z_q)	-1	1
Im(z_q)	0	0

Table 19: Constellation mapping for real part of QPSK

$y_{0,q}$	1	0
Re(z_q)	-1	1

Table 20: Constellation mapping for imaginary part of QPSK

$y_{1,q}$	1	0
Im(z_q)	-1	1

Table 21: Constellation mapping for real part of 16-QAM

$y_{0,q}$ $y_{2,q}$	1 0	1 1	0 1	0 0
Re(z_q)	-3	-1	1	3

Table 22: Constellation mapping for imaginary part of 16-QAM

$y_{1,q}$ $y_{3,q}$	1 0	1 1	0 1	0 0
Im(z_q)	-3	-1	1	3

Table 23: Constellation mapping for real part of 64-QAM and NU-64-QAM

$y_{0,q}$ $y_{2,q}$ $y_{4,q}$	1 0 0	1 0 1	1 1 1	1 1 0	0 1 0	0 1 1	0 0 1	0 0 0	
Re(z_q)	-7	-5	-3	-1	1	3	5	7	**64-QAM**
	-7.2	-5.2	-1.9	-1.4	1.4	1.9	5.2	7.2	**NU-64-QAM, code rate 1/3**
	-7.4	-4.9	-2.0	-1.3	1.3	2.0	4.9	7.4	**NU-64-QAM, code rate 2/5**
	-7.5	-4.6	-2.3	-1.0	1.0	2.3	4.6	7.5	**NU-64-QAM, code rate 7/15**
	-7.5	-4.6	-2.4	-0.9	0.9	2.4	4.6	7.5	**NU-64-QAM, code rate 8/15**
	-7.5	-4.6	-2.5	-0.9	0.9	2.5	4.6	7.5	**NU-64-QAM, code rate 3/5**
	-7.4	-4.7	-2.6	-0.9	0.9	2.6	4.7	7.4	**NU-64-QAM, code rate 2/3**
	-7.3	-4.7	-2.7	-0.9	0.9	2.7	4.7	7.3	**NU-64-QAM, code rate 11/15**

Table 24: Constellation mapping for imaginary part of 64-QAM and NU-64-QAM

$y_{1,q}$ $y_{3,q}$ $y_{5,q}$	1 0 0	1 0 1	1 1 1	1 1 0	0 1 0	0 1 1	0 0 1	0 0 0	
Im(z_q)	-7	-5	-3	-1	1	3	5	7	**64-QAM**
	-7.2	-5.2	-1.9	-1.4	1.4	1.9	5.2	7.2	**NU-64-QAM, code rate 1/3**
	-7.4	-4.9	-2.0	-1.3	1.3	2.0	4.9	7.4	**NU-64-QAM, code rate 2/5**
	-7.5	-4.6	-2.3	-1.0	1.0	2.3	4.6	7.5	**NU-64-QAM, code rate 7/15**
	-7.5	-4.6	-2.4	-0.9	0.9	2.4	4.6	7.5	**NU-64-QAM, code rate 8/15**
	-7.5	-4.6	-2.5	-0.9	0.9	2.5	4.6	7.5	**NU-64-QAM, code rate 3/5**
	-7.4	-4.7	-2.6	-0.9	0.9	2.6	4.7	7.4	**NU-64-QAM, code rate 2/3**
	-7.3	-4.7	-2.7	-0.9	0.9	2.7	4.7	7.3	**NU-64-QAM, code rate 11/15**

Table 25: Constellation mapping for real part of 256-QAM and NU-256-QAM

$y_{0,q}$ $y_{2,q}$ $y_{4,q}$ $y_{6,q}$	1 0 0 0	1 0 0 1	1 0 1 1	1 0 1 0	1 1 1 0	1 1 1 1	1 1 0 1	1 1 0 0	0 1 0 0	0 1 0 1	0 1 1 1	0 1 1 0	0 0 1 0	0 0 1 1	0 0 0 1	0 0 0 0	
Re(z_q)	-15	-13	-11	-9	-7	-5	-3	-1	1	3	5	7	9	11	13	15	**256-QAM**
	-17.2	-12.6	-9.7	-9.3	-3.8	-4.1	-2.5	-2.4	2.4	2.5	4.1	3.8	9.3	9.7	12.6	17.2	**NU-256-QAM, code rate 1/3**
	-17.3	-13.1	-9.4	-8.8	-4.2	-4.3	-2.1	-2.1	2.1	2.1	4.3	4.2	8.8	9.4	13.1	17.3	**NU-256-QAM, code rate 2/5**
	-17.5	-13.1	-9.2	-8.2	-4.7	-4.6	-1.6	-1.7	1.7	1.6	4.6	4.7	8.2	9.2	13.1	17.5	**NU-256-QAM, code rate 7/15**
	-17.5	-13.0	-9.3	-8.1	-5.0	-4.6	-1.6	-1.5	1.5	1.6	4.6	5	8.1	9.3	13	17.5	**NU-256-QAM, code rate 8/15**
	-16.7	-13.1	-10.3	-8.0	-5.9	-4.2	-2.3	-0.9	0.9	2.3	4.2	5.9	8	10.3	13.1	16.7	**NU-256-QAM, code rate 3/5**
	-16.7	-13.1	-10.3	-8.0	-5.9	-4.2	-2.3	-0.9	0.9	2.3	4.2	5.9	8	10.3	13.1	16.7	**NU-256-QAM, code rate 2/3**
	-16.6	-13.1	-10.3	-8.0	-6.0	-4.2	-2.4	-0.9	0.9	2.4	4.2	6	8	10.3	13.1	16.6	**NU-256-QAM, code rate 11/15**

Table 26: Constellation mapping for imaginary part of 256-QAM and NU-256-QAM

$y_{0,q}$ $y_{2,q}$ $y_{4,q}$ $y_{6,q}$	1 0 0 0	1 0 0 1	1 0 1 1	1 0 1 0	1 1 1 0	1 1 1 1	1 1 0 1	1 1 0 0	0 1 0 0	0 1 0 1	0 1 1 1	0 1 1 0	0 0 1 0	0 0 1 1	0 0 0 1	0 0 0 0	
Re(z_q)	-15	-13	-11	-9	-7	-5	-3	-1	1	3	5	7	9	11	13	15	**256-QAM**
	-17.2	-12.6	-9.7	-9.3	-3.8	-4.1	-2.5	-2.4	2.4	2.5	4.1	3.8	9.3	9.7	12.6	17.2	**NU-256-QAM, code rate 1/3**
	-17.3	-13.1	-9.4	-8.8	-4.2	-4.3	-2.1	-2.1	2.1	2.1	4.3	4.2	8.8	9.4	13.1	17.3	**NU-256-QAM, code rate 2/5**
	-17.5	-13.1	-9.2	-8.2	-4.7	-4.6	-1.6	-1.7	1.7	1.6	4.6	4.7	8.2	9.2	13.1	17.5	**NU-256-QAM, code rate 7/15**
	-17.5	-13.0	-9.3	-8.1	-5.0	-4.6	-1.6	-1.5	1.5	1.6	4.6	5	8.1	9.3	13	17.5	**NU-256-QAM, code rate 8/15**
	-16.7	-13.1	-10.3	-8.0	-5.9	-4.2	-2.3	-0.9	0.9	2.3	4.2	5.9	8	10.3	13.1	16.7	**NU-256-QAM, code rate 3/5**
	-16.7	-13.1	-10.3	-8.0	-5.9	-4.2	-2.3	-0.9	0.9	2.3	4.2	5.9	8	10.3	13.1	16.7	**NU-256-QAM, code rate 2/3**
	-16.6	-13.1	-10.3	-8.0	-6.0	-4.2	-2.4	-0.9	0.9	2.4	4.2	6	8	10.3	13.1	16.6	**NU-256-QAM, code rate 11/15**

The constellation points z_q for each input cell word ($y_{0,q}..y_{\eta mod\text{-}1,q}$) are normalized according to table 27 to obtain the correct complex cell value f_q to be used.

Table 27: Normalization factors for data cells

Modulation	Normalization
BPSK	$f_q = z_q$
QPSK	$f_q = \frac{z_q}{\sqrt{2}}$
16-QAM	$f_q = \frac{z_q}{\sqrt{10}}$
64-QAM or NU-64-QAM	$f_q = \frac{z_q}{\sqrt{42}}$
256-QAM or NU-256-QAM	$f_q = \frac{z_q}{\sqrt{170}}$

6.3 Cell interleaver

The pseudo random cell interleaver (CI), which is illustrated in figure 26, shall uniformly spread the cells in the FEC codeword, to ensure in the receiver an uncorrelated distribution of channel distortions and interference along the FEC codewords, and shall differently "rotate" the interleaving sequence in each of the FEC blocks of one time interleaver block (see clause 6.6).

The input of the CI, $F(r)=(f_{r,0}, f_{r,1}, f_{r,2},..., f_{r,Ncells-1})$ shall be the data cells $(f_0, f_1, f_2,..., f_{Ncells-1})$ of the FEC block of index '*r*', generated by the QAM mapper that maps cells to constellations (see clause 6.2), '*r*' represents the incremental index of the FEC block within the TI-block and is reset to zero at the beginning of each TI-block. When time interleaving is not used, the value of '*r*' shall be 0 for every FEC block. The output of the CI shall be a vector $D(r) = (d_{r,0}, d_{r,1}, d_{r,2},..., d_{r,Ncells-1})$ defined by:

$$d_{r,L_r(q)} = f_{r,q} \text{ for each } q = 0,1,...,N_{cells}-1,$$

where N_{cells} is the number of output data cells per FEC block $N_{cells} = N_{LDPC}/\eta_{mod}$ as defined by table 9 and $L_r(q)$ is a permutation function applied to FEC block *r* of the TI-block.

When rotated constellations in 4 dimensions are used, the cell interleaver shall keep pairs of adjacent cells together.The L_r sequence shall have a length of Ncells/2 and the CI output shall be:

$$d_{r,2L_r(q)} = f_{r,2q},\ d_{r,2L_r(q)+1} = f_{r,2q+1} \text{ for each } q = 0,1,...,N_{cells}/2-1,$$

$L_r(q)$ is based on a maximum length sequence, of degree (N_d-1), where $N_d = \lceil \log_2(N_{cells}) \rceil$ or $N_d = \lceil \log_2(N_{cells}/2) \rceil$ plus MSB toggling at each new address generation. When an address is generated larger than or equal to N_{cells}, it is discarded and a new address is generated. To have different permutations for different FEC blocks, a constant shift (modulo N_{cells}) is added to the permutation, generated as a bit-reversed N_d-bit sequence, with values greater than or equal to N_{cells} discarded.

The permutation function $L_r(q)$ is given by:

$$L_r(q) = [L_0(q) + P(r)] \bmod N_{cells},$$

where $L_0(q)$ is the basic permutation function (used for the first FEC block of a TI-block) and $P(r)$ is the shift value to be used in FEC block *r* of the TI-block.

The basic permutation function $L_0(q)$ is defined by the following algorithm.

An N_d bit binary word S_i is defined as follows:

For all i,

$S_i[N_d\text{-}1] = (i \bmod 2)$ // (toggling of top bit)

$i = 0,1$:

$S_i[N_d\text{-}2, N_d\text{-}3,\ldots,1,0] = 0,0,\ldots,0,0$

$i = 2$:

$S_2[N_d\text{-}2, N_d\text{-}3,\ldots,1,0] = 0,0,\ldots,0,1$

$2 < i < 2^{N_d}$:

$S_i[N_d\text{-}3, N_d\text{-}4,\ldots,1,0] = S_{i\text{-}1}[N_d\text{-}2, N_d\text{-}3,\ldots,2,1]$;

for $N_d = 11$: $S_i[9] = S_{i\text{-}1}[0] \oplus S_{i\text{-}1}[3]$

for $N_d = 12$: $S_i[10] = S_{i\text{-}1}[0] \oplus S_{i\text{-}1}[2]$

for $N_d = 13$: $S_i[11] = S_{i\text{-}1}[0] \oplus S_{i\text{-}1}[1] \oplus S_{i\text{-}1}[4] \oplus S_{i\text{-}1}[6]$

for $N_d = 14$: $S_i[12] = S_{i\text{-}1}[0] \oplus S_{i\text{-}1}[1] \oplus S_{i\text{-}1}[4] \oplus S_{i\text{-}1}[5] \oplus S_{i\text{-}1}[9] \oplus S_{i\text{-}1}[11]$

for $N_d = 15$: $S_i[13] = S_{i\text{-}1}[0] \oplus S_{i\text{-}1}[1] \oplus S_{i\text{-}1}[2] \oplus S_{i\text{-}1}[12]$.

The sequence $L_0(q)$ is then generated by discarding values of S_i greater than or equal to N_{cells} as defined in the following algorithm:

```
q = 0;
for (i = 0; i < 2^Nd; i = i + 1)
{
    $L_0(q) = \sum_{j=0}^{N_d-1} S_i(j) \cdot 2^j$;
    if ($L_0(q) < N_{\text{cells}}$)
        q = q+1;
}
```

The shift $P(r)$ to be applied in FEC block index r is calculated by the following algorithm. The FEC block index r is the index of the FEC block within the TI block and counts up to $N_{FEC\_TI}(n,s) - 1$, where $N_{FEC\_TI}(n,s)$ is the number of FEC blocks in TI-block index 's' of interleaving frame 'n' (see clause 6.6.1). $P(r)$ is the conversion to decimal of the bit-reversed value of a counter k in binary notation over N_d bits. The counter is incremented if the bit-reversed value is too great.

```
k=0;
for (r=0; r<$N_{FEC\_TI}(n,s)$; r++)
{
```

```
        $P(r)=N_{\text{cells}}$;
        while ($P(r)>=N_{cells}$)
        {
            $P(r)=\sum_{j=0}^{N_d-1}\left\lfloor \frac{k-\left\lfloor \frac{k}{2^{j+1}}\right\rfloor 2^{j+1}}{2^{j}}\right\rfloor \cdot 2^{N_d-1-j}$;
            $k=k+1$;
        }
    }
```

So for N_{cells}= 10 8002700, N_d= 14, and the shift $P(r)$ to be added to the permutation for r =0, 1, 2, 3, etc. would be 0, 8 1922048, 4 0961024, 2 048512, 10 2402560, 6 1441536, 1 024256, 9 2162304, etc.

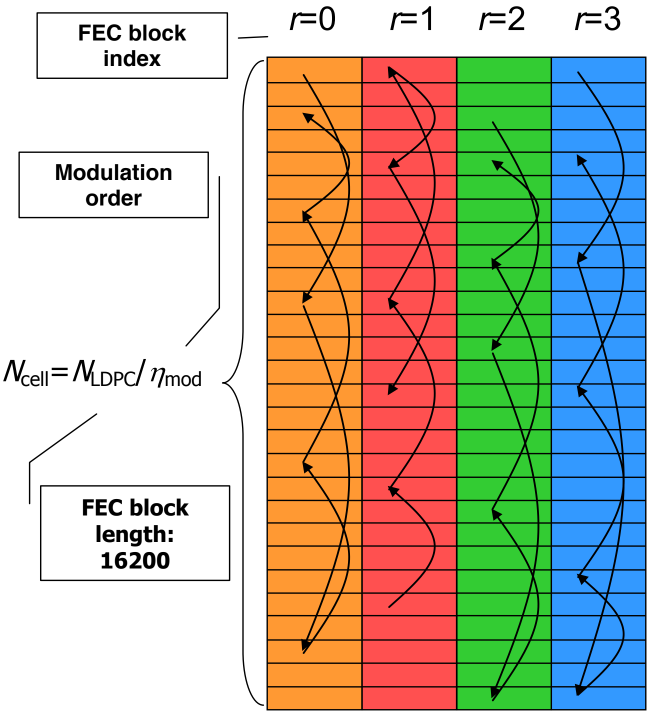


Figure 26: Cell Interleaving scheme

6.4 Constellation rotation

In order to increase the reception robustness under difficult fading conditions, rotated constellations in two (2D) and four (4D) dimensions are specified. Their use is configurable for each PLP individually through the PLP_ROTATION parameter (see clause 8.1.3.1). Throughout this clause and the subsequent ones the number of rotation dimensions is denoted by N_D. Table 28 summarizes the number of rotation dimensions that are allowed for each modulation and code rate. Rotated constellations are not used with 256-QAM modulation.

Table 28: The number of rotation dimensions for all code rates and modulations

Modulation	Code rate						
	1/3	2/5	7/15	8/15	3/5	2/3	11/15
QPSK	2D ($N_D = 2$)			4D ($N_D = 4$)			
16-QAM	2D ($N_D = 2$)						
64-QAM or NU-64-QAM	2D ($N_D = 2$)						
256-QAM or NU-256-QAM	No rotation						

The constellation rotation shall be applied to the output of the cell interleaver, which consists of vectors of complex cells $D = (d_0, d_1, d_2,\ldots, d_{Ncells-1})$. The rotated constellations are written to output vectors of the same size as the input, denoted by $E = (e_0, e_1, e_2,\ldots, e_{Ncells-1})$.

Note: Constellation rotation is never applied to L1-PRE cells.

The rotation is performed by multiplying vectors ***x*** of 2 or 4 real components by an orthogonal rotation matrix **R** of size 2x2 or 4x4 respectively:

$$\begin{bmatrix} y_0 \\ y_1 \end{bmatrix} = \begin{bmatrix} +a & -b \\ +b & +a \end{bmatrix} \begin{bmatrix} x_0 \\ x_1 \end{bmatrix}$$

$$\begin{bmatrix} y_0 \\ y_1 \\ y_2 \\ y_3 \end{bmatrix} = \begin{bmatrix} +a & -b & -b & -b \\ +b & +a & -b & +b \\ +b & +b & +a & -b \\ +b & -b & +b & +a \end{bmatrix} \begin{bmatrix} x_0 \\ x_1 \\ x_2 \\ x_3 \end{bmatrix}$$

The values of the parameter *b* of matrix **R** are summarized in table 29 below.

Table 29: Values of the parameter *b* for all rotations and modulations

Rotation	2D										4D
Modulation	QPSK	16-QAM	64-QAM	NU-64-QAM							QPSK
Code rate	1/3 to 7/15	all code rates	all code rates	1/3	2/5	7/15	8/15	3/5	2/3	11/15	8/15 to 11/15
Parameter *b*	0.4848	0.2890	0.1495	0.2045	0.1478	0.1184	0.1097	0.0958	0.1011	0.1080	0.3162

The parameter *a* is derived from the power normalization constraint:

$$a^2 + (N_D - 1)b^2 = 1 \Rightarrow a = \sqrt{1-(N_D-1)b^2}$$

The vectors **x** consist of the N_D components of $N_D/2$ adjacent cells according to the patterns:

$$\mathbf{x} = [x_0, x_1] = [\mathrm{Re}(d_i), \mathrm{Im}(d_i)]$$

$$\mathbf{x} = [x_0, x_1, x_2, x_3] = [\mathrm{Re}(d_{2i+0}), \mathrm{Im}(d_{2i+0}), \mathrm{Re}(d_{2i+1}), \mathrm{Im}(d_{2i+1})]$$

This is illustrated in figure 27 for the first four input cells ($d_0 \ldots d_3$), the curly braces grouping the elements of the same vector. The components of the rotated vectors ***y*** are packed to output cells *e* according to the same rules.

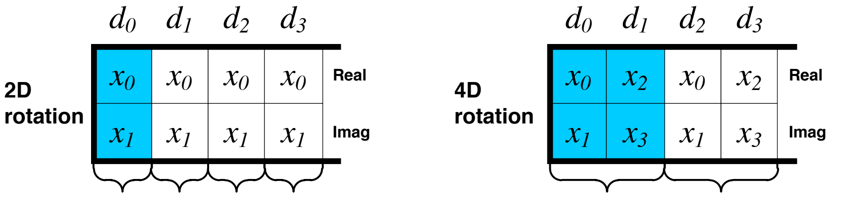


Figure 27: Extracting constellation vectors from the input cells

6.5 I/Q component interleaver

Following the rotation step, the complex cells undergo an interleaving step, whose purpose is to shuffle the N_D components of each constellation so that the fading they experience through the channel is as uncorrelated as possible. This step is referred to as I/Q component interleaving and is performed on each FEC block independently: $D=[d_0,d_1,\ldots,d_{Ncells-1}]$.

In a *first step*, the real and the imaginary components of the cells belonging to a FEC block are each written column by column into a matrix having N_R rows, i.e. there is one such matrix for the real components and one for the imaginary components. The resulting number of columns is $N_C=\lceil N_{cells}/N_R \rceil$, where $\lceil x \rceil$ denotes the smallest integer $\geq x$. If N_{cells}/N_R is not an integer, padding is added to the end of the last column. In a *second step*, a certain cyclic shift is applied to each column of the matrix for the imaginary components. If padding is used in the last column, no cyclic shift will be applied to it. In a *third step*, the two matrices are read out synchronously row by row and complex cells are formed by each read pair of a real and an imaginary component. The padding, if it exists, is skipped. The so-generated complex cells $(g_0, g_1, .., g_{N_{\text{cells}}-1})$ are the output of the component interleaver.

The number of rows N_R and the values of the cyclic shifts depend on whether or not LC type C or D is used.

When LC type C or D is not used, the I/Q component interleaver distributes the N_D dimensions of each constellation evenly over the FEC block, the resulting distance between the N_D components of each constellation being 1/ N_D of the FEC length. In this case, N_R is equal to N_D, and the cyclic shifts of all columns are equal to N_D /2. The three steps are illustrated in figure 28 for 4D rotated constellations and a hypothetical FEC block consisting of 24 cells. The numbers in the squares represent the indices of the cells in the input FEC block.

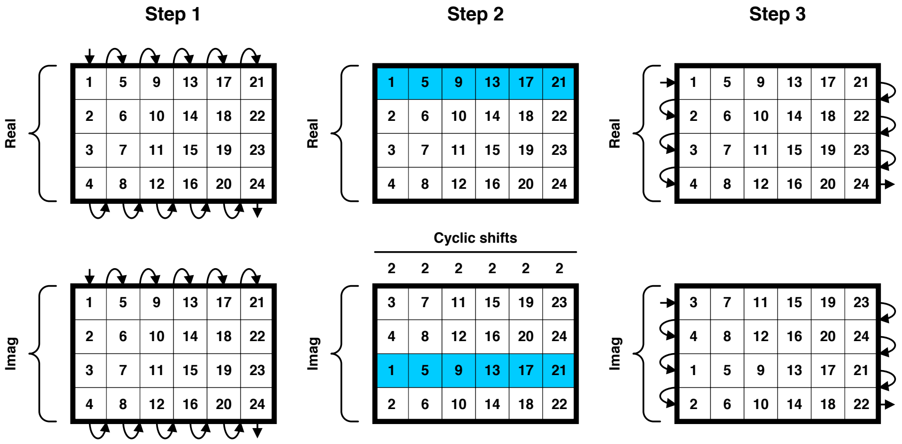
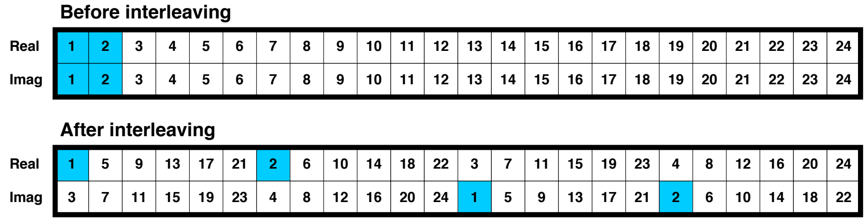


Figure 28: Example illustrating the three steps of the I/Q component interleaving, for the case of 4D rotated constellations (N_D = 4) and no TFS

The corresponding FEC blocks before and after the I/Q component interleaving are shown in figure 29, where the four components of the first constellation are emphasized through a darker background.



Before interleaving

Real	**1**	**2**	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Imag	**1**	**2**	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

After interleaving

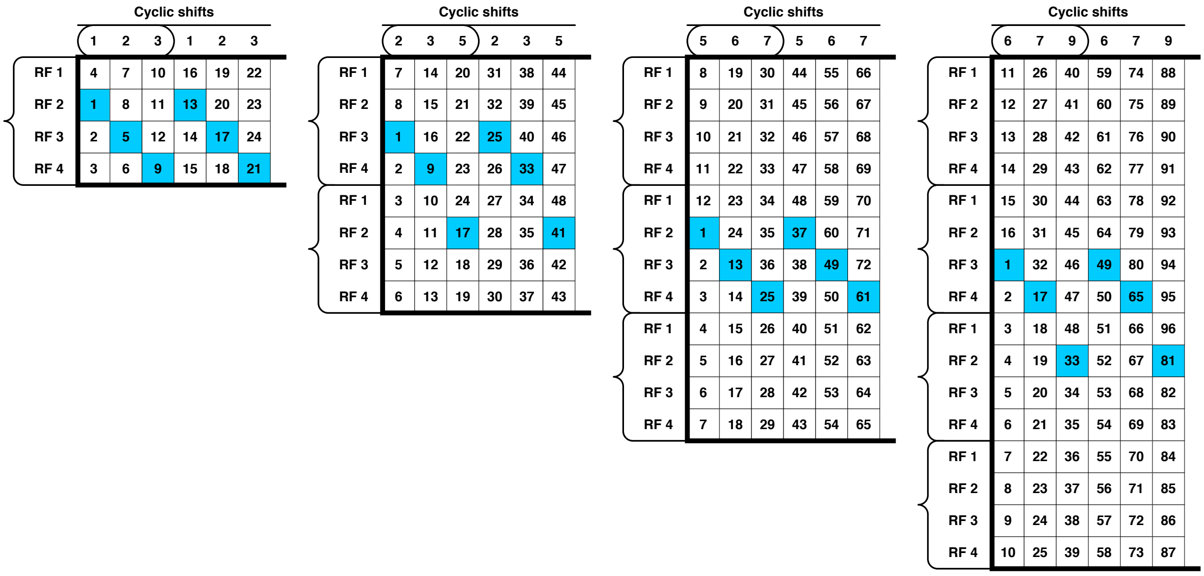
Real	**1**	5	9	13	17	21	**2**	6	10	14	18	22	3	7	11	15	19	23	4	8	12	16	20	24
Imag	3	7	11	15	19	23	4	8	12	16	20	24	**1**	5	9	13	17	21	**2**	6	10	14	18	22

Figure 29: Example illustrating the spreading of the constellation dimensions over the entire FEC block, for the case of 4D rotated constellations and no TFS

With LC types C and D, the component interleaver ensures that the N_D dimensions of each constellation are transmitted over all possible combinations of RF channels. The relevant parameters are the number of RF channels N_{RF} and the number of frequency hopping cycles (LC type C or D) over which a FEC block is time interleaved, denoted by N_K. In this case $N_R = N_{RF} N_K$ and the cyclic shifts are selected from a set having N_{RF}-1 elements, denoted by $S = \left(s_0, s_1, \dots, s_{N_{RF}-1}\right)$. For column index c (from 0 to $N_R - 1$), the corresponding index in the cyclic-shift set is computed as c *mod* (N_{RF}-1), where *mod* represents the modulo operation.

The cyclic-shift set is determined in a two-step process. In a first step, the set contains all $(N_{RF} - 1)N_K$ integers from 0 to $N_R - 1$ that are not multiples of N_{RF}. In a second step, which is needed only if $N_K > 1$, a contiguous set of $N_{RF} - 1$ elements is selected starting with index $\lceil (N_{RF} - 2)N_K/2 \rceil$.

Figure 30 shows the cyclic shift of the first six columns of the imaginary matrix for N_{RF} = 4 and N_K = 1...4.



	Cyclic shifts					
	1	2	3	1	2	3
RF 1	4	7	10	16	19	22
RF 2	**1**	8	11	**13**	20	23
RF 3	2	**5**	12	14	**17**	24
RF 4	3	6	**9**	15	18	**21**

	Cyclic shifts					
	2	3	5	2	3	5
RF 1	7	14	20	31	38	44
RF 2	8	15	21	32	39	45
RF 3	**1**	16	22	**25**	40	46
RF 4	2	**9**	23	26	**33**	47
RF 1	3	10	24	27	34	48
RF 2	4	11	**17**	28	35	**41**
RF 3	5	12	18	29	36	42
RF 4	6	13	19	30	37	43

	Cyclic shifts					
	5	6	7	5	6	7
RF 1	8	19	30	44	55	66
RF 2	9	20	31	45	56	67
RF 3	10	21	32	46	57	68
RF 4	11	22	33	47	58	69
RF 1	12	23	34	48	59	70
RF 2	**1**	24	35	**37**	60	71
RF 3	2	**13**	36	38	**49**	72
RF 4	3	14	**25**	39	50	**61**
RF 1	4	15	26	40	51	62
RF 2	5	16	27	41	52	63
RF 3	6	17	28	42	53	64
RF 4	7	18	29	43	54	65

	Cyclic shifts					
	6	7	9	6	7	9
RF 1	11	26	40	59	74	88
RF 2	12	27	41	60	75	89
RF 3	13	28	42	61	76	90
RF 4	14	29	43	62	77	91
RF 1	15	30	44	63	78	92
RF 2	16	31	45	64	79	93
RF 3	**1**	32	46	**49**	80	94
RF 4	2	**17**	47	50	**65**	95
RF 1	3	18	48	51	66	96
RF 2	4	19	**33**	52	67	**81**
RF 3	5	20	34	53	68	82
RF 4	6	21	35	54	69	83
RF 1	7	22	36	55	70	84
RF 2	8	23	37	56	71	85
RF 3	9	24	38	57	72	86
RF 4	10	25	39	58	73	87

Figure 30: Example illustrating the cyclic shift of the columns of the matrix for the imaginary components

When N_{cells} is not an integer multiple of N_R, padding is used and the last column is not cyclically shifted, similarly to the LC type A, B and C cases.

6.6 Time interleaver

The time interleaver (TI) shall operate at PLP level. The parameters of the time interleaving may be different for different PLPs within an NGH system.

The following parameters being part of the L1-POST configurable signalling (see clause 8.1.3.1) configure the TI:

- TIME_IL_TYPE (allowed values: 0 or 1): Determines the interleaving mode; ‘0’ represents the mode with multiple TI blocks per interleaving frame and no inter-frame interleaving, while ‘1’ means that only one TI block is present per interleaving frame, and the TI block may be spread over multiple logical frames (inter-frame interleaving).
- TIME_IL_LENGTH (allowed values: 0 to 16): If TIME_IL_TYPE = ‘0’, this gives the number N_{TI} of TI blocks per interleaving frame, and for TIME_IL_TYPE = ‘1’, it represents the number P_{I} of logical frames, over which cells stemming from one TI-block are carried.
- PLP_NUM_BLOCKS_MAX (allowed values: 0 to 1023): Represents the maximum number $N_{BLOCKS\_IF\_MAX}$ of FEC blocks per interleaving frame.
- PLP_LF_INTERVAL (allowed values: 1 to 16): Represents the distance I_{JUMP} between any two logical frames carrying cells from one TI block (used only for inter-frame interleaving)

Moreover, the parameter PLP_NUM_BLOCKS from the L1-POST dynamic signalling (see clause 8.1.3.3) is used to represent the number of FEC blocks for the current Interleaving Frame.

When time interleaving is not used for a PLP (i.e. when the L1-POST signalling parameter TIME_IL_LENGTH is set to 0, see clause 8.1.3.1), the remainder of clause 6.6, and clauses 6.6.1 to 6.6.4 do not apply, but clause 6.6.5 applies instead.

The FEC blocks from the component interleaver for each PLP shall be grouped into interleaving frames (which are mapped onto one or more logical frames). Each interleaving frame is the set of FEC blocks that belong to a PLP in one uninterleaved logical frame and shall contain a dynamically variable integer number of FEC blocks. The number of FEC blocks in the interleaving frame of index *n* is denoted by $N_{BLOCKS\_IF}(n)$ and is signalled as PLP_NUM_BLOCKS in the L1-POST dynamic signalling.

$N_{\mathrm{BLOCKS\_IF}}$ may vary from a minimum value of 0 to a maximum value $N_{BLOCKS\_IF\_MAX}$. $N_{BLOCKS\_IF\_MAX}$ is signalled in the L1-POST configurable signalling as PLP_NUM_BLOCKS_MAX. The largest value this may take is 1023.

Each interleaving frame is either mapped directly onto one logical frame or spread out over several (P_{I}) logical frames as described in clause 6.6.3.

Instead of spreading an interleaving frame over multiple logical frames, it can be divided into one or more (N_{TI}) TI blocks, where a TI block corresponds to one self-contained time interleaver operation, as described in clause 6.6.1. The TI blocks within an interleaving frame can contain a slightly different number of FEC blocks. If an interleaving frame is divided into multiple TI blocks, it shall be mapped to only one logical frame.

There are therefore two options for time interleaving for each PLP (besides the aforementioned option to skip the time interleaving):

1) Each interleaving frame contains one TI block and is mapped to one or more than one logical frame. Figure 31 shows on the right-hand side an example in which one interleaving frame is mapped onto two logical frames. This gives greater time diversity for low data-rate services. This

option is signalled in the L1-signalling by TIME_IL_TYPE='1'. For this option, the number of TI-blocks per Interleaving Frame is set to N_{TI} = 1, while the length of the time interleaver is P_I = TIME_IL_LENGTH.

2) Each Interleaving Frame is mapped directly to one logical frame and the Interleaving Frame is divided into one or several TI-blocks as shown in figure 31 on the left-hand side. Each of the TI blocks may be de-interleaved and decoded immediately after its complete reception in the receiver. From the Receiver Buffer Model in annex C.2, we find thus, that the maximum bit-rate for a PLP is increased. This option is signalled in the L1-POST configurable signalling by TIME_IL_TYPE='0'. For this option, the number of TI blocks per interleaving frame is set to N_{TI} = TIME_IL_LENGTH, while the length of the time interleaver is P_I = 1.

Observe that when TIME_IL_LENGTH is set to ‘1’, each interleaving frame contains one TI block and is mapped directly to one logical frame, irrespective of the value of TIME_IL_TYPE (both examples in the middle of figure 31).

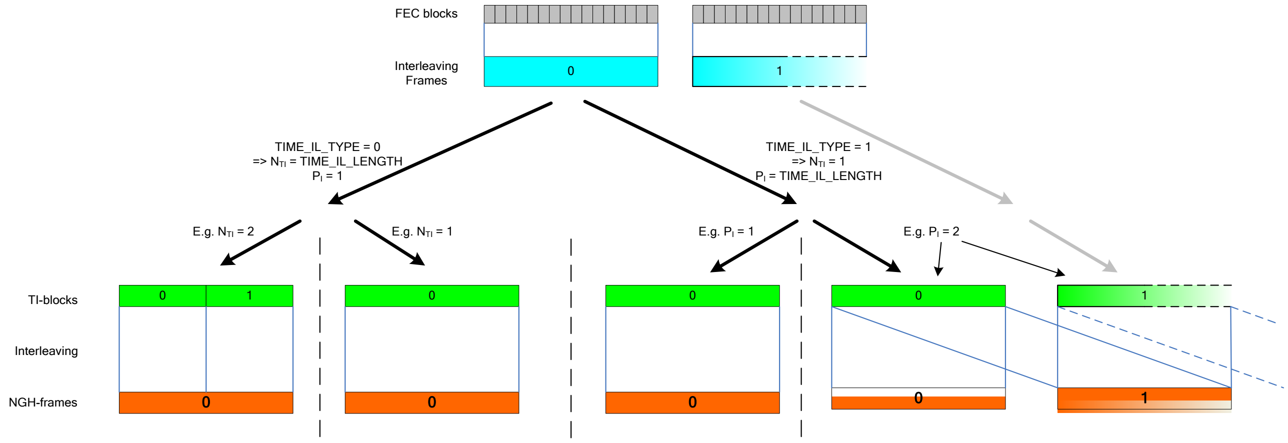


Figure 31: Time interleaving for TIME_IL_TYPE = 0 and 1, and for TIME_IL_LENGTH = 1 and 2 (with PLP_LF_INTERVAL = 1)

6.6.1 Division of interleaving frames into time interleaving blocks

The time interleaver interleaves cells over one TI block, which contains a dynamically variable integer number of FEC blocks.

In one interleaving frame there may be one or more TI blocks. The number of TI blocks in an interleaving frame, denoted by N_{TI}, shall be an integer and is signalled in the L1 configurable signalling by TIME_IL_LENGTH in conjunction with TIME_IL_TYPE.

NOTE: If an interleaving frame extends over multiple logical frames (TIME_IL_TYPE = ‘1‘), then N_{TI} is always equal to 1, i.e. one interleaving frame contains exactly one TI block.

The number of FEC blocks in TI block index '*s*' of interleaving frame '*n*' is denoted by $N_{FEC\_TI}(n,s)$, where $0 \leq s < N_{TI}$.

If N_{TI} = 1, then there will be only one TI-block, with index s=0, per Interleaving Frame and $N_{FEC\_TI}(n,s)$ shall be equal to the number of FEC blocks in the Interleaving Frame, $N_{BLOCKS\_IF}(n)$.

If $N_{TI} > 1$, then the value of $N_{FEC\_TI}(n,s)$ for each TI-block (index *s*) within the Interleaving Frame (index *n*) shall be calculated as follows:

$$N_{FEC\_TI}(n,s) = \begin{cases} \left\lfloor \dfrac{N_{BLOCKS\_IF}(n)}{N_{TI}} \right\rfloor & s < N_{TI} - [N_{BLOCKS\_IF}(n) \bmod N_{TI}] \\ \left\lfloor \dfrac{N_{BLOCKS\_IF}(n)}{N_{TI}} \right\rfloor + 1 & s \geq N_{TI} - [N_{BLOCKS\_IF}(n) \bmod N_{TI}] \end{cases}$$

This ensures that the values of $N_{FEC\_TI}(n,s)$ for the TI-blocks within an Interleaving Frame differ by at most one FEC block and that the smaller TI-blocks come first.

$N_{FEC\_TI}(n,s)$ may vary in time from a minimum value of 0 to a maximum value $N_{FEC\_TI\_MAX}$. $N_{FEC\_TI\_MAX}$ may be determined from $N_{BLOCKS\_IF\_MAX}$ (see clause 6.6) by the following formula:

$$N_{FEC\_TI\_MAX} = \left\lceil \frac{N_{BLOCKS\_IF\_MAX}}{N_{TI}} \right\rceil$$

Any TI configuration and the payload scheduling have to adhere to the Receiver Buffer Model in clause C1.1.

The FEC blocks at the input shall be assigned to TI-blocks in increasing order of *s*. Each TI-block shall be interleaved as described in clauses 6.6.2 and 6.6.3 and then the cells of each interleaved TI-block shall be concatenated together to form the Time Interleaver's output.

6.6.2 Writing of each TI-block into the time interleaver

The input of the TI are the cells ($g_{n,s,0,0}, g_{n,s,0,1},\ldots,g_{n,s,0,\mathrm{Ncells}-1}, g_{n,s,1,0}, g_{n,s,1,1},\ldots, g_{n,s,1,N\mathrm{cells}-1}, \ldots, g_{n,s,N\mathrm{FEC\_TI}(n,s)-1,0}, g_{n,s,N\mathrm{FEC\_TI}(n,s)-1,1},\ldots, g_{n,s,N\mathrm{FEC\_TI}(n,s)-1,N\mathrm{cells}-1}$) of the $N_{FEC\_TI}(n,s)$ FEC blocks from the output of the component interleaver, where $g_{n,s,r,q}$ is the output cell g_q from the component interleaver for the *r*-th FEC block belonging to the current TI-block *s* of the current Interleaving Frame *n*. Observe that r represents the index of the FEC block inside the TI-block and that q represents the cell index inside the FEC block.

Note that for interleaving over multiple logical frames (TIME_IL_TYPE = '1'), there is only 1 TI-block per Interleaving Frame, hence we always have $s = 0$ in this case.

Each FEC block is partitioned into $N_{\mathrm{IU}} = P_{\mathrm{I}}$ Interleaver Units (IUs). For this we define the minimum IU length $L_{\mathrm{IU,min}} = \mathrm{floor}(N_{cells}/N_{IU})$, where floor(*x*) is the largest integer ≤ *x*.

- the first $N_{\mathrm{large}} = N_{\mathrm{cells}} \bmod N_{\mathrm{IU}}$ IUs contain $L_{\mathrm{IU,min}} + 1$ cells, where cells $g_{n,s,r,k\cdot(L_{\mathrm{IU,min}}+1)}$ to $g_{n,s,r,(k+1)\cdot(L_{\mathrm{IU,min}}+1)-1}$ go to the k-th IU ($k = 0,..,N_{\mathrm{large}} - 1$). Here mod represents the modulo-operation.
- the following $N_{\mathrm{IU}} - N_{\mathrm{large}}$ IUs contain $L_{\mathrm{IU,min}}$ cells, where cells $g_{n,s,r,k\cdot L_{\mathrm{IU,min}}+N_{\mathrm{large}}}$ to $g_{n,s,r,(k+1)\cdot L_{\mathrm{IU,min}}+N_{\mathrm{large}}-1}$ go to the k-th IU ($k = N_{\mathrm{large}},..,N_{\mathrm{IU}} - 1$)
- Observe that all N_{IU} IUs contain exactly $L_{\mathrm{IU,min}}$ cells for the case where N_{cells} is an integer multiple of N_{IU} such that $N_{\mathrm{large}} = 0$.

The cells of each IU are now grouped into memory units (MU). These are the units in which the TI memory is written and read. An MU can correspond to one or two cells, depending on the used signal constellation:

For QPSK and 16-QAM modulation, a pair of two consecutive cells of the IU become one MU. This case is called pairwise interleaving. The first N_{large} IUs (the 'large' IUs) contain therefore

$M_{\text{large}} = \text{ceil}(\,(L_{\text{IU,min}} + 1)/2)$ MUs each, where ceil(x) is the smallest integer ≥ x. The following $N_{\text{IU}} - N_{\text{large}}$ 'small' IUs contain $M_{\text{small}} = \text{ceil}(L_{\text{IU,min}}/2)$ cells each. If the number of cells in the IU is odd, then the last MU contains only one cell (and padding instead of a second cell). Observe that the case $M_{\text{large}} = M_{\text{small}}$ is possible.

For 64- and 256-QAM, pairwise interleaving isnot used, and one cell corresponds directly to one MU, i.e. the first N_{large} IUs contain $M_{\text{large}} = L_{\text{IU,min}} + 1$ MUs each, while the following $N_{\text{IU}} - N_{\text{large}}$ IUs contain $M_{\text{small}} = L_{\text{IU,min}}$ MUs each. No padding is required in the last MU of an IU.

There are N_{IU} block interleavers for the IUs of the FEC blocks in the current TI-block of the current Interleaving Frame. All of them have $N_{\text{FEC\_TI\_MAX}}$ columns. The first N_{large} block interleavers have M_{large} rows, while the remaining $N_{\text{IU}} - N_{\text{large}}$ block interleavers have M_{small} rows. Each element in the block interleaver corresponds to one MU.

The k-th IU of all of these FEC blocks is written column-wise into the k-th block interleaver, where the r-th column contains the IU from FEC block r. When pairwise interleaving is used, both cells in an MU are written together. When $N_{\text{FEC\_TI}} < N_{\text{FEC\_TI\_MAX}}$, then there are unused columns in the block interleavers. The writing process is shown in figure 32.

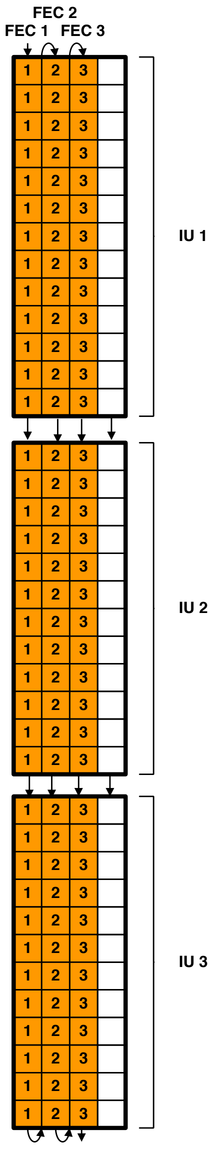


Figure 32: Writing process for a (hypothetical) example with $N_{\mathrm{IU}} = 3$, $N_{\mathrm{cells}} = 37$, , $N_{\mathrm{FEC\_TI}} = 3$, and $N_{\mathrm{FEC\_TI\_MAX}} = 4$ (non-pairwise case).

If inter-frame interleaving is not used (P_{I} for TIME_IL_TYPE = '0' or '1'), the same procedure is used as described above. Accordingly, there is only $N_{\mathrm{IU}} = P_{\mathrm{I}} = 1$ block interleaver with $N_{\mathrm{FEC\_TI\_MAX}}$ columns and M_{small} rows. For $N_{\mathrm{TI}} > 1$ TI-blocks per Interleaver Frame, this block interleaver is sequentially used several times for each logical frame.

6.6.3 Mapping of interleaving frames onto one or more logical frames

Each TI-block is either mapped directly onto one logical frame or spread out over several logical frames. The frame sequence, that one TI-block is spread over, contains $L_{\mathrm{TI}} = (P_{\mathrm{I}} - 1) \cdot I_{\mathrm{JUMP}} + 1$ logical frames.

Note: L_{TI} accounts for the complete length of the sequence, over which one TI-block is spread, including the gaps caused by the jumping over I_{JUMP} logical frames, while P_{I} counts only those logical frames, that actually carry content from the TI-block.

The TI uses N_{IU} delay values in order to achieve this temporal spreading. Each delay $D(k)$ is an integer multiple of logical frames. It is calculated as follows for delay index $k = 0,..,N_{\mathrm{IU}} - 1$:

$$D(k) = k \cdot I_{\mathrm{JUMP}}.$$

For each TI-block in each Interleaving Frame, the k-th IU is read $D(k)$ logical frames later than when it was written.

The reading for the next logical frame to be transmitted (index m) is done row-wise in the following order, where $j = 0,..,M_{\mathrm{small}} - 1$ is the row index. We start with row $j = 0$.

Start with block interleaver $k = 0$. Read all used MUs of the k-th block interleaver, that was written in Interleaving Frame $m - D(k)$, rightwards along row j beginning with the left-most column. Unused MUs are skipped. For pairwise interleaving, both cells contained in an MU are read together. Then continue with the $k + 1^{\mathrm{st}}$ block interleaver in the same way.

When the used MUs in row j have been read in this way from all N_{IU} corresponding block interleavers, then we continue with row $j + 1$, until row $j = M_{\mathrm{small}} - 1$ has been read.

Finally,if $N_{\mathrm{large}} > 0$ and $M_{\mathrm{large}} = M_{\mathrm{small}} + 1$, then there is one more row $j = M_{\mathrm{small}}$, that is read in the same way as the previous rows (i.e. skipping unused columns), but only the first N_{large} block interleavers are read that contain $M_{\mathrm{small}} + 1$ rows.

In the bottom row (either with $j = M_{\mathrm{small}} - 1$ or $j = M_{\mathrm{small}}$), any padding present in the MUs is skipped.

The output of the time interleaver is the sequence of cells read in the described way. In the case of pairwise interleaving, the order within each pair is the same after reading as before writing.

When all rows have been read from a block interleaver, then this block interleaver is not needed any more in the modulator and can be discarded. Therefore, the delaying of the block interleavers can be considered as a delay line structure as depicted in figure 33.

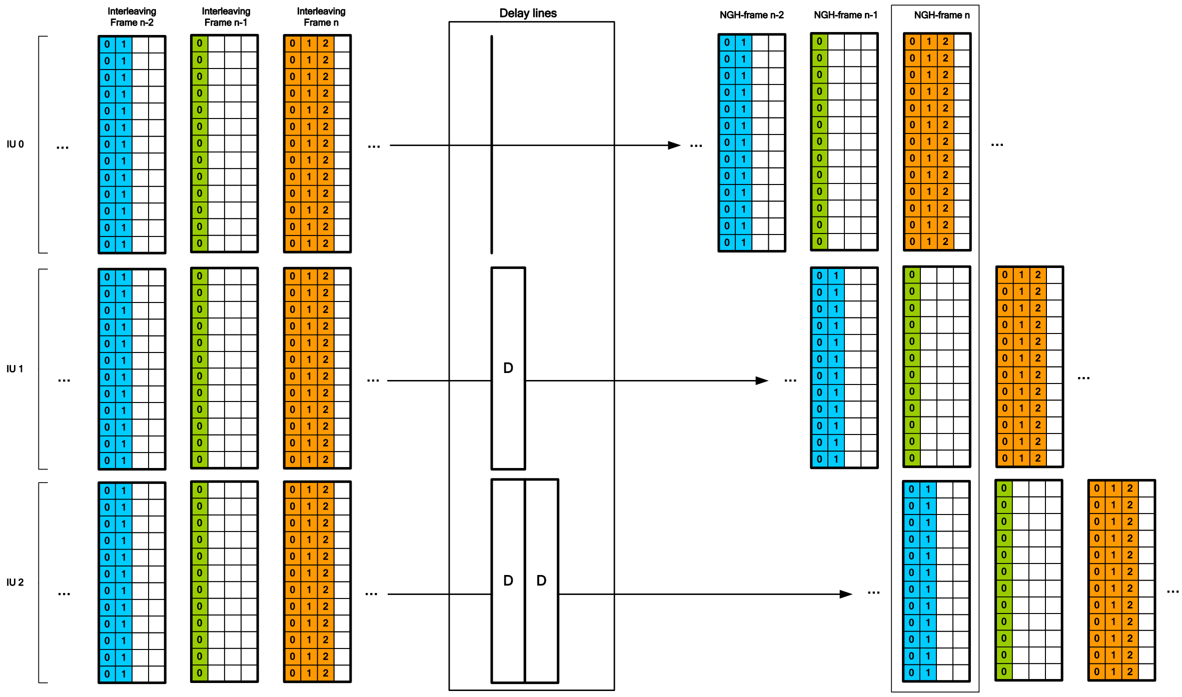


Figure 33: Delaying process for a (hypothetical) example with $N_{\mathrm{IU}} = 3$, $N_{\mathrm{cells}} = 37$, $N_{\mathrm{FEC\_TI}} = 2$, 1 and 3, and $N_{\mathrm{FEC\_TI\_MAX}} = 4$ (for $I_{\mathrm{JUMP}} = 1$) (non-pairwise case).

For TIME_IL_TYPE = 1, N_{IU} block interleavers are written per Interleaving Frame (as there is only 1 TI-block), and for $P_{\mathrm{I}} > 1$ the above reading operation accesses block interleavers from different Interleaving Frames. Figure 34 shows an example of the reading process.

For TIME_IL_TYPE = 0, only $N_{\mathrm{IU}} = 1$ block interleaver is written column-wise per TI-block per Interleaving Frame, and only this block interleaver is read row-wise to generate the output for the current TI-block (as we have $P_{\mathrm{I}} = 1$ for this option). The following TI-block in the same Interleaving Frame is treated in the same way, and its generated output is appended to the output generated for the previous TI-blocks. An example for this is displayed in figure 35.

Observe that the number of used columns can vary among the block interleavers, as this number is strictly linked to the dynamic parameter N_{BLOCKS_IF} = PLP_NUM_BLOCKS of the Interleaving Frame, when the corresponding block interleaver was written.

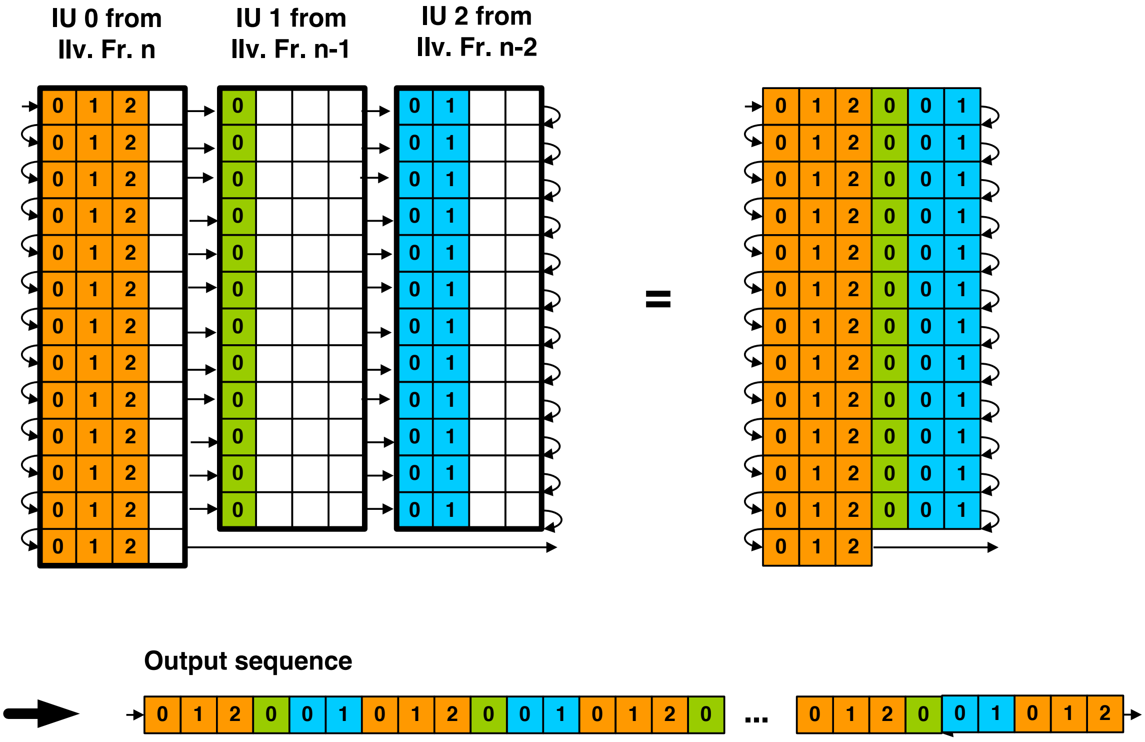


Figure 34: Reading process and generated output for a (hypothetical) example with $N_{\text{IU}} = 3$, $N_{\text{cells}} = 37$, $N_{\text{FEC\_TI}} = 2$, 1 and 3, and $N_{\text{FEC\_TI\_MAX}} = 4$ (for $I_{\text{JUMP}} = 1$) (non-pairwise case).

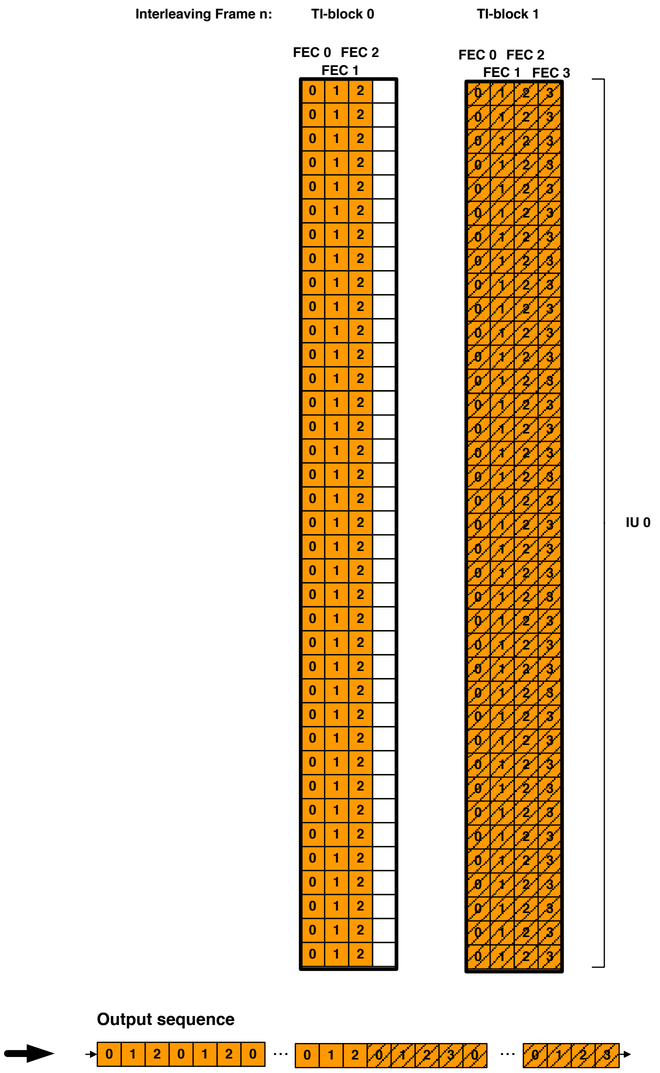


Figure 35: Time interleaving in a hypothetical example for $N_{:\text{TI}} = 2$ TI-blocks per Interleaving Frame, $N_{\text{cells}} = 37$, $N_{\text{FEC\_TI}} = 3$ and 4, and $N_{\text{FEC\_TI\_MAX}} = 4$ (non-pairwise case). Writing is done column-wise, reading is done row-wise.

6.6.4 Number of cells available in the time interleaver

A single large TI memory in the transmitter and a single large Time De-Interleaver (TDI) memory in the receiver shall be shared by all PLPs in a given PLP cluster (for the definition of a PLP cluster, see clause 3.1).

The admissible TI configurations in the transmitter is indirectly specified by the acceptable TDI configurations in the receiver, which is defined as follows:

The total size of the TDI memory for time de-interleaving all PLPs associated with a service is 2^{18} memory units (MU). An MU is an abstract entity, which corresponds simply to 2 cells for all PLPs with QPSK and 16-QAM, and to 1 cell for all PLPs with 64-QAM, NU-64-QAM, 256-QAM and NU-256-QAM modulation.

For any one PLP, its required number of MUs is calculated as follows:

$$N_{\text{MUs,PLP}} = \sum_{k=0}^{N_{\text{large}}-1} M_{\text{large}} \cdot N_{\text{FEC\_TI\_MAX}} \cdot [L_{\text{TI}} - D(k)] + \sum_{k=N_{\text{large}}}^{N_{\text{IU}}-1} M_{\text{small}} \cdot N_{\text{FEC\_TI\_MAX}} \cdot [L_{\text{TI}} - D(k)]$$

It means that when adding up the number $N_{\mathrm{MUs,PLP}}$ of required MUs of all PLPs in a given PLP cluster, the sum shall not exceed 2^{18}.

Any valid NGH configuration must ensure that the above condition is satisfied. Besides this condition, every NGH configuration and the employed payload scheduling have to ensure that the Receiver Buffer Model as described in Annex C.2 is respected.

6.6.5 PLPs for which time interleaving is not used

If time interleaving is not used (i.e. TIME_IL_LENGTH=0), the output of the time interleaver shall consist of the cells presented at the input in the same order and without modification. In this case, when the term Interleaving Frame is used elsewhere in the present document, it shall be taken to mean logical frame.

Note: the time interleaver will typically act as a buffer for PLP data and therefore the output may be delayed by a varying amount with respect to the input even when time interleaving is not used. In this case, a compensating delay for the dynamic configuration information from the scheduler will still be required, as shown in figure 4.

7 Distributed and cross-polar MISO

7.1 System overview

A MISO transmission option is included in the base profile in order to exploit the diversity advantage made possible by the use of multiple transmission elements either co-sited or distributed. Channel estimation suitable for MISO is provided by an appropriate pilot structure during MISO frames, which may form part of a transmission also including SISO frames. Within MISO frames, all data and signalling must have the MISO format except for the P1 and AP1 which are never MISO encoded.

7.2 Transmit/receive system compatibility

To make use of MISO transmissions, the proposed transmission architecture must include either

1. *Distributed SFN application*: SFN-based SISO transmitting stations are to be assigned in pairs to groups 1 and 2, i.e. each carrying a different component of the MISO transmission

or

2. *Cross-polar MISO application*: Individually-fed co-sited cross-polar antennas (horizontal (HP) and vertical polarisation (VP)). To receive and decode the MISO signal, a cross-polar receive antenna is recommended but a single antenna is sufficient.

7.3 MISO precoding

MISO processing is applied at PLP level (all PLPs in a MISO frame must be MISO) and consists of taking sets of two QAM symbols and producing MISO encoded sets of two data cells at the output to be directed to the two antennas. MISO processing is never applied to the preamble symbols P1 or AP1 and the pilots are processed as described in clause 11.1.9. The encoding process is carried out on pairs of normalised QAM symbols, f_q, f_{q+1} from the output of the time interleaver (clause 6.6). For MISO these must be drawn from the same constellation. The encoded OFDM payload cells $g_q(Tx1)$, $g_q(Tx2)$, $g_{q+1}(Tx1)$ and $g_{q+1}(Tx2)$ for transmit antennas 1 and 2 shall be generated from the input symbols according to:

$$\begin{bmatrix} g_q(Tx1) & g_q(Tx2) \\ g_{q+1}(Tx1) & g_{q+1}(Tx2) \end{bmatrix} = \begin{bmatrix} f_q & -f_{q+1}^* \\ f_{q+1} & f_q^* \end{bmatrix}$$

$$q = 0,2,4,6..,N_{data} - 2$$

where * denotes the complex conjugation operation and N_{data} is the number of cells required to transmit one LDPC block by using MISO encoding which is calculated by $N_{\mathrm{ldpc}}/n_{\mathrm{bpcu}}$.

Pairs of constellation points generated by MISO encoding for a particular transmitter must be kept together at the output by use of a pairwise frequency interleaver (clause 9.11).

NOTE 1: The MISO processing for MISO transmitter group 1 copies the input cells unmodified to the output.

NOTE 2: It is necessary that both parts of a MISO encoded pair of cells are located in the same OFDM symbol.

7.4 Block diagram

The block diagram of the scheme for MISO frame generation is shown in figure 36.

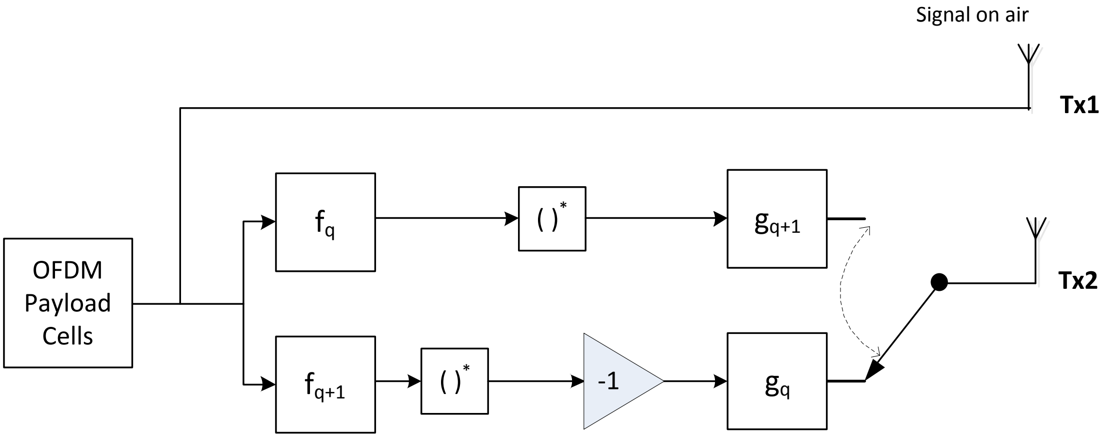


Figure 36: MISO frame generation in NGH transmssion chain

The encoding process is repeated for each pair of payload cells in turn. MISO processing shall not be applied to the P1 and AP1 symbols. The contents of the P1 and AP1 symbols will be identical between the two groups of transmitters.

If MISO is not used, the input cells shall be copied directly to the output, i.e. $g_p = f_p$. for p=0,1,2,...,N_{data}-1.

7.5 eSFN processing for MISO

eSFN is applied at frame level to modulate the OFDM symbols using the eSFN predistortion term Φ_k as described in clause 11.4.1.

The principle role of eSFN in this context is application to SISO frames as part of transmission containing both SISO and MISO frames. This applies to both distributed SFN and cross-polar MISO applications. Each SISO transmission element is assigned a different Tx ID. It may also be used in conjunction with the MISO transmission (i.e. Alamouti coding) if the transmitter ID function is required to be present during both frame types.

7.6 Power imbalance

MISO transmission is specified for use with one of three fixed power imbalances (e.g. in the cross-polar case the HP/VP or VP/HP power ratio), in order to facilitate time-sharing with SISO services without undesired station envelope power fluctuations or excessive SISO link budget loss.

The available power imbalances are 0 dB, 3 dB and 6 dB.

The imbalance may be optionally applied during all PLP and both frame types, i.e. SISO and MISO. Where Alamouti coding is used in a cross-polar context an imbalancing matrix may be introduced as follows, the value of β taken from table 30.

$$\begin{bmatrix} g'_q(Tx1) \\ g'_q(Tx2) \end{bmatrix} = \begin{bmatrix} \sqrt{\beta} & 0 \\ 0 & \sqrt{1-\beta} \end{bmatrix} \begin{bmatrix} g_q(Tx1) \\ g_q(Tx2) \end{bmatrix}$$
$$q = 0 \ldots N_{data} - 1$$

In the case of cross-polar transmission, during SISO frames, the two transmission elements may be generated as

$$\begin{bmatrix} g'_q(Tx1) \\ g'_q(Tx2) \end{bmatrix} = \begin{bmatrix} \sqrt{\beta} & 0 \\ 0 & \sqrt{1-\beta} \end{bmatrix} \begin{bmatrix} g_q \\ g_q \end{bmatrix}$$
$$q = 0 \ldots N_{data} - 1$$

Table 30: Power imbalance parameter β

Intentional power imbalance between two Tx antennas	0 dB	3 dB	6 dB
β	1/2	1/3	1/5

Note 1: For the distributed Alamouti application, the 0 dB imbalance is usually appropriate.

Note 2: If the specified options for fixed power imbalance are not used, and envelope power fluctuations are acceptable, then the MISO frames are transmitted with 0 dB power imbalance and the SISO on a single polarisation (infinite imbalance).

7.7 SISO/MISO options for P1, aP1 and P2 symbols

Table 31 specifies the SISO/MISO coding options applicable to P1, aP1 and P2 symbols.

Table 31: P1, aP1 and P2 SISO/MISO coding options

Symbol type	P1/AP1	P2	P2	P2	Data Symbols

Frame type					
		L1-pre	**L1-post**	**Data**	
SISO	Uncoded SISO or eSFN	Uncoded SISO or eSFN	Uncoded SISO or eSFN	Uncoded SISO or eSFN	Uncoded SISO or eSFN
MISO	Uncoded SISO or eSFN	Alamouti	Alamouti	Alamouti	Alamouti

NOTE: When Alamouti is used, eSFN may be optionally added with a unique tx code applied per station or per antenna

8 Generation, coding and modulation of layer 1 signalling

8.1 Introduction

This clause describes the layer 1 (L1) signalling. The L1 signalling provides the receiver with a means to access physical layer pipes within the NGH frames. **Error! Reference source not found.** illustrates the L1 ignalling structure, which is split into three main sections: the P1 signalling, the L1-PRE signalling and the L1-POST signalling. The purpose of the P1 signalling, which is carried by the P1 symbol in every NGH frame, is to indicate the transmission type and basic transmission parameters. The L1-PRE signalling, which is carried in every NGH frame, enables the reception and decoding of the L1-POST signalling, which in turn conveys the parameters needed by the receiver to access the physical layer pipes. The L1-POST signalling is carried in every logical frame, and is further split into two main parts: configurable and dynamic, and these may be followed by an optional extension field. The L1-POST finishes with a CRC and padding (if necessary). For more details of the frame structure, see clause 9.

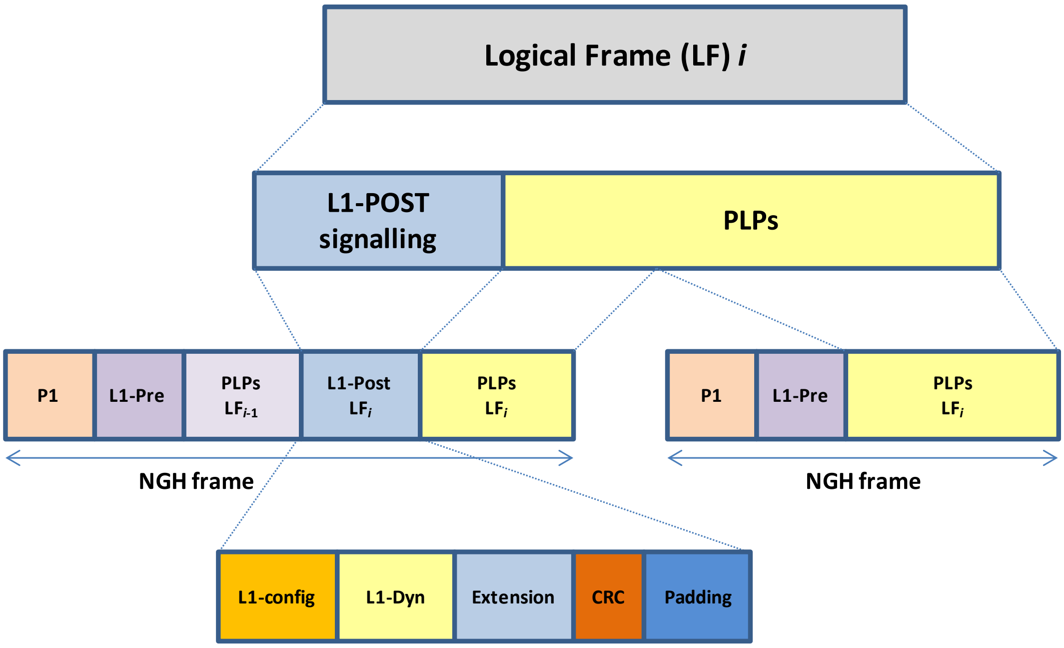


Figure 37: The L1 signalling structure.

8.1 L1 signalling data

All signalling data in L1-PRE, except those associated with the mapping of logical channels to the NGH frames, shall remain unchanged for the entire duration of one super-frame. Hence any changes implemented to this data of L1-PRE signalling shall be always done within the border of two super-frames. Sub-clause 8.1.2 defines the L1-PRE signalling data and describes which fields shall remain unchanged for the entire duration of one super-frame.

All signalling data in the configurable part (L1-CONF) of the L1-POST signalling shall remain unchanged for the entire duration of one logical super-frame. Hence any changes implemented to L1-CONF shall be always done within the border of two logical super-frames.

8.1.1 P1 signalling data

The P1 symbol has the capability to convey 7 bits for signalling. Since the preamble (both P1 and P2 symbols) may have different formats, the main use of the P1 signalling is to identify the preamble itself. The information it carries is of two types: the first type (associated to the S1 bits of the P1) is needed to distinguish the preamble format (and, hence, the frame type); the second type (associated to the S2 bits of the P1) helps the receiver to rapidly characterize the basic TX parameters.

The S1 field: Preamble Format:

- The preamble format is carried in the S1 field of the P1 symbol. It identifies the format of the P2 symbol(s) that take part of the preamble.

Table 32: S1 Field

S1	Preamble Format / P2 Type	Description
000	T2_SISO	The preamble is a preamble of a T2-base signal [i.1] and the P2 part is transmitted in its SISO format.
001	T2_MISO	The preamble is a preamble of a T2-base signal [i.1] and the P2 part is transmitted in its MISO format.
010	Non-T2	See table 19(b) in [i.1].
011	T2_LITE_SISO	The preamble is a preamble of a T2-Lite signal (annex I in [i.1]) and the P2 part is transmitted in its SISO format.
100	T2_LITE_MISO	The preamble is a preamble of a T2-Lite signal (annex I in [i.1]) and the P2 part is transmitted in its MISO format.
101	NGH_SISO	The preamble is a preamble of an NGH signal and the P2 part is transmitted in its SISO format.
110	NGH_MISO	The preamble is a preamble of an NGH signal and the P2 part is transmitted in its MISO format.
111	ESC	General escape code. The current P1 may be followed with an additional symbol providing additional signalling.

The S2 field 1 (the first 3 bits of the S2 field): Complementary information:

- When the preamble format is of the type T2_SISO, T2-MISO, T2_LITE_SISO or T2_LITE_MISO, S2 field 1 indicates the FFT size and gives partial information about the guard interval for the remaining symbols in the T2-frame, as described in table 19(a) in [i.1]. When the preamble is of the type "Non-T2", S2 field 1 is described by table 19(b) in [i.1].
- When the preamble format is of the type NGH_SISO, or NGH_MISO, S2 field 1 indicates the FFT size and gives partial information about the guard interval for the remaining symbols in the NGH-frame, as described in table 33 below.
- When the preamble is of the type "ESC", the value of the S2 field 1 shall be defined as described in table 34 below.

Table 33: S2 Field 1 (for NGH preamble types, S1=101, and 110)

S2 field 1	S2 field 2	FFT/GI size	Description
000	X	FFT Size: 1K – any allowed guard interval	Indicates the FFT size and guard interval of the symbols in the NGH-frame
001	X	FFT Size: 2K – any allowed guard interval	
010	X	FFT Size: 4K – any allowed guard interval	
011	X	FFT Size: 8K – guard intervals 1/32; 1/16; 1/8 or 1/4	
100	X	FFT Size: 8K – guard intervals 1/128; 19/256 or 19/128	
101	X	FFT Size: 16K – guard intervals 1/128; 19/256 or 19/128	
110	X	FFT Size: 16K – guard intervals 1/32; 1/16; 1/8 or 1/4	
111	X	Reserved for future use	

Table 34: S2 Field 1 (for ESC preamble, S1=111).

S2 field 1	S2 field 2	Meaning	Description
000	X	Preamble format of the NGH MIMO signal	The preamble P1 is a preamble of an NGH MIMO signal. P1 is followed by an aP1 symbol with the signalling format described in clause 21.1.
001	X	Preamble format of the NGH hybrid SISO signal	The preamble P1 is a preamble of an NGH hybrid SISO signal. P1 is followed by an aP1 symbol with the signalling format described in clause 21.1.
010	X	Preamble format of the NGH hybrid MISO signal	The preamble P1 is a preamble of an NGH hybrid MISO signal. P1 is followed by an aP1 symbol with the signalling format described in clause 21.1.
011	X	Preamble format of the NGH hybrid MIMO signal	The preamble P1 is a preamble of an NGH hybrid MIMO signal. P1 is followed by an aP1 symbol with the signalling format described in clause 21.1.
100-111	X	Reserved for future use	Reserved for future use.

The S2 field 2: 'Mixed' bit:

- This bit indicates whether the preambles are all of the same type or not. The bit is valid for all values of S1 and S2 field 1. The meaning of this bit is given intable 35.

Table 35: S2 field 2.

S1	S2 field 1	S2 field 2	Meaning	Description
XXX	XXX	0	Not mixed	All preambles in the current transmission are of the same type as this preamble.
XXX	XXX	1	Mixed	Preambles of different types are transmitted.

The modulation and construction of the P1 symbol is described in clause 11.7.2. The modulation and construction of the aP1 symbol is described in clause 11.7.3.2.

8.1.2 L1-PRE signalling data

Error! Reference source not found. illustrates the signalling fields of the L1-PRE signalling, followed by the etailed definition of each field.

Table 36: The signalling fields of L1-PRE.

TYPE	8
BWT_EXT	1
S1	3
S2	4
aP1	7

For i=0..3{
EBF_PREAMBLE
}
	4

EBF_GAP_1	24
EBF_GAP_2	24
FEF_PREAMBLES	14
FEF_LENGTH	22
FEF_INTERVAL	14
GUARD_INTERVAL	3
PILOT_PATTERN	4
OLSI_PILOT_PATTERN	3
OLSI_START_SYMBOL	12
OLSI_NUM_SYMBOLS	9
PAPR	4
POWER_IMBALANCE	3
PH_FLAG	1

L1_POST_MOD	4
L1_POST_COD	2
L1_POST_FEC_TYPE	2
L1_REPETITION_FLAG	1
L1_POST_EXTENSION	1
L1_POST_SIZE	18
L1_POST_CONF_SIZE	12
L1_POST_DYN_CURRENT_SIZE	12
L1_POST_DYN_NEXT_SIZE	12
L1_POST_EXT_SIZE	8
L1_POST_AP_RATIO_CURRENT	2
L1_POST_AP_SIZE_NEXT	18
L1_POST_MIMO	4
L1_POST_NUM_BITS_PER_CHANNEL_USE	3
L1_POST_DELTA	24
CELL_ID	16
NETWORK_ID	16
NGH_SYSTEM_ID	16
NUM_EBFS	8
NUM_SYMBOLS	12
FRAME_INTERVAL	24
FRAME_IDX	8
REGEN_FLAG	3
LC_GROUP_ID	2
LC_NUM	3
LC_ID	3
LC_TYPE	3
LC_NUM_RF	3
LC_CURRENT_FRAME_RF_IDX	3
LC_CURRENT_FRAME_RF_POS	3
LC_NEXT_FRAME_RF_IDX	3
LC_NEXT_FRAME_DELTA	24
NGH_VERSION	4
RESERVED	9

CRC_32	32

TYPE: This 8-bit field indicates the types of the Tx input streams carried within the current NGH super-frame. The mapping of different types is given intable 37.

Table 37: The mapping of Tx input stream types.

Value	Type
0x00	Transport Stream (TS) [1] only
0x01	Generic Stream (GSE [3] and/or GCS) but not TS
0x02	Both TS and Generic Stream (i.e. TS and at least one of GSE, GCS)
0x03 to 0xFF	Reserved for future use

NOTE: For Transport Steams (TYPE = 0x00), header compression may be used as described in clause 5.1.1.1.

BWT_EXT: This 1-bit field indicates whether the extended carrier mode is used in the case of 8K and 16K FFT sizes. When this field is set to '1', the extended carrier mode is used. If this field is set to '0', the normal carrier mode is used. See clause 11 for more details on the extended carrier mode.

S1: This 3-bit field has the same value as in the P1 signalling.

S2: This 4-bit field has the same value as in the P1 signalling.

aP1: This 7-bit field has the same value as in the aP1 signalling when the aP1 preamble is used (i.e. S1 = ‘111’ and S2 field 1 = ‘000’). If aP1 is not used, this field does not carry any useful information (dummy field).

The following loop consists of four instances of a single parameter – EBF_PREAMBLE. This enables four frame types (preamble formats) to be configured in an EBF. The order of signalling is equivalent to the order of frame types in the current EBF. These frame types can (partly) be identical. The related frames belong to the same NGH system as the current frame. The described frame sequence is repeated throughout the same super-frame.

EBF_PREAMBLE: This 4-bit field indicates the preamble format of a frame being part of the same NGH system. The value “0000” indicates that there is no other preamble/frame in this EBF. The values of this field are given in table38.

Table 38: Signalling format for EBF_PREAMBLE

Value	Description
0000	No further preamble
0001	The remaining part carries a preamble of a T2 SISO signal [i.1].
0010	The remaining part carries a preamble of a T2 MISO signal [i.1].
0011	The remaining part carries a preamble of a T2 LITE SISO signal [i.1].
0100	The remaining part carries a preamble of a T2 LITE MISO signal [i.1].
0101	The remaining part carries a preamble of an NGH SISO base profile signal.
0110	The remaining part carries a preamble of an NGH MISO base profile signal.
0111	The remaining part carries a preamble of an NGH MIMO profile signal (see part II of the present document).
1000	The remaining part carries a preamble of an NGH hybrid SISO profile signal (see part III of the present document).
1001	The remaining part carries a preamble of an NGH hybrid MIMO profile signal (see part IV of the present document).
1010 to 1111	Reserved for future use

EBF_GAP_1: This 24 bit field indicates the duration in elementary samples of the first NGH frame following the current NGH frame and belonging to the same EBF as the current NGH frame whose preamble type is different from the current preamble type. For configurations in which all the following NGH frames in the EBF are of the same preamble type as the current NGH frame, this field shall be set to zero.

EBF_GAP_2: This 24 bit field indicates the duration in elementary samples of the second NGH frame following the current NGH frame that belongs to the same EBF as the current NGH frame but whose preamble type is different from the current NGH frame preamble type. For configurations in which all the following NGH frames in the EBF are of the same preamble type as the current NGH frame, this field shall be set to zero.

FEF_PREAMBLES: This 14-bit field indicates the presence of a given preamble associated with a given signal in the FEF part of the current NGH signal. The values of this field are given in table 39below.

Table 39: Signalling format for FEF PREAMBLES

Value	Description
xxxxxxxxxxxxx1	The FEF part carries a preamble of a T2 SISO signal [i.1].
xxxxxxxxxxxx1x	The FEF part carries a preamble of a T2 MISO signal [i.1].
xxxxxxxxxxx1xx	The FEF part carries a preamble of a T2 LITE SISO signal [i.1].
xxxxxxxxxx1xxx	The FEF part carries a preamble of a T2 LITE MISO signal [i.1].
xxxxxxxxx1xxxx	The FEF part carries a preamble of an NGH SISO base profile signal.
xxxxxxxx1xxxxx	The FEF part carries a preamble of an NGH MISO base profile signal.
xxxxxxx1xxxxxx	The FEF part carries a preamble of an NGH MIMO profile signal (see part II of the present document).
xxxxxx1xxxxxxx	The FEF part carries a preamble of an NGH hybrid SISO profile signal (see part III of the present document).
xxxxx1xxxxxxxx	The FEF part carries a preamble of an NGH hybrid MIMO profile signal (see part IV of the present document).
xxxx1xxxxxxxxx to x1xxxxxxxxxxxx	Reserved for future use
1xxxxxxxxxxxxx	The FEF part carries a TX-SIG [4]

FEF_LENGTH: This 22-bit field indicates the length of the FEF part of the current NGH signal as the number of elementary periods T (see clause 9.10), from the start of the P1 symbol of the FEF part to the start of the P1 symbol of the next NGH frame of the current NGH signal.

FEF_INTERVAL: This 8-bit field indicates the number of NGH frames between two FEF parts (see clause 9.8) of the current NGH signal. The NGH frame shall always be the first frame in the NGH super-frame which contains both FEF parts and NGH frames of the current NGH signal.

GUARD_INTERVAL: This 3-bit field indicates the guard interval of the current super-frame, according totable 40.

Table 40: Signalling format for the guard interval

Value	Guard interval fraction
000	1/32
001	1/16
010	1/8
011	1/4
100	1/128
101	19/128
110	19/256
111	Reserved for future use

PILOT_PATTERN: This 4-bit field indicates the scattered pilot pattern used for the data OFDM symbols. Each pilot pattern is defined by the D_x and D_y spacing parameters (see clause 11.1.3.1). The used pilot pattern is signalled according to table 41.

Table 41: Signalling format for the pilot pattern.

Value	Pilot pattern type
0000	PP1
0001	PP2
0010	PP3
0011	PP4
0100	PP5
0101	PP6
0110	PP7
0111 to 1111	Reserved for future use

O_LSI_PILOT_PATTERN: This 3-bit field indicates the scattered pilot pattern used for the data OFDM symbols when Orthogonal Local Service Insertion is used (see clause 10.1.3). The used pilot pattern is signalled according to table 42. A value of "000" of this field indicates that there are no symbols using O-LSI pilots in any NGH frame carrying logical frames of the current logical channel of the current super-frame.

Table 42: Signalling format for the pilot pattern of O-LSI.

Value	Pilot pattern type
000	No O-LSI pilots
001	PP3
010	PP4
011	PP5
100	PP6
101	PP7
110 to 111	Reserved for future use

OLSI_START_SYMBOL: This 12-bit field indicates the symbol number of the first symbol that uses O-LSI pilots in the NGH frames carrying logical frames of the current logical channel of the current super-frames. The value "0xFFF" indicates that there are no symbols using O-LSI pilots in any NGH frame carrying logical frames of the current logical channel of the current super-frame.

OLSI_NUM_SYMBOLS: This 9 bit-field indicates the total number of symbols that use O-LSI pilots in the NGH frames carrying logical frames of the current logical channel of the current super-frame.

PAPR: This 4-bit field describes what kind of PAPR reduction is used, if any. The values shall be signalled according to table 43.

Table 43: Signalling format for PAPR reduction

Value	PAPR reduction
0000	No PAPR reduction is used
0001	ACE-PAPR only is used
0010	TR-PAPR only is used
0011	Both ACE and TR are used
0100 to 1111	Reserved for future use

POWER_IMBALANCE: This 3-bit field indicates the intentional power imbalance between the two transmitter antennas, when a second antenna is used. The value of this field shall be defined according to table 44.

Table 44: Signalling format for POWER_IMBALANCE

Value	Power imbalance (dB)
000	Single antenna transmission
001	0
010	3
011	6
100 to 111	Reserved for future use

PH_FLAG: This 1-bit field indicates if the phase hopping (PH) option is used or not.. In the absence of VMIMO (see annex L) this flag is set to "1". The PH scheme is described in clause 18.2.

Table 45: SIgnalling format for the PH indication

Value	PH mode
0	PH not applied
1	PH applied

L1_POST_MOD: This 4-bit field indicates the constellation of the L1-POST signalling data block. The constellation values shall be signalled according to table 46.

Table 46: Signalling format for the L1-post constellations

Value	Constellation
0000	BPSK
0001	QPSK
0010	16-QAM
0011	64-QAM
0100	NU-64-QAM
0101 to 1111	Reserved for future use

L1_POST_COD: This 2-bit field describes the coding of the L1-POST signalling data block. The coding values shall be signalled according to table 47.

Table 47: Signalling format for the L1-post code rates.

Value	Code rate
00	1/2
01 to 11	Reserved for future use

L1_POST_FEC_TYPE: This 2-bit field indicates the type of the L1 FEC used for the L1-POST signalling data block. The L1_POST_FEC_TYPE shall be signalled according totable 48.

Table 48: Signalling format for the L1-post FEC type.

Value	L1-POST FEC type
00	LDPC 4K
01 to 11	Reserved for future use

L1_POST_REPETITION_FLAG: This 1-bit flag indicates whether the dynamic L1-POST signalling is provided also for the next logical frame. If this field is set to value '1', the dynamic signalling shall be also provided for the next logical frame within this logical frame. When this field is set to value '0', dynamic signalling shall not be provided for the next logical frame within this logical frame. If dynamic signalling is provided for the next logical frame within this logical frame, it shall follow immediately after the dynamic signalling of the current logical frame, see clause 8.1.3.4).

L1_POST_EXTENSION: This 1-bit field indicates the presence of the L1-POST extension field (see clause 8.1.3.6).

L1_POST_SIZE: This 18-bit field indicates the size, in QAM cells, of the coded and modulated L1-post signalling data block for every logical frame in the current logical super-frame. This value is constant during the entire duration of one logical super-frame.

L1_POST_CONF_SIZE: This 12-bit field indicates the size, in bits, of the configurable part of L1 signalling data (L1-CONF) for every logical frame in the current logical super-frame. This value is constant during the entire duration of the current logical super-frame.

L1_POST_DYN_CURRENT_SIZE: This 12-bit field indicates the size, in bits, of the dynamic part of L1 signalling data (L1-DYN) for the current logical frame in the current logical super-frame. This value is constant during the entire duration of the current logical super-frame.

