ATSC Standard: A/322:2024-04 Amendment No. 1, "ATSC 3.0 MIMO Extension"

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Advanced Television Systems Committee