L1_POST_DYN_NEXT_SIZE: This 12-bit field indicates the size, in bits, of the dynamic part of L1 signalling data (L1-DYN) for the next logical frame in the current logical super-frame, when L1-post repetition is used (i.e. L1_POST_REPETITION_FLAG set to ‘1’). If L1_POST_REPETITION_FLAG is set to ‘0’ (i.e. repetition is not used), the value of this field shall be equal to 0. This value is constant during the entire duration of the current logical super-frame.

L1_POST_EXT_SIZE: This 8-bit field indicates the size, in bits, of the extension field for the current logical frame in the current logical super-frame, when the extension field is present in the L1-POST (L1_POST_EXTENSION set to ‘1’). If L1_POST_EXTENSION is set to ‘0’ (i.e. extension field is not present), the value of this field shall be equal to 0. This value is constant during the entire duration of the current logical super-frame.

L1_POST_AP_RATIO_CURRENT: This 2-bit field gives the ratio of the amount of the additional parity bits to the amount of parity bits for every logical frame in the current logical super-frame. This value is constant during the entire duration of the current logical super-frame. Table 49 gives the values of this field. When this field is set to value '00', additional parity shall not be provided for the L1-POST signalling of every logical frame in the current logical super-frame. The construction of additional parity for L1-POST signalling is described in clause 8.2.2.6.

Table 49: Signalling format for L1_POST_AP_RATIO_RATIO_CURRENT.

Value	L1_POST_AP_RATIO_CURRENT
00	0
01	1
10	2
11	3

L1_POST_AP_SIZE_NEXT: This 18-bit field indicates the size, in QAM cells, of the additional parity blocks of L1-POST signalling in every logical frame of the next logical super-frame. This value is constant during the entire duration of the current logical super-frame.

L1_POST_MIMO: This 4-bit field indicates the MIMO scheme of the L1-POST signalling data block. The MIMO schemes shall be signalled as defined in clause 20.2 for the MIMO profile and in clause 32.2 for the hybrid MIMO profile.

L1_POST_NUM_BITS_PER_CHANNEL_USE: This 3-bit field indicates the number of bits per channel use for the MIMO scheme used by L1-POST. The value of this field is defined in clause 20.2 for the MIMO profile and clause 32.2 for the hybrid MIMO profile.

L1-POST_DELTA: This 24-bit field indicates the gap, in QAM cells, between the last cell carrying L1-PRE signalling and the first cell of the first logical frame starting in the current NGH frame. The value (HEX) FFFFFF means that no new logical frame starts in the current NGH frame.

CELL_ID: This is a 16-bit field which uniquely identifies a geographic cell in a DVB-NGH network. A DVB-NGH cell coverage area may consist of one or more frequencies, depending on the number of frequencies used per NGH system. If the provision of the CELL_ID is not foreseen, this field shall be set to '0'.

NETWORK_ID: This is a 16-bit field which uniquely identifies the current DVB network.

NGH_SYSTEM_ID: This 16-bit field uniquely identifies an NGH system within the DVB network (identified by NETWORK_ID).

NUM_EBFS: This 8-bit field indicates the number of EBFs per super-frame. The minimum value of NUM_EBFS shall be 2.

NUM_SYMBOLS: This 12-bit field indicates the length, in OFDM symbols, of the current NGH frame, excluding P1 and aP1 symbols. In the hybrid and hybrid MIMO profiles (Parts III and IV of the present document, respectively), when SC-OFDM is used, this field indicates the length, in SC-OFDM symbols, of the current NGH frame, excluding P1 and aP1 symbols. The minimum value of NUM_SYMBOLS is defined in clause 9.9.1. This value is constant during the entire duration of the current super-frame.

FRAME_INTERVAL: This 24-bit field indicates the number of T periods between two consecutive NGH frames in the current super-frame. The minimum value of FRAME_INTERVAL is defined in clause 9.8. This value is constant during the entire duration of the current super-frame.

FRAME_IDX: This 8-bit field is the index of the current NGH frame within a super-frame. The index of the first frame of the super-frame shall be set to ‘0’.

REGEN_FLAG: This 3-bit field indicates how many times the DVB-NGH signal has been re-generated. Value '000' indicates that no regeneration has been done. Each time the DVB-NGH signal is regenerated this field is increased by one.

LC_GROUP_ID: This 2-bit field gives the ID of the group of logical channels the current logical channel (carried in the current NGH frame) belongs to. It shall be possible to receive with a single tuner all the logical channels member of a logical channel group.

LC_NUM: This 3-bit field indicates the total number of logical channels member(s) of the current LC group (i.e. which ID is given by LC_GROUP_ID) which may be carried in the current NGH frame. The minimum value of LC_NUM is equal to 1.

LC_ID: This 3-bit field indicates the ID of the current logical channel carried in the current NGH frame. The value of LC_ID ranges from 0 to LC_NUM-1.

LC_TYPE: This 3-bit field indicates the type of the current logical channel carried in the current NGH frame. The values shall be signalled according totable 50. A detailed description of the different LC_TYPEs is provided in clause 9.4.

Table 50: Signalling format for LC_TYPE.

Value	LC Type	Description

000	LC type A	A logical channel type A corresponds to the case when each logical frame of the logical channel is mapped to only one NGH frame on a single RF channel (see clause 9.4.1).
001	LC type B	A logical channel type B corresponds to the case when each logical frame of the logical channel is mapped to multiple (N) NGH frames on a single RF channel. The NGH frames shall be of equal length. Each logical frame may therefore map in parts onto multiple NGH frames on the same RF channel (see clause 9.4.2).
010	LC type C	A logical channel type C corresponds to the case when each logical frame of the logical channel is mapped to multiple (N) NGH frames on multiple (M) RF channels. The NGH frames from different RF channels may be of different lengths. Each logical frame may therefore map in parts onto multiple NGH frames on multiple (M) RF channels (see clause 9.4.3).
011	LC type D	A logical channel type D corresponds to the case when each logical frame of the logical channel is mapped one-to-one to multiple (N) equal-length and time-synchronised NGH frames on multiple (N) RF frequencies. Each NGH frame contains cells from only one logical frame and each logical frame is available on all simultaneous NGH frames (see clause 9.4.4).
100 to 111	Reserved for future use	Reserved for future use

LC_NUM_RF: This 3-bit field indicates N_{RF}, the number of frequencies used by the current logical channel. The frequencies are listed within the configurable parameters of the L1-POST signalling.

LC_CURRENT_FRAME_RF_IDX: This 3-bit field indicates the index of the RF channel of the current NGH frame which carries logical frames of the current logical channel.

LC_CURRENT_FRAME_RF_POS: This 3-bit field indicates the position of the RF channel of the current NGH frame in the cycle of RF channels used to carry the logical frames of the current logical channel. If the current logical channel uses only one single RF channel, the value of this field shall be always equal to '0'.

LC_NEXT_FRAME_RF_IDX: This 3-bit field indicates the index of the RF channel of the next NGH frame which carries logical frames of the current logical channel.

LC_NEXT_FRAME_DELTA: This 24-bit field indicates the relative timing in T periods between the current NGH frame and the next NGH frame which carries logical frames of the current logical channel.

NGH_VERSION: This 4-bit field indicates the latest version of the present document on which the transmitted signal is based. NGH_VERSION shall be signalled according to table 51.

Table 51: Signalling format for the NGH_VERSION field

Value	Specification version
0000	1.1.1
0001 to 1111	Reserved for future use

RESERVED: This 9-bit field is reserved for future use.

CRC-32: This 32-bit error detection code is applied to the entire L1-PRE signalling. The CRC-32 code is defined in annex E.

8.1.2.1 N-periodic spreading of L1-PRE data

To reduce the overhead of the L1-PRE data per NGH frame the bit-interleaved shortened and punctured L1-PRE LDPC codeword may be spread onto n_{pre} = 1, 2 or 4 succeeding NGH frames, as depicted in figure 38. This furthermore increases the robustness in mobile environments by additional time diversity. To allow the receiver to synchronize to the spread L1-PRE data, a PRBS sequence is modulated onto the LDPC codeword before modulation. The modulation of the PRBS sequence and the mapping of the L1-PRE LDPC codeword to the NGH frame structure are described in details in clause 8.2.3.1.

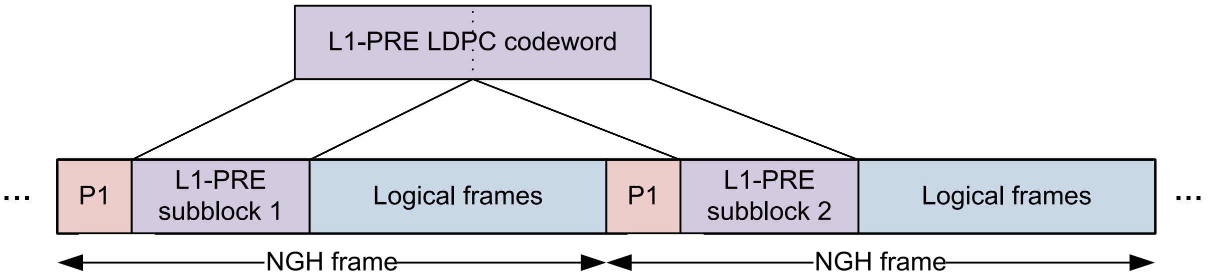


Figure 38: N-periodic transmission of L1-pre (n_{pre} = 2)

8.1.3 L1-POST signalling data

The L1-POST signalling contains parameters which provide sufficient information for the receiver to decode the desired physical layer pipes. The L1-POST signalling further consists of two types of parameters, configurable and dynamic, plus an optional extension field. The configurable parameters shall always remain the same for the duration of one logical super-frame, whilst the dynamic parameters provide information which is specific for the current logical frame. The values of the dynamic parameters may change during the duration of one logical super-frame, while the size of each field shall remain the same.

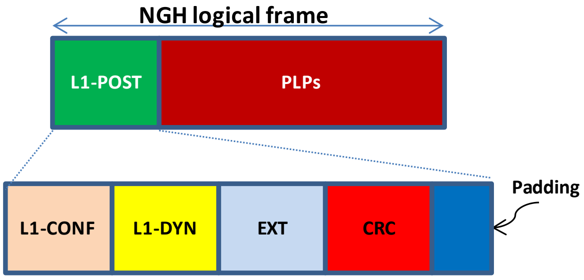


Figure 52: L1-POST signalling

8.1.3.1 L1-POST configurable signalling data

Table 53 illustrates the signalling fields of the configurable L1-POST signalling, followed by the detailed definition of each field.

Table 53: The signalling fields of configurable L1-POST

OPTIONS_FLAG	8
NUM_STREAMS	8
NUM_PLP_MODES	8
NUM_PLP_PER_LSF	8
NUM_PLP_PER_LF	8
LC_NUM_LF	8
LC_LF_SIZE	22
IF OPTIONS_FLAG="xx1xxxxx"{	
PARTITION_CYCLE_LENGTH	4
PARTITION_NUM_ADD_PLP	4
}	
IF OPTIONS_FLAG="xxxxxxx1"{	
SUB_SLICES	15
}	
for i=0..LC_NUM_RF-1{	
LC_RF_IDX	3
LC_RF_POS	8
FREQUENCY	32
}	
for i=0..NUM_PLP_PER_LF{	
PLP_ID	8
IF PLP_PAYLOAD_TYPE = 00xx{	8
NUM_STREAMS_PER_PLP	

for j=0..NUM_STREAMS_PER_PLP{
STREAM_ID
}}
ELSE {
STREAM_ID
}
	8	

PLP_MODE_ID	6	
PLP_ANCHOR_FLAG	1	
PLP_IN_BAND_A_FLAG	1	
PLP_GROUP_ID	8	
PLP_FIRST_LF_IDX	8	
PLP_LF_INTERVAL	8	
IF PLP_TYPE="011" {		
REUSE_FACTOR	4	
REUSE_ID	4	
}		
IF PLP_TYPE="100" {		
ALPHA	3	
REUSE_FACTOR	3	
REUSE_SNUM	3	
NATIONAL_PLP_ID	8	
}		
IF OPTIONS_FLAG="xxxxx1xx"{		
RESERVED_1	8	
}		
IF OPTIONS_FLAG="xx1xxxxx"{		
PLP_PARTITION_CLUSTER_ID	2	
}		
}		
IF OPTIONS_FLAG="xx1xxxxx"{		
for i=0..PARTITION_NUM_ADD_PLP{		
RESERVED_2	48	
IF OPTIONS_FLAG="xxxxx1xx"{		
RESERVED_3	8	
}		

```
            PLP_PARTITION_CLUSTER_ID            2
        }
}

for i=0..NUM_PLP_MODE-1{
        PLP_MODE_ID                             6
        PLP_TYPE                                6
        PLP_PAYLOAD_TYPE                        8
        PLP_NPDI                                1
        PLP_ISSY_MODE                           2
        PLP_FEC_TYPE                            2
        PLP_COD                                 4
        PLP_ROTATION                            1
        PLP_NON_UNIFORM_CONST                   1
        IF S1 = “111” and S2 = “000x” or “011x” {
            PLP_MIMO_TYPE                       4
            IF PLP_MIMO_TYPE = “0001” or “0010”
            {
                PLP_NUM_BITS_PER_CHANNEL_USE    3
            }
            ELSE {
                PLP_MOD                         3
            }
        }
        ELSE {
            PLP_MOD                             3
        }
        PLP_NUM_BLOCKS_MAX                      10
        TIME_IL_LENGTH                          8
        TIME_IL_TYPE                            1
        IF S1 = “111” and S2 = “001x” or “0x0x” {
            TIME_IL_LATE_LENGTH                 3
            NUM_ADD_IUS_PER_LATE_FRAME          4
        }
}
```

```
IF OPTIONS_FLAG="xxxxxx1x"{
      NUM_AUX                              4
      AUX_CONFIG_RFU                       8
      for i=0..NUM_AUX-1{
         AUX_STREAM_TYPE                   4
         AUX_PRIVATE_CONF                  28
      }
}

RESERVED_5                                 8
```

OPTIONS_FLAG: This 8-bit field indicates with one bit whether a given option with related signalling in L1-POST is used or not. If an option is used, then the signalling fields associated with this option shall be signalled in L1-POST, otherwise they shall be removed. This allows for overhead reduction when some options are not used by the NGH system. Table 54 gives the different options covered by this field.

Table 54: OPTIONS_FLAG field

Value	Option enabled
xxxxxxx1	Sub-slicing
xxxxxx1x	Auxiliary streams
xxxxx1xx	RESERVED_1 field in the NUM_PLP_PER_LF loop and RESERVED_3 field in the PARTITION_NUM_ADD_PLP
xxxx1xxx	RESERVED_4 field in the NUM_PLP_MODE loop
xxx1xxxx	RESERVED_2 field in the NUM_PLP_PER_LSF loop in L1-DYN
xx1xxxxx	Partitioning of the PLP loop
x1xxxxxx	Reserved for future use
1xxxxxxx	Reserved for future use

NUM_STREAMS: This 8-bit field indicates the total number of NGH streams with PLPs mapped into the logical frames of the current logical channel.

NUM_PLP_MODES: This 8-bit field indicates the total number of PLP modes used in the current logical super-frame. The minimum value of this field shall be “1”.

NUM_PLP_PER_LSF: This 8-bit field indicates the total number of PLPs carried within the current logical super-frame. The minimum value of this field shall be '1'.

NUM_PLP_PER_ LF: This 8-bit field indicates the total number of PLPs carried within the current logical frame of the current logical super-frame. This field is constant for every logical frame in the current logical super-frame. If OPTIONS_FLAG is equal to “xx0xxxxx“ (i.e. the partitioning of the PLP loop in L1-CONF is not used), this field has the same value of the field NUM_PLP_PER_LSF. The minimum value of this field shall be '1'.

LC_NUM_LF: This 8-bit field indicates the number of logical frames in the current logical super-frame of the current logical channel. The minimum value of this field shall be '1'.

LC_LF_SIZE: This 22-bit field indicates the size, in QAM cells, of every logical frame in the current logical super-frame of the current logical channel.

The following fields appear only if the OPTIONS_FLAG field is equal to ‘xx1xxxxx‘:

PARTITION_CYCLE_LENGTH: This 4-bit field indicates the length, in number of logical frames, of one cycle across which the signalling in the PLP loop of L1-CONF for all the PLPs in the current logical super-frame is complete. From one cycle to another in the current logical super-frame, the signalling in the PLP loop of all PLPs in the current logical super-frame shall be exactly the same. The signalling in the PLP loop of L1-CONF for each PLP shall repeat at the same logical frame position every L logical frames in the current logical super-frame, where L is the value given by PARTITION_CYCLE_LENGTH. This value shall stay constant in the current logical super-frame. The partitioning of the signalling in the PLP loop of L1-CONF is detailed in section 8.1.3.2.

PARTITION_NUM_ADD_PLP: This 4-bit field indicates the number of additional signalling blocks added in the PLP loop of the current logical frame in order for each logical frame in the partition cycle to carry the signalling of an integer number of PLPs for each cluster of PLPs, as detailed in section 8.1.3.2.

The following fields appear only if the OPTIONS_FLAG field is equal to ‘xxxxxxx1‘:

SUB_SLICES: This 15-bit field indicates $N_{\text{sub-slices\_total}}$, the total number of sub-slices for the type 2 data PLPs across all RF channels in one NGH logical frame. When LC type D is used, this is equal to, $N_{\text{sub-slices}} \times N_{\text{RF}}$, i.e. the number of sub-slices in each RF channel multiplied by the number of RF channels. When LC type D is not used, $N_{\text{sub-slices\_total}} = N_{\text{sub-slices}}$. If there are no type 2 PLPs, this field shall be set to '1_D'. Allowable values of this field are listed in annex B.

The following fields appear in the frequency loop:

LC_RF_IDX: This 3-bit field indicates the index of each FREQUENCY listed within this loop. The LC_RF_IDX value is allocated a unique value between 0 and LNC_NUM_RF-1. In the case of LC type C , this field indicates the index of each frequency within the structure of the current logical channel.

LC_RF_POS: This 8-bit field indicates the positions of each FREQUENCY listed within this loop in one cycle of RF channels used to carry the logical frames of the current logical channel. If the current logical channel uses only one single RF channel (i.e. LC_NUM_RF = 1), the value of this field shall be equal to ‘11111111’. A value equal to “1” at the i-th bit position in the sequence of 8 bits representing this field indicates that the RF channel with index given by LC_RF_IDX is used at the i-th position in the cycle of RF channels to carry the logical frames of the current logical channel. The maximum length of one cycle of RF channels to carry the logical frames of a given logical is 8.

FREQUENCY: This 32-bit field indicates the centre frequency in Hz of the RF channel whose index is LC_RF_IDX. The order of the frequencies within the logical channel structure is indicated by the LC_RF_IDX. The value of FREQUENCY may be set to '0', meaning that the frequency is not known at the time of constructing the signal. If this field is set to 0, it shall not be interpreted as a frequency by a receiver.

The FREQUENCY fields can be used by a receiver to assist in finding the signals which form a part of the logical channel structure when multiple RF channels are used (i.e. LC_TYPE = ‘01x’ and

LC_NUM_RF > 1). Since the value will usually be set at a main transmitter but not modified at a transposer, the accuracy of this field shall not be relied upon.

The following fields appear in the PLP loop (i.e. the loop over **NUM_PLP_PER_LF**):

PLP_ID: This 8-bit field identifies uniquely a PLP within the NGH system.

NUM_STREAMS_PLP: This 8-bit field indicates the number of NGH streams, each identified by its STREAM_ID, packets of which are carried by the PLP of index given by the value PLP_ID.

STREAM_ID: If PLP_PAYLOAD_TYPE equals “TS” or “TS with header compression”, this 8-bit field identifies the NGH stream within the NGH system which carries the PLP of index given by the value PLP_ID. In the case PLP_PAYLOAD_TYPE equals “GSE” or “GCS”, this field identifies the group of GS input streams, one of which is carried by the PLP of index given by the value PLP_ID.

PLP_MODE_ID: This 8-bit field identifies uniquely a PLP mode within the NGH system. In total, there is a maximum of 256 PLP modes within the NGH system.

PLP_ANCHOR_FLAG: This 1-bit field indicates if the PLP identified by PLP_ID is an anchor PLP for all its associated PLPs. The value “1” indicates an anchor PLP.

PLP_IN-BAND_A_FLAG: This 1-bit field indicates whether the current PLP carries in-band type A signalling information. When this field is set to the value '1' the associated PLP carries in-band type A signalling information. When set to the value '0', in-band type A signalling information is not carried. If the value of PLP_ANCHOR_FLAG is set to '0' (i.e. not an anchor PLP), the value of PLP_IN-BAND_A_FLAG shall then be set to '0'.

PLP_GROUP_ID: This 8-bit field identifies the PLP group within the NGH system the current PLP is associated with. This can be used by a receiver to link the data PLP to its corresponding common PLP, which will have the same PLP_GROUP_ID.

PLP_FIRST_LF_IDX: This 8-bit field indicates the index of the first logical frame of the logical super-frame which carries the current PLP. The value of PLP_FIRST_LF_IDX shall be less than the value of PLP_LF_INTERVAL.

PLP_LF_INTERVAL: This 8-bit field indicates the interval (I_{JUMP}) in a number of logical frames between any two logical frames carrying cells from the corresponding PLP within the logical super-frame. For PLPs which do not appear in every logical frame of the logical super-frame, the value of this field shall equal the interval between successive logical frames. For example, if a PLP appears on logical frames 1, 4, 7 etc, this field would be set to '3'. For PLPs which appear in every logical frame, this field shall be set to '1'. For further details, see clause 6.6.

The following fields appear only if the PLP_TYPE field is equal to ‘011‘ (see clause 10.1):

REUSE_FACTOR: This 4-bit field indicates the number of frequency chunks used in type 3 PLP for orthogonal local service insertion.

REUSE_ID: This 4-bit field identifies the frequency chunk used by the current PLP of type 3 in the current logical super-frame.

The following fields appear only if the PLP_TYPE field is equal to ‘100‘ (see clause 10.2):

ALPHA: This 3-bit field indicates the value of parameter “alpha” used for hierarchical local service insertion.

REUSE_FACTOR: This 3-bit field indicates the number of slots used for the hierarchical local service insertion time division multiplex (TDM) frame i.e. how many neighbouring transmitters insert local services.

REUSE_SNUM: This 3-bit field indicates the TDM slot number of the HLSI burst in the current NGH-frame.

NATIONAL_PLP_ID: This 8-bit field indicates the ID of the national PLP on top of which the current H-LSI PLP is hierarchically modulated.

The following field appears only if the OPTIONS_FLAG field is equal to ‘xxxxx1xx‘:

RESERVED_1: This 8-bit field is reserved for future use.

The following field appears only if the OPTIONS_FLAG field is equal to ‘xx1xxxxx‘:

PLP_PARTITION_CLUSTER_ID: This 2-bit field indicates the partition cluster of the signalling in the PLP loop associated with the PLP identified by the PLP_ID. The partition cluster ID is defined in table 55.

Table 55: PLP_PARTITION_CLUSTER_ID field.

Value	Description
00	The signalling in the PLP loop associated with the given PLP tolerates 0 frame delay. It shall be carried in every logical frame of the current logical super-frame.
01	The signalling in the PLP loop associated with the given PLP tolerates 1 logical frame delay. It may be carried in every 2nd logical frame of the current logical super-frame.
10	The signalling in the PLP loop associated with the given PLP tolerates 2 logical frames delay. It may be carried in every 3rd logical frame of the current logical super-frame.
11	The signalling in the PLP loop associated with the given PLP tolerates 3 logical frames delay. It may be carried in every 4th logical frame of the current logical super-frame.

The following fields appear only if the OPTIONS_FLAG field is equal to ‘xx1xxxxx‘:

The following fields appear in the loop over PARTITION_NUM_ADD_PLP:

RESERVED_2: This 48-bit field is reserved for future use. The length of this field (i.e 32) is equal to the sum of the lengths of the first six fields in the PLP loop (namely, PLP_ID, STREAM_ID, PLP_MODE_ID, PLP_ANCHOR_FLAG, PLP_IN_BAND_A_FLAG, PLP_GROUP_ID, PLP_FIRST_LF_IDX, PLP_LF_INTERVAL) in order to guarantee the same amount of signalling in the PLP loop associated with each PLP of PLP_PARTITION_CLUSTER_ID greater than “000”.

The following field appears only if the OPTIONS_FLAG field is equal to ‘xxxxx1xx‘:

> **RESERVED_3:** This 8-bit field is reserved for future use. The length of this field (i.e. 8) is equal to the lengths of the field RESERVED_1 in the PLP loop in order to guarantee the same amount of signalling in the PLP loop associated with each PLP of PLP_PARTITION_CLUSTER_ID greater than “000”.

PLP_PARTITION_CLUSTER_ID: This 2-bit field indicates the partition cluster of the signalling in the PLP loop associated with the PLP identified by the PLP_ID. The partition cluster ID is defined in **Error! Reference source not found.**.

The following fields appear in the PLP MODE loop:

PLP_MODE_ID: This 8-bit field identifies uniquely a PLP mode within the NGH system. In total, there is a maximum of 256 PLP modes within the NGH system.

PLP_TYPE: This 3-bit field indicates the type of the associated PLP_MODE. PLP_TYPE shall be signalled according totable 56.

Table 56: Signalling format for the PLP_TYPE field.

Value	Type
000	Common PLP
001	Data PLP Type 1
010	Data PLP Type 2
011	Data PLP Type 3
100	Data PLP Type 4
101 to 111	Reserved for future use

If value of the PLP_TYPE field is one of the values reserved for future use, the total number of bits in the PLP_MODE loop shall be the same as for the other types, but the meanings of the fields other than PLP_TYPE shall be reserved for future use and shall be ignored.

PLP_PAYLOAD_TYPE: This 5-bit field indicates the type of the payload data carried by the given PLP. PLP_PAYLOAD_TYPE shall be signalled according to table 57. See clause 5.1.1 for more information.

Table 57: Signalling format for the PLP_PAYLOAD_TYPE field.

Value	Payload type
00000	GCS
00001	GSE
00010	TS
00011	TS with header compression
00100 to 11111	Reserved for future use

PLP_NPDI: This 1-bit field indicates if null packet deletion is part of the related PLP MODE or not.

“0”: No null packet deletion applied

“1”: Null packet deletion applied

PLP_ISSY_MODE: This 2-bit field indicates whether an ISSY-BF, ISSY-LF, or ISSY-UP mode is used for the given PLP (see clause 5.1). The mode is signalled according to table 58.

Table 58: Signalling format for the PLP_ISSY_MODE

Value	PLP mode
00	ISSY-BF mode
01	ISSY-LF mode
10	ISSY-UP mode
11	Reserved for future use

PLP_FEC_TYPE: This 2-bit field indicates the FEC type used by the given PLP. The FEC types are signalled according to table 59.

Table 59: Signalling format for the PLP FEC type.

Value	PLP FEC type
00	16K LDPC
01 to 11	Reserved for future use

PLP_COD: This 4-bit field indicates the code rate used by the given PLP. The code rate shall be signalled according to table 60 for PLP_FEC_TYPE=00. The two lowest code rates, 3/15 and 4/15, are only applicable to QPSK and 16-QAM.

Table 60: Signalling format for the code rates for PLP_FEC_TYPE=00.

Value	Code rate for
0000	3/15
0001	4/15
0010	5/15
0011	6/15
0100	7/15
0101	8/15
0110	9/15
0111	10/15
1000	11/15
1001 to 1111	Reserved for future use

PLP_ROTATION: This 1-bit flag indicates whether constellation rotation is in use or not by the associated PLP. When this field is set to the value '1', rotation is used. The value '0' indicates that the rotation is not used.

PLP_NON_UNIFORM_CONST: This 1-bit flag indicates whether non-uniform constellation is used or not by the given PLP. When this field is set to the value '1', non-uniform constellation is used. The value '0' indicates that non-uniform constellation is not used.

The following fields appear only if the S1 = "111" and S2 field 1 = "000" or "011" (see clause 20.3.1 and clause 31.3.1 for the MIMO profile (Part II) and the hybrid MIMO profile (Part IV), respectively):

PLP_MIMO_TYPE: This 4-bit field indicates the MIMO scheme used by the given PLP..

The following fields appear only if PLP_MIMO_TYPE = "0001" or "0010":

PLP_NUM_BITS_PER_CHANNEL_USE: This 3-bit field indicates the number of bits per channel use for the MIMO scheme used by the given PLP.

The following field appears only if PLP_MIMO_TYPE is not equal to “0001” or “0010”:

PLP_MOD: 3-bit field indicates the modulation used by the given PLP.

The following fields appear for all S1 and S2 values except the combinations of the MIMO profile and hybrid MIMO profile (i.e. S1 = “111” and S2 field 1 = “000”, or “011”):

PLP_MOD: 3-bit field indicates the modulation used by the given PLP. The modulation shall be signalled according to table 61 for the base profile. For the hybrid profile, the modulation shall be signalled as defined in clause 24.3.1.

Table 61: Signalling format for the modulation.

Value	Modulation
000	QPSK
001	16-QAM
010	64-QAM
011	256-QAM
100	NU-64-QAM
101	NU-256-QAM
110 to 111	Reserved for future use

PLP_NUM_BLOCKS_MAX: This 10-bit field indicates the maximum value of the number of FEC blocks, PLP_NUM_BLOCKS, per interleaving frame.

TIME_IL_LENGTH: The use of this 8-bit field is determined by the values set within the TIME_IL_TYPE -field as follows:

- If the TIME_IL_TYPE is set to the value '1', this field shall indicate P_I, the number of logical frames which carry cells from one TI-block, and there shall be one TI-block per Interleaving Frame (N_{TI}=1).
- If the TIME_IL_TYPE is set to the value '0', this field shall indicate N_{TI}, the number of TI-blocks per Interleaving Frame, and there shall be one Interleaving Frame per logical frame (P_I=1).

If there is one TI-block per Interleaving Frame and one logical frame per Interleaving Frame, TIME_IL_LENGTH shall be set to the value '1' and TIME_IL_TYPE shall be set to '0'. If time interleaving is not used for the associated PLP, the TIME_IL_LENGTH-field shall be set to the value '0' and TIME_IL_TYPE shall be set to '0'.

TIME_IL_TYPE: This 1-bit field indicates the type of time-interleaving. A value of '0' indicates that one or multiple TI-blocks are present per Interleaving Frame but without inter-frame interleaving, while ‘1’ indicates that only one TI-block is present per Interleaving Frame, and the TI-block may be spread over multiple logical frames (inter-frame interleaving).

The following fields appear only if the S1 = “111” and S2 field 1 = “001” or “01x” (see clause 24.3.1 and clause 31.3.1 for the hybrid profile (Part III) and hybrid MIMO profile (Part IV), respectively):

TIME_IL_LATE_LENGTH: This 3-bit field represents the length P_{late} of the Late part in terms of logical frames. The Late part is the last part of the full Time Interleaver length, which is signalled by TIME_IL_LENGTH.

NUM_ADD_IUS_PER_LATE_FRAME: This 4-bit field represents the number $N_{ADD\_IU\_PER\_LATE}$ of additional Interleaver Units (IUs) per logical frame in the Late part (additional to the one IU always present in every logical frame).

The following field appears only if the OPTIONS_FLAG field is equal to ‘xxxx1xxx‘:

RESERVED_4: This 8-bit field is reserved for future use.

The following fields appear only if the OPTIONS_FLAG field is equal to ‘xxxxxx1x‘:

NUM_AUX: This 4-bit field indicates the number of auxiliary streams. Zero means no auxiliary streams are used, and clause 9.2.3 shall be ignored.

AUX_CONFIG_RFU: This 8-bit field is reserved for future use.

The following fields appear in the auxiliary stream loop:

AUX_STREAM_TYPE: This 4-bit indicates the type of the current auxiliary stream. The auxiliary stream type is signaled according to table 62.

Table 62: Signalling format for the auxiliary stream type.

Value	Auxiliary stream type
0000	TX-SIG (see [4])
All other values	Reserved for future use

AUX_PRIVATE_CONFIG: This 28-bit field is for future use for signalling auxiliary streams.

RESERVED_5: This 8-bit field is reserved for future use.

8.1.3.2 Self-decodable partitioning of the PLP loop in L1-POST configurable

In order to reduce the overhead of L1-POST configurable, the signalling in the PLP loop of L1-POST configurable may be split into equal length partitions, so that each logical frame carries only one partition of the total signalling in the PLP loop. The L1-POST configurable data is arranged in two parts, a first part which contains all the signalling data in L1-POST configurable except of the PLP loop signalling, and a second part which contains the signalling in the PLP loop. Only the second part, i.e. the signalling in the PLP loop, may be subject to partitioning. The first part will always appear in every logical frame of the logical super-frame.

A value of the field OPTIONS_FLAG equal to ‘xx1xxxxx‘ indicates that partitioning of the PLP loop in L1-POST configurable is used.

When partitioning is used, each logical frame carries the signalling in the PLP loop associated with a number of PLPs equal to the value NUM_PLP_PER_LF, which is less than or equal to the total number of PLPs in the current logical super-frame NUM_PLP_PER_LSF. If partitioning is not used (i.e. OPTIONS_FLAG = ‘xx0xxxxx‘), the two fields NUM_PLP_PER_LF and NUM_PLP_PER_LSF have the same value.

The logical frame may also carry an additional signalling associated with a number of dummy PLPs equal to PARTITION_NUM_ADD_PLP. The summation NUM_PLP_PER_LF + PARTITION_NUM_ADD_PLP shall be constant for every logical frame in the super-frame, in order to guarantee the same amount of L1-POST configurable signalling in every logical frame of the current logical super-frame.

When partitioning is used, every PLP in the logical super-frame is assigned a partition cluster indicated by the field PLP_PARTITION_CLUSTER_ID. As defined in table 34, if PLP_PARTITION_CLUSTER_ID is equal to “000“, the signalling in the PLP loop associated with the given PLP shall be transmitted in every logical frame of the current logical super-frame, and hence does not tolerate any delay for its acquisition. The PLPs associated with Local Service Insertion (PLP_TYPE = “011“ or “100“) shall be assigned to the first partition cluster PLP_PARTITION_CLUSTER_ID = “000“, as they require additional signalling fields in the PLP loop compared to the other (i.e. non Local Service Insertion) PLPs and in order to guarantee the same amount of signalling in every logical frame of the current logical super-frame.

If the value of PLP_PARTITION_CLUSTER_ID is equal to *n* strictly greater than 0, then the signalling in the PLP loop associated with the given PLP tolerates *n* logical frame delays, and hence may be transmitted every (*n*+1)-th logical frame in the logical super-frame.

In order to ensure that every partition of L1-POST configurable is self-decodable (i.e. the receiver can decode and use the information as it arrives in every logical frame of the current logical super-frame), an integer number of PLPs for each partition cluster *n* (*n* > 0) is guaranteed in every logical frame of the current logical super-frame. If the actual number of PLPs which tolerate *n* logical frame delays for for the acquisition of their associated signalling in the PLP loop is not equal to or a multiple integer of the partition cluster value *n*, then some of these PLPs may be assigned or re-assigned to a lower partition cluster value, and hence transmitted at a rate higher than the tolerable rate of every (*n*+1)-th logical frame in the logical super-frame, e.g. every *n*-th or (*n*-1)-th logical frame. Alternatively, all PLPs which tolerate *n* logical frame delays are assigned to the same partition cluster *n*, and an additional signalling associated with a number of dummy PLPs equal to PARTITION_NUM_ADD_PLP may be added to some partition clusters (n > 0) in some logical frames in the current logical super-frame. In the latter alternative, in order to maximize overhead reduction, only the minimum number of dummy PLPs should be considered if required. This minimum number PARTITION_NUM_ADD_PLP can be determined from all the numbers of actual PLPs and their corresponding partition cluster values {*n*} over a period equal to the least common multiplier of all partition cluster values {*n*}. The additional signalling associated with the number PARTITION_NUM_ADD_PLP of dummy PLPs may be used for some purpose in the future.

If we denote by $P_{actual}(n,\ell)$ the number of actual PLPs in the partition cluster *n* (n = 0 to *N*-1) in the ℓ-th logical frame of the current logical super-frame, and $P_{dummy}(n,\ell)$ the number of dummy PLPs associated with the additional signalling in the PLP loop for the partition cluster *n* (n = 0 to *N*-1) in the ℓ-th logical frame of the current logical super-frame, the signalling in the PLP loop of every logical frame ℓ shall be associated with a constant number of PLPs, given by *Q* in equation xx.

$$P_{actual}(0,\ell)+\sum_{n=1}^{N-1}\left(P_{actual}(n,\ell)+P_{dummy}(n,\ell)\right)=Q \quad \text{(equation xx)}$$

The signalling in the PLP loop of L1-POST configurable for a given PLP repeats at the same logical frame position every *L* logical frames in the current logical super-frame, where *L* is the value of the field PARTITION_CYCLE_LENGTH. From one cycle to another in the current logical super-frame, the signalling in the PLP loop of all PLPs in the current logical super-frame is exactly the same. The partition cycle helps the receiver anticipate the pattern of appearance in the logical frames of the signalling in the PLP loop associated with the desired PLP. It also helps the receiver know when the full L1-CONF signalling repeats exactly in the current logical super-frame. The cycle length *L* is equal to the least common multiplier of all partition cluster values {*n*}.

Example: Let's assume a total number of actual PLPs in the super-frame equal to 5. All these 5 PLPs tolerate 1 frame delay for the acquisition of their associated signalling in the PLP loop, hence ideally all the 5 PLPs should be assigned to the partition cluster *n* = 2. However, the number of PLPs (= 5) is not a multiple of the partition cluster value (*n* = 2). In order to guarantee a self-decodable partitioning with an equal amount of L1-CONF signalling in every logical frame, two equivalent alternatives may be considered:

- The first alternative assigns 1 PLP to the partition cluster *n* = 1, and all the remaining 4 PLPs to the partition cluster *n* = 2. Thus, the signalling of 1 PLP (PLP#1) will be repeated in every logical frame, whilst the signalling of 4 PLPs will be split into two partitions of 2 PLPs. The signalling of the first 2 PLPs (e.g. PLP#2, PLP#3) will then be repeated in odd logical frames (e.g. 1, 3, 5, 7) whilst the signalling of the other two PLPs (i.e. PLP#4 and PLP#5) will be repeated in even logical frames (e.g. 2, 4, 6, 8). This is illustrated infigure 39.

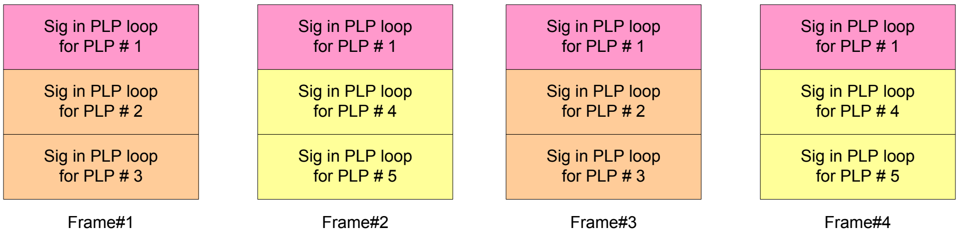


Figure 39: Self-decodable partitioning in the first alternative.

- This second alternative assigns all 5 PLPs to the partition cluster *n* = 2, and adds an additional signalling associated with 1 dummy PLP in the partition cluster *n* = 2. The signalling of the first 3 PLPs (e.g. PLP#1, PLP#2, PLPL#3) will then be repeated in odd logical frames (i.e. 1, 3, 5, 7, etc), whilst the signalling of the remaining two PLPs (i.e. PLP#4 and PLP#5) and the additional signalling associated with the dummy PLP will be repeated in even logical frames (e.g. 2, 4, 6, 8). This is illustrated in figure 40.

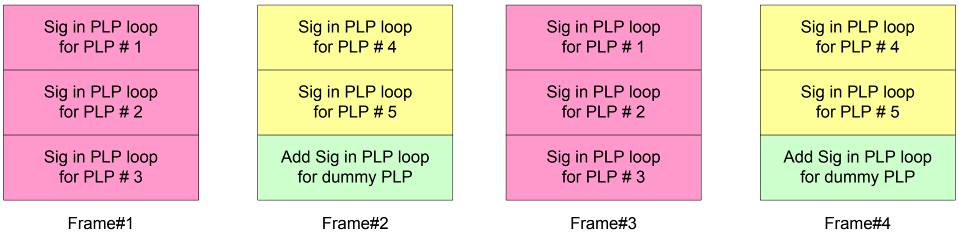


Figure 40: Self-decodable partitioning in the second alternative.

If partitioning is not used, every logical frame will have a PLP loop with a signalling amount equal to 5 x A, where A denotes the amount of signalling per PLP in the PLP loop. If partitioning is used, every logical frame will have a PLP loop with a signalling amount equal to 3 x A, in both alternatives. The overhead reduction of the PLP loop is therefore equal to ((5 – 3) x A)/(5 x A) = 40%. By accounting for the amount (= C) of signalling in the constant part of L1-CONF (i.e. the part which is repeated in every logical frame), the overall overhead reduction amounts to (2xA)/(C+5xA).

8.1.3.3 L1-POST dynamic signalling

The dynamic L1-POST signalling is illustrated in table 63, followed by the detailed definition of each field.

Table 63: The signalling fields of L1-POST dynamic.

```
LF_IDX                                8

IF OPTIONS_FLAG="xxxxxxx1"{
    SUB_SLICE_INTERVAL                22
}

TYPE_2_START                          22
L1CONF_CHANGE_COUNTER                 8
RESERVED_1                            8

for i=0..NUM_PLP_PER_LSF-1{
    RF_IDX                            3
    for j=0..TIME_IL_LENGTH-1{        8
        PLP_NUM_BLOCKS                8
        IF OPTIONS_FLAG="xxx1xxxx"{
            RESERVED_2                8
        }
    }
}
```

IF OPTIONS_FLAG="xxxxxx1x"{	
for i=0..NUM_AUX-1{	
AUX_PRIVATE_DYN	48
}	
}	
RESERVED_3	5

LF_IDX: This 8-bit field is the index of the current logical frame within the current logical super-frame. The index of the first logical frame of the logical super-frame shall be set to '0'.

The following field appears only if the OPTIONS_FLAG field is equal to ‘xxxxxxx1‘ (see clause 9.2.2.2.2 for more details on sub-slicing for type 2 PLPs):

> **SUB_SLICE_INTERVAL:** This 22-bit field indicates the number of cells from the start of one sub-slice of one PLP to the start of the next sub-slice of the same PLP on the same RF channel for the current logical frame. If the number of sub-slices per logical frame equals the number of RF channels, then the value of this field indicates the number of cells on one RF channel for the type 2 data PLPs. If there are no type 2 PLPs in the relevant logical frame, this field shall be set to '0'.

TYPE_2_START: This 22-bit field indicates the start position of the first of the type 2 PLPs using the cell addressing scheme defined in clause 9.2.2.2.2. If there are no type 2 PLPs, this field shall be set to '0'. It has the same value on every RF channel, and with TFS can be used to calculate when the sub-slices of a PLP are 'folded' (see clause 9.2.2.2.3).

L1CONF_CHANGE_COUNTER: This 8-bit field indicates the number of logical super-frames ahead where the configuration (i.e. the contents of the fields in the configurable part of the L1-POST signalling) will change. The next logical super-frame with changes in the configuration is indicated by the value signalled within this field. If this field is set to the value '0', it means that no scheduled change is foreseen. E.g. value '1' indicates that there is change in the next logical super-frame. This counter shall always start counting down from a minimum value of 2.

RESERVED_1: This 8-bit field is reserved for future use.

RF_IDX: For LC type D PLPs this 3-bit field indicates the RF frequency of the current PLP in the next logical frame where the PLP occurs. The value shall be interpreted according to the LC_CURRENT_FRAME_RF_IDX of L1-PRE. For LC types A, B and C this field shall be reserved for future use.

The following fields appear in the loop over NUM_PLP_PER_LSF:

> The following fields appear in the loop over TIME_IL_LENGTH:
>
> > **PLP_NUM_BLOCKS:** This 8-bit field indicates the number of FEC blocks for the current PLP in each logical frame of the N (equal to TIME_IL_LENGTH) logical frames included in the convolutional interleaving of the current PLP, as described in clause 6.6.

The following fields appear only if the OPTIONS_FLAG field is equal to ‘xxx1xxxx‘:

RESERVED_2: This 8-bit field is reserved for future use.

The following fields appear only if the OPTIONS_FLAG field is equal to ‘xxxxxx1x‘:

The following field appears in the auxiliary stream loop:

AUX_PRIVATE_DYN: This 48-bit field is reserved for future use for signalling auxiliary streams. The meaning of this field depends on the value of AUX_STREAM_TYPE in the configurable L1-POST signalling (see clause 8.1.3.1) and shall be as defined by the relevant specification document as listed in table 62.

The protection of L1 dynamic signalling is further enhanced by transmitting the L1 signalling also in a form of in-band signalling, see clause 5.2.3.1.

RESERVED_3: This 5-bit field is reserved for future use.

8.1.3.4 Repetition of L1-POST dynamic data

To obtain increased robustness for the dynamic part of L1-POST signalling, the information may be repeated in the preambles of two successive logical frames. The use of this repetition is signalled in L1-PRE parameter L1_REPETITION_FLAG. If the flag is set to '1', dynamic L1-POST signalling for the current and next logical frames are present in the L1-POST signalling as illustrated infigure 41. Thus, if repetition of L1-POST dynamic data is used, the L1-POST signalling consists of one configurable and two dynamic parts as depicted.

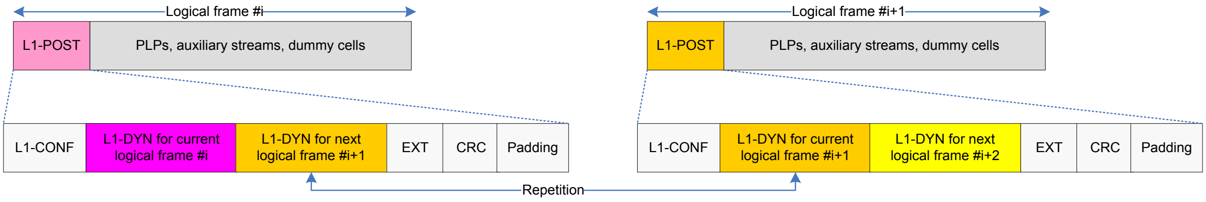


Figure 41: Repetition of L1-POST dynamic information.

The L1-POST signalling shall not change size between the logical frames of one logical super-frame. If there is to be a configuration change at the start of logical super-frame *j*, the loops of both parts of the dynamic information of the last logical frame of logical super-frame *j*-1 shall contain only the PLPs and AUXILIARY_STREAMs present in logical super-frame *j*-1. If a PLP or AUXILIARY_STREAM is not present in logical super-frame *j*, the fields of the relevant loop shall be set to '0' in logical super-frame *j*-1.

EXAMPLE: Logical Super-frame 7 contains 4 PLPs, with PLP_IDs 0, 1, 2 and 3. A configuration change means that logical super-frame 8 will contain PLP_IDs 0, 1, 3 and 4 (i.e. PLP_ID 2 is to be dropped and replaced by PLP_ID 4). The last logical frame of logical super-frame 7 contains 'current logical frame' and 'next logical frame' dynamic information where the PLP loop signals PLP_IDs 0, 1, 2 and 3 in both cases, even though this is not the correct set of PLP_IDs for the next logical frame. In this case the receiver will need to read all of the new configuration information at the start of the new logical super-frame.

8.1.3.5 Additional parity of L1-POST dynamic data

To increase further the robustness of the L1-POST signalling, additional parity bits may be transmitted in a previous logical frame preceding the current logical frame which carries the current L1-POST signalling. This is illustrated in figure 42. Additional parity bits are generated by selecting punctured parity bits according to the puncturing pattern given in clauses 8.2.2.5.2.

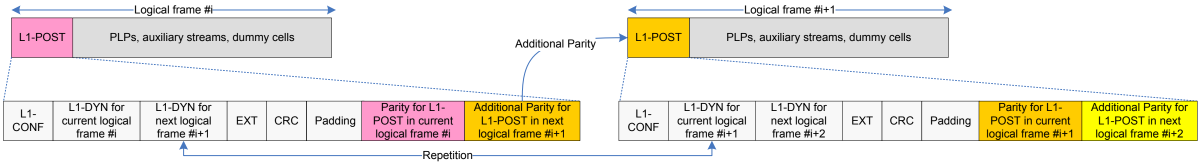


Figure 42: Additional parity for L1-POST information.

The use of additional parity is signaled in L1-PRE parameter L1_POST_AP_RATIO_CURRENT. When this field is set to value '00', additional parity shall not be provided for the L1-POST signalling of any logical frame in the current logical super-frame. Otherwise, additional parity shall be provided for the L1-POST signalling in every logical frame of the current logical frame. The amount of additional parity is indicated by the value of the field L1-POST_AP_RATIO_CURRENT, which gives the ratio of the amount of the additional parity bits to the amount of the parity bits for every logical frame in the current logical super-frame.

Another L1-PRE parameter corresponding to the use of additional parity is L1_POST_AP_SIZE_NEXT. This field indicates the size, in QAM cells, of the additional parity blocks of L1-POST signalling in every logical frame of the next logical super-frame. This field gives the amount of additional parity transmitted in the last logical frame of the current logical super-frame for the L1-POST signalling of the first logical frame in the next logical super-frame. It allows seamless usage of the additional parity at the border of two logical super-frames, where the amount of additional parity may change.

The values of the parameters L1_POST_AP_RATIO_CURRENT and L1_POST_AP_SIZE_NEXT shall be constant within the current logical super-frame.

8.1.3.6 L1-POST extension field

The L1-POST extension field allows for the possibility for future expansion of the L1 signalling. Its presence is indicated by the L1-PRE field L1_POST_EXTENSION.

If it is present, the L1-POST extension shall contain one or more L1-POST extension blocks. The syntax of each block shall be as shown in table 64.

Table 64: Syntax of an L1-POST extension block.

Field	Length (bits)	Description
L1_ EXT_ BLOCK_TYPE	8	Indicates the type of L1-POST extension block. See **Error! Reference source not found.**
L1_EXT_DATA_LEN	16	Indicates the length of the L1_EXT_BLOCK_DATA field in bits.
L1_EXT_BLOCK_DATA	Variable	Contains data specific to the type of L1-POST extension block.

Where more than one block is present, each block shall follow contiguously after the previous block. The block or blocks shall exactly fill the L1-POST extension field.

The values of **L1_EXT_BLOCK_TYPE** are defined in table 65.

Table 65: Values of L1_EXT_BLOCK_TYPE.

L1_EXT_BLOCK_TYPE value	Description
00000000 – 11111110	Reserved for future use
11111111	Padding L1-POST extension block

Receivers not aware of the meaning of a particular L1-POST extension block shall ignore its contents but shall use the L1_EXT_DATA_LEN field to locate the next L1-POST extension block, if any.

8.1.3.7 CRC for the L1-POST signalling

A 32-bit error detection code is applied to the entire L1-post signalling including the configurable, the dynamic for the current logical frame, the dynamic for the next logical frame, if present, and the L1-POST extension field, if present. The location of the CRC field can be found from the length of the L1-POST, which is obtained as the summation of the values of all four fields: L1_POST_CONF_SIZE, L1_POST_DYN_CURRENT_SIZE, L1_POST_DYN_NEXT_SIZE, L1_POST_EXT_SIZE. The CRC-32 is defined in annex E.

8.1.3.8 L1 padding

This variable-length field is inserted following the L1-POST CRC field to ensure that multiple LDPC blocks of the L1-POST signalling have the same information size when the L1-POST signalling is segmented into multiple blocks and these blocks are separately encoded. Details of how to determine the length of this field are described in clause 8.2.1.2. The values of the L1 padding bits, if any, are set to 0.

8.2 Modulation and error correction coding of the L1 data

8.2.1 Overview

8.2.1.1 Error correction coding and modulation of the L1-PRE signalling

The L1-PRE signalling is protected by a concatenation of BCH outer code and LDPC inner code. The L1-PRE signalling bits have a fixed length and they shall be first BCH-encoded, where the BCH parity bits of the L1-PRE signalling shall be appended to the L1-PRE signalling. The concatenated L1-PRE signalling and BCH parity bits are further protected by a shortened and punctured 4K LDPC code with code rate 1/5 (N_{ldpc}=4320). Details of how to shorten and puncture the 4K LDPC code are described in clauses 8.2.2.2, 8.2.2.5.1 and 8.2.2.7. Note that an input parameter used for defining the shortening operation, K_{sig} shall be 424 equivalent to the information length of the L1-PRE signalling, K_{pre}. An input parameter used for defining the puncturing operation, N_{punc} shall be as follows:

$N_{punc} = \left(K_{bch} - K_{sig}\right) \times \left(\frac{1}{R} - 1\right) - 4 = 1516$ where K_{bch} denotes the number of BCH information bits (= 804), and R denotes the LDPC code rate (=1/5) for L1-PRE signalling. Note that N_{punc} indicates the number of LDPC parity bits to be punctured. After shortening and puncturing, the encoded bits of the L1-PRE signalling shall be mapped to: $\left(K_{sig} + N_{bch\_parity}\right) + \left(N_{ldpc\_parity} - N_{punc}\right) = 2424$ QPSK symbols according to clause 8.2.3.1, where N_{bch_parity} and N_{ldpc_parity} denotes the number of BCH parity bits, 60 and the number of LDPC parity bits, 3456 for 4K LDPC codes, respectively. Finally, the QPSK symbols are mapped to OFDM cells of 1, 2 or 4 consecutive NGH frames as described in clause 9.9.3.

Note: Constellation rotation is never applied to L1-PRE cells.

8.2.1.2 Error correction coding and modulation of the L1-POST signalling

The number of L1-POST signalling bits is variable, and the bits shall be segmented and transmitted over one or multiple 4K LDPC coded blocks depending on the length of L1-POST signalling. The 4K LDPC may be extended with an incremental redundancy (IR) part with the aim for higher error protection. The number of LDPC blocks for L1-POST signalling, $N_{post\_FEC\_Block}$ shall be determined as follows:

$$N_{post\_FEC\_Block} = \begin{cases} 1 & \text{if } K_{post\_ex\_pad} \le K_{bch} \\ \left\lceil \dfrac{K_{post\_ex\_pad}}{K_{bch} - 3} \right\rceil & \text{otherwise} \end{cases}$$

where $\lceil x \rceil$ means the smallest integer larger than or equal to *x*, K_{bch} is 2100 for the 4K LDPC code with code rate 1/2 (the extended code rate of the corresponding incremental redundancy code is 1/4), and $K_{post\_ex\_pad}$ is obtained by adding the value 32 (CRC) to the sum of values of the following four parameters: L1_POST_CONF_SIZE, L1_POST_DYN_CURRENT_SIZE, L1_POST_DYN_NEXT_SIZE and L1_POST_EXT_SIZE, which denote respectively the length of the L1-POST configurable signalling, L1-POST dynamic signalling for the current logical frame, L1-POST dynamic signalling for the next logical frame, and L1-POST extension, excluding the length of the L1 padding field (see clause 8.1.3.8). The length of the L1 padding field, $K_{L1\_PADDING}$ shall be calculated as follows:

$$K_{L1\_PADDING} = K_{L1\_conf\_PAD} + K_{L1\_dyn,c\_PAD} + K_{L1\_dyn,n\_PAD} + K_{L1\_ext\_PAD}$$

Where $K_{L1\_conf\_PAD}$, K_{L1_dyn,c_PAD}, K_{L1_dyn,n_PAD}, and $K_{L1\_ext\_PAD}$, denote the length of the padding fields for the L1-POST configurable signalling, L1-POST dynamic signalling for the current logical frame, L1-POST dynamic signalling for the next logical frame, and L1-POST extension with CRC, respectively (cf.figure 43). The length of each of these padding fields shall be calculated as follows:

$$K_{L1\_conf\_PAD} = \left\lceil \frac{K_{L1\_conf}}{N_{post\_FEC\_Block}} \right\rceil \times N_{post\_FEC\_Block} - K_{L1\_conf}$$

$$K_{L1\_dyn,c\_PAD} = \left\lceil \frac{K_{L1\_dyn,c}}{N_{post\_FEC\_Block}} \right\rceil \times N_{post\_FEC\_Block} - K_{L1\_dyn,c}$$

$$K_{L1\_dyn,n\_PAD} = \left\lceil \frac{K_{L1\_dyn,n}}{N_{post\_FEC\_Block}} \right\rceil \times N_{post\_FEC\_Block} - K_{L1\_dyn,n}$$

$$K_{L1\_ext\_PAD} = \left\lceil \frac{K_{L1\_ext}+32}{N_{post\_FEC\_Block}} \right\rceil \times N_{post\_FEC\_Block} - \left(K_{L1\_ext}+32\right)$$

where K_{L1_conf}, $K_{L1\_dyn,c}$, $K_{L1\_dyn,n}$, and K_{L1_ext}, correspond to the values of L1_POST_CONF_SIZE, L1_POST_DYN_CURRENT_SIZE, L1_POST_DYN_NEXT_SIZE, and L1_POST_EXT_SIZE, respectively (see clause 8.2.2). Note that the length of the L1-POST dynamic signalling for the next logical frame, $K_{L1\_dyn,n}$, is equal to '0' when L1_REPETITION_FLAG is set to '0'.

The final length of the whole L1-POST signalling including the padding field, K_{post}, shall be calculated as follows:

$$K_{post} = K_{post\_ex\_pad} + K_{L1\_PADDING}$$

The number of information bits in each of the $N_{post\_FEC\_Block}$ blocks, K_{sig}, is given by:

$$K_{sig} = \frac{K_{post}}{N_{post\_FEC\_Block}}$$

Each part of the L1-POST signalling, namely, L1-POST configurable, L1-POST dynamic for the current logical frame, L1-POST dynamic for the next logical frame, shall be segmented into $N_{post\_FEC\_Block}$ segments spread uniformly across all the $N_{post\_FEC\_Block}$ FEC blocks, as illustrated in figure 43. This is in order to achieve equal protection for all FEC blocks.

The first segment is composed of four parts as follows:

- A first part including all the bits of indices 1 to $K_{L1\_conf}/N_{post\_FEC\_block}$ from within the L1-POST configurable signaling;
- A second part including all the bits of indices 1 to $K_{L1\_dyn,c}/N_{post\_FEC\_block}$ from within the L1-POST dynamic signaling for the current logical frame;
- A third part including all the bits of indices 1 to $K_{L1\_dyn,n}/N_{post\_FEC\_block}$ from within the L1-POST dynamic signaling for the next logical frame;
- A fourth part including all the bits of indices 1 to $K_{L1\_ext}/N_{post\_FEC\_block}$ from within the L1-POST extension field and the CRC.

All the other segments except of the last segment, i.e. from the second segment to the $\{N_{post\_FEC\_block}\ -1\}^{th}$ segment, follow the same composition of the first segment, hence with each composed of four parts of the same amount of bits of the four parts in the first segment, selected sequentially in an increased order of the segment number. The *m*-th segment, *m*=2.. $N_{post\_FEC\_block}$ -1, is composed of the following four parts:

- A first part including all the bits of indices ((*m*-1)*$K_{L1\_conf}/N_{post\_FEC\_block}$ +1) to *m**$K_{L1\_conf}/N_{post\_FEC\_block}$ from within the L1-POST configurable signaling;
- A second partincluding all the bits of indices ((*m*-1)*$K_{L1\_dyn,c}/N_{post\_FEC\_block}$ +1) to *m**$K_{L1\_dyn,c}/N_{post\_FEC\_block}$ from within the L1-POST dynamic signaling for the current logical frame;
- A third part including all the bits of indices ((*m*-1)*$K_{L1\_dyn,c}/N_{post\_FEC\_block}$ +1) to *m**$K_{L1\_dyn,n}/N_{post\_FEC\_block}$ from within the L1-POST dynamic signaling for the next logical frame;
- A fourth part including all the bits of indices ((*m*-1)*$K_{L1\_ext}/N_{post\_FEC\_block}$ +1) to *m**$K_{L1\_ext}/N_{post\_FEC\_block}$ from within the L1-POST extension field and the CRC.

The last segment is composed of the four parts below:

- A first part including all the remaining bits of indices ($K_{L1\_conf}/N_{post\_FEC\_block}$ * ($N_{post\_FEC\_block}$ -1) +1) to K_{L1_conf}, from within the L1-POST configurable signaling, followed by the padding field of the L1-POSTconfigurable;
- A second part including all the remaining bits of indices ($K_{L1\_dyn,c}/N_{post\_FEC\_block}$ * ($N_{post\_FEC\_block}$ -1) +1) to $K_{L1\_dyn,c}$, from within L1-POST dynamic signaling for the current logical frame, followed by the padding field of the L1-POST dynamic signaling for the current logical frame;
- A third part including all the remaining bits of indices ($K_{L1\_dyn,n}/N_{post\_FEC\_block}$ * ($N_{post\_FEC\_block}$ -1) +1)to $K_{L1\_dyn,n}$, from within the L1-POST dynamic signaling for the next logical frame, followed by the padding field of the L1-POST dynamic signaling for the next logical frame;
- A fourth part including all the remaining bits of indices ($K_{L1\_ext}/N_{post\_FEC\_block}$ * ($N_{post\_FEC\_block}$ -1) +1) to K_{L1_ext}, from within the L1-POST extension field and CRC, followed by the padding field of the L1 extension field and CRC.

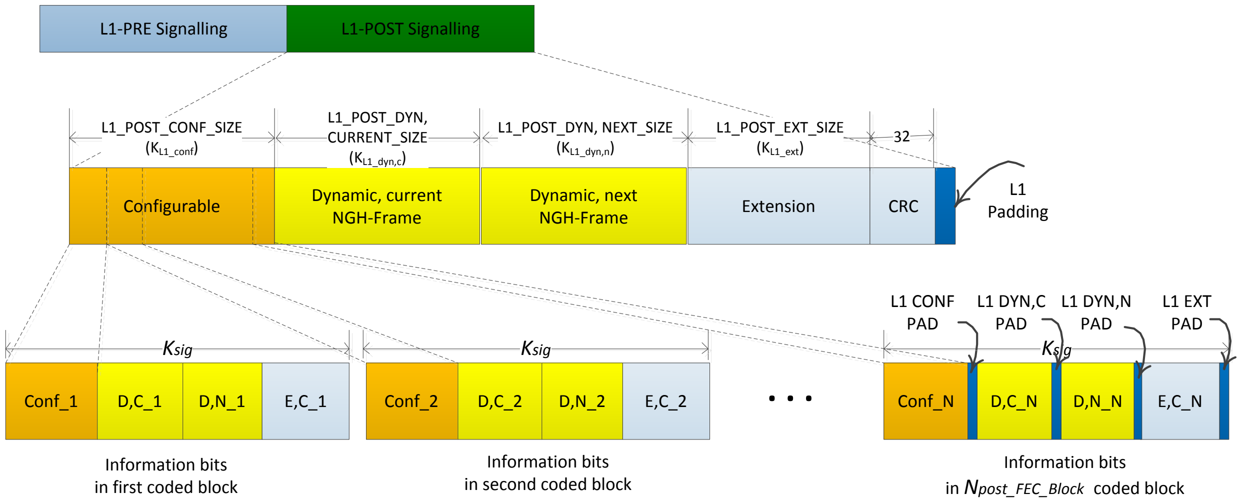


Figure 43: Segmentation and spreading of L1-POST signalling across the $N_{post\_FEC\_Block}$ blocks.

All the bits of each L1-POST block with information size K_{sig} are scrambled according to clause 8.2.2.1. Each L1-POST block is then protected by a concatenation of an outer BCH code and an inner LDPC code. Each block shall be first BCH-encoded, with N_{bch_parity} (= 60) BCH parity bits appended to the information bits of each block. The concatenated information and BCH parity bits of each block are next protected by a shortened and punctured 4K LDPC code with code rate 1/2. The 4K LDPC code is further extended with an incremental redundancy (IR) part. The effective code rate of the extended 4K LDPC with code rate 1/2, $R_{eff\_ext\_4K\_LDPC\_1\_2}$, is 1/4. Details of how to encode, shorten and puncture the extended 4K LDPC code are described in clauses 8.2.2.4.2, 8.2.2.2, 8.2.2.5.2, 8.2.2.6 and 8.2.2.7.

For a given K_{sig} and modulation order (BPSK, QPSK, 16-QAM, 64-QAM or NU-64-QAM are used for the L1-POST signalling), N_{punc}, the number of parity bits to be punctured per LDPC codeword, shall be determined by following the steps below:

- Step 1) $N_{punc\_temp} = \begin{cases} \left\lfloor 1.3 \times \left(K_{bch} - K_{sig}\right) + 3357 \right\rfloor & \text{if } K_{sig} < 1350 \\ \left\lfloor 1.35 \times \left(K_{bch} - K_{sig}\right) + 3320 \right\rfloor & \text{otherwise} \end{cases}$,

  where the operation $\lfloor x \rfloor$ means the largest integer less than or equal to *x*. The constant factors 1.3 and 1.35 indicate the ratio of the number of bits to be shortened to the number of bits to be punctured. The values 3357 and 3320 are added as correction factors.

  This makes sure that the effective LDPC code rate of the L1-POST signalling, R_{eff_post} decreases as the information length K_{sig} decreases, in order to compensate for the performance penalty of the shortening and puncturing operation.

- Step 2) $N_{post\_temp} = K_{sig} + N_{bch\_parity} + N_{ldpc\_parity\_ext\_4K} - N_{punc\_temp}$

  For the extended 4K LDPC code, the number of parity bits $N_{ldpc\_parity\_ext\_4K} = 6480$.

- Step 3) $N_{post} = \left\lceil \frac{N_{post\_temp}}{2\eta_{MOD}} \right\rceil \times 2\eta_{MOD}$,

  where η_{MOD} denotes the modulation order 1, 2, 4, and 6 for BPSK, QPSK, 16-QAM, and 64-QAM/NU-64-QAM, respectively. This step guarantees that N_{post} is a multiple of the number of columns of the bit interleaver (described in clause 8.2.2.8).

- Step 4) $N_{punc} = N_{punc\_temp} - (N_{post} - N_{post\_temp})$.

N_{post} denotes the number of encoded bits for each information block. After shortening and puncturing, the encoded bits of each block shall be mapped to $N_{MOD\_per\_Block}=N_{post}/\eta_{MOD}$ modulated symbols. The total number of modulation symbols for all $N_{post\_FEC\_Block}$ blocks is, $N_{MOD\_Total}=N_{MOD\_per\_Block}*N_{post\_FEC\_block}$. This value is signalled by the field L1_POST_SIZE in L1-PRE (see clause 8.1.2).

When 16-QAM, 64-QAM or NU-64-QAM is used, bit interleaving shall be applied across each LDPC block. Details of the bit interleaving of the encoded bits are described in clause 8.2.2.8. When BPSK or QPSK is used, bit interleaving shall not be applied. Demultiplexing is then performed as described in clause 8.2.3.2. The demultiplexer output is then mapped to modulation symbols using either BPSK, QPSK, 16-QAM, 64-QAM or NU-64-QAM constellations, as described in clause 8.2.3.3. Finally, the modulation symbols are then mapped to logical frames as described in clause 9.2.

8.2.2 Scrambling and FEC encoding

8.2.2.1 Scrambling of L1-PRE and L1-POST information bits

All K_{sig} signalling bits of L1-PRE and the $N_{post\_FEC\_Block}$ L1-POST blocks shall be scrambled using the same scrambling sequence as for BBFRAMES (see clause 5.2.4). The scrambling shall be performed before BCH encoding and shortened and punctured LDPC encoding. The scrambling sequence shall be synchronous with the L1-PRE and each L1-POST block, starting from the MSB and ending after K_{sig} bits.

The scrambling sequence shall be generated by the feed-back shift register of figure44. The polynomial for the Pseudo Random Binary Sequence (PRBS) generator shall be:

$$1 + X^{14} + X^{15}$$

Loading of the sequence (100101010000000) into the PRBS register, as indicated in figure 44, shall be initiated at the start of every L1-PRE and L1-POST block.

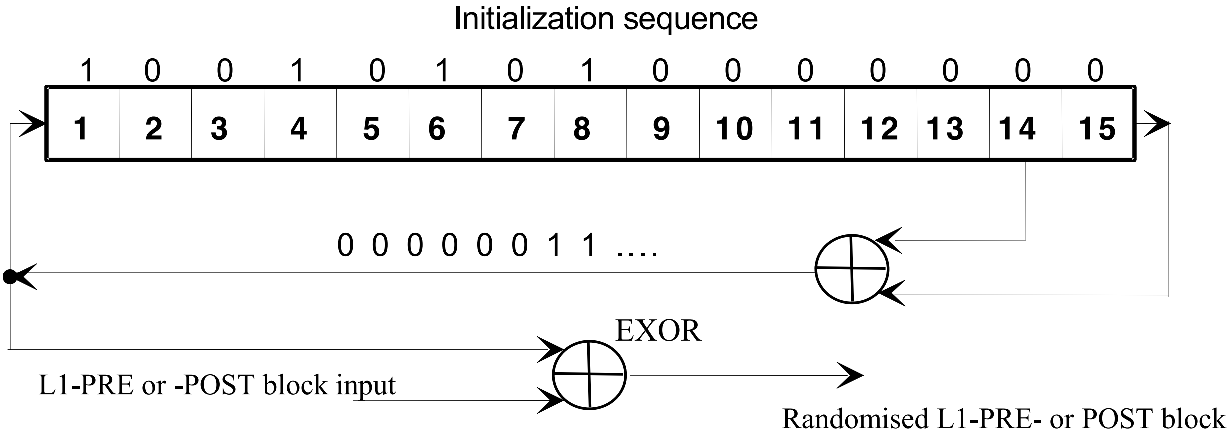


Figure 44: Possible implementation of the PRBS encoder.

8.2.2.2 Zero padding of BCH information bits

K_{sig} bits defined in clauses 8.2.1.1 and 8.2.1.2, and scrambled according to clause 8.2.2.1, shall be encoded into a 4K (N_{ldpc}=4320) LDPC codeword for L1-PRE or an extended 4K (N_{ldpc2}=8640) LDPC codeword for L1-POST after BCH encoding, respectively.

If K_{sig} is less than the number of BCH information bits (= K_{bch}) for a given code rate, the BCH/LDPC code will be shortened. A part of the information bits of the code shall be padded with zeros in order to fill K_{bch} information bits. The padding bits shall not be transmitted.

All K_{bch} BCH information bits, denoted by $\{m_0, m_1, \ldots, m_{Kbch-1}\}$, are divided into N_{group} (= $K_{\mathrm{ldpc}}/72$) bit groups as follows:

$$X_j = \left\{ m_k \middle| j = \left\lfloor \frac{k}{72} \right\rfloor, 0 \le k < K_{bch} \right\} \text{for } 0 \le j < N_{group}$$

where X_j represents the j-th bit group. The code parameters (K_{bch}, K_{ldpc}) are given in table 66 for L1-PRE and L1-POST.

Table 66: Code parameters (K_{bch}, K_{ldpc}) for L1-PRE and L1-POST

	K_{bch}	K_{ldpc}
L1-PRE signalling	804	864
L1-POST signalling	2100	2160

For $0 \le j \le N_{group} - 2$, each bit group X_j has 72 bits, except of the last bit group $X_{N_{group}-1}$ which has 72 - (K_{ldpc} - K_{bch})= 12 bits, as illustrated in figure 45

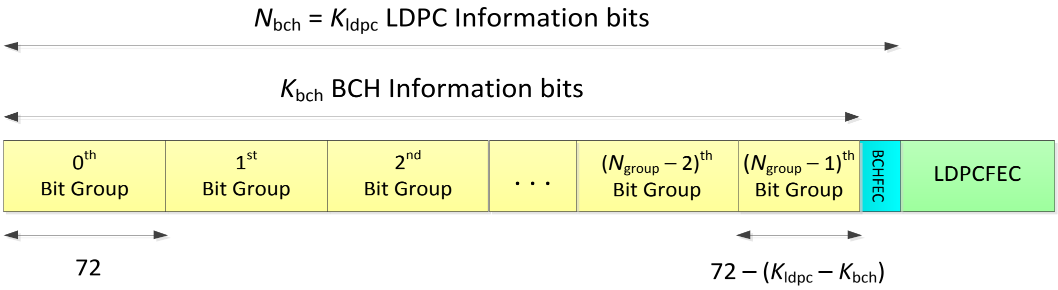


Figure 45: Format of data after LDPC encoding of L1 signalling

For the given K_{sig}, the number of zero-padding bits is given by (K_{bch} - K_{sig}). The shortening procedure is as follows:

- Step 1) Compute the number of groups in which all the bits shall be zero-padding bits, N_{pad} as given below:

$$N_{pad} = \left\lfloor \frac{K_{bch} - K_{sig}}{72} \right\rfloor$$

- Step 2) Determine the list of N_{pad} groups, $X_{\pi_S(0)}$, $X_{\pi_S(1)}$, ..., $X_{\pi_S(N_{pad}-1)}$, with $\pi_S(j)$ being the shortening pattern order of the j-th bit group to be shortened in accordance with the code rate, as described in tables 67 and68.
- Step 3) For the group $X_{\pi_S(N_{pad})}$, the last $(K_{bch} - K_{sig} - 72 \times N_{pad})$ information bits of $X_{\pi_S(N_{pad})}$ shall be zero-padding bits.
- Step 4) Finally, K_{sig} information bits are sequentially mapped to bit positions in K_{bch} BCH information bits, {m_0, m_1, ..., m_{Kbch-1} }, which are not zero-padding bits as determined in the above steps..

EXAMPLE: Assume for example the value 360 for K_{sig} and 804 for K_{bch}. The number of zero padding bits is 804-360 = 444. From step (1), 6 groups have all 72 bits as zero padding bits, and from step (2) these groups are those with indices 6, 5, 4, 9, 3, 2. From step (3), the last 12 bits of the 72 bits are set to zero-padding bits in the group of index 1. Finally from step (4), the 360 information bits are mapped sequentially to group 0 (72 bits), the first part of group 1 (60 bits), groups 7 (72 bits), 8 (72 bits), 10 (72 bits) and group 11 (12 bits). Figure 46 illustrates the shortening of the BCH information part in this case, i.e. filling BCH information bit positions (excluding zero padded bits) with K_{sig} information bits.

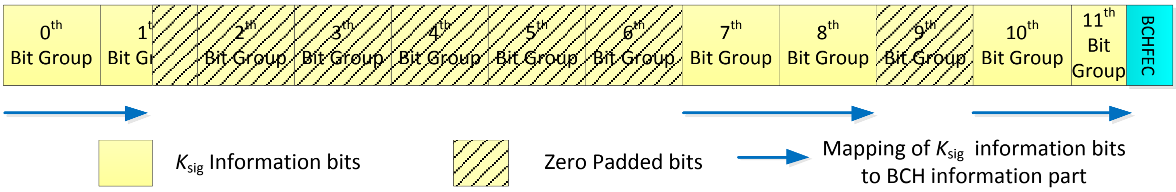


Figure 46: Example of shortening of BCH information part

Table 67: Shortening pattern of bit groups to be padded for L1-PRE signalling

Modulation and code rate		N_{group}	Order of bits group to be shortened $\pi_S(j)$ ($0 \leq j < N_{group}$)					
			$\pi_S(0)$	$\pi_S(1)$	$\pi_S(2)$	$\pi_S(3)$	$\pi_S(4)$	$\pi_S(5)$
			$\pi_S(6)$	$\pi_S(7)$	$\pi_S(8)$	$\pi_S(9)$	$\pi_S(10)$	$\pi_S(11)$
QPSK	1/5	12	6	5	4	9	3	2
			1	8	0	7	10	11

Table 68: Shortening pattern of bit groups to be padded for L1-POST signalling

Modulation and code rate		N_{group}	Order of bits group to be shortened $\pi_S(j)$ ($0 \leq j < N_{group}$)									
			$\pi_S(0)$	$\pi_S(1)$	$\pi_S(2)$	$\pi_S(3)$	$\pi_S(4)$	$\pi_S(5)$	$\pi_S(6)$	$\pi_S(7)$	$\pi_S(8)$	$\pi_S(9)$
			$\pi_S(10)$	$\pi_S(11)$	$\pi_S(12)$	$\pi_S(13)$	$\pi_S(14)$	$\pi_S(15)$	$\pi_S(16)$	$\pi_S(17)$	$\pi_S(18)$	$\pi_S(19)$
			$\pi_S(20)$	$\pi_S(21)$	$\pi_S(22)$	$\pi_S(23)$	$\pi_S(24)$	$\pi_S(25)$	$\pi_S(26)$	$\pi_S(27)$	$\pi_S(28)$	$\pi_S(29)$
BPSK/ QPSK/ 16QAM/ 64QAM/NU-64-QAM	1/2	30	9	8	15	10	0	12	5	27	6	7
			19	22	1	16	26	20	21	18	11	3
			17	24	2	23	25	14	28	4	13	29

8.2.2.3 BCH encoding

The K_{bch} information bits (including the K_{bch} - K_{sig} zero padding bits) shall be first BCH encoded according to clause 6.1.1 to generate $N_{bch} = K_{ldpc}$ output bits (i_0 , ..., i_{Nbch-1}).

The generator polynomial of the t (=5) error correcting BCH encoder for L1-PRE and L1-POST is obtained by multiplying the t polynomials in table 69.

Table 69: BCH polynomials for L1 signalling

$g_1(x)$	$1+x+x^4+x^6+x^{12}$
$g_2(x)$	$1+x+x^3+x^4+x^6+x^{10}+x^{12}$
$g_3(x)$	$1+x^2+x^3+x^6+x^{12}$
$g_4(x)$	$1+x+x^3+x^5+x^6+x^{10}+x^{12}$
$g_5(x)$	$1+x^2+x^4+x^5+x^6+x^7+x^8+x^9+x^{12}$

8.2.2.4 LDPC encoding

The N_{bch}=K_{ldpc} output bits (i_0, ... , i_{Nbch-1}) from the BCH encoder, including the (K_{bch} - K_{sig}) zero padding bits and the (K_{ldpc} - K_{bch}) BCH parity bits form the K_{ldpc} information bits $\boldsymbol{I} = (i_0, i_1, ..., i_{Kldpc-1})$ for the LDPC encoder. The LDPC encoder shall systematically encode the K_{ldpc} information bits into a codeword $\boldsymbol{\Lambda}$ of size N_{ldpc}:

$$\boldsymbol{\Lambda} = (i_0, i_1, ..., i_{Kldpc-1}, p_0, p_1, ..., p_{Nldpc-Kldpc-1})$$

The LDPC encoding parameters for L1-PRE and L1-POST are given in table 70.

Table 70: Coding parameters for L1-PRE and L1-POST

	BCH Uncoded Block K_{bch}	**BCH coded block N_{bch} LDPC Uncoded Block K_{ldpc}**	**BCH t-error correction**	**N_{bch}-K_{bch}**	**LDPC Coded Block N_{ldpc}**
L1-PRE	804	864	5	60	4320
L1-POST (Extended 1/2)	2100	2160	5	60	4320 (8640)

8.2.2.4.1 LDPC encoding for L1-PRE

The LDPC encoder for L1-PRE shall encode the K_{ldpc} (=864) output bits of the outer BCH encoder into a codeword Λ of size N_{ldpc} = 4320. The procedure is as follows:

- Initialize $p_0 = p_1 = p_2 = \ldots = p_{N_{ldpc}-K_{ldpc}-1} = 0$.
- Accumulate the first information bit, i_0, at parity bit addresses specified in the first row of table F.1 (all additions are in GF(2)):

$$p_{384} = p_{384} \oplus i_0 \qquad p_{2169} = p_{2169} \oplus i_0$$

$$p_{944} = p_{944} \oplus i_0 \qquad p_{2266} = p_{2266} \oplus i_0 .$$

- For the next 71 information bits, i_m (m = 1 to 71), accumulate i_m at parity bit addresses $\{x + (m\, mod 72) \times Q_{ldpc}\}\, mod(N_{ldpc} - K_{ldpc})$, where x denotes the address of the parity bit accumulator corresponding to the first bit i_0, and Q_{ldpc} is 48 . For example for information bit i_1, the following operations are performed:

$$p_{432} = p_{432} \oplus i_1 \qquad p_{2217} = p_{2217} \oplus i_1$$

$$p_{992} = p_{992} \oplus i_1 \qquad p_{2314} = p_{2314} \oplus i_1 .$$

- For the 73rd information bit i_{72}, the addresses of the parity bit accumulators are given in the second row of the table F.1. In the same manner the addresses of the parity bit accumulators for the following 71 information bits i_m (m = 73 to 143) are obtained using the formula $\{x + (m\, mod 72) \times Q_{ldpc}\}\, mod(N_{ldpc} - K_{ldpc})$, where x denotes the address of the parity bit accumulator corresponding to the information bit i_{72}, i.e. the entries in the second row of the table F.1.
- In the same manner, for every group of 72 information bits, a new row from table F.1 is used to find the addresses of the parity bit accumulators.

Once all the information bits are processed, the final parity bits are obtained as follows:

- Perform sequentially the following operations starting with $i = 1$:

$$p_i = p_i \oplus p_{i-1}, \qquad i = 1,2,\ldots,N_{ldpc} - K_{ldpc} - 1$$

- Set the final content of p_i, $i = 0,1,..,N_{ldpc} - K_{ldpc} - 1$ equal to the parity bit p_i .

8.2.2.4.2 LDPC encoding for L1-POST

The extended LDPC encoder takes the output of the outer BCH encoder, $\boldsymbol{I} = (i_0, i_1, \ldots, i_{K\mathrm{ldpc}-1})$ as an input information block of size $N_{\mathrm{bch}}=K_{\mathrm{ldpc}}$ (=2160), and systematically encodes it into a codeword Λ of size $N_{\mathrm{ldpc2}} = N_{\mathrm{ldpc}} + M_{\mathrm{IR}}$ where N_{ldpc}(=4320) is the length of a 4K LDPC codeword and M_{IR} (=4320) is the number of IR parity bits. The extended LDPC codeword is given by:

$$\Lambda=\left(\lambda_0,\lambda_1,\lambda_2,\ldots,\lambda_{N_{ldpc2-1}}\right)=(i_0,i_1,\ldots,i_{K_{ldpc}-1},p_0,p_1,\ldots,p_{N_{ldpc2}-K_{ldpc}-1})$$

The following encoding procedure ensures that the first bits of the extended codeword λ_i, for $i\in\left\{0,\cdots,N_{ldpc}-K_{ldpc}-1\right\}$ are the same as if the non-extended 4K LDPC code would have been used.

The task of the encoder is to determine $N_{ldpc2}-K_{ldpc}$ parity bits $(p_0,p_1,\ldots,p_{N_{ldpc2}-K_{ldpc}-1})$ for every block of K_{ldpc} information bits, $(i_0,i_1,\ldots.,i_{K_{ldpc}-1})$. The procedure is as follows:

- Initialize $p_0=p_1=p_2=\ldots=p_{N_{ldpc2}-K_{ldpc}-1}=0$.
- Accumulate the first information bit, i_0, at parity bit addresses specified in the first row of table F.2 (all additions are in GF(2)):

$p_{142}=p_{142}\oplus i_0$

$p_{150}=p_{150}\oplus i_0$

$p_{213}=p_{213}\oplus i_0$

$p_{247}=p_{247}\oplus i_0$

and so on …

$p_{2106}=p_{2106}\oplus i_0$

$p_{2117}=p_{2117}\oplus i_0$

$p_{2536}=p_{2536}\oplus i_0$

$p_{2748}=p_{2748}\oplus i_0$

$p_{3073}=p_{3073}\oplus i_0$

$p_{6181}=p_{6181}\oplus i_0$

$p_{6186}=p_{6186}\oplus i_0$

$p_{6192}=p_{6192}\oplus i_0$

- For the next 71 information bits, i_m (m = 1 to 71), accumulate i_m at parity bit addresses $\{x+(m\,mod72)\times Q_{ldpc1}\}\,mod\left(N_{ldpc}-K_{ldpc}\right)$ if $x<N_{ldpc}-K_{ldpc}$ or $N_{ldpc}-K_{ldpc}+\{x-\left(N_{ldpc}-K_{ldpc}\right)+(m\bmod 72)\times Q_{ldpc2}\}\,\mathrm{mod}M_{IR}$ if $x\geq N_{ldpc}-K_{ldpc}$, where x denotes the address of the parity bit accumulator corresponding to the first bit i_0, Q_{ldpc1}=30 and Q_{ldpc2}=60. So for example for information bit i_1, the following operations are performed:

$p_{172}=p_{172}\oplus i_1$

$p_{180}=p_{180}\oplus i_1$

$p_{243}=p_{243}\oplus i_1$

$p_{277}=p_{277}\oplus i_1$

and so on ...

$p_{2596}=p_{2596}\oplus i_1$

$p_{2808}=p_{2808}\oplus i_1$

$p_{3133}=p_{3133}\oplus i_1$

$p_{6241}=p_{6241}\oplus i_1$

$p_{6246}=p_{6246}\oplus i_1$

$p_{2136} = p_{2136} \oplus i_1$ $p_{6252} = p_{6252} \oplus i_1$

$p_{2147} = p_{2147} \oplus i_1$ (all additions are in GF(2))

- For the 73rd information bit i_{72}, the addresses of the parity bit accumulators are given in the second row of the table F.2. In the same manner, the addresses of the parity bit accumulators for the following 71 information bits i_m (m = 73 to 143) are obtained using the formula $\{x + (m\, mod 72) \times Q_{ldpc1}\}\, mod(N_{ldpc} - K_{ldpc})$ if $x < N_{ldpc} - K_{ldpc}$ or $N_{ldpc} - K_{ldpc} + \{x - (N_{ldpc} - K_{ldpc}) + (m \bmod 72) \times Q_{ldpc2}\} \bmod M_{IR}$ if $x \geq N_{ldpc} - K_{ldpc}$, where x denotes the address of the parity bit accumulator corresponding to the information bit i_{72}, i.e. the entries in the second row of the table F.2.

  In the same manner, for every group of 72 new information bits, a new row from table F.2 is used to find the addresses of the parity bit accumulators. In general, the addresses for the information bit i_m are given by the$(\lfloor m/72 \rfloor + 1)^{th}$ row of the address table.

After all information bits are processed, the final parity bits are obtained as follows:

- Sequentially perform the following operations starting with $i = 1$:

$$p_i = p_i \oplus p_{i-1}, \qquad i = 1, 2, ..., N_{ldpc2} - K_{ldpc} - 1$$

- Set the final content of p_i, $i = 0, 1, .., N_{ldpc2} - K_{ldpc} - 1$ equal to the parity bit p_i.

8.2.2.5 Puncturing of LDPC parity bits

8.2.2.5.1 Puncturing of LDPC parity bits for L1-PRE

When shortening is applied to the signalling bits, some LDPC parity bits shall be punctured after the LDPC encoding. These punctured bits shall not be transmitted.

All N_{ldpc} - K_{ldpc} LDPC parity bits, denoted by $\{p_0, p_1, ..., p_{N_{ldpc}-K_{ldpc}-1}\}$, are divided into Q_{ldpc} parity bit groups where each parity bit group is formed from a sub-set of the N_{ldpc} - K_{ldpc} LDPC parity bits as follows:

$$P_j = \left\{ p_k \,\middle|\, k \bmod Q_{\mathrm{ldpc}} = j,\ 0 \leq k < N_{\mathrm{ldpc}} - K_{\mathrm{ldpc}} \right\} \qquad \text{for} \qquad 0 \leq j < Q_{\mathrm{ldpc}}$$

where P_j represents the j-th parity bit group and Q_{ldpc} is 48. Each group has $(N_{ldpc} - K_{ldpc})/Q_{ldpc}$ = 72 bits, as illustrated in figure 47.

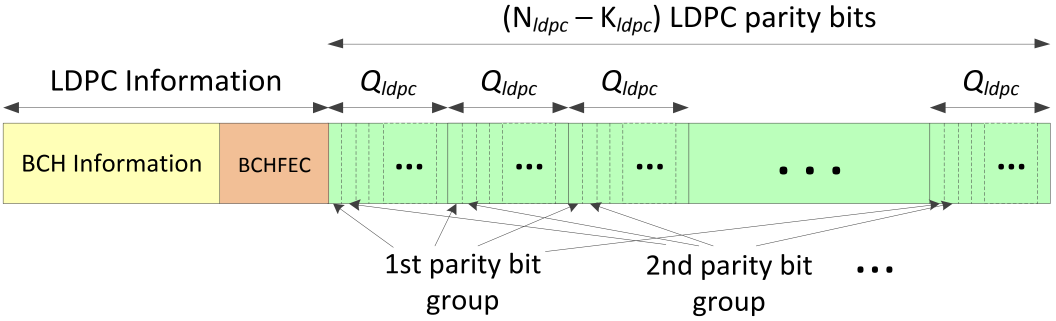


Figure 47: Parity bit groups in a FEC block

For the number of parity bits to be punctured, N_{punc} given in clause 8.2.1.1, the following operations shall be performed:

- Step 1) Compute the number of groups in which all parity bits shall be punctured, N_{punc_groups} such that:

$$N_{punc\_groups} = \left\lfloor \frac{N_{punc}}{72} \right\rfloor \text{ for } 0 \le N_{punc} < N_{ldpc} - K_{ldpc}.$$

- Step 2) Determine the list of N_{punc_groups} parity bit groups $P_{\pi_P(0)}$, $P_{\pi_P(1)}$, …, $P_{\pi_P(N_{punc\_groups}-1)}$, with $\pi_P(j)$ being the puncturing pattern order of the parity bits group to be punctured, as described in table 71.
- Step 3) For the last group $P_{\pi_P(N_{punc\_groups})}$, the first $(N_{punc} - 72 \times N_{punc\_groups})$ parity bits in the group shall be punctured.

Table 71: Puncturing pattern of parity bit groups for L1-PRE signalling

Modulation and Code rate		**Order of parity groups to be punctured, {$\pi_P(j)$, 0 ≤ *j* < Q_{ldpc} = *48*}**																	
		$\pi_P(0)$	$\pi_P(1)$	$\pi_P(2)$	$\pi_P(3)$	$\pi_P(4)$	$\pi_P(5)$	$\pi_P(6)$	$\pi_P(7)$	$\pi_P(8)$	$\pi_P(9)$	$\pi_P(10)$	$\pi_P(11)$	$\pi_P(12)$	$\pi_P(13)$	$\pi_P(14)$	$\pi_P(15)$	$\pi_P(16)$	$\pi_P(17)$
		$\pi_P(18)$	$\pi_P(19)$	$\pi_P(20)$	$\pi_P(21)$	$\pi_P(22)$	$\pi_P(23)$	$\pi_P(24)$	$\pi_P(25)$	$\pi_P(26)$	$\pi_P(27)$	$\pi_P(28)$	$\pi_P(29)$	$\pi_P(30)$	$\pi_P(31)$	$\pi_P(32)$	$\pi_P(33)$	$\pi_P(34)$	$\pi_P(35)$
		$\pi_P(36)$	$\pi_P(37)$	$\pi_P(38)$	$\pi_P(39)$	$\pi_P(40)$	$\pi_P(41)$	$\pi_P(42)$	$\pi_P(43)$	$\pi_P(44)$	$\pi_P(45)$	$\pi_P(46)$	$\pi_P(47)$						
QPSK	1/5	29	45	43	27	32	35	40	38	0	19	8	16	41	4	26	36	30	2
		13	42	46	24	37	1	33	11	44	28	20	9	34	3	17	6	21	14
		23	7	22	47	5	10	12	15	18	25	31	39						

8.2.2.5.2 Puncturing of LDPC parity bits for L1-POST

For the L1-POST signalling, some LDPC parity bits shall be punctured after the LDPC encoding. These punctured bits shall not be transmitted in the same frame with the information part.

All LDPC parity bits, denoted by $\{p_0, p_1, \ldots, p_{N\text{ldpc}-K\text{ldpc}-1}, p_{N\text{ldpc}-K\text{ldpc}}, p_{N\text{ldpc}-K\text{ldpc}+1}, \ldots, p_{N\text{ldpc2}-K\text{ldpc}-1}\}$ are divided into two parity parts, a first parity part $\{p^1_0, p^1_1, \ldots, p^1_{N\text{ldpc}-K\text{ldpc}-1}\} = \{p_0, p_1, \ldots, p_{N\text{ldpc}-K\text{ldpc}-1}\}$, and a second parity part $\{p^2_0, p^2_1, \ldots, p^2_{N\text{ldpc2}-N\text{ldpc}-1}\} = \{p_{N\text{ldpc}-K\text{ldpc}}, \ldots, p_{N\text{ldpc2}-K\text{ldpc}-1}\}$. Each parity part is then divided into Q_{ldpc1} and Q_{ldpc2} parity bit groups, respectively, where each parity bit group is formed from a sub-set of the $N_{\text{ldpc2}} - K_{\text{ldpc}}$ LDPC parity bits as shown below:

$$P^1_j = \left\{ p^1_k \,\middle|\, \left(k \bmod Q_{\text{ldpc1}}\right) = j,\ 0 \le k < N_{\text{ldpc}} - K_{\text{ldpc}} \right\} \quad \text{for} \quad 0 \le j < Q_{\text{ldpc1}},$$

$$P^2_j = \left\{ p^2_k \,\middle|\, \left(k \bmod Q_{\text{ldpc2}}\right) = j,\ 0 \le k < N_{\text{ldpc2}} - N_{\text{ldpc}} \right\} \quad \text{for} \quad 0 \le j < Q_{\text{ldpc2}},$$

where P^1_j and P^2_j represent the *j*-th parity bit group in the first parity part and second parity part, respectively. Q_{ldpc1} and Q_{ldpc2} are equal to 30 and 60, respectively. Each group has $(N_{\text{ldpc}} - K_{\text{ldpc}})/Q_{\text{ldpc1}} = (N_{\text{ldpc2}} - N_{\text{ldpc}})/Q_{\text{ldpc2}} = 72$ bits, as illustrated in figure 48.

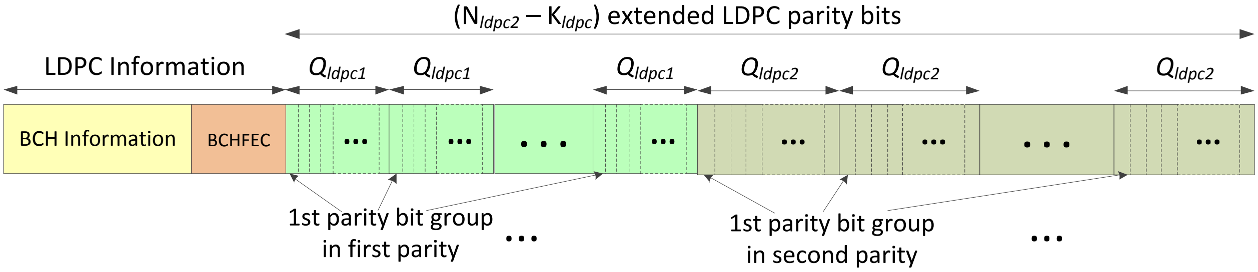


Figure 48: Parity bit groups in a FEC block for L1-POST

Using the number of parity bits to be punctured, N_{punc} given in clauses 8.2.1.2, the following operations shall be performed:

- Step 1) Compute the number of groups in which all parity bits shall be punctured, N_{punc_groups} such that:

$$N_{punc\_groups} = \left\lfloor \frac{N_{punc}}{72} \right\rfloor \text{ for } 0 \le N_{punc} < N_{ldpc2} - K_{ldpc}\,.$$

- If $N_{punc\_groups} \geq Q_{ldpc2}$,
  - Step 2) All parity bits in the second parity part are punctured since the second parity part shall be punctured first. In addition, for the next (N_{punc_groups} – Q_{ldpc2}) parity bit groups $P^1_{\pi^1_P(0)}$, $P^1_{\pi^1_P(1)}$, …, $P^1_{\pi^1_P(N_{punc\_groups}-Q_{ldpc2}-1)}$, all parity bits in each group shall be punctured, with $\pi^1_P(j)$ denoting the puncturing pattern order of first parity bits group to be punctured, as described in table 72.
  - Step 3) Furthermore for the last group $P^1_{\pi^1_P(N_{punc\_groups}-Q_{ldpc2})}$, the last $(N_{punc} - 72 \times N_{punc\_groups})$ parity bits in the group shall be punctured.
- Otherwise,
  - Step 2) For the following list of N_{punc_groups} parity bit groups $P^2_{\pi^2_P(0)}$, $P^2_{\pi^2_P(1)}$, …, $P^2_{\pi^2_P(N_{punc\_groups}-1)}$, all parity bits in each group shall be punctured, with $\pi^2_P(j)$ denoting the puncturing pattern order of second parity bits group to be punctured, as described in table 73.
  - Step 3) Furthermore for the last group $P^2_{\pi^2_P(N_{punc\_groups})}$, the first $(N_{punc} - 72 \times N_{punc\_groups})$ parity bits of the group shall be punctured.

Table 72: Puncturing pattern of parity groups in the first parity part to be punctured

Modulation and Code rate		Order of parity group in first parity part to be punctured, { $\pi_P(j)$, 0 ≤ *j* < Q_{ldpc} = 30}												
		$\pi_P^1(0)$	$\pi_P^1(1)$	$\pi_P^1(2)$	$\pi_P^1(3)$	$\pi_P^1(4)$	$\pi_P^1(5)$	$\pi_P^1(6)$	$\pi_P^1(7)$	$\pi_P^1(8)$	$\pi_P^1(9)$	$\pi_P^1(10)$	$\pi_P^1(11)$	$\pi_P^1(12)$
		$\pi_P^1(13)$	$\pi_P^1(14)$	$\pi_P^1(15)$	$\pi_P^1(16)$	$\pi_P^1(17)$	$\pi_P^1(18)$	$\pi_P^1(19)$	$\pi_P^1(20)$	$\pi_P^1(21)$	$\pi_P^1(22)$	$\pi_P^1(23)$	$\pi_P^1(24)$	$\pi_P^1(25)$
		$\pi_P^1(26)$	$\pi_P^1(27)$	$\pi_P^1(28)$	$\pi_P^1(29)$									
BPSK/QPSK/16-QAM/64-QAM/NU-64-QAM	1/2	21	17	0	24	7	10	14	12	23	1	16	3	5
		26	28	19	4	15	8	2	27	20	6	9	25	13
		11	18	22	29									

Table 73: Puncturing pattern of parity groups in the second parity part to be punctured

Modulation and Code rate		Order of parity group in second parity part to be punctured, { $\pi_P(j)$, 0 ≤ *j* < Q_{ldpc} = 60}												
		$\pi_P^2(0)$	$\pi_P^2(1)$	$\pi_P^2(2)$	$\pi_P^2(3)$	$\pi_P^2(4)$	$\pi_P^2(5)$	$\pi_P^2(6)$	$\pi_P^2(7)$	$\pi_P^2(8)$	$\pi_P^2(9)$	$\pi_P^2(10)$	$\pi_P^2(11)$	$\pi_P^2(12)$
		$\pi_P^2(13)$	$\pi_P^2(14)$	$\pi_P^2(15)$	$\pi_P^2(16)$	$\pi_P^2(17)$	$\pi_P^2(18)$	$\pi_P^2(19)$	$\pi_P^2(20)$	$\pi_P^2(21)$	$\pi_P^2(22)$	$\pi_P^2(23)$	$\pi_P^2(24)$	$\pi_P^2(25)$
		$\pi_P^2(26)$	$\pi_P^2(27)$	$\pi_P^2(28)$	$\pi_P^2(29)$	$\pi_P^2(30)$	$\pi_P^2(31)$	$\pi_P^2(32)$	$\pi_P^2(33)$	$\pi_P^2(34)$	$\pi_P^2(35)$	$\pi_P^2(36)$	$\pi_P^2(37)$	$\pi_P^2(38)$
		$\pi_P^2(39)$	$\pi_P^2(40)$	$\pi_P^2(41)$	$\pi_P^2(42)$	$\pi_P^2(43)$	$\pi_P^2(44)$	$\pi_P^2(45)$	$\pi_P^2(46)$	$\pi_P^2(47)$	$\pi_P^2(48)$	$\pi_P^2(49)$	$\pi_P^2(50)$	$\pi_P^2(51)$
		$\pi_P^2(52)$	$\pi_P^2(53)$	$\pi_P^2(54)$	$\pi_P^2(55)$	$\pi_P^2(56)$	$\pi_P^2(57)$	$\pi_P^2(58)$	$\pi_P^2(59)$					
BPSK/ QPSK /16-QAM /64-QAM/NU-64-QAM	1/2	16	41	34	11	19	6	26	44	3	47	22	10	50
		39	30	14	56	28	55	21	9	40	31	51	20	17
		8	25	54	18	5	33	42	12	23	49	57	1	37
		52	45	36	2	32	27	48	43	29	24	0	13	38
		15	58	7	53	35	4	46	59					

8.2.2.6 Generation of additional parity for L1-POST signalling

If the L1_AP_RATIO (see clause 8.1.3.1) is larger than or equal to 1, additional parity bits for the L1-POST signalling shall be transmitted in previous logical frames preceding the current logical frame carrying the L1-POST signalling bits. This allows for higher error protection for the L1-POST signalling. Additional parity bits are generated by selecting punctured parity bits according to the puncturing pattern given in clause 8.2.2.5.2.

For the extended 4K LDPC codeword, all N_{ldpc2} - K_{ldpc} LDPC parity bits, denoted by $\{p_0, p_1, \ldots, p_{N\mathrm{ldpc2}-K\mathrm{ldpc}-1}\}$, are divided into ($Q_{\mathrm{ldpc1}}$ + Q_{ldpc2}) parity bit groups, where each parity bit group is formed from the parity groups described in 8.2.2.5.2 as follows:

$$P_j = P_j^1, \qquad \text{for} \qquad 0 \le j < Q_{\mathrm{ldpc1}}$$

$$P_j = P_{j-Q_{ldpc1}}^2, \qquad \text{for} \qquad Q_{\mathrm{ldpc1}} \le j < Q_{\mathrm{ldpc1}} + Q_{\mathrm{ldpc2}}$$

In addition, the puncturing pattern for additional parity can be derived from the puncturing pattern described in 8.2.2.5.2 as follows:

$$\pi_P(j) = \pi_P^2(j) \qquad \text{for} \qquad 0 \le j < Q_{\mathrm{ldpc2}}$$

$$\pi_P(j) = \pi_P^1(j - Q_{ldpc2}) \text{for} \qquad Q_{\mathrm{ldpc2}} \le j < Q_{\mathrm{ldpc2}} + Q_{\mathrm{ldpc1}}$$

Using the number of parity bits to be punctured, N_{punc} given in clause 8.2.1.2, the following operations shall be performed:

- Step 1) Compute the number of additional parity such that :

$$N_{add\_parity\_temp} = \min\left(\left(N_{parity} - N_{punc}\right), \left\lfloor 0.35 \times K \cdot \left(N_{parity} - N_{punc}\right)\right\rfloor\right),$$

where K corresponds to the field L1_AP_RATIO in L1-PRE**,** and derive:

$$N_{add\_parity} = \left\lfloor \frac{N_{add\_parity\_temp}}{2\eta_{MOD}} \right\rfloor \times 2\eta_{MOD},$$

where η_{MOD} denotes the modulation order taking the values 1, 2, 4, and 6 for BPSK, QPSK, 16-QAM, and 64-QAM or NU-64-QAM, respectively.

- Step 2) Compute the number of additional parity bits which shall be selected in group $P_{\pi_P(N_{punc\_groups})}$:

  $$y = \min\left(N_{punc} - 72 \times N_{punc\_groups}, N_{add\_parity}\right),$$

  where min(a, b) = a if a < b, and N_{punc_groups}, which is given in 8.2.2.5.2, denotes the number of groups in which all parity bits shall be punctured.

- Step 3) For the group $P_{\pi_P(N_{punc\_groups})}$, *y* parity bits in the first part of the group shall be selected. If $\mathrm{N}_{\mathrm{add\_parity}}$ is greater than *y*, the following operations from step 4 to step 6 are performed. Otherwise, no further operations are performed.

- Step 4) Compute the number of additional parity groups in which all parity bits shall be selected, $N_{add\_parity\_groups}$ such that:

  $$N_{add\_parity\_groups} = \left\lfloor \frac{N_{add\_parity} - y}{72} \right\rfloor$$

- Step 5) For the groups $P_{\pi_P(N_{punc\_groups}-1)}, P_{\pi_P(N_{punc\_groups}-2)}, \cdots, P_{\pi_P(N_{punc\_groups}-N_{add\_parity\_groups})}$ all parity bits of the groups shall be selected.

- Step 6) For group $P_{\pi_P(N_{punc\_groups}-N_{add\_parity\_groups}-1)}$, the first $\left(N_{add\_parity} - 72 \times N_{add\_parity\_groups} - y\right)$ parity bits of the group shall be selected.

When 16-QAM, 64-QAM or NU-64-QAM is used, bit interleaving shall be applied across each LDPC block. Details of the bit interleaving of the encoded bits are described in clause 8.2.2.8. When BPSK or QPSK is used, bit interleaving shall not be applied. Demultiplexing is then performed as described in clause 8.2.3.2. The demultiplexer output is then mapped to modulation symbols using either BPSK, QPSK, 16-QAM, 64-QAM, or NU-64-QAM constellation, as described in clause 8.2.3.3. Finally, the modulation symbols are then mapped to logical frames as described in clause 9.2.

8.2.2.7 Removal of zero padding bits

The (K_{bch}-K_{sig}) zero padding bits are removed and shall not be transmitted. This leaves a word consisting of the K_{sig} information bits, followed by the 60 BCH parity bits and (N_{ldpc}-K_{ldpc} - N_{punc}) LDPC parity bits and (N_{ldpc2}-K_{ldpc} - N_{punc}) LDPC parity bits for L1-PRE and L1-POST, respectively.

8.2.2.8 Bit interleaving for L1-POST signalling

When 16-QAM, 64-QAM or NU-64-QAM modulation is used for the L1-POST signalling, the LDPC codeword of length N_{post}, consisting of K_{sig} information bits, 60 BCH parity bits, and (6480 - N_{punc}) LDPC parity bits, shall be bit-interleaved using a block interleaver. In addition, for the L1-POST signalling, N_{add_parity} additional parity bits, shall be bit-interleaved using a block interleaver. The configuration of the bit interleaver for each modulation is specified in table 74.

Table 74: Bit Interleaver structure

Modulation and Code rate		Rows Nr	Columns Nc
16-QAM	1/2	N_{post} / 8	8
64-QAM / NU-64-QAM	1/2	N_{post} / 12	12

The LDPC codeword and additional parity bits are serially written into the interleaver column-wise, and serially read out row-wise (the MSB of the L1-POST signalling is read out first) as shown in figure49.

When BPSK or QPSK is used, bit interleaving shall not be applied.

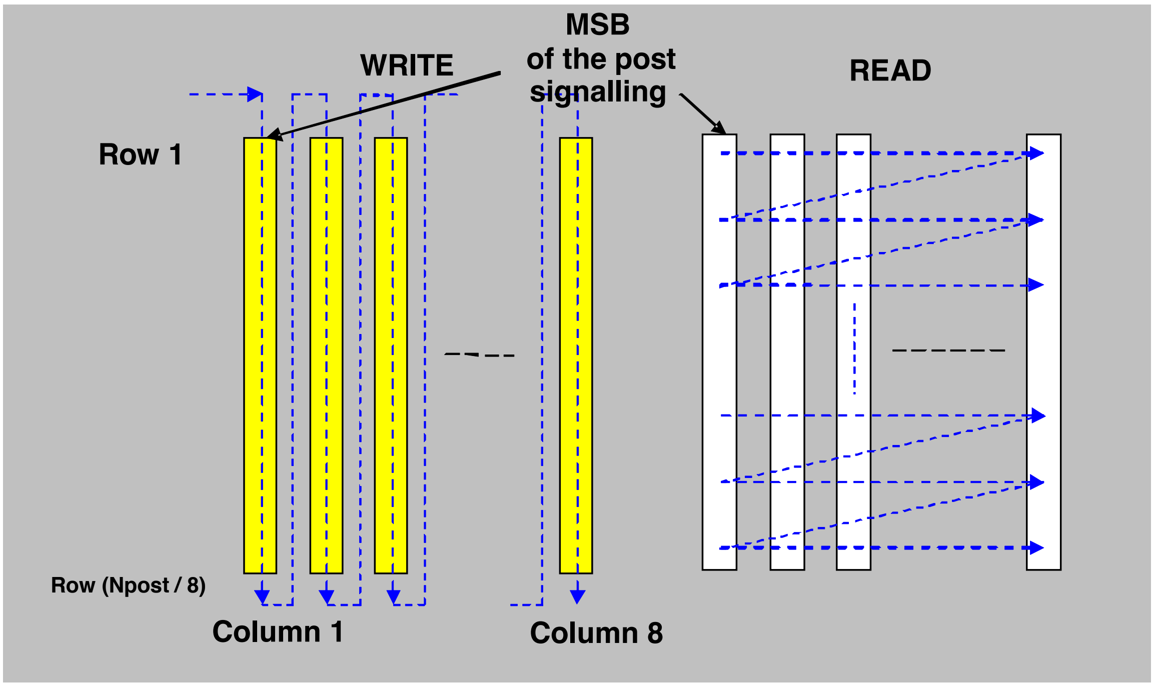


Figure 49: Bit Interleaving scheme for L1-POST (16-QAM, 64-QAM, NU-64-QAM)

8.2.3 Mapping bits onto constellations

Each bit-interleaved shortened and punctured LDPC codeword shall be mapped onto constellations. Each bit of the L1-PRE signalling is mapped after a rearrangement into a QPSK constellation according to clause 8.2.3.1, whereas the L1-POST signalling and additional parity bits are first demultiplexed into cell words according to clause 8.2.3.2 and the cell words are then mapped into constellations according to clause 8.2.3.3.

8.2.3.1 Mapping of L1-PRE signalling

Each bit-interleaved shortened and punctured L1-PRE LDPC codeword, a sequence of $N_{pre} = 2424$ bits $b_0 \ldots b_{N_{pre}-1}$, shall be mapped onto 2424 QPSK symbols as described by the block diagram in figure 48. Each bit of the LDPC bit stream c_i is duplicated to form an upper and a lower branch. The lower branch applies a cyclic shift within each LDPC codeword and scrambles the resulting data using a PRBS sequence. The data is then mapped on a QPSK constellation, the upper branch forming the real part and the lower branch forming the imaginary part of each QPSK symbol. The QPSK symbols are cyclically shifted and mapped to n_{pre} consecutive NGH physical frames, forming n_{pre} L1-PRE subblocks, where the parameter n_{pre} may have the value 1, 2 or 4.

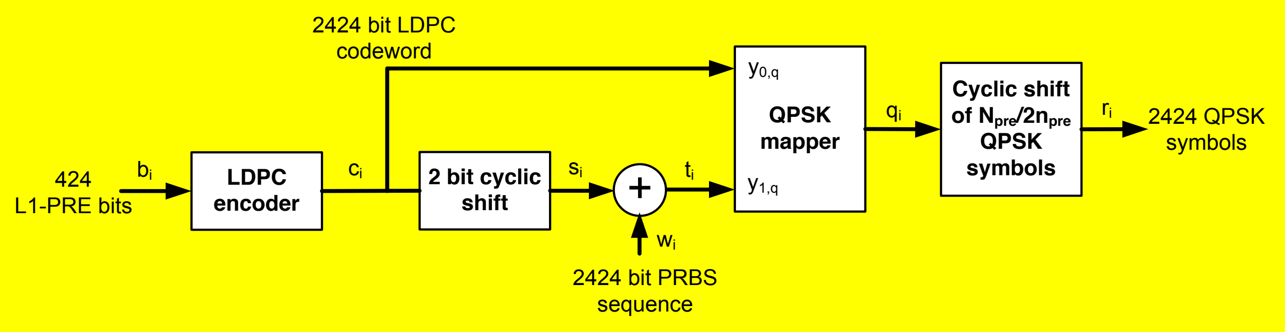


Figure 50: Modulation of L1-PRE

As depicted in figure 50, the 2424 LDPC encoded L1-PRE bits of the lower branch shall be 2 bit cyclically shifted by two values within each LDPC block. The output s_i of the cyclic shift block shall be:

$$s_{i+2 \bmod 2424} = c_i \qquad i = 0,1,...,2423$$

The data of the lower branch shall be scrambled with the PRBS sequence w_i defined in clause 9.2.2.1. The resulting 2424 bit output sequence t_i is obtained by applying modulo 2 addition of the cyclically shifted bits s_i and the PRBS sequence w_i:

$$t_i = s_i \oplus w_i \qquad i = 0,1,...,2423$$

The 2424 bits of the upper and the 2424 bits of the lower branch shall be modulated using QPSK, according to clause 6.2.2. The 2424 mapper input cell words shall be defined as:

$$\left[y_{0,i}, y_{1,i}\right] = \left[c_i, t_i\right] \qquad i = 0,1,...,2423$$

That is the bits of the upper branch are always mapped onto the real part and the bits of the lower branch are always mapped onto the imaginary part of the QPSK symbol. The resulting 2424 QPSK output symbols q_i shall be cyclically shifted by $N_{pre}/(2n_{pre})$ values if n_{pre} is greater than 1:

$$r_{i+(N_{pre}/2n) \bmod 2424} = q_i \qquad i = 0,1,...,2423$$

If n_{pre} is equal to 1, no cyclic shifting of the QPSK symbols shall be performed. The output of the cyclic shift block r_i, forming n_{pre} equally sized L1-PRE subblocks, is then mapped to n_{pre} consecutive NGH frames, where the first L1-PRE subblock, consisting of the QPSK symbols $r_0 \ldots r_{N_{pre}/n_{pre}-1}$, is mapped to the first NGH frame, the following subblock, consisting of the QPSK symbols $r_{N_{pre}/n_{pre}} \ldots r_{2N_{pre}/n_{pre}-1}$, is mapped to the second frame, and so on.

The number of NGH frames per NGH super-frame must be a multiple of n_{pre}, to assure that the last NGH frame of an NGH super-frame is modulated with the last L1-PRE subblock. If LC type C or D is present within the NGH system, the parameter n_{pre} must be set to 1 to ensure the receiver being able to decode the L1-PRE signalling within one NGH frame and to tune to the next frequency in time.

8.2.3.2 Demultiplexing of L1-POST signalling

Each bit-interleaved punctured and shortened LDPC codeword, a sequence of N_{post} bits, $V = (v_0 . . v_{N_{post}-1})$, where $N_{post} = K_{sig} + 60 + 6480 - N_{punc}$, shall be mapped onto constellations by first de-multiplexing the input bits into parallel cell words and then mapping these cell words into constellation values. The number of output data cells and the effective number of bits per cell, η_{MOD} are defined by table 52.

The input bit-stream v_{di} is demultiplexed into $N_{\text{substreams}}$ sub-streams $b_{e,do}$, as shown in figure 25 in clause 6.2.1. The value of $N_{\text{substreams}}$ is defined in table 10. Details of demultiplexing are described in clause 6.2.1. For QPSK, 16-QAM, 64-QAM and NU-64-QAM, the parameters for de-multiplexing of bits to cells are the same as those of table 13 in clause 6.2.1. For BPSK, the input number and the output bit-number are 0, and in this case the demultiplexing has no effect.

Table 75: Parameters for bit-mapping into constellations

Modulation mode	η_{MOD}	Number of output data cells per codeword	Number of sub-streams, $N_{\text{substreams}}$
BPSK	1	N_{post}	1
QPSK	2	N_{post} / 2	2
16-QAM	4	N_{post} / 4	8
64-QAM/NU-64-QAM	6	N_{post} / 6	12

For 16-QAM, 64-QAM and NU-64-QAM, the output words from the demultiplexing of width $N_{substreams}$ $[b_{0,\text{do}}..b_{Nsubstreams\text{-}1,\text{do}}]$ are split into two words of width $\eta_{MOD} = N_{substreams}/2$ $[y_{0,2\text{do}}..\ y_{\eta mod\text{-}1,\ 2\text{do}}]$ and $[y_{0,\ 2\text{do}+1}..y_{\eta mod\text{-}1,2\text{do}+1}]$ as described in clause 6.2.1. For BPSK and QPSK, the output words are fed directly to the constellation mapper, so: $[y_{0,do}..y_{\eta mod\text{-}1,\text{do}}] = [b_{0,\text{do}}..b_{Nsubstreams\text{-}1,\text{do}}]$.

8.2.3.3 Mapping into I/Q constellations

The bits of the L1-PRE signalling $y_{0,q}$ and the cell words of the L1-POST signalling $[y_{0,q}..y_{\eta mod\text{-}1,\text{q}}]$ are mapped onto constellations f_pre_q and f_post_q, respectively, according to clause 6.2.2, where q is the index of the cells within each bit-interleaved LDPC codeword. For the L1-PRE signalling, $0 \le q < 2424/\text{n}_{\text{pre}}$, and for the L1-POST signalling $0 \le q < N_{MOD\_per\_Block}$. The coded and modulated cells of the L1-POST signalling corresponding to each codeword of NGH frame number m are then concatenated to form a single block of cells $f\_post_{m,i}$, where i is the index of the cells within the single block $0 \le i < N_{MOD\_Total}$. The coded and modulated cells of the L1-PRE signalling for NGH frame number m form a single block of cells $f\_pre_{\text{m,i}}$, where i is the index of the cells within the single block $0 \le i < 2424/\text{n}_{\text{pre}}$.

9 Frames

9.1 Frame builder

This clause defines the frame builder functions of a NGH system. Frame building in NGH progresses in two stages: logical frame building described in clause 9.2 and NGH frame building described in clause 9.5. A logical frame is a container of cells that comprise modulated L1-POST signalling, common and data PLPs, auxillary streams and any dummy cells added. Logical frames are carried in NGH frames which represent the physical containers of the NGH system. An NGH frame provides cell capacity for the carrying of modulated L1-PRE signalling followed by the contents of the logical frames. The two frame builders are illustrated in figure 51.

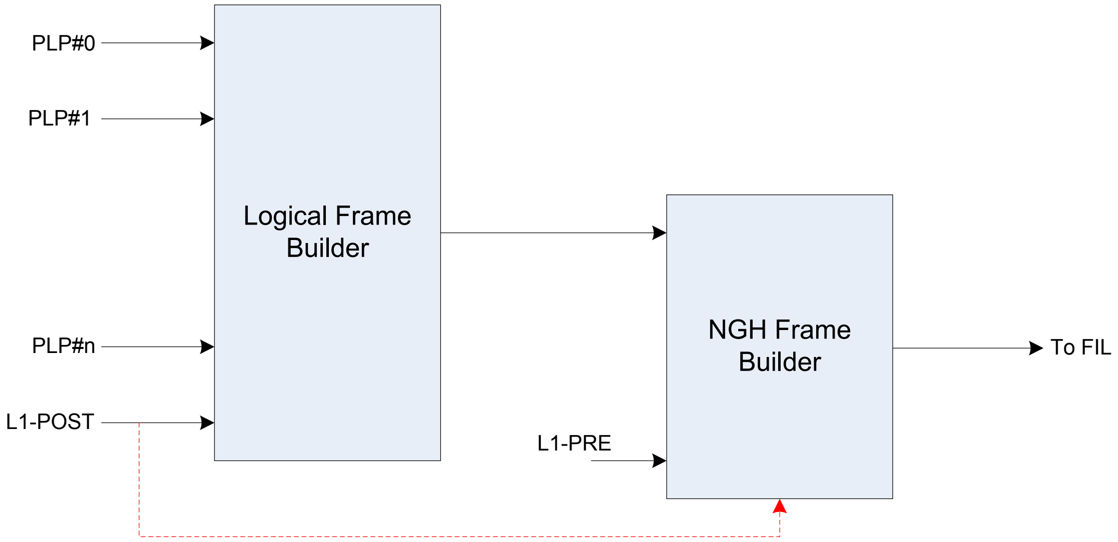


Figure 51: Two stages of NGH frame building

The function of the logical frame builder is to assemble the cells produced by the time interleavers for each of the common and data PLPs and the cells of the modulated L1-POST signalling into an array cells. The function of the NGH frame builder is to assemble the cells of the logical frame and the cells of the modulated L1-PRE signalling into arrays corresponding to the active cells of the OFDM symbols which make up the overall frame structure. The frame builder operates according to the dynamic information produced by the scheduler (see clause 5.2.1) and the configuration of the frame structure.

9.2 Logical frame structure

A logical frame (LF) in DVB-NGH is a data container including L1-POST signalling, PLPs, auxiliary streams and dummy cells. Each logical frame starts with L1-POST signalling and is followed by the common PLP, data PLPs (Type 1, 2, 4), auxiliary streams, dummy cells, and data PLPs type 3, whichever of these are applicable in the particular case. The structure of the logical frame is depicted in figure 52.

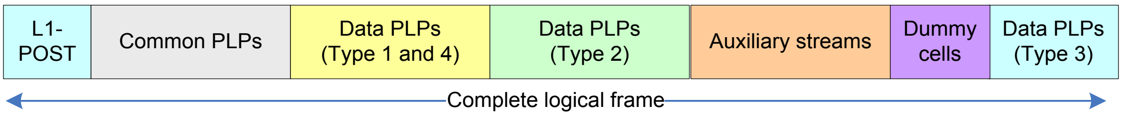


Figure 52: Structure of the logical frame

The capacity C_{tot} of the logical frame is defined in terms of number of QAM cells. The logical frame starts with cells of L1-POST signalling. The address of the first cell of L1-POST shall be equal to 0. Then, it follows with the cells of the common and data PLPs (Type 1, 2, 4). It may then be followed with the cells of one or more auxiliary streams and some dummy cells. It may then be followed with the cells of data PLPs type 3. Together, the L1-POST cells, data PLP cells, auxiliary streams and dummy cells exactly fill the capacity of the logical frame. The total number of cells used for auxiliary streams and dummy cells shall not exceed 50 % of the total capacity of the logical frame.

9.2.1 Signalling of the logical frame

The configuration of the logical frame structure is signalled by L1-POST signalling (see clause 8.1.3). The capacity C_{tot} of the logical frame is signalled by the value of the field LC_LF_SIZE in L1 configurable signalling. The locations of the PLPs themselves within the logical frame can change dynamically from logical frame to logical frame, and this is signalled both in the dynamic part of the L1-POST signalling (see clause 8.1.3.3), and in the in-band signalling (see clause 5.2.3). Repetition of the dynamic part of the

L1-POST signalling may be used to improve robustness, as described in clause 8.1.3.4. Moreover, additional parity of the L1-POST signalling may be used to improve further robustness, as described in clause 8.1.3.5. Self-decodable partitioning of the configurable part of L1-POST signalling may be used to reduce overhead, as described in clause 8.1.3.2.

The L1-POST dynamic signalling refers to the current logical frame (and the next logical frame when repetition and/or additional parity is used, see clause 8.1.3.4 and 8.1.3.5) and the in-band signalling refers to the next logical frame. This is depicted in figure 53.

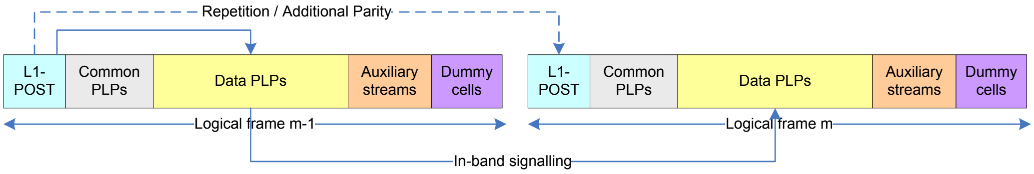


Figure 53: L1 signalling for the logical frame

9.2.2 Mapping the PLPs onto logical frames

A PLP is carried in sub-slices, where the number of sub-slices is between 1 and 6 480. PLPs are classified into 5 types, signalled in L1-POST signalling field **PLP_TYPE**: common PLP, data PLP Type 1, data PLP type 2, data PLP Type 3, and data PLP Type 4. C

Common, data Type 1, 3, and 4 PLPs have exactly one sub-slice per logical frame, whereas data Type 2 PLPs have between 2 and 6 480 sub-slices per logical frame. The number of cells allocated to data PLPs of type 2 in one logical frame must be a multiple of $N_{\text{sub-slices}}$.

The slices and sub-slices of the PLPs, the auxiliary streams and dummy cells are mapped into the cells of the logical frame as illustrated in figure 54. The logical frame starts with the L1-POST signalling. The common PLPs are transmitted at the beginning of the logical frame, right after the L1-POST signalling. Data PLPs of type 1 and 4 are transmitted after the common PLPs, with the cells of the type 4 PLPs hierarchically modulating the cells of the type 1 PLPs (see clause xxx). Data PLPs of type 2 are transmitted after the data PLPs of type 1. The auxiliary stream or streams, if any, follow the type 2 PLPs, and this can be followed by dummy cells. Data PLPs of type 3 are transmitted after any dummy cells.

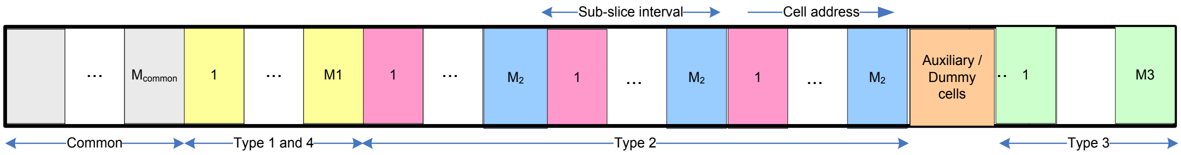


Figure 54: Mapping the PLPs into the logical frame

9.2.2.1 Allocating the cells at the output of the time interleaver for a given PLP

In general the cells of one interleaving frame of the time interleaver for a given PLP *i* will be mapped to $P_I(i)$ logical frames (see clause 6.5), and these cells shall be divided into $P_I(i)$ slices, each slice transmitted in one logical frame. The length, in cells, for the given PLP i mapped onto the m-th logical frame is given by:

$$L_m(i) = \sum_{j=0}^{N_{IU}(i)-1} L_{m,j}(i)$$

where $L_{m,j}(i)$ denotes the number of cells coming from the *j*-th interleaving unit for the PLP *i* and mapped to the m-th logical frame. It is obtained as:

$$L_{m,j}(i)=\sum_{k=0}^{N_{TI}(j)-1} N_{FEC-TI}(m-D(j),k)\begin{cases} L_{IU,\min}+1 & for \quad j<N_{\text{large}} \\ L_{IU,\min} & otherwise \end{cases}$$

Where $N_{TI}(j)$ is the number of TI blocks in the *j*-th interleaving unit, $N_{FEC-TI}(m-D(j),k)$ is the number of FEC blocks in the *k*-th TI block in the interleaving frame of index *m-D(j)*, with *D(j)* denoting the delay of the *j*-th interleaving unit. $L_{IU,min}$ is the minimum interleaving unit length, and *N* is the number of large interleaving units, as detailed in section 6.5.

For each logical frame *m*, the time interleaver produces an output of size $L_m(i)$ cells for the given PLP i, which is mapped to this logical frame *m*. In case the value of the frame interval (I_{JUMP}) is greater than 1, the time interleaver will not produce any output cells for I_{JUMP}-1 out of I_{JUMP} consecutive logical frames, which do not carry any cells of the given PLP *i*, and therefore the value $L_m(i)$ is equal to zero for the corresponding values of *m*.

9.2.2.2 Allocating the cells of the PLPs

The allocation of slices and sub-slices to the logical frames is done by the scheduler. The scheduler uses the method described in section 9.2.2 to perform the allocation of the cells of the PLPs to the logical frame, as described by the L1 signalling.

The allocation of all the sub-slices of the common and data PLPs (type 1, 2, 3, 4) shall be in ascending order of their respective PLP_IDs independently for each of the different PLP types.

NOTE: If it is required that several modulators produce identical output given the same input, for example when operating in a single frequency network, it will be necessary to define the mapping in a single scheduler located in a centralised place, such as an NGH gateway (see the note in clause xxx). The individual modulators can then all produce an identical mapping.

Since the number of cells needed to carry all of the data may be lower than the number of available cells (D_{PLP}), some cells may remain unallocated for data. These unallocated cells are dummy cells, and shall be set as described by clause 9.2.4.

9.2.2.2.1 Allocating the cells of the common and type 1 PLPs

The cells of the common PLPs, if any, shall be mapped into the first part of the logical frame (i.e. they shall have lower cell addresses than for the other types of PLP). The cells of any one common PLP for a particular logical frame shall be mapped sequentially into a single contiguous range of cell addresses of the logical frame, in order of increasing address.

In the case of logical channel type D, each common PLP shall be sent on all RF frequencies with identical allocation in a logical frame (see clause xxx).

The cells of a type 1 PLP for a particular logical frame shall also be mapped sequentially into a single contiguous range of cell addresses of the logical frame, in order of increasing address. The cells of all the type 1 PLPs shall follow after the common PLPs, if any, and before any type 2 PLPs or auxiliary streams, if any.

The common or type 1 PLPs are allocated in an increasing order of their PLP IDs in a given logical frame. The address of the first cell of a given common or type 1 PLP *i* in a given logical frame, *slice_start(i)*, shall be calculated as follows:

$$slice\_start(i)=L1\_POST\_SIZE+\sum_{k=0}^{i-1}L(k)$$

Where L1_POST_SIZE gives the number of cells of the L1-POST signalling in the given logical frame, and $L(k)$ gives the number of cells for the k-th common or type 1 PLP present in the given logical frame, with a PLP_ID strictly lower than the PLP_ID of the given PLP i.

The address of the last cell, 'slice_end', occupied by a given common or type 1 PLP i, shall be calculated as follows:

$$slice\_end(i) = slice\_start(i) + L(i)$$

Where $L(i)$ gives the number of cells for the given common or type 1 PLP i in the given logical frame.

9.2.2.2.2 Allocating the cells of type 2 PLPs

For each type 2 PLP the time interleaver outputs cells for one logical frame, which together with any padding cells (defined in this clause), are mapped to that logical frame by the following two conceptual steps:

1. Allocation of cells positions in the logical frame for each of the type 2 PLPs, together with any padding
2. Mapping of the time interleaver output cells for each type 2 PLP, together with any padding, to the allocated cell postions in the logical frame

For each type 2 PLP the PLP cells in the logical frame, plus any padding cells, are together called a slice. For type 2 PLPs this slice is divided into equally large sub-slices. The number of sub-slices is a configurable parameter, but must be the same for all type 2 PLPs. The total number of slice cells for the PLP, including any padding cells, must be a multiple of the total number of sub-slices, $N_{sub\text{-}slices\_total}$ in the logical frame. In order to achieve this, a minimum number of padding cells, n_{pad} ($0 \leq n_{pad} \leq N_{sub\text{-}slices\_total} - 1$), shall be appended right after the last time interleaved cell of the PLP for the particular logical frame to form the slice that will be mapped to the logical frame for the particular PLP.

Due to VBR variations of the input streams the number of time interleaved cells per PLP and logical frame may vary dynamically between logical frames. This means that also the number of padding cells for a PLP may vary between logical frames.

In general a slice is divided into $N_{sub\text{-}slices\_total}$ sub-slices in the logical frame. Depending on the logical channel type the logical frame consists of a matrix of cells with only one column (LC type A, B and C) or several columns (LC type D), with one column of the matrix corresponding to each RF channel.

For LC type A, B and C there are $N_{sub\text{-}slices} = N_{sub\text{-}slices\_total}$ sub-slices in the logical frame.

For LC type D the $N_{sub\text{-}slices\_total}$ subslices are divided into $N_{sub\text{-}slices}$ per column of the logical frame matrix (one RF channel per column) so that we have the relation:

$N_{sub\text{-}slices\_total} = N_{sub\text{-}slices} * N_{RF}$

NOTE: This formula only applies to LC type D. The value of N_{RF} is signalled by LC_NUM_RF in L1-PRE signalling.

9.2.2.2.3 Allocation of cells positions in the logical frame for each of the type 2 PLPs

A matrix, M_1, is conceptually assumed, with $N_{sub\text{-}slices\_total}$ columns and a number of rows, N_{rows}, that enables all type 2 slices to exactly fill M_1.

For the allocation process, described in this paragraph, the slices (one slice per PLP) may be considered to be dummy and empty but having the same length as the real slices defined in the previous paragraph, since this process only defines the cell *positions* of the logical frame for each PLP. In the following section the mapping of the real slices to these allocated cell positions is defined.

The empty slices of all type 2 PLPs are introduced into M_1 according to figure 55, which shows an example with six PLPs and six subslices each (i.e. six columns). In the figure each column corresponds to one subslice and the height of each PLP is proportional to the number of rows in M_1.

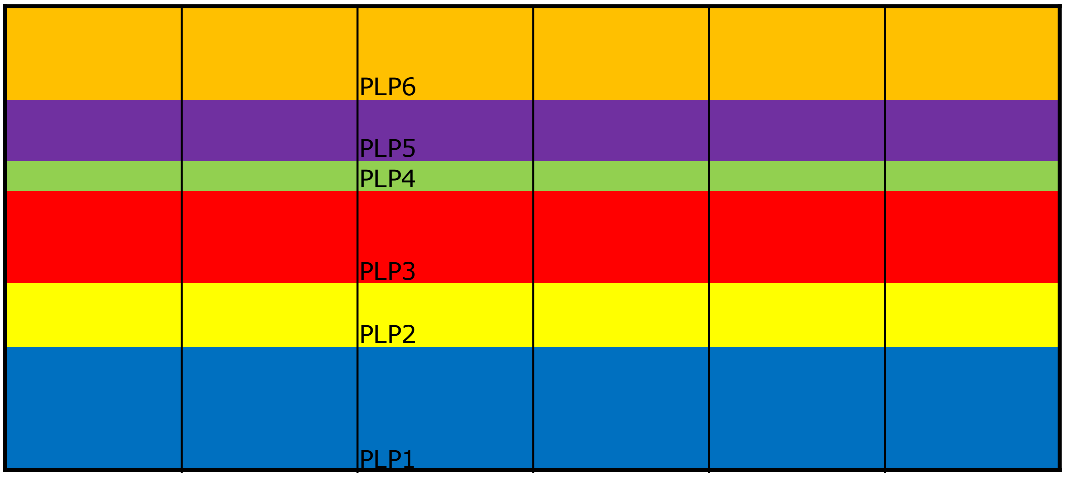


Figure 55: The dummy slices of the six type 2 PLPs are introduced into the matrix M_1, having six columns being equal to the total number of sub-slices

Since the length of each (dummy) slice is a multiple of $N_{sub\text{-}slices\_total}$, each slice will occupy exactly an integer number of rows in M_1. For each PLP the slice cells are introduced in M_1 row by row, from bottom to top, in order of PLP_id starting with the PLP with the lowest PLP_id in the bottom of the matrix and starting with the lowest column index. The value of N_{rows} is adapted so that all type 2 slices exactly fill M_1.

In the following step the content of M_1 is conceptually moved to a new matrix, M_2, with $p=N_{sub\text{-}slices\_total}/N_{sub\text{-}slices}$ columns. For LC type A, B and C this means that p=1 and for LC type D $p=N_{RF}$.

The move from M_1 to M_2 is done in such a way that columns 1+(n-1)*p to n*p of M_1 constitute a block A_n, with 1≤n≤N_sub-slices and all such blocks A_n are moved to M2 with A_1 in the bottom of M_2 and all other A_n blocks appended on top of this with increasing n, as shown in figure 56 with an example of LC type D with two sub-slices per RF channel and three RF channels. In this case p=3 and M_2 therefore has three columns – one for each RF channel.

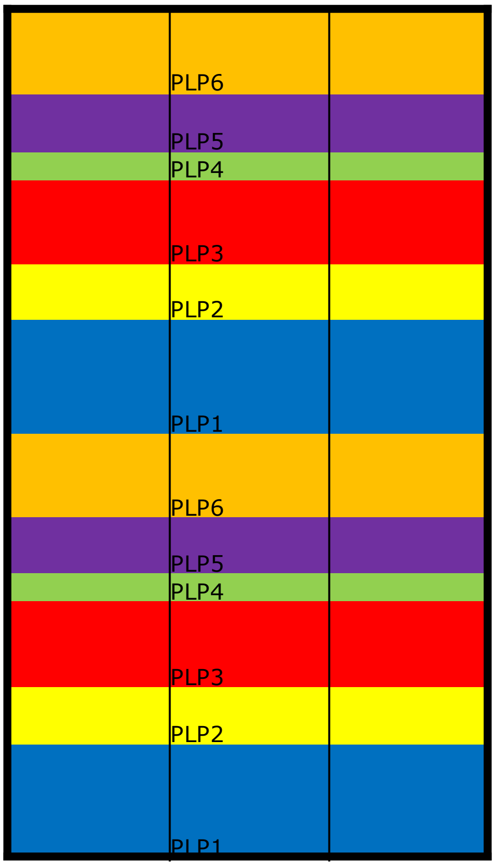


Figure 56: The matrix M_2, showing the three rightmost columns having been moved on top of the three first columns. Each column corresponds to one RF channel (LC type D)

For LC type A, B and C the matrix M_2 has necessarily a single column (and is therefore a vector) and the cell allocation process is thereby complete.

For LC type D M_2 has N_{RF} columns and an additional step is performed to ensure that all sub-slices appear with enough space for frequency hopping in the RF signals.

The N_{RF} columns are labelled RF_0, …, RF_{N_RF-1} from right to left, see example in fig. x3 with 3 RF channels, RF_0, RF_1 and RF_2.. The column labeled RF_k is then cyclically shifted (k-1)*RF_shift cells, $0 \le k \le N_{RF}-1$, upwards and folded back so that the cells of the (k-1)*RF_shift highest rows are moved to the bottom of the matrix, see figure 57.

$RF\_Shift = SUB\_SLICE\_INTERVAL/N_{RF}$

SUB_SLICE_INTERVAL is signalled in L1-POST dynamic and in IBS type A.

The modified M_2 then shows the cell allocation of all type 2 PLPs for LC type D.

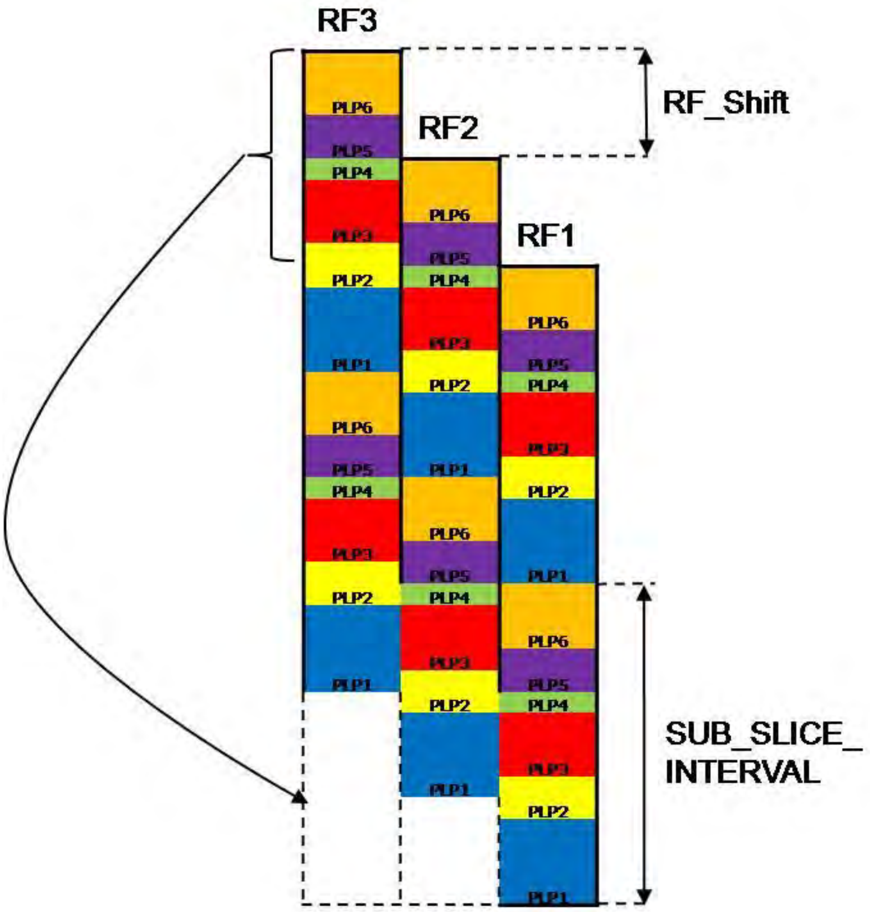


Figure 57: Shifting and folding process to ensure a constant cell distance between subslices in the logical frame for LC type D

9.2.2.2.4 Mapping of the time interleaver output cells for each type 2 PLP, together with any padding, to the allocated cell positions in the logical frame

The indexing of the cells of the logical frame is done in the following way:

The cells of the logical frame are conceptually assumed to be contained in a matrix M(i,j) with the following index ranging:

a) $0 \leq i \leq LC\_LF\_SIZE-1$ and $j=1$, for LC types A, B and C
b) $0 \leq i \leq LC\_LF\_SIZE/N_{RF} -1$ and $0 \leq j \leq LC\_LF\_SIZE$, for $1 \leq j \leq N_{RF}$

The i index can be considered as a time index, which increases with time for a given logical frame. The j index can be considered as a frequency index, but with the i index increasing only following the RF channel numbering, this however being independent of the values of the actual RF frequencies used.

For each PLP_id the cells of the slice are mapped to the allocated cell positions in the logical frame in order of cell index i of the logical frame, irrespective of RF channel index, see figure 58.

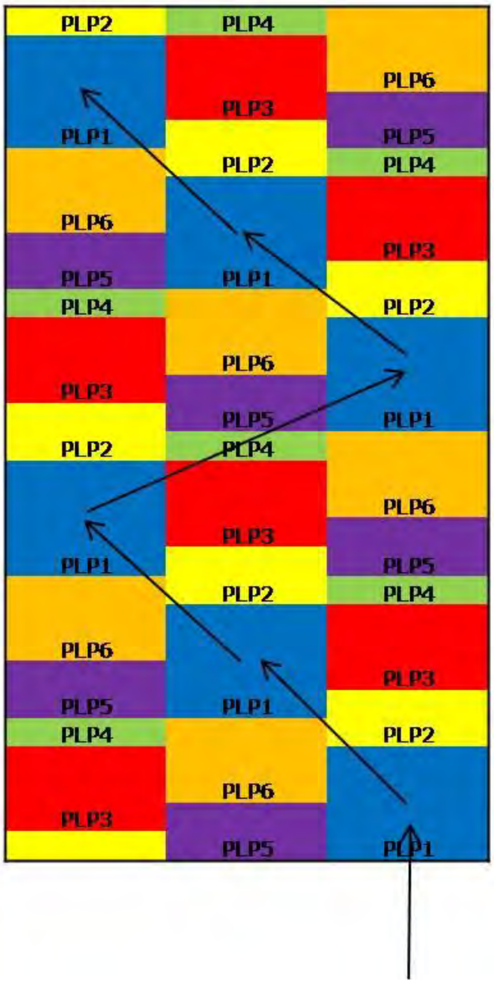


Figure 58: Mapping of slice cells to the allocated cell positions of the logical frame. The arrows show the mapping for PLP1

For all LC types this means that the first cell of the slice is mapped to the allocated cell position, for the current PLP, with the lowest cell available i index of the matrix M(i,j), irrespective of RF channel index j. Following time interleaved cells are then introduced after this first cell with increasing cell index in the logical frame for the allocated PLP, independent of RF channel index. When padding is used this will appear with the highest cell indices in the logical frame.

9.2.2.2.5 Allocating the cells of type 3 PLPs

Type 3 PLPs are only used for logical channel types A and D. The cells of type 3 PLPs are allocated at the end of the logical frame after any dummy cells.

9.2.2.2.6 Allocating the cells of type 4 PLPs

Type 4 PLPs are only used for logical channel types A and D. The cells of each type 4 PLP hierarchically modulate the cells of the type 1 PLP whose PLP_ID is equal to the NATIONAL_PLP_ID field of the type 4 PLP concerned (see clause xxx). The allocation of each type 4 PLP therefore coincides with the allocation of the corresponding type 1 PLP whose PLP_ID is equal to the NATIONAL_PLP_ID field of the type 4 PLP.

9.2.3 Auxiliary stream insertion

Following the data PLPs (type 1, 2, 4), one or more auxiliary streams may be added. Each auxiliary stream consists of a sequence of $D_{i,aux}$ cell values $x_{i,k}$ in each logical frame, where i is the auxiliary stream index and k is the cell index. The cell values shall have the same mean power as the data cells of the data PLPs, i.e.

$E(x_{i,k}. x_{i,k}^{*})=1$, but apart from this restriction they may be used as required by the broadcaster or network operator. The auxiliary streams are mapped one after another onto the cells in order of increasing cell address, starting after the last cell of the last data PLP.

The start position and number of cells $D_{i,\mathrm{aux}}$ for each auxiliary stream may vary from logical frame to logical frame, and bits are reserved to signal these parameters in the L1 dynamic signalling.

The cell values for auxiliary streams need not be the same for all transmitters in a single frequency network. If auxiliary streams are used that are different between the transmitters of a single frequency network, it is recommended that Active Constellation Extension (see clause 11.5.1) should not be used, unless steps are taken to ensure that the same modifications are applied to each data cell from each transmitter.

The cells of an auxiliary stream with AUX_STREAM_TYPE '0000' (see clause xxx), when MISO and MIMO frame types are being used, shall be mapped such that none of the relevant auxiliary stream cells occupy the same symbol as any cells of data PLPs. In this case, the MIXO processing (see clause xxx) shall not be applied to the symbols occupied by the relevant auxiliary stream cells. However, the modifications of the pilots for MIXO (see clause 11.1.9) shall still be applied to these symbols.

Specific uses of auxiliary streams, including coding and modulation, will be defined either in future editions of the present document or elsewhere. The auxiliary streams may be ignored by the receiver. If the number of auxiliary streams is signalled as zero, this clause is ignored.

9.2.4 Dummy cell insertion

If the L1-POST signalling, PLPs and auxiliary streams do not exactly fill the C_{tot} capacity in one logical frame, dummy cells shall be inserted in the remaining N_{dummy} cells (see clause xxx), where:

$$N_{\mathrm{dummy}} = D_{\mathrm{plp}} - \left(\sum_{i=1}^{M_{\mathrm{common}}} D_{i,\mathrm{common}} + \sum_{i=1}^{M_1} D_{i,1} + \sum_{i=1}^{M_2} D_{i,2} + \sum_{i=1}^{M_{AUX}} D_{i,\mathrm{aux}} \right)$$

The dummy cell values are generated by taking the first N_{dummy} values of the BBF scrambling sequence defined in clause 5.2.4. The sequence is reset at the beginning of the dummy cells of each logical frame. The resulting bits $b_{\mathrm{BS},j}$, $0 \le j < N_{\mathrm{dummy}}$, are then mapped to cell values x_k according to the following rule:

$$\mathrm{Re}\{x_k\} = 2\,(1/2 - b_{\mathrm{BS},j})$$

$$\mathrm{Im}\{x_k\} = 0,$$

where the bits $b_{\mathrm{BS},j}$ are mapped to cells x_k in order of increasing cell address starting from the first unallocated address.

9.3 Logical super-frame structure

A logical super-frame can carry logical frames as illustrated in figure 59.

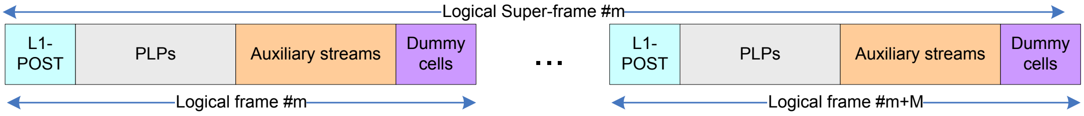


Figure 59: Structure of the logical super-frame

The number of logical frames in a logical super-frame is a configurable parameter that is signalled by the field LC_NUM_LF in the configurable signalling (L1-POST configurable). The maximum number of logical frames in a given super-frame is equal to 255.

All parameters defined in L1-PRE to signal the L1-POST signalling format, and the configurable part of L1-POST signalling (L1-POST configurable), can be changed only at the border of two logical super-frames. If the receiver receives only the in-band type A, there is a counter that indicates the next logical super-frame with changes in L1 configurable parameters. Then the receiver can check the new L1 configurable parameters from the L1-POST in the first logical frame of the announced logical super-frame, where the change applies.

A data PLP does not have to be mapped into every logical frame. It can jump over multiple logical frames. This frame interval (I_{JUMP}) is determined by the LF_INTERVAL parameter. The first logical frame where the data PLP appears is determined by PLP_FIRST_LF_IDX. PLP_LF_INTERVAL and PLP_FIRST_LF_IDX shall be signalled in the configurable signalling (L1-CONF) (see clause 8.1.3.1). In order to have unique mapping of the data PLPs between logical super-frames, the number of logical frames per logical super-frame LC_NUM_LF shall be divisible by LF_INTERVAL for every data PLP. The PLP shall be mapped to the logical frames for which:

$$(\text{LF\_IDX} - \text{PLP\_FIRST\_LF\_IDX}) \bmod \text{PLP\_LF\_INTERVAL} = 0.$$

Note that when the in-band signalling is determined and inserted inside the data PLP, this requires receiver buffering of LF_INTERVAL+1 logical frames. In order to avoid buffering, in-band signalling type A is optional for PLPs that do not appear in every logical frame and for PLPs that are time interleaved over more than one logical frame.

The number of logical frames in a logical super-frame LC_NUM_LF must be chosen so that for every data PLP there is an integer number of interleaving frames per logical super-frame.

9.4 Logical channel structure

A logical channel (LC) is defined as a sequence of logical frames. After mapping to NGH-frames, see xxx, the logical channel is transmitted over 1 to N RF frequencies available in the NGH network. The NGH network may have different values of the bandwidth and the frame duration used over the different RF frequencies. There may be a number M of logical channels in the same NGH network. Four different types of logical channels are defined, namely, type A, type B, type C and type D. These are detailed in the following sub-clauses.

9.4.1 Logical channel type A

A logical channel type A corresponds to the case when each logical frame of the logical channel is mapped to one NGH frame on a single RF channel. Each NGH frame shall contain cells from only one logical frame of the logical channel. This is illustrated in figure 60. This type is identified with the value "000" of the field **LC_TYPE** in L1-PRE signalling. All NGH frames which carry the logical frames of a given logical channel shall have the same L1-PRE signalling, except the FRAME_IDX.

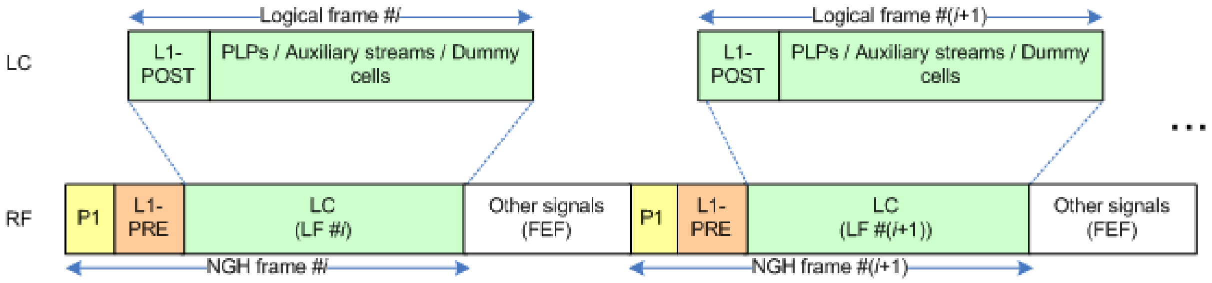


Figure 60: Logical channel type A

9.4.2 Logical channel type B

A logical channel Type B corresponds to the case when each logical frame of the logical channel is mapped to multiple (N) NGH frames on a single RF channel. The NGH frames shall be of equal length. Each logical frame may therefore map in parts onto multiple NGH frames on the same RF channel, and hence each NGH-frame may contain cells from multiple logical frames of the same logical channel. This is illustrated in Figure 61where one NGH-frame may carry cells from two logical frames of the same logical channel. This type is identified with the value "001" of the field **LC_TYPE** in L1-PRE signalling. All NGH frames shall have the same L1-PRE signalling, except for the fields LF_DELTA, and FRAME_IDX.

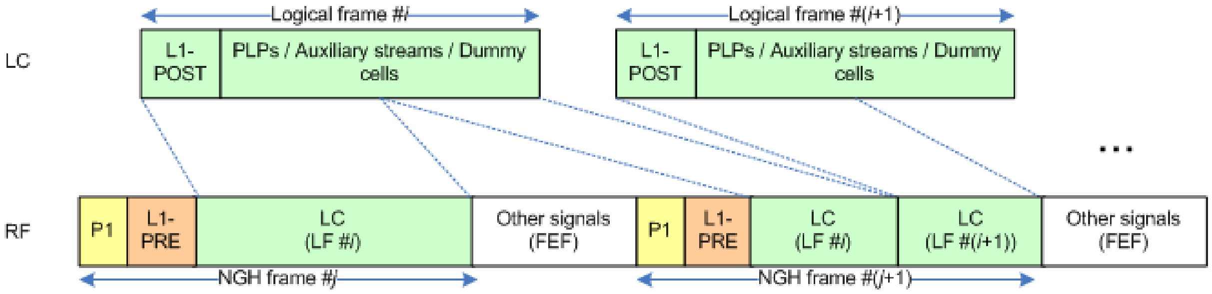


Figure 61: Logical channel type B

9.4.3 Logical channel type C

A logical channel type C corresponds to the case when each logical frame of the logical channel is mapped to multiple (N) NGH frames on multiple (M) RF channels. The NGH frames from different RF channels shall be separated in time to allow for reception with one single tuner. The NGH frames from different RF channels may be of different lengths. Each logical frame may therefore map in parts onto multiple NGH frames on multiple (M) RF channels, and hence each NGH-frame may contain cells from multiple logical frames of the same logical channel. This is illustrated in figure 6062 with 2 logical channels using 3 RF channels. This type is identified with the value "010" of the field **LC_TYPE** in L1-PRE signalling. All NGH frames shall have the same L1-PRE signalling, except for the fields LF_DELTA, LC_CURRENT_FRAME_RF_IDX, and LC_NEXT_FRAME_IDX, FRAME_IDX.

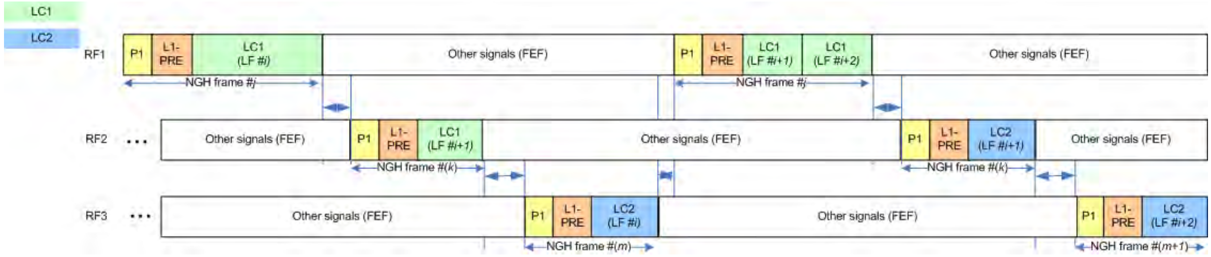


Figure 62: Logical channel type C

9.4.4 Logical channel type D

A logical channel type D corresponds to the case when each logical frame of the logical channel is mapped one-to-one to multiple (N) equal-length and time-synchronised NGH frames on multiple (N) RF frequencies. The time synchronisation means that the P1 symbol of each of the NGH frames, carrying the logical channel, using the same frame index shall start at the same time. Each column of the logical frame matrix, see xxx, is thereby mapped to exactly one NGH frame, with L1-POST data being the first logical frame part of the NGH frame on each RF channel. Each NGH frame contains cells from only one LF and each LF is available on all simultaneous NGH frames. This is illustrated in figure 63 using 3 RF channels. This type is identified with the value “011” of the field LC_TYPE in L1-PRE signalling. All time-synchronised NGH frames shall have the same L1-PRE signalling, except for the fields LC_ID and LC_CURRENT_FRAME_RF_IDX.

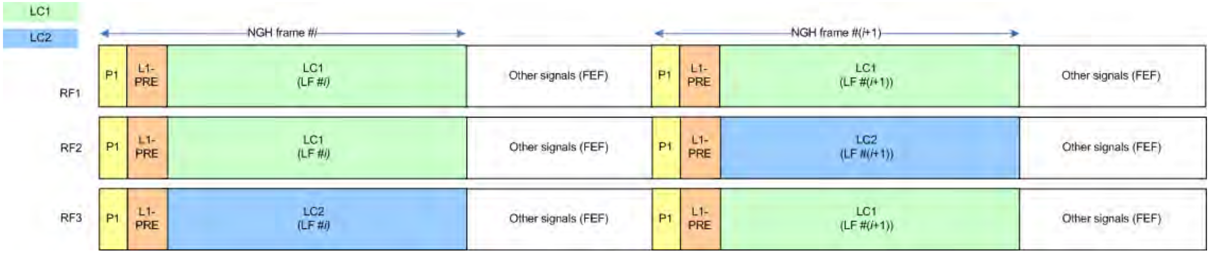


Figure 63: Logical Channel type D

9.4.5 Logical channel group

The logical channels are arranged in groups, where the NGH frames which carry the logical frames of one logical channel in a given group shall be separable in time from the NGH frames which carry the logical frames of another logical channel in the same given group. Hence, it shall always be possible to receive all logical channels members of a group with a single tuner. Each group of logical channels is identified by a unique identifier **LC_GROUP_ID** in the L1-PRE signalling. Figure 64 illustrates an example of two logical channels member of the same group, a first logical channel LC1 of type C and a second logical channel LC2 of type A.

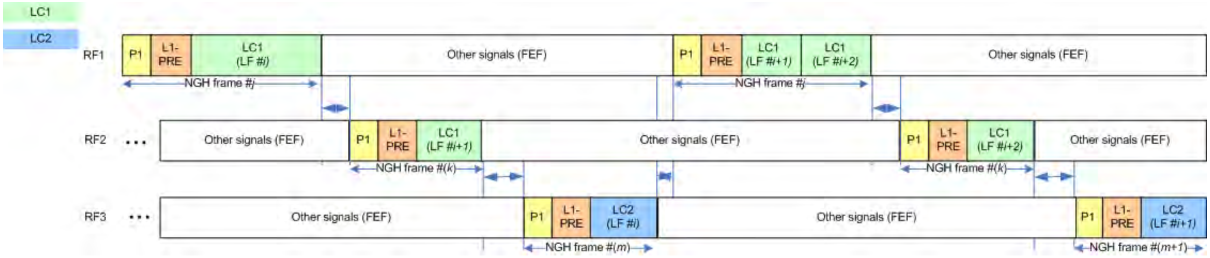


Figure 64: Logical Channel Group

9.5 Mapping of logical channels to NGH frames

Each logical frame consists of a configurable number, LC_LF_SIZE, cells. For LC Type A, B and C these cells are conceptually arranged in a single logical frame vector, LFV, with LC_LF_SIZE elements. For LC type D the logical frame is arranged in a single logical frame matrix, LFM, with LC_NUM_RF columns and LC_LF_SIZE/ LC_NUM_RF rows. LC_LF_SIZE must be a multiple of LC_NUM_RF.

A logical channel is composed by a continuous sequence of logical frames without gaps and is therefore a continuous stream of cells (LC types A, B and C) or LC_NUM_RF parallel streams of cells (LC type D). The i^{th} logical frame is denoted LF_i and the corresponding vector and matrix are denoted LVF_i and LFM_i respectively.

Each NGH frame, to which the logical channel is mapped, consists of a reconfigurable number of data cells, NF_SIZE, which are available to transport logical frame cells without gaps.

NOTE: NF_SIZE is not an L1 parameter, but the indirect effect of the selection of L1 parameters.

The j^{th} NGH frame in the sequence of such frames is denoted NF_j. A continuous stream of NGH frames, carrying a particular logical channel, constitutes a continuous stream of data cells.

9.5.1 Mapping for logical channels type A

Each logical frame is synchronized to one NGH frame in such a way that the first logical frame cell is mapped to the first NGH data cell (lowest cell address in the NGH frame) and the last logical frame cell is mapped to the last NGH data cell (highest address in the NGH frame). All logical frames are carried on a single RF frequency. A sequence of LFs are therefore carried on a sequence of NGH frames, with exactly one LF per NGH frame carrying the particular logical channel.

9.5.2 Mapping for logical channels type B

The stream of logical frame cells is mapped to the stream of NGH data cells in such a way that the first cell of a logical frame is mapped to any of the data cells in an NGH frame. A cell of the logical frame stream that appears P cells later than the mentioned first cell shall be mapped to an NGH stream cell that appears P cells later than the NGH frame cell to which the mentioned first logical frame was mapped. If the logical frame is not completed in the current NGH frame it continues on the following NGH frame of the same logical channel from the first data cell of that NGH frame. If the logical frame is completed in the current NGH frame the following logical frame of the same logical channel starts immediately after without any gap. All logical frames are carried on a single RF frequency. Logical channel type B is a superset of logical channel type A, which it includes as a special case.

9.5.3 Mapping for logical channels type C

For logical channel type C the logical frames are mapped in the same way as for logical channels type B, except that the NGH frames used to carry the logical channel may be transmitted on different RF frequencies and that successive NGH frames using different RF frequencies need to be time separated according to requirements in xxx. Logical channel type C is a superset of logical channel type B, which it includes as a special case.

9.5.4 Mapping for logical channels type D

Each logical frame is synchronized to one NGH frame in such a way that each column of the logical frame is mapped to the cells of its corresponding RF frequency in such a way that the first cell of the logical frame is mapped to the first NGH data cell (lowest cell address in the NGH frame) and the last logical frame cell is mapped to the last NGH data cell (highest address in the NGH frame). A sequence of LFs are therefore carried on a sequence of sets of NGH frames, with exactly one LF per each set of NGH frames, with one NGH frame per RF frequency. The set of RF frequencies that are used to carry an LC of type D is configurable.

9.5.5 Restrictions on frame structure to allow tuner switching time for logical channels of types C and D

When logical channels of types C and D are used there are additional restrictions for the configuration of the NGH signal to enable enough time for switching between the RF channels. These restrictions apply jointly to all the PLPs that are members of the PLP cluster of interest.

When $N_{\mathrm{RF}} > 1$ the following restrictions for the NGH frame structure apply:

- A minimum time interval must be guaranteed between the occurrences of two consecutive sub-slices of any given PLP on different RF channels to be received with a single tuner. This requirement shall be met jointly for all PLPs that are members of a PLP cluster.

- The minimum frequency hopping time between such consecutive sub-slices, on different RF channels, for a tuner is $\left(2*S_{CHE}+S_{tuning}\right)*T_s$, where S_{CHE} is the number of additional symbols needed for channel estimation and $S_{tuning}=\left\lceil \frac{5x10^{-3}\sec}{T_s} \right\rceil$ is the number of symbols needed for tuning rounded up to the nearest integer (figure 65). T_s is the symbol duration on the destination RF frequency.
- When frequency hopping is performed between RF signals using *different* values of T_S the minimum frequency hopping time shall be calculated as $A*T_{s1}+\left(B+S_{tuning}\right)*T_{s2}$, where A is the S_{CHE} for the starting RF frequency for which the symbol duration is T_{s1}, and B is the S_{CHE} for the destination RF frequency for which the symbol duration is T_{s2}.
- The minimum tuning time is 5 ms, so that $S_{tuning}\times T_S\geq 5$ms. The values for S_{tuning} are presented in table 76.
- The value for S_{CHE} is dependent on the used pilot pattern, which may be different between the RF frequencies. $S_{CHE} = D_Y - 1$, where D_Y is the number of symbols forming one scattered pilot sequence defined in table yyy. For the P2 symbol and any frame closing symbol the value $S_{CHE} = 0$ shall be assumed, since no additional symbols are required for the channel estimation.

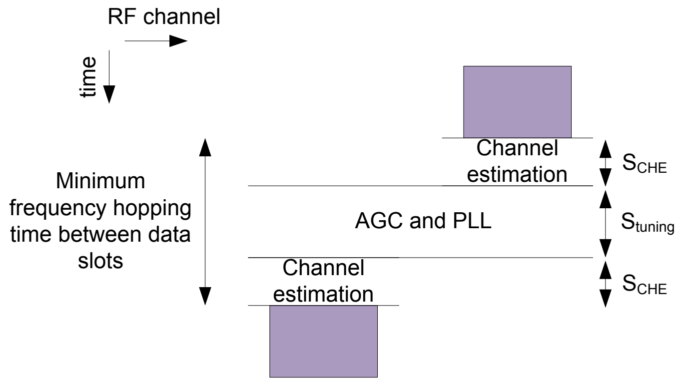


Figure 65: Minimum required frequency hopping time between two sub-slices to be received with a single tuner

Table 76: Values for S_{tuning} (number of symbols needed for tuning, rounded up, for 8 MHz bandwidth), when minimum tuning time = 5 ms

FFT size	*Tu* [ms]	Guard interval fraction						
		1/128	1/32	1/16	19/256	1/8	19/128	1/4
16K	1,792	3	3	3	3	3	3	3
8K	0,896	6	6	6	6	5	5	5
4K	0,448	NA	11	11	NA	10	NA	9
2K	0,224	NA	22	22	NA	20	NA	18
1K	0,112	NA	NA	43	NA	40	NA	36

NOTE: To achieve the minimum frequency hopping time between NGH frames for Logical Channels of Type D, a FEF part of appropriate length may be inserted between the NGH frames concerned. Alternatively, PLPs of Type 1 or 3 may be introduced before or after the Type 2 PLPs, respectively. The insertion of Type 3 PLPs may be combined with the insertion of a FEF part.

9.6 Physical frames

This clause defines the frame builder functions that always apply to an NGH system.

The function of the frame builder is to assemble the cells produced by the time interleavers for each of the PLPs and the cells of the modulated L1 signalling data into arrays of active OFDM cells corresponding to each of the OFDM symbols which make up the overall frame structure. The frame builder operates according to the dynamic information produced by the scheduler (see clause 5.2.1) and the configuration of the frame structure.

9.7 Frame structure

The DVB-NGH frame structure is shown in figure 66. At the top level, the frame structure consists of super-frames, which are divided into Elementary Block of Frames (EBF), each of which is composed of NGH frames and these are further divided into OFDM symbols. The super-frame may in addition have FEF parts (see clause 9.10).

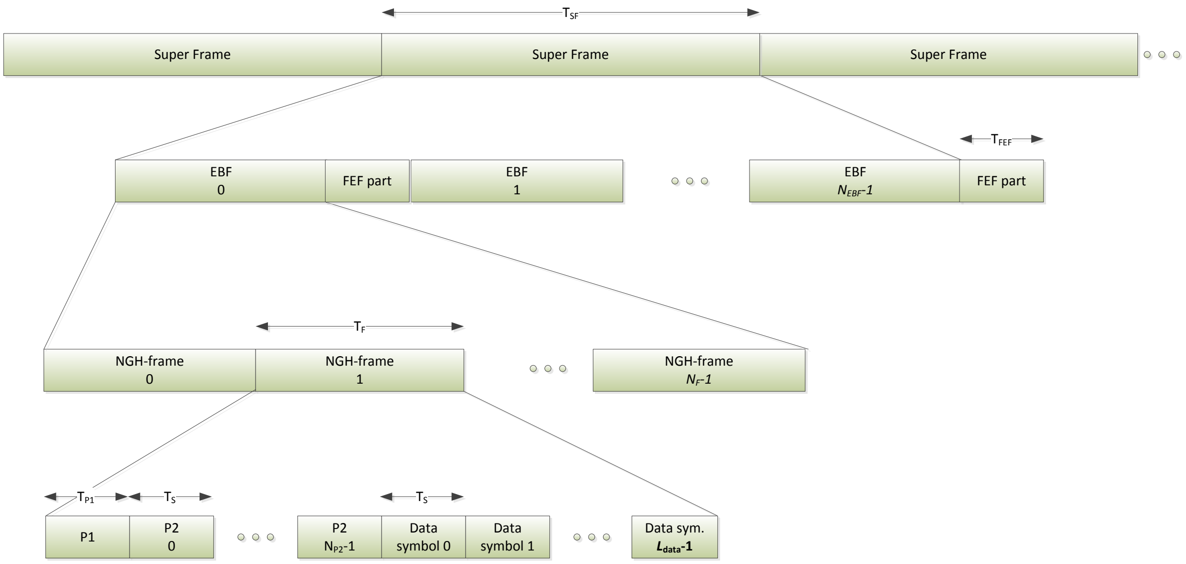


Figure 66: The DVB-NGH frame structure, showing the division into super-frames, EBFs, NGH frames and OFDM symbols

9.8 Super-frame

A super-frame is composed of EBFs and may also have FEF parts, see figure **67**.

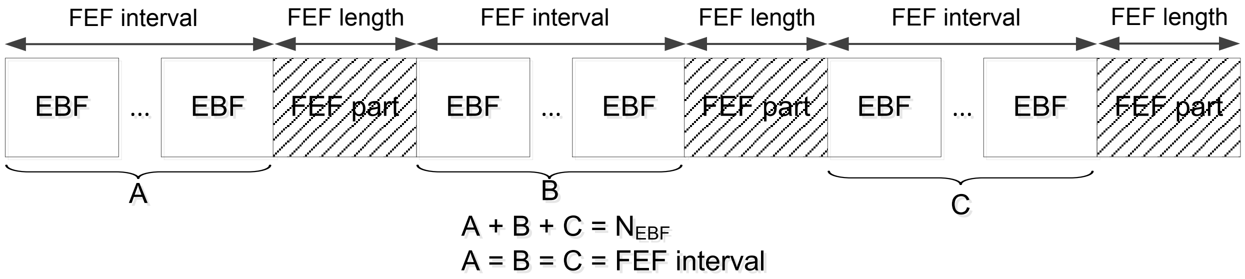


Figure 67: The super-frame, including NGH frames and FEF parts

The number of EBFs in a super-frame is a configurable parameter N_{EBF} that is signalled in L1-PRE signalling, i.e. N_{EBF} = NUM_EBFS (see clause 8.1.2). The EBFs are numbered from 0 to N_{EBF}-1. The current frame is signalled by FRAME_IDX in the dynamic L1-POST signalling.

A FEF part may be inserted between EBFs. There may be several FEF parts in the super-frame, but a FEF part shall not be adjacent to another FEF part. The location in time of the FEF parts is signalled based on the super-frame structure. The super-frame duration T_{SF} is determined by:

$$T_{SF} = N_{EBF} \times \sum_{i=0}^{N_F-1} T_F(i) + N_{FEF} \times T_{FEF}$$

where $T_F(i)$ is the frame duration of the i^{th} frame in the EBF, N_{FEF} is the number of FEF parts in a super-frame and T_{FEF} is the duration of the FEF part and is signalled by FEF_LENGTH. N_{FEF} can be derived as:

$$N_{\text{FEF}} = N_{\text{NGH}} / \text{FEF\_interval}.$$

If FEFs are used, the super-frame ends with a FEF part.

The maximum value for the super-frame length T_{SF} is 63.75s if FEFs are not used (equivalent to 255 frames of 250 ms) and 127,5 s if FEFs are used. Note also that the indexing of NGH frames (see FRAME_IDX in clause 8.1.3.3) and N_{NGH} are independent of Future Extension Frames.

The L1-PRE signalling and the configurable part of the L1-POST signalling can be changed only on the border of two super-frames. If the receiver receives only the in-band signalling type A, there is a counter that indicates the next super-frame with changes in L1 parameters. Then the receiver can check the new L1 parameters from the P2 symbol(s) in the first frame of the announced super-frame, where the change applies.

A data PLP does not have to be mapped into every NGH frame. It can jump over multiple frames. This frame interval (I_{JUMP}) is determined by the FRAME_INTERVAL parameter. The first frame where the data PLP appears is determined by FIRST_FRAME_IDX. FRAME_INTERVAL and FIRST_FRAME_IDX shall be signalled in the L1-POST signalling (see clause **Error! Reference source not found.**). In order to have unique mapping of the data PLPs between super-frames, N_{NGH} shall be divisible by FRAME_INTERVAL for every data PLP. The PLP shall be mapped to the T2-frames for which:

(FRAME_IDX-FIRST_FRAME_IDX) mod FRAME_INTERVAL = 0.

Note that when the in-band signalling is determined and inserted inside the data PLP, this requires buffering of FRAME_INTERVAL+1 T2-frames in a T2 system with one RF channel. If using TFS, the buffering is over FRAME_INTERVAL+2 T2-frames. In order to avoid buffering, in-band type A is optional for PLPs that do not appear in every frame and for PLPs that are time interleaved over more than one frame.

N_{NGH} must be chosen so that for every data PLP there is an integer number of interleaving frames per super-frame.

9.9 NGH frame

The NHG-frame comprises one P1 preamble symbol that may be followed by one aP1 symbol which is, in turn followed by one or more P2 preamble symbols, followed by a configurable number of data symbols. In certain combinations of FFT size, guard interval and pilot pattern (see clause 11.1.7), the last data symbol of a NGH-frame shall be a frame closing symbol. The details of the NGH-frame structure are described in clause 9.9.2.

The P1 and aP1 symbols are unlike ordinary OFDM symbols and are inserted later (see clause 11.7). The aP1 symbol follows the P1 symbol when any of the MIMO, hybrid or hybrid MIMO frame types of NGH are used. These frame types are described in sections xxa, xxb, and xxc respectively.

The P2 symbol(s) follow immediately after the P1 symbol or when present, the aP1 symbol. The main purpose of the P2 symbol(s) is to carry L1-PRE signalling data. The L1-PRE signalling data to be carried is described in clause 8.1.2, its modulation and error correction coding are described in clause 8.2 and the mapping of this data onto the P2 symbol(s) is described in clause 8.2.3.1.

9.9.1 Duration of the NGH frame

The beginning of the first preamble symbol (P1) marks the beginning of the NGH frame. The occurrence of the aP1 symbol depends on the NGH frame type.

The number of P2 symbols N_{P2} is determined by the FFT size as given in table 82, whereas the number of data symbols L_{data} in a NGH frame is a configurable parameter signalled in the L1-PRE signalling, i.e. L_{data} = NUM_DATA_SYMBOLS. The total number of symbols in a NGH-frame (excluding P1 and aP1) is given by $L_F = N_{P2}+L_{data}$. The NGH frame duration is therefore given by:

$$T_F = L_F \times T_s + T_{P1} \quad \text{when the aP1 symbol is not present or}$$

$$T_F = L_F \times T_s + 2T_{P1} \qquad \text{when the aP1 symbol is present}$$

where T_s is the total OFDM symbol duration and T_{P1} is the duration of the P1 and aP1 symbols (see clause 11.4).

The maximum value for the frame duration T_F shall be 250 ms. Thus, the maximum number for L_F is as defined in table 77 (for 8 MHz bandwidth).

Table 77: Maximum frame length L_F in OFDM symbols for different FFT sizes and guard intervals (for 8 MHz bandwidth)

FFT size	T_u [ms]	Guard interval						
		1/128	1/32	1/16	19/256	1/8	19/128	1/4
16K	1,792	138	135	131	129	123	121	111
8K	0,896	276	270	262	259	247	242	223
4K	0,448	NA	540	524	NA	495	NA	446
2K	0,224	NA	1081	1 049	NA	991	NA	892
1K	0,112	NA	NA	2 098	NA	1 982	NA	1 784

The minimum number of OFDM symbols L_F shall be N_{P2}+7.

The P1 symbol carries only P1 specific signalling information (see clause 8.1.1). Similarly, the aP1 symbol when present, carries only aP1 specific signalling information (see clause xxx). P2 symbol(s) carry all the L1-PRE signalling information (see clause xxx), and, if there is P2 capacity left, cells from logical frames. Data symbols carry cells from the logical frame that comprise L1-POST signalling information, common PLPs and/or data PLPs as defined in clauses 9.2.2.2.1, 9.2.2.2.2, 9.2.2.2.5 and 9.2.2.2.6. The mapping of the logical frame into the symbols is done at the OFDM cell level. If there is capacity left in the NGH-frame, it is filled with dummy cells as defined in clauses 9.2.3 and 9.2.4. The mapping of logical frames into the NGH-frame is defined in clause 9.5.

9.9.2 Capacity and structure of the NGH frame

The NGH frame builder shall map the logical frame cells and L1-PRE cells from the constellation mapper onto the data cells $x_{m,l,p}$ of each OFDM symbol in the NGH frame, where:

- m is the NGH frame number;
- l is the index of the symbol within the frame, starting at 0 for the first P2 symbol, $0 \le l < L_F$;
- p is the index of the data cell within the symbol prior to frequency interleaving and pilot insertion.

Data cells are the cells of the OFDM symbols which are not used for pilots or tone reservation.

The P1 and aP1 symbols are not ordinary OFDM symbols and do not contain any active OFDM cells (see clause 11.7).

The number of active carriers, i.e. carriers not used for pilots or tone reservation, in one P2 symbol is denoted by C_{P2} and is defined in table 78. Thus, the number of active carriers in all P2 symbol(s) is $N_{P2} \times C_{P2}$.

The number of active carriers, i.e. carriers not used for pilots, in one data symbol is denoted by C_{data} - table 79 gives values of C_{data} for each FFT mode and scattered pilot pattern for the case where tone reservation is not used. The values of C_{data} when tone reservation is used (see clause 11.5.2) are calculated by subtracting the value in the "TR cells" column from the C_{data} value without tone reservation. For 8K and 16K two values are given corresponding to normal carrier mode and extended carrier mode (see clause 11.4).

In some combinations of FFT size, guard interval and pilot pattern, as described in clause 11.1.7, the last symbol of the NGH-frame is a special frame closing symbol. It has a denser pilot pattern than the other data symbols and some of the cells are not modulated in order to maintain the same total symbol energy (see clause 9.9.5). When there is a frame closing symbol, the number of data cells it contains is denoted by N_{FC} and is defined in table80. The lesser number of active cells, i.e. data cells that are modulated, is denoted by C_{FC}, and is defined in table81. Both N_{FC} and C_{FC} are tabulated for the case where tone reservation is not used and the corresponding values when tone reservation is used (see clause 11.5.2) are calculated by subtracting the value in the "TR cells" column from the value without tone reservation.

Hence the cell index p takes the following range of values:

- $0 \le p < C_{P2}$ for $0 \le l < N_{P2}$;
- $0 \le p < C_{data}$ for $N_{P2} \le l < L_F - 1$;
- $0 \le p < N_{FC}$ for $l = L_F - 1$ when there is a frame closing symbol;
- $0 \le p < C_{data}$ for $l = L_F - 1$ when there is no frame closing symbol.

Table 78: Number of available data cells C_{P2} in one P2 symbol

FFT Size	C_{P2}	
	SISO	MIxO
1K	558	546
2K	1 118	1 098
4K	2 236	2 198
8K	4 472	4 398
16K	8 944	8 814

Table 79: Number of available data cells C_{data} in one normal symbol

FFT Size		Cdata (no tone reservation)							TR cells
		PP1	PP2	PP3	PP4	PP5	PP6	PP7	
1K		764	768	798	804	818			10
2K		1 522	1 532	1 596	1 602	1 632		1 646	18
4K		3 084	3 092	3 228	3 234	3 298		3 328	36
8K	Normal	6 208	6 214	6 494	6 498	6 634		6 698	72
	Extended	6 296	6 298	6 584	6 588	6 728		6 788	72
16K	Normal	12 418	12 436	12 988	13 002	13 272	13 288	13 416	144
	Extended	12 678	12 698	13 262	13 276	13 552	13 568	13 698	144

NOTE: An empty entry indicates that the corresponding combination of FFT size and pilot pattern is never used.

Table 80: Number of data cells N_{FC} in the frame closing symbol

FFT Size		N_{FC} for frame closing symbol (no tone reservation)							TR cells
		PP1	PP2	PP3	PP4	PP5	PP6	PP7	
1K		568	710	710	780	780			10
2K		1 136	1 420	1 420	1 562	1 562		1 632	18
4K		2 272	2 840	2 840	3 124	3 124		3 266	36
8K	Normal	4 544	5 680	5 680	6 248	6 248		6 532	72
	Extended	4 608	5 760	5 760	6 336	6 336		6 624	72
16K	Normal	9 088	11 360	11 360	12 496	12 496	13 064	13 064	144
	Extended	9 280	11 600	11 600	12 760	12 760	13 340	13 340	144

NOTE: An empty entry indicates that frame closing symbols are never used for the corresponding combination of FFT size and pilot pattern.

Table 81: Number of available active cells C_{FC} in the frame closing symbol

FFT Size		C_{FC} (no tone reservation)							TR cells
		PP1	PP2	PP3	PP4	PP5	PP6	PP7	
1K		402	654	490	707	544			10
2K		804	1 309	980	1 415	1 088		1 396	18
4K		1 609	2 619	1 961	2 831	2 177		2 792	36
8K	Normal	3 218	5 238	3 922	5 662	4 354		5 585	72
	Extended	3 264	5 312	3 978	5 742	4 416		5 664	72
16K	Normal	6 437	10 476	7 845	11324	8 709	11 801	11 170	144
	Extended	6 573	10 697	8 011	11563	8 893	12 051	11 406	144

NOTE: An empty entry indicates that frame closing symbols are never used for the corresponding combination of FFT size and pilot pattern.

Thus, the number of active OFDM cells in one NGH frame (C_{tot}) depends on the frame structure parameters including whether or not there is a frame closing symbol (see clause 11.1.7) and is given by:

$$C_{tot} = \begin{cases} N_{P2} * C_{P2} + (L_{data} - 1) * C_{data} + C_{FC} & \text{when there is a frame closing symbol} \\ N_{P2} * C_{P2} + L_{data} * C_{data} & \text{when there is no frame closing symbol} \end{cases}$$

The number of P2 symbols N_{P2} is dependent on the used FFT size and is defined in table 82.

Table 82: Number of P2 symbols denoted by N_{P2} for different FFT modes

FFT size	N_{P2}
1k	4
2k	2
4k	1
8k	1
16k	1

The number of OFDM cells needed to carry all L1-PRE signalling is denoted by D_{L1}. The number of OFDM cells available for transmission of logical frame content in one NGH-frame is given by:

$$D_{\mathrm{PLP}} = C_{\mathrm{tot}} - D_{\mathrm{L1}}\,.$$

The value of D_{L1} does not change between NGH frames. The value of D_{PLP} can change between NGH-frames because C_{tot} can change.

All the $D_{L1\,pre}$ cells are mapped into P2 symbol(s) as described in clause 9.9.3. The logical frame is then mapped onto the remaining active OFDM cells of the P2 symbol(s) (if any) and the data symbols. The mapping of the logical frame cells is described in clause 9.9.3.1.

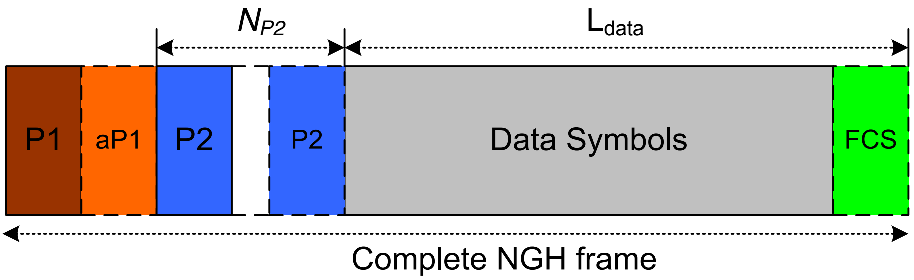


Figure 68: Structure of the NGH frame

9.9.3 Mapping of L1-PRE signalling information to P2 symbol(s)

Coded and modulated L1-PRE cells for NGH frame m are mapped to the P2 symbol(s) as follows:

1) L1-PRE cells are mapped to the active cells of P2 symbol(s) in row-wise zig-zag manner as illustrated in figure 69 by the blue blocks and described in the following equation:

$$x_{m,l,p} = f'\_pre_{m,\,p \times N_{P2}+l}\,,\ \text{for } 0 \le l < N_{P2} \text{ and } 0 \le p < \frac{D_{L1pre}}{N_{P2}}\,,$$

where: $f'\_pre_{m,i}$ are the modulated L1-PRE cells; D_{L1pre} is the number of L1-PRE cells per NGH-frame, $D_{L1pre} = 2150$;

N_{P2} is the number of P2 symbols as shown in table 82; and

$x_{m,l,p}$ are the active cells of each OFDM symbol as defined in clause 9.9.2.

NOTE: The zig-zag writing may be implemented by the time interleavers presented in figure 69. The data is written to the interleaver column-wise, while the read operation is performed row-wise. The number of rows in the interleaver is equal to N_{P2}. The number of columns depends on the amount of data to be interleaved and is equal to D_{L1pre}/N_{P2}.

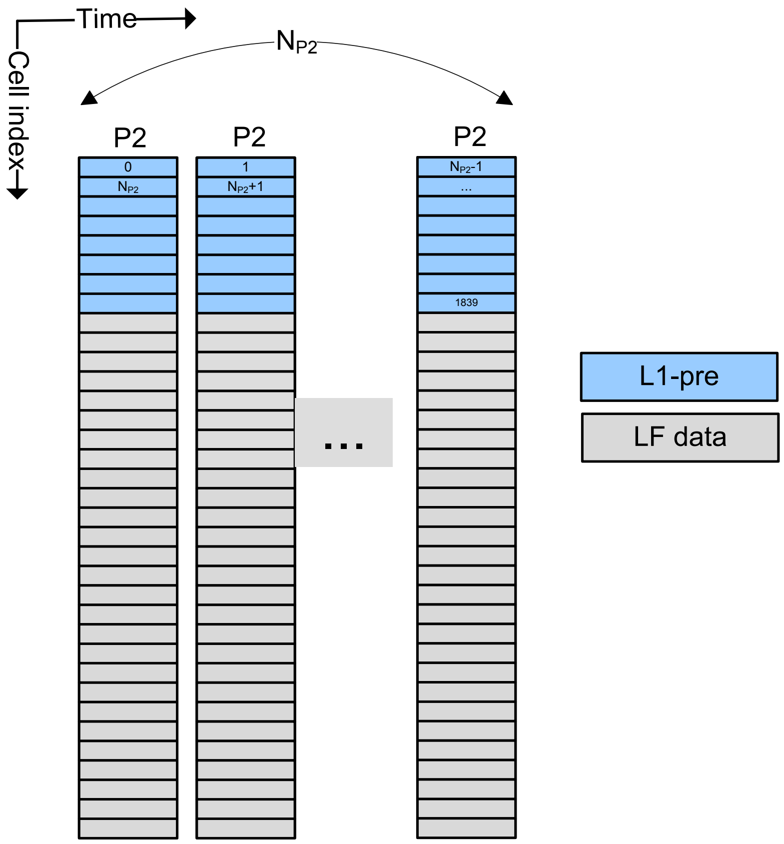
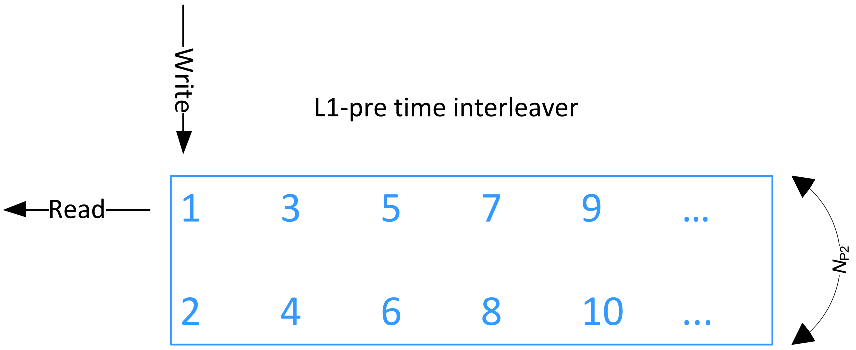


Figure 69: Mapping of L1-PRE data into P2 symbol(s), showing the index of the cells within the L1-PRE data fields



NOTE: The number of rows is equal to N_{P2}.

Figure 70: P2 time interleaver

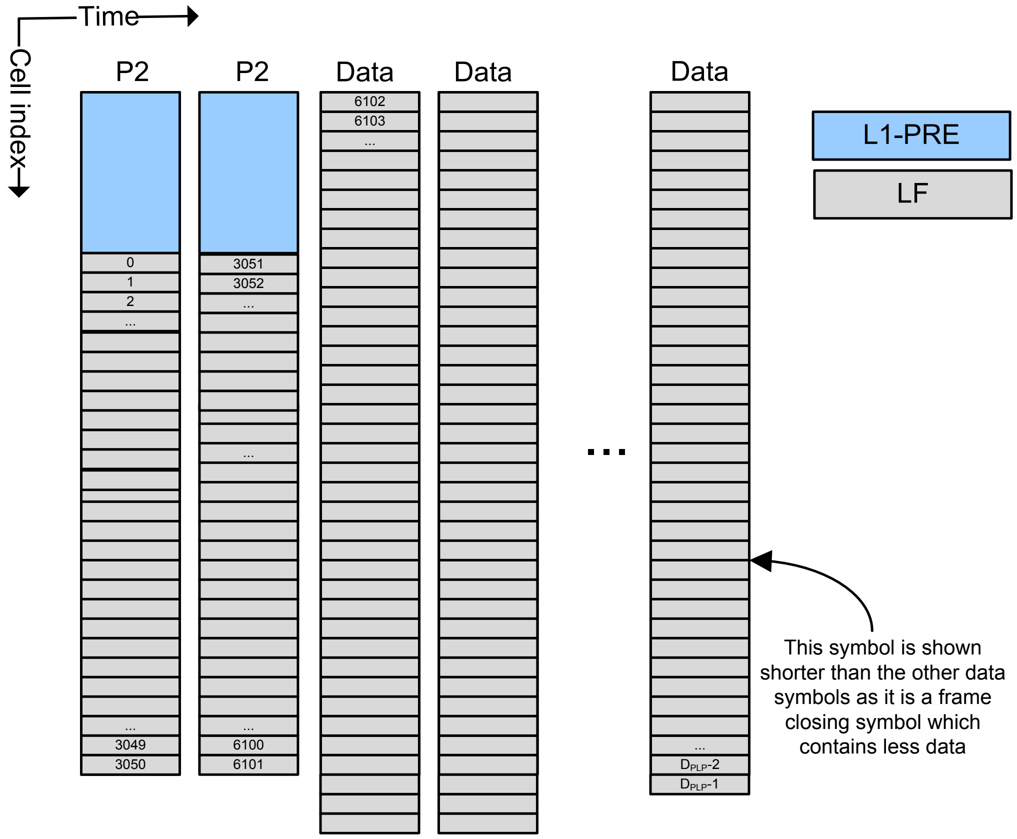
9.9.3.1 Addressing of OFDM cells

A one-dimensional addressing scheme ($0..D_{PLP}-1$) is defined for the active data cells that are not used for L1-PRE signalling. The addressing scheme defines the order in which the cells from the logical frame are allocated to the active data cells. The addressing scheme also defines the order of any dummy cells.

Address 0 shall refer to the cell $x_{m,0,\frac{D_{L1pre}}{N_{P2}}}$, the cell immediately following the last cell carrying L1-PRE signalling in the first P2 symbol. The addresses 0, 1, 2, … shall refer to the cells in the following sequence:

- $x_{m,l,\frac{D_{L1}}{N_{P2}}} \ldots x_{m,l,C_{P2-1}}$ for each $l=0 \ldots N_{P2}-1$, followed by
- $x_{m,l,0} \ldots x_{m,l,C_{data}-1}$ for each $l=N_{P2} \ldots L_F-2$, followed by
- $x_{m,L_F-1,0} \ldots x_{m,L_F-1,C_{FC}-1}$ if there is a frame closing symbol; or
- $x_{m,L_F-1,0} \ldots x_{m,L_F-1,C_{data}-1}$ if there is no frame closing symbol.

The location addresses are depicted in figure **71**.



This symbol is shown shorter than the other data symbols as it is a frame closing symbol which contains less data

Figure 71: Addressing of the OFDM cells for common PLPs and data PLPs The numbers (cell addresses) are exemplary

9.9.4 Dummy cell insertion

If the L1-PRE signalling, and allocated logical frame data D_{LF} do not exactly fill the C_{tot} active cells in one NGH-frame, dummy cells shall be inserted in the remaining N_{dummy} cells (see clause 9.2.4), where:

$$N_{\text{dummy}} = D_{\text{PLP}} - D_{LF}$$

The dummy cell values are generated by taking the first N_{dummy} values of the BB scrambling sequence defined in clause 5.2.4. The sequence is reset at the beginning of the dummy cells of each NGH-frame. The resulting bits $b_{\text{BS},j}$, $0 \leq j < N_{\text{dummy}}$, are then mapped to cell values $x_{\text{m,l,p}}$ according to the following rule:

$$\text{Re}\{x_{\text{m,l,p}}\} = 2\ (1/2 - b_{\text{BS},j})$$

$$\text{Im}\{\ x_{\text{m,l,p}}\} = 0,$$

where the bits $b_{\text{BS},j}$ are mapped to cells $x_{\text{m,l,p}}$ in order of increasing cell address starting from the first unallocated address.

9.9.5 Insertion of unmodulated cells in the frame closing symbol

When a frame closing symbol is used (see clauses 9.9.2 and 11.1.7), some of its data cells carry no modulation in order to maintain constant symbol power in the presence of a higher pilot density.

The last N_{FC}-C_{FC} cells of the Frame Closing Symbol, ($x_{m,\ L\text{F-1},C\text{FC}} \dots x_{m,\ L\text{F-1},N\text{FC-1}}$), shall all be set to 0+j0.

9.10 Future Extension Frames (FEF)

Future Extension Frame (FEF) insertion enables carriage of frames either defined in a future extension of the NGH standard or defined for a previous standard such as T2 in the same multiplex as regular NGH-frames. The use of future extension frames is optional.

A future extension frame may carry data in ways unknown to a DVB-NGH receiver addressing the current standard version. A receiver addressing the current standard version is not expected to decode future extension frames. All receivers are expected to detect FEF parts.

A FEF part shall begin with a P1 symbol that can be detected by all DVB-NGH receivers. The maximum length of a FEF part is 1s. All other parts of the future extension frames will be defined in future extensions of the present document or are (or will be) defined elsewhere.

The FEF parts of one profile may contain frames of other profiles and/or non-NGH signals. Since each FEF part may contain multiple frames of other profiles, each FEF part may also have several P1 symbols, at varying intervals throughout its length. The minimum interval between two P1 symbols shall be 10 000T, where T is the elementary period (see clause 11.4).

> NOTE 1: This minimum interval between P1 symbols (which is approximately 1,1 ms for 8 MHz bandwidth) allows a receiver to determine the frame start positions correctly in the presence of long echoes. In this case, the receiver synchronisation circuitry may 'see' P1 symbols separated by the echo delay, but this delay could never be expected to exceed about 4 900T. So P1 symbols apparently separated by less than 5 000T can be assumed to be due to the effect of echoes, whereas a separation of more than 5 000T can be assumed to be due to independent P1 symbols. The constraints on NGH-frame lengths mean that their duration will always exceed 10 000T.

The detection of FEF parts is enabled by the L1-PRE signalling carried in the P2 symbol(s) (see clause 8.1.2). The configurable L1 fields signal the size and structure of the NGH super-frame. The NUM_ FRAMES parameter describes the number of NGH-frames carried during one NGH super-frame. The location of the FEF parts is described by the L1-PRE signalling field FEF_INTERVAL, which is the number of NGH-frames at the beginning of a NGH super-frame, before the beginning of the first FEF part. The same field also describes the number of NGH-frames between two FEF parts. The length of the FEF part is given by the FEF_LENGTH field of the L1-PRE signalling. This field describes the time between two DVB-NGH frames preceding and following a FEF part as the number of elementary time periods T, i.e. samples in the receiver (see clause 11.4).

The parameters affecting the configuration of FEFs shall be chosen to ensure that, if a receiver obeys the TTO signalling (see annex C.1) and implements the model of buffer management defined in clause C.2, the receiver's de-jitter buffer and time de-interleaver memory shall neither overflow nor underflow.

NOTE 2: In order not to affect the reception of the NGH data signal, it is assumed that the receiver's automatic gain control will be held constant for the duration of FEF part, so that it is not affected by any power variations during the FEF part.

9.11 Frequency interleaver

The purpose of the frequency interleaver, operating on the data cells of one OFDM symbol, is to map the data cells from the frame builder onto the N_{data} available data carriers in each symbol. $N_{data} = C_{P2}$ for the P2 symbol(s), $N_{data} = C_{data}$ for the normal symbols (see clause 9.9.2), and $N_{data} = N_{FC}$ for the Frame Closing symbol, if present.

For the P2 symbol(s) and all other symbols, the frequency interleaver shall process the data cells $X_{m,l} = (x_{m,l,0}, x_{m,l,1}, \ldots, x_{m,l,\mathrm{Ndata}-1})$ of the OFDM symbol l of NGH-frame m, from the frame builder.

Thus for example in the 8k mode with scattered pilot pattern PP7 and no tone reservation, blocks of 6 698 data cells from the frame builder during normal symbols form the input vector $X_{m,l} = (x_{m,l,0}, x_{m,l,1}, x_{m,l,2}, \ldots x_{m,l,6697})$.

A parameter M_{max} is then defined according to table 83.

Table 83: Values of M_{max} for the frequency interleaver

FFT Size	M_{max}
1K	1 024
2K	2 048
4K	4 096
8K	8 192
16K	16 384

The interleaved vector $A_{m,l} = (a_{m,l,0}, a_{m,l,1}, a_{m,l,2} \ldots a_{m,l,N\mathrm{data}-1})$ is defined by:

$a_{m,l,p} = [x_{m,l,H_0(p)} + S(l)] \bmod N_{data}$ for even symbols of the frame ($l \bmod 2 = 0$) for $p = 0,\ldots,N_{data}-1$; and

$a_{m,l,p} = [x_{m,l,H_1(p)} + S(l)] \bmod N_{data}$ for odd symbols of the frame ($l \bmod 2 = 1$) for $p = 0,\ldots,N_{data}-1$.

$H_0(p)$ and $H_1(p)$ are permutation functions based on sequences R'_i defined by the following.

An $(N_r - 1)$ bit binary word R'_i is defined, with $N_r = \log_2 M_{max}$, where R'_i takes the following values:

$i = 0,1$: $R'_i [N_r-2, N_r-3,\ldots,1,0] = 0,0,\ldots,0,0$

$i = 2$: $R'_i [N_r-2, N_r-3,\ldots,1,0] = 0,0,\ldots,0,1$

$2 < i < M_{max}$: { $R'_i [N_r-3, N_r-4,\ldots,1,0] = R'_{i-1} [N_r-2, N_r-3,\ldots,2,1]$;

in the 0.5k mode: $R'_i [7] = R'_{i-1} [0] \oplus R'_{i-1} [1] \oplus R'_{i-1} [5] \oplus R'_{i-1} [6]$

in the 1k mode: $R'_i [8] = R'_{i-1} [0] \oplus R'_{i-1} [4]$

in the 2k mode: $R'_i [9] = R'_{i-1} [0] \oplus R'_{i-1} [3]$

in the 4k mode: $R'_i [10] = R'_{i-1} [0] \oplus R'_{i-1} [2]$

in the 8k mode: $R'_i [11] = R'_{i-1} [0] \oplus R'_{i-1} [1] \oplus R'_{i-1} [4] \oplus R'_{i-1} [6]$

in the 16k mode: $R'_i [12] = R'_{i-1} [0] \oplus R'_{i-1} [1] \oplus R'_{i-1} [4] \oplus R'_{i-1} [5] \oplus R'_{i-1} [9] \oplus R'_{i-1} [11]$

```
        }
```

A vector R_i is derived from the vector R'_i by the bit permutations given in tables 84 to 89.

Table 84: Bit permutations for the 0.5k mode

R'_i bit positions	7	6	5	4	3	2	1	0
R_i bit positions (H_0)	3	7	4	6	1	2	0	5
R_i bit positions (H_1)	4	2	5	7	3	0	1	6

Table 85: Bit permutations for the 1k mode

R'_i bit positions	8	7	6	5	4	3	2	1	0
R_i bit positions (H_0)	4	3	2	1	0	5	6	7	8
R_i bit positions (H_1)	3	2	5	0	1	4	7	8	6

Table 86: Bit permutations for the 2k mode

R'_i bit positions	9	8	7	6	5	4	3	2	1	0
R_i bit positions (H_0)	0	7	5	1	8	2	6	9	3	4
R_i bit positions (H_1)	3	2	7	0	1	5	8	4	9	6

Table 87: Bit permutations for the 4k mode

R'_i bit positions	10	9	8	7	6	5	4	3	2	1	0
R_i bit positions (H_0)	7	10	5	8	1	2	4	9	0	3	6
R_i bit positions (H_1)	6	2	7	10	8	0	3	4	1	9	5

Table 88: Bit permutations for the 8k mode

R'_i bit positions	11	10	9	8	7	6	5	4	3	2	1	0
R_i bit positions (H_0)	5	11	3	0	10	8	6	9	2	4	1	7
R_i bit positions (H_1)	8	10	7	6	0	5	2	1	3	9	4	11

Table 89: Bit permutations for the 16k mode

R'_i bit positions	12	11	10	9	8	7	6	5	4	3	2	1	0
R_i bit positions (H_0)	8	4	3	2	0	11	1	5	12	10	6	7	9
R_i bit positions (H_1)	7	9	5	3	11	1	4	0	2	12	10	8	6

Note: The 0.5k frequency interleaving mode (see figure 79 above) is only applicable when MISO is applied with 1k FFT size.

The permutation function $H(p)$ is defined by the following algorithm:

```
$p = 0;$
for ($i = 0; i < M_{max}; i = i + 1$)
```

```
{ $H(p) = (i \bmod 2).2^{N_r-1} + \sum_{j=0}^{N_r-2} R_i(j).2^j$;
if ($H(p) < N_{data}$) $p = p+1$; }
```

For symbol *l*, the address offset S(*l*) is defined by the following algorithm:

```
for ($l = 0$; $l < L_F$; $l = l + 2$)
{
    $S(l) = \sum_{j=0}^{N_r-1} G_l(j).2^j$; and $S(l+1) = \sum_{j=0}^{N_r-1} G_l(j).2^j$;
}
```

An (N_r - 1) bit binary word G_l is defined, with $N_r = \log_2 2M_{max}$, where G_l takes the following values:

```
$l = 0, 1$:        $G_l [N_r-1, N_r-2, ..., 1, 0] = 1, 1, ..., 1, 1$
$1 < l < L_F$:     { $G_l[N_r-2, N_r-3, ..., 1, 0] = G_{l-1} [N_r-1, N_r-2, ..., 2, 1]$;
                     in the 0.5k mode: $G_l[8] = G_{l-1}[0] \oplus G_{l-1}[4]$
                     in the 1k mode: $G_l[9] = G_{l-1}[0] \oplus G_{l-1}[3]$
                     in the 2k mode: $G_l[10] = G_{l-1}[0] \oplus G_{l-1}[2]$
                     in the 4k mode: $G_l[11] = G_{l-1}[0] \oplus G_{l-1}[1] \oplus G_{l-1}[4] \oplus G_{l-1}[6]$
                     in the 8k mode: $G_l[12] = G_{l-1}[0] \oplus G_{l-1}[1] \oplus G_{l-1}[4] \oplus G_{l-1}[5] \oplus G_{l-1}[9] \oplus G_{l-1}[11]$
                     in the 16k mode: $G_l[13] = G_{l-1}[0] \oplus G_{l-1}[1] \oplus G_{l-1}[2] \oplus G_{l-1}[12]$ }
}
```

G_l is held constant for two symbols and applied to symbol *l* and symbol *l*+1.

Pairwise Frequency Interleaving for MIxO

In MIxO mode, data carriers are interleaved in pairs. This means that the frequency interleaver in a given FFT mode is required to generate only half of the interleaver addresses compared to when operating with SISO. Therefore, for:

- 1K mode, the 0.5K interleave circuit is used.
- 2K mode, the 1K interleave circuit is used
- 4K mode, the 2K interleave circuit is used
- 8K mode, the 4K interleave circuit is used
- 16K mode, the 8K interleave circuit is used

Each interleaver memory location is thus twice as wide as in SISO and pairs of carriers are written and read from each such memory location.

A schematic block diagram of the algorithm used to generate the permutation function is represented in figures 72to77.

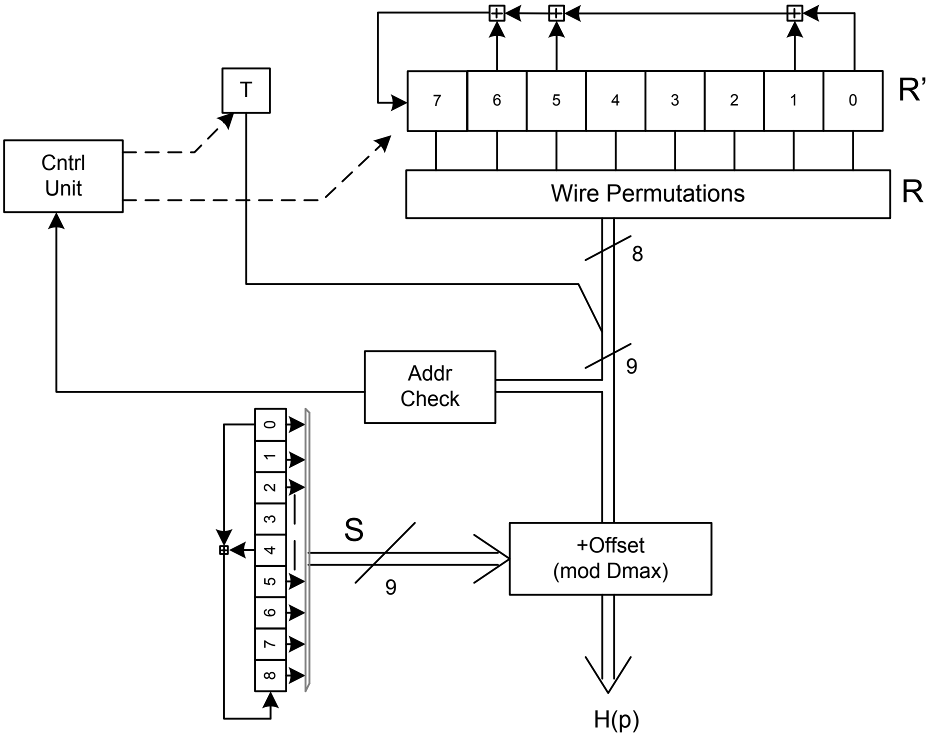


Figure 72: Frequency interleaver address generation scheme for the 0.5k mode

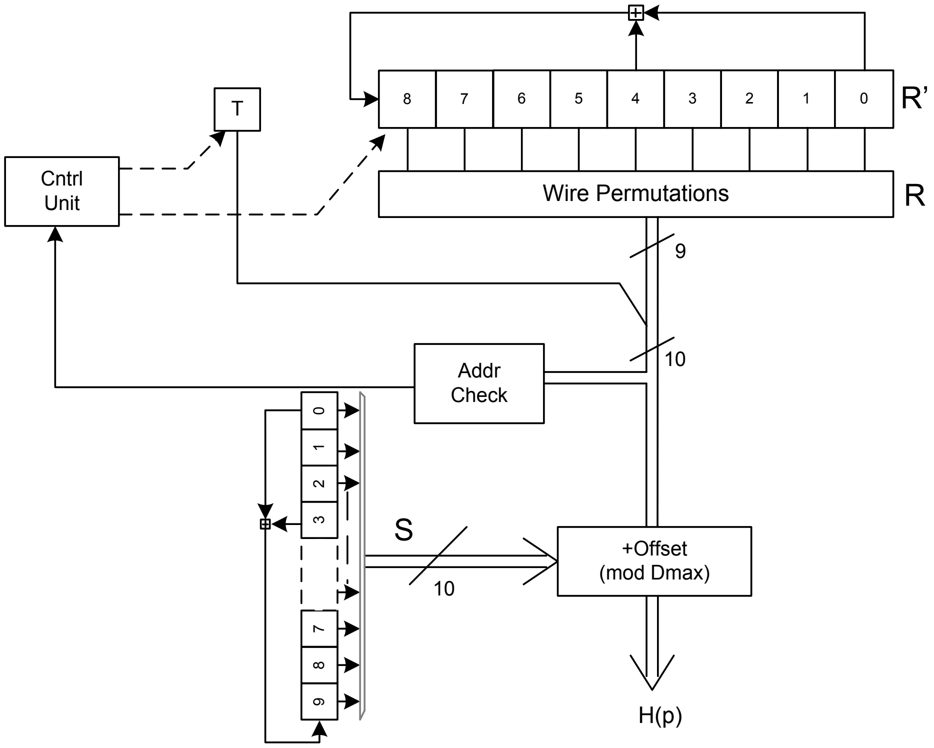


Figure 73: Frequency interleaver address generation scheme for the 1k mode

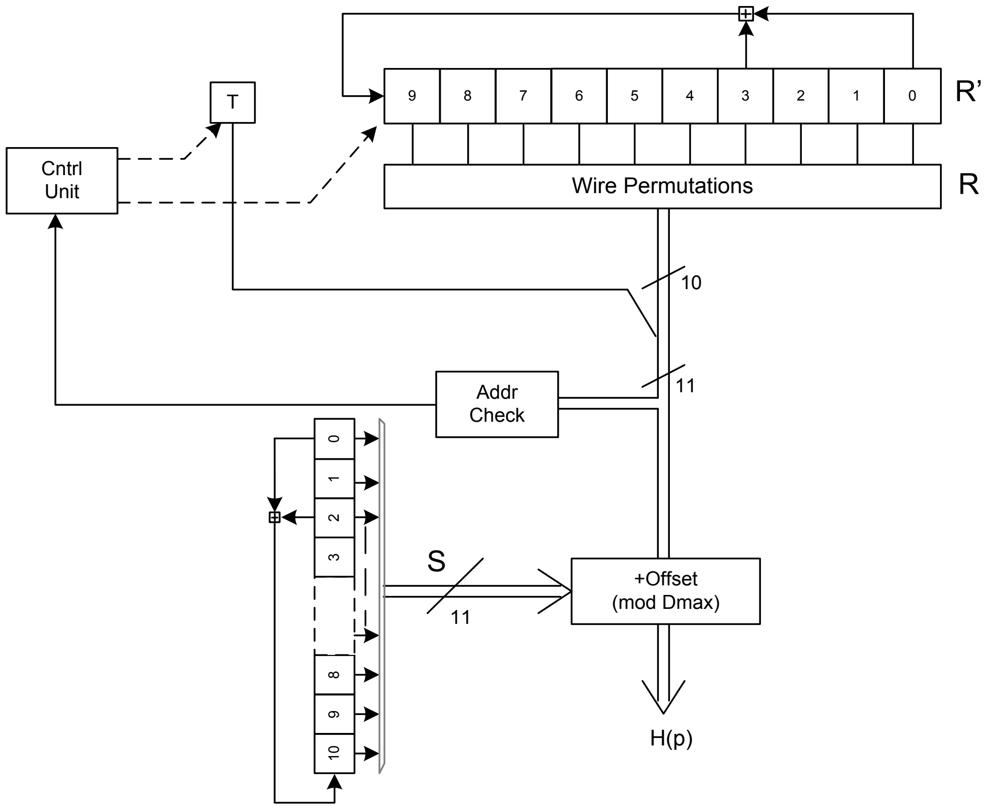


Figure 74: Frequency interleaver address generation scheme for the 2k mode

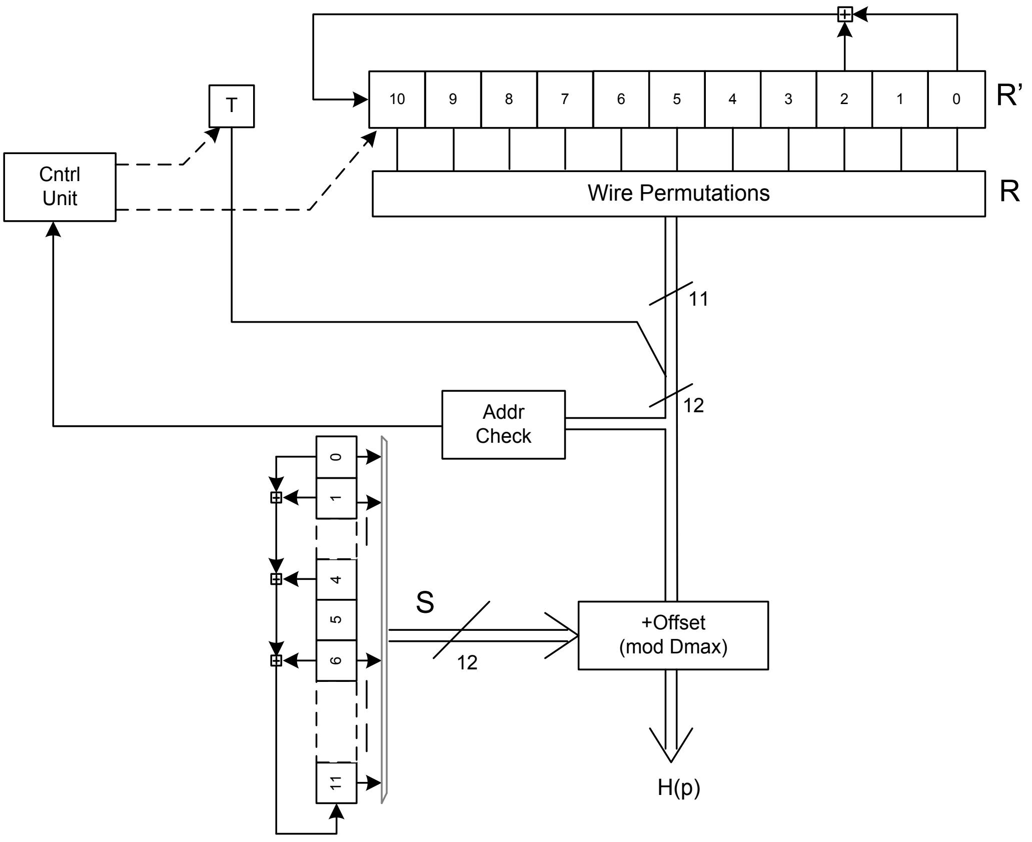


Figure 75: Frequency interleaver address generation scheme for the 4k mode

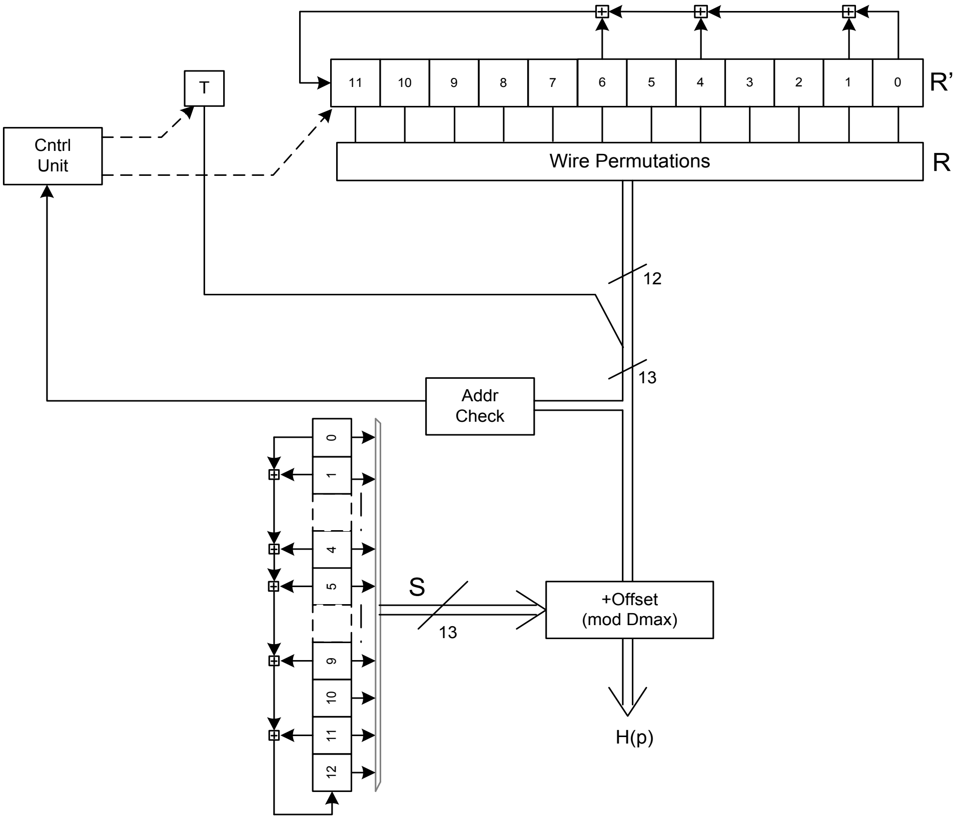


Figure 76: Frequency interleaver address generation scheme for the 8k mode

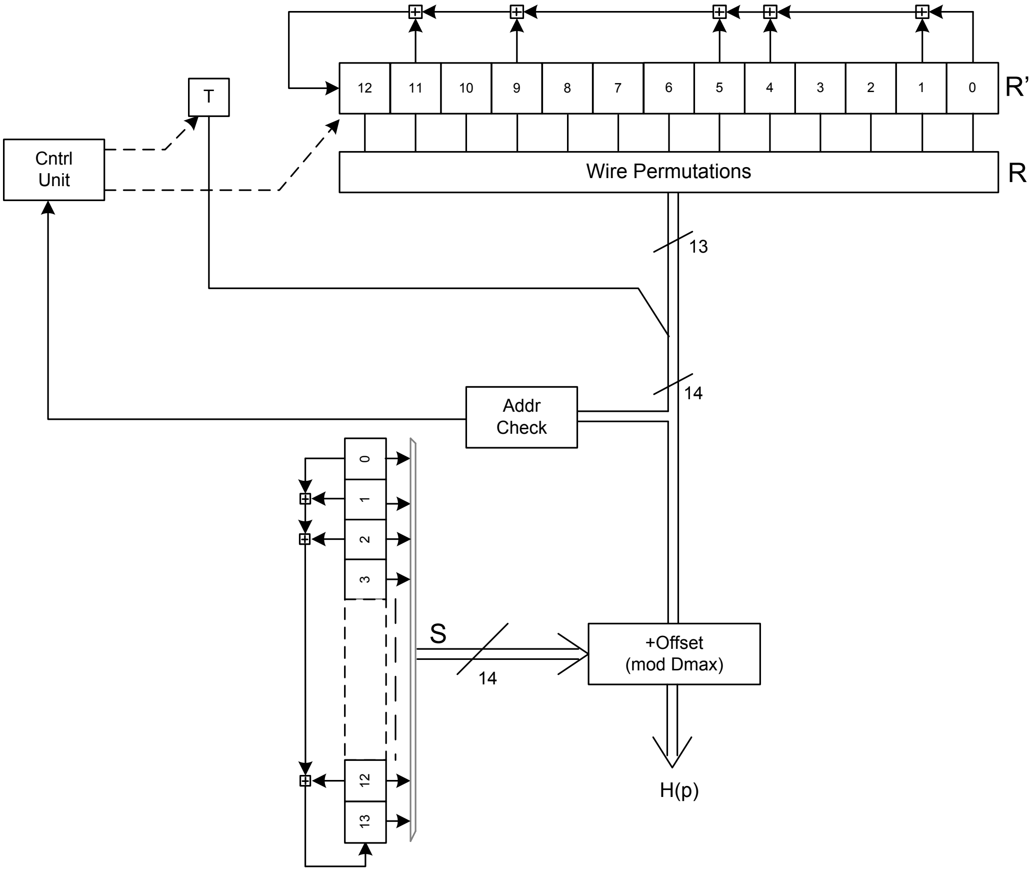


Figure 77: Frequency interleaver address generation scheme for the 16k mode

The output of the frequency interleaver is the interleaved vector of data cells $A_{m,l} = (a_{m,l,0}, a_{m,l,1}, a_{m,l,2},\ldots a_{m,l,N\text{data}-1})$ for symbol l of NGH frame m.

10 Local service insertion

10.1 Orthogonal local service insertion (O-LSI)

10.1.1 Overview

Orthogonal local service insertion (O-LSI) allows a number of, typically adjacent, transmitters in an SFN to transmit different - but orthogonal - input data.

10.1.2 O-LSI symbols and data cells

10.1.2.1 Overview

PLP data using O-LSI is transmitted as type 3 PLPs in the last part of the LF, after any preceding type 1 and type 2 PLPs, auxiliary streams and dummy cells. In LCs including O-LSI PLPs each LF must be time synchronized with a corresponding NGH frame with a 1-to-1 mapping, i.e. only LC type 0 and 3 may be used with O-LSI.

All type 3 PLP data in a LF has to be transmitted in a number of consecutive OFDM symbols, which are disjoint from those using other PLP types and auxiliary streams. The first O-LSI symbol and the number of O-LSI symbols in the NGH frame are signalled by the L1-pre parameters O-LSI_START_SYMBOL and O-LSI_NUM_SYMBOLS. The first and the last O-LSI symbols are denoted O-LSI starting symbol and O-LSI closing symbol respectively. These share an identical pilot patterns, which is denser than the pilot pattern in any of the intermediate O-LSI symbols. The first and last O-LSI symbol may be the same symbol, in which case there is only a single O-LSI symbol in the NGH frame.

The orthogonality is obtained by dividing the available number of OFDM sub-carriers N in each O-LSI symbol into REUSE_FACTOR (2 ≤ REUSE_FACTOR ≤ 7) equally sized parts and only transmitting one of these from a particular transmitter. When N/REUSE_FACTOR is not an integer a small number p (1 ≤ p ≤ REUSE_FACTOR) of the last cells are used as padding cells in such a way that N'=(N-p)/ REUSE_FACTOR is an integer. Padding cells are modulated with zero amplitude (empty cells). When the amount of input PLP data does not fill the allocated O-LSI symbols any remaining data cell capacity is filled with dummy cells so that after the final dummy cell in the frame there are only O-LSI cells up to the end of the frame, some of which may be padding cells or empty cells. Any padding cells or dummy cells are not part of the O-LSI process, but are transmitted on the same cell positions from all transmitters.

Each of the REUSE_FACTOR parts is referenced by the L1 parameter REUSE_ID (1 ≤ REUSE_ID ≤ REUSE_FACTOR). The value of this parameter increases with carrier numbering in such a way that the part with REUSE_ID = k will use the k^{th} part of carriers in each O-LSI symbol (before frequency interleaving). From a given transmitter only the part referenced by REUSE_ID is used for transmission of the LF data and the remaining parts all transmit the value 0 on all their OFDM sub-carriers.

NOTE: When the number of transmitters in the SFN exceeds RESUSE_FACTOR there is in principle some non-orthogonality between some of the transmitters. This may however be acceptable when the transmitters with non-orthogonal parts are sufficiently separated geographically. Each transmitter, even in a large SFN, may therefore potentially transmit unique input data.

10.1.2.2 Power level of the O-LSI data cells

The O-LSI part referenced by the L1 parameter REUSE_ID, i.e. the part using non-zero cell values, are transmitted with an amplitude boosting factor equal to √M followed by a normalization factor K. The value of K is defined in clause 10.1.5.

10.1.2.3 Filling of O-LSI symbols with LF data cells

The TI cells of the O-LSI part of the LF are introduced into the O-LSI part of the NGH frame symbol by symbol starting immediately after the last dummy cell (if any). For each symbol the data cells are introduced in the order of increased carrier index and excluding all positions already filled with pilot cells. When all O-LSI data cells have been introduced frequency interleaving is performed symbol by symbol, see clause 9.11. Before frequency interleaving the different parts appear one after the other, with all cells belonging to a part in a homogenous group, as shown in figure x. After frequency interleaving, the data cells of a particular part is quasi-randomly distributed over the full bandwidth.

NOTE: Since the frequency interleaving is the same, irrespective of REUSE_ID, for a given symbol index, the original orthogonality of data cells (and pilot patterns) between different REUSE_ID transmissions, will remain valid also after frequency interleaving.

10.1.3 O-LSI scattered pilot patterns

10.1.3.1 Location of O-LSI scattered pilot patterns

The scattered pilot patterns for the O-LSI starting and closing symbols are identical and denser than the patterns of any intermediate O-LSI symbols.

The location of scattered pilot patterns for O-LSI starting/closing symbols, or intermediate symbols, are based on the corresponding regular scattered pilot patterns for the frame closing symbol and the normal symbols respectively, as defined in annex H. Table 90 shows the allowed PPs for O-LSI depending on FFT size.

Table 90: Allowed combinations of FFT sizes and pilot patterns (PP) for O-LSI

FFT size	Allowed pilot patterns (PPs)	
16K	PP6	PP4
8K	PP7	PP5
4K	PP5	PP3
2K	PP3	-
1K	NA	NA

The PP for the transmitter with REUSE_ID =1 is defined by the following four steps:

1. Start with the corresponding PP taken from table 90 using the same entry (e.g. PP7)
2. Let the carrier index = 0 be a CP for all O-LSI symbols
3. Let the carrier index K_{max}-M be a CP in all O-LSI symbols
4. Let the carriers with index > K_{max}-M be non-pilots in all O-LSI symbols

The PP of a transmitter using REUSE_ID >1 is given by taking the PP of REUSE_ID =1 and shift this REUSE_ID -1 cells in the direction of increasing carrier index.

Note: The respective PPs from all M transmitters are now orthogonal and each of them may be used for channel estimation of the signal received from the respective transmitter, or set of transmitters using the same REUSE_ID.

10.1.3.2 Power level of scattered pilot cells

The scattered pilot cells of O-LSI PPx shall be transmitted with a total boosting factor, which is the pilot boosting, relative to the power of the transmitted non-zero data cells, as specified in clause 11.1.3.2, followed by a normalization factor K*√(REUSE_FACTOR). The value of K is defined in clause 10.1.5.

10.1.3.3 Modulation of scattered pilot cells

The phases of the scattered pilot cells are derived from the reference sequence given in clause 11.1.2.
The corresponding modulation is given by:

$$\mathrm{Re}\{c_{m,l,k}\} = 2\,A\mathrm{SP}\,(1/2 - r_{l,k})$$

$$\mathrm{Im}\{c_{m,l,k}\} = 0$$

Where *m* is the NGH frame index, *k* is the frequency index of the carriers and *l* is the time index of the symbols.

10.1.4 O-LSI continual pilots

10.1.4.1 Overview

In addition to the PPs defined above the O-LSI part of the frame also consists of continual pilots (CPs) as defined in this paragraph.

In contrast to the data cells and PPs, which need to be orthogonal from the M transmitters, the set of continual pilots, defined in this paragraph, is the same irrespective of the value of REUSE_ID.

10.1.4.2 Location of O-LSI CPs

In contrast to the rest of the NGH signal (i.e. non-O-LSI), where the carrier index for a continual pilot may coincide with the carrier index of a scattered pilot, these two pilot types must be separated for O-LSI, since the CPs apply to all transmitters, whereas each transmitter (or group of transmitters) transmits a dedicated scattered pilot pattern.

The set of CP indices for O-LSI, for a given FFT size and pilot pattern, are the same as in the corresponding set of CPs for the rest of the NGH signal (see annex H), except when there is a collision between the CP index and a scattered pilot index. When a CP coincides with a scattered pilot, cell the closest carrier index that does not coincide with a SP shall be selected for this particular CP. When two cases are equally close the one with the highest carrier index shall be selected.

10.1.4.3 Power level of CP cells

The CPs of O-LSI shall be transmitted with a boosting factor, which is the same boosting as is used for the actual scattered pilot pattern multiplied by √(REUSE_FACTOR)..

10.1.4.4 Modulation of continual pilot cells

The phases of the continual pilots are derived from the reference sequence given in clause 11.1.2. The corresponding modulation is given by:

$$\mathrm{Re}\{c_{m,l,k}\} = 2\,A\mathrm{SP}\,(1/2 - r_{l,k})$$

$$\mathrm{Im}\{c_{m,l,k}\} = 0$$

Where m is the NGH frame index, k is the frequency index of the carriers and l is the time index of the symbols.

10.1.5 Normalisation factor K

A normalization factor K shall be applied to all O-LSI cells (data, SPs, CPs) in such a way that the power of the O-LSI starting and closing symbols have the same expected average power level as the P2 symbol.

10.2 Hierarchical local service insertion (H-LSI)

Hierarchical local service insertion is used to insert new services in an isolated transmitter or group of transmitters within a single frequency network. In using this method, a local service PLP is hierarchically modulated over an appropriate regional service PLP, which already exists within the SFN. Receivers can either continue to receive the regional service PLP or jump to the hierarchically modulated local service PLP. Hierarchical local services are inserted over Type 1 PLPs carried in Logical channel Types A and D. The PLP_ID of the regional or national PLP over which local service is hierarchically modulated is signalled in L1-POST in the NATIONAL_PLP_ID field of the local service PLP.

10.2.1 Overview

For each NGH frame carrying QAM cells of the regional PLP whose PLP_ID is equal to NATIONAL_PLP_ID field of the local service PLP, the local service PLP data is hierarchically modulated using QPSK onto the regional PLP QAM cells. Figure 78 illustrates a typical BICM chain for HLSI in the lower branch.

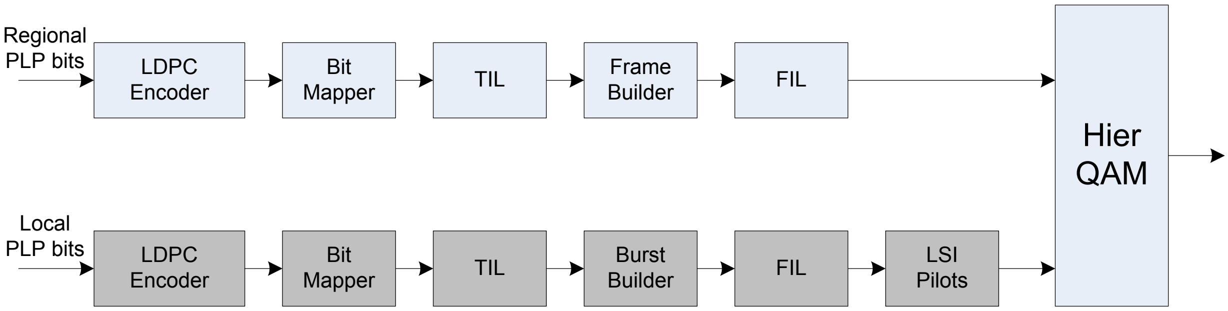


Figure 78: Signalling flow for local insertion BICM and hierarchical modulation

The local service PLP bits are first encoded using one of the LDPC codes as described in clause 6.1 and are then mapped into bit pairs for later QPSK modulation. The output of the bit mapper goes through the time interleaver as described in clause 6.6. This time interleaver uses the same configuration as the regional PLP whose PLP_ID is equal to NATIONAL_PLP_ID field of this local service PLP. The local service PLP (L-PLP) is said to be carried on top of a regional PLP (R-PLP). The burst builder collects enough cells of the L-PLP to cover a given number of cells of the R-PLP within the particular NGH frame for a particular transmitter. The maximum number of cells (**BURST_LEN** * N_{cells}**)** in one LS burst is taken from an integer number (**BURST_LEN)** of FECFRAMES each providing $N_{\text{cells}} = N_{\text{ldpc}} /2 = 8100$ (since the L-PLP always uses QPSK). The burst builder also creates a burst header in accordance with clause 10.2.3 to carry the signalling related to the LS burst. This burst header is then added to the beginning of the LS burst to form a complete LS frame of total length [64 + (**BURST_LEN** * N_{cells}**))**. Figure 79 illustrates the structure of the LS-frame.

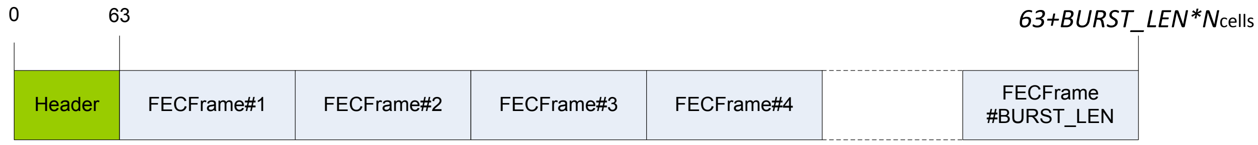


Figure 79: Structure of the LS frame

Cells of the LS-frame are allocated to the logical frame from a start address that is the same as the starting address of the R-PLP over which the local service will be inserted in the current logical frame. When frequency interleaving begins, sequences of C_{LSI} L-PLP cells are taken in turn from the logical frame. Each sequence is then frequency interleaved as described in clause 9.11. Local service pilots are then added to each frequency interleaved sequence as described in clause 10.2.5. Each sequence now contains the right number of L-PLP cells and pilots needed to hierarchically modulate all the non-pilot R-PLP QAM cells that fit into a single OFDM symbol. The QAM labels from the R-PLP enter the high priority port and the QPSK labels from the L-PLP enter the low priority port of a hierarchical modulator which functions as described in clause 10.2.6.

10.2.2 L1 signalling for hierarchical local service

The L-PLP shall be signalled in L1-POST as a data PLP of Type 4 . Accordingly, the related section of L1-POST has the field NATIONAL_PLP_ID used to indicate R-PLP which this particular L-PLP will hierarchically modulate. This signalling in L1-POST is made up of 17 bits partitioned between three parameters as follows:

- **ALPHA:** This 3 bit field shall signal the hierarchical modulation parameter used for the modulation of the L-PLP in the current logical frame according to table 91

Table 91: Signalling format for LDPC code rates of HLSI FECFRAMES

Bit Pattern	α value
000	$\alpha = 1$
001	$\alpha = 2$
010	$\alpha = 3$
011	$\alpha = 4$

100 – 111	RFU

- REUSE_FACTOR: This 3-bit field indicates the number of slots used for the hierarchical local service insertion time division multiplex (TDM) frame i.e. the number of neighbouring transmitters that take turns to insert different local services on top of the given R-PLP or anchor PLP.

- **REUSE_SNUM:** This 3-bit field is the TDM slot number of the HLSI burst in the current NGH-frame for the particular L-PLP.

- **NATIONAL_PLP_ID:** This 8-bit field indicates the PLP_ID of the national or regional PLP on top of which the current L- PLP is hierarchically modulated.

10.2.3 LS burst header encoding

For a particular L-PLP with PLP-ID = LPLP-ID, one slice of the L-PLP occurs in any logical frame that carries cells of the L-PLP. The LS burst header at the head of the LS frame carries 16 bits of information which signal the following:

- **LPLP-ID:** This 8 bit field carries the PLP-ID of the L-PLP associated to the R-PLP that is being hierarchically modulated by the L-PLP.

- **LPLP_COD**: This 4 bit field shall signal the LDPC code rate used for all FECFRAMES in the LS-frame of according to table 92.

Table 92: Signalling format for LDPC code rates of FECFRAMES in LS-frame

Bit Pattern	LDPC Code Rate
0000	3/15
0001	4/15
0010	5/15
0011	6/15
0100	7/15
0101	8/15
0110	9/15
0111	10/15
1000	11/15
1001 to 1111	Reserved for future use

- **BURST_LEN**: This 4 bit field shall signal the number of FECFRAMES present in the LS burst to which this LS burst header relates.

The encoding of the LS burst beader ensures a robust synchronisation and decoding of the LS signalling data. Therefore, the encoding scheme shown in figure 80 is applied. Initially, the 16 signalling bits are encoded with a Reed-Muller (32,16) encoder. The RM(32, 16) codeword is then replicated to give a dual-codeword of 64 bits. Subsequently, each bit of the 64 bit dual-codeword goes through both an upper and a lower branch. The lower branch applies a cyclic shift on each dual-codeword and scrambles the resulting bit sequence using a specific Walsh-Hadamard sequence. The data is then mapped onto bit pairs with the upper branch providing the LSB and the lower branch providing the MSB of each pair. The resulting 64 QPSK labels form the LS Burst Header. This burst header is then concatenated to the beginning of the LS Burst QAM labels to form the LS frame.

Figure 80 illustrates how the signalling bits are treated to create 64 bits which are then used to create the 64 QPSK cells of the LS burst header.

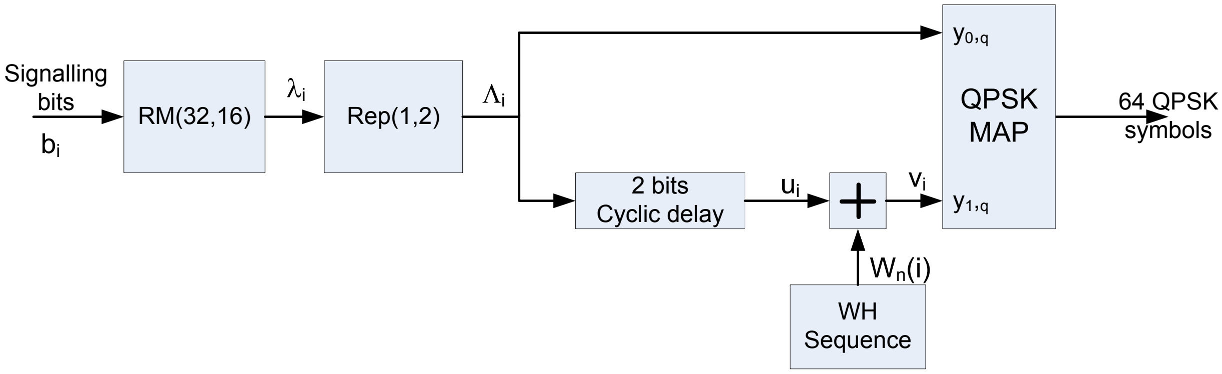


Figure 80: Encoding of the LS Burst Header

10.2.3.1 LS burst header coding

The 16 signalling bits are encoded with a Reed-Muller (32,16) code. The generator matrix for this Reed-Muller (32,16) code G is as follows:

Table93: Definition of the Reed-Muller encoder matrix

$$\mathbf{G}=\begin{pmatrix}
1&1&1&1&1&1&1&1&1&1&1&1&1&1&1&1&1&1&1&1&1&1&1&1&1&1&1&1&1&1&1&1\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&1&1&1&1&1&1&1&1&1&1&1&1&1&1&1\\
0&0&0&0&0&0&0&0&1&1&1&1&1&1&1&1&0&0&0&0&0&0&0&0&1&1&1&1&1&1&1&1\\
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0&0&0&0&0&0&0&0&0&0&0&0&1&1&1&1&0&0&0&0&0&0&0&0&0&0&0&0&1&1&1&1\\
0&0&0&0&0&0&0&0&0&0&1&1&0&0&1&1&0&0&0&0&0&0&0&0&0&0&1&1&0&0&1&1\\
0&0&0&0&0&0&0&0&0&1&0&1&0&1&0&1&0&0&0&0&0&0&0&0&0&1&0&1&0&1&0&1\\
0&0&0&0&0&0&1&1&0&0&0&0&0&0&1&1&0&0&0&0&0&0&1&1&0&0&0&0&0&0&1&1\\
0&0&0&0&0&1&0&1&0&0&0&0&0&1&0&1&0&0&0&0&0&1&0&1&0&0&0&0&0&1&0&1\\
0&0&0&1&0&0&0&1&0&0&0&1&0&0&0&1&0&0&0&1&0&0&0&1&0&0&0&1&0&0&0&1
\end{pmatrix}$$

The 32 Reed-Muller encoded bits vector $\lambda = [\lambda_0,\ldots,\lambda_{31}]$ is obtained by the matrix multiplication of the 16 bit long signalling data vector $b=[b_0,\ldots,b_{15}]$ with the generator matrix, i.e.

$$\lambda = b\cdot G$$

All operations are applied modulo 2. Replication produces Λ from λ as follows:

$$\Lambda=[\lambda \mid \lambda]$$

10.2.3.2 Cyclic delay

As depicted in figure 80the replicated codeword bits Λ_i of the lower branch shall be cyclically delayed by two values within each replicated codeword. The output of the cyclic delay block shall be:

$$u_{(i+2)\bmod 64}=\Lambda_i \quad i=0,1,..,63$$

10.2.3.3 Scrambling of the lower branch

The lower branch data is scrambled with one of the 64 chip Walsh-Hadamard scrambling sequences taken from the first REUSE_FACTOR entries of table 94. Each sequence is given in hexadecimal notation with the MSB first. The choice of *n* (the sequence number for W_n) for use at a particular transmitter shall be determined by the operator and signalled as the value REUSE_SNUM in the L1-post signalling as described in clause 8.1.3.1. The number of sequences from this table 94 that can be assigned to neighbouring cells or cell clusters in a given network is set by the REUSE_FACTOR parameter in the L1-POST ???? signalling. This number shall indicate the cell re-use pattern adopted by the operator for transmitting local services over neighbouring SFN cells.

Table 94: Scrambling sequences for the 7-cell re-use pattern

N	W_n

0	9696696969699800
1	AAAAAAAAAAAAA800
2	C3C3C3C33C3C4000
3	F0F00F0F0F0FF000
4	5A5A5A5A5A5A5800
5	6969969669699800
6	3333CCCC3333CC00
7	3C3CC3C3C3C33C00

The 64 bit output sequence v_i is obtained by XOR-ing the cyclically shifted data u_i and the scrambling sequence $W_n(i)$ where *n* is the number of the chosen sequence:

$$v_i = u_i \oplus W_n(i) \quad i = 0,1,..,63$$

10.2.4 Frequency interleaving of local service cells

The frequency interleaver pertaining to the FFT mode of the NGH-frame is used to interleave the local service cells of each OFDM symbol. As $C_{LSI} < C_{data}$, the frequency interleaver address generator described in clause 9.11 only needs to generate C_{LSI} instead of the usual C_{data} addresses. Otherwise, the frequency interleaver for the local service cells functions in much the same way as for the normal OFDM cells. The values of C_{LSI} for different pilot patterns are can be derived for normal data symbols from each entry of table 79 by $C_{LSI} = 2C_{data}$,- N_{data} + 1. For frame closing symbols, the value can be similarly derived from the entries in table 80 and table 81 as:

$C_{LSI} = C_{FC}$- (N_{data} - N_{FC} -1).

10.2.5 Insertion of local service pilots

The local service frequency interleaver outputs N_{LSI} cells for use in the hierarchical modulation of each OFDM symbol. The number of L-PLP payload cells per OFDM symbol N_{LSI} is less than the number of R-PLP payload cells per symbol N_{data}, because not all of the R-PLP payload cells in the symbol will be hierarchically modulated with L-PLP payload cells. Some R-PLP payload cells are instead hierarchically modulated by LS scattered pilots. These pilots are to be used at the receiver to estimate the channel to the LS insertion transmitter.

10.2.5.1 Location of local service pilot cells

For the symbol of index l (ranging from 0 to L_f-L_{P2}), OFDM sub-carriers for which index k belongs to the carrier subset

$S = \{k = K_{min} + D_x (l \bmod D_y) + (D_x D_y)p \mid p$ integer, $p \geq 0$, $k \in [K_{min}; K_{max}]\}$ are scattered pilots. In this, p is an integer that takes all possible values greater than or equal to zero, provided that the resulting value for k does not exceed the valid range $[K_{min};K_{max}]$. For each $k \in S$, $K_{min} \leq k+1 \leq K_{max}$ marks the position of a local service pilot. In the absence of LS insertion, this carrier k+1 would normally be modulated only by a R-PLP data cell, a continuous pilot or be a reserved tone. Whenever such a carrier is modulated by a continuous pilot or is a reserved tone, a LS pilot is not inserted. However, when modulated by a data cell of the R-PLP, a local service pilot can be used to hierarchically modulate the data cell. Figure 81 illustrates the locations of local service pilot cells in relation to the normal scattered pilots for the case where the scattered pilots have $D_x = 3$, $D_y = 4$.

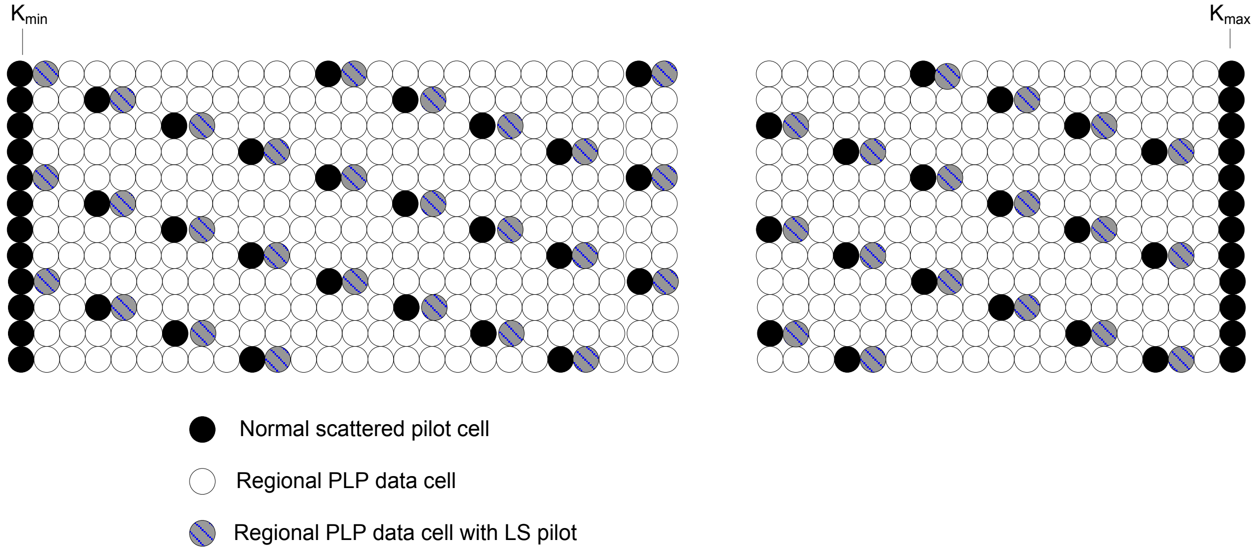


Figure 81: Example LS pilot locations for Dx = 3, Dy = 4

10.2.5.2 Amplitude of local service pilot

The local service pilot for carrier k has amplitude:

$$P_k = \frac{1 + j(2w_k - 1)}{2}$$

Where $\{k = K_{min} + D_x (l \bmod D_y) + (D_x D_y + 1)p \mid p \text{ integer}, p \geq 0 \text{ and } k \in [K_{min}; K_{max}]\}$ and w_k is the *k*-th bit of the symbol-level reference PRBS.

10.2.6 Hierarchical modulator

Data cells in one OFDM symbol are hierarchically modulated with the R-PLP as the high priority stream and the L-PLP or local service pilot as the low priority stream. The constellations and the Gray code mapping used for these are illustrated in figures G.5. to G.8.

The exact shapes of the constellations depend on the parameter α , which can take the values 1, 2, 3 or 4, thereby giving rise to the constellations in figures G.5. to G.8. α is the minimum distance separating two constellation points carrying different high priority bit values divided by the minimum distance separating any two constellation points.

Non-hierarchical transmission uses the same uniform constellation as the case when α =1.

The exact values of the constellation points are z ∈{ $\mathrm{Re}(z_q) + j\,\mathrm{Im}(z_q)$ } with values of $\mathrm{Re}(z_q)$, $\mathrm{Im}(z_q)$ for each combination of the relevant input bits $y_{e,q}$ given in tables 95 to 100for the various constellations:

Table 95: Constellation mapping for real part of QPSK

$y_{0,q}$	1	0
Re(z_q)	-1	1

Table 96: Constellation mapping for imaginary part of QPSK

$y_{1,q}$	1	0
Im(z_q)	-1	1

Table 97: Constellation mapping for real part of 16-QAM

$y_{0,q}$ $y_{2,q}$	1 0	1 1	0 1	0 0
Re(z_q) [α = 1]	-3	-1	1	3
Re(z_q)) [α = 2]	-4	-2	2	4
Re(z_q)) [α = 4]	-6	-4	4	6

Table 98: Constellation mapping for imaginary part of 16-QAM

$y_{1,q}$ $y_{3,q}$	1 0	1 1	0 1	0 0
Im(z_q) [α = 1]	-3	-1	1	3
Im(z_q)) [α = 2]	-4	-2	2	4
Im(z_q)) [α = 4]	-6	-4	4	6

Table 99: Constellation mapping for real part of 64-QAM

$y_{0,q}$ $y_{2,q}$ $y_{4,q}$	1 0 0	1 0 1	1 1 1	1 1 0	0 1 0	0 1 1	0 0 1	0 0 0
Re(z_q) [α = 1]	-7	-5	-3	-1	1	3	5	7
Re(z_q) [α = 3]	-13	-11	-5	-3	3	5	11	13

Table 100: Constellation mapping for imaginary part of 64-QAM

$y_{1,q}$ $y_{3,q}$ $y_{5,q}$	1 0 0	1 0 1	1 1 1	1 1 0	0 1 0	0 1 1	0 0 1	0 0 0
Im(z_q) [α = 1]	-7	-5	-3	-1	1	3	5	7
Im(z_q) [α = 3]	-13	-11	-5	-3	3	5	11	13

The $y_{u,q'}$ denote the bits representing a complex modulation symbol z. In each case, the transmitted complex symbol *c* is derived by normalising *z* according to table 101.

For hierarchical 16-QAM:

The high priority bits are the $y_{0,q'}$ and $y_{1,q'}$ bits from the regional PLP. The low priority bits are $y_{2,q'}$ and $y_{3,q'}$ bits from the local service PLP. The mappings of figures G.5, G.6 and G.8 are applied as appropriate.

For example, the top left constellation point, corresponding to 1 000 represents $y_{0,q'} =1$, $y_{1,q'} = y_{2,q'} = y_{3,q'} = 0$. If this constellation is decoded as if it were QPSK, the high priority bits, $y_{0,q'}$, $y_{1,q'}$ = 1,0 will be deduced. To decode the low priority bits, the full constellation shall be examined and the appropriate bits ($y_{2,q'}$, $y_{3,q'}$) extracted from $y_{0,q'}$, $y_{1,q'}$, $y_{2,q'}$, $y_{3,q'}$.

For hierarchical 64-QAM:

The high priority bits are $y_{0,q'}$ $y_{1,q'}$ $y_{2,q'}$, $y_{3,q'}$ from the regional PLP. The low priority bits are $y_{4,q'}$ and $y_{5,q'}$ from the local service PLP. The mappings of figures G.5 or G.7 are applied as appropriate. If this constellation is decoded as if it were 16-QAM, the high priority bits, $y_{0,q'}$, $y_{1,q'}$ $y_{2,q'}$, $y_{3,q'}$ will be deduced.

To decode the low priority bits, the full constellation shall be examined and the appropriate bits ($y_{4,q'}$, $y_{5,q'}$,) extracted from $y_{0,q'}$, $y_{1,q'}$, $y_{2,q'}$, $y_{3,q'}$, $y_{4,q'}$, $y_{5,q'}$.

Table 101: Normalisation factors for data symbols

Modulation scheme		Normalisation factor
QPSK		$c = z/\sqrt{2}$
16-QAM	$\alpha = 1$	$c = z/\sqrt{10}$
	$\alpha = 2$	$c = z/\sqrt{20}$
	$\alpha = 4$	$c = z/\sqrt{52}$
64-QAM	$\alpha = 1$	$c = z/\sqrt{42}$
	$\alpha = 3$	$c = z/\sqrt{162}$

11 OFDM generation

The function of the OFDM generation module is to take the cells produced by the frame builder, as frequency domain coefficients, to insert the relevant reference information, known as pilots, which allow the receiver to compensate for the distortions introduced by the transmission channel, and to produce from this the basis for the time domain signal for transmission. It then inserts guard intervals and, if relevant, applies PAPR reduction processing to produce the completed NGH signal.

11.1 Pilot insertion

11.1.1 Introduction

Various cells within the NGH frame are modulated with reference information whose transmitted value is known to the receiver. Cells containing reference information are transmitted at "boosted" power level. The information transmitted in these cells are scattered, continual, edge, P2 or frame-closing pilot cells. The locations and amplitudes of these pilots are defined in clauses 11.1.3 to 11.1.8 for SISO transmissions, and are modified according to clauses 11.1.9 and 11.1.10 for MISO transmissions. The value of the pilot information is derived from a reference sequence, which is a series of values, one for each transmitted carrier on any given symbol (see clause 11.1.2).

The pilots can be used for frame synchronization, frequency synchronization, time synchronization, channel estimation, transmission mode identification and can also be used to follow the phase noise.

Table 102 gives an overview of the different types of pilot and the symbols in which they appear.

Table 102: Presence of the various types of pilots in each type of symbol (X=present)

Symbol	PILOT TYPE				
	Scattered	Continual	Edge	P2	FRAME-CLOSING
P1					
P2				X	
Normal	X	X	X		
Frame closing			X		X

The following clauses specify values for $c_{m,l,k}$, for certain values of m, l and k, where m and l are the NGH-frame and symbol number as previously defined, and k is the OFDM carrier index (see clause 11.4).

11.1.2 Definition of the reference sequence

The pilots are modulated according to a reference sequence, $r_{l,k}$, where l and k are the symbol and carrier indices as previously defined. The reference sequence is derived from a symbol level PRBS, w_k (see clause 11.1.2.1) and a frame level PN-sequence, pn_l (see clause 11.1.2.2). This reference sequence is applied to all the pilots (i.e. Scattered, Continual Edge, P2 and Frame Closing pilots) of each symbol of a NGH frame, including both P2 and Frame Closing symbols (see clause 9.9).

The output of the symbol level sequence, w_k, is inverted or not inverted according to the frame level sequence, pn_l, as shown in figure 82.

The symbol-level PRBS is mapped to the carriers such that the first output bit (w_0) from the PRBS coincides with the first active carrier ($k= K_{min}$) in 1K, 2K and 4K. In 8K and 16K bit w_0 coincides with the first active carrier ($k=K_{min}$) in the extended carrier mode. In the normal carrier mode, carrier $k=K_{min}$ is modulated by the output bit of the sequence whose index is K_{ext} (see table **113** for values of K_{ext}). This ensures that the same modulation is applied to the same physical carrier in both normal and extended carrier modes.

A new value is generated by the PRBS on every used carrier (whether or not it is a pilot).

Hence:

$$r_{l,k} = \begin{cases} w_{k+K_{ext}} \oplus pn_l & \text{normal carrier mode} \\ w_k \oplus pn_l & \text{extended carrier mode} \end{cases}$$

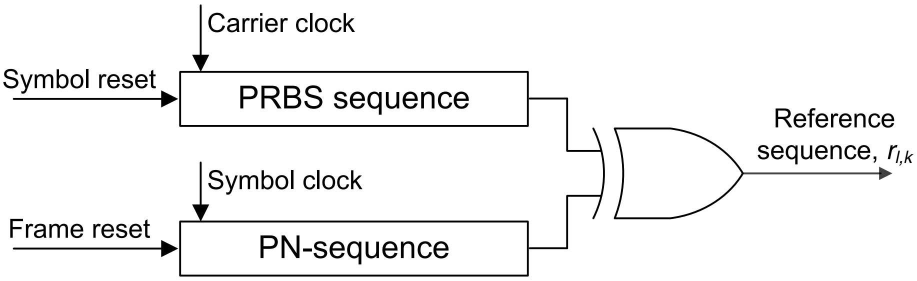


Figure 82: Formation of the reference sequence from the PN and PRBS sequences

11.1.2.1 Symbol level

The symbol level PRBS sequence, w_i is generated according to figure 83.

The shift register is initialized with all '1's so that the sequence begins $w_0, w_1, w_2\ldots$ = 1,1,1,1,1,1,1,1,1,1,1,0,0...

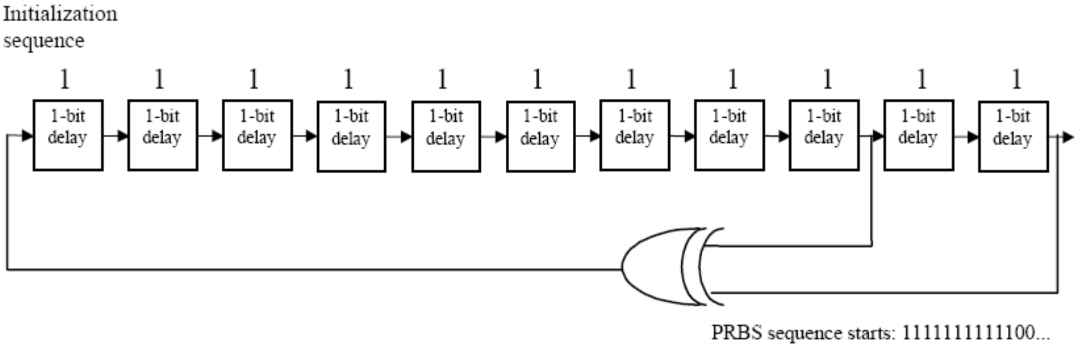


Figure 83: Generation of PRBS sequence

The polynomial for the PRBS generator shall be:

$$X^{11} + X^2 + 1 \text{ (see figure 83)}$$

NOTE: This sequence is used regardless of the FFT size and provides a unique signature in the time domain for each FFT size and also for each pilot pattern configuration.

11.1.2.2 Frame level

Each value of the frame level PN sequence is applied to one OFDM symbol of the NGH frame. The length of the frame level PN-sequence N_{PN} is therefore equal to the NGH frame length L_F (see clause 9.9.1) i.e. the number of symbols in the NGH frame excluding P1. Table 103 shows the maximum length of PN sequence for different FFT modes in 8 MHz channels. The maximum number of symbols per frame will be different for channel bandwidths other than 8 MHz (see table **112**). The greatest possible value of N_{PN} is 2 624 (for 10 MHz bandwidth).

Table 103: Maximum lengths of PN sequences for different FFT modes (8 MHz channel)

FFT mode	Maximum sequence length, N_{PN} (chips)
1K	2 098
2K	1 081
4K	540
8K	276
16K	138

The sequence (pn_0, pn_1, ..., pn_{NPN-1}) of length N_{PN} =L_F, shall be formed by taking the first N_{PN} bits from an overall PN-sequence. The overall PN sequence is defined by table 104, and each four binary digits of the overall sequence are formed from the hexadecimal digits in table **Error! Reference source not found.** taking the MSB first.

NOTE: The overall PN-sequence has been optimized by fragment by using as starting point the fully optimized short PN-sequence of length 15. Each relevant length of a given PN-sequence derives from this latter sequence. This unique sequence can be used to achieve frame synchronization efficiently.

Table 104: PN sequence frame level (up to 2 624 chips) hexadecimal description

```
4DC2AF7BD8C3C9A1E76C9A090AF1C3114F07FCA2808E9462E9AD7B712D6F4AC8A59BB069CC50BF1149927E6B
B1C9FC8C18BB949B30CD09DDD749E704F57B41DEC7E7B176E12C5657432B51B0B812DF0E14887E24D80C97F09
374AD76270E58FE1774B2781D8D3821E393F2EA0FFD4D24DE20C05D0BA1703D10E52D61E013D837AA62D007CC
2FD76D23A3E125BDE8A9A7C02A98B70251C556F6341EBDECB801AAD5D9FB8CBEA80BB619096527A8C475B3D8
DB28AF8543A00EC3480DFF1E2CDA9F985B523B879007AA5D0CE58D21B18631006617F6F769EB947F924EA5161E
C2C0488B63ED7993BA8EF4E552FA32FC3F1BDB19923902BCBBE5DDABB824126E08459CA6CFA0267E5294A98C6
32569791E60EF659AEE9518CDF08D87833690C1B79183ED127E53360CD86514859A28B5494F51AA4882419A25A2
D01A5F47AA27301E79A5370CCB3E197F
```

11.1.3 Scattered pilot insertion

Reference information, taken from the reference sequence, is transmitted in scattered pilot cells in every symbol except P1, P2 and the frame-closing symbol (if applicable) of the NGH frame. The locations of the scattered pilots are defined in clause 11.1.3.1, their amplitudes are defined in clause 11.1.3.2 and their modulation is defined in clause 11.1.3.3.

11.1.3.1 Locations of the scattered pilots

A given carrier k of the OFDM signal on a given symbol l will be a scattered pilot if the appropriate equation below is satisfied:

$$k \bmod (D_X . D_Y) = D_X (l \bmod D_Y) \quad \text{normal carrier mode}$$

$$(k - K_{ext}) \bmod (D_X . D_Y) = D_X (l \bmod D_Y) \quad \text{extended carrier mode}$$

where: D_X, D_Y are defined in table **Error! Reference source not found.**:

$k \in [K_{\min}; K_{\max}]$; and

$l \in [N_{P2}; L_F\text{-}2]$ when there is a frame closing symbol; and

$l \in [N_{P2}; L_F\text{-}1]$ when there is no frame closing symbol.

N_{P2} and L_F are as defined in clause 9.9.1 and K_{ext} is defined in table 113.

Table 105: Parameters defining the scattered pilot patterns

Pilot pattern	Separation of pilot bearing carriers (D_X)	Number of symbols forming one scattered pilot sequence (D_Y)
PP1	3	4
PP2	6	2
PP3	6	4
PP4	12	2
PP5	12	4
PP6	24	2
PP7	24	4

The combinations of scattered pilot patterns, FFT size and guard interval which are allowed to be used are defined in table 106 for SISO mode and in table 107 for MISO mode.

NOTE 2: The modifications of the pilots for MISO mode are described in clause 11.1.9.

Table 106: Scattered pilot pattern to be used for each allowed combination of FFT size and guard interval in SISO mode

FFT size	Guard interval						
	1/128	1/32	1/16	19/256	1/8	19/128	1/4
16K	PP7	PP7 PP6	PP4 PP5	PP2 PP4 PP5	PP2 PP3	PP2 PP3	PP1
8K	PP7	PP7 PP4	PP4 PP5	PP4 PP5	PP2 PP3	PP2 PP3	PP1
4K, 2K	NA	PP7 PP4	PP4 PP5	NA	PP2 PP3	NA	PP1
1K	NA	NA	PP4 PP5	NA	PP2 PP3	NA	PP1

Table 107: Scattered pilot pattern to be used for each allowed combination of FFT size and guard interval in MIXO mode

FFT size	Guard interval						
	1/128	1/32	1/16	19/256	1/8	19/128	1/4
16K	PP4 PP5	PP4	PP3	PP3	PP1	PP1	NA
8K	PP4 PP5	PP4 PP5	PP3	PP3	PP1	PP1	NA
4K, 2K	NA	PP4 PP5	PP3	NA	PP1	NA	NA
1K	NA	NA	PP3	NA	PP1	NA	NA

NOTE 1: When the value $D_X D_Y$ (with D_X and D_Y taken from table 105) is less than the reciprocal of the guard interval fraction, it is assumed that frequency only interpolation will be used in SISO mode, and hence the frame closing symbol is also not required.

The scattered pilot patterns are illustrated in annex J.

11.1.3.2 Amplitudes of the scattered pilots

The amplitudes of the scattered pilots, A_{SP}, depend on the scattered pilot pattern as shown in table 108.

Table 108: Amplitudes of the scattered pilots

Scattered pilot pattern	Amplitude (A_{SP})	Equivalent Boost (dB)
PP1, PP2	4/3	2,5
PP3, PP4	7/4	4,9
PP5, PP6, PP7	7/3	7,4

11.1.3.3 Modulation of the scattered pilots

The phases of the scattered pilots are derived from the reference sequence given in clause 11.1.2.

The modulation value of the scattered pilots is given by:

$$\mathrm{Re}\{c_{m,l,k}\} = 2\, A_{SP}\, (1/2 - r_{l,k})$$

$$\mathrm{Im}\{\, c_{m,l,k}\, \} = 0$$

where A_{SP} is as defined in clause 11.1.3.2, $r_{l,k}$ is defined in clause 11.1.2, m is the NGH frame index, k is the frequency index of the carriers and l is the time index of the symbols.

11.1.4 Continual pilot insertion

In addition to the scattered pilots described above, a number of continual pilots are inserted in every symbol of the frame except for P1 and P2 and the frame closing symbol (if any). The number and location of continual pilots depends on both the FFT size and scattered pilot pattern PP1-PP7 in use (see clause 11.1.3).

11.1.4.1 Locations of the continual pilots

The continual pilot locations are taken from one or more "CP groups" depending on the FFT mode. Table yyy indicates which CP groups are used in each FFT mode. The pilot locations belonging to each CP group depend on the scattered pilot pattern in use; table yyy gives the carrier indices $k_{i,16K}$ for each pilot pattern in the 16K FFT mode. In other FFT modes, the carrier index for each CP is given by $k = k_{i,16K} \bmod K_{mod}$, where K_{mod} for each FFT size is given in table 109.

Table 109: Continual pilot groups used with each FFT size

FFT size	CP Groups used	K_{mod}
1K	CP_1	816
2K	CP_1, CP_2	1 632
4K	CP_1, CP_2, CP_3	3 264
8K	CP_1, CP_2, CP_3, CP_4	6 528
16K	CP_1, CP_2, CP_3, CP_4, CP_5	13 056

11.1.4.2 Locations of additional continual pilots in extended carrier mode

In extended carrier mode, extra continual pilots are added to those defined in the previous clause. The carrier indices k for the additional continual pilots are given in table H.2 (see annex H) for each FFT size and scattered pilot pattern.

11.1.4.3 Amplitudes of the continual pilots

The continual pilots are transmitted at boosted power levels, where the boosting depends on the FFT size. Table 110 gives the modulation amplitude A_{CP} for each FFT size.

Table 110: Boosting for the continual pilots

FFT size	1K	2K	4K	8K	16K
A_{CP}	4/3	4/3	(4√2)/3	8/3	8/3

When a carrier's location is such that it would be both a continual and scattered pilot, the boosting value for the scattered pilot pattern shall be used (A_{SP}).

11.1.4.4 Modulation of the continual pilots

The phases of the continual pilots are derived from the reference sequence given in clause 11.1.2.

The modulation value for the continual pilots is given by:

$$\mathrm{Re}\{c_{m,l,k}\} = 2\, A_{\mathrm{CP}}\,(1/2 - r_{l,k})$$

$$\mathrm{Im}\{\, c_{m,l,k}\,\} = 0.$$

where A_{CP} is as defined in clause 11.1.4.3.

11.1.5 Edge pilot insertion

The edge carriers, carriers $k=K_{\min}$ and $k=K_{\max}$, are edge pilots in every symbol except for the P1 and P2 symbol(s). They are inserted in order to allow frequency interpolation up to the edge of the spectrum. The modulation of these cells is exactly the same as for the scattered pilots, as defined in clause 11.1.3:

$$\mathrm{Re}\{c_{m,l,k}\} = 2\, A_{\mathrm{SP}}\,(1/2 - r_{l,k})$$

$$\mathrm{Im}\{\, c_{m,l,k}\,\} = 0.$$

11.1.6 P2 pilot insertion

11.1.6.1 Locations of the P2 pilots

In all modes (including MIXO), cells in the P2 symbol(s) for which k mod 3 = 0 are P2 pilots.

In extended carrier mode, all cells for which $K_{\min} \le k < K_{\min} + K_{\mathrm{ext}}$ and for which $K_{\max} - K_{\mathrm{ext}} < k \le K_{\max}$ are also P2 pilots.

11.1.6.2 Amplitudes of the P2 pilots

The pilot cells in the P2 symbol(s) are transmitted at boosted power levels. P2 pilots shall use an amplitude of $A_{\mathrm{P2}} = \frac{\sqrt{31}}{5}$.

11.1.6.3 Modulation of the P2 pilots

The phases of the P2 pilots are derived from the reference sequence given in clause 11.1.2.

The corresponding modulation is given by:

$$\mathrm{Re}\{c_{m,l,k}\} = 2\, A_{\mathrm{P2}}\, (1/2 - r_{l,k})$$

$$\mathrm{Im}\{c_{m,l,k}\} = 0$$

where *m* is the NGH-frame index, *k* is the frequency index of the carriers and *l* is the symbol index.

11.1.7 Insertion of frame closing pilots

When any of the combinations of FFT size, guard interval and scattered pilot pattern listed in table 111 (for SISO mode) is used, the last symbol of the frame is a special frame closing symbol (see also clause 9.9.2). Frame closing symbols are always used in MIXO mode.

Table 111: Combinations of FFT size, guard interval and pilot pattern for which frame closing symbols are used in SISO mode

FFT size	Guard interval						
	1/128	1/32	1/16	19/256	1/8	19/128	1/4
16K		PP7 PP6	PP4 PP5	PP4 PP5	PP2 PP3	PP2 PP3	PP1
8K		PP7	PP4 PP5	PP4 PP5	PP2 PP3	PP2 PP3	PP1
4K, 2K	NA	PP7	PP4 PP5	NA	PP2 PP3	NA	PP1
1K	NA	NA	PP4 PP5	NA	PP2 PP3	NA	PP1

NOTE: The entry 'NA' indicates that the corresponding combination of FFT size and guard interval is not allowed. An empty entry indicates that the combination of FFT size and guard interval is allowed, but frame closing symbols are never used.

11.1.7.1 Locations of the frame closing pilots

The cells in the frame closing symbol for which $k \bmod D_X = 0$, except when $k = K_{\min}$ and $k = K_{\max}$, are frame closing pilots, where D_X is the value from table 105 for the scattered pilot pattern in use. With an FFT size of 1K with pilot patterns PP4 and PP5, and with an FFT size of 2K with pilot pattern PP7, carrier $K_{\max}$-1 shall be an additional frame closing pilot.

NOTE: Cells in the frame closing symbol for which $k = K_{\min}$ or $k = K_{\max}$ are edge pilots, see clause 11.1.5.

11.1.7.2 Amplitudes of the frame closing pilots

The frame closing pilots are boosted by the same factor as the scattered pilots, A_{SP}.

11.1.7.3 Modulation of the frame closing pilots

The phases of the frame closing pilots are derived from the reference sequence given in clause 11.1.2.

The corresponding modulation is given by:

$$\mathrm{Re}\{c_{m,l,k}\} = 2\, A_{\mathrm{SP}}\, (1/2 - r_{l,k})$$

$$\mathrm{Im}\{c_{m,l,k}\} = 0$$

Where *m* is the NGH-frame index, *k* is the frequency index of the carriers and *l* is the time index of the symbols.

11.1.8 Amplitudes of pilots in the presence of intentional power imbalance (SISO)

SISO frames, where they are transmitted through a physical pair of antennas, and in the presence of intentional power imbalance (clauses 7.6 and 17) shall have the same imbalance applied to all pilot types in the frame, such that the ratio of the average power of data and reference signals is preserved on the output to be fed to each transmit antenna.

The following equation describes this, where $c_{m,l,k}$ r epresents any type of pilot on the SISO output and $c'_{m,l,k}Tx(1)$ and $c'_{m,l,k}Tx(2)$ the corresponding pilots sent to antennas 1 and 2 after the imbalance has been applied:

$$\begin{bmatrix} c'_{m,l,k}Tx(1) \\ c'_{m,l,k}Tx(2) \end{bmatrix} = \begin{bmatrix} \sqrt{\beta} & 0 \\ 0 & \sqrt{1-\beta} \end{bmatrix} \begin{bmatrix} c_{m,l,k} \\ c_{m,l,k} \end{bmatrix}$$

β is given as a function of imbalance in table30.

11.1.9 Modification of the pilots for MIXO

In MIxO modes, the phases of the scattered, continual, edge and frame-closing pilots are modified in the signal transmitted from any transmitter from transmitters in MIXO group 2.

The scattered pilots from transmitters in MIXO group 2 are inverted compared to MIXO group 1 on alternate scattered-pilot-bearing carriers:

$$\mathrm{Re}\{c_{m,l,k}\} = 2(-1)^{k/D_X} A_{SP}(1/2 - r_{l,k})$$

$$\mathrm{Im}\{ c_{m,l,k} \} = 0.$$

The continual pilots from transmitters in MIXO group 2 falling on scattered-pilot-bearing carriers are inverted compared to MIXO group 1 on carriers for which the scattered pilots are inverted, continual pilots on non-scattered-pilot-bearing carriers are not inverted:

$$\mathrm{Re}\{c_{m,l,k}\} = \begin{cases} 2(-1)^{k/D_X} A_{CP}(1/2 - r_{l,k}) & k \bmod D_X = 0 \\ 2A_{CP}(1/2 - r_{l,k}) & \text{otherwise} \end{cases}$$

$$\mathrm{Im}\{ c_{m,l,k} \} = 0.$$

NOTE: Those cells which would be both a continual and a scattered pilot are treated as scattered pilots as described above and therefore have the amplitude A_{SP}.

The edge pilots from transmitters in MIXO group 2 are inverted compared to MIXO group 1 on odd-numbered OFDM symbols:

$$\mathrm{Re}\{c_{m,l,k}\} = 2\,(-1)^l A_{SP}\,(1/2-r_{l,k})$$

$$\mathrm{Im}\{c_{m,l,k}\} = 0.$$

The P2 pilots from transmitters in MIXO group 2 are inverted compared to MIXO group 1 on carriers whose indices are odd multiples of three:

$$\mathrm{Re}\{c_{m,l,k}\} = \begin{cases} 2(-1)^{k/3} A_{P2}(1/2 - r_{l,k}) & k \bmod 3 = 0 \\ 2A_{P2}(1/2 - r_{l,k}) & \text{otherwise} \end{cases}$$

$$\mathrm{Im}\{c_{m,l,k}\} = 0.$$

The frame closing pilots from transmitters in group 2 are inverted compared to group 1 on alternate scattered-pilot-bearing carriers:

$$\mathrm{Re}\{c_{m,l,k}\} = 2(-1)^{k/D_X} A_{SP}(1/2 - r_{l,k})$$

$$\mathrm{Im}\{c_{m,l,k}\} = 0.$$

The locations and amplitudes of the pilots in MIXO are the same as in SISO mode for transmitters from both MIXO group 1 and MIXO group 2, but additional P2 pilots are also added.

In normal carrier MIXO mode, carriers in the P2 symbol(s) for which $k = K_{\min}+1$, $k = K_{\min}+2$, $k=K_{\max}-2$ and $k=K_{\max}-1$ are additional P2 pilots, but are the same for transmitters from both MIXO group 1 and MIXO group 2.

In extended carrier MIXO mode, carriers in the P2 symbol(s) for which $k = K_{\min}+K_{\mathrm{ext}}+1$, $k = K_{\min}+K_{\mathrm{ext}}+2$, $k=K_{\max}-K_{\mathrm{ext}}-2$ and $k=K_{\max}-K_{\mathrm{ext}}-1$ are additional P2 pilots, but are the same for transmitters from both MIXO group 1 and MIXO group 2.

Hence for these additional P2 pilots in MIXO mode:

$$\mathrm{Re}\{c_{m,l,k}\} = 2\,A_{\mathrm{P2}}\,(1/2 - r_{l,k})$$

$$\mathrm{Im}\{c_{m,l,k}\} = 0.$$

Further additional P2 pilots are also added in MIXO mode in the cells adjacent to the tone reservation cells which are not already defined to be P2 pilots except when these adjacent cells are also defined as tone reservation cells.

The carrier indices k are therefore given:

$$k = \begin{cases} k_i + 1 & k_i \bmod 3 = 1, k_i \in S_{P2}, k_i + 1 \notin S_{P2} \\ k_i - 1 & k_i \bmod 3 = 2, k_i \in S_{P2}, k_i - 1 \notin S_{P2} \end{cases}$$

and S_{P2} is the set of reserved tones in the P2 symbol given in table I.1 in annex I .

11.1.10 Amplitudes of pilots in the presence of intentional power imbalance (MIXO)

MISO or MIMO frames in the presence of intentional power imbalance (clauses 7.6 and17) shall have the same imbalance applied to all pilot types in the frame, such that the ratio of the average power of data and reference signals is preserved on the output to be fed to each transmit antenna.The following equation describes this, where $c_{m,l,k}Tx(1)$ and $c_{m,l,k}Tx(2)$ and represent any type of pilot on each the MIXO outputs and $c'_{m,l,k}Tx(1)$ and $c'_{m,l,k}Tx(2)$ the corresponding pilots sent to antennas 1 and 2 after the imbalance has been applied:

$$\begin{bmatrix} c'_{m,l,k}Tx(1) \\ c'_{m,l,k}Tx(2) \end{bmatrix} = \begin{bmatrix} \sqrt{\beta} & 0 \\ 0 & \sqrt{1-\beta} \end{bmatrix} \begin{bmatrix} c_{m,l,k}Tx(1) \\ c_{m,l,k}Tx(2) \end{bmatrix}$$

β is given as a function of imbalance in table 30.

11.2 Dummy tone reservation

Some OFDM cells can be reserved for the purpose of PAPR reduction and they shall be initially set to $c_{m,l,k}$=0+0*j*.

In P2 symbol(s), the set of carriers corresponding to carrier indices defined in table I.1 shall be always reserved in normal carrier mode. In extended carrier mode, the reserved carrier indices shall be equal to the values from the table plus K_{ext}. The reserved carrier indices shall not change across the P2 symbol(s), i.e. keep the same positions across the P2 symbol(s).

In the data symbols excluding any frame closing symbol, the set of carriers corresponding to carrier indices defined in table I.2 (see annex I) or their circularly shifted set of carriers shall be reserved depending on OFDM symbol index of the data symbol, when TR is activated by a relevant L1-pre signalling field, 'PAPR'. The amount of shift between two consecutive OFDM symbols shall be determined by the separation of pilot bearing carriers, D_X and the number of symbols forming one scattered pilot sequence, D_Y (see table 105 in clause 11.1.3.1). In the data symbol corresponding to data symbol index *l* of an NGH frame, the reserved carrier set, S_l shall be determined as:

$$S_l = \left\{ \begin{array}{ll} i_k + D_X * (l \bmod D_Y) & \text{normal carrier mode} \\ i_k + D_X * \left(\left(l + \dfrac{K_{ext}}{D_X} \right) \bmod D_Y \right) & \text{extended carrier mode} \end{array} \right| i_n \in S_0, 0 \le n < N_{RT}, N_{P2} \le l < N_{P2} + L_{normal}$$

where S_0 represents the set of reserved carriers corresponding to carrier indices defined in table I.2 and L_{normal} denotes the number of normal symbols in an NGH frame, i.e. not including P1, P2 or any frame closing symbol.

When the frame closing symbol is used (see clause 11.1.7), the set of carriers in the frame closing symbol corresponding to the same carrier indices as for the P2 symbol(s), defined in table I.1, shall be reserved when TR is activated.

11.3 Mapping of data cells to OFDM carriers

Any cell $c_{m,l,k}$ in the P2 or data symbols which has not been designated as a pilot (see clause 11.1) or as a reserved tone (see clause 11.2) shall carry one of the data cells from the MISO processor, i.e. $c_{m,l,k} = e_{m,l,p}$. The cells $e_{m,l,p}$ for symbol *l* in NGH frame *m* shall be taken in increasing order of the index *p*, and assigned to $c_{m,l,k}$ of the symbol in increasing order of the carrier index *k* for the values of *k* in the range $K_{\text{min}} \le k \le K_{\text{max}}$ designated as data cells by the definition above.

11.4 IFFT - OFDM Modulation

This clause specifies the OFDM structure to use for each transmission mode. The transmitted signal is organized in NGH-frames. Each NGH-frame has a duration of T_F, and consists of L_F OFDM symbols. Each symbol is constituted by a set of K_{total} carriers transmitted with a duration T_S. It is composed of two parts: a useful part with duration T_U and a guard interval with a duration Δ. The guard interval consists of a cyclic continuation of the useful part, T_U, and is inserted before it. The allowed combinations of FFT size and guard interval are defined in table 114.

The symbols in an OFDM frame (excluding P1 and AP1) are numbered from 0 to L_F-1. All symbols contain data and reference information and may also contain local service inserted data and its reference information.

Since the OFDM signal comprises many separately-modulated carriers, each symbol can in turn be considered to be divided into cells, each corresponding to the modulation carried on one carrier during one symbol.

The carriers are indexed by $k \in [K_{min}; K_{max}]$ and determined by K_{min} and K_{max}. The spacing between adjacent carriers is $1/T_U$ while the spacing between carriers K_{min} and K_{max} are determined by $(K_{total}-1)/T_U$.

The emitted signal, when neither FEFs nor PAPR reduction are used, is described by the following expression:

$$s(t) = \mathrm{Re}\left\{ e^{j2\pi f_c t} \sum_{m=0}^{\infty} \left[p_1(t - mT_F) + \frac{5}{\sqrt{27 \times K_{total}}} \sum_{l=0}^{L_F-1} \sum_{k=K_{\min}}^{K_{\max}} c_{m,l,k} \times \psi_{m,l,k}(t) \right] \right\}$$

(when aP1 is absent)

$$s(t) = \mathrm{Re}\left\{ e^{j2\pi f_c t} \sum_{m=0}^{\infty} \left[p_1(t - mT_F) + ap_1(t - mT_F) + \frac{5}{\sqrt{27 \times K_{total}}} \sum_{l=0}^{L_F-1} \sum_{k=K_{\min}}^{K_{\max}} c_{m,l,k} \times \psi_{m,l,k}(t) \right] \right\}$$

(when aP1 is present)

where:

$$\psi_{m,l,k}(t) = \begin{cases} e^{j2\pi \frac{k'}{T_U}(t-\Delta-T_{P1}-lT_s-mT_F)} & mT_F + T_{P1} + lT_S \le t \le mT_F + T_{P1} + (l+1)T_S \\ 0 & \text{otherwise} \end{cases}$$

and:

k	denotes the carrier number;
l	denotes the OFDM symbol number starting from 0 for the first P2 symbol of the frame;
m	denotes the NGH-frame number;
K_{total}	is the number of transmitted carriers defined in table Error! Reference source not found.;
L_F	number of OFDM symbols per frame;
T_S	is the total symbol duration for all symbols except P1, and $T_S = T_U + \Delta$;

T_U is the active symbol duration defined in table yyy;

Δ is the duration of the guard interval, see clause 11.6;

f_c is the central frequency of the RF signal;

k' is the carrier index relative to the centre frequency, $k' = k - (K_{max} + K_{min}) / 2$;

$c_{m,l,k}$ is the complex modulation value for carrier k of the OFDM symbol number l in NGH frame number m;

T_{P1} is the duration of the P1 symbol, given by T_{P1}=2048T, and T is defined below;

T_F is the duration of a frame, $T_F = L_F T_s + T_{P1}$;

$p_1(t)$ is the P1 waveform as defined in clause 11.7.2.4.

$ap_1(t)$ is the AP1 waveform as defined in clause 11.7.3.2.

NOTE 1: The power of the P1 symbol (and of the aP1 symbol when present) is defined to be essentially the same as the rest of the frame, but since the rest of the frame is normalized based on the number of transmitted carriers, the relative amplitudes of carriers in the P1 compared to the carriers of the normal symbols will vary depending whether or not extended carrier mode is used.

NOTE 2: The normalization factor $5/\sqrt{27}$ in the above equation approximately corrects for the average increase in power caused by the boosting of the pilots, and so ensures the power of the P1 symbol is virtually the same as the power of the remaining symbols.

The OFDM parameters are summarized in table yyy. The values for the various time-related parameters are given in multiples of the elementary period T and in microseconds. The elementary period T is specified for each bandwidth in table 112. For 8K and 16K FFT, an extended carrier mode is also defined.

Table 112: Elementary period as a function of bandwidth

Bandwidth (MHz)	Elementary Period T (µs)
1.7	71/131
2.5	7/20
5	7/40
6	7/48
7	1/8
8	7/64
10	7/8
15	7/120
20	7/160

Table 113: OFDM parameters

Parameter		**1K mode**	**2K mode**	**4K mode**	**8K mode**	**16K mode**
Number of carriers K_{total}	normal carrier mode	853	1 705	3 409	6 817	13 633
	extended carrier mode	NA	NA	NA	6 913	13 921
Value of carrier number K_{min}	normal carrier mode	0	0	0	0	0
	extended carrier mode	NA	NA	NA	0	0
Value of carrier number K_{max}	normal carrier mode	852	1 704	3 408	6 816	13 632
	extended carrier mode	NA	NA	NA	6 912	13 920
Number of carriers added on each side in extended carrier mode K_{ext} (see note 2)		0	0	0	48	144
Duration T_U		1 024T	2 048T	4 096T	8 192T	16 384T
Duration T_U µs (see note 3)		112	224	448	896	1 792
Carrier spacing $1/T_U$ *(Hz)* *(see notes 1 and 2)*		*8 929*	*4 464*	*2 232*	*1 116*	*558*
Spacing between carriers K_{min} and K_{max} $(K_{total}-1)/T_U$ (see note 3)	normal carrier mode	*7,61 MHz*	*7,61 MHz*	*7,61 MHz*	*7,61 MHz*	*7,61 MHz*
	extended carrier mode	NA	NA	NA	*7,71 MHz*	*7,77 MHz*

NOTE 1: Numerical values in italics are approximate values.
NOTE 2: This value is used in the definition of the pilot sequence in both normal and extended carrier mode.
NOTE 3: Values for 8 MHz channels.

11.4.1 eSFN predistortion

The eSFN (enhanced SFN) processing is applied to decorrelate the transmitted signal between multiple transmitters in an SFN configuration. The eSFN predistortion term for carrier *k* is calculated using

$$\Phi_k = \sum_{p=0}^{L} \left[e^{j\Theta(p)} \cdot H_{RC}\left(k - p \cdot \frac{N_{FFT}}{L} \right) \right],$$

where $L = N_{FFT}/512$, $N_{FFT} = T_U/T$, and $k = K_{\min},\dots,K_{\max}$. The term $H_{RC}(n)$ is a Raised Cosine function, which is shifted by $\left(p \cdot \frac{N_{FFT}}{L} \right)$. The Raised Cosine function itself is defined as:

$$H_{RC}(n) = \begin{cases} 1 & if \quad |n| \le \frac{1-\alpha}{2T_C} \\ \cos^2\left[\frac{\pi T_C}{2\alpha} \left(|n| - \frac{1-\alpha}{2T_C} \right) \right] & if \quad \frac{1-\alpha}{2T_C} < |n| \le \frac{1+\alpha}{2T_C} \\ 0 & otherwise \end{cases}$$

with the time constant $T_C = L/N_{FFT}$ and the roll-off-factor $\alpha = 0.5$.

The phase term $\Theta(p)$ recursively defines the phase of each Raised Cosine function and is obtained by:

$$\Theta(p) = \begin{cases} TX_0 \cdot 2\pi/3 & \text{if } p = 0 \\ \Theta(p-1) + TX_p \cdot \pi/4 & \text{else} \end{cases}$$

in which the values $TX_p \in \{-1,0,1\}$, with $p = 0,\ldots,L$, identify each transmitter within the network. An example for a transmitter identification sequence in case of the 4K OFDM mode (i.e. $L = 8$) is $TX = (TX_0,\ldots,TX_8) = (0,1,0,-1,0,1,-1,1,0)$. If only one transmitter identification sequence in the network is used, it shall consist of zeros only, i.e. $TX = (0,0,\ldots,0,0)$.

11.5 PAPR reduction

Two modifications of the transmitted OFDM signal are allowed in order to decrease PAPR. One or both techniques may be used simultaneously. The use (or lack thereof) of the techniques shall be indicated in L1 signalling (see clause 8.1). The active constellation extension technique is described in clause 11.5.1 and the Tone Reservation Technique is described in clause 11.5.2. Both techniques, when used, are applied to the active portion of each OFDM symbol (except P1), and following this, guard intervals shall be inserted (see clause 11.6). The active constellation extension technique shall not be applied to pilot carriers or reserved tones, nor when rotated constellations are used (see clause 6.4), nor when MISO is used (see clause 7). When both techniques are used, the active constellation extension technique shall be applied to the signal first.

11.5.1 Active constellation extension (ACE)

The active constellation extension algorithm produces a time domain signal $\mathbf{x}_{ACE}$ that replaces the original time domain signal $\mathbf{x} = \lfloor x_0, x_1, \cdots, x_{N_{FFT}-1} \rfloor$ produced by the IFFT from a set of frequency domain values $\mathbf{X} = \lfloor X_0, X_1, \cdots, X_{N_{FFT}-1} \rfloor$.

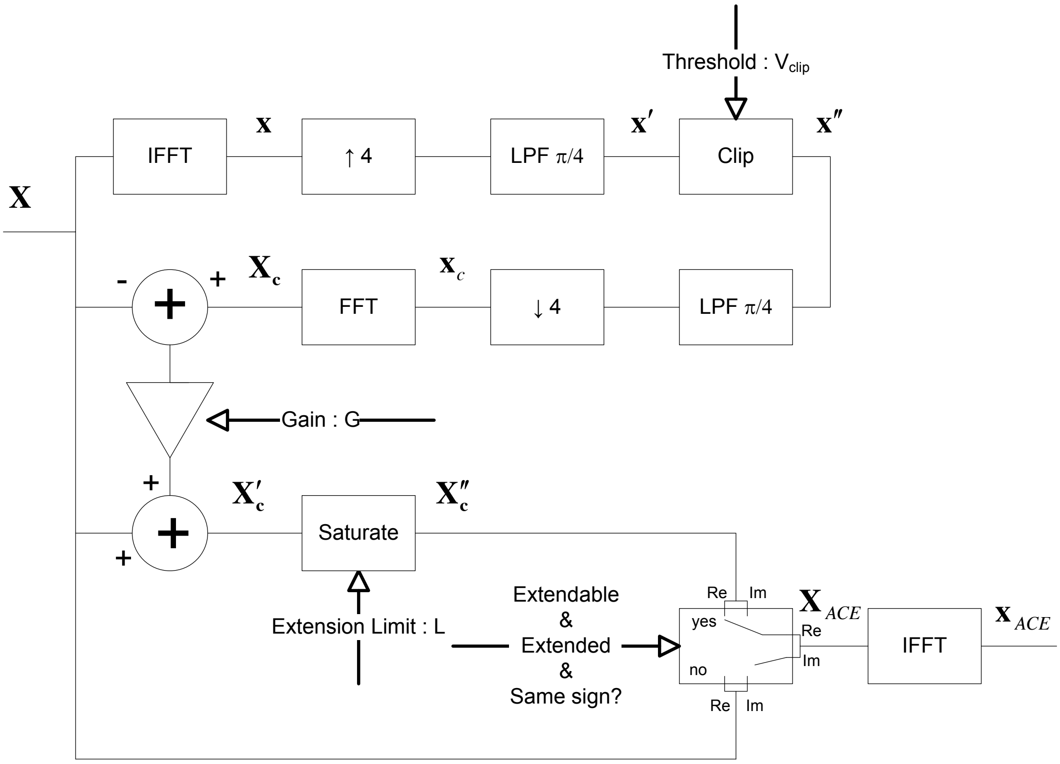


Figure 84: Implementation of the active constellation extension algorithm

$\mathbf{x}' = \lfloor x'_0, x'_1, \cdots, x'_{4\cdot N_{FFT}-1} \rfloor$ is obtained from $\mathbf{x}$ through interpolation by a factor of 4.

The combination of IFFT, oversampling and lowpass filtering is implemented using zero padding and a four times oversized IFFT operator.

$\mathbf{x}'' = \lfloor x''_0, x''_1, \cdots, x''_{4\cdot N_{FFT}-1} \rfloor$ is obtained by applying a clipping operator to $\mathbf{x}'$.

The clipping operator is defined as follows:

$$x''_k = \begin{cases} x'_k & \text{if } \|x'_k\| \le V_{clip} \\ V_{clip} \cdot \dfrac{x'_k}{\|x'_k\|} & \text{if } \|x'_k\| \ge V_{clip} \end{cases}$$

The clipping threshold V_{clip} is a parameter of the ACE algorithm.

$\mathbf{x}_\mathrm{c} = \lfloor x_{c0}, x_{c1}, \cdots, x_{cN_{FFT}-1} \rfloor$ is obtained from $\mathbf{x}''$ through decimation by a factor of 4.

The combination of lowpass filtering, downsampling and FFT is implemented using a four times oversized FFT operator.

$\mathbf{X_c}$ is obtained from $\mathbf{x}_c$ through FFT.

A new signal $\mathbf{X'_c}$ is obtained by combining $\mathbf{X_c}$ and $\mathbf{X}$ as follows:

$$\mathbf{X'_c} = \mathbf{X} + G \cdot (\mathbf{X}_\mathrm{c} - \mathbf{X})$$

The extension gain G is a parameter of the ACE algorithm.

$\mathbf{X''_c}$ is obtained from $\mathbf{X'_c}$ using a saturation operator which operates separately with real and imaginary components, ensuring that individual component magnitude cannot exceed a given value L.

$$\mathrm{Re}\{X''_{c,k}\} = \begin{cases} \mathrm{Re}\{X'_{c,k}\} & \text{if } |\mathrm{Re}\{X'_{c,k}\}| \le L \\ L & \text{if } \mathrm{Re}\{X'_{c,k}\} \ge L \\ -L & \text{if } \mathrm{Re}\{X'_{c,k}\} < -L \end{cases}$$

$$\mathrm{Im}\{X''_{c,k}\} = \begin{cases} \mathrm{Im}\{X'_{c,k}\} & \text{if } |\mathrm{Im}\{X'_{c,k}\}| \le L \\ L & \text{if } \mathrm{Im}\{X'_{c,k}\} \ge L \\ -L & \text{if } \mathrm{Im}\{X'_{c,k}\} < -L \end{cases}$$

The extension limit L is a parameter of the ACE algorithm.

$\mathbf{X}_{ACE}$ is then constructed by simple selection real and imaginary components from those of $\mathbf{X}, \mathbf{X''_c}$.

$$\mathrm{Re}\{X_{ACE,k}\} = \begin{cases} \mathrm{Re}\{X''_{c,k}\} & \begin{array}{l} \mathit{if}\ \mathrm{Re}\{X_k\} \text{ is extendable} \\ \mathit{AND}\ |\mathrm{Re}\{X''_{c,k}\}| > |\mathrm{Re}\{X_k\}| \\ \mathit{AND}\ \mathrm{Re}\{X''_{c,k}\} \cdot \mathrm{Re}\{X_k\} > 0 \end{array} \\ \mathrm{Re}\{X_k\} & \mathit{else} \end{cases}$$

$$\mathrm{Im}\{X_{ACE,k}\} = \begin{cases} \mathrm{Im}\{X''_{c,k}\} & \begin{array}{l} \mathit{if}\ \mathrm{Im}\{X_k\}\ \text{is extendable} \\ \mathit{AND}\ \left|\mathrm{Im}\{X''_{c,k}\}\right| > \left|\mathrm{Im}\{X_k\}\right| \\ \mathit{AND}\ \mathrm{Im}\{X''_{c,k}\} \cdot \mathrm{Im}\{X_k\} > 0 \end{array} \\ \mathrm{Im}\{X_k\} & \mathit{else} \end{cases}$$

$\mathbf{x}_{ACE}$ is obtained from $\mathbf{X}_{ACE}$ through IFFT.

A component is defined as extendable if it is an active cell (i.e. an OFDM cell carrying a constellation point for L1 signalling or a PLP), and if its absolute amplitude is greater than or equal to the maximal component value associated to the modulation constellation used for that cell; a component is also defined as extendable if it is a dummy cell, a bias balancing cell or an unmodulated cell in the Frame Closing Symbol. As an example, a component belonging to a 256 QAM modulated cell is extendable if its absolute amplitude is greater than or equal to $\frac{15}{\sqrt{170}}$.

The value for the gain G shall be selectable in the range between 0 and 31 in steps of 1.

The clipping threshold V_{clip} shall be selectable in the range between +0 dB and +12,7 dB in 0,1 dB steps above the standard deviation of the original time-domain signal.

The maximal extension value L shall be selectable in the range between 0,7 and 1,4 in 0,1 steps.

NOTE: If *L* is set to 0,7 there will be no modification of the original signal. When L is set to its maximum value, the maximal power increase per carrier after extension is obtained for QPSK and bounded to +6 dB.

11.5.2 PAPR reduction using tone reservation

The reserved carriers described in clause 11.2 shall not carry data nor L1/L2 signalling, but arbitrary complex values to be used for PAPR reduction.

If the NGH_VERSION field (see clause 8.1.2) is set to a value greater than '0000', and the PAPR field is set to a value of '0000', then 1 iteration only of the tone reservation algorithm specified in clause 11.5.2.1 shall be applied to the P2 symbols, but not to the data symbols.

11.5.2.1 Algorithm of PAPR reduction using tone reservation

Signal peaks in the time domain are iteratively cancelled out by a set of impulse-like kernels made using the reserved carriers.

The following definitions will be used in the description of the PAPR reduction algorithm:

n	The sample index, $0 \le n < N_{FFT}$. The sample for which *n*=0 shall correspond to the beginning of the active symbol period, i.e. to time $t = mT_F + lT_S + T_{P1} + \Delta$ in the equation of clause 11.4.
i	The iteration index.
x_n	The *n*-th sample of the complex baseband time-domain input data signal.
x'_n	The *n*-th sample of the complex baseband time-domain output data signal.

$c_n^{(i)}$ The *n*-th sample of the time-domain reduction signal in the *i*-th iteration

$r_k^{(i)}$, The modulation value in the *i*-th iteration for the reserved tone whose carrier index is *k*

p_n The *n*-th sample of the reference kernel signal, defined by:

$$p_n = \frac{1}{N_{TR}} \sum_{k \in S_l} e^{j\frac{2\pi n(k-K_c)}{N_{FFT}}},$$

where *l* is the OFDM symbol index and S_l is the set of reserved carrier indices for symbol *l* (see clause 11.2), and $K_C = (K_{\max} + K_{\min})/2$ is the index *k* of the centre ("DC") carrier.

NOTE 1: The reference kernel corresponds to the inverse Fourier Transform of a (N_{FFT}, 1) vector $\mathbf{1}_{TR}$ having N_{TR} elements of ones at the positions corresponding to the reserved carrier indices $k \in S_l$.

The procedures of the PAPR reduction algorithm are as follows:

Initialization:

The initial values for peak reduction signal are set to zeros:

$$c_n^{(0)} = 0,\ 0 \le n < N_{FFT}$$

$$r_k^{(0)} = 0, k \in S_l$$

Iteration:

1) *i* starts from 1.

2) Find the maximum magnitude of $x_n + c_n^{(i-1)}$, denoted by $y^{(i)}$, and the corresponding sample index, $m^{(i)}$ in the *i*th iteration.

$$\begin{cases} y^{(i)} = \max\limits_n \left| x_n + c_n^{(i-1)} \right| \\ m^{(i)} = \arg \max\limits_n \left| x_n + c_n^{(i-1)} \right| \end{cases}, \qquad \text{for } n = 0,1,..N_{FFT} - 1,$$

If $y^{(i)}$ is less than or equal to a desired clipping magnitude level, V_{clip} then decrease *i* by 1 and go to the step 9.

3) Calculate a unit-magnitude phasor $u^{(i)}$ in the direction of the peak to be cancelled:

$$u^{(i)} = \frac{x_{m^{(i)}} + c_{m^{(i)}}^{(i-1)}}{y^{(i)}}$$

4) For each reserved tone, calculate the maximum magnitude of correction $\alpha_k^{(i)}$ that can be applied without causing the reserved carrier amplitude to exceed the maximum allowed value $A_{\max} = \frac{5\sqrt{10} \times N_{\text{TR}}}{\sqrt{27 K_{\text{total}}}}$ as follows:

$$\alpha_k^{(i)} = \sqrt{A_{\max}^2 - \mathrm{Im}\left\{\left(v_k^{(i)}\right)^* r_k^{(i-1)}\right\}^2} + \mathrm{Re}\left\{\left(v_k^{(i)}\right)^* r_k^{(i-1)}\right\}$$

where $v_k^{(i)} = u^{(i)} \exp\left(-\frac{j2\pi(k-K_C)m^{(i)}}{N_{FFT}}\right)$

5) Find $\alpha^{(i)}$, the largest magnitude of correction allowed without causing any reserved carrier amplitudes to exceed $A_{\max}$:

$$\alpha^{(i)} = \min\left(y^{(i)} - V_{clip}, \min_{k \in S_l} \alpha_k^{(i)}\right)$$

If $\alpha^{(i)} = 0$, then decrease i by 1 and go to step 9.

6) Update the peak reduction signal $\mathbf{c}_n^{(i)}$ by subtracting the reference kernel signal, scaled and cyclically shifted by $m^{(i)}$:

$$c_n^{(i)} = c_n^{(i-1)} - \alpha^{(i)} u^{(i)} p_{(n-m^{(i)}) \bmod N_{FFT}}$$

7) Update the frequency domain coefficient for each reserved tone $k \in S_l$:

$$r_k^{(i)} = r_k^{(i-1)} - \alpha^{(i)} v_k^{(i)},$$

NOTE 2: If only one iteration is required, step 7 can be omitted, and steps 4 and 5 reduce to the following:

$$\alpha^{(1)} = \min(y^{(1)} - V_{clip}, A_{\max}).$$

8) If *i* is less than a maximum allowed number of iterations, increase *i* by 1and return to step 2. Otherwise, go to step 9.

9) Terminate the iterations. The transmitted signal, x'_n is obtained by adding the peak reduction signal to the data signal:

$$x'_n = x_n + c_n^{(i)}$$

11.6 Guard interval insertion

Seven different guard interval fractions (Δ/T_u) are defined. Table 114 gives the absolute guard interval duration Δ, expressed in multiples of the elementary period T (see clause 11.4) for each combination of FFT size and guard interval fraction. Some combinations of guard interval fraction and FFT size shall not be used and are marked 'NA' in table 114.

Table 114: Duration of the guard interval in terms of the elementary period T

FFT size	**Guard interval fraction (Δ/T_u)**						
	1/128	**1/32**	**1/16**	**19/256**	**1/8**	**19/128**	**1/4**
16K	128T	512T	1 024T	1 216T	2 048T	2 432T	4 096T
8K	64T	256T	512T	608T	1 024T	1 216T	2 048T
4K	NA	128T	256T	NA	512T	NA	1 024T
2K	NA	64T	128T	NA	256T	NA	512T
1K	NA	NA	64T	NA	128T	NA	256T
0.5K	NA	16T	32T	NA	NA	NA	NA

NOTE: 0.5K FFT size is only used for SC-OFDM.

The emitted signal, as described in clause 11.4, includes the insertion of guard intervals when PAPR reduction is not used. If PAPR reduction is used, the guard intervals shall be inserted following PAPR reduction.

11.7 P1 symbol insertion

11.7.1 P1 symbol overview

Preamble symbol P1 has four main purposes. First it is used during the initial signal scan for fast recognition of the NGH signal, for which just the detection of the P1 is enough. Construction of the symbol is such that any frequency offsets can be detected directly even if the receiver is tuned to the nominal centre frequency. This saves scanning time as the receiver does not have to test all the possible offsets separately.

The second purpose for P1 is to identify the preamble itself as a NGH preamble. The P1 symbol is such that it can be used to distinguish itself from other formats used in the FEF parts coexisting in the same super-frame. The third task is to signal basic TX parameters that are needed to decode the rest of the preamble which can help during the initialization process. The fourth purpose of P1 is to enable the receiver to detect and correct frequency and timing synchronization.

11.7.2 P1 symbol description

P1 is a 1K OFDM symbol with two 1/2 "guard interval-like" portions added. The total symbol lasts 224 μs in 8 MHz system, comprising 112 μs, the duration of the useful part 'A' of the symbol plus two modified 'guard-interval' sections 'C' and 'B' of roughly 59 μs (542 samples) and 53 μs (482 samples), see figure 85.

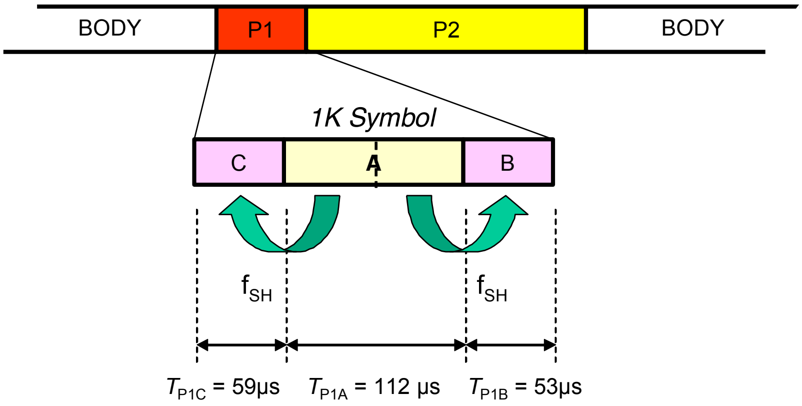


Figure 85: P1 symbol structure

Out of the 853 useful carriers of a 1K symbol, only 384 are used, leaving others set to zero. The used carriers occupy roughly 6,83 MHz band from the middle of the nominal 7,61 MHz signal bandwidth. Design of the symbol is such that even if a maximum offset of 500 kHz is used, most of the used carriers in P1 symbol are still within the 7,61 MHz nominal bandwidth and the symbol can be recovered with the receiver tuned to nominal centre frequency. The first active carrier corresponds to 44, while the last one is 809 (see figure 86).

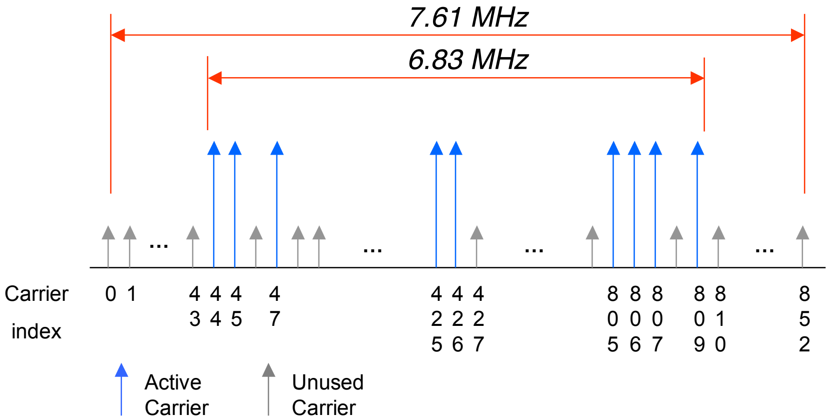


Figure 86: Active carriers of the P1 symbol

The scheme in figure 87 shows how the P1 symbol is generated. Later clauses describe each functional step in detail.

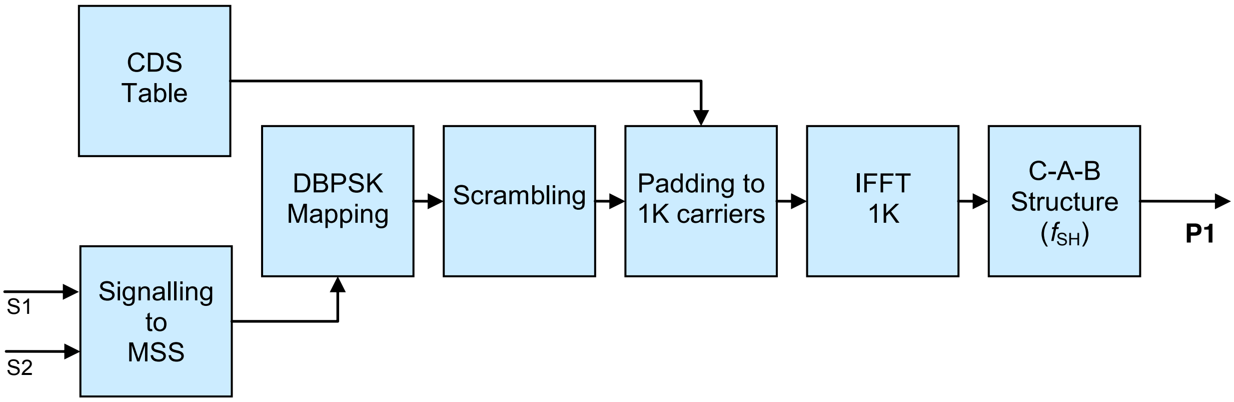


Figure 87: Block diagram of the P1 symbol generation

11.7.2.1 Carrier distribution in P1 symbol

The active carriers are distributed using the following algorithm: out of the 853 carriers of the 1K symbol, the 766 carriers from the middle are considered. From these 766 carriers, only 384 carry pilots; the others are set to zero. In order to identify which of the 766 carriers are active, three complementary sequences are concatenated: the length of the two sequences at the ends is 128, while the sequence in the middle is 512 chips long. The last two bits of the third concatenated sequence are zero, resulting in 766 carriers where 384 of them are active carriers.

The resulting carrier distribution is shown in table 115.

Table 115: Distribution of active carriers in the P1 symbol

Modulation Sequence (see clause Error! Reference source not found.**)**	**Active Carriers in P1 $k_{P1}(0)..k_{P1}(383)$**
$k_{P1}(0)..k_{P1}(63)$ CSS_{S1}	44 45 47 51 54 59 62 64 65 66 70 75 78 80 81 82 84 85 87 88 89 90 94 96 97 98 102 107 110 112 113 114 116 117 119 120 121 122 124 125 127 131 132 133 135 136 137 138 142 144 145 146 148 149 151 152 153 154 158 160 161 162 166 171
$k_{P1}(64)..k_{P1}(319)$ CSS_{S2}	172 173 175 179 182 187 190 192 193 194 198 203 206 208 209 210 212 213 215 216 217 218 222 224 225 226 230 235 238 240 241 242 244 245 247 248 249 250 252 253 255 259 260 261 263 264 265 266 270 272 273 274 276 277 279 280 281 282 286 288 289 290 294 299 300 301 303 307 310 315 318 320 321 322 326 331 334 336 337 338 340 341 343 344 345 346 350 352 353 354 358 363 364 365 367 371 374 379 382 384 385 386 390 395 396 397 399 403 406 411 412 413 415 419 420 421 423 424 425 426 428 429 431 435 438 443 446 448 449 450 454 459 462 464 465 466 468 469 471 472 473 474 478 480 481 482 486 491 494 496 497 498 500 501 503 504 505 506 508 509 511 515 516 517 519 520 521 522 526 528 529 530 532 533 535 536 537 538 542 544 545 546 550 555 558 560 561 562 564 565 567 568 569 570 572 573 575 579 580 581 583 584 585 586 588 589 591 595 598 603 604 605 607 611 612 613 615 616 617 618 622 624 625 626 628 629 631 632 633 634 636 637 639 643 644 645 647 648 649 650 654 656 657 658 660 661 663 664 665 666 670 672 673 674 678 683
$k_{P1}(320)..k_{P1}(383)$ CSS_{S1}	684 689 692 696 698 699 701 702 703 704 706 707 708 712 714 715 717 718 719 720 722 723 725 726 727 729 733 734 735 736 738 739 740 744 746 747 748 753 756 760 762 763 765 766 767 768 770 771 772 776 778 779 780 785 788 792 794 795 796 801 805 806 807 809

11.7.2.2 Modulation of the active carriers in P1

Active carriers are DBPSK modulated with a modulation pattern. The patterns, described later, encode two signalling fields S1 and S2. Up to 8 values (can encode 3 bits) and 16 values (can encode 4 bits) can be signalled in each field, respectively. Patterns to encode S1 are based on 8 orthogonal sets of 8 complementary sequences of length 8 (total length of each S1 pattern is 64), while patterns to encode S2 are based of 16 orthogonal sets of 16 complementary sequences of length 16 (total length of each S2 pattern is 256).

The two main properties of these patterns are:

a) The sum of the auto-correlations (SoAC) of all the sequences of the set is equal to a Krönecker delta, multiplied by *KN* factor, being *K* the number of the sequences of each set and *N* the length of each sequence. In the case of S1 $K=N=8$; in the case of S2, $K=N=16$.

b) Each set of sequences are mutually uncorrelated (also called "mates").

The S1 and S2 modulation patterns are shown in table 116.

Table 116: S1 and S2 modulation patterns

Field	Val	Sequence (hexadecimal notation)
S1	000	124721741D482E7B
	001	47127421481D7B2E
	010	217412472E7B1D48
	011	742147127B2E481D
	100	1D482E7B12472174
	101	481D7B2E47127421
	110	2E7B1D4821741247
	111	7B2E481D74214712
S2	0000	121D4748212E747B1D1248472E217B7412E247B721D174841DED48B82EDE7B8B
	0001	4748121D747B212E48471D127B742E2147B712E2748421D148B81DED7B8B2EDE
	0010	212E747B121D47482E217B741D12484721D1748412E247B72EDE7B8B1DED48B8
	0011	747B212E4748121D7B742E2148471D12748421D147B712E27B8B2EDE48B81DED
	0100	1D1248472E217B74121D4748212E747B1DED48B82EDE7B8B12E247B721D17484
	0101	48471D127B742E214748121D747B212E48B81DED7B8B2EDE47B712E2748421D1
	0110	2E217B741D124847212E747B121D47482EDE7B8B1DED48B821D1748412E247B7
	0111	7B742E2148471D12747B212E4748121D7B8B2EDE48B81DED748421D147B712E2
	1000	12E247B721D174841DED48B82EDE7B8B121D4748212E747B1D1248472E217B74
	1001	47B712E2748421D148B81DED7B8B2EDE4748121D747B212E48471D127B742E21
	1010	21D1748412E247B72EDE7B8B1DED48B8212E747B121D47482E217B741D124847
	1011	748421D147B712E27B8B2EDE48B81DED747B212E4748121D7B742E2148471D12
	1100	1DED48B82EDE7B8B12E247B721D174841D1248472E217B74121D4748212E747B
	1101	48B81DED7B8B2EDE47B712E2748421D148471D127B742E214748121D747B212E
	1110	2EDE7B8B1DED48B821D1748412E247B72E217B741D124847212E747B121D4748
	1111	7B8B2EDE48B81DED748421D147B712E27B742E2148471D12747B212E4748121D

The bit sequences CSS_{S1} =($CSS_{S1,0}$ … $CSS_{S1,63}$) and CSS_{S2}=($CSS_{S2,0}$ … $CSS_{S2,255}$) for given values of S1 and S2 respectively is obtained by taking the corresponding hexadecimal sequence from left to right and from MSB to LSB, i.e. $CSS_{S1,0}$ is the MSB of the first hexadecimal digit and $CSS_{S1,63}$ is the LSB of the last digit of the S1 sequence.

The final modulation signal is obtained as follows:

10) The Modulation sequence is obtained by concatenating the two CSS_{S1} and CSS_{S2} sequences; the CSS_{S1} sequence is attached at both sides of the CSS_{S2}:

$$\begin{aligned}\{MSS\_SEQ_0 . MSS\_SEQ_{383}\} &= \{CSS_{S1}, CSS_{S2}, CSS_{S1}\} \\ &= \{CSS_{S1,0}, \ldots, CSS_{S1,63}, CSS_{S2,0}, \ldots, CSS_{S2,255}, CSS_{S1,0}, \ldots, CSS_{S1,63}\}\end{aligned}$$

11) Then, the sequence is modulated using DBPSK:

$$MSS\_DIFF = DBPSK(MSS\_SEQ)$$

The following rule applies for the differential modulation of element *i* of the *MSS_SEQ*:

$$MSS\_DIFF_i = \begin{cases} MSS\_DIFF_{i-1} & MSS\_SEQ_i = 0 \\ -MSS\_DIFF_{i-1} & MSS\_SEQ_i = 1 \end{cases}$$

The differential encoding is started from "dummy" value of +1, i.e. MSS_DIFF_{-1} = +1 by definition. This bit is not applied to any carrier.

12) A scrambling is applied on the MSS_DIFF by bit-by-bit multiplying by a 384-bit scrambler sequence:

$$MSS\_SCR = SCRAMBLING\{MSS\_DIFF\}$$

The scrambler sequence shall be equal to the 384-length sequence of '+1' or '-1' converted from the first 384 bits ($PRBS_0 \ldots PRBS_{383}$) of the PRBS generator described in clause 5.2.4 with initial state '100111001000110', where a PRBS generator output bit with a value of '0' is converted into '+1' and a PRBS generator output bit with a value of '1' is converted into '-1'.

$$MSS\_SCR_i = MSS\_DIFF_i \times 2\left(\frac{1}{2} - PRBS_i\right)$$

13) The scrambled modulation pattern is applied to the active carriers.

EXAMPLE: If S1=000 and S2=0000, then:

The sequence is:

$$\begin{aligned} MSS\_SEQ &= \{\underbrace{1247\ldots 2E7B}_{CSS_{S1}}, \underbrace{121D\ldots 7B8B}_{CSS_{S2}}, \underbrace{1247\ldots 2E7B}_{CSS_{S1}}\} \\ &= \{\underbrace{0,0,0,1,\ldots,1,0,1,1}_{CSS_{S1}}, \underbrace{0,0,0,1,\ldots,1,0,1,1}_{CSS_{S2}}, \underbrace{0,0,0,1,\ldots,1,0,1,1}_{CSS_{S1}}\} \end{aligned}$$

Then, DBPSK is applied:

$$MSS\_DIFF = \{\underbrace{1,1,1,-1,\ldots,1,1,-1,1}_{CSS_{S1}}, \underbrace{1,1,1,-1,\ldots,1,1,-1,1}_{CSS_{S2}}, \underbrace{1,1,1,-1,\ldots,1,1,-1,1}_{CSS_{S1}}\}$$

The DBPSK output is scrambled by the scrambling sequence, *SCR_SEQ*.

$$\begin{aligned} SCR\_SEQ &= 2(\frac{1}{2} - PRBS_i) \\ &= \{\underbrace{-1,1,-1,1,\ldots,-1,-1,1,1}_{64}, \underbrace{-1,-1,-1,-1,\ldots,1,-1,-1,1}_{256}, \underbrace{1,1,-1,-1,\ldots,1,1,-1,1}_{64}\} \end{aligned}$$

after scrambling:

$$MSS\_SCR = \{\underbrace{-1,1,-1,-1,\ldots,-1,-1,-1,1}_{CSS_{S1}}, \underbrace{-1,-1,-1,1,\ldots,1,-1,1,1}_{CSS_{S2}}, \underbrace{1,1,-1,1,\ldots,1,1,1,1}_{CSS_{S1}}\}$$

The scrambled modulation MSS is mapped to the active carriers, MSB first:

$$\begin{gathered} c_{44} = -1, c_{45} = 1, c_{47} = -1, c_{51} = -1, \ldots, c_{171} = 1 \\ c_{172} = -1, c_{173} = -1, c_{175} = -1, \ldots, c_{683} = 1 \\ c_{684} = 1, \ldots, c_{805} = 1, c_{806} = 1, c_{807} = 1, c_{809} = 1 \end{gathered}$$

where c_k is the modulation applied to carrier k.

The equation for the modulation of the P1 carriers is given in clause 11.7.2.4.

11.7.2.3 Boosting of the active Carriers

Taking into account that in a 1K OFDM symbol only 853 carriers are used, and in P1 there are only 384 active carriers, the boosting applied to the P1 active carriers is a voltage ratio of $\sqrt{(853/384)}$ or 3,47 dB, relative to the mean value of all K_{total} of the used carriers of a 1K normal symbol.

11.7.2.4 Generation of the time domain P1 signal

11.7.2.4.1 Generation of the main part of the P1 signal

The useful part 'A' of the P1 signal is generated from the carrier modulation values, according to the following equation:

$$p_{1A}(t) = \frac{1}{\sqrt{384}} \sum_{i=0}^{383} MSS\_SCR_i \times e^{j2\pi \frac{k_{\mathrm{P1}}(\mathrm{i})-426}{1024T} t}$$

where $k_{\mathrm{p1}}(i)$ for i=0,1,…, 383 are the indices of the 384 active carriers, in increasing order, as defined in clause 11.7.2.1. MSS_SCR_i for i=0,1,… , 383 are the modulation values for the active carriers as defined in clause 11.7.2.2, and T is the elementary time period and is defined in table 112.

NOTE: This equation, taken together with the equation in clause 11.4, includes the effect of the boosting described in clause 11.7.2.3, which ensures the power of the P1 symbol is virtually the same as the power of the remaining symbols.

11.7.2.4.2 Frequency-shifted repetition in guard intervals

In order to improve the robustness of the P1, two guard intervals are defined at both sides of the useful part of the symbol. Instead of cyclic continuation like normal OFDM symbols, a frequency shift version of the symbol is used. Thus, denoting P1[C], the first guard interval, P1[A] the main part of the symbol and P1[B] the last guard interval of the symbol, P1[C] carries the frequency shifted version of the first 542T of P1[A], while P1[B] conveys the frequency shifted version of the last 482T of P1[A] (see figure 85).

The frequency shift f_{SH} applied to P1[C] and P1[B] is:

$$f_{SH} = 1/(1\,024T)$$

The time-domain baseband waveform $p_1(t)$ of the P1 symbol is therefore defined as follows:

$$p_1(t) = \begin{cases} p_{1A}(t) e^{j\frac{2\pi}{1024T}t} & 0 \le t < 542T \\ p_{1A}(t-542T) & 542T \le t < 1\,566T \\ p_{1A}(t-1\,024T) e^{j\frac{2\pi}{1\,024T}t} & 1\,566 \le t < 2\,048T \\ 0 & \text{otherwise} \end{cases}$$

11.7.3 Additional P1 (aP1) symbol

11.7.3.1 aP1 symbol overview

The signalling capacity of a preamble can be increased by adding an additional P1 (aP1) preamble. aP1 provides 7 bits for additional signalling field. When aP1 is added to P1, the preamble can carry total 14 bits of signalling field. This capacity increase is the first purpose of aP1.

The second purpose for aP1 is, together with P1, to identify the preamble itself as a preamble defined in aP1. The aP1 symbol is such that it can be used to distinguish itself from other formats used in the FEF parts coexisting in the same super-frame. The third task is to signal basic transmission parameters that are needed to decode the rest of the preamble which can help during the initialization process. The fourth purpose of aP1 is, in addition to P1, to improve the performance of detecting and correcting frequency and timing synchronization in the receiver side.

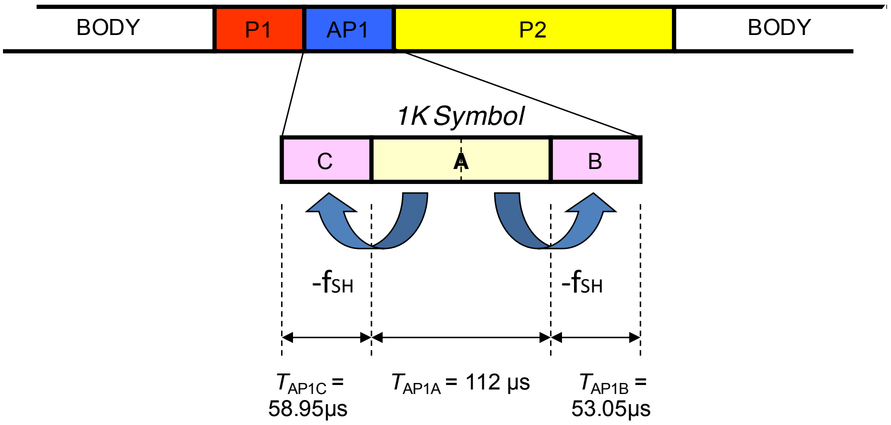


Figure 88: Concatenated P1 and aP1 transmission

11.7.3.2 aP1 symbol description

When aP1 is used, it directly follows P1 as shown in Figure 88. aP1 has same signal structure as P1 but with different parameters. aP1 has also C-A-B structure with a 1K OFDM symbol as an effective part A. The difference of aP1 from P1 arises in three parameters:

1) Scrambling sequence in AP1 symbol generation
2) Frequency shift value of C-A-B structure
3) The length of guard-interval-like C and B part

The three parameters above were carefully chosen to make aP1 have same performance as P1 in both detection and decoding performance in the receiver side. The legacy T2 or T2-lite receiver will never be affected by aP1 because there should not be any interference in detecting one preamble casued by the other one. All the properties and advantages of P1 should be kept because of the same structure.

All the process and parameters required for AP1 generation except above three points are exactly same as those for P1. For carrier distribution in aP1 symbol, modulation of the active carriers in AP1, boosting of the active carriers and generation of the main part of the aP1 signal, please see the corresponding parts of P1 in clause 11.7.2.

11.7.3.2.1 aP1 scrambling sequence

For scrambling in figure 89, the PRBS generator same as that used in P1 described in clause 5.2.4 is used with different initial state '111001100110001'.

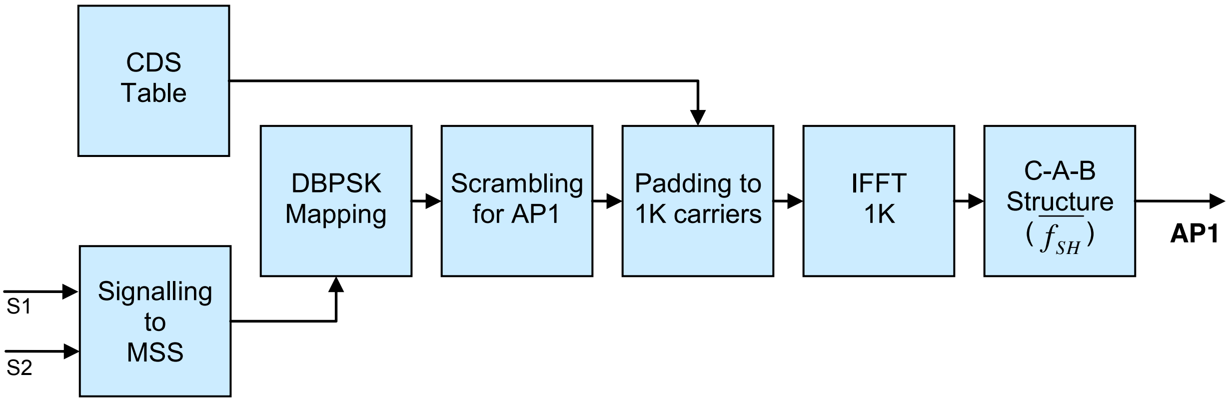


Figure 89: Block diagram of the aP1 symbol generation

11.7.3.2.2 Frequency-shifted repetition in guard intervals

aP1 also uses two guard intervals at both sides of the useful part of the symbol as like P1. With the similar notation in clause 11.7.2.4.2, denoting aP1[C], the first guard interval, aP1[A] the main part of the symbol and aP1[B] the last guard interval of the symbol, aP1[C] carries the frequency shifted version of the first 539T of aP1[A], while aP1[B] conveys the frequency shifted version of the last 485T of aP1[A] (see Figure 88). Please note that the lengths of aP1[C] and aP1[B] are changed from those of P1. When the length of C and B part is calculated as 512+*K* and 512-*K* samples respectively, *K*=30 for P1 symbol (C and B consists of 542 and 482 samples respectively) and *K*=27 for aP1 symbol.

The frequency shift ($-f_{SH}$) applied to aP1[C] and aP1[B] is:

$$-f_{SH} = -1/(1\,024T).$$

The time-domain baseband waveform $ap_1(t)$ of the aP1 symbol is therefore defined as follows:

$$ap_1(t) = \begin{cases} ap_{1A}(t)e^{-j\frac{2\pi}{1024T}t} & 0 \le t < 539T \\ ap_{1A}(t-539T) & 539T \le t < 1\,563T \\ ap_{1A}(t-1\,024T)e^{-j\frac{2\pi}{1\,024T}t} & 1\,563 \le t < 2\,048T \\ 0 & \text{otherwise} \end{cases}.$$

The only difference from P1 is the opposite sign of frequency shift value: aP1 uses negative signed value whereas P1 uses positive.

12 Spectrum characteristics

The OFDM symbols constitute a juxtaposition of equally-spaced orthogonal carriers. The amplitudes and phases of the data cell carriers are varying symbol by symbol according to the mapping process previously described.

The power spectral density $P_{k'}(f)$ of each carrier at frequency:

$$f_{k'} = f_c + \frac{k'}{T_u} \text{ for } \left(-\frac{K_{total}-1}{2}\right) \le k' \le \frac{K_{total}-1}{2}$$

is defined by the following expression:

$$P_{k'}(f) = \left[\frac{\sin \pi (f - f_{k'})T_s}{\pi (f - f_{k'})T_s}\right]^2$$

The overall power spectral density of the modulated data cell carriers is the sum of the power spectral densities of all these carriers. A theoretical DVB transmission signal spectrum is illustrated in figure 90 (for 8 MHz channels). Because the OFDM symbol duration is larger than the inverse of the carrier spacing, the main lobe of the power spectral density of each carrier is narrower than twice the carrier spacing. Therefore the spectral density is not constant within the nominal bandwidth.

NOTE 1: This theoretical spectrum takes no account of the variations in power from carrier to carrier caused by the boosting of the pilot carriers.

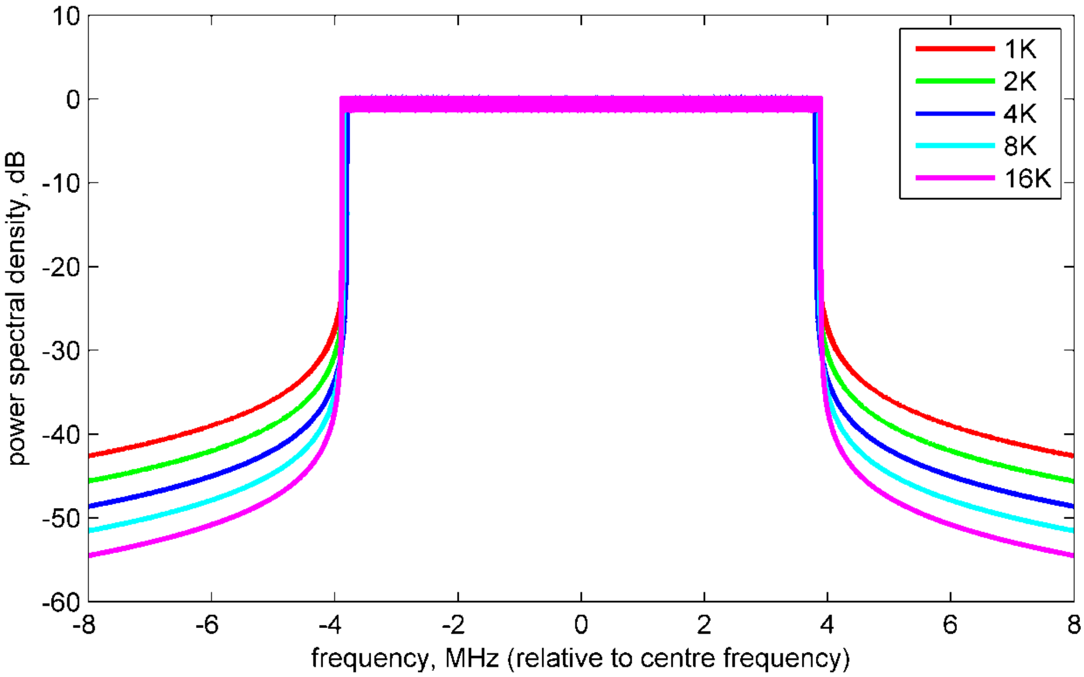


Figure 90: Theoretical NGH signal spectrum for guard interval fraction 1/8 (for 8 MHz channels and with extended carrier mode for 8K, 16K)

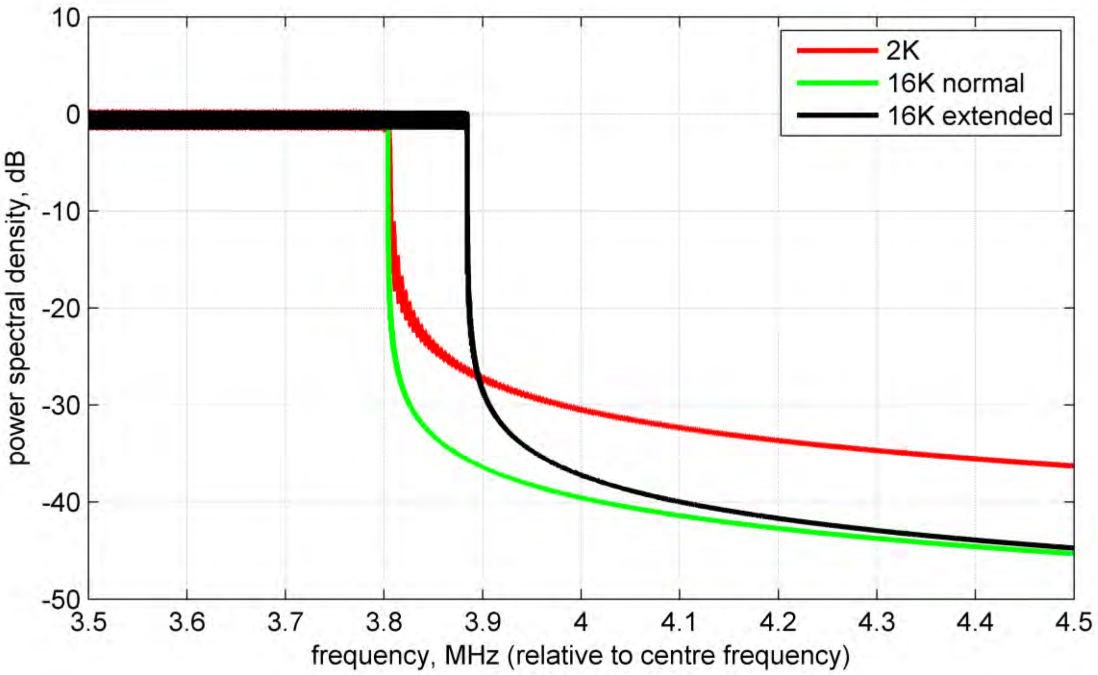


Figure 91: Detail of theoretical NGH spectrum for guard interval fraction 1/8 (for 8 MHz channels)

No specific requirements are set in terms of the spectrum characteristics after amplification and filtering, since it is considered to be more appropriately defined by the relevant national or international authority, depending on both the region and the frequency band in which the NGH system is to be deployed.

NOTE 2: The use of PAPR reduction techniques described here can significantly help to reduce the level of out-of-band emissions following high power amplification. It is assumed that these techniques are likely to be needed when the extended carrier modes are being used.

Annex A (normative): Splitting of input MPEG-2 TSs into the data PLPs and common PLP of a group of PLPs

A.1 Overview

This annex defines an extension of the DVB-NGH system in the case of MPEG-2 Transport Streams [1], which allows the separation of data to be carried in the common PLP for a group of TSs. It also allows the splitting of an input TS to several TSPSs to be carried in several data PLPs. It includes the processing (remultiplexing) that shall be applied for transporting N (N≥1) MPEG-2 TSs (TS_1 to TS_N) over K data PLPs (PLP1 to PLPK)) and the common PLP (CPLP) of a group of PLPs, see figure A.1.

If this first processing is not applied to a group of Transport Streams, there shall be no common PLP for this group, and the data PLPs of the group shall carry the input TSs of the group, either without modification or with the second processing , as defined in D.4, splitting the TS into several data PLPs. When several groups of PLPs are used to carry TSs, each such group has its own independent extension functionality.

This annex also describes the processing that can be carried out by the receiver to reconstruct a single input TS from the received data PLP and its corresponding common PLP.

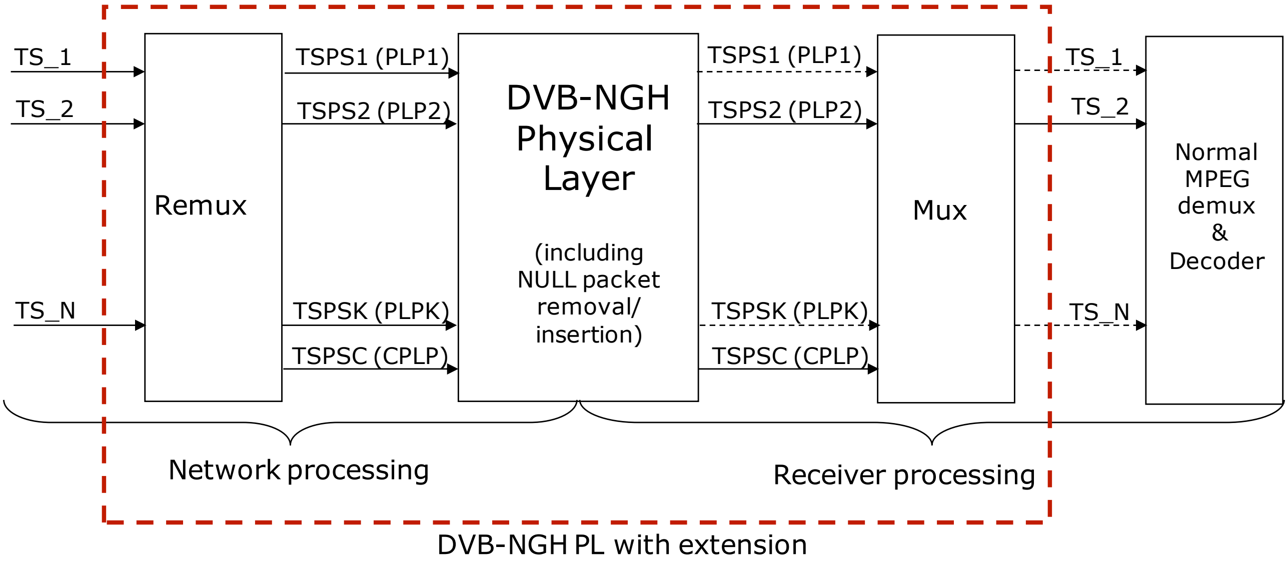


Figure A.1: Multiple TS input/output to/from the extended DVB-NGH PL

The extension consists on the network side conceptually of a remultiplexer and on the receiver side of a multiplexer. In-between the remultiplexer and the multiplexer we have the DVB-NGH system, as described in other parts of the present document. The inputs/outputs to the DVB-NGH system are syntactically correct TSs, each with unique transport_stream_ids, containing all relevant layer 2 (L2) signalling information (i.e. PSI/SI - see [1] and [2]). The various input TSs may have PSI/SI tables, or other L2 data, in common with other input TSs. When the extension is used the generated TSPS (Transport Stream Partial Stream) and TSPSC (Transport Stream Partial Stream Common) streams are however typically not syntactically correct MPEG-2 TSs [1]. This is due to the fact that some of the original TS data is carried in the common PLP and/or in other data PLPs.

NOTE: The parallel TSs may only exist internally in equipment generating the DVB-NGH signal. The parallel TSs may e.g. be generated from a single high bit rate TS source, or may alternatively be generated by centrally-controlled parallel encoders, each producing a constant bit rate TS, with variable proportion of null packets. The bit rates of the input TSs may be significantly higher than the capacity of the respective PLPs, because of the existence of a certain proportion of null packets, which are removed by the DNP procedure.

An input MPEG-2 TS shall be transported either:

- in its entirety within a single PLP, in which case the TS does not belong to any group of PLPs (and there is no common PLP); or
- split into a TSPS stream, carried in a data PLP, and a TSPSC stream, carried in the common PLP. This annex specifies the splitting and describes how the recombination of the output streams from a data PLP and the common PLP can conceptually be achieved by the receiver to form the output TS; or
- split into 1-4 TSPS streams, carried in the same number of data PLPs. This annex specifies the splitting and describes how the recombination of the output streams from the data PLPs can conceptually be achieved by the receiver to form the output TS; or
- as a combination of the two preceding points.

A.2 Splitting of input TS into a TSPS stream and a TSPSC stream

A.2.1 General

When a set of N TSs (TS_1, …, TS_N, N ≥ 2) are sent through a group of N+1 PLPs, one being the common PLP of a group, all TSs shall have the same input bit rate, including null packets. All input TS streams shall also be packet-wise time synchronized. All TSPSs and the TSPSC shall have the same bit rate as the input TSs and maintain the same time synchronization. For the purpose of describing the split operation this is assumed to be instantaneous so that TSPSs and the TSPSC are still co-timed with input TSs after the split.

NOTE: The input TSs may contain a certain proportion of null packets. The split operation will introduce further null packets into the TSPSs and the TSPSC. Null packets will however be removed in the modulator and reinserted in the demodulator in a transparent way, so that the DVB-T2 system will be transparent for the TSPSs and the TSPSC, despite null packets not being transmitted. Furthermore, the DNP and ISSY mechanism of the DVB-T2 system will ensure that time synchronization of the TSPSs and the TSPSC at the output of the demodulator is maintained.

When reference is made to TS packets carrying SDT or EIT in the current annex the intended meaning is *TS packets carrying sections carrying SDT or EIT*, i.e. the data being carried within the TS packet is not limited to the SDT or EIT itself but includes the full section (i.e. with CRC).

For the purpose of specifying the split operation the TS packets that shall be transmitted in the common PLP fall into the following three categories:

14) TS packets that are co-timed and identical on all input TSs of the group before the split.
15) TS packets carrying Service Description Table (SDT) and not having the characteristics of category (1).
16) TS packets carrying Event Information Table (EIT) and not having the characteristics of category (1).

For reference to SDT and EIT, see [i.2].

Figures A.2 to A.6 are simplified in so far as they do not show any data packets or null packets in the input TSs. In real input TSs these are of course to be expected. Similarly, a section is not necessarily wholly contained in a TS packet, but may be segmented over several TS packets and may also share capacity of a TS packet with other sections of the same or other types using the same PID value. These simplifications do not in any way affect the general applicability of the splitting/re-combining process, as described in this annex.

A.2.2 TS packets that are co-timed and identical on all input TSs of the group before the split

TS packets that are co-timed and identical on all input TSs of the group before the split shall, after the split, appear at the same time positions in the TSPSC and, if so, shall be replaced by null packets in the respective TSPSs at the same time positions.

The receiver can recreate the input TS when any packets other than null packets appear in the TSPSC, by replacing null packets in the currently received TSPS with the corresponding TS packets in the TSPSC at the same time positions, see figure A.2.

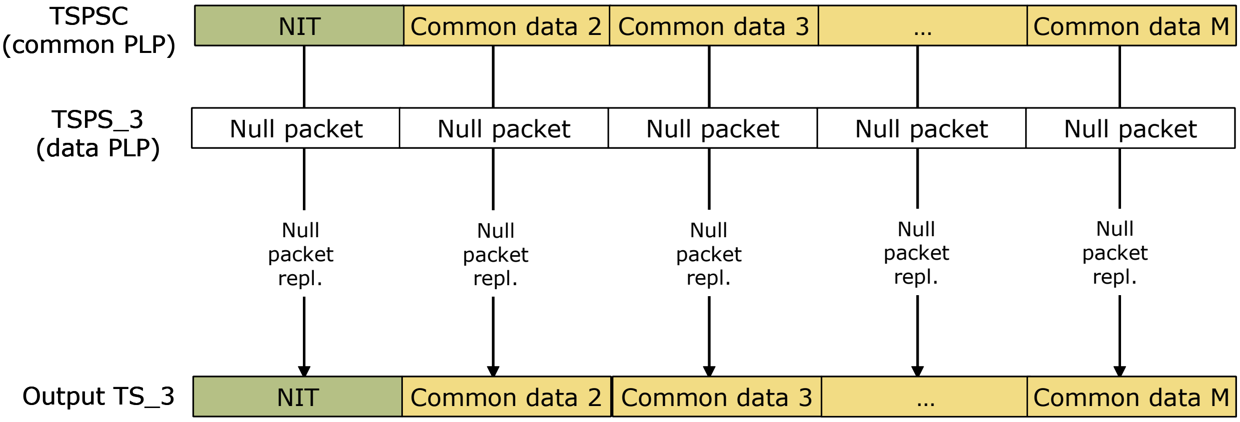


Figure A.2: Example of recombination of input TS from TSPS and TSPSC for category 1

A.2.3 TS packets carrying Service Description Table (SDT) and not having the characteristics of category (1)

Sections with table_id=0x42 (HEX) are referred to as SDT actual TS.
Sections with table_id=0x46 (HEX) are referred to as SDT other TS.

TS packets with PID=0x0011 and table_id of all carried sections equal to 0x46 (HEX), shall be carried in the TSPSC provided the following conditions are fulfilled:

17) At a given time position there is in one input TS a TS packet which is not a null packet.

18) In all the other input TSs of the group there are, at this time position, mutually identical TS packets, not equal to that in condition (1), with PID=0x0011, with the section header table_id field of all carried section headers equal to 0x46 and with the value of the transport_stream_id field in all carried sections equal to the transport_stream_id of the TS in condition (1).

19) Sections with table_id 0x42 and 0x46 are never partly or fully carried in the same TS packet with PID=0x0011.

If these conditions are met, the input TS packets carrying the SDT actual shall not be modified, but copied directly to the corresponding TSPS at the same time position. The input TS packets carrying SDT other shall be replaced by null packets in the corresponding TSPS, and the TS packets carrying SDT other shall be carried in the TSPSC, as shown in figure A.3.

NOTE: TS packets carrying SDT sections (partly or fully) may also carry other section types using the same PID, such as BAT and ST, see reference zzz.

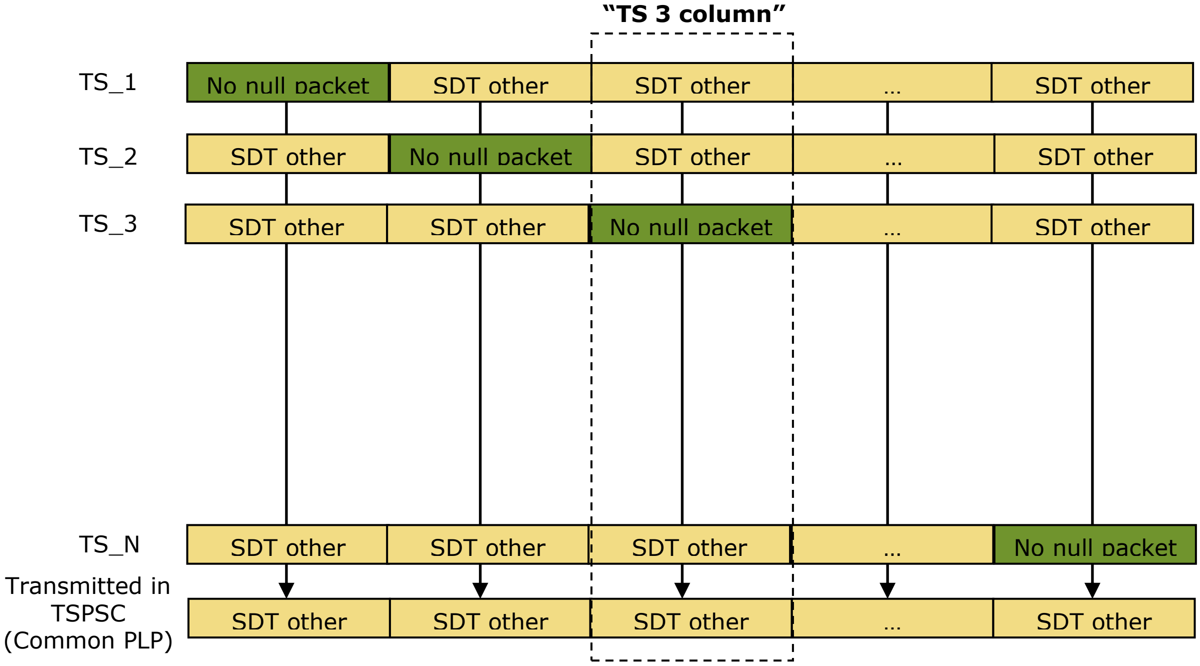


Figure A.3: Arrangement of SDT other in input TSs and relationship with TSPSC

As a result of the split all TS packets carrying SDT actual are therefore left unmodified in the respective TSPS at the same time position as in the input TS, whereas all TS packets carrying SDT other are found in the TSPSC at the same time position as in the input TS.

The receiver can recreate the input TS when SDT other packets appear in the TSPSC, by replacing null packets in the currently received TSPS with the corresponding SDT other packets from the TSPSC at the same time positions. When there is not a co-timed null packet in the TSPS, the receiver shall not modify the TSPS to achieve full transparency. This is shown in figure A.4.

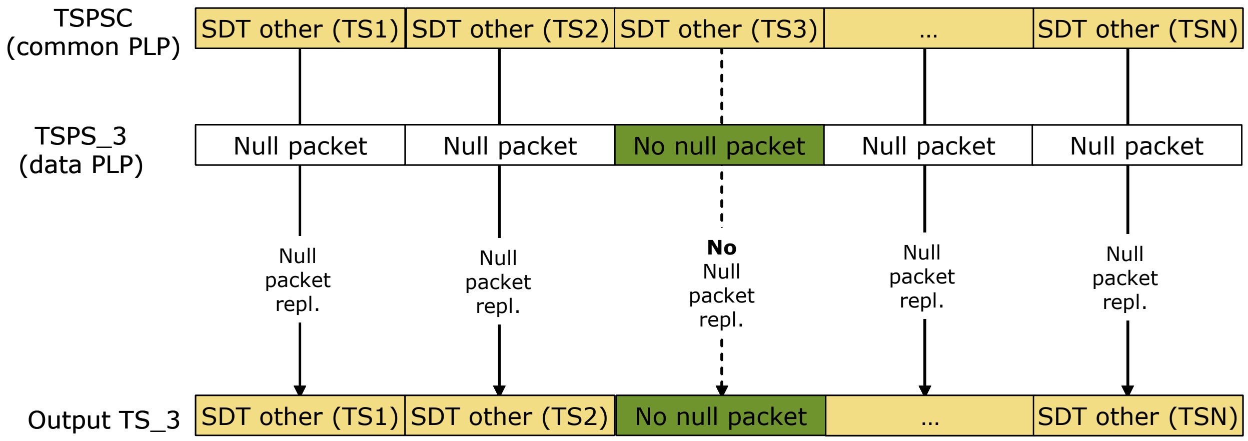


Figure A.4: Receiver operation to re-combine of TSPS and TSPSC into output TS for SDT

A.2.4 TS packets carrying Event Information Table (EIT) and not having the characteristics of category (1)

- Sections with table_id=0x4E (HEX) are referred to as EIT actual TS, present/following.
- Sections with table_id=0x4F (HEX) are referred to as EIT other TS, present/following.
- Sections with table_id=0x50 to 0x5F (HEX) are referred to as EIT actual TS, schedule.
- Sections with table_id=0x60 to 0x6F (HEX) are referred to as EIT other TS, schedule.

The operations described in clause A.2.4.1 shall be performed when the conditions described in clause A.2.4.2 are fulfilled.

A.2.4.1 Required operations

At a particular time position a TS packet carrying EIT other (PID=0x0012) shall be copied into the same time position in the TSPSC and the input TS packets of all TSPSs of the group at the same time position shall be replaced by null packets.

A.2.4.2 Conditions

In all input TSs of the group except one there shall, at this time position, be identical TS packets carrying EIT other, with value of the section header transport_stream_id field equal to the transport_stream_id of the remaining input TS. At the same time position there shall be, in the remaining input TS, a TS packet carrying EIT actual, with the value of the section header transport_stream_id field equal to the transport_stream_id of the same input TS. At this time position, the TS packet carrying EIT actual shall be identical to those carrying EIT other, except for the table_id, last_table_id and CRC of the carried section. The table_ids and last_table_ids of co-timed TS packets carrying EIT actual and EIT other shall have the 1-to-1 mapping given in table yyy. The required operations at a particular time position, given in clause xxx, shall only be performed if the TS packets carrying other parts, if any, of the same section(s) are also subject to the same required operation, i.e. an EIT section shall either be completely transported in the common PLP or in a data PLP.

Table A.1: Correspondence between table_ids of co-timed EIT actual and EIT other in input TSs

table_id or last_table_id of EIT actual in input TS	table_id or last_table_id of co-timed EIT other in input TS
0x4E	0x4F
0x50	0x60
0x51	0x61
0x52	0x62
0x53	0x63
0x54	0x64
0x55	0x65
0x56	0x66
0x57	0x67
0x58	0x68
0x59	0x69
0x5A	0x6A
0x5B	0x6B
0x5C	0x6C
0x5D	0x6D
0x5E	0x6E
0x5F	0x6F

This means that at a particular time position with TS packets carrying EIT all these TSs carry identical TS packets with the exception of section table_id in one TS being set to "actual" rather than "other" and the CRC of the corresponding sections being different for EIT actual and other, see table A.1 and figure A.5.

NOTE 1: TS packets carrying EIT sections (partly or fully) may also carry other section types using the same PID, such as ST and CIT, see [i.2].

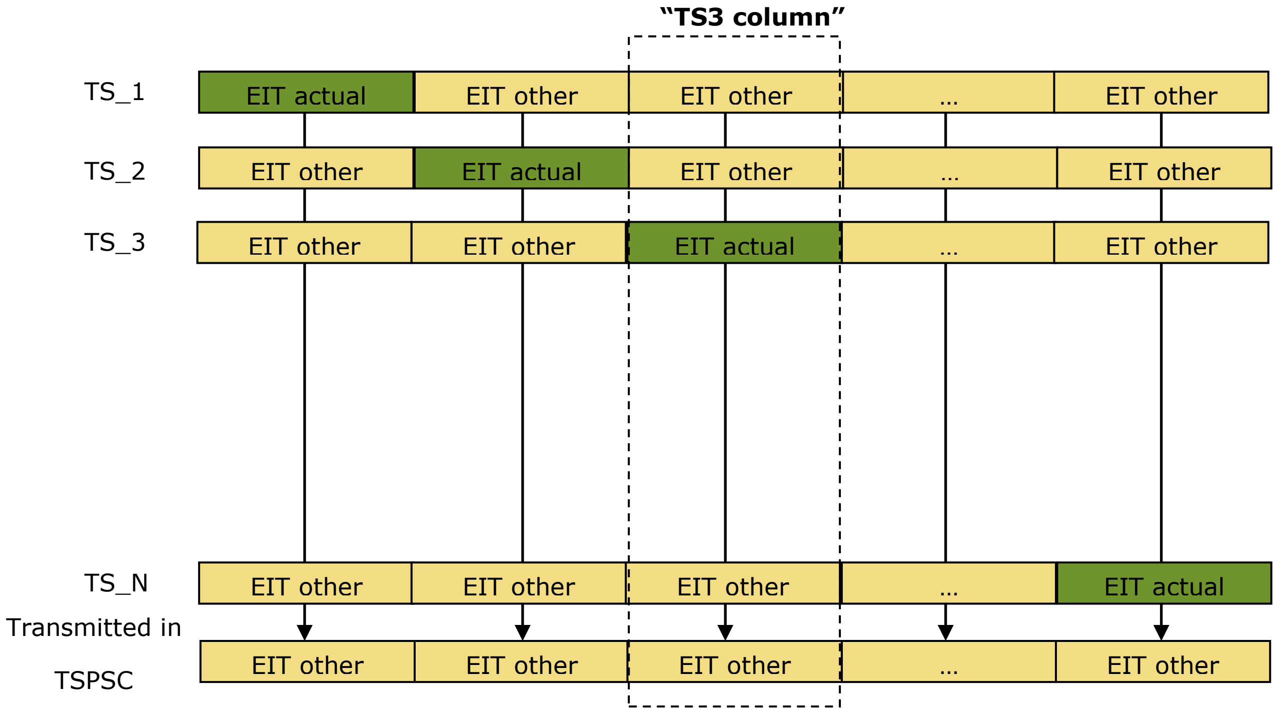


Figure A.5: Example of arrangement of EIT actual/other in input TSs and relationship with TSPSC

As a result of the split all TS packets carrying EIT actual and EIT other are replaced by null packets in the respective TSPS at the same time position. All TS packets carrying a section or sections with EIT other in the input TSs are copied to the TSPSC at the same time position as in the input TS.

The receiver can recreate the input TS when EIT other packets appear in the TSPSC, by replacing null packets in the currently received TSPS with the corresponding EIT other packets from the TSPSC at the same time positions. For TS packets carrying EIT other, with the value of the section header transport_stream_id field equal to the transport_stream_id of the currently decoded TS, the receiver should also modify the table_id and last_table_id from "other" to "actual" and modify the CRC, so that it is calculated from the "actual" table_id and last_table_id rather than the "other" table_id and "other" last_table_id, to achieve full TS transparency, see table A.1 and figure A.6.

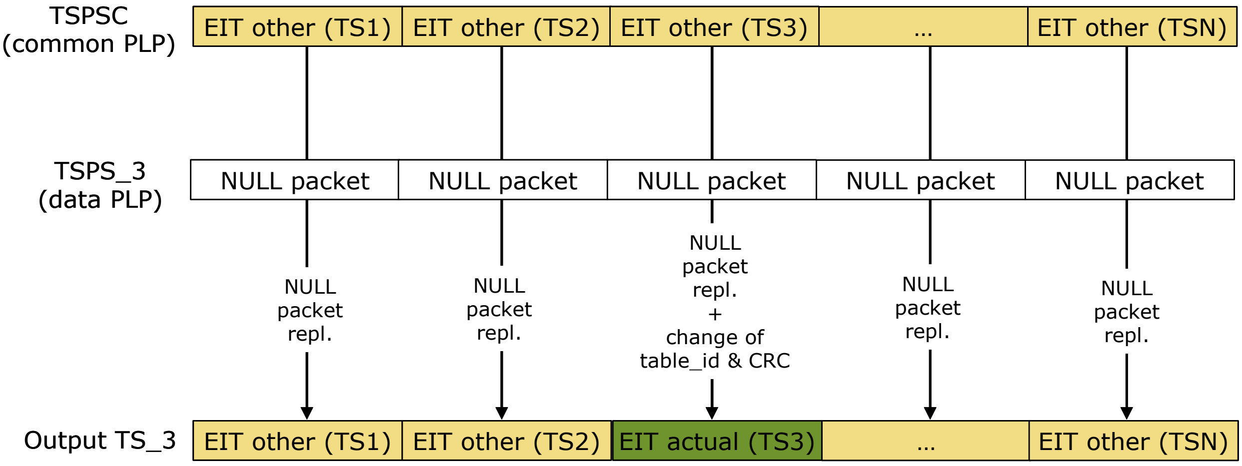


Figure A.6: Receiver operation to re-combine of TSPS and TSPSC into output TS for EIT

NOTE 2: For TS packets carrying *scrambled EIT schedule* it may be difficult to perform the above-mentioned modification of table_id and last_table_id from "other" to "actual" and change of CRC. Therefore, in such cases the output TS may contain only EIT other. The information of the EIT actual of the input TS, referring to the currently decoded TS, is however available in the EIT other, referring to the same TS.

A.3 Receiver Implementation Considerations

In view of the key role played by the transport stream as a physical interface in many existing and future receivers it is strongly recommended that at least the core of the merging function as described in this annex is implemented in a channel decoder silicon. In particular this applies to the generic merging function between TSPSC and TSPS to form a transport stream:

- for category-1 (generic data) as defined in clause A.2.2 illustrated in figure A.2;
- for category-2 (SDT) as defined in clause A.2.3 and illustrated in figure A.4; and
- for category-3 (EIT) as defined in clause A.2.4 and illustrated in figure A.6.

It may be possible that the change of table_id and CRC, as defined for category-3 data (to reconstruct EIT_actual from EIT_other) could be handled by software on an MPEG system processor (which avoids that channel decoders would have to implement section level processing).

The channel decoder implementations as defined above should ensure correct integration of many existing DVB system hardware and software solutions for DVB with such channel decoders.

A.4 Splitting of an input TS into several TSPS streams

Each TS_i of the TSs in a set of N input TSs may be split into K_i TSPS streams. When there is a common PLP in the group of PLPs the parameter K_i may take values in the range $1 \leq K_i \leq 3$ and when there is no such common PLP the corresponding range is $1 \leq K_i \leq 4$. The case $K_i = 1$ is equivalent to no split.

NOTE: $K_i=1$ means that no split is performed and the input TS is mapped directly to a single TSPS.

The value of K_i may be chosen idependently for each input TS_i.

The splitting process is specified below:

When a set of N TSs (TS_1, …, TS_N, N ≥ 1) are sent through the M PLPs of a PLP group, all TSs shall have the same input bit rate, including null packets. All input TS streams shall also be packet-wise time synchronized. All TSPSs shall have the same bit rate as the input TSs and maintain the same time synchronization. For the purpose of describing the split operation this is assumed to be instantaneous so that all TSPSs are still co-timed with input TSs after the split.

A particular input TS_i is split into K_i TSPS streams by the following logical steps:

1. K_i temporary streams containing null packets are created while keeping packet time synchronisation with the original TS.
2. Each input TS packet of TS_i is copied to the same time position in exactly one of the temporary streams.
3. Each temporary streams that result from copying all input TS packets according to (2) above become a TSPS stream.

TSPS streams originating from different TS_i streams may in addition be arbitrarily merged as long as there is no collision of non-null packets at any packet time position.

NOTE: This means that the TS packets that are carried by a particular PLP originate from more than one input TS.

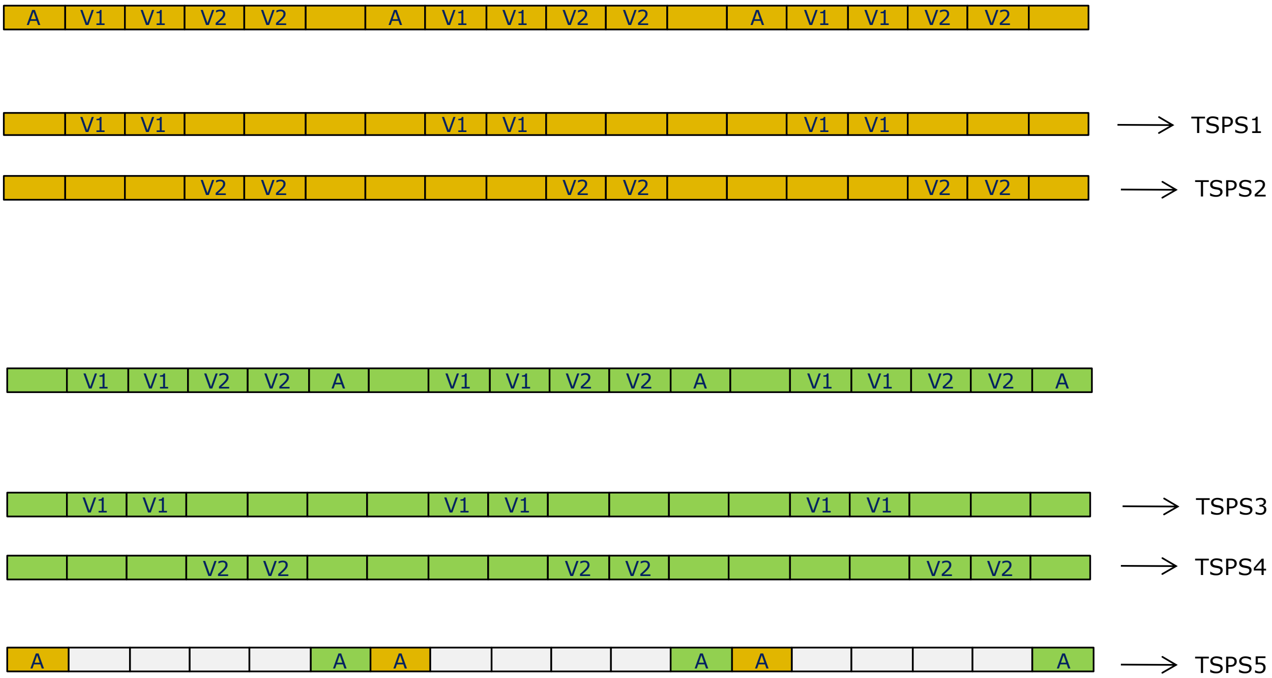
Merging of two or more TSPS streams is achieved by the following logical steps:

1. A temporary stream containing null packets is created while keeping packet time synchronisation with the TSPS streams to be merged.
2. In each TSPS packet of each TSPS stream to be merged the sync byte is replaced by the NGH stream id, representing the identity (transport stream id) of the corresponding original input TS.
3. For each TSPS packet time position, if exactly one TSPS packet at this position is a non-null packet the null packet of the temporary stream at this packet position is replaced by the non-null packet. If, at any packet time position, there is more than one non-null packet (i.e. packet collision) no merging of the TSPS streams shall be performed.
4. Each temporary stream that results from step 1-2 above is considered a merged TSPS stream.

NOTE: The NGH stream id allows the receiver to reconstruct the input TS streams by copying all TSPS packets with the same NGH stream id to a common TS. This is possible since the NGH system allows the packet time synchronisation of the respective TSPSs to be kept.

Fig. D.7 illustrates the end result of a splitting of two input TSs with three types of packets: A, V1 and V2 (corresponding to audio, video base layer and video enhancement layer). For each input TS the V1 and V2 packets end up in separate TSPSs (TSPS1 and TPS2 for inpuyt TS1 and TSPS3 and TSPS4 for input TS2). In addition the A packets of both input TSs end up in a separate TSPS (TSPS5) as a result of a merge.

The same figure may also be used to illustrate how a receiver recombines the packets of the respective TSPSs belonging to the same NGH system id to form the original TS. This is done by merging the TSPS packets, in each TSPS packet time position, so that one single stream is obtained.



Note: Empty boxes denote null packets

Figure A.7: Splitting of original TSs into TSPSs

A.5 Splitting of an input TS into several TSPS streams and a common PLP

The processing specified in appendix A.4 and A.5 may also be combined so that a set of N input TSs are first subject to the processing specified in D.3, resulting in N TSPS streams and one TSPSC stream. These N TSPS streams are then subject to a second split operation, as specified in appendix A.4, where the N TSPS streams take the role of the N TS streams in appendix A.4. The result of these two steps is a set of K TSPS streams (K≥N) and one TSPSC stream.

Annex B (informative): Allowable sub-slicing values

Table B.1 shows the allowed value for the total number of sub-slices $N_{\text{sub-slices\_total}} = N_{RF} \times N_{\text{sub-slices}}$ (see clause 9.2.2.2.2) at the output of each time interleaver block of each type 2 PLP. Since the same value of $N_{\text{sub-slices\_total}}$ is used for all type 2 PLPs, the value selected from the table will need to be suitable for all modulation types currently in use by type 2 PLPs. The safest possible options are those from the table with a 'Y' in all four columns, since this will always be suitable for all PLPs. These are listed in the table B.2.

Table B.1: List of available number of sub-slices for different constellations

	Constellation			
	QPSK	16-QAM	64-QAM	256-QAM
1	Y	Y	Y	Y
2	Y	Y	Y	
3	Y	Y	Y	Y
4	Y		Y	
5	Y	Y	Y	Y
6	Y	Y	Y	
9	Y	Y	Y	Y
10	Y	Y	Y	
12	Y		Y	
15	Y	Y	Y	Y
18	Y	Y	Y	
20	Y		Y	
27	Y	Y	Y	Y
30	Y	Y	Y	
36	Y		Y	
45	Y	Y	Y	Y
54	Y	Y	Y	
60	Y		Y	
81	Y	Y		Y
90	Y	Y	Y	
108	Y		Y	
135	Y	Y	Y	Y
162	Y	Y		
180	Y		Y	
270	Y	Y	Y	
324	Y			
405	Y	Y		Y
540	Y		Y	
810	Y	Y		
1 620	Y			

Table B.2: List of values for number of sub-slices which may be used with any combination of PLPs

1	3	5	9	15	27	45	135

Annex C (normative): Input stream synchronizer and receiver buffer model

C.1 Input stream synchronizer

Delays and packet jitter introduced by DVB-NGH modems may depend on the transmitted bit-rate and may change in time during bit and/or code rate switching. The "Input Stream Synchronizer" (see figure C.1) shall provide a mechanism to regenerate, in the receiver, the clock of the Transport Stream (or packetized Generic Stream) at the modulator Mode Adapter input, in order to guarantee end-to-end constant bit rates and delays. Table C.1 gives the details of the coding of the ISSY field generated by the input stream synchronizer.

When ISSYI = 1 in MATYPE field (see clause 5.1.6) a counter shall be activated (22 bits), clocked by the modulator sampling rate (frequency $R_s=1/T$, where T is defined in clause 11.4). The Input Stream SYnchronization field (ISSY, 3 bytes) shall be transmitted according to clause 5.1.7.

ISSY shall be coded according to table C.1, sending the following variables:

- ISCR (short: 15 bits; long: 22 bits) (ISCR = Input Stream Clock Reference), loaded with the LSBs of the counter content at the instant the relevant input packet is processed (at constant rate R_{IN}), and specifically the instant the MSB of the relevant packet arrives at the modulator input stream interface. In case of continuous streams the content of the counter is loaded when the MSB of the Data Field is processed.

  ISCR shall be transmitted in the third ISSY field of each Interleaving Frame for each PLP. Where applicable, ISCR shall be transmitted in all subsequent ISSY fields of each Interleaving Frame for each PLP. In HEM, for BBFrames for which no UP begins in the Data Field, ISCR is not applicable and BUFS shall be sent instead (see below).

  Two successive ISCR values shall not correspond to time instants separated by more than $2^{15}T$ for $ISCR_{short}$ or $2^{22}T$ for $ISCR_{long}$. This may be achieved by using Normal Mode and/or transmitting null packets which would normally be deleted, as necessary.

  In a given PLP, either $ISCR_{short}$ or $ISCR_{long}$ shall be used, together with the short or long versions respectively of BUFS and TTO. A PLP shall not change from short to long ISSY except at a reconfiguration.

  In HEM, $ISCR_{long}$ shall always be used.

- BUFS (2+10 bits) (BUFS = maximum size of the requested receiver buffer to compensate delay variations). This variable indicates the size of the receiver buffer assumed by the modulator for the relevant PLP. It shall have a maximum value of 2 Mbits. When a group of data PLPs share a common PLP, the sum of the buffer size for any data PLP in the group plus the buffer size for the common PLP shall not exceed 2 Mbits. BUFS shall be transmitted in the second ISSY field of each Interleaving Frame for each PLP. In HEM, BUFS shall also be transmitted for BBFrames for which no UP begins in the Data Field.

- TTO (7/15 bits mantissa + 5 bits exponent). This provides a mechanism to manage the de-jitter buffer in DVB-T2. The value of TTO is transmitted in a mantissa+exponent form and is calculated from the transmitted fields TTO_M, TTO_L and TTO_E by the formula: $TTO=(TTO\_M+TTO\_L/256)\times 2^{TTO\_E}$. If $ISCR_{short}$ is used, TTO_L is not sent and shall equal zero in the above calculation.

TTO defines the time, in units of *T* (see clause 11.4), between the beginning of the P1 symbol of the first T2-frame to which the Interleaving Frame carrying the relevant User Packet is mapped, and the time at which the MSB of the User Packet should be output, for a receiver implementing the model defined in clause C.2. This value may be used to set the receiver buffer status during reception start-up procedure, and to verify normal functioning in steady state. TTO shall be transmitted in the first ISSY field of each Interleaving Frame for each PLP in High Efficiency Mode, and in the first complete packet of the Interleaving Frame in Normal Mode.

- The ISSY code 0xEXXXXX shall not be transmitted in DVB-NGH. This range of codes transmitted BUFSTAT in DVB-S2 [**Error! Reference source not found.**], but this parameter is replaced by TTO in DVB-NGH.

Each Interleaving Frame for each PLP shall carry a TTO, a BUFS and at least one ISCR field.

NOTE 1: This requires that there are always at least three ISSY fields in every Interleaving Frame. It might be necessary to use short FEC blocks and/or Normal Mode in order to ensure that this is the case. Furthermore, both TTO and ISCR apply to a transmitted User Packet and so it might be necessary to transmit a null packet which would otherwise be deleted to provide a packet for the ISSY field to refer to.

The choice of the parameters of a DVB-NGH system and the use of TTO shall be such that, if a receiver obeys the TTO signalling and implements the model of buffer management defined in clause C.1.1, the receiver's de-jitter buffer and time de-interleaver memory and frequency de-interleaver shall neither overflow nor underflow as defined in clause C.2.3.

NOTE 2: Particular attention should be paid to the frame length, the PLP type, the number of sub-slices per frame, the number of TI-blocks per interleaving frame and number of NGH frames to which an interleaving frame is mapped, the scheduling of sub-slices within the frame, the peak bit-rate, and the frequency and duration of FEFs.

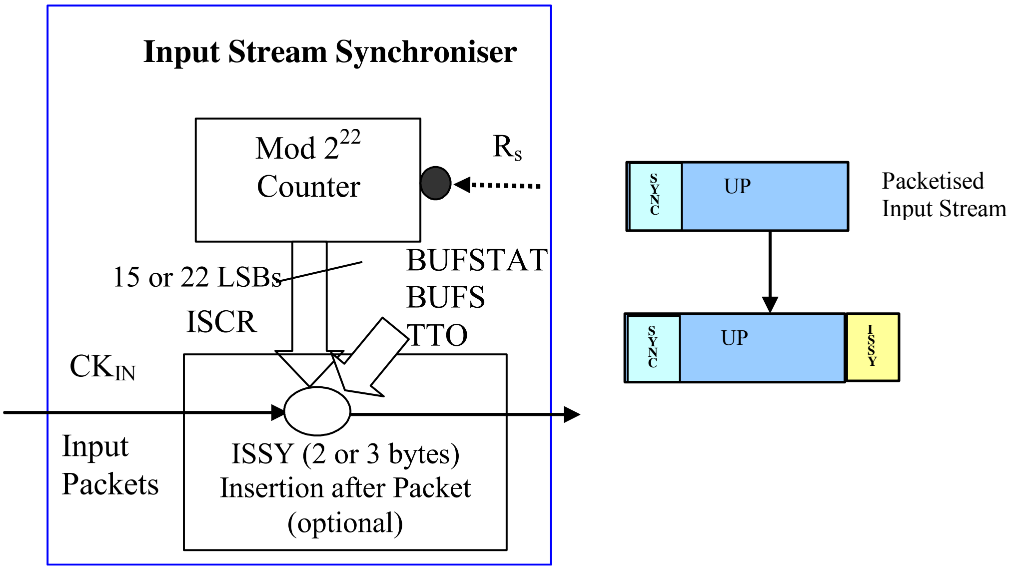


Figure C.1: Input stream synchronizer block diagram

Table C.1: ISSY field coding (3 bytes)

First Byte					Second Byte	Third Byte
bit-7 (MSB)	**bit-6**	**bit-5 and bit-4**	**bit-3 and bit-2**	**bit-1 and bit-0**	**bit-7 to bit-0**	**bit-7 bit-0**
0 = ISCR$_{short}$	MSB of ISCR$_{short}$	next 6 bits of ISCR$_{short}$			next 8 bits of ISCR$_{short}$	not present
1	0 = ISCR$_{long}$	6 MSBs of ISCR$_{long}$			next 8 bits of ISCR$_{long}$	next 8 bits of ISCR$_{long}$
1	1	00 = BUFS	BUFS unit 00 = bits 01 = Kbits 10 = Mbits 11 = 8Kbits	2 MSBs of BUFS	next 8 bits of BUFS	not present when ISCR$_{short}$ is used; else reserved for future use
1	1	01 = TTO	4 MSBs of TTO_E		Bit 7:LSB of TTO_E Bit 6-Bit0: TTO_M	not present when ISCR$_{short}$ is used; else TTO_L
1	1	others = reserved for future use	reserved for future use	Reserved for future use	Reserved for future use	not present when ISCR$_{short}$ is used; else reserved for future use

C.2 Receiver buffer model

The purpose of the receiver buffer model presented in this annex is to specify limits on the maximum decoding rate of the FEC chain (executing the IQ de-interleaving, de-rotation, cell de-interleaving, demapping, de-puncturing and de-shortening, bit de-interleaving, LDPC decoding, BCH decoding and BBF descrambling) and the maximum storage capabilities of the de-jitter buffer. An NGH signal compliant with the model will therefore be processed correctly by any receiver.

The following points need to be considered for the definition of the receiver buffer model:

- It is assumed that the most critical requirements on the throughput of the input streams are due to the FEC chain and the de-jitter buffer, as exposed in this section, while all further modules (like frame extractor, stream de-adaptation etc.) are able to process all signals that comply to these critical requirements.
- For the sake of simplicity, the processing delay for all modules is assumed to be zero, i.e. the output is generated immediately when all necessary data has been input. Of course, reading the input and outputting the result is carried out at a finite rate, if the input and/or output for one module execution consists of multiple symbols. For the time de-interleaver, FEC chain and de-jitter buffer, these rates are stated below, for all other modules, the rates are irrelevant in the context of this model and can be assumed infinite.
- Some simplifications (e.g. processing/decoding of L1 signalling in zero time, and L1 signalling is not taken into account in the required decoding rate) and approximations (e.g. ignored padding of sub-slices, ignored that the size of the TI blocks in the same Interleaving Frame from a PLP can differ by 1 FEC block) have been used.
- To IGs: Therefore, receiver manufacturers should include an adequate margin in their implementation above the maximum decoding rate and de-jitter buffer size specified here.

C2.1 Modelling of the PLP cell streams

The PLPs can be sorted according to their appearance in the Logical Frames. According to their order, they can be assigned a sorting index > 1 (that remains the same over time and that is in general different from the PLP_ID), such that the following becomes true for any pair of PLPs A and B with sorting indices i and j, respectively:

If $j \leq i$, then the last cell of PLP B in an LF is transmitted earlier or at the same time (in units of OFDM symbols) as the last cell of PLP A in the same LF. This relationship is true for all LFs, which carry cells from both PLPs A and B.

Whenever an index for a PLP is used in the Receiver Buffer Model chapter, this represents the associated sorting index (not the PLP_ID). Change from sorting index to PLP_ID.

Note: PLPs with $I_{\mathrm{JUMP}} =$ PLP_LF_INTERVAL > 1 are not carried in every LF.

Let $N_{\mathrm{codebits}}(n, i)$ represent the number of code bits that the LDPC encoder generates for PLP i in the uninterleaved logical frame n. Moreover, let $N_{\mathrm{cells,map}}(n, i) = \frac{N_{\mathrm{codebits}}(n,i)}{R_M}$ represent the corresponding number of mapped cells, where the modulation rate R_M represents the number of mapped bits per constellation (e.g. $R_M = 4$ for 16-QAM).

Note: An uninterleaved logical frame n is the collection of all interleaving frames from all PLPs, whose cells are transmitted in LF n and possibly the following LFs.

The case that a PLP does not use time interleaving, i.e. TIME_IL_LENGTH=0 (see clause 6.6.5), is treated further below. In the rest of this sub-section, the use of time interleaving is assumed.

The simplified model of the time interleaver used in this receiver buffer model operates as follows:

Let $M(i, \delta)$ represent the number of interleaver delays of value δ for PLP i (cf. clause 6.6.3) , i.e. there are $M(i, \delta)$ indices k with $D(k) = \delta$. Hence, it follows that $\sum_{\delta=0}^{\infty} M(i, \delta) = N_{\mathrm{IU}}$.

Then the number of cells transmitted from the modulator and received in the demodulator for PLP i and in Logical Frame n is:

$$N_{\mathrm{cells,rec}}(n, i) = \sum_{\delta} N_{\mathrm{cells,map}}(n - \delta, i) \cdot \frac{M(i, \delta)}{N_{\mathrm{IU}}}$$

Next, let $N_{\mathrm{cells,rec,acc}}(n, i) = \sum_{j \leq i} N_{\mathrm{cells,rec}}(n, j)$ represent the accumulated number of cells received in LF n over all PLPs j of PLP types 1, 2, or 3 with $j \leq i$ (i.e. last cell is transmitted/received earlier or simultaneously to PLP i).

When the modulator is currently generating LF n, the values for future LFs $n + \delta$ ($\delta > 0$) is in general still unknown. Instead, a lower bound $N_{\mathrm{cells,rec,acc,min}}(n,\ \delta, i)$ is introduced that has the following meaning: in LF n the modulator can forecast, that $N_{\mathrm{cells,rec,acc}}(n + \delta, i)$ cannot fall below $N_{\mathrm{cells,rec,acc,min}}(n, \delta, i)$.

As a worst case, this bound can be calculated by using the minimum possible value of $N_{\mathrm{codebits}}(m, j)$ for all future LFs m with $n < m \leq n + \delta$ and all PLPs $j \leq i$. However, in general the number of bits per uninterleaved logical frame goes up for one PLP, when it drops for another PLP, such that a more *realistic* lower bound is significantly above this worst case bound.

Let I_1 and I_2 be the maximum sorting index of the PLPs of types 1 and of type 2, respectively. If there are no PLPs of type 1, the value $I_1 = 0$ is used in the sequel.

Then $N_{\text{cells,rec,acc}}(n, I_2)$ is the number of received cells belonging to PLPs of type 1 and 2 in LF n. Similarly, the number of cells belonging to type 1 and 2 in LF $n+\delta$ cannot drop below $N_{\text{cells,rec,acc,min}}(n,\ \delta, I_2)$.

The number of received cells from PLPs of type 2 in LF n is $N_{\text{cells,rec,acc}}(n, I_2) - N_{\text{cells,rec,acc}}(n, I_1)$.

The basic assumption is that the decoding of a TI block of PLP i starts immediately after the reception of its last cell in LF n at time $t_{\text{dec,start}}(n, i)$, and then the decoding is carried out at a constant decoding rate $R_{\text{codebits,rec}}(n, i)$ (LDPC code bits per second). The decoding has to be complete latest when the last cell of the next TI block of PLP i is received at time $t_{\text{dec,end}}(n, i)$, hence the time available for decoding is $t_{\text{dec,end}}(n, i) - t_{\text{dec,start}}(n, i)$.

The requirement for decoding the last TI block of a PLP in an LF is less demanding than that for the other TI blocks, therefore we will consider the max. required decoding rate for these other TI blocks.

Case $\mathbf{N_{TI}} > 1$, PLP *i* is of type 1 or 3:

If PLP i uses multiple TI blocks per Interleaving Frame ($N_{\text{TI}} > 1$), then the next TI block of PLP i is transmitted in the same LF as the preceding TI block. The following time span can be used for decoding:

$$t_{\text{dec,end,min}}(n, i) - t_{\text{dec,start}}(n, i) = N_{\text{cells,rec}}(n, i)/N_{\text{TI}} \cdot T_{\text{cell}}$$

where $t_{\text{dec,end,min}}(n, i)$ is a lower bound on $t_{\text{dec,end}}(n, i)$ (in this case: identical) and T_{cell} is the average time for the reception of one PLP cell.

Note: For $N_{\text{TI}} > 1$, the time-interleaver uses delay zero for all codebits, i.e. there is no inter-frame interleaving.

Case $\mathbf{N_{TI}} > 1$, PLP *i* is of type 2, N_{TI} is an integer multiple > 1 of $N_{\text{sub-slices\_total}}$:

$N_{\text{sub-slices\_total}}$ represents the total number of sub-slices (see clause 9.2.2.2.2). In this case, the following equation is obtained

$$t_{\text{dec,end,min}}(n, i) - t_{\text{dec,start}}(n, i) = N_{\text{cells,rec}}(n, i)/N_{\text{TI}} \cdot T_{\text{cell}}$$

Case $\mathbf{N_{TI}} > 1$, PLP *i* is of type 2, else:

The following lower bound for the available decoding time can be used

$$\begin{aligned} t_{\text{dec,end,min}}(n, i) &- t_{\text{dec,start}}(n, i) \\ &= \left(\left\lfloor \frac{N_{\text{sub-slices\_total}}}{N_{\text{TI}}} \right\rfloor \cdot \frac{N_{\text{cells,rec,acc}}(n, I_2) - N_{\text{cells,rec,acc}}(n, I_1)}{N_{\text{sub-slices\_total}}} + \text{frac}\left(\frac{N_{\text{sub-slices\_total}}}{N_{\text{TI}}}\right) \right. \\ &\quad \left. \cdot N_{\text{cells,rec}}(n, i) \right) \cdot T_{\text{cell}} \end{aligned}$$

where $\text{frac}(x)$ is the fractional part of x, i.e. $\text{frac}(x) = x - \lfloor x \rfloor$.

Example: There are two PLPs (i and j) of type 2, and there are $N_{\text{sub-slices\_total}} = 8$ sub-slices. The considered PLP i has $N_{\text{TI}} = 3$ TI blocks, such that each TI block occupies 8/3 sub-slices of PLP i. As figure C.2 displays, the time for transmitting the cells of a TI block differs between TI blocks 0 and 2 and TI block 1. The above equation uses the approximation that each TI block of PLP i stretches over at least over $\lfloor N_{\text{sub-slices\_total}}/N_{\text{TI}} \rfloor = 2$ full sub-slices (including cells from all type 2 PLPs – here i and j) plus

$\text{frac}\left(\frac{N_{\text{sub-slices\_total}}}{N_{\text{TI}}}\right) = 2/3$ of the cells of a TI block. Observe that TI blocks 0 and 2 stretch exactly over the calculated time span, while TI block 1 is longer than this lower bound.

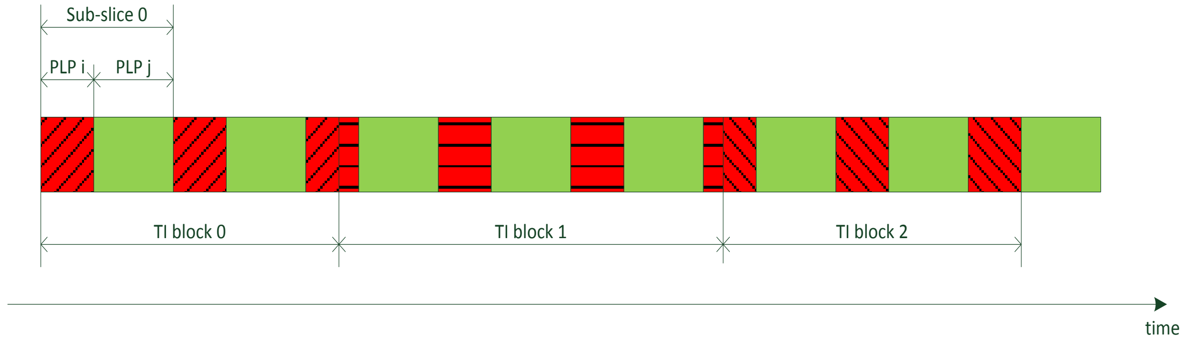


Figure C.2: Type 2 PLP with 8 sub-slices and 3 TI blocks

Case $\mathbf{N_{TI} = 1}$, PLP i is of type 1 or 3:

In this case, the next TI block is TI block 0 in LF $n + I_{\text{jump}}$, where I_{JUMP} = PLP_LF_INTERVAL denotes the time slicing cycle length of PLP i.

Let $t_{\text{FS}}(n)$ represent the frame starting time of LF n. Based on this value and on $N_{\text{cells,rec,acc}}(n, i)$ and taking the time scheduling of the LFs into account, the time $t_{\text{last}}(n, i)$ of the reception of PLP i's last cell in LF n can be calculated using the average time T_{cell} for the reception of one PLP cell.

In case that LF start and last cell of PLP i of LF n reside in the same NGH frame (see clause 9.4), this time is

$$t_{\text{last}}(n, i) = t_{\text{FS}}(n) + \Delta t_{\text{pre}} + N_{\text{cells,rec,acc}}(n, i) \cdot T_{\text{cell}}$$

where Δt_{pre} is the time occupied by the preambles and L1 signalling, i.e. the time between the frame start and the first cell of a type 1 PLP.

If the last cell of PLP i of LF n is in a different NGH frame than the LF start (only possible for channel types B and C), then the time gap between these two NGH frames has to be included in the above equation.

Based on $N_{\text{cells,rec,acc,min}}(n,\ I_{\text{jump}}, i)$, a similar calculation can be done for the earliest time of receiving the last cell of PLP i in LF $n + I_{\text{jump}}$:

$$t_{\text{last,min}}(n, I_{\text{jump}}, i) = t_{\text{FS}}(n + I_{\text{jump}}) + \Delta t_{\text{pre}} + N_{\text{cells,rec,acc,min}}(n, I_{\text{jump}}, i) \cdot T_{\text{cell}}$$

Therefore the time difference that can be used for decoding is

$$t_{\text{dec,end,min}}(n, i) - t_{\text{dec,start}}(n, i) = t_{\text{last,min}}(n, I_{\text{jump}}, i) - t_{\text{last}}(n, i)$$

In the case of PLP i residing in the same NGH frames as the frame starts, it turns out that:

$$\begin{aligned} t_{\text{dec,end,min}}(n, i) - t_{\text{dec,start}}(n, i) \\ = t_{\text{FS}}(n + I_{\text{jump}}) - t_{\text{FS}}(n) + (N_{\text{cells,rec,acc,min}}(n, I_{\text{jump}}, i) - N_{\text{cells,rec,acc}}(n, i)) \cdot T_{\text{cell}} \end{aligned}$$

Note: $t_{\text{FS}}(n + I_{\text{jump}}) - t_{\text{FS}}(n) = I_{\text{jump}} \cdot T_{\text{LF}}$ in case that the time distance between frame starts is a constant T_{LF}.

Case $\mathrm{N_{TI}} = 1$, PLP i is of type 2:

As sub-slicing mixes all type 2 PLPs, for the case that LF start and last cell of PLP i reside in the same NGH frame, $t_{\text{last}}(n,i)$ is calculated as follows:

$$t_{\text{last}}(n,i) = t_{\text{FS}}(n) + \Delta t_{\text{pre}} + \frac{1}{N_{\text{sub-slices\_total}}}\left(\left(N_{\text{sub-slices\_total}} - 1\right) \cdot N_{\text{cells,rec,acc}}(n, I_2) + N_{\text{cells,rec,acc}}(n,i)\right) \cdot T_{\text{cell}}$$

Again, the time gap has to be taken into account, if the last cell of PLP i of LF n is in a different NGH frame than the LF start.

Similarly, the following is obtained (if LF start and last cell are in the same NGH frame)

$$t_{\text{last,min}}\left(n, I_{\text{jump}}, i\right) = t_{\text{FS}}\left(n + I_{\text{jump}}\right) + \Delta t_{\text{pre}} + \frac{1}{N_{\text{subslices\_total}}}\left(\left(N_{\text{sub-slices\_total}} - 1\right) \cdot N_{\text{cells,rec,acc,min}}\left(n, I_{\text{jump}}, I_2\right) + N_{\text{cells,rec,acc,min}}\left(n, I_{\text{jump}}, i\right)\right) \cdot T_{\text{cell}}$$

and again

$$t_{\text{dec,end,min}}(n,i) - t_{\text{dec,start}}(n,i) = t_{\text{last,min}}\left(n, I_{\text{jump}}, i\right) - t_{\text{last}}(n,i)$$

C.2.2 Decoding rate limit

In any of the above cases, the required decoding rate for decoding those FEC blocks of PLP i, whose last cell is received in LF n, can be upper bounded by

$$R_{\text{codebits,rec}}(n,i) \le R_{\text{codebits,rec,max}}(n,i) \triangleq \frac{N_{\text{codebits}}(n - L_{\text{TI}}(i) + 1, i)}{N_{\text{TI}} \cdot \left(t_{\text{dec,end,min}}(n,i) - t_{\text{dec,start}}(n,i)\right)}$$

where $L_{\text{TI}}(i)$ is the duration of PLP i's time interleaver in units of LFs (see clause 6.6.3).

In case (n – PLP_FIRST_LF_IDX) mod $I_{\text{jump}} \neq 0$ (with the parameter PLP_FIRST_LF_IDX of PLP i defined in clause 8.1.3.1), i.e. no time slice of PLP i is transmitted in LF n (cf. section 9.3), the applicable max. decoding rate is $R_{\text{codebits,rec,max}}(m,i)$, where is the most recent LF with (m – PLP_FIRST_LF_IDX) mod $I_{\text{jump}} = 0$ (previous time slice).

In case that $I_{\text{jump}} > 1$ for PLP i, and that LF n does not carry any cells of this PLP, then the max. required decoding rate is equal to that calculated for the most recent LF, which carries cells of PLP i.

Note 1: I_{jump} and N_{TI} are a PLP-specific parameter. Use of PLP index parameter i has been omitted for the sake of readability.

Note 2: The max. required decoding rate given above is calculated based on TI block 0, but all further TI blocks (for $N_{\text{TI}} > 1$) require only a lower or equal decoding rate.

If time interleaving is not used (i.e. TIME_IL_LENGTH=0), the maximum required decoding rate is

$$R_{\text{codebits,rec,max}}(n,i) \triangleq R_M / T_{\text{cell}}$$

and decoding starts already, when the last cell of the first FEC block has been received in LF n.

The FEC chain performs the appropriate subset of the operations of IQ de-interleaving, de-rotation, cell de-interleaving, soft demapping, de-puncturing and de-shortening, bit-deinterleaving, LDPC decoding, BCH decoding and BBF descrambling.

It is assumed that the FEC chain of any receiver is able to decode at a rate of 12 million codebits per second. Therefore, the modulator shall not transmit any signal, where the sum of the decoding rates over all PLPs in a PLP cluster exceeds 12 Mbit/s:

$$\sum_i R_{\text{codebits,rec,max}}(n,i) \leq 12 \text{ Mbit/s}$$

where the sum is over all PLPs in a PLP cluster.

Note: the concerned PLPs may differ in their values of parameters $N_{\text{TI}}(i)$, $I_{\text{jump}}(i)$ and $L_{\text{TI}}(i)$.

The operation of the time de-interleaver is independent of the current filling state of the de-jitter buffer.

C.2.3 De-jitter buffer

When ISSY is used (i.e. ISSYI=1), the following model of the de-jitter buffer applies. If ISSY is not used, it is assumed that the BBF decoded by the FEC chain are input immediately to the BBF decapsulator, such that the de-jitter buffer cannot overflow.

For the sake of simplicity, it is assumed that LDPC and BCH decoding are carried out with zero processing delay and that the complete decoding result is written to the de-jitter buffer (DJB) in zero time. Decoding of PLP i starts, once its last cell has been received in an LF, and subsequent decodings take place at intervals of $16200/R_{\text{codebits,rec,max}}(n,i)$ seconds.

For writing the decoded BBFs into the DJB, their data field bits are converted to a canonical form, independent of the mode adaptation options in use. The canonical form is equivalent to Normal Mode with 3-byte ISSY and NPD enabled (see clause ???). Bits are read out from the DJB according to a read clock; removed sync bytes and deleted null packets (TS cases) are re-inserted at the output of the de-jitter buffer.

include Decompression

When the receiver is decoding a PLP cluster with multiple PLPs, it shall be assumed that the Time De-interleaver, the FEC chain and the DJB are present once for each PLP as shown in figure C.3, such that all PLPs can be processed in parallel.

NOTE: This is only a conceptional assumption. In a real implementation all time de-interleavers will share a single memory, there is only a single FEC chain and all DJBs will share a single memory. Processing is done in time-multiplexing.

The following assumptions shall be made about the DJB:

- The de-jitter buffer will initially discard all input bits until it receives a bit for which a value of TTO is indicated.
- Subsequent input bits will be written to the de-jitter buffer, except that the de-jitter buffer will discard the initial 80 bits of each FEC block (corresponding to the BBHDR), and all of the bits following the DFL payload bits. In order to allow for the canonical form described above, for every remaining bit that is output from the FEC chain, (O-UPL+24)/UPL bits are stored in the de-jitter buffer (where O-UPL is the original user packet length defined in clause ??? and UPL is the transmitted user packet length as defined in clause ???).
- No bits will be output until the time indicated by the value of TTO for the first bit written.

- The bits will then be read and output from the de-jitter buffer at a constant rate calculated from the received ISCR values, using a read clock generated from a recovered clock perfectly synchronized to the modulator's sampling rate clock.
- The total size of the de-jitter buffer memory is 2 Mbits. For any PLP cluster, the overall sum of the buffer sizes for the PLPs in the PLP cluster shall not exceed 2 Mbits.
- Sync bytes will not be stored in the DJB; they will be reinserted at the DJB output (TS cases).

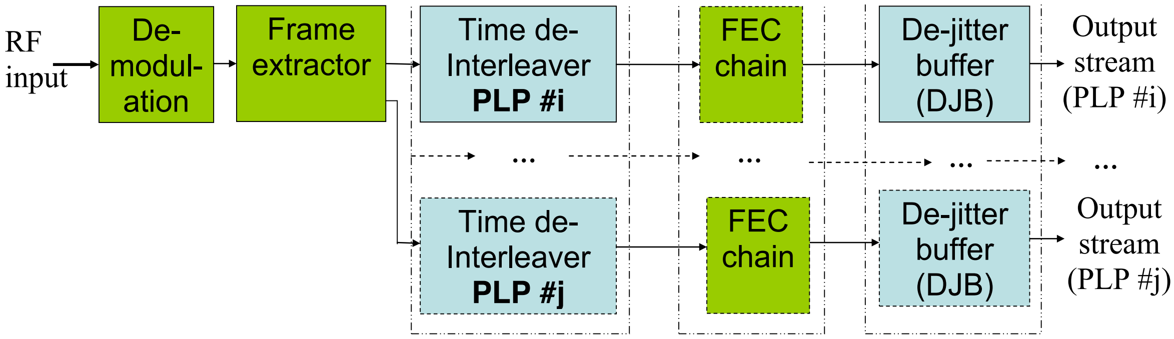


Figure C.3: Receiver buffer model

The modulator shall output only signals that do not lead to an underflow or overflow of the DJB.

The following features of a real receiver need not be taken into account by the modulator and should be considered by receiver implementers when interpreting the TTO values and choosing the exact size of the memory to allocate to the de-jitter buffer:

- Additional delays incurred in the various processing stages for practical reasons.
- Error in the regenerated output read-clock frequency and phase.
- Adjustments made to the read-clock frequency and phase in order to track successive ISCR and TTO values. A possible mechanism for doing this is outlined in annex C above.
- The limited precision of the TTO signalling.
- The delay of N_{P2} symbols implicit in the frequency/L1 de-interleaver behaviour
-

Annex D (normative):
Calculation of the CRC word

The implementation of Cyclic Redundancy Check codes (CRC-codes) allows the detection of transmission errors at the receiver side. For this purpose CRC words shall be included in the transmitted data. These CRC words shall be defined by the result of the procedure described in this annex.

A CRC code is defined by a polynomial of degree *n*:

$$G_n(x) = x^n + g_{n-1}x^{n-1} + \ldots + g_2x^2 + g_1x + 1$$

with $n \geq 1$ and: $g_i \in \{0,1\}, \quad i = 1....n-1$

The CRC calculation may be performed by means of a shift register containing *n* register stages, equivalent to the degree of the polynomial (see figure D.1). The stages are denoted by b_0... b_{n-1}, where b_0 corresponds to 1, b_1 to *x*, b_2 to x^2,..., b_{n-1} to x^{n-1}. The shift register is tapped by inserting XORs at the input of those stages, where the corresponding coefficients g_i of the polynomial are '1'.

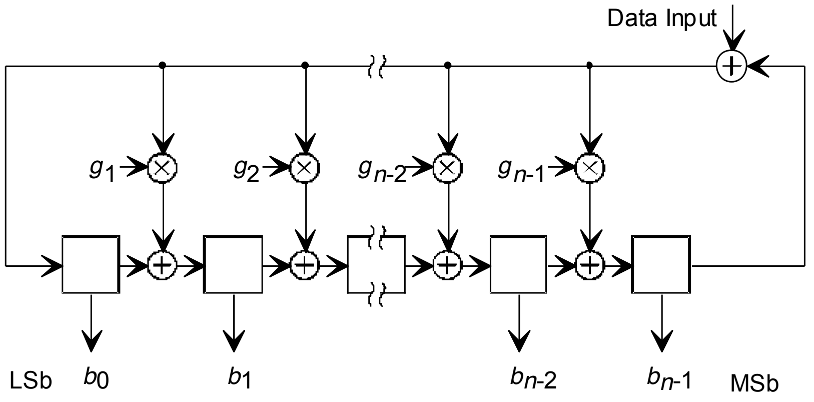


Figure D.1: General CRC block diagram

At the beginning of the CRC-8 calculation (used for TS, ISSY-UP mode only and BBF-HDR), all register stage contents are initialized to zeros.

At the beginning of the CRC-32 calculation (used for the L1-PRE and L1-POST signalling), all register stage contents are initialized to ones.

After applying the first bit of the data block (MSB first) to the input, the shift clock causes the register to shift its content by one stage towards the MSB stage (b_{n-1}), while loading the tapped stages with the result of the appropriate XOR operations. The procedure is then repeated for each data bit. Following the shift after applying the last bit (LSB) of the data block to the input, the shift register contains the CRC word which is then read out. Data and CRC word are transmitted with MSB first.

The CRC codes used in the DVB-NGH system are based on the following polynomials:

- $G_{32}(x) = x^{32} + x^{26} + x^{23} + x^{22} + x^{16} + x^{12} + x^{11} + x^{10} + x^8 + x^7 + x^5 + x^4 + x^2 + x + 1$
- $G_8(x) = x^8 + x^7 + x^6 + x^4 + x^2 + 1$

The assignment of the polynomials to the respective applications is given in each clause.

NOTE: The CRC-32 coder defined in this annex is identical to the implicit encoder defined in [**Error! Reference source not found.**].

Annex E:
Addresses of parity bit accumulators for N_{ldpc} = 16 200

Example of interpretation of the table E.3.

$$p_{416} = p_{416} \oplus i_0 \quad p_{8909} = p_{8909} \oplus i_0 \quad p_{4156} = p_{4156} \oplus i_0 \quad p_{3216} = p_{3216} \oplus i_0 \quad p_{3112} = p_{3112} \oplus i_0$$

$$p_{2560} = p_{2560} \oplus i_0 \quad p_{2912} = p_{2912} \oplus i_0 \quad p_{6405} = p_{6405} \oplus i_0 \quad p_{8593} = p_{8593} \oplus i_0 \quad p_{4969} = p_{4969} \oplus i_0$$

$$p_{6723} = p_{6723} \oplus i_0 \quad p_{6912} = p_{6912} \oplus i_0$$

$p_{446} = p_{446} \oplus i_1 \quad p_{8939} = p_{8939} \oplus i_1 \quad p_{4186} = p_{4186} \oplus i_1 \quad p_{3246} = p_{3246} \oplus i_1 \quad p_{3142} = p_{3142} \oplus i_1$

$p_{2590} = p_{2590} \oplus i_1 \quad p_{2942} = p_{2942} \oplus i_1 \quad p_{6435} = p_{6435} \oplus i_1 \quad p_{8623} = p_{8623} \oplus i_1 \quad p_{4999} = p_{4999} \oplus i_1$

$p_{6753} = p_{6753} \oplus i_1 \quad p_{6942} = p_{6942} \oplus i_1$

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$p_{386} = p_{386} \oplus i_{359} \quad p_{8879} = p_{8879} \oplus i_{359} \quad p_{4126} = p_{4126} \oplus i_{359} \quad p_{3186} = p_{3186} \oplus i_{359} \quad p_{3082} = p_{3082} \oplus i_{359}$

$p_{2530} = p_{2530} \oplus i_{359} \quad p_{2882} = p_{2882} \oplus i_{359} \quad p_{6375} = p_{6375} \oplus i_{359} \quad p_{8563} = p_{8563} \oplus i_{359} \quad p_{4939} = p_{4939} \oplus i_{359}$

$p_{6693} = p_{6693} \oplus i_{359} \quad p_{6882} = p_{6882} \oplus i_{359}$

$p_{8978} = p_{8978} \oplus i_{360} \quad p_{3011} = p_{3011} \oplus i_{360} \quad p_{4339} = p_{4339} \oplus i_{360} \quad p_{9312} = p_{9312} \oplus i_{360} \quad p_{6396} = p_{6396} \oplus i_{360}$

$p_{2957} = p_{2957} \oplus i_{360} \quad p_{7288} = p_{7288} \oplus i_{360} \quad p_{5485} = p_{5485} \oplus i_{360} \quad p_{6031} = p_{6031} \oplus i_{360} \quad p_{10218} = p_{10218} \oplus i_{360}$

$p_{2226} = p_{2226} \oplus i_{360} \quad p_{3575} = p_{3575} \oplus i_{360}$

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Table E.1: Rate 3/15 (N_{ldpc} = 16 200)

6295 9626 304 7695 4839 4936 1660 144 11203 5567 6347 12557
10691 4988 3859 3734 3071 3494 7687 10313 5964 8069 8296 11090
10774 3613 5208 11177 7676 3549 8746 6583 7239 12265 2674 4292
11869 3708 5981 8718 4908 10650 6805 3334 2627 10461 9285 11120
7844 3079 10773
3385 10854 5747
1360 12010 12202
6189 4241 2343
9840 12726 4977

Table E.2: Rate 4/15 (N_{ldpc} = 16 200)

1953 2331 2545 2623 4653 5012 5700 6458 6875 7605 7694 7881 8416 8758 9181 9555 9578 9932 10068 11479 11699
514 784 2059 2129 2386 2454 3396 5184 6624 6825 7533 7861 9116 9473 9601 10432 11011 11159 11378 11528 11598
483 1303 1735 2291 3302 3648 4222 4522 5511 6626 6804 7404 7752 7982 8108 8930 9151 9793 9876 10786 11879
1956 7572 9020 9971
13 1578 7445 8373
6805 6857 8615 11179
7983 8022 10017 11748
4939 8861 10444 11661
2278 3733 6265 10009
4494 7974 10649
8909 11030 11696
3131 9964 10480

Table E.3: Rate 5/15 (N_{ldpc} = 16 200)

416 8909 4156 3216 3112 2560 2912 6405 8593 4969 6723 6912
8978 3011 4339 9312 6396 2957 7288 5485 6031 10218 2226 3575
3383 10059 1114 10008 10147 9384 4290 434 5139 3536 1965 2291
2797 3693 7615 7077 743 1941 8716 6215 3840 5140 4582 5420
6110 8551 1515 7404 4879 4946 5383 1831 3441 9569 10472 4306
1505 5682 7778
7172 6830 6623
7281 3941 3505
10270 8669 914
3622 7563 9388
9930 5058 4554
4844 9609 2707
6883 3237 1714
4768 3878 10017
10127 3334 8267

Table E.4: Rate 6/15 (N_{ldpc} = 16 200)

5650 4143 8750 583 6720 8071 635 1767 1344 6922 738 6658
5696 1685 3207 415 7019 5023 5608 2605 857 6915 1770 8016
3992 771 2190 7258 8970 7792 1802 1866 6137 8841 886 1931
4108 3781 7577 6810 9322 8226 5396 5867 4428 8827 7766 2254
4247 888 4367 8821 9660 324 5864 4774 227 7889 6405 8963
9693 500 2520 2227 1811 9330 1928 5140 4030 4824 806 3134
1652 8171 1435
3366 6543 3745
9286 8509 4645
7397 5790 8972
6597 4422 1799
9276 4041 3847
8683 7378 4946
5348 1993 9186
6724 9015 5646
4502 4439 8474
5107 7342 9442
1387 8910 2660

Table E.5: Rate 7/15 (N_{ldpc} = 16 200)

3 137 314 327 983 1597 2028 3043 3217 4109 6020 6178 6535 6560 7146 7180 7408 7790 7893 8123 8313 8526 8616 8638
356 1197 1208 1839 1903 2712 3088 3537 4091 4301 4919 5068 6025 6195 6324 6378 6686 6829 7558 7745 8042 8382 8587 8602
18 187 1115 1417 1463 2300 2328 3502 3805 4677 4827 5551 5968 6394 6412 6753 7169 7524 7695 7976 8069 8118 8522 8582
714 2713 2726 2964 3055 3220 3334 3459 5557 5765 5841 6290 6419 6573 6856 7786 7937 8156 8286 8327 8384 8448 8539 8559
3452 7935 8092 8623
56 1955 3000 8242
1809 4094 7991 8489
2220 6455 7849 8548
1006 2576 3247 6976
2177 6048 7795 8295
1413 2595 7446 8594
2101 3714 7541 8531
10 5961 7484
3144 4636 5282
5708 5875 8390
3322 5223 7975
197 4653 8283
598 5393 8624
906 7249 7542
1223 2148 8195
976 2001 5005

Table E.6: Rate 8/15 (N_{ldpc} = 16 200)

32 384 430 591 1296 1976 1999 2137 2175 3638 4214 4304 4486 4662 4999 5174 5700 6969 7115 7138 7189
1788 1881 1910 2724 4504 4928 4973 5616 5686 5718 5846 6523 6893 6994 7074 7100 7277 7399 7476 7480 7537
2791 2824 2927 4196 4298 4800 4948 5361 5401 5688 5818 5862 5969 6029 6244 6645 6962 7203 7302 7454 7534
574 1461 1826 2056 2069 2387 2794 3349 3366 4951 5826 5834 5903 6640 6762 6786 6859 7043 7418 7431 7554
14 178 675 823 890 930 1209 1311 2898 4339 4600 5203 6485 6549 6970 7208 7218 7298 7454 7457 7462
4075 4188 7313 7553
5145 6018 7148 7507
3198 4858 6983 7033
3170 5126 5625 6901
2839 6093 7071 7450
11 3735 5413
2497 5400 7238
2067 5172 5714
1889 7173 7329
1795 2773 3499
2695 2944 6735
3221 4625 5897
1690 6122 6816
5013 6839 7358
1601 6849 7415
2180 7389 7543
2121 6838 7054
1948 3109 5046
272 1015 7464

Table E.7: Rate 9/15 (N_{ldpc} = 16 200)

71 1478 1901 2240 2649 2725 3592 3708 3965 4080 5733 6198
393 1384 1435 1878 2773 3182 3586 5465 6091 6110 6114 6327
160 1149 1281 1526 1566 2129 2929 3095 3223 4250 4276 4612
289 1446 1602 2421 3559 3796 5590 5750 5763 6168 6271 6340
947 1227 2008 2020 2266 3365 3588 3867 4172 4250 4865 6290
3324 3704 4447
1206 2565 3089
529 4027 5891
141 1187 3206
1990 2972 5120
752 796 5976
1129 2377 4030
6077 6108 6231
61 1053 1781
2820 4109 5307
2088 5834 5988
3725 3945 4010
1081 2780 3389
659 2221 4822
3033 6060 6160
756 1489 2350
3350 3624 5470
357 1825 5242
585 3372 6062
561 1417 2348
971 3719 5567
1005 1675 2062

Table E.8: Rate 10/15 (N_{ldpc} = 16 200)

0 2084 1613 1548 1286 1460 3196 4297 2481 3369 3451 4620 2622
1 122 1516 3448 2880 1407 1847 3799 3529 373 971 4358 3108
2 259 3399 929 2650 864 3996 3833 107 5287 164 3125 2350
3 342 3529
4 4198 2147
5 1880 4836
6 3864 4910
7 243 1542
8 3011 1436
9 2167 2512
10 4606 1003
11 2835 705
12 3426 2365
13 3848 2474
14 1360 1743
0 163 2536
1 2583 1180
2 1542 509
3 4418 1005
4 5212 5117
5 2155 2922
6 347 2696
7 226 4296
8 1560 487
9 3926 1640
10 149 2928
11 2364 563
12 635 688
13 231 1684
14 1129 3894

Table E.9: Rate 11/15 (N_{ldpc} = 16 200)

3 3198 478 4207 1481 1009 2616 1924 3437 554 683 1801
4 2681 2135
5 3107 4027
6 2637 3373
7 3830 3449
8 4129 2060
9 4184 2742
10 3946 1070
11 2239 984
0 1458 3031
1 3003 1328
2 1137 1716
3 132 3725
4 1817 638
5 1774 3447
6 3632 1257
7 542 3694
8 1015 1945
9 1948 412
10 995 2238
11 4141 1907
0 2480 3079
1 3021 1088
2 713 1379
3 997 3903
4 2323 3361
5 1110 986
6 2532 142
7 1690 2405
8 1298 1881
9 615 174
10 1648 3112
11 1415 2808

Annex F (normative): Addresses of parity bit accumulators for N_{ldpc} = 4 320

Table F.1: Rate 1/5 (N_{ldpc} = 4320)

384 944 1269 2266
407 1907 2268 2594
1047 1176 1742 1779
304 890 1817 2645
102 316 353 2250
488 811 1662 2323
31 2397 2468 3321
102 514 828 1010 1024 1663 1737 1870 2154 2390 2523 2759 3380
216 383 679 938 970 975 1668 2212 2300 2381 2413 2754 2997
536 889 993 1395 1603 1691 2078 2344 2545 2741 3157 3334 3377
694 1115 1167 2548
1266 1993 3229 3415

Table F.2: Rate 1/2 (N_{ldpc} = 4320)

142 150 213 247 507 538 578 828 969 1042 1107 1315 1509 1584 1612 1781 1934 2106 2117 **2536 2748 3073 6181 6186 6192**
3 17 20 31 97 466 571 580 842 983 1152 1226 1261 1392 1413 1465 1480 2047 2125 **2374 2523 2813 4797 4898 5332**
49 169 258 548 582 839 873 881 931 995 1145 1209 1639 1654 1776 1826 1865 1906 1956 **2997 4265 4843 6118 6130 6381**
148 393 396 486 568 806 909 965 1203 1256 1306 1371 1402 1534 1664 1736 1844 1947 2055 **2247 3337 3419 3602 4638 5528**
185 191 263 290 384 769 981 1071 1202 1357 1554 1723 1769 1815 1842 1880 1910 1926 1991 **2518 2984 4098 4307 4373 4953**
424 444 923 1679 **2416 2673 3127 3151 3243 3538 3820 3896 4072 4183 4256 4425 4643 4834 4882 5421 5750 5900 5929 6029 6030**
91 436 535 978 **2573 2789 2847 3356 3868 3922 3943 4085 4228 4357 4712 4777 4852 5140 5313 5381 5744 5931 6101 6250 6384**
362 677 821 1695 **2375 2622 2631 2782 2815 2827 2897 3031 3034 3314 3351 3369 3560 3857 4784 5283 5295 5471 5552 5995 6280**
1117 1392 1454 2030 **2667 2826 2877 2898 3504 3611 3765 4079 4100 4159 4362 4385 4442 4651 4779 5395 5446 5450 5472 5730 6311**
35 840 1477 2152 **3977 6205 6455**
1061 1202 1836 1879 **2239 5659 5940**
242 286 1140 1538 **3869 4260 4336**
111 240 481 760 **2485 4509 5139**
59 1268 1899 2144 **5044 5228 5475**
737 1299 1395 2072 **2664 3406 6395**
34 288 810 1903 **3266 5954 6059**
232 1013 1365 1729 **2952 4298 4860**
410 783 1066 1187 **3014 4134 6105**
113 885 1423 1560 **2761 3587 5468**
760 909 1475 2048 **4046 4329 4854**
68 254 420 1867 **2210 2293 2922**
283 325 334 970 **5308 5953 6201**
168 321 479 554 **2676 4106 4658**
378 836 1913 1928 **2587 2626 4239**
101 238 964 1393 **2346 3516 3923**
304 460 1497 1588 **2295 5785 6332**
151 192 1075 1614 **2464 5394 5987**
297 313 677 1303 **3090 3288 3829**
329 447 1348 1832 **4236 4741 4848**
582 831 984 1900 **4129 4230 5783**

Annex G (informative): Constellation diagrams for uniform, non-uniform and hierarchical constellations

The uniform constellations, and the details of the Gray mapping applied to them, are illustrated in figures G.1 and G.2.

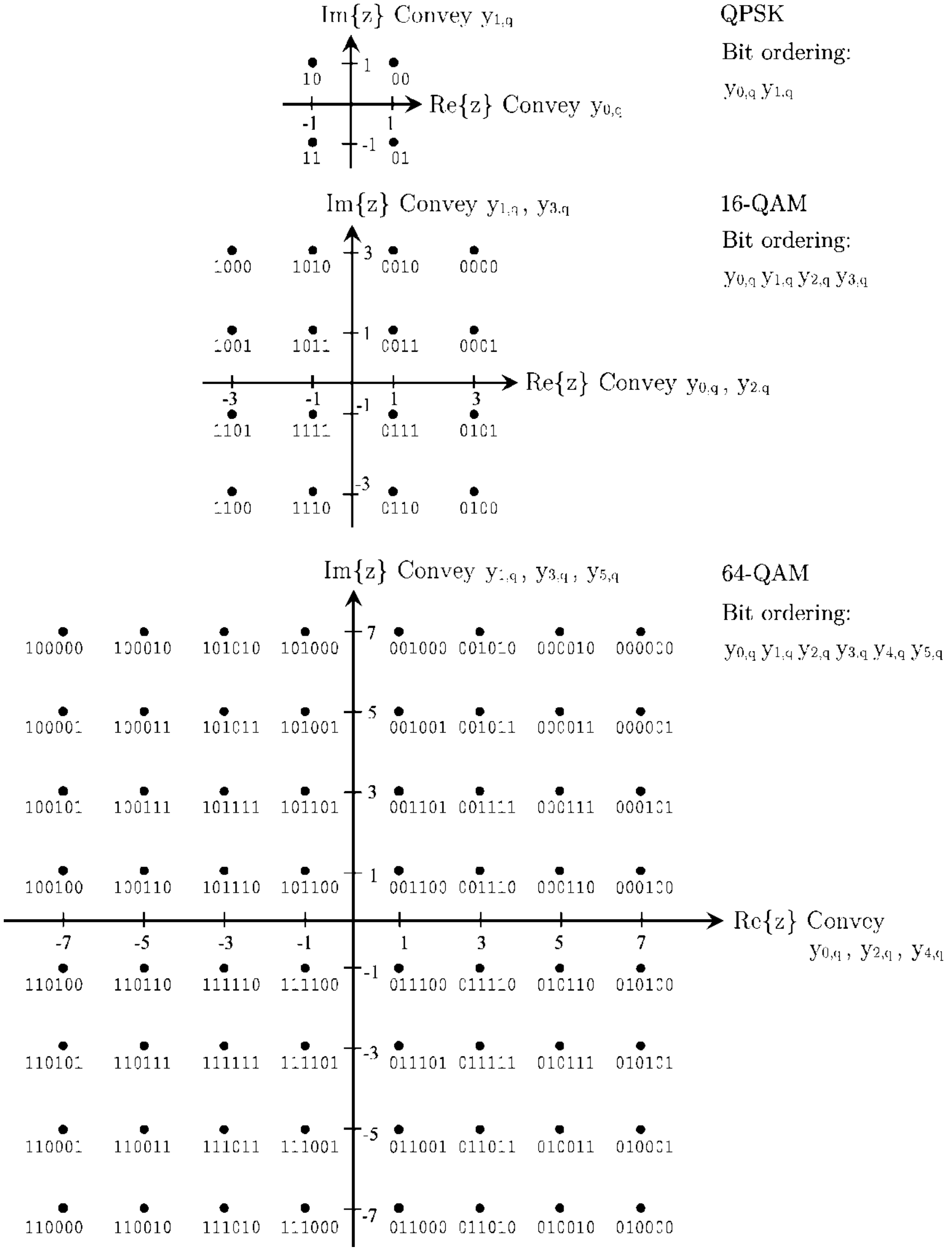


Figure G.1: The QPSK, 16-QAM and 64-QAM mappings and the corresponding bit patterns

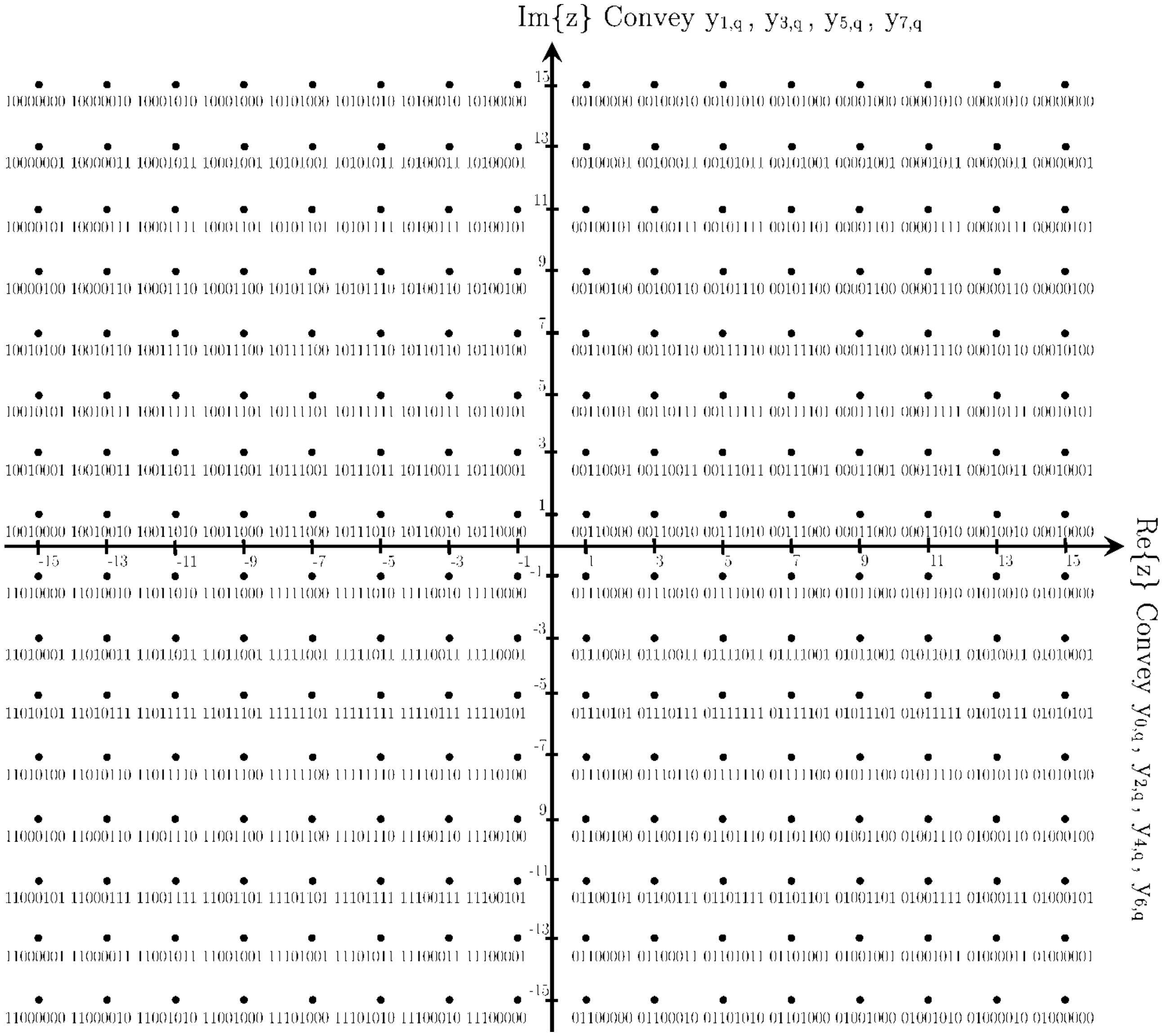


Figure G.2: The 256-QAM mapping and the corresponding bit pattern

Non-uniform constellations, NU-64-QAM and NU-256-QAM,may be illustrated in an analogous way, the non-uniform spacings then being apparent. Where there is a non-monotonic increase of constellation value, see e. g. tables 25 and **Error! Reference source not found.**, the Gray mapping shall depend on the abulated order not the constellation value.

Example plots of NU-64-QAM and NU-256-QAM are shown in figures G.3 and G.4 for illustrative purposes.

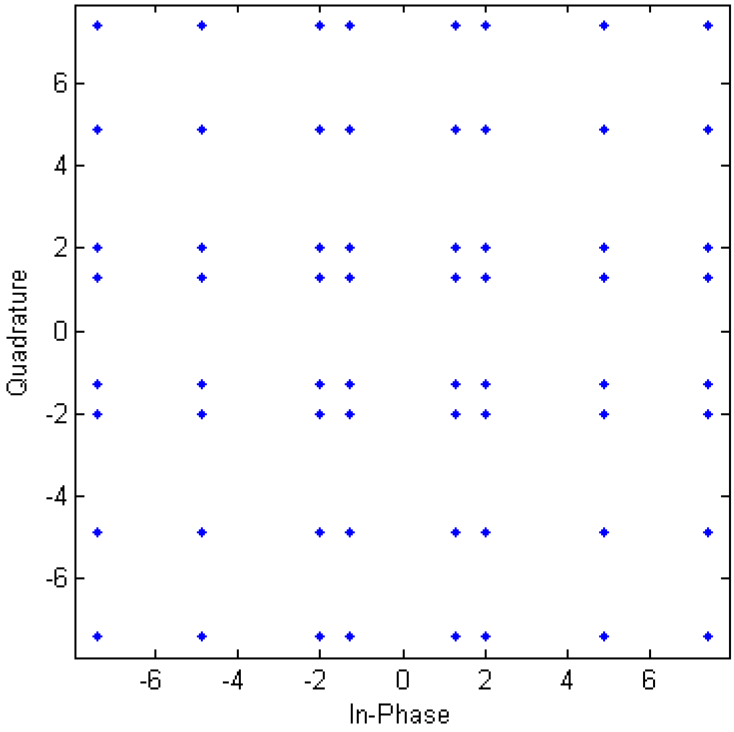


Figure G.3: NU-64-QAM for code rate 2/5

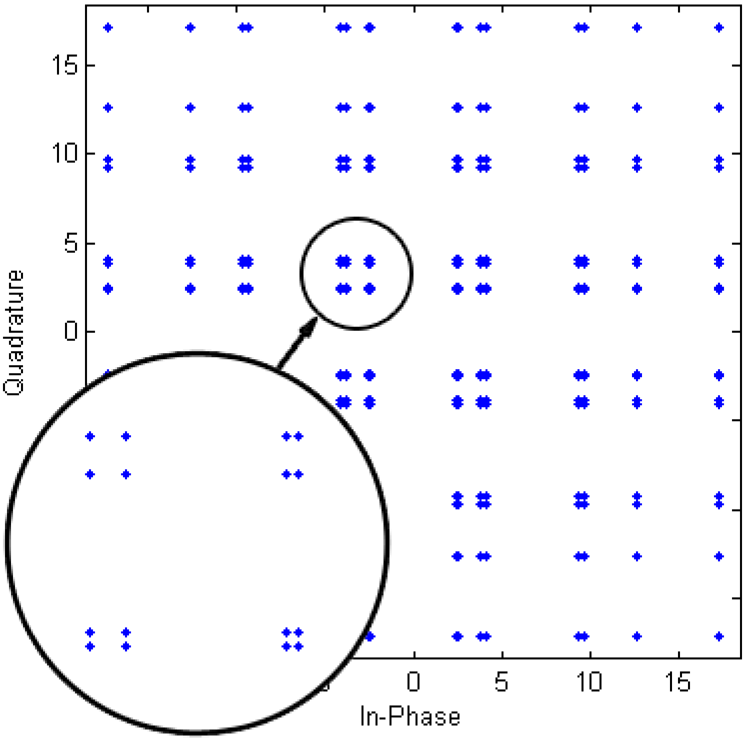


Figure G.4: NU-256-QAM for code rate 1/3

The constellation points z_q for each input cell word ($y_{0,q}..y_{\eta mod\text{-}1,q}$) are normalized according to table G.1 to obtain the correct complex cell value f_q to be used.

Table G.1: Normalization factors for data cells

Modulation	Normalization
BPSK	$f_q = z_q$
QPSK	$f_q = \frac{z_q}{\sqrt{2}}$
16-QAM	$f_q = \frac{z_q}{\sqrt{10}}$
64-QAM or NU-64-QAM	$f_q = \frac{z_q}{\sqrt{42}}$
256-QAM or NU-256-QAM	$f_q = \frac{z_q}{\sqrt{170}}$

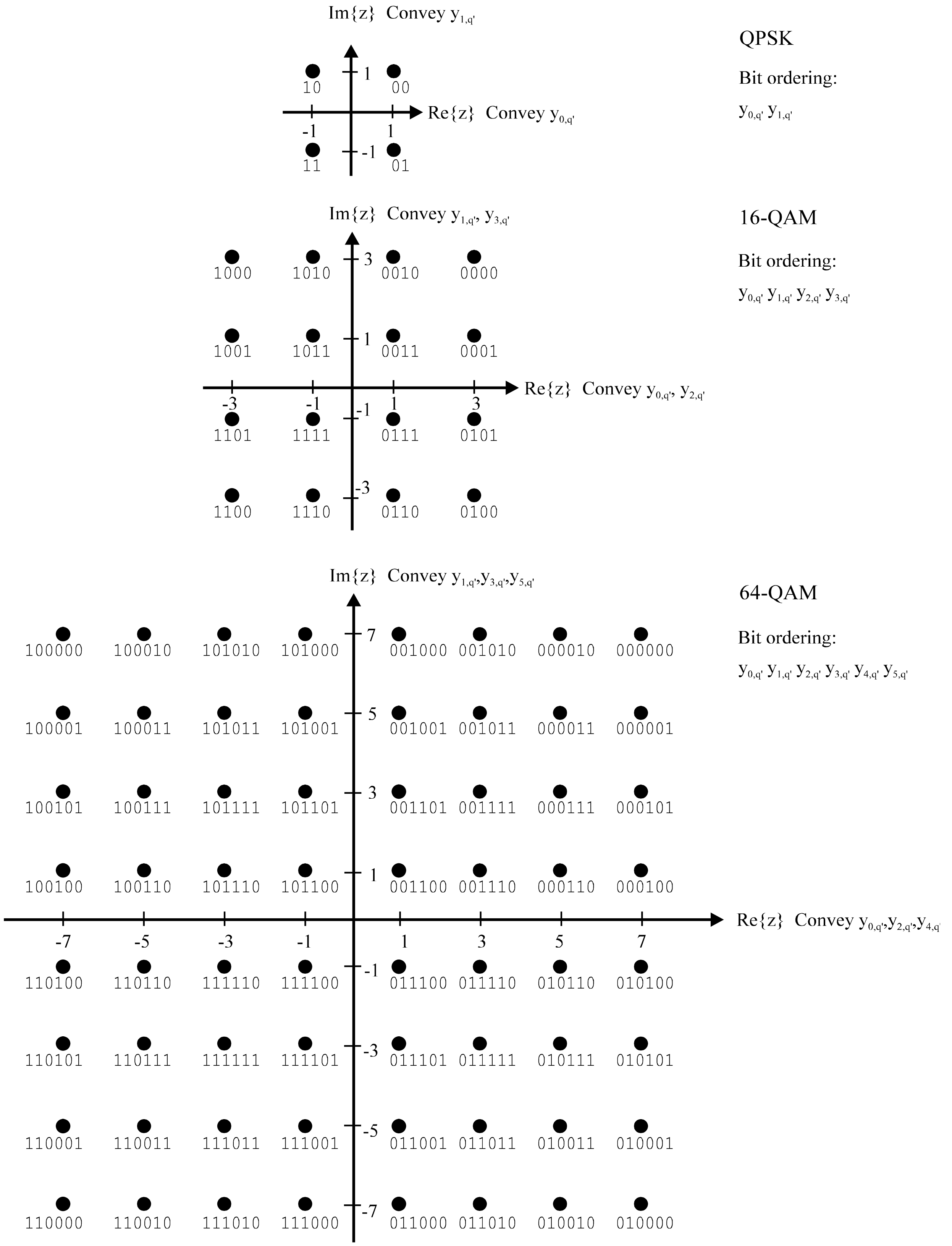


Figure G.5: The QPSK, 16-QAM and 64-QAM mappings and the corresponding bit patterns (hierarchical with α = 1)

The $y_{u,q'}$ denote the bits representing a complex modulation symbol z.

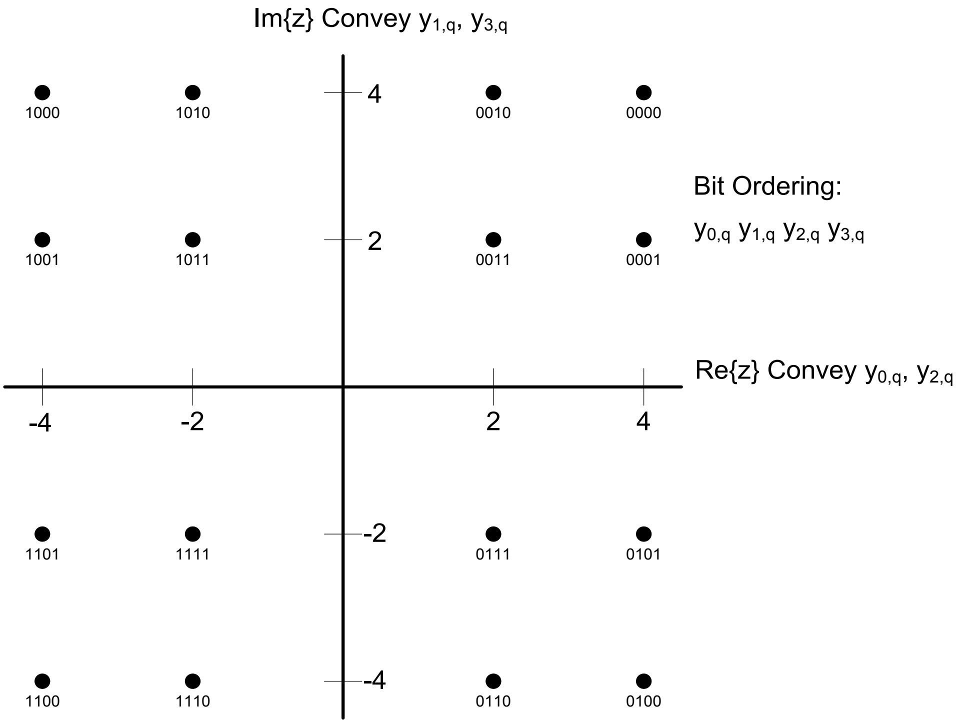


Figure G.6: Hierarchical 16-QAM mapping with $\alpha = 2$

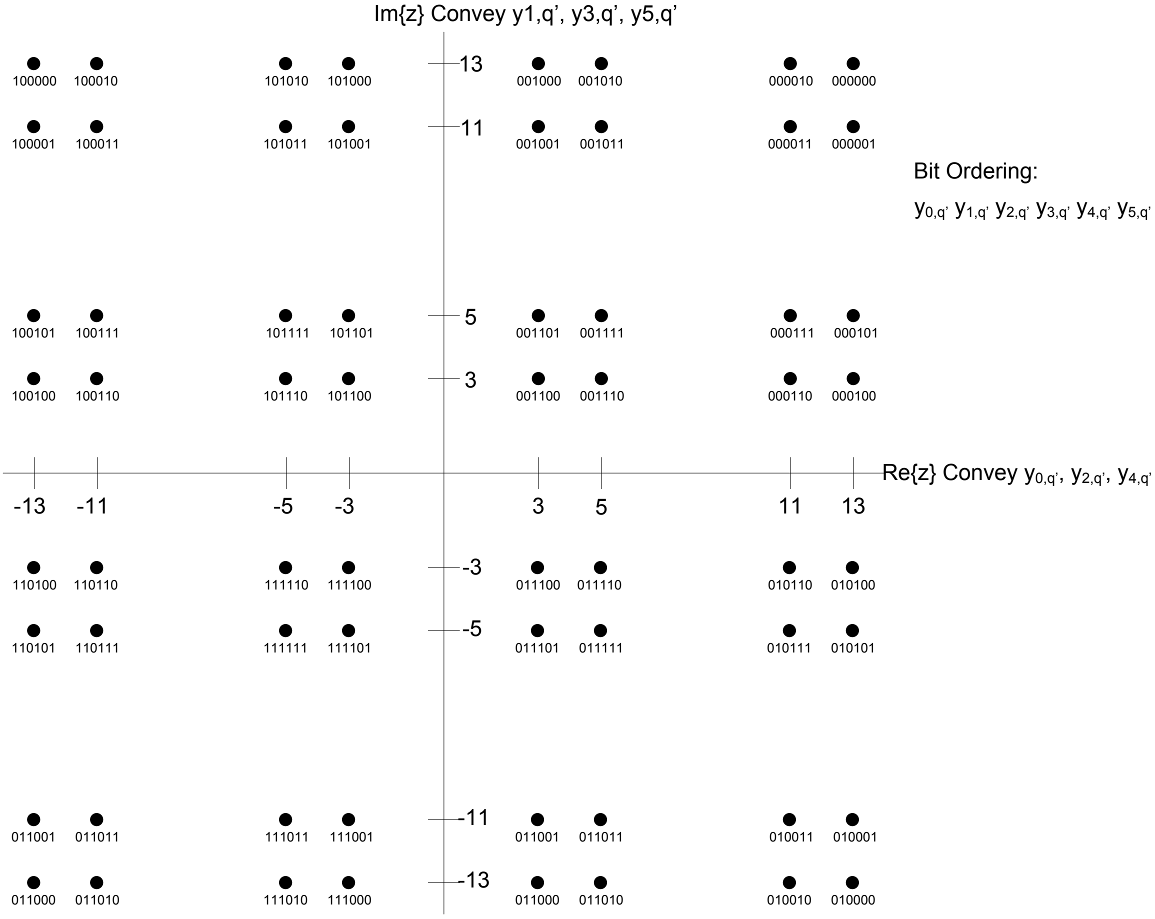


Figure G.7: Hierarchical 64-QAM mapping with $\alpha = 3$

The $y_{u,q'}$ denote the bits representing a complex modulation symbol z.

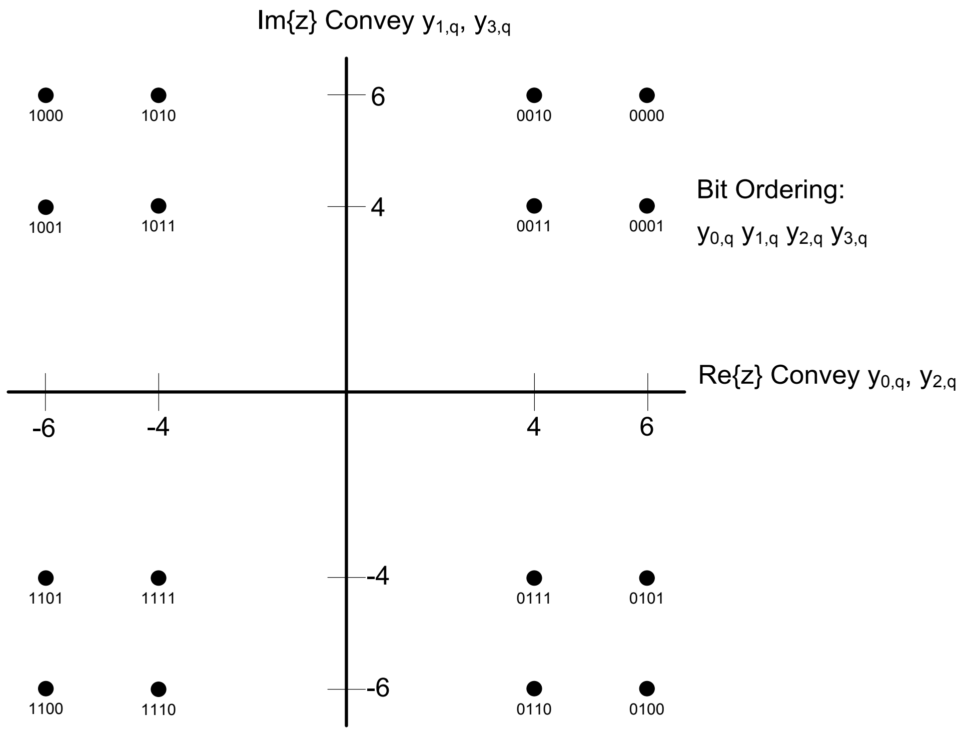


Figure G.8: Hierarchical 16-QAM mapping with $\alpha = 4$

The $y_{u,q'}$ denote the bits representing a complex modulation symbol z. In each case, the transmitted complex symbol *c* is derived by normalising *z* according to table G.2.

For hierarchical 16-QAM:

The high priority bits are the $y_{0,q'}$ and $y_{1,q'}$ bits from the regional PLP. The low priority bits are $y_{2,q'}$ and $y_{3,q'}$ bits from the local service PLP. The mappings of figures G.5, G.6 and G.8 are applied as appropriate.

For example, the top left constellation point, corresponding to 1 000 represents $y_{0,q'} =1$, $y_{1,q'} = y_{2,q'} = y_{3,q'} = 0$. If this constellation is decoded as if it were QPSK, the high priority bits, $y_{0,q'}$, $y_{1,q'} = 1,0$ will be deduced. To decode the low priority bits, the full constellation shall be examined and the appropriate bits ($y_{2,q'}$, $y_{3,q'}$) extracted from $y_{0,q'}$, $y_{1,q'}$, $y_{2,q'}$, $y_{3,q'}$.

For hierarchical 64-QAM:

The high priority bits are $y_{0,q'}$ $y_{1,q'}$ $y_{2,q'}$, $y_{3,q'}$ from the regional PLP. The low priority bits are $y_{4,q'}$ and $y_{5,q'}$ from the local service PLP. The mappings of figures G.5 and G.7are applied as appropriate. If this constellation is decoded as if it were 16-QAM, the high priority bits, $y_{0,q'}$, $y_{1,q'}$ $y_{2,q'}$, $y_{3,q'}$ will be deduced. To decode the low priority bits, the full constellation shall be examined and the appropriate bits ($y_{4,q'}$, $y_{5,q'}$,) extracted from $y_{0,q'}$, $y_{1,q'}$, $y_{2,q'}$, $y_{3,q'}$, $y_{4,q'}$, $y_{5,q'}$.

Table G.2: Normalisation factors for data symbols

Modulation scheme		**Normalisation factor**
QPSK		$c = z/\sqrt{2}$
16-QAM	$\alpha = 1$	$c = z/\sqrt{10}$
	$\alpha = 2$	$c = z/\sqrt{20}$
	$\alpha = 4$	$c = z/\sqrt{52}$
64-QAM	$\alpha = 1$	$c = z/\sqrt{42}$
	$\alpha = 3$	$c = z/\sqrt{162}$

Annex H (normative): Locations of the continual pilots

Table H.1 gives the carrier indices for the continual pilots for each of the pilot patterns in 16K. Table H.2 gives the carrier indices for the additional continual pilots in extended carrier mode. For further details of the use of these, see clause 11.1.4.

Table H.1: Continual pilot groups for each pilot pattern

Group	PP1	PP2	PP3	PP4	PP5	PP6	PP7	PP8
CP$_1$ [*All FFT sizes*]	116 255 285 430 518 546 601 646 744 1662 1893 1995 2322 3309 3351 3567 3813 4032 5568 5706	116 318 390 430 474 518 601 646 708 726 1752 1758 1944 2100 2208 2466 3792 5322 5454 5640	116 318 342 426 430 518 582 601 646 816 1758 1764 2400 3450 3504 3888 4020 4932 5154 5250 5292 5334	108 116 144 264 288 430 518 564 636 646 828 2184 3360 3396 3912 4032 4932 5220 5676 5688	108 116 228 430 518 601 646 804 1644 1680 1752 1800 1836 3288 3660 4080 4932 4968 5472		264 360 1848 2088 2112 2160 2256 2280 3936 3960 3984 5016 5136 5208 5664	
CP$_2$ [*2K-16K*]	1022 1224 1302 1371 1495 2261 2551 2583 2649 2833 2925 3192 4266 5395 5710 5881 8164 10568 11069 11560 12631 12946 13954 16745 21494	1022 1092 1369 1416 1446 1495 2598 2833 2928 3144 4410 4800 5710 5881 6018 6126 10568 11515 12946 13954 15559 16681	1022 1495 2261 2551 2802 2820 2833 2922 4422 4752 4884 5710 8164 10568 11069 11560 12631 12946 16745 21494	601 1022 1092 1164 1369 1392 1452 1495 2261 2580 2833 3072 4320 4452 5710 5881 6048 10568 11515 12946 13954 15559 16681	852 1022 1495 2508 2551 2604 2664 2736 2833 3120 4248 4512 4836 5710 5940 6108 8164 10568 11069 11560 12946 13954 21494		116 430 518 601 646 1022 1296 1368 1369 1495 2833 3024 4416 4608 4776 5710 5881 6168 7013 8164 10568 10709 11515 12946 15559 23239 24934 25879 26308 26674	
CP$_3$ [4*K-16K*]		2261 8164	13954	8164	648 4644 16745		456 480 2261 6072 17500	
CP$_4$ [8*K-16K*]		10709 19930		10709 19930	12631		1008 6120 13954	116 132 180 430 518 601 646 1022 1266 1369 1495 2261 2490 2551 2712 2833 3372 3438 4086 4098 4368 4572 4614 4746 4830 4968 5395 5710 5881 7649 8164 10568 11069 11560 12631 12946

Group	PP1	PP2	PP3	PP4	PP5	PP6	PP7	PP8
								13954 15760 16612 16745 17500 19078 19930 21494 22867 25879 26308
CP$_5$ [*16K*]	1369 7013 7215 7284 7649 7818 8025 8382 8733 8880 9249 9432 9771 10107 10110 10398 10659 10709 10785 10872 11115 11373 11515 11649 11652 12594 12627 12822 12984 15760 16612 17500 18358 19078 19930 20261 20422 22124 22867 23239 24934 25879 26308 26674	6744 7013 7020 7122 7308 7649 7674 7752 7764 8154 8190 8856 8922 9504 9702 9882 9924 10032 10092 10266 10302 10494 10530 10716 11016 11076 11160 11286 11436 11586 12582 13002 17500 18358 19078 22124 23239 24073 24934 25879 26308	1369 5395 5881 6564 6684 7013 7649 8376 8544 8718 8856 9024 9132 9498 9774 9840 10302 10512 10566 10770 10914 11340 11418 11730 11742 12180 12276 12474 12486 15760 16612 17500 18358 19078 19930 20261 20422 22124 22867 23239 24934 25879 26308 26674	6612 6708 7013 7068 7164 7224 7308 7464 7649 7656 7716 7752 7812 7860 8568 8808 8880 9072 9228 9516 9696 9996 10560 10608 10728 11148 11232 11244 11496 11520 11664 11676 11724 11916 17500 18358 19078 21284 22124 23239 24073 24934 25879 26308	1369 2261 5395 5881 6552 6636 6744 6900 7032 7296 7344 7464 7644 7649 7668 7956 8124 8244 8904 8940 8976 9216 9672 9780 10224 10332 10709 10776 10944 11100 11292 11364 11496 11532 11904 12228 12372 12816 15760 16612 17500 19078 22867 25879	116 384 408 518 601 646 672 960 1022 1272 1344 1369 1495 1800 2040 2261 2833 3192 3240 3768 3864 3984 4104 4632 4728 4752 4944 5184 5232 5256 5376 5592 5616 5710 5808 5881 6360 6792 6960 7013 7272 7344 7392 7536 7649 7680 7800 8064 8160 8164 8184 8400 8808 8832 9144 9648 9696 9912 10008 10200 10488 10568 10656 10709 11088 11160 11515 11592 12048 12264 12288 12312 12552 12672 12946 13954 15559 16681 17500 19078 20422 21284 22124 23239 24934	6984 7032 7056 7080 7152 7320 7392 7536 7649 7704 7728 7752 8088 8952 9240 9288 9312 9480 9504 9840 9960 10320 10368 10728 10752 11448 11640 11688 11808 12192 12240 12480 12816 16681 22124	6720 6954 7013 7026 7092 7512 7536 7596 7746 7758 7818 7986 8160 8628 9054 9096 9852 9924 10146 10254 10428 10704 11418 11436 11496 11550 11766 11862 12006 12132 12216 12486 12762 18358 20261 20422 22124 23239 24934

Group	PP1	PP2	PP3	PP4	PP5	PP6	PP7	PP8
						25879 26308 26674		

Table H.2: Locations of additional continual pilots in extended carrier mode

FFT size	PP1	PP2	PP3	PP4	PP5	PP6	PP7	PP8
8K	None	6820 6847 6869 6898	6820 6869	6820 6869	None	NA	6820 6833 6869 6887 6898	6820 6833 6869 6887 6898
16K	13636 13724 13790 13879	13636 13790	13636 13790	13636 13790	13636 13790	13636 13790	13636 13724 13879	13636 13724 13879

Annex I (normative):
Reserved carrier indices for PAPR reduction

Table I.1 gives the indices of the reserved carriers for the P2 symbol. Table I.2 gives the starting indices for the reserved carriers for pilot patterns PP1 to PP7. For further details of the use of these, see clauses 11.2 and 11.5.2.

Table I.1: Reserved carrier indices for P2 symbol

FFT size (Number of reserved carriers)	Reserved Carrier Indices
1K (10)	116, 130, 134, 157, 182, 256, 346, 478, 479, 532
2K (18)	113, 124, 262, 467, 479, 727, 803, 862, 910, 946, 980, 1201, 1322, 1342, 1396, 1397, 1562, 1565
4K (36)	104, 116, 119, 163, 170, 173, 664, 886, 1064, 1151, 1196, 1264, 1531, 1736, 1951, 1960, 2069, 2098, 2311, 2366, 2473, 2552, 2584, 2585, 2645, 2774, 2846, 2882, 3004, 3034, 3107, 3127, 3148, 3191, 3283, 3289
8K (72)	106, 109, 110, 112, 115, 118, 133, 142, 163, 184, 206, 247, 445, 461, 503, 565, 602, 656, 766, 800, 922, 1094, 1108, 1199, 1258, 1726, 1793, 1939, 2128, 2714, 3185, 3365, 3541, 3655, 3770, 3863, 4066, 4190, 4282, 4565, 4628, 4727, 4882, 4885, 5143, 5192, 5210, 5257, 5261, 5459, 5651, 5809, 5830, 5986, 6020, 6076, 6253, 6269, 6410, 6436, 6467, 6475, 6509, 6556, 6611, 6674, 6685, 6689, 6691, 6695, 6698, 6701
16K (144)	104, 106, 107, 109, 110, 112, 113, 115, 116, 118, 119, 121, 122, 125, 128, 131, 134, 137, 140, 143, 161, 223, 230, 398, 482, 497, 733, 809, 850, 922, 962, 1196, 1256, 1262, 1559, 1691, 1801, 1819, 1937, 2005, 2095, 2308, 2383, 2408, 2425, 2428, 2479, 2579, 2893, 2902, 3086, 3554, 4085, 4127, 4139, 4151, 4163, 4373, 4400, 4576, 4609, 4952, 4961, 5444, 5756, 5800, 6094, 6208, 6658, 6673, 6799, 7208, 7682, 8101, 8135, 8230, 8692, 8788, 8933, 9323, 9449, 9478, 9868, 10192, 10261, 10430, 10630, 10685, 10828, 10915, 10930, 10942, 11053, 11185, 11324, 11369, 11468, 11507, 11542, 11561, 11794, 11912, 11974, 11978, 12085, 12179, 12193, 12269, 12311, 12758, 12767, 12866, 12938, 12962, 12971, 13099, 13102, 13105, 13120, 13150, 13280, 13282, 13309, 13312, 13321, 13381, 13402, 13448, 13456, 13462, 13463, 13466, 13478, 13492, 13495, 13498, 13501, 13502, 13504, 13507, 13510, 13513, 13514, 13516

Table I.2: Reserved carrier indices for PP 1, 2, 3, 4, 5, 6 and 7

FFT size (Number of reserved carriers)	Reserved Carrier Indices
1K (10)	109, 117, 122, 129, 139, 321, 350, 403, 459, 465
2K (18)	250, 404, 638, 677, 700, 712, 755, 952, 1125, 1145, 1190, 1276, 1325, 1335, 1406, 1431, 1472, 1481
4K (36)	170, 219, 405, 501, 597, 654, 661, 745, 995, 1025, 1319, 1361, 1394, 1623, 1658, 1913, 1961, 1971, 2106, 2117, 2222, 2228, 2246, 2254, 2361, 2468, 2469, 2482, 2637, 2679, 2708, 2825, 2915, 2996, 3033, 3119
8K (72)	111, 115, 123, 215, 229, 392, 613, 658, 831, 842, 997, 1503, 1626, 1916, 1924, 1961, 2233, 2246, 2302, 2331, 2778, 2822, 2913, 2927, 2963, 2994, 3087, 3162, 3226, 3270, 3503, 3585, 3711, 3738, 3874, 3902, 4013, 4017, 4186, 4253, 4292, 4339, 4412, 4453, 4669, 4910, 5015, 5030, 5061, 5170, 5263, 5313, 5360, 5384, 5394, 5493, 5550, 5847, 5901, 5999, 6020, 6165, 6174, 6227, 6245, 6314, 6316, 6327, 6503, 6507, 6545, 6565
16K (144)	109, 122, 139, 171, 213, 214, 251, 585, 763, 1012, 1021, 1077, 1148, 1472, 1792, 1883, 1889, 1895, 1900, 2013, 2311, 2582, 2860, 2980, 3011, 3099, 3143, 3171, 3197, 3243, 3257, 3270, 3315, 3436, 3470, 3582, 3681, 3712, 3767, 3802, 3979, 4045, 4112, 4197, 4409, 4462, 4756, 5003, 5007, 5036, 5246, 5483, 5535, 5584, 5787, 5789, 6047, 6349, 6392, 6498, 6526, 6542, 6591, 6680, 6688, 6785, 6860, 7134, 7286, 7387, 7415, 7417, 7505, 7526, 7541, 7551, 7556, 7747, 7814, 7861, 7880, 8045, 8179, 8374, 8451, 8514, 8684, 8698, 8804, 8924, 9027, 9113, 9211, 9330, 9479, 9482, 9487, 9619, 9829, 10326, 10394, 10407, 10450, 10528, 10671, 10746, 10774, 10799, 10801, 10912, 11113, 11128, 11205, 11379, 11459, 11468, 11658, 11776, 11791, 11953, 11959, 12021, 12028, 12135, 12233, 12407, 12441, 12448, 12470, 12501, 12548, 12642, 12679, 12770, 12788, 12899, 12923, 12939, 13050, 13103, 13147, 13256, 13339, 13409

Annex J (informative): Pilot patterns

This annex illustrates each of the scattered pilot patterns, showing the pattern of pilots at the low frequency edge of the ensemble and for the last few symbols of a frame. It shows first the patterns in SISO mode (figures J.1 to J.7) and then the patterns in MISO mode (figures J.8 to J.11). Continual pilots and reserved carriers are not shown.

The patterns of pilots around the P2 symbol(s) are shown in figures J.12 and J.13.

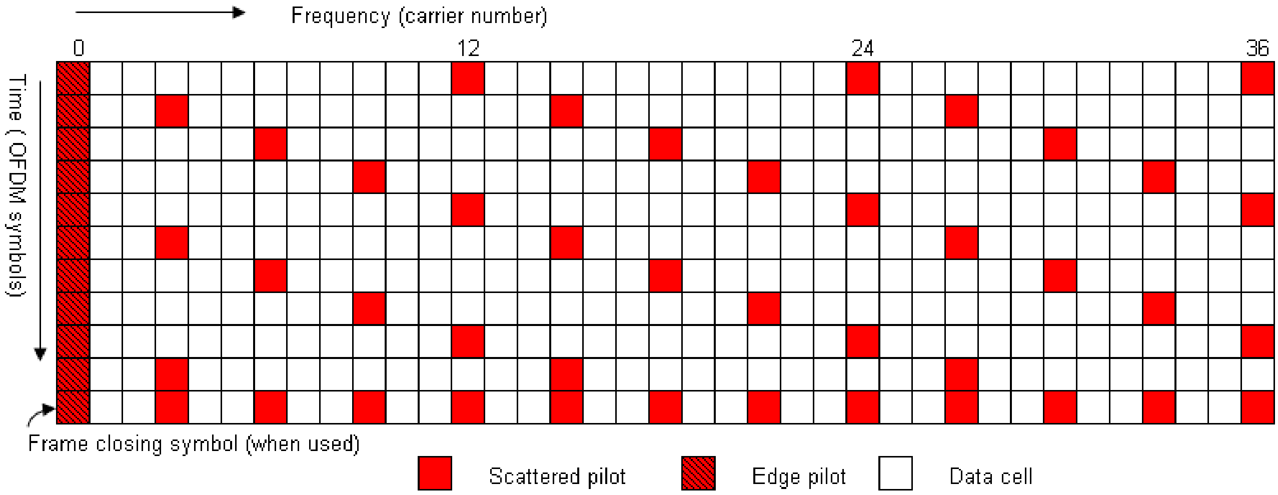


Figure J.1: Scattered pilot pattern PP1 (SISO)

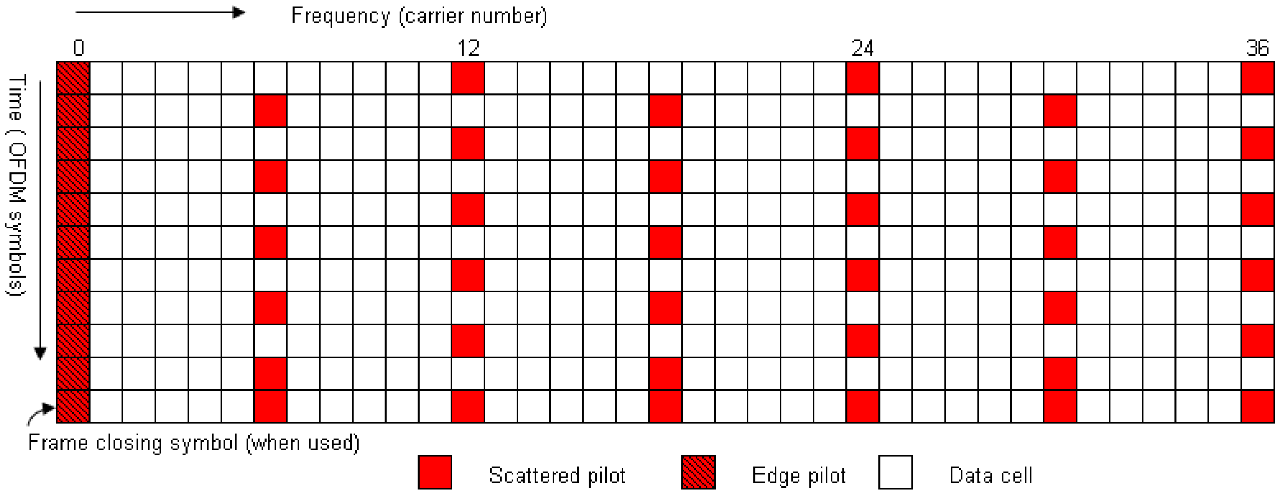


Figure J.2: Scattered pilot pattern PP2 (SISO)

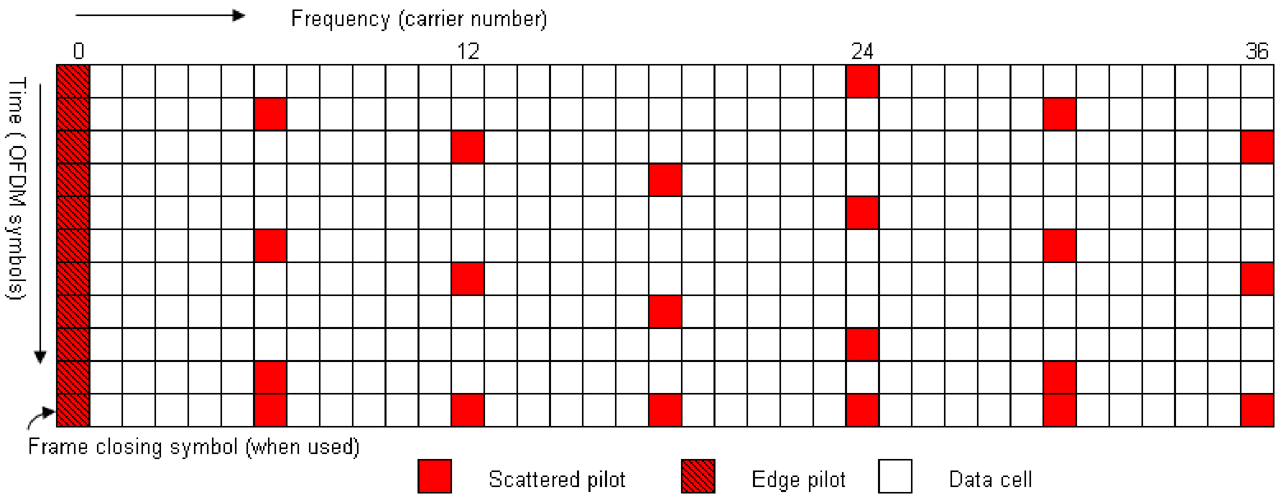


Figure J.3: Scattered pilot pattern PP3 (SISO)

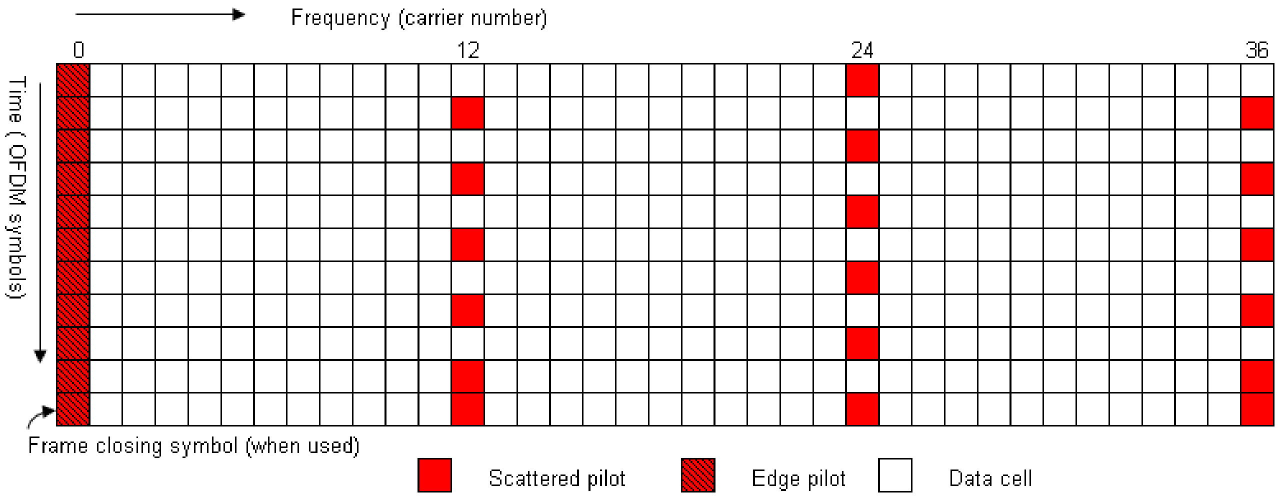


Figure J.4: Scattered pilot pattern PP4 (SISO)

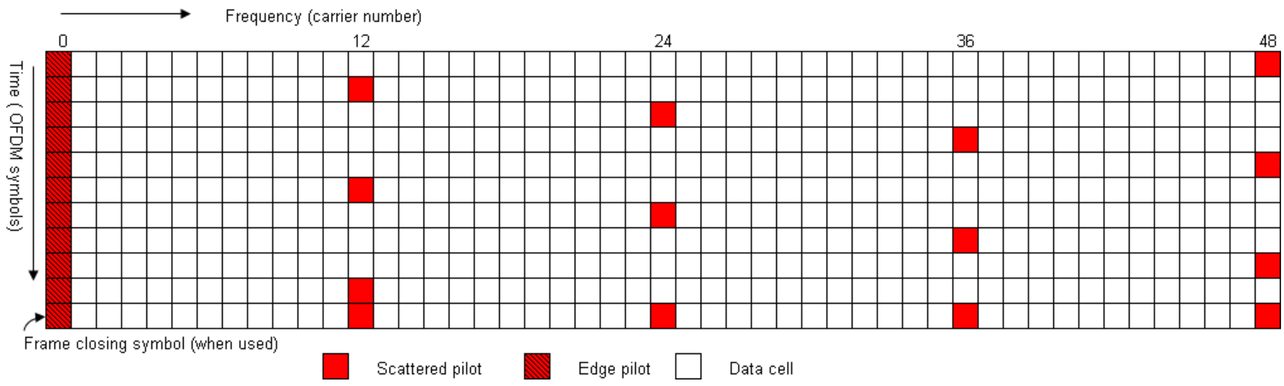


Figure J.5: Scattered pilot pattern PP5 (SISO)

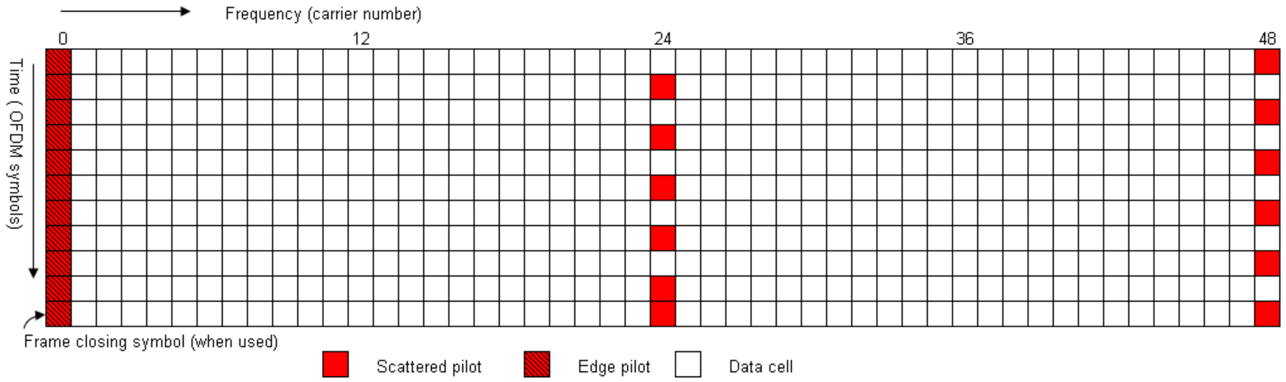


Figure J.6: Scattered pilot pattern PP6 (SISO)

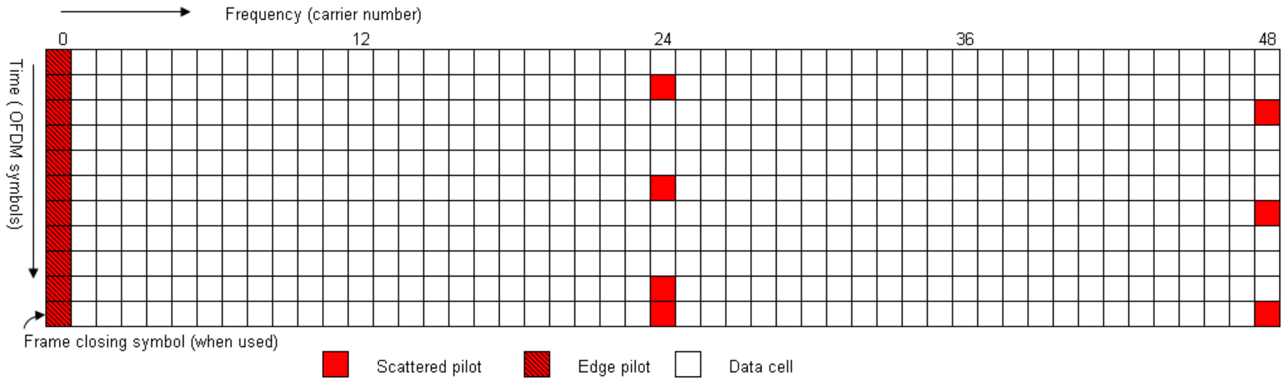


Figure J.7: Scattered pilot pattern PP7 (SISO)

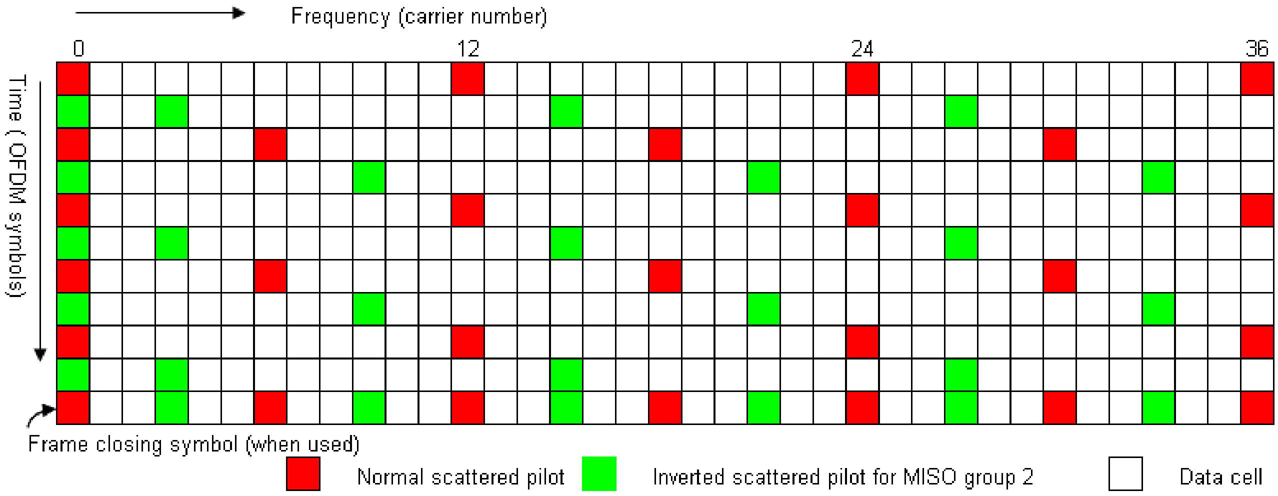


Figure J.8: Scattered pilot pattern PP1 (MISO)

NOTE: PP2 was defined in DVB-T2 [i.1] but is not used in DVB-NGH.

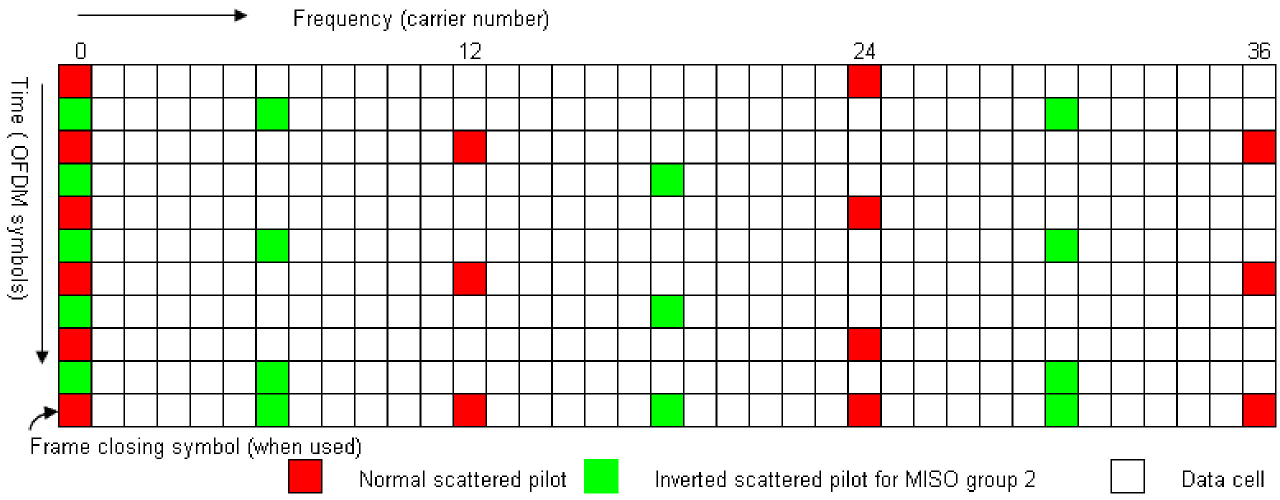


Figure J.9: Scattered pilot pattern PP3 (MISO)

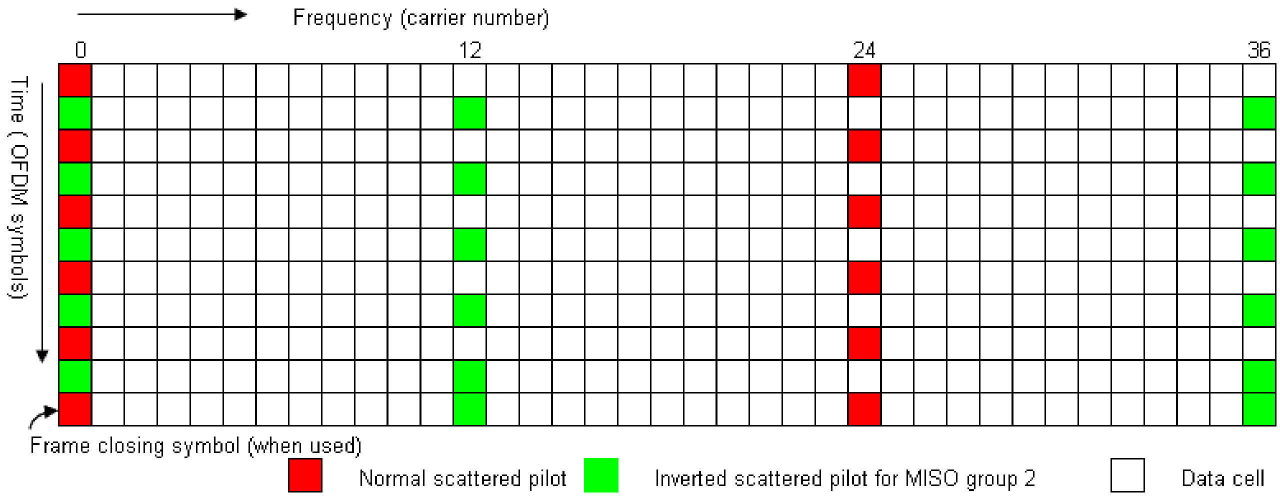


Figure J.10: Scattered pilot pattern PP4 (MISO)

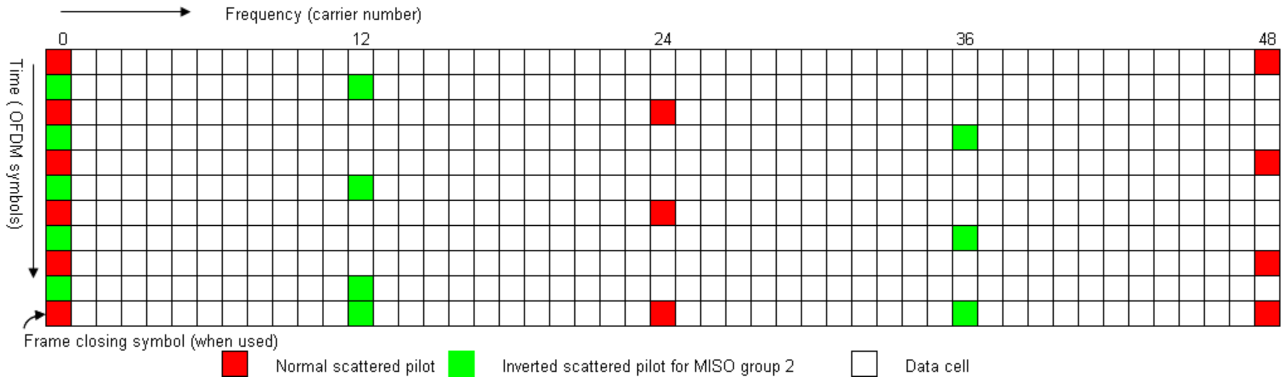


Figure J.11: Scattered pilot pattern PP5 (MISO)

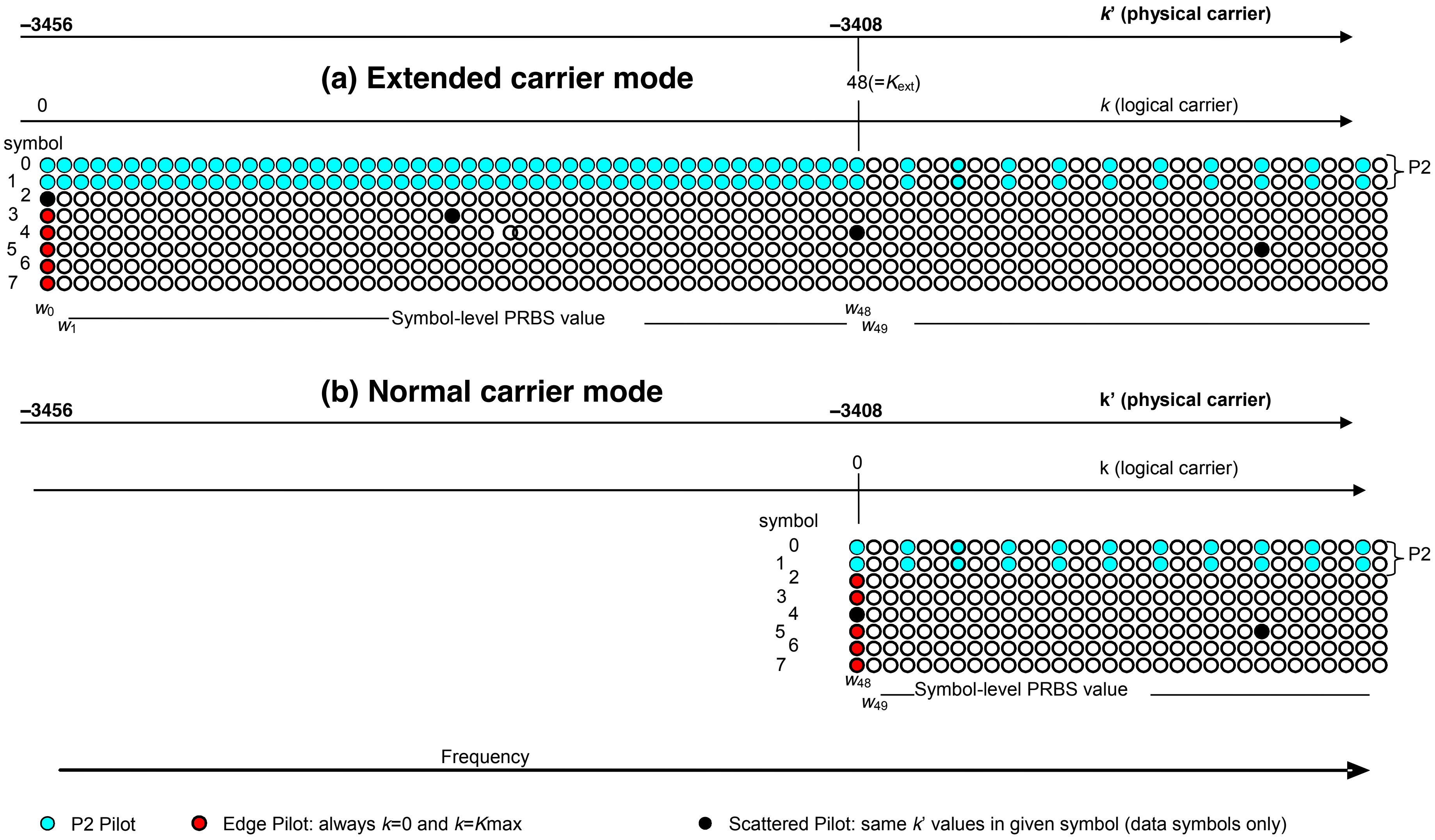


Figure J.12: Example of pilot and TR cells at the edge of the spectrum in extended and normal carrier mode (8K PP7)

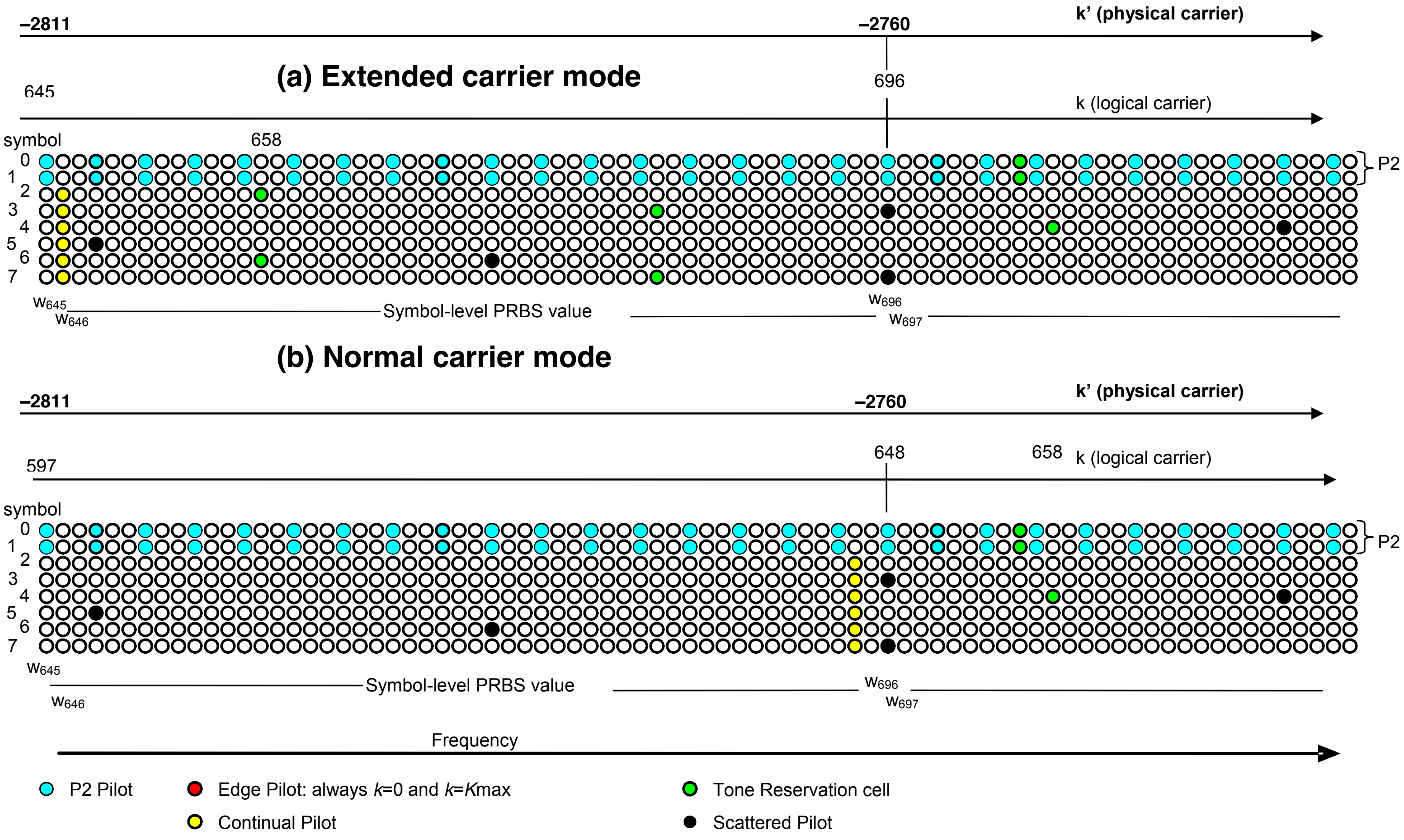


Figure J.13: Example of pilot and TR cells in extended and normal carrier mode (8K PP7)

Part II: MIMO profile

13 DVB-NGH MIMO system definition

13.1 System overview and architecture

MIMO transmission options are included in the optional MIMO profile in order to exploit the diversity and capacity advantages made possible by the use of multiple transmission elements at the transmitter and receiver. Channel estimation suitable for MIMO is provided by an appropriate pilot structure, identical to that provided in the base profile for MISO frames. The term ‘MIXO frames’ encompasses all frames containing such pilots.. MIMO may hence form part of a transmission including MISO PLPs as well as SISO frames as defined in the base profile. Within MIXO frames, different schemes may be applied to constituent PLPs according to the desired transmission characteristics; for instance MISO is specified for L1 signalling and may also be used for any other low-rate high-robustness transmission. Rate 2 MIMO, which increases the data multiplexing rate by sending distinct information from each transmit element, can be chosen where high data throughput efficiency is the primary goal.

In the following clauses, the differences to the base profile are outlined with reference to their base profile counterparts.

Compared to the base profile, only the BICM and the OFDM generation stage contains functional differences.

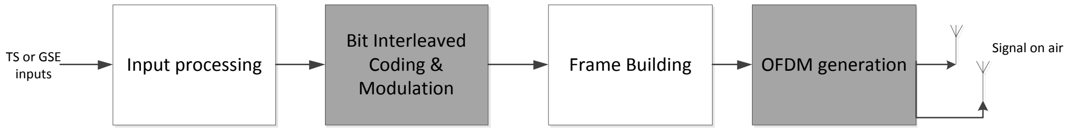


Figure 92: High level NGH phy layer block diagram of the MIMO profile. Blocks differing from the base profile are shaded to grey.

13.1.1 Bit interleaved coding and modulation, MISO and MIMO precoding

The block diagram illustrating the functional differences in the BICM stage is shown in figure93:.

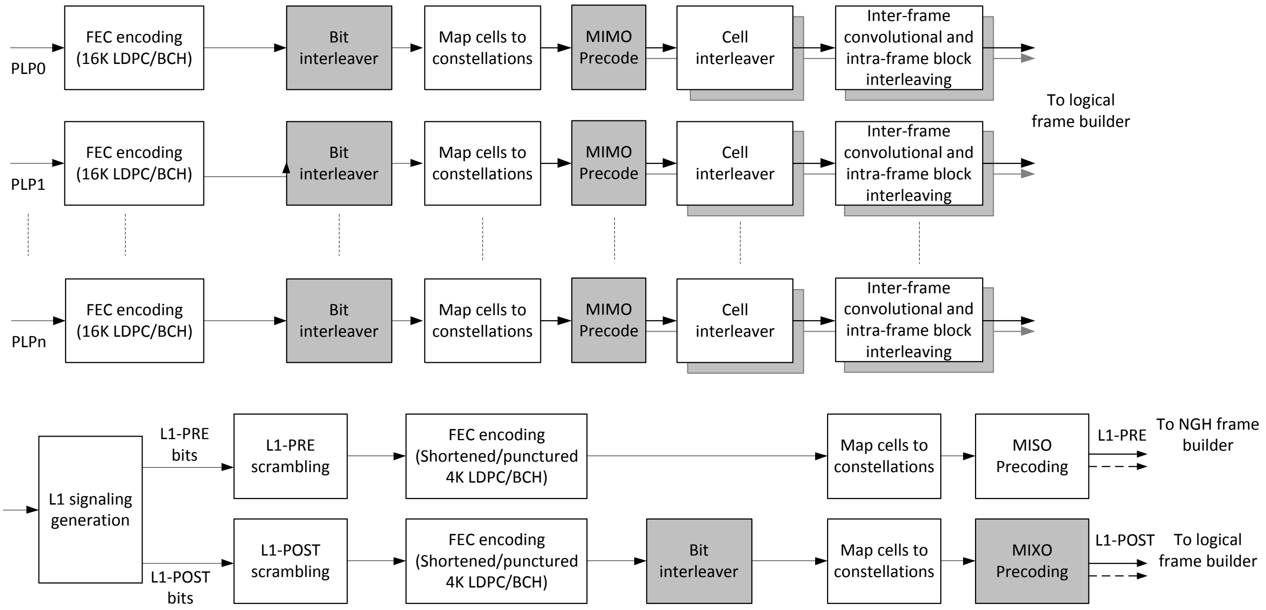


Figure 93: Bit Interleaved Coding and Modulation (BICM) of the MIMO profile

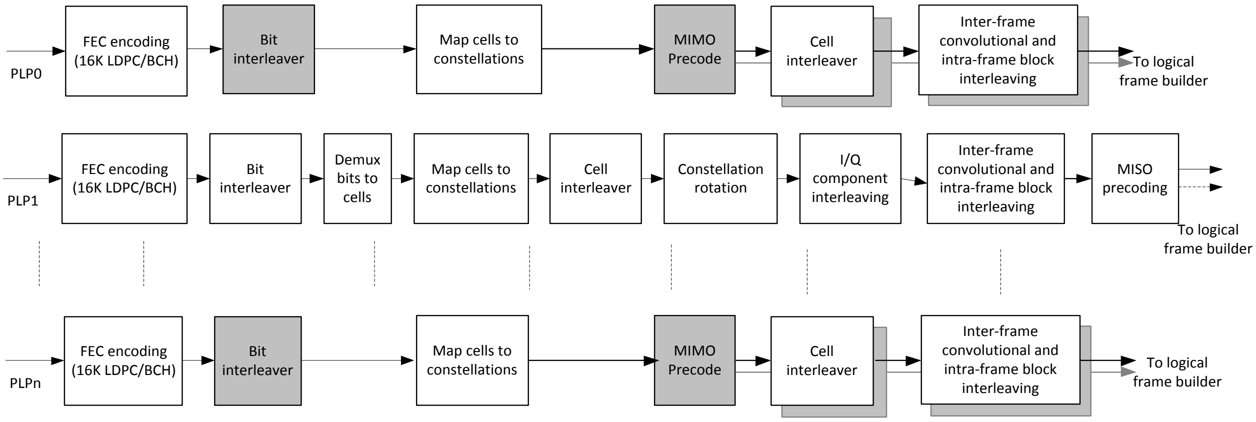


Figure 94: Bit Interleaved Coding and Modulation (BICM) with mixed MIMO and MISO PLPs (Layer 1 signalling as in figure 93above)

13.1.2 FEC encoding and interleaving inside a FEC block

MIMO PLPs within the MIMO profile employ a revised bit interleaver intended to simplify iterative MIMO decoding at the receiver. The base profile bit to cell demultiplexing is no longer explicitly present.

13.1.3 Modulation and component interleaving

The constellation is non-rotated QPSK, 16-QAM and 64-QAM. The constellation may be the same or different on the output MIMO pair depending on the chosen operational mode.

13.1.4 Time interleaving (inter-frame convolutional interleaving plus intra-frame block interleaving)

Since the time interleaving is carried out after the generation of two MIMO streams there are two parallel time interleavers. The time interleaving applied to both MIMO streams is identical. To keep the total memory requirement the same, each of these MIMO streams has half the maximum depth as the base profile.

13.1.5 Frame building, frequency interleaving

MIMO frames are built according to figure 95. This is the same architecture as the base profile except for the allocation of space for the aP1 symbol.

The frequency interleaver is a pairwise interleaver defined in clause 9.11

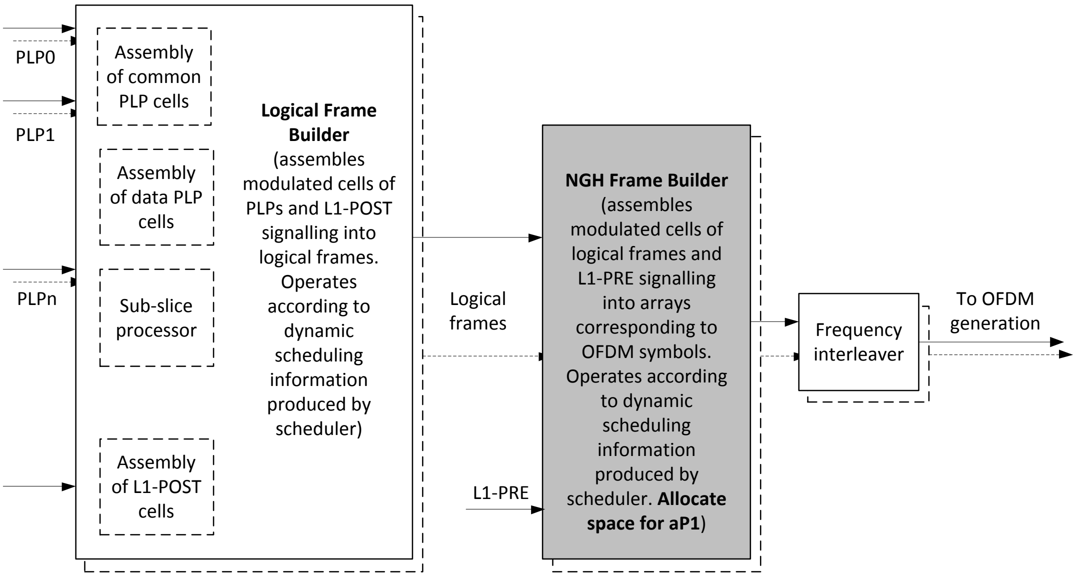


Figure 95: MIMO Frame Builder

14 Transmit/receive system compatibility

To make use of the MIMO profile, the proposed transmitter hardware must include individually-fed cross-polar antennas (horizontal (HP) and vertical polarisation (VP)). In addition, to receive and decode the MIMO signal, a cross-polar pair of antennas is necessary at the receive terminal.

In a given PLP, only one of MISO or MIMO encoding may be used, i.e. they are not cascadable.

The bit interleaver for the MIMO profile described below in clause 15 is a replacement for that described in part 1 of the specification.

15 Bit interleaver

The bit interleaver used for MIMO PLPs is different from the one used in the base profile. Figure 96 shows the basic block diagram:

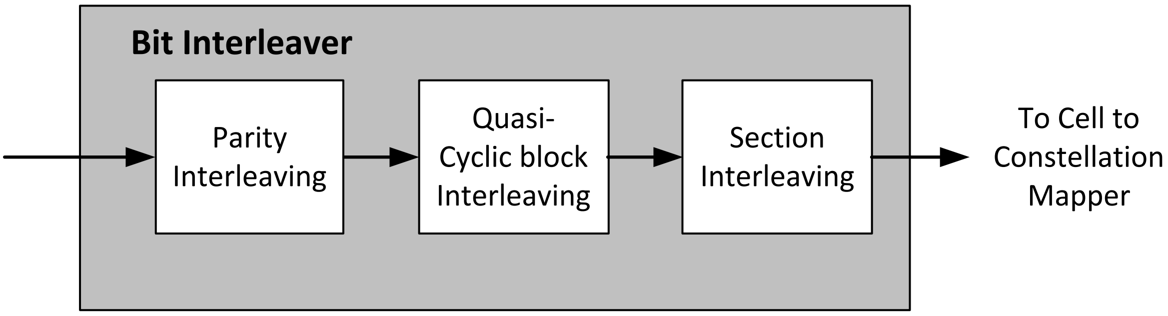


Figure 96: Bit Interleaver of the MIMO profile

In order to allow for a more efficient receiver implementation, the new bit interleaver is adapted to the quasi-cyclic structure of the LDPC code. The new bit interleaver for MIMO consists of two components: a parity interleaver and a parallel bit interleaver.

The parity interleaver is identical to the one used in the bit interleaver of the base profile (see clause 6.1.3). Its role is to convert the staircase structure of the parity-part of the LDPC parity-check matrix into a quasi-cyclic structure similar to the information-part of the matrix. At the output of the parity interleaver the LDPC codeword consists of 45 adjacent quasi-cyclic blocks (QB), each block consisting of 360 bits (the Q parameter in clause 6.1.2). The parity-interleaved codeword is interleaved by the parallel bit interleaver and then mapped to a sequence of spatial-multiplexing (SM) blocks of N_{BPCU} bits each, as shown in figure 97 for $N_{BPCU} = 8$.

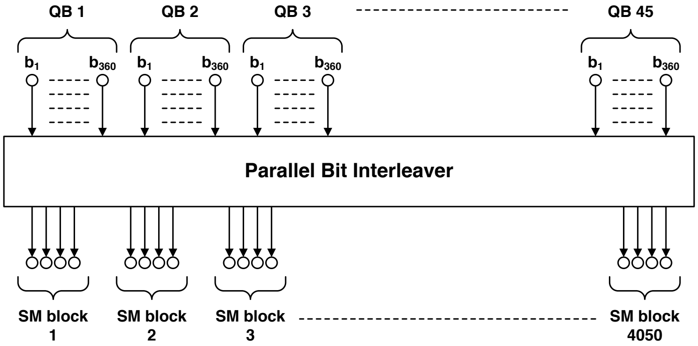


Figure 97: Parallel bit interleaver, QB and section interleaver part

The parallel interleaver in turn comprises two stages: a QB interleaver and a section interleaver.

The QB interleaver permutes the order of the 45 quasi-cyclic blocks (QBs) of the LDPC codeword. The corresponding QB permutation is optimized for each combination of N_{BPCU}, code rate, and power imbalance. Tables 117 to 119 show these permutations for N_{BPCU} = 6, 8 and 10, respectively, each table containing the permutations for all code rates and power imbalances. The QB indices range from 1 to 45.

Table 117: QB permutations for 6 bits per channel use

Code rate	Power imbalance	QB permutations for 6 bits per channel use																																												
		Section 1			Section 2			Section 3			Section 4			Section 5			Section 6			Section 7			Section 8			Section 9			Section 10			Section 11			Section 12			Section 13			Section 14			Section 15		
1/3	1:1	17	5	34	33	28	38	22	13	32	14	44	7	27	23	18	41	10	35	21	15	45	42	26	31	39	29	12	4	1	2	40	36	19	20	43	9	16	3	24	11	37	25	30	8	6
	1:2	20	23	40	15	19	21	27	44	9	10	11	36	18	38	32	35	39	31	16	33	42	30	1	7	34	43	45	17	28	22	8	4	2	14	24	41	37	25	12	26	5	3	6	13	29
	1:4	6	27	36	3	19	1	28	38	16	8	32	24	33	13	35	15	2	7	41	43	31	42	25	22	11	30	44	23	18	21	4	26	39	5	29	45	20	34	40	37	14	17	10	9	12
2/5	1:1	20	16	34	41	28	36	19	35	42	45	43	2	1	8	30	12	9	14	10	38	15	22	6	5	24	13	31	32	23	27	40	39	18	33	3	29	25	7	21	44	17	26	37	11	4
	1:2	20	16	34	41	28	36	19	35	42	45	43	2	1	8	30	12	9	14	10	38	15	22	6	5	24	13	31	32	23	27	40	39	18	33	3	29	25	7	21	44	17	26	37	11	4
	1:4	20	16	34	41	28	36	19	35	42	45	43	2	1	8	30	12	9	14	10	38	15	22	6	5	24	13	31	32	23	27	40	39	18	33	3	29	25	7	21	44	17	26	37	11	4
7/15	1:1	13	11	44	41	24	12	16	27	14	22	32	5	17	29	39	6	35	30	10	8	37	3	38	1	7	42	26	15	28	34	9	23	43	4	40	2	20	25	36	21	33	31	18	19	45
	1:2	34	13	24	16	40	19	23	38	1	28	36	21	9	6	2	42	44	8	43	33	5	22	41	32	29	45	15	18	26	37	27	31	10	17	30	11	14	20	7	3	35	4	39	25	12
	1:4	34	13	24	16	40	19	23	38	1	28	36	21	9	6	2	42	44	8	43	33	5	22	41	32	29	45	15	18	26	37	27	31	10	17	30	11	14	20	7	3	35	4	39	25	12
8/15	1:1	12	27	14	35	13	38	7	39	9	19	43	33	24	25	10	6	45	21	2	28	4	3	17	15	40	42	22	8	41	11	32	16	18	44	31	37	30	26	29	34	36	23	5	20	1
	1:2	8	25	22	18	28	20	3	23	4	33	38	19	27	31	11	6	45	24	29	39	7	26	41	2	10	40	32	13	14	9	1	34	5	35	36	21	42	37	12	16	30	17	15	44	43
	1:4	34	13	24	16	15	18	23	32	1	28	36	21	9	6	2	42	44	8	37	33	5	22	19	14	29	45	40	41	26	43	27	31	10	17	30	11	38	20	7	3	35	4	39	25	12
3/5	1:1	32	38	25	18	28	34	7	39	15	20	40	44	19	12	29	14	17	21	33	5	24	36	41	31	10	6	27	45	42	37	13	43	11	26	16	22	2	1	3	8	30	9	23	4	35
	1:2	31	43	26	20	44	39	18	28	11	37	12	36	34	42	40	9	7	21	22	6	16	27	29	13	8	30	19	38	45	32	4	2	10	5	1	14	17	41	24	35	3	23	15	33	25
	1:4	23	5	22	42	45	20	43	18	11	27	39	34	41	37	6	24	16	8	30	40	12	35	21	31	36	10	33	44	38	14	4	3	13	9	29	19	32	15	25	28	26	17	1	2	7
2/3	1:1	19	33	39	10	14	34	27	3	40	20	36	32	16	17	43	7	9	26	11	44	21	5	42	31	6	41	8	4	24	13	25	15	18	23	1	45	30	2	38	12	29	22	35	28	37
	1:2	10	24	31	4	5	43	22	34	21	18	36	12	11	9	13	35	41	15	20	29	8	16	2	40	27	25	39	6	33	45	30	28	37	23	1	14	7	3	26	42	44	38	19	17	32
	1:4	45	39	28	38	16	20	10	8	14	44	35	4	24	34	12	26	32	15	30	22	11	21	43	17	19	13	6	2	5	37	31	42	9	7	40	18	25	1	27	23	3	29	33	41	36
11/15	1:1	5	35	39	3	25	16	44	17	4	32	13	12	8	26	45	10	6	15	21	40	43	27	24	33	2	28	41	29	19	38	14	20	30	36	7	23	34	1	18	22	42	11	9	37	31
	1:2	5	35	39	3	25	16	44	17	4	32	13	12	8	26	45	10	6	15	21	40	43	27	24	33	2	28	41	29	19	38	14	20	30	36	7	23	34	1	18	22	42	11	9	37	31
	1:4	45	1	39	13	34	18	22	3	19	20	37	17	36	30	27	16	31	2	8	42	35	6	38	33	28	23	9	21	43	4	12	15	29	32	40	24	14	7	5	10	41	44	25	11	26

Table 118: QB permutations for 8 bits per channel use

Code rate	Power imbalance	QB permutations for 8 bits per channel use																																												
		Section 1				Section 2				Section 3				Section 4				Section 5				Section 6				Section 7				Section 8				Section 9				Section 10				Section 11				
1/3	1:1	9	37	33	39	38	28	14	3	43	36	1	20	4	7	12	6	13	35	8	23	19	32	42	25	41	10	44	30	24	31	40	27	15	26	21	29	5	17	11	34	22	16	18	2	45
	1:2	4	16	25	1	19	42	36	8	13	34	41	6	37	9	12	17	3	35	32	22	2	39	11	21	14	33	15	23	44	18	26	40	43	24	10	5	28	20	29	31	7	27	30	38	45
	1:4	4	16	25	1	19	42	36	8	13	34	41	6	37	9	12	17	3	35	32	22	2	39	11	21	14	33	15	23	44	18	26	40	43	24	10	5	28	20	29	31	7	27	30	38	45
2/5	1:1	7	21	43	35	27	4	24	5	16	20	30	10	17	42	41	44	15	13	31	36	23	12	37	18	1	19	40	22	29	9	38	8	6	34	14	26	39	3	25	32	28	33	11	2	45
	1:2	7	21	43	35	27	4	24	5	16	20	30	10	17	42	41	44	15	13	31	36	23	12	37	18	1	19	40	22	29	9	38	8	6	34	14	26	39	3	25	32	28	33	11	2	45
	1:4	38	3	28	4	17	9	16	12	36	29	19	6	8	35	7	40	37	10	44	34	2	15	14	39	32	5	42	20	1	26	18	13	23	33	11	22	31	25	43	21	27	24	41	30	45
7/15	1:1	8	12	38	21	28	19	24	6	31	17	27	20	32	5	35	2	37	1	4	3	43	9	41	33	26	15	39	18	29	11	30	7	44	23	25	16	14	10	34	36	22	42	13	40	45
	1:2	41	14	33	22	27	10	21	12	35	19	34	8	37	15	5	20	28	24	29	32	11	4	1	3	30	44	6	7	23	42	25	17	26	2	36	13	39	43	38	16	40	9	31	18	45
	1:4	35	15	8	5	40	20	42	1	2	11	31	3	41	37	6	10	36	14	34	28	44	22	12	30	29	17	26	27	23	43	9	4	38	18	24	21	32	16	13	39	33	19	25	7	45
8/15	1:1	17	39	38	26	41	10	33	6	28	5	14	3	42	22	31	43	25	40	44	24	8	1	12	4	29	15	7	20	34	2	36	23	37	16	11	9	30	27	32	21	35	13	18	19	45
	1:2	28	29	19	22	35	43	44	16	21	38	41	5	27	37	15	42	7	18	9	20	25	10	40	4	34	3	31	2	12	14	6	17	26	8	30	1	33	39	23	13	36	11	32	24	45
	1:4	16	24	44	3	39	34	8	11	37	25	26	7	29	43	42	1	35	22	21	17	4	2	33	5	27	10	13	14	36	19	23	9	41	40	32	20	28	18	31	15	30	12	6	38	45
3/5	1:1	24	3	15	2	40	11	29	18	42	12	34	16	31	21	41	19	44	14	38	25	37	36	32	7	1	28	5	10	33	9	6	17	4	13	39	23	30	26	43	8	35	20	27	22	45
	1:2	27	20	32	18	41	33	6	12	35	21	14	9	31	37	23	16	42	40	43	13	36	34	26	22	30	28	8	19	1	44	3	38	11	39	10	24	29	25	17	7	5	15	4	2	45
	1:4	27	20	32	18	41	33	6	12	35	21	14	9	31	37	23	16	42	40	43	13	36	34	26	22	30	28	8	19	1	44	3	38	11	39	10	24	29	25	17	7	5	15	4	2	45
2/3	1:1	40	38	36	35	1	23	18	9	24	29	43	27	2	19	3	10	25	20	37	6	4	7	41	39	42	17	14	11	8	22	32	12	28	15	21	5	34	26	13	30	16	33	44	31	45
	1:2	2	23	3	16	1	12	19	17	30	41	43	24	35	33	22	42	34	13	5	40	15	8	11	32	28	29	36	10	38	39	21	14	44	18	7	26	4	31	9	6	37	27	25	20	45
	1:4	2	23	3	16	1	12	19	17	30	41	43	24	35	33	22	42	34	13	5	40	15	8	11	32	28	29	36	10	38	39	21	14	44	18	7	26	4	31	9	6	37	27	25	20	45
11/15	1:1	15	5	37	20	18	43	1	33	12	29	30	27	21	24	34	4	7	44	41	36	25	16	40	11	19	32	28	23	8	22	38	35	17	2	42	13	14	26	39	3	31	6	10	9	45
	1:2	15	5	37	20	18	43	1	33	12	29	30	27	21	24	34	4	7	44	41	36	25	16	40	11	19	32	28	23	8	22	38	35	17	2	42	13	14	26	39	3	31	6	10	9	45
	1:4	37	28	20	21	22	27	12	6	44	25	18	13	1	14	3	42	9	41	26	24	19	11	30	33	39	2	23	32	15	5	17	43	34	16	4	29	7	38	35	10	36	40	8	31	45

Table 119: QB permutations for 10 bits per channel use

Code rate	Power imbalance	QB permutations for 10 bits per channel use																																												
		Section 1					Section 2					Section 3					Section 4					Section 5					Section 6					Section 7					Section 8					Section 9				
1/3	1:1	27	17	42	8	30	38	6	15	32	36	22	18	40	26	14	41	45	29	23	9	20	4	44	37	2	43	12	11	10	28	21	16	5	13	31	33	3	1	35	7	39	34	24	19	25
	1:2	27	17	42	8	30	38	6	15	32	36	22	18	40	26	14	41	45	29	23	9	20	4	44	37	2	43	12	11	10	28	21	16	5	13	31	33	3	1	35	7	39	34	24	19	25
	1:4	42	30	27	8	17	38	32	36	6	15	26	14	40	18	22	9	45	23	41	29	20	4	44	37	2	43	12	11	10	28	21	16	5	13	31	33	3	1	35	7	24	25	39	34	19
2/5	1:1	30	35	13	26	38	22	14	1	10	19	7	21	24	45	33	41	3	43	20	31	9	16	11	34	4	17	32	42	23	36	28	15	44	5	2	40	18	12	39	29	27	25	8	37	6
	1:2	30	35	13	26	38	22	14	1	10	19	7	21	24	45	33	41	3	43	20	31	9	16	11	34	4	17	32	42	23	36	28	15	44	5	2	40	18	12	39	29	27	25	8	37	6
	1:4	44	23	13	45	1	2	21	14	4	25	41	20	22	29	19	30	24	17	42	33	27	5	36	11	3	40	8	18	7	35	16	10	38	31	28	43	34	6	12	9	39	26	37	15	32
7/15	1:1	9	1	33	4	20	16	29	41	38	6	19	14	35	30	39	43	15	27	44	10	11	3	24	18	7	45	8	37	34	22	31	2	40	36	12	32	13	42	25	17	28	21	26	5	23
	1:2	43	20	44	31	7	28	19	26	23	3	40	35	42	22	16	34	21	27	17	4	33	32	2	38	1	39	10	36	11	8	6	24	41	15	5	18	25	45	13	29	14	9	30	37	12
	1:4	39	32	44	31	10	33	19	36	11	4	28	7	18	22	1	41	35	14	13	29	34	2	3	24	9	40	25	30	6	23	43	16	42	37	5	38	21	26	17	12	45	20	27	15	8
8/15	1:1	27	3	43	12	17	18	8	40	22	15	31	7	41	29	21	30	6	26	28	36	39	9	19	16	32	5	13	24	1	4	10	23	14	35	2	42	37	44	38	34	33	11	45	25	20
	1:2	31	43	28	25	10	36	16	35	38	13	44	20	21	30	15	12	4	24	1	5	7	14	34	45	18	33	11	42	27	9	39	17	26	40	23	32	3	22	41	6	8	19	29	37	2
	1:4	28	25	44	37	8	2	10	38	3	6	13	42	39	35	1	16	41	18	9	17	34	19	27	11	4	33	24	30	23	7	12	14	45	32	15	40	21	36	22	29	43	20	26	31	5
3/5	1:1	17	28	39	7	14	29	16	35	41	45	2	5	18	1	32	42	13	37	34	21	33	25	40	12	6	30	31	24	8	20	23	4	3	9	11	27	22	38	44	15	10	19	43	36	26
	1:2	17	28	39	7	14	41	16	35	29	45	2	5	18	1	32	37	13	34	42	21	33	12	40	25	6	30	31	24	8	20	23	4	3	9	11	15	27	38	44	22	43	26	36	10	19
	1:4	35	12	38	32	24	28	11	45	23	33	42	14	40	6	31	3	8	17	2	15	19	43	37	20	22	5	18	1	9	4	10	30	41	21	13	44	25	36	34	26	29	39	16	27	7
2/3	1:1	14	6	24	15	23	39	28	36	30	11	13	8	22	34	10	9	44	33	41	5	12	31	2	3	29	40	43	32	7	18	16	20	38	45	4	26	27	21	19	25	37	35	1	17	42
	1:2	17	23	45	21	6	42	24	3	29	16	32	27	1	25	38	26	7	18	39	20	37	44	41	43	12	5	10	11	35	33	28	40	34	4	8	30	13	19	2	22	9	14	31	15	36
	1:4	38	30	11	27	17	16	22	45	21	44	1	23	3	2	35	7	8	12	39	13	40	6	42	36	14	18	34	31	28	24	10	5	15	26	9	20	19	37	32	29	25	33	4	43	41
11/15	1:1	45	43	10	35	16	24	29	1	41	27	26	5	25	23	44	8	13	30	12	9	17	39	22	4	38	21	28	19	20	37	14	31	34	6	3	32	11	15	7	42	33	40	36	2	18
	1:2	27	11	10	37	45	25	6	32	28	5	18	4	23	22	9	36	30	41	34	43	35	29	1	31	38	7	3	16	44	12	2	40	33	39	20	17	26	8	42	15	24	19	13	21	14
	1:4	1	30	15	7	35	26	22	27	21	44	17	23	37	31	39	9	8	13	36	24	4	42	34	20	28	16	41	6	45	2	29	10	19	33	40	14	18	12	38	5	43	32	3	25	11

Following the QB interleaver, the LDPC codeword is divided into parallel sections, each section containing $N_{BPCU}/2$ adjacent quasi-cyclic blocks. Each section is interleaved independently by a section interleaver. The number of sections per LDPC codeword for $N_{BPCU} = 6$, 8 and 10 is 15, 11 and 9, respectively. For $N_{BPCU} = 8$, since 4 is not a divisor of 45 the last quasi-cycle block does not belong to any section and shall not be permuted by a section interleaver.

The section interleaving consists in writing the bits of each section row by row into a matrix with 360 columns and $N_{BPCU}/2$ rows and reading them out column by column. Such an interleaving strategy ensures that each spatially multiplexed block contains 2 adjacent bits from each quasi-cyclic block in the corresponding section, as shown in figure 98 for $N_{BPCU} = 8$. The bits from all sections are then merged into an interleaved LDPC codeword.

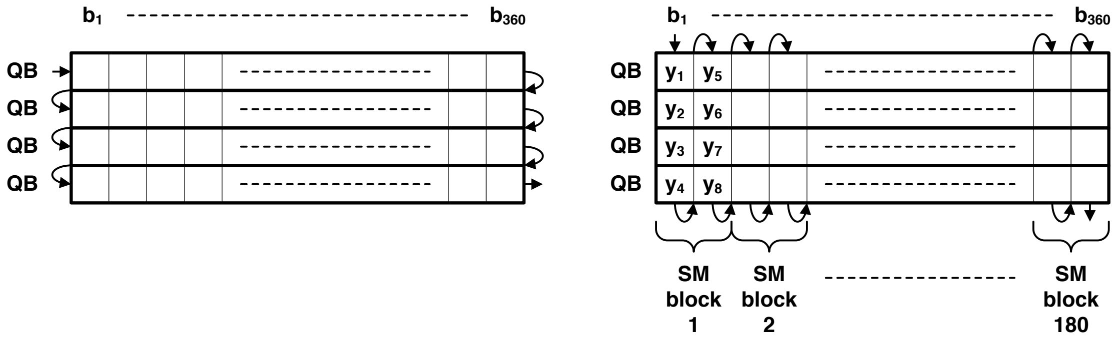


Figure 98: Section interleaver, write and read sequences

16 Complex symbol generation

The N_{BPCU} bits of each SM block modulate two complex symbols (s_1 and s_2), which are spatially multiplexed over the two antennas. The mapping of the bits to complex symbols is shown in figure 99 for $N_{BPCU} = 6$, 8 and 10, the corresponding bit encoding/labelling of the real pulse-amplitude modulation symbols being illustrated in figure 100. Bit b_1 is always the least significant.

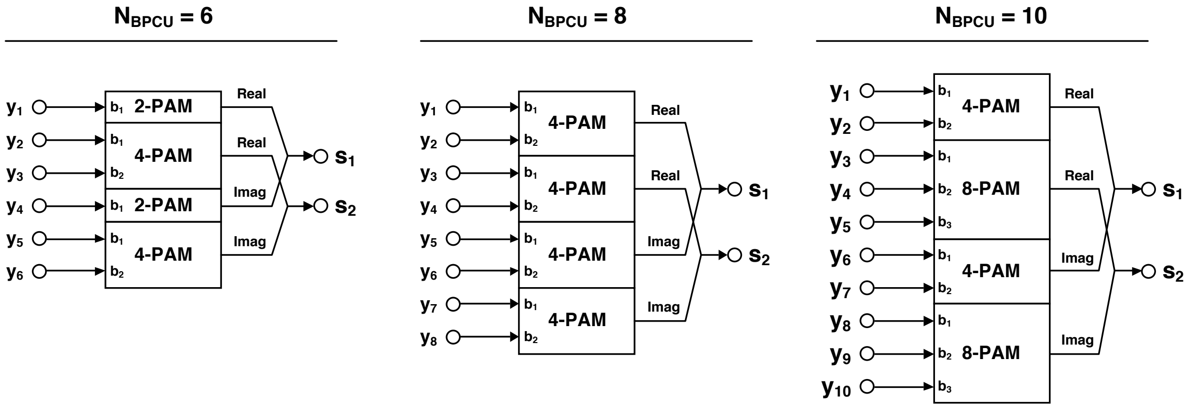
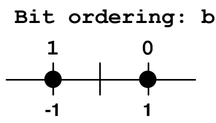
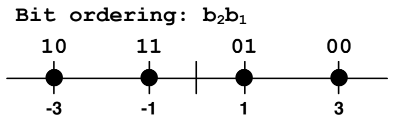


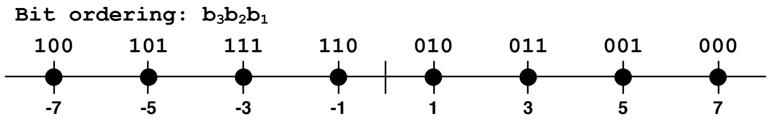
Figure 99: Mapping of SM blocks to pairs of complex symbols



2-PAM encoding



4-PAM encoding



8-PAM encoding

Figure 100: Bit encoding/labelling for real PAM symbols

The resulting constellations for the symbols s_1 and s_2 are summarized in table 120.

Table 120: Constellations sizes

	$N_{BPCU} = 6$	$N_{BPCU} = 8$	$N_{BPCU} = 10$
s_1	QPSK	16-QAM	16-QAM
s_2	16-QAM	16-QAM	64-QAM

NOTE: 64-QAM is using uniform constellation mapping only (see clause 6.2.2)

17 Power imbalance

The MIMO profile is specified for use with one of three fixed power imbalances (HP/VP or VP/HP), in order to facilitate time-sharing with SISO services without undesired station envelope power fluctuations or excessive SISO link budget loss.

The available power imbalances are 0 dB, 3 dB and 6 dB.

The imbalance may be optionally applied during all PLP and frame types, SISO, MISO and MIMO. So where Alamouti coding is used in a cross-polar context (6.6) an imbalancing matrix may be introduced as follows, the value of β taken from table 30.

$$\begin{bmatrix} g'_q(Tx1) \\ g'_q(Tx2) \end{bmatrix} = \begin{bmatrix} \sqrt{\beta} & 0 \\ 0 & \sqrt{1-\beta} \end{bmatrix} \begin{bmatrix} g_q(Tx1) \\ g_q(Tx2) \end{bmatrix}$$

$$q = 0 \ldots N_{data} - 1$$

In the case of cross-polar transmission, during SISO frames, the two transmission elements may be generated as

$$\begin{bmatrix} g'_q(Tx1) \\ g'_q(Tx2) \end{bmatrix} = \begin{bmatrix} \sqrt{\beta} & 0 \\ 0 & \sqrt{1-\beta} \end{bmatrix} \begin{bmatrix} g_q \\ g_q \end{bmatrix}$$

$$q = 0 \ldots N_{data} - 1$$

Note : If the specified options for fixed power imbalance are not used, and envelope power fluctuations are acceptable, then the MIMO frames are transmitted with 0dB power imbalance and the SISO on a single polarisation (infinite imbalance).

18 MIMO precoding

MIMO processing is intended for a 2x2 MIMO system which means that at least two antenna aerials are equipped at both transmitter and receiver side. MIMO processing acts on a pair of input constellation points (not necessarily drawn from the same constellation) and creates a pair of outputs intended for the two elements of a dual-polar transmitter. MIMO processing is never applied to the preamble symbols P1, AP1 and P2 and the pilots are processed as described in clause 11.1.

The MIMO precoding shall be applied at PLP level and consists in multiplying cell pairs (f_{2i}, f_{2i+1}) by a variable precoding matrix **W**(i). Encoded cell pairs (g_{2i}, g_{2i+1}) shall be transmitted on the same OFDM symbol and carrier from Tx-1 and Tx-2 respectively.

$$\begin{pmatrix} g_{2i} \\ g_{2i+1} \end{pmatrix} = \mathbf{W}(i) \begin{pmatrix} f_{2i} \\ f_{2i+1} \end{pmatrix}, \quad i = 0, 1, \ldots, Ncells/2 - 1$$

where i is the index of the cell pair within the FEC block and *Ncells* is the number of cells per FEC block as given in table 9.

The MIMO precoding process consists of a spatial-multiplexing precoding followed by an additional phase-hopping, as shown in Figure 4. The combined precoding matrix **W**(i) is the product of the fixed spatial-multiplexing precoding matrix **F** and the variable phase-hopping matrix **X**(i).

For rate 2 MIMO schemes, both MIMO branches, i.e. the signal generation for both transmit antennas, shall use the same time interleaver configuration. The required time de-interleaver memory size $N_{\mathrm{MUs,PLP}}$ per MIMO branch can be calculated in the same way as described for the SISO scheme of the base profile in Clause 6.6.4, when setting 1 MU corresponding always to 1 cell (for any signal constellation – QPSK, 16-, 64- and 256-QAM). The total required de-interleaver memory for both MIMO branches is twice this size. The applicable limit for the MIMO profile is still $\sum 2N_{\mathrm{MUs,PLP}} \leq 2^{18}$ MUs, where the sum is taken over all PLPs in a given PLP clusterand the factor 2 comes from the fact, that the size for both MIMO branches is double that per single MIMO branch.

If MIMO precoding is not used, only transmit antenna 1 (tx1) path is used and the input QAM symbols shall be copied directly to the output, i.e. $g_k = f_k$. for k=0,1,2,…,N_{data}-1.

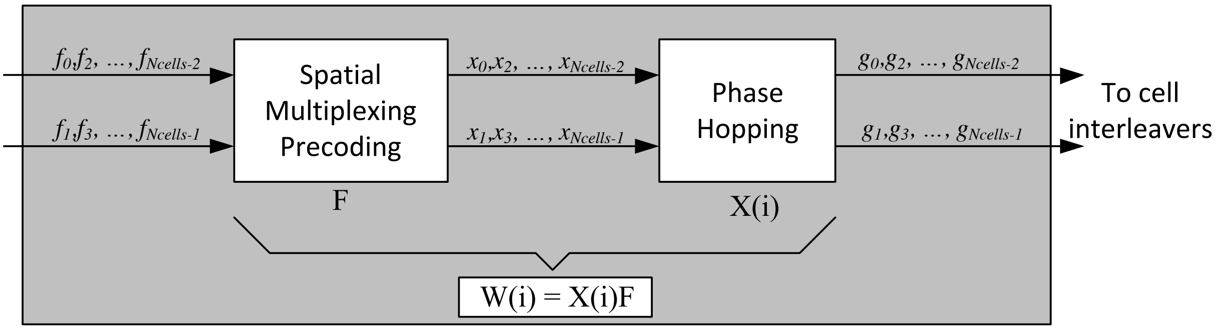


Figure 101: Block diagram of the MIMO precoding

18.1 Spatial-multiplexing encoding

The spatial multiplexing encoding process is carried out on pairs of normalised QAM symbols (f_{2i}(Tx1) ,f_{2i+1}(Tx2)) from the output of the constellation mapper. These payload cells, prior to the application of phase hopping, are x_{2i}(Tx1) for transmit antenna 1 and x_{2i+1}(Tx2) for transmit antenna 2 and shall be generated from the input symbols according to:

$$\begin{bmatrix} x_{2i}(Tx1) \\ x_{2i+1}(Tx2) \end{bmatrix} = \sqrt{2} \begin{bmatrix} \sqrt{\beta} & 0 \\ 0 & \sqrt{1-\beta} \end{bmatrix} \begin{bmatrix} \cos\theta & \sin\theta \\ \sin\theta & -\cos\theta \end{bmatrix} \begin{bmatrix} \sqrt{\alpha} & 0 \\ 0 & \sqrt{1-\alpha} \end{bmatrix} \begin{bmatrix} f_{2i}(Tx1) \\ f_{2i+1}(Tx2) \end{bmatrix}$$

$$i = 0,..,(N_{cells}/2)-1$$

N_{cells} is the number of cells required to transmit one LDPC block by using MIMO encoding which is calculated by $N_{\text{ldpc}}/n_{\text{bpcu}}$.

MIMO processing may be applied for 6, 8, 10 bits/cell unit(bpcu) and also for intentional power imbalance of 0, 3, 6dB between two transmit antennas. MIMO encoding process shall use defined parameter values for each case according to table121:

Table 121: eSM parameters

Intentional power imbalance between two Tx antennas			0dB			3dB			6dB		
n_{bpcu}	Modulation		β	Θ	α	β	θ	α	β	θ	α
6	f_{2i}(tx1)	QPSK	0.50	45°	0.44	1/3	0°	0.50	0.20	0°	0.50
	f_{2i+1}(tx2)	16-QAM									
8	f_{2i}(tx1)	16-QAM	0.50	$\text{atan}\left(\frac{\sqrt{2}+4}{\sqrt{2}+2}\right)$	0.50	1/3	25°	0.50	0.20	0°	0.50
	f_{2i+1}(tx2)	16-QAM									
10	f_{2i}(tx1)	16-QAM	0.50	22°	0.50	1/3	15°	0.50	0.20	0°	0.50
	f_{2i+1}(tx2)	64-QAM									

The encoding process is repeated for each pair of QAM symbols in turn.

18.2 Phase hopping

Except in the case of the hybrid MIMO profile where VMIMO has been used (see appendix N.1), phase hopping shall be applied to the output of the spatial-multiplexing precoding and consists of applying an incremental phase change to the complex cells transmitted on tx-2. The phase change is performed by multiplying each cell pair (x_{2i}, x_{2i+1}) by a variable matrix **X**(*i*), resulting in a cell pair (g_{2i},g_{2i+1}), i.e. the encoded OFDM payload cells:

$$\begin{pmatrix} g_{2i} \\ g_{2i+1} \end{pmatrix} = \mathbf{X}(i) \begin{pmatrix} x_{2i} \\ x_{2i+1} \end{pmatrix}, \; i = 0, 1, \ldots, Ncells/2-1.$$

where *X(i)* has the following expression

$$X(i) = \begin{pmatrix} 1 & 0 \\ 0 & e^{j\Phi_{PH(i)}} \end{pmatrix}, \; i = 0, 1, \ldots, Ncells/2-1$$

The phase change for cell pair *i* is $\Phi_{PH(i)} = 2\pi i/9$, i.e. it is initialized to 0 at the beginning of each FEC block and is incremented by $2\pi/9$ for every cell pair. The resulting hopping pattern is periodic with a period of 9 cell pairs, i.e. **X**(*i+9*) = **X**(*i*). Since the number of cell pairs per FEC block is a multiple of 9 for all modulations, there is always an integer number of phase-hopping periods in each FEC block.

The phase-hopping matrix **X**(*i*) is independent of the modulation and the power imbalance.

19 eSFN processing for MIXO

The principle role of eSFN with MIMO (also MISO, see clause 7) is to carry SISO frames as part of transmission containing both SISO and MIXO frames. The eSFN signal power is split in the same way as the MIXO power over different transmission components (e.g. the HP/VP parts in case of crosspolar transmission), to achieve the corresponding power imbalance, such that the average power is the same on each transmission component during SISO and MIXO transmission. Thus eSFN is applied within the MIMO profile at frame level to modulate the OFDM symbols using the eSFN predistortion term Φ_k as described in chapter 11.4.1.

If continuity of the transmitter identification property of eSFN is required during MIMO frames as well as SISO, then eSFN may optionally be continuously applied over all frame types.

20 SISO/MIXO options for P1, aP1 and P2 symbols

Table 122 specifies the SISO/MIXO coding options applicable to P1, AP1 and P2 symbols.

Table 122: SISO/MIXO coding options for P1, AP1 and P2 symbols.

Symbol type / **PLP type**	**P1/AP1**	**P2**	**P2**	**P2**	**Data Symbols**
		L1-pre	**L1-post**	**Data**	
SISO	Uncoded SISO or	Uncoded SISO or	Uncoded SISO or	Uncoded SISO or	Uncoded SISO or

	eSFN	eSFN	eSFN	eSFN	eSFN
MISO	Uncoded SISO or eSFN	Alamouti	Alamouti	Alamouti	Alamouti
MIMO	Uncoded SISO or eSFN	Alamouti	Alamouti or eSM/PH	Alamouti or eSM/PH	Alamouti or eSM/PH

NOTE 1: The SISO row is shown for information only

NOTE 2: When Alamouti or eSM/PH is used, eSFN may be optionally added with a unique tx code applied per station or per-antenna

21 Layer 1 signalling data specific for the MIMO profile

21.1 P1 and additional P1 signalling data

The MIMO profile is signalled in the preamble P1 with the values S1 = 111 (ESC code) and S2 field 1 = 000, as described in clause 8.1.1.

The preamble P1 is followed by an additional P1 (aP1) symbol. The aP1 symbol has the capability to convey 7 bits for signalling, as illustrated in figure 102 below.

S3 (3b)	S4 (4b)
FFT size/GI	Reserved

Figure 102: aP1 signalling format for the MIMO profile.

- The S3 field (3 bits) indicates the FFT size and gives partial information about the guard interval for the remaining symbols in the NGH frame in the MIMO profile, as described intable 123.

Table 123: S3 (3 bits) for NGH MIMO preamble type.

S3 field	FFT/GI size	Description
000	FFT Size: 1K – any allowed guard interval	Indicates the FFT size and guard interval of the symbols in the NGH-frame of the MIMO profile
001	FFT Size: 2K – any allowed guard interval	
010	FFT Size: 4K – any allowed guard interval	
011	FFT Size: 8K – guard intervals 1/32; 1/16; 1/8 or 1/4	
100	FFT Size: 8K – guard intervals 1/128; 19/256 or 19/128	
101	FFT Size: 16K – guard intervals 1/128; 19/256 or 19/128	
110	FFT Size: 16K – guard intervals 1/32; 1/16; 1/8 or 1/4	
111	Reserved for future use	

- The S4 field (4 bits): Reserved for future use.

The modulation and construction of the aP1 symbol is described in clause 11.7.3 of the base profile.

21.2 L1-PRE signalling data

Error! Reference source not found. highlights the signalling specific to the MIMO profile added to the L1-RE signalling data defined in clause 8.1.2 of the base profile.

Table 124: L1-PRE signalling fields specific to the MIMO profile.

…	
PH_FLAG	1 Bit
…	…
L1_POST_MIMO	4 Bits
L1_POST_NUM_BITS_PER_CHANNEL_USE	3 Bits
…	

PH_FLAG: This 1-bit flag indicates if the Phase Hopping (PH) option is used or not. A value equal to “0“ indicates that the PH option is not used. The PH scheme is described in clause 18.2.

L1-POST_MIMO: This 4-bit field indicates the MIMO scheme of the L1-POST signalling data block. The MIMO schemes shall be signalled according totable 125.

Table 125: Signalling format for the L1-POST MIMO scheme.

Value	Constellation
0000	Alamouti
0001	eSM/PH
0010 to 1111	Reserved for future use

L1_POST_NUM_BITS_PER_CHANNEL_USE: This 3-bit field indicates the number of bits per channel use for the MIMO scheme used by L1-POST. The value of this field is defined in table 128.

21.3 L1-POST signalling data

21.3.1 L1-POST-configurable signalling data

Table 126 highlights the signalling fields specific to the MIMO profile added to the L1-POST configurable signalling defined in clause 8.1.3.1 of the base profile.

Table 126: The signalling fields of configurable L1-POST signalling.

```
IF S1 = “111” and S2 = “000x” or “011x” {
        PLP_MIMO_TYPE
        IF PLP_MIMO_TYPE = “0001” or “0010”    4 Bits
        {
           PLP_NUM_BITS_PER_CHANNEL_USE        3 Bits
        }
        ELSE {
           PLP_MOD                             3 Bits
        }
     }
     ELSE {
        PLP_MOD                                3 Bits
     }
```

PLP_MIMO_TYPE: This 4-bit field indicates the MIMO scheme used by the given PLP. The MIMO schemes shall be signalled according totable 127.

Table 127: Signalling format for the PLP_MIMO_TYPE scheme.

Value	Constellation
0000	Alamouti
0001	eSM/PH
0010 to 1111	Reserved for future use

The following fields appear only if PLP_MIMO_TYPE = “0001” (i.e. eSM/PH):

PLP_NUM_BITS_PER_CHANNEL_USE: This 3-bit field indicates the number of bits per channel use for the MIMO scheme used by the given PLP. The value of this field shall be defined according totable 124.

Table 128: Signalling format for PLP_NUM_BITS_PER_CHANNEL_USE.

Value	n_{bpcu}	Modulation	
000	6	f_{2i}(Tx1)	QPSK
		f_{2i+1}(Tx2)	16-QAM
001	8	f_{2i}(Tx1)	16-QAM
		f_{2i+1}(Tx2)	16-QAM
010	10	f_{2i}(Tx1)	16-QAM
		f_{2i+1}(Tx2)	64-QAM
011 to 111	Reserved for future use	Reserved for future use	

The following field appears only if PLP_MIMO_TYPE is equal to “0000” (e.g. Alamouti):

PLP_MOD: 3-bit field indicates the modulation used by the given PLP. The modulation shall be signalled according to table 61of the base profile.

21.3.2 L1-POST-dynamic signalling data

The MIMO profile uses the same L1-Dynamic signalling defined in clause 8.1.3.3 of the base profile.

21.3.3 In-band signalling type A

The MIMO profile uses the same in-band type A signalling defined in clause 5.2.3.1 of the base profile.

Part III: Hybrid profile

22 DVB-NGH hybrid system definition

22.1 System overview and architecture

The hybrid profile specifies the hybrid signal format, composed of a component coming from the terrestrial network, and an additional component, coming from the satellite. Hybrid signals according to this NGH profile include an additional P1 symbol (aP1, see clause 11.7.3). The satellite component of the hybrid profile is defined for channel bandwidths 1.7, 2.5 and 5 MHz (these three bandwidths are also covered by the base profile).

Hybrid NGH signals can also be base profile compliant, in which case they are covered by part I of this specification.

Besides defining the hybrid signals, the hybrid profile defines moreover the mechanisms to receive two signals simultaneously (one signal from a terrestrial transmitter and one from the satellite) and to combine their outputs to a single stream.

Figure xxx represents the high level NGH physical layer block diagram of the hybrid profile. Two chains are present, one for the terrestrial component and the other for the satellite component. Compared to the base profile, the terrestrial and satellite chains of the hybrid profile present potential functional differences in the BICM, frame building and waveform generation. The system architecture of the satellite component is that of the terrestrial component, with the possibility of replacing the OFDM modulation block by the SC-OFDM modulation block, characterised additionally by the absence of particular functional blocks as explained in clauses x.y.z, ……. and illustrated in figure z. The system input(s) to the terrestrial and the satellite path may differ from each other in the MFN case. Time frequency slicing can be applied to both, the terrestrial and the satellite components.

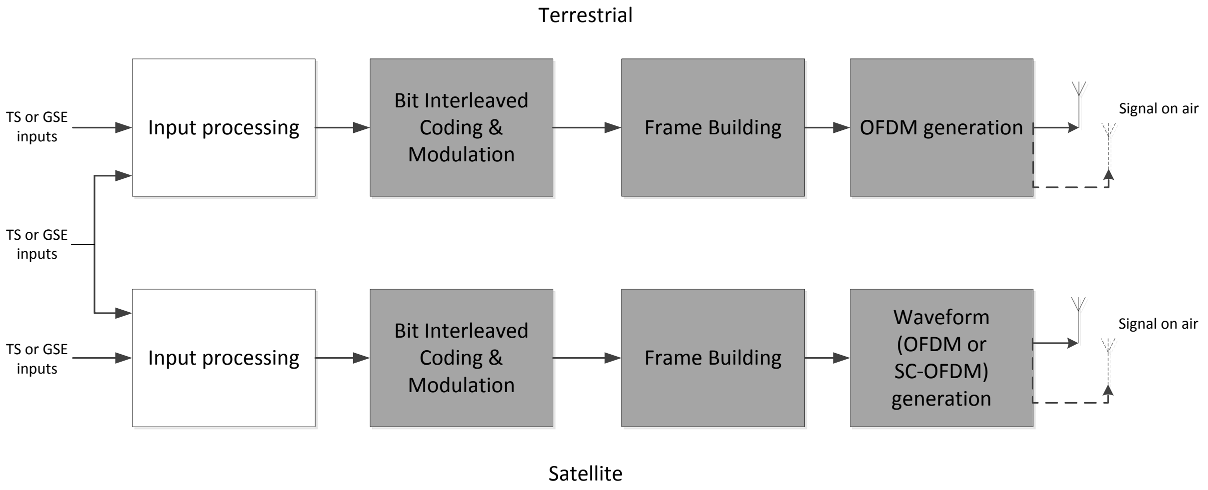


Figure 103: High level NGH phy layer block diagram of the hybrid profile. Blocks differing from the base profile are shaded grey

Both SFN and MFN configurations are possible for the hybrid profile. In the SFN case, when the satellite and terrestrial components share the same frequency, the signal transmitted in the two components shall be exactly the same. In the MFN case, the system architecture of the hybrid profile of DVB-NGH is composed of two components: the terrestrial component, as specified in the part I, and the satellite component, as represented in figure xxx.

Table yyy indicates the allowed parameter settings for the hybrid profile. According to it, the following hybrid cases can be devised:

- SFN, OFDM: The terrestrial network and the satellite share the same frequency and the same signal is transmitted on the two components. The signal waveform is OFDM and the preambles of both components consist of a P1 plus an aP1 symbol. The OFDM parameter set is applicable to both components, terrestrial and satellite. Alternatively, the base profile could be adopted for both components. In that case the P1 part of the preamble of both components consists of a P1 symbol only.

- MFN , OFDM: The satellite signal is transmitted on a different frequency, OFDM is used on both components. The terrestrial component is transmitted according to the base profile, the satellite component according to the OFDM settings listed in table 125 below. The preamble of the terrestrial component consists of a P1 symbol and the preamble of the satellite component consists of a P1 plus an aP1 symbol.

- SFN, SC-OFDM: This case consists of the satellite coverage and of terrestrial gap fillers sharing the same frequency of the satellite signal. The SC-OFDM settings are applicable to both components, terrestrial and satellite. Preambles consist of P1 plus aP1 symbols for the satellite and the terrestrial component.

- MFN, SC-OFDM on the satellite component, OFDM on the terrestrial component: The terrestrial component is configured in line with the base profile, the satellite component using the permitted SC-OFDM settings outlined in table 125 below. The preamble of the terrestrial component consists of a P1 symbol and the one of the satellite component of a P1 plus an aP1 symbol.

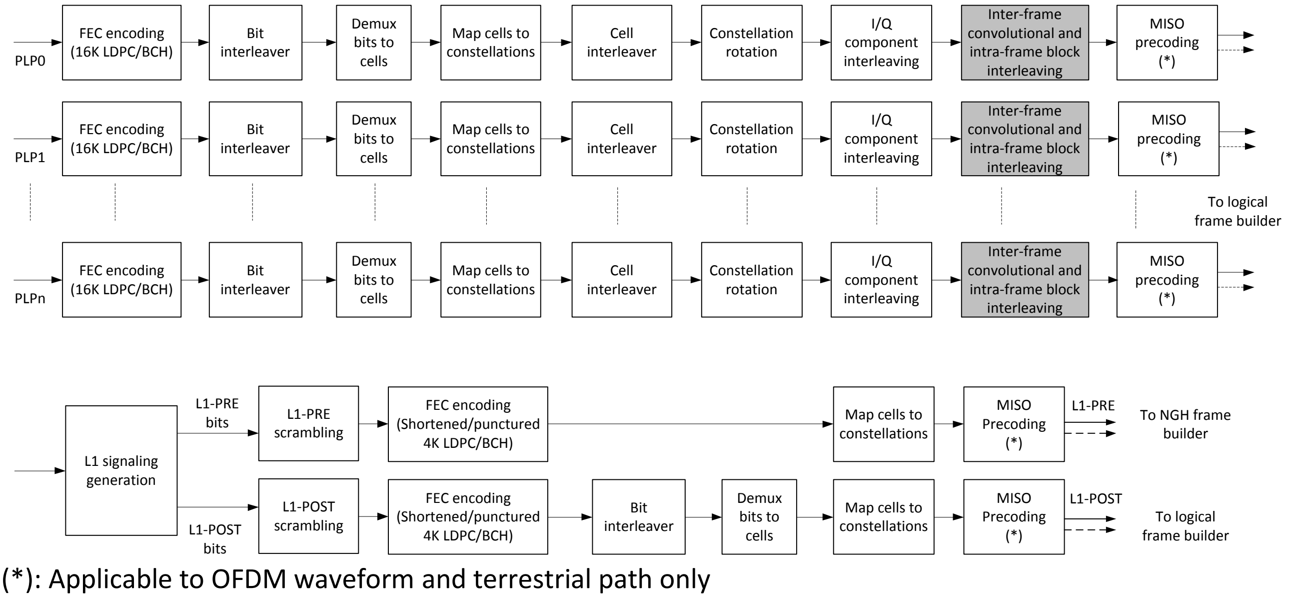
Table 129: Allowed parameter settings for the hybrid profile

Parameters		**Hybrid waveform**	
Modulation		**OFDM**	**SC-OFDM**
Bandwidths	1.7 MHz	**X**	**X**
	2.5 MHz	**X**	**X**
	5.0 MHz	**X**	**X**
	6.0 MHz		
	7.0 MHz		
	8.0 MHz		
	10.0 MHz		
	15.0 MHz		
	20.0 MHz		
Constellations	QPSK	**X**	**X**
	16-QAM	**X**	**X**
	64-QAM		
	256-QAM		
FFT sizes	0.5k		**X**
	1k	**X**	**X**
	2k	**X**	**X**
	4k		
	8k		
	16k		
Guard intervals	1/128		
	1/32	**X**	**X**
	1/16	**X**	**X**

	19/256		
	1/8	X	
	19/128		
	1/4	X	
Preambles	Single P1		
	P1 + aP1	X	X
Pilot patterns	Continuous pilot symbols	x	
	PP1	X	
	PP2	X	
	PP3	X	
	PP4	X	
	PP5	X	
	PP6		
	PP7		
	PP9		X
FEC code rates	1/5 (=3/15)	X	X
	4/15	X	X
	1/3 (=5/15)	X	X
	2/5 (=6/15)	X	X
	7/15	X	X
	8/15	X	X
	3/5 (=9/15)	X	X
	2/3 (=10/15)	X	X
	11/15	X	X
	3/4	X	X
MISO		X	
Time de-interleaver size	See note 2	According to clause x.y.z	According to clause x.y.z
Note 1: Not all parameter settings listed above can be combined with each other. The exceptions are described in the following clauses. Note 2: In situations where a receiver needs to time de-interleave both, the terrestrial and the satellite signal, in parallel, limits for the time de-interleaver size outlined in clause 26.2 apply to the combination of both signals, i.e. they cannot simultaneously make use of the full specified time de-interleaver memory size.			

22.1.1 Bit-interleaved coding and modulation, MISO precoding

The block diagram, illustrating the functional differences in the BICM stage, is shown in figure xxx. Further to the time interleaving configurations of the base profile, the hybrid profile allows a concentration of cells at the end of the logical frame sequence over which a FEC block is spread (uniform-late interleaving).



(*): Applicable to OFDM waveform and terrestrial path only

Figure 104: BICM of the hybrid profile (applicable to the terrestrial and the satellite path)

22.1.2 Frame building, frequency interleaving

The block diagram, illustrating the functional differences in frame building stage, is shown in figure xxx. This is the same architecture as the base profile except for the allocation of space for the aP1 symbol. As far as the physical and the logical framing is concerned, the same mechanisms are used for the terrestrial and satellite components. These mechanisms are described in clause 9. The frequency interleaver is applicable to OFDM only.

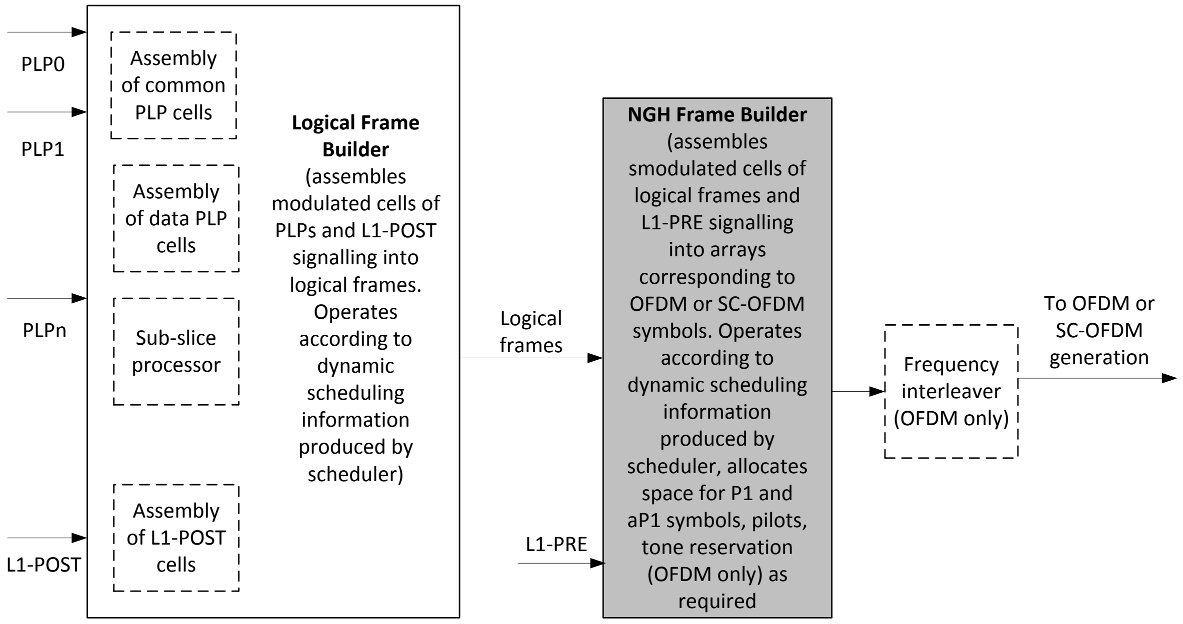


Figure 105: Frame builder of the hybrid profile (applicable to the terrestrial and the satellite path)

22.1.3 OFDM generation

The block diagram, illustrating the functional differences in the OFDM generation stage, is shown in figure xxx. The only functional difference is the insertion of the additional preamble symbol aP1, following the preamble symbol P1, as specified in clause 11.7.3.

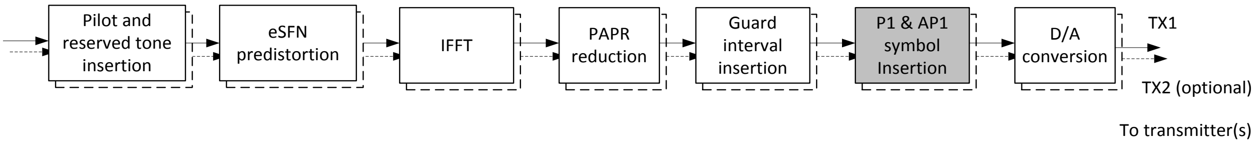


Figure 106: OFDM generation (applicable to the terrestrial and the satellite path)

22.1.4 SC-OFDM generation

The block diagram, illustrating the SC-OFM generation stage, is shown in figure xxx. The functional differences are the additional spreading stage (see clause 33.x.y below), a different pilot pattern, the absence of continual pilots, the absence of edge pilots, the absence of a frame closing symbol (see annex K for the latter three) and the additional preamble symbol aP1 (specified in clause 11.7.3). Furthermore, the number of sub-carriers per SC-OFDM symbol is even.

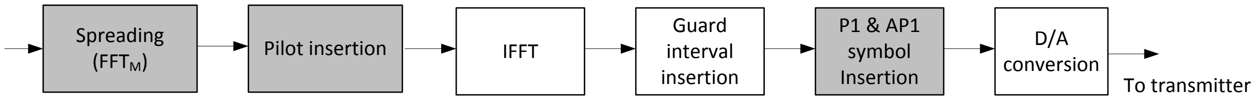


Figure 107: SC-OFDM generation (applicable to the satellite path only)

Table 130: Allowed parameter settings for the hybrid profile

23 Input processing

Input processing follows the same mechanism as the base profile. The compensating delay function enables the end-to-end delay of services transmitted in both the terrestrial and satellite signals to be aligned. An important use case for this is hybrid combining of a terrestrial and a satellite signal in a hybrid multi-frequency network (MFN). For instance, the terrestrial signal may use time interleaving of duration 1 s for the considered input stream, while the satellite signal uses 10 s. Hence, a compensating delay of 9 s shall be used in the terrestrial modulator for this input stream, while the satellite modulator does not need any compensating delay.

24 Bit interleaved coding and modulation

The bit interleaved coding and modulation module is almost identical to the one of the base profile. The differences are described in this clause.

24.1 Constellation mapping

64-QAM and 256-QAM constellations shall not be used for the satellite component, i.e. 64-QAM and 256-QAM are only allowed in the hybrid profile for the terrestrial component in the MFN configuration.

24.2 Time interleaver

The time interleaving in hybrid signals is almost similar to the procedure described in clause 6.6 of the base profile. The differences are explained in this clause.

While the base profile spreads the IUs uniformly over the configured time interleaver length P_{I}, hybrid signals allow a concentration of cells at the end of the NGH logical frame sequence, over which a FEC block is spread (uniform-late interleaving). Hence it is possible to transmit fewer cells of a FEC block in the first logical frames than in the last logical frames, over which the FEC block is distributed. This group of last logical frames is referred to as the “late” part of the time interleavering frame.

There are two new hybrid-specific parameters: P_{late} = TI_LATE_LENGTH represents the length of the late part of the time interleaving in terms of logical frames inside the full time interleaver length P_{I} (allowed value range is 0 to 7), and $N_{\mathrm{ADD\_IU\_PER\_LATE}}$ = NUM_ADD_IUS_PER_LATE_FRAME is the number of additional IUs per logical frame in the late part (additional to the 1 IU per logical frame that is present according to clause 6.6) – its allowed values range from 0 to 15.

If multiple TI blocks are used per interleaving frame (TIME_IL_TYPE = ‘0’), then P_{late} = TI_LATE_LENGTH shall be 0.

In the case of hybrid signals and TIME_IL_TYPE = ‘1’, the parameter P_{I} = TIME_IL_LENGTH takes a value ranging from 0 to 63 and shall be greater than or equal to P_{late}.

The number N_{IU} of IUs per FEC block (equivalent to the number of block interleavers per TI-block) is calculated by using the additional parameters P_{late} and $N_{\mathrm{ADD\_IU\_PER\_LATE}}$:

$$N_{\mathrm{IU}} = P_{\mathrm{I}} + P_{\mathrm{late}} \cdot N_{\mathrm{ADD\_IU\_PER\_LATE}}$$

The value of N_{IU} shall not exceed 128.

Moreover, the delays are calculated differently from clause 6.6 of the base profile:

For delay index $k = 0, .., P_{\mathrm{I}} - 1$:

$$D(k) = k \cdot I_{\text{JUMP}}.$$

For delay index $k = P_{\text{I}},..,N_{\text{IU}} - 1$:

$$D(k) = ([k - P_{\text{I}}] \bmod P_{\text{late}} + P_{\text{I}} - P_{\text{late}}) \cdot I_{\text{JUMP}}.$$

The delay values $D(k)$ shall not exceed 128.

The same delay value may be used for several IUs in the late part, as is illustrated in figure fig_delay_late. For this example, there are three times as many IUs in the last two logical frames than in the first two logical frames.

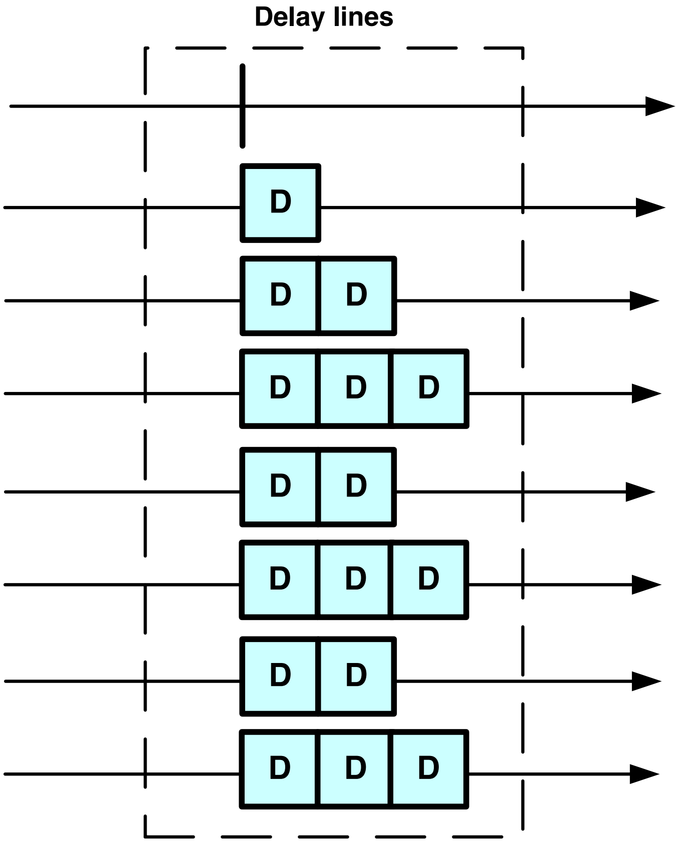


Figure 108: Delay lines for $P_{\text{I}} = 4$, $P_{\text{late}} = 2$, $N_{\text{ADD\_IU\_PER\_LATE}} = 2$, and $I_{\text{JUMP}} = 1$. Each delay element represents a delay of one logical frame.

Hybrid receivers can make use of two levels of time de-interleaving (TDI) memory (for instance one on-chip memory and one external memory). Therefore for hybrid signals two TDI memory limits are applicable:

- The sum of $N_{\text{MUs,PLP}}$ (as specified in clause 6.6.4) over all PLPs in a given PLP cluster shall not exceed $2^{21}\cdot$ memory units (MU). As in clause 6.6.4, an MU corresponds to 2 cells for QPSK and 16-QAM, and to 1 cell for 64-QAM and 256-QAM.
- For specifying the second limit, the following definition of the number of MUs of a given PLP that can be transmitted in one TI-block applies:

  $$N_{\text{MUs,PLP,frame}} = (N_{\text{large}} \cdot M_{\text{large}} + \left(N_{\text{IU}} - N_{\text{large}}\right) \cdot M_{\text{small}}) \cdot N_{\text{FEC\_TI\_MAX}}$$

  where the required parameters are defined in clause 6.6.2. The second memory limit is as follows: The sum of $N_{\text{MUs,PLP,frame}}$ over all PLPs associated with the same service shall not exceed $2^{18}\cdot$.

When the components (terrestrial and satellite) of a hybrid signal are combined in the receiver, its TDI memory has to allow for the simultaneous de-interleaving of PLPs from *both* received signals. Therefore, the two limits outlined above shall be observed in respect of the sum of the TDI requirements of all PLPs carrying the desired service components from *both* these signals. That means that the MU sum has to be calculated not only over the PLPs from one signal but from both.

Note 1: The two limits allow a first level of de-interleaving to store all relevant PLPs from one or two received signals into a first memory of size 2^{18} memory units during the current logical frame. At the end of the current logical frame, some of these stored IUs are forwarded to the decoder, while the rest can be transferred to a second memory of size 2^{21} - 2^{18} memory units that implements the required delay lines (see clause 6.6.3) representing the second level of de-interleaving.

Note 2: It is explicitly allowed to have, within a PLP cluster, on the one hand PLPs, which use multiple TI blocks per interleaving frame (TIME_IL_TYPE = ‘0’) and on the other hand PLPs using multi-frame TI (TIME_IL_TYPE = ‘1’). Similarily, the PLPs within a PLP cluster may have different interleaver depths P_I.

Finally, the receiver buffer model (RBM) to consider is the one for the hybrid profile building annex L.

24.3 Distributed and cross-polar MISO

MISO is only available in the hybrid profile for the terrestrial path and follows the same mechanisms as defined in clause 7.

25 Layer 1 signalling data specific for the hybrid profile

25.1 P1 and additional P1 signalling data

The hybrid profile is signalled in the preamble P1 with the values S1 = 111 (ESC code) and S2 field 1 = 001 or 010 respectively for hybrid SISO and hybrid MISO, as described in clause 8.1.1.

The preamble P1 is followed by an additional P1 (aP1) symbol. The aP1 symbol has the capability to convey 7 bits for signalling and the information it carries is illustrated in figure 91.

S3 (3b)	S4 Field 1 (3b)	S4 Field 2 (1b)
Waveform	FFT/GI size	Reserved

Figure 109: aP1 signalling field for NGH hybrid profile.

- The S3 field (3 bits) indicates the waveform used in the NGH frame in the hybrid SISO and MISO profiles, as described in table 108**Error! Reference source not found.**.

Table 131: S3 Field.

S3 field	Waveform	Description
000	OFDM	P2 and all data symbols in NGH-frame are modulated using OFDM waveform
001	SC-OFDM	P2 and all data symbols in NGH-frame are modulated using SC-OFDM waveform
010 - 111	Reserved for future use	

The combination S1 = “111”, S2= “001x” or “010x”, and S3 = “001” shall not be used.

- The S4 field 1 (3 bits): FFT and GI size:

  The first 3 bits of the S4 field are referred to as S4 field 1. According to the waveform information carried by S3 field, S4 field 1 indicates the corresponding FFT size and the guard interval for the remaining symbols in the NGH frame. The value and meaning of S4 field 1 are given in **Error! eference source not found.** and **Error! Reference source not found.** for OFDM and SC-OFDM waveform case respectively.

Table 132: S4 Field 1 (for OFDM waveform, S3 = 000).

S3	S4 field 1	FFT/GI size	Description
000	000	FFT Size: 1K – guard interval 1/32	Indicates the FFT size and guard interval of the OFDM symbols in the NGH-frame
	001	FFT Size: 1K – guard interval 1/16	
	010	FFT Size: 2K – guard interval 1/32	
	011	FFT Size: 2K – guard interval 1/16	
	1XX	Reserved for future use	

Table 133: S4 Field 1 (for SC-OFDM waveform, S3 = 001).

S3	S4 field 1	FFT/GI size	Description
001	000	FFT Size: 0.5K – guard interval 1/32	Indicates the FFT size and guard interval of the SC-OFDM symbols in the NGH-frame
	001	FFT Size: 0.5K – guard interval 1/16	
	010	FFT Size: 1K – guard interval 1/32	
	011	FFT Size: 1K – guard interval 1/16	
	100	FFT Size: 2K – guard interval 1/32	
	101	FFT Size: 2K – guard interval 1/16	
	110 - 111	Reserved for future use	

- The S4 field 2 (1 bit): Reserved for future use

  The last 1 bit of the S4 field is referred to as S4 field 2 and it is reserved for future use.

The modulation and construction of the aP1 symbol is described in clause 11.7.3.

25.2 L1-PRE signalling data

The hybrid profile uses the same L1-PRE signalling as defined in clause 8.1.2 of the base profile.

25.3 L1-POST signalling data

25.3.1 L1-POST configurable signalling data

Error! Reference source not found. highlights the signalling specific to the hybrid profile added to the L1-OST configurable signalling defined in clause 8.1.3.1 of the base profile.

Table 134: Signalling fields of L1-POST configurable.

```
    …                                              …
    ELSE {
       PLP_MOD                                     3 Bits
    }
    …                                              …
    IF S1 = "111" and S2 = "001x" or "0x0x" {
       TIME_IL_LATE_LENGTH                         3 Bits
       NUM_ADD_IUS_PER_LATE_FRAME                  4 Bits
    }
…                                                  …
```

PLP_MOD: 3-bit field indicates the modulation used by the given PLP. The modulation shall be signalled according to **Error! Reference source not found.**.

Table 135: Signalling format for the modulation.

Value	Modulation
000	QPSK
001	16-QAM
010 to 111	Reserved for future use

TIME_IL_LATE_LENGTH: This 3-bit field represents the length P_{late} of the late part in terms of logical frames. The Late part is the last part of the full Time Interleaver length, which is signalled by TIME_IL_LENGTH.

NUM_ADD_IUS_PER_LATE_FRAME: This 4-bit field indicates the number $N_{ADD\_IU\_PER\_LATE}$ of interleaver units (IUs) in the late part in addition to the one IU present in every logical frame.

25.3.2 L1-POST dynamic signalling data

The hybrid profile uses the same L1-Dynamic signalling defined in clause 8.1.3.3 of the base profile.

25.3.3 In-band signalling type A

The hybrid profile uses the same in-band type A signalling defined in clause 5.2.3.1 of the base profile.

26 Frame Builder

26.1 SC-OFDM

26.1.1 NGH hybrid SC-OFDM frames

26.1.1.1 Duration of the NGH hybrid SC-OFDM frame

The beginning of the first preamble symbol (P1) marks the beginning of the NGH hybrid SISO frame.

The number of P2 symbols N_{P2} is determined by the FFT size as given in table z, whereas the number of data symbols L_{data} in the NGH hybrid SC-OFDM frame is a configurable parameter signalled in the L1-PRE signalling, i.e. L_{data} = NUM_DATA_SYMBOLS. The total number of symbols in a frame (excluding P1 and aP1) is given by $L_F = N_{P2}+L_{data}$. The NGH SISO frame duration is therefore given by:

$$T_F = L_F \times T_s + 2 \times T_{P1},$$

where T_s is the total OFDM symbol duration and T_{P1} is the duration of the P1 and aP1 symbols (see clause 11.4). For theSC-OFDM component, L_{data} must be a multiple of 6, so as to form data sections of 6 symbols each.

T_F shall be 250 ms, as for the base profile. Thus, the maximum number for L_F is as defined in table **Error! Reference source not found.** (for 5 MHz bandwidth).

Table 136: Maximum frame length L_F in number of SC-OFDM symbols for different FFT sizes and guard intervals (for 5 MHz bandwidth) (satellite component)

FFT size	Tu [ms]	L_F for Guard interval fractions	
		1/32	1/16
2K	0,3584	674 (676)	656 (656)
1K	0,1792	1348 (1352)	1312 (1313)
512	0,0896	2702 (2705)	2624 (2626)

The minimum number of OFDM symbols L_F shall be N_{P2} + 12. In all cases, the number of OFDM symbols L_F shall be N_{P2} + 6xn, where n is an integer number. The values provided in the table above take this constraint into account, considering the values of N_{P2} provided in **Error! Reference source not found.**z.

The P1 and aP1 symbols carry only P1-specific signalling information (see clause 25.1). P2 symbol(s) carry L1-PRE signalling information (see clause 8.1.2) and, if there is free capacity, they also carry data from the common PLPs and/or data PLPs. Data symbols carry only common PLPs or data PLPs as defined in clauses xx and xx. The mapping of PLPs onto the symbols is done at the SC-OFDM cell level, and thus, P2 or data symbols can be shared between multiple PLPs. If there is free capacity left in the NGH hybrid SISO frame, it is filled with auxiliary streams (if any) and dummy cells as defined in clauses 9.2.3 and 9.2.4. In the NGH hybrid SC-OFDM frame, the common PLPs are always located before the data PLPs. The mapping of PLPs onto the NGH hybrid SC-OFDM frame is defined in clause 26.1.1.2.

26.1.1.2 Capacity and structure of the NGH hybrid SC.-OFDM frame

The frame builder shall map the the logical frame cells and L1-PRE cells from the constellation mapper onto the data cells $x_{m,l,p}$ of each SC-OFDM symbol in each frame, where:

- m is the NGH- hybrid SC-OFDM frame number;
- l is the index of the symbol within the frame, starting at 0 for the first P2 symbol, $0 \le l < L_F$;
- p is the index of the data cell within the symbol prior to pilot insertion.

Data cells are the cells of the SC-OFDM data symbols which are not used for scattered pilots.

The P1 and aP1 symbols are OFDM symbols, but not ordinary ones, and do not contain any active SC-OFDM data cells (see clause 11.7).

The number of active carriers, i.e. carriers not used for scattered pilots, in one P2 symbol is denoted by C_{P2} and is defined in table y. Thus, the number of active carriers in all P2 symbol(s) is $N_{P2} \times C_{P2}$.

The number of active carriers, i.e. carriers not used for pilots, in one normal symbol is denoted by C_{data}. Table z gives values of C_{data} for each FFT mode. These values must be divided by two to compute the number of active carriers for the data symbols carrying also scattered pilots.

Note: Extended carrier modes are not used for the satellite component when the SC-OFDM waveform is applied.

Note: Tone reservation is not used together with frames using the waveform SC-OFDM.

In all combinations of FFT sizes and guard interval lengths, the last symbol of the NGH hybrid SC-OFDM frame is a data symbol carrying also scattered pilots.

Hence the cell index p takes the following range of values:

- $0 \le p < C_{P2}$ for $0 \le l < N_{P2}$;
- $0 \le p < C_{data}$ for $N_{P2} \le l < L_F - 1$ and $(l - N_{P2})\%6 \neq (D_Y-1)$; $(D_Y = 6)$
- $0 \le p < C_{data}/2$ for $N_{P2} \le l < L_F - 1$ and $(l - N_{P2})\%6 = (D_Y-1)$;

Table 137: Number of available data cells C_{P2} in one P2 symbol

FFT size	C_{P2} (SISO)
512	216
1K	432
2K	864

Table 138: Number of available data cells C_{data} in one data symbol not consisting of scattered pilots

FFT size	C_{data}
512	432
1K	864
2K	1728

Table 139: ~~Number of data cells N_{FC} in the frame closing symbol~~Number of available data cells C_{data} in one data symbol not consisting of scattered pilots

Thus, the number of active SC-OFDM cells in one NGH hybrid SISO frame (C_{tot}) is given by:

$$C_{tot} = N_{P2} * C_{P2} + \frac{11}{12} * L_{data} * C_{data}$$

This formula takes into account the fact that one data symbol over six contains data for one half and pilots for the other half.

The number of P2 symbols N_{P2} is dependent on the used FFT size and is defined in table **Error! Reference source not found.**.

Table 140: Number of P2 symbols denoted by N_{P2} for different FFT modes
(temporary values, to be checked)

FFT size	N_{P2}
512	32
1k	16
2k	8

26.1.2 Frequency interleaver

For frames of preamble format NGH hybrid SISO and the waveform SC-OFDM there is no frequency interleaving applied.

27 OFDM Generation

The OFDM generation for the hybrid profile follows the same rules as specified in clause 11 for the base profile, with a limitation on the number of allowed FFT sizes (see table 118 below) and bandwidths.

The satellite component of the hybrid profile is defined for the following channel bandwidths: 1.7, 2.5 and 5 MHz (these three bandwidths are also covered by the base profile).

Table 141: Scattered pilot pattern to be used for each allowed combination of FFT size and guard interval for the hybrid profile waveform OFDM

FFT size	Guard interval			
	1/32	1/16	1/8	1/4
2K	PP7 PP4	PP4 PP5	PP2 PP3	PP1
1K	NA	PP4 PP5	PP2 PP3	PP1

The preamble symbol P1 is followed for the hybrid profile by an additional preamble symbol aP1, as specified in clause 11.7.3.

28 SC-OFDM generation

The function of the SC-OFDM generation module is to take the cells produced by the frame builder, as time domain coefficients, and to spread these cells to obtain frequency domain coefficients. Next, to insert the pilots, which allow the receiver to compensate for the distortions introduced by the transmission channel, and to produce from this the basis for the time domain signal for transmission. It then inserts guard intervals in order to produce the completed NGH hybrid SISO signal of waveform SC-OFDM.

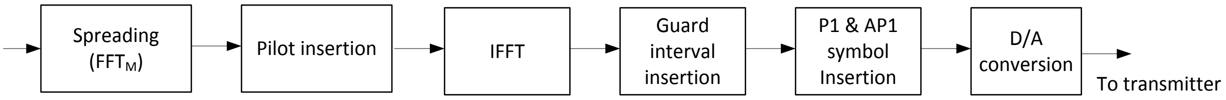


Figure 110: SC-OFDM generation

28.1 Spreading

This clause specifies the spreading applied to cells, prior to pilot insertion and OFDM modulation.

The transmitted signal is organized in frames. Each frame has a duration of T_F, and consists of L_F SC-OFDM symbols and two OFDM preamble symbols (P1 and aP1). Each SC-OFDM symbol is constituted by a set of K_{total} carriers transmitted with a duration T_S.

The symbols in an SC-OFDM frame (excluding P1 and aP1) are numbered from 0 to L_F-1. All SC-OFDM symbols contain data and some of them contain reference information (see clause ??? below)

The input cells are grouped in blocks of size *M*, where *M* is variable, and a spreading, i.e. an FFT of size *M*, is applied to each such group of cells.

The spreading size M_l of SC-OFDM symbol *l* is equal to:

$M_l = C_{data}$ if symbol *l* is a data-only symbol, i.e. if $l < N_{P2} \quad or \quad (l - N_{P2}) \bmod(D_Y) \neq (D_Y - 1)$

$M_l = C_{data} / 2$ if symbol *l* carries scattered pilots, i.e. if $(l - N_{P2}) \bmod(D_Y) = (D_Y - 1) \quad and \quad l \geq N_{P2}$

C_{data} depends on the FFT size and is described in clause 9.9.2.

D_Y is 6 for the SC-OFDM waveform. x_i is the information to be transmitted on the SC-OFDM symbols (including P2 symbols).

Index *i* varies from *0* to $L_F * C_{data} * (2D_Y-1)/(2\ D_Y) - 1$

First, this complex information is mapped onto (L_F-N_{P2}) blocks of size M_l, according to clause ???.

$$y_{l,j} = x_i$$

- The symbol index l varies from 0 to L_F -1
- The cell index j varies from 0 to M_l-1

Then, an FFT of size M_l is applied to each block:

$$z_{l,k} = \frac{1}{\sqrt{M_l}} \sum_{j=0}^{M_l-1} y_{l,j} e^{-i2\pi kj/M_l}$$

28.2 Pilot insertion

28.2.1 Introduction

Cells containing reference information are not transmitted at "boosted" power level in the SC-OFDM symbols. These cells are scattered pilot cells. The locations and amplitudes of these pilots are defined in clause 11.1.3 for SISO transmissions. The value of the pilot information is derived from a reference sequence, which is a series of values, one for each transmitted carrier on any given symbol (see clause 11.1.2).

Table f gives an overview of the different types of pilots and the symbols in which they appear.

Table 142: Presence of pilots in each type of symbol (X=present)

Symbol	Scattered Pilots
P1	
P2	X
Data	
Data with scattered pilots (PP9)	X

The following clauses specify values for $c_{m,l,k}$, for certain values of m, l and k, where m and l are the NGH frame and symbol number as previously defined, and k is the SC-OFDM carrier index (see clause ???).

Moreover, for the SC-OFDM multiplex, the following applies:

- No continual pilots
- No edge pilots
- The P2 pilots are identical to the scattered pilots in the data symbols.
- Each last symbol in an SC-OFDM frame is a data symbol with scattered pilots. Therefore, no frame closing symbol is needed.
- No cell is reserved for PAPR reduction

28.2.2 Definition of the reference NGH hybrid sequence

The pilots are modulated according to a reference complex sequence, $r_{l,k}$, where l and k are the symbol and carrier indices as previously defined. For the hybrid component, the reference sequence is fixed for each FFT size, and derived from a modified Zadoff-Chu sequence:

$$r_{l,k} = s_k = e^{-i\frac{2\pi}{n_p}\left(\frac{k^2}{2}+0.5\,k\right)}$$

Where the number of pilots in a related data symbol, n_p, is equal to: $n_p = K_{total}/2 = C_{data}/2$

The symbol-level sequence is mapped to the carriers such that the first output complex value (s_0) from the sequence coincides with the first active carrier ($k = K_{\min}$) in symbols of FFT size 0.5K, 1K, and 2K.

28.2.3 Scattered pilot insertion

Reference information, taken from the reference sequence, is transmitted in scattered pilot cells in every P2 and every sixth data symbol of the NGH hybrid frame. The locations of the scattered pilots are defined in clause 11.1.3.1, their amplitudes are defined in clause 11.1.3.2 and their modulation is defined in clause 11.1.3.3.

28.2.3.1 Locations of the scattered pilots

A given carrier *k* of the SC-OFDM signal on a given symbol *l* will be a scattered pilot if the appropriate equations below are satisfied:

$$\begin{aligned} & l < N_{P2} \quad or \quad (l - N_{P2}) \bmod (D_Y) = (D_Y - 1) \\ & and \quad l = 0 \bmod (D_X) \end{aligned}$$

where: D_X and D_Y are defined in table w

$k \in [K_{\min}; K_{\max}]$; and

$l \in [0; L_F\text{-}1]$

N_{P2} is as defined in clause 9.9.2.

L_F is as defined in clause 9.9.1.

Table 143: Parameters defining the scattered pilot patterns

Pilot pattern	Separation of pilot bearing carriers (D_X)	Number of symbols forming one scattered pilot sequence (D_Y)
PP9	2	6

For the NGH hybrid SISO frames, all combinations of the scattered pilot pattern (PP9), FFT size and guard intervals are allowed. The scattered pilot pattern is illustrated in annex K.

28.2.3.2 Amplitudes of the scattered pilots

The amplitudes of the scattered pilots, A_{SP}, are shown in table z below.

Table 144: Amplitudes of the scattered pilots

Scattered pilot pattern	Amplitude (A_{SP})	Equivalent Boost (dB)
PP9	1	0

28.2.3.3 Modulation of the scattered pilots

The phases of the scattered pilots are derived from the reference sequence given in clause 11.1.2.

The modulation value of the scattered pilots is given by:

$$c_{m,l,k} = A_{SP}\, r_{l,k}$$

where A_{SP} is as defined in clause 11.1.3.2, $r_{l,k}$ is defined in clause 11.1.2, *m* is the NGH hybrid SISO frame index, *k* is the frequency index of the carriers and *l* is the time index of the symbols.

28.3 IFFT – SC-OFDM modulation

$$s(t) = \mathrm{Re}\left\{ e^{j2\pi f_c t} \sum_{m=0}^{\infty} \left[p_1(t - mT_F) + ap_1(t - mT_F) + \frac{1}{\sqrt{K_{total}}} \sum_{l=0}^{L_F - 1} \sum_{k=K_{\min}}^{K_{\max}} c_{m,l,k} \times \psi_{m,l,k}(t) \right] \right\}$$

The IFFT mechanism for the SC-OFDM mode follows the same mechanism as in the base profile. The SC-OFDM parameters are summarized in table a. The values for the various time-related parameters are given in multiples of the elementary period *T* and in microseconds. The elementary period *T* is specified for each bandwidth in table b.

Table 145: Elementary period as a function of bandwidth (NGH)

Bandwidth	1.7 MHz	2.5 MHz	5 MHz
Elementary period *T*	71/131 μs	7/20 μs	7/40 μs

Table 146: SC-OFDM parameters

Parameter	0.5K mode	1K mode	2K mode
Number of carriers K_{total}	432	864	1728
Value of carrier number K_{min}	0	0	0
Value of carrier number K_{max}	431	863	1727
Duration T_U	512*T*	1024*T*	2048*T*
Duration T_U μs (see notes 1 and 2)	*89,6*	*179,2*	*358,4*
Carrier spacing $1/T_U$ (*Hz*) *(see notes 1 and 2)*	*11161*	*5580*	*2790*
Spacing between carriers K_{min} and K_{max} equivalent to $(K_{total}-1)/T_U$ (see notes 1 and 2)	*4.81 MHz*	*4.82 MHz*	*4.82 MHz*

NOTE 1: Numerical values in italics are approximate values.
NOTE 2: Values for 5 MHz channels.

28.4 Guard interval insertion

Two different guard interval fractions (Δ/T_u) are defined. Table 124 gives the absolute guard interval duration Δ, expressed in multiples of the elementary period T (see clause 28.3) for each combination of FFT size and guard interval fraction.

Table 147: Duration of the guard interval in terms of the elementary period T

FFT size	Guard interval fraction (Δ/T_u)	
	1/32	1/16
2K	64T	128T
1K	32T	64T
0.5K	16T	32T

The emitted signal, as described in clause 28.3, includes the insertion of guard intervals.

Annex K (informative): SC-OFDM pilot pattern

This annex illustrates the scattered pilot pattern PP9 for the SC-OFDM waveform, which is used for the satellite path of the hybrid profile. It shows the pattern in SISO mode (figure K.1). There are no continual pilots associated with this waveform.

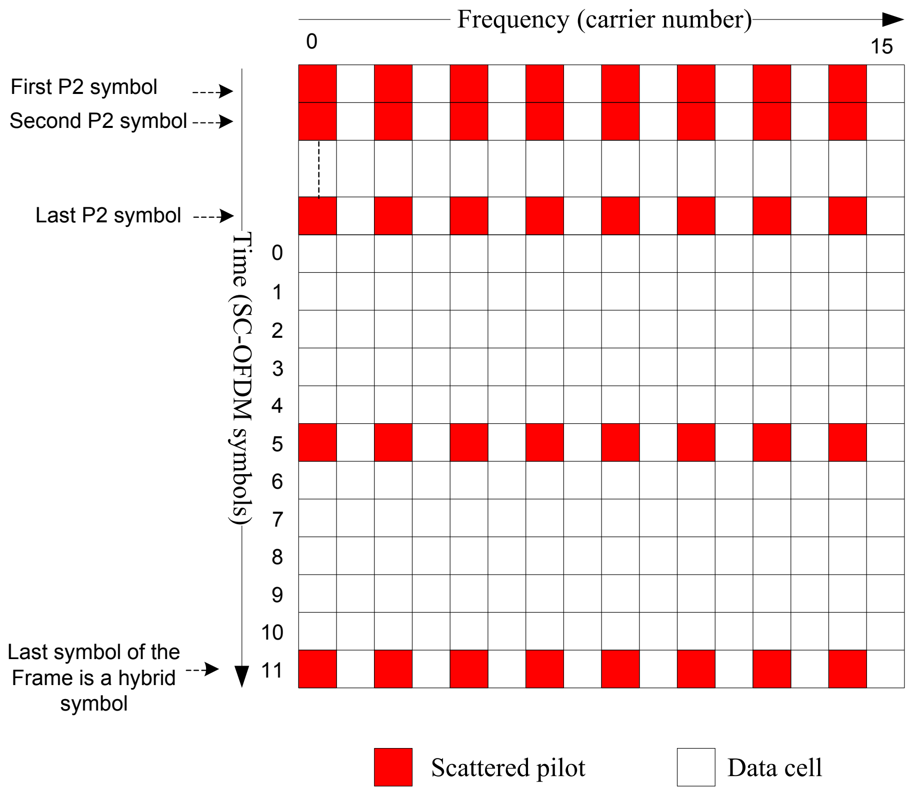


Figure K.1: Scattered pilot pattern PP9 (hybrid profile, SC-OFDM, SISO mode)

Annex L (normative): Receiver Buffer Model extension

For the MFN case of the hybrid profile, the receiver buffer model described in annex C.2 applies, where the sum of the decoding rates has to be over all PLPs in a PLP cluster from the terrestrial signal and over those from the satellite signal:

$$\sum_{\mathrm{Terr:}\, i} R_{\mathrm{codebits,rec,max}}(n,i) + \sum_{\mathrm{Sat:}\, j} R_{\mathrm{codebits,rec,max}}(n,j) \leq 12\ \mathrm{Mbit/s}$$

Moreover, the total size of the de-jitter buffer for storing all PLPs in a PLP cluster from the terrestrial and satellite signals is 2 Mbits.

For the SFN case, the receiver buffer model of the base profile applies.

Part IV: Hybrid MIMO profile

29 DVB-NGH hybrid MIMO system definition

29.1 System overview and architecture

The hybrid MIMO profile is an optional profile facilitating the use of MIMO on the terrestrial and/or satellite elements within a hybrid transmission scenario. Two modes within this profile are available:

29.1.1 Hybrid MIMO SFN

The hybrid MIMO SFN describes the case where the satellite and terrestrial parts of the transmission utilise the same carrier frequency and radiate synchronised signals intended to create an effective SFN. In the case of a SISO SFN, covered in the hybrid profile, the signals are nominally identical (except for the possible application of eSFN) but in the case of a hybrid MIMO SFN MIMO pre-coding may exist in conjunction with eSFN pre-processing. The cases defined in the hybrid MIMO SFN mode are those where MIXO pre-coding is applied within or across the satellite and terrestrial transmission elements. In the case of mixed SISO/MIXO transmission the MIXO pre-coding is applicable solely during MIXO frames; during the hybrid SISO frames eSFN may be applied.

29.1.2 Hybrid MIMO MFN

The hybrid MIMO MFN describes the case where the satellite and terrestrial parts of the transmission are on different carrier frequencies, and do not necessarily share any common frame or symbol timing at the physical layer. They may however share content in terms of data payload. At least one of the transmission elements (i.e. terrestrial or satellite) must be configured using multiple antennas, otherwise the form of transmission belongs to the hybrid profile, not the hybrid MIMO profile.

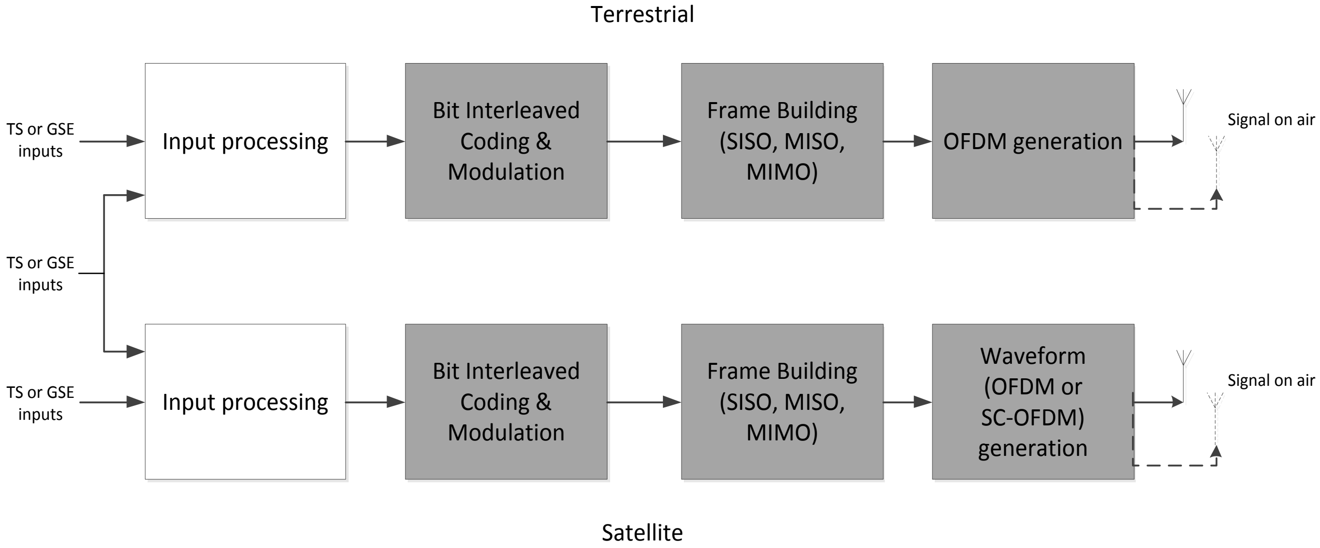


Figure 111: High level NGH hybrid MIMO physical layer block diagram

Note 1: This block diagram is common to both hybrid MIMO MFN and hybrid MIMO SFN.

Note 2: One of the two paths must use two transmission antennas.

29.1.3 Time interleaving

For rate 2 schemes of the hybrid MIMO profile, both MIMO branches, i.e. the signal generation for both transmit antennas, shall use the same time interleaver configuration. The required time de-interleaver memory sizes $N_{\text{MUs,PLP}}$ and $N_{\text{MUs,PLP,1 frame}}$ per MIMO branch can be calculated in the same way as described for the SISO scheme of the hybrid profile in clause 25.2 time interleaver, when setting 1 MU corresponding always to 1 cell. The total required de-interleaver memory for both MIMO branches is twice this size. The applicable limits for the hybrid MIMO profile are still $\sum 2N_{\text{MUs,PLP}} \leq 2^{21}$ and $\sum 2N_{\text{MUs,PLP,1 frame}} \leq 2^{18}$, where the sum is taken over all PLPs in a given PLP cluster and the factor 2 comes from the fact, that the size for both MIMO branches is double that per single MIMO branch.

When two signals are transmitted that shall be (hybridly) combined in the receiver, the same rules apply as laid down in clause 25.2 time interleaver, i.e. the sum of the required time de-interleaver sizes (in MUs) for both signals must not exceed the aforementioned limits.

The receiver buffer model (RBM) to use for the hybrid MIMO profile is the one of the hybrid profile in annex L.

30 Hybrid MIMO SFN

30.1 Transmit/receive system compatibility

To make use of the hybrid MIMO SFN, the proposed transmission hardware must include individually-fed terrestrial and satellite transmitters with suitable antennas as outlined below, delivering an OFDM waveform on both the terrestrial and satellite sides. Cases included are one or two (cross-polar, linear polarisation) terrestrial antennas in combination with one or two (cross-polar, counter-rotating circular polarisation) satellite antennas. In the case of rate 2 MIMO transmission (e.g. eSM) from either the satellite or terrestrial equipments the receiver must be equipped with a dual-polarised (linear polarisation or counter-rotating circular) pair of antennas. For rate 1 transmission, (e.g. Alamouti, eSFN) a cross-polar receive antenna is recommended but a single antenna is sufficient.

In all SFN cases the satellite transmission appears as ‘transparent’ to the receiver which sees an equivalent terrestrial transmission via an enhanced channel partly delivered by the satellite transmission. The pilot patterns for SISO/MIXO are retained on both the terrestrial and satellite transmission.

SC-OFDM is not an option for the hybrid SFN profile

30.2 Operational SFN modes

In each of the operational mode combinations shown in tables 126 and 127, the technical descriptions of the signals specified as forming the terrestrial and satellite components can be found in one or more of the NGH-base, NGH-satellite or NGH-MIMO profiles.

Note 1: Where a modulation is described as A+B, ‘A’ refers to the terrestrial part, ‘B’ to the satellite part.

Note 2: eSFN may optionally be applied to any transmission component not already having it present

Note 3: The TX identifier mentioned in the table below is described in clause 11.4.1.

Table 148: Rate 1 transmission schemes for hybrid SFN

Rate 1	Terrestrial transmission	Satellite transmission	MIXO scheme(s)
	Single polarisation (VP or HP)	Single polarisation (RHCP or LHCP)	eSFN: Terr and Sat with 2 different TX identifiers (during SISO frames)
			Alamouti code (during MIXO frames)

	Dual polarisation (VP and HP)	Single polarisation (RHCP or LHCP)	eSFN : 2 x Terr + Sat with 3 different TX identifiers (during SISO frames)
			Alamouti+ QAM (during MIXO frames)
	Single polarisation (VP or HP)	Dual polarisation (RHCP and LHCP)	eSFN: Terr + 2 x Sat with 3 different TX identifiers (during SISO frames)
			Alamouti+ QAM (during MIXO frames)
	Dual polarisation (VP and HP)	Dual polarisation (RHCP and LHCP)	eSFN: 2 x Terr + 2 x Sat with 4 different TX identifiers (during SISO frames)
	Dual polarisation (VP and HP)	Dual polarisation (RHCP and LHCP)	Alamouti + Alamouti (during MIXO frames)

Table 149: Rate 2 transmission schemes for hybrid SFN

Rate 2	**Terrestrial transmission**	**Satellite transmission**	**MIXO scheme(s)**
	Dual polarisation (VP and HP)	Dual polarisation (RHCP and LHCP)	eSM+PH Terr + eSM+PH+eSFN Sat (during MIMO frames)

30.3 Power imbalance cases

In the case of terrestrial power imbalance, the satellite transmission maintains a fixed 0 dB imbalance, but adopts the same values of parameters θ and α as the terrestrial transmission for the chosen imbalance. Table XXX shows the corresponding set of parameters.

Table XXX: eSM parameters for satellite, SFN case

Intentional power imbalance between two terrestrial Tx antennas			0dB			3dB			6dB		
n_{bpcu}	Modulation		β	Θ	α	β	θ	α	β	θ	α
6	f_{2i}(tx1)	QPSK	0.50	45°	0.44	0.50	0°	0.50	0.50	0°	0.50
	f_{2i+1}(tx2)	16-QAM									
8	f_{2i}(tx1)	16-QAM	0.50	$\operatorname{atan}\left(\frac{\sqrt{2}+4}{\sqrt{2}+2}\right)$	0.50	0.50	25°	0.50	0.50	0°	0.50
	f_{2i+1}(tx2)	16-QAM									
10	f_{2i}(tx1)	16-QAM	0.50	22°	0.50	0.50	15°	0.50	0.50	0°	0.50
	f_{2i+1}(tx2)	64-QAM									

31 Hybrid MIMO MFN

31.1 Transmit/receive system compatibility

To make use of the hybrid MIMO MFN, the proposed transmission hardware must include individually-fed terrestrial and satellite transmitters with suitable antennas, delivering an OFDM waveform on the terrestrial side and OFDM or SC-OFDM on the satellite side. Cases included are one or two (cross-polar, linear polarisation) terrestrial antennas in combination with one or two (cross-polar, counter-rotating circular polarisation) satellite antennas. In the case of rate 2 MIMO transmission (e.g. eSM) from either or both of the satellite or terrestrial equipments the receiver must be equipped with a cross-polar (linear polarisation or counter-rotating circular) pair of antennas in the corresponding frequency band or bands. For rate 1 transmission from either the satellite or terrestrial equipments, (e.g. Alamouti, eSFN) a dual-polarised receive antenna is recommended but a single antenna is sufficient for the corresponding satellite or terrestrial frequency band.

31.2 Operational MFN modes

Any terrestrial SISO or MIMO mode (from base and MIMO profiles respectively) may be used in conjunction with any satellite SISO mode (taken from the hybrid profile) or the MIMO modes defined in table B4 or para. ???, with the following addition/exception:

1. The satellite rate 2 MIMO modes add a 2 x QPSK option but excludes any use of 64-QAM;

The resulting eSM parameters for the satellite component delivering an OFDM waveform are indicated in table 149.

Table 150:eSM parameters for satellite OFDM, MFN case

n_{bpcu}	Modulation		β	θ	α
4	f_{2i}(Tx1) f_{2i+1}(Tx2)	QPSK QPSK	0.50	$\mathrm{atan}\left(\sqrt{2}+1\right)$	0.50
6	f_{2i+1}(Tx2)	QPSK	0.50	45°	0.44
	f_{2i+1}(Tx2)	16-QAM			
8	f_{2i}(Tx1)	16-QAM	0.50	$\mathrm{atan}\left(\frac{\sqrt{2}+4}{\sqrt{2}+2}\right)$	0.50
	f_{2i+1}(Tx2)	16-QAM			

Note 1: In the case that the satellite waveform is SC-OFDM, spatial multiplexing encoding for rate 2 MIMO is simple SM as described in clause 18.1 instead of eSM.

Note 2: All parameters are for 0 dB intentional power imbalance between satellite transmitting antennas

The only constraint is that at least one transmission should be MIXO in order to qualify as hybrid MIMO; otherwise the transmission falls within the hybrid profile.

31.3 Spatial Multiplexing encoding for SC-OFDM waveform for rate 2 satellite MIMO

The satellite SM encoding for SC-OFDM waveform is similar to the rate 2 terrestrial MIMO scheme, except that neither MIMO precoding (eSM) nor phase hopping is applied.

As for terrestrial part, MIMO processing is never applied to the preamble symbols P1, aP1 and P2.

The MIMO processing shall be applied at PLP level and consists in transmitting cell pairs (f_{2i}, f_{2i+1}) on the same SC-OFDM symbol and carrier from Tx-1 and Tx-2 respectively.

$$\begin{pmatrix} g_{2i} \\ g_{2i+1} \end{pmatrix} = \begin{pmatrix} f_{2i} \\ f_{2i+1} \end{pmatrix}, \quad i = 0, 1, \ldots, Ncells/2 - 1$$

where *i* is the index of the cell pair within the FEC block and *Ncells* is the number of cells per FEC block.

The pilot patterns for each transmit antenna are derived from the one of the SC-OFDM SISO signal:

- Tx1 transmits the same pilot pattern as the SC-OFDM SISO signal (see section 30.2 of the hybrid profile)
- Tx2 transmits the same pilot pattern as Tx1, expect that the phase of the reference sequence is inverted on pilot carrier over two:

$$\begin{aligned} r_{l,k}^{Tx2} &= s_k^{Tx2} = s_k^{Tx1} && \text{if k even} \\ r_{l,k}^{Tx2} &= s_k^{Tx2} = \left(s_k^{Tx1}\right)^* && \text{if k odd} \end{aligned}$$

Where *l* and *k* are the symbol and carrier indices as defined in SISO hybrid clause.

For the constellations, both the 2 x QPSK and 2 x 16-QAM schemes can be applied.

32 Layer 1 signalling data for the hybrid MIMO profile

32.1 P1 and additional P1 signalling data

The hybrid profile is signalled in the preamble P1 with the values S1 = 111 (ESC code) and S2 field 1 = 011, as described in clause 8.1.1 of the base profile.

The preamble P1 is followed by an additional P1 (aP1) symbol. The aP1 symbol has the capability to convey 7 bits for signalling and the information it carries is illustrated in figure 112.

S3 (3b)	S4 Field 1 (3b)	S4 Field 2 (1b)
Waveform	FFT/GI size	Reserved

Figure 112: aP1 signalling field

- The S3 field (3 bits) indicates the waveform used in the NGH frame in the hybrid MIMO profile, as described in Table 151.

Table 151: S3 Field

S3 field	Waveform	Description
000	OFDM	P2 and all data symbols in NGH-frame are modulated using OFDM waveform
001	SC-OFDM	P2 and all data symbols in NGH-frame are modulated using SC-OFDM waveform
010 - 111	Reserved for future use	

The combination S1 = “111”, S2= “011x”, and S3 = “001” shall not be used.

- The S4 field 1 (3 bits): FFT and GI size:

  The first 3 bits of the S4 field are referred to as S4 field 1. According to the waveform information carried by S3 field, S4 field 1 indicates the corresponding FFT size and the guard interval for the remaining symbols in the NGH-frame. The value and meaning of S4 field 1 are given in Table 152 and Table 153 for OFDM and SC-OFDM waveform case respectively.

Table 152: S4 Field 1 (for OFDM waveform, S3 = 000)

S3	S4 field 1	FFT/GI size	Description
000	000	FFT Size: 1K – guard interval 1/32	Indicates the FFT size and guard interval of the OFDM symbols in the NGH-frame
	001	FFT Size: 1K – guard interval 1/16	
	010	FFT Size: 2K – guard interval 1/32	
	011	FFT Size: 2K – guard interval 1/16	
	1XX	Reserved for future use	

Table 153: S4 Field 1 (for SC-OFDM waveform, S3 = 001)

S3	S4 field 1	FFT/GI size	Description
001	000	FFT Size: 0.5K – guard interval 1/32	Indicates the FFT size and guard interval of the SC-
	001	FFT Size: 0.5K – guard interval 1/16	

	010	FFT Size: 1K – guard interval 1/32	OFDM symbols in the NGH-frame
	011	FFT Size: 1K – guard interval 1/16	
	100	FFT Size: 2K – guard interval 1/32	
	101	FFT Size: 2K – guard interval 1/16	
	110 - 111	Reserved for future use	

- The S4 field 2 (1 bit): Reserved for future use

  The last 1 bit of the S4 field is referred to as S4 field 2 and it is reserved for future use.

The modulation and construction of the aP1 symbol is described in clause 11.7.3 of the base profile.

32.2 L1-PRE signalling data

Table 153 highlights the signalling specific to the hybrid MIMO profile added to the L1-PRE signalling data defined in clause 8.1.2 of the base profile.

Table 154: L1-PRE signalling fields specific to the hybrid MIMO profile

…	
PH_FLAG	1 Bit
…	…
L1_POST_MIMO	4 Bits
L1_POST_NUM_BITS_PER_CHANNEL_USE	3 Bits
…	

PH_FLAG: This 1-bit field indicates if the phase hopping (PH) option is used or not. In the absence of VMIMO (see annex L) this flag is set to "1". The PH scheme is described in clause 18.2.

Table 155: Signalling format for the PH indication

Value	PH mode
0	PH not applied
1	PH applied

L1-POST_MIMO: This 4-bit field indicates the MIMO scheme of the L1-POST signalling data block. The MIMO schemes shall be signalled according to table 155.

Table 156: Signalling format for the L1-POST MIMO scheme

Value	Constellation
0000	Alamouti
0001	eSM/PH
0010	SM
0010 to 1111	Reserved for future use

32.3 L1-POST signalling data

32.3.1.1 L1-POST configurable signalling data

Table 157 highlights the signalling specific to the hybrid MIMO profile added to the L1-POST configurable signalling defined in clause 8.1.3.1 of the base profile.

Table 157: Signalling fields of L1-POST configurable

```
IF S1 = “111” and S2 = “000x” or “011x” {
    PLP_MIMO_TYPE                                4 Bits
    IF PLP_MIMO_TYPE = “0001” or “0010”
    {
        PLP_NUM_BITS_PER_CHANNEL_USE             3 Bits
    }
    ELSE {
        PLP_MOD                                  3 Bits
    }
}
ELSE {
    PLP_MOD                                      3 Bits
}
…                                                …
IF S1 = “111” and S2 = “001x” or “0x0x” {
TIME_IL_LATE_LENGTH                              3 Bits
NUM_ADD_IUS_PER_LATE_FRAME                       4 Bits
}
…                                                …
```

PLP_MIMO_TYPE: This 4-bit field indicates the MIMO scheme used by the given PLP. The MIMO schemes shall be signalled according to table 157.

Table 158: Signalling format for the PLP_MIMO_TYPE scheme

Value	Constellation
0000	Alamouti
0001	eSM/PH
0010	SM
0010 to 1111	Reserved for future use

The following fields appear only if PLP_MIMO_TYPE = “0001” or “0010” (i.e. eSM/PH or SM):

PLP_NUM_BITS_PER_CHANNEL_USE: This 3-bit field indicates the number of bits per channel use for the MIMO scheme used by the given PLP. The value of this field shall be defined according to Table 159.

Table 159: Signalling format for PLP_NUM_BITS_PER_CHANNEL_USE.

Value	n_{bpcu}	Modulation	
000	4	f_{2i}(Tx1)	QPSK
		f_{2i+1}(Tx2)	QPSK
001	6	f_{2i+1}(Tx2)	QPSK
		f_{2i+1}(Tx2)	16-QAM
010	8	f_{2i}(Tx1)	16-QAM
		f_{2i+1}(Tx2)	16-QAM
011 to 111	Reserved for future use	Reserved for future use	

The following field appears only if PLP_MIMO_TYPE is equal to “0000” (e.g. Alamouti):

PLP_MOD: 3-bit field indicates the modulation used by the given PLP. The modulation shall be signalled according to Table.

Table 160: Signalling format for the modulation.

Value	Modulation
000	QPSK
001	16-QAM
010 to 111	Reserved for future use

TIME_IL_LATE_LENGTH: This 3-bit field represents the length P_{late} of the late part in terms of logical frames. The Late part is the last part of the full Time Interleaver length, which is signalled by TIME_IL_LENGTH.

NUM_ADD_IUS_PER_LATE_FRAME: This 4-bit field represents the number $N_{ADD\_IU\_PER\_LATE}$ of interleaver units (IUs) in the late part additional to the one IU present in every logical frame.

32.3.2 L1-POST dynamic signalling data

The hybrid MIMO profile uses the same L1-Dynamic signalling defined in clause 8.1.3.3 of the base profile.

32.3.3 In-band signalling type A

The hybrid MIMO profile uses the same in-band type A signalling defined in clause 5.2.3.1 of the base profile.

Annex M (informative): SC-OFDM pilot pattern

This annex illustrates the scattered pilot pattern PP9 for the hybrid MIMO profile when the satellite component waveform is SC-OFDM. The pilots are sent at the same locations in SISO and MIMO modes (figure M.1).

In hybrid MIMO mode, the first antenna (tx1) sends exactly the same pilot pattern as in the SISO hybrid mode. The second antenna (tx2) sends a pilot pattern at the same locations as tx1, but with different phases, as detailed in clause 31.3.

There are no continual pilots in this profile.

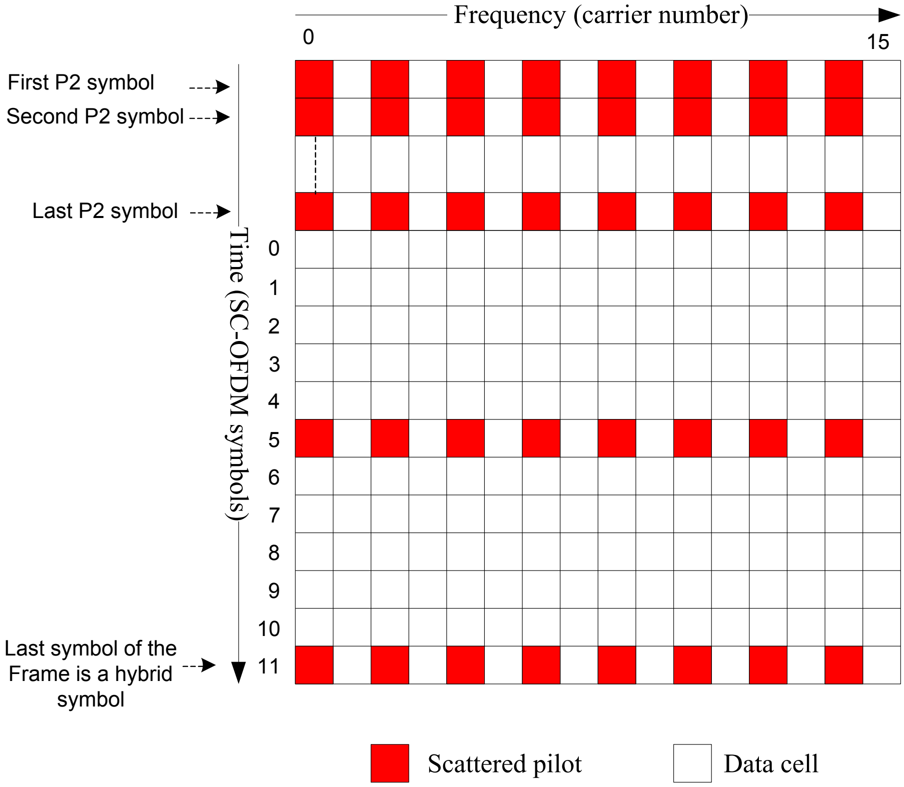


Figure M.1: Scattered pilot pattern PP9 (SC-OFDM)

Annex N (informative): Rate-2 transmission with one transmit antenna

N.1VMIMO

N.1.1 Overview

MIMO transmission options are included in the optional MIMO profile in order to exploit the diversity and capacity advantages made possible by the use of multiple transmission elements at the transmitter and receiver. However, in a SFN network, it may happens that some terrestrial transmitters are equipped with one transmit antenna only, while the other terrestrial transmitters and the satellite transmitter are normally equiped with two transmlit antennas. In such situations, one possibility would be that the 1-Tx transmitters simply transmit the signal transmitted by one of the antennas of the 2-Tx transmitters . From a performance point of view, a better possibility is to set up a virtual MIMO (VMIMO) scheme, i.e. to emulate at the transmitter side an optimised 2x1 channel. This allows to send an unique signal which is representative of the two normal rate-2 signals, while optimising performance. Another advantage is that the receiver is kept unaware of this possibility, i.e. no consequence on the receiver design is foreseen.

N.1.2 Block diagram

The block diagram illustrating the introduction of a VMIMO scheme is provided in figure XX1.

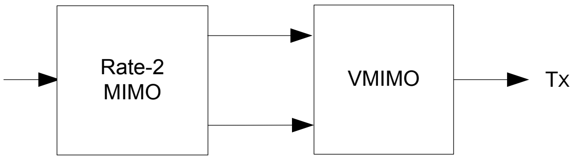


Figure N.1: VMIMO scheme

N.1.3 VMIMO processing

Basically, the VMIMO scheme consists of inserting an optimised and virtual 2x1 MISO channel prior to transmission. This virtual channel can be processed on all the input streams. Another possibility is to restrict it to the MISO and MIMO parts of the multiplex and in particular not applying it to the synchronisation (P1 and P2) symbols.

The VMIMO 2x1 channel is characterised by two coefficients a_1 and a_2. The process is illustrated in table tt1, where SHS stands for synchronisation, headers, signalling, etc.

Table N.1: VMIMO processing

	2-TX signal, antenna 1	2-Tx signal, antenna 2	1-Tx signal (VMIMO)
Pilot	p_1	p_2	$a_1 p_1 + a_2 p_2$
Data	d_1	d_2	$a_1 d_1 + a_2 d_2$
SHS, rate-1 signals	Sig	sig	sig

N.1.4 Parameter setting

The a_1 and a_2 parameters do not need to be known by the receivers. The channel estimation process will simply estimate the overall chanel, consisting of the juxtaposition of the VMIMO channel and the real multipath channel. Therefore they do not need to be standardised. However, some optimised values are provided in table tt2, according to the constellation used and depending on whether or not eSM is implemented.

The rationale for these values is the following: With and without eSM, the selected values insure that a regular QAM constellation is transmitted. Without eSM, the selection of the a_i values is straighforward. With eSM, the values are modified in the folowing way: If φ is the eSM angle and if ${}^{a_2}\!/_{a1} = tg(\varphi)$, then $tg(\theta - \varphi) = 2$ for QPSK and $tg(\theta - \varphi) = 4$ for 16-QAM. In table tt2, the values are provided for the 0 dB power imbalance case, i.e. $\alpha = \beta = 0.5$.

Table N.2: VMIMO parameters

	No eSM	eSM	
2 x QPSK	$a_1 = {}^{1}\!/_{\sqrt{5}}$ $a_2 = {}^{2}\!/_{\sqrt{5}}$	$\theta = \text{atan}\left(\sqrt{2}+1\right)$ =67.5°	$a_1 = 0.99748$ $a_2 = 0.0708$
2 x 16-QAM	$a_1 = {}^{1}\!/_{\sqrt{17}}$ $a_2 = {}^{4}\!/_{\sqrt{17}}$	$\theta = \text{atan}\left(\frac{\sqrt{2}+4}{\sqrt{2}+2}\right)$	$a_1 = 0.95$ $a_2 = -0.312$

N.1.5 Phase Hopping

The use of VMIMO is incompatible with phase hopping (clause 18.2) which shall therefore be disabled when VMIMO is used.

N.1.6 Miscellaneous

For good performance with one transmit antenna only, it is assumed that the MIMO decoder is optimal (ML) or quasi-optimal, whatever the values of the a_i coefficients.

It must be noted that selecting $a_1 = 1$ and $a_2 = 0$ corresponds to the case where the transmitter equipped with one antenna simply transmits one of the signals of the rate-2 MIMO scheme.

Annex O (informative): Bibliography

History

Document history		
V1.1.1	April 2013	Publication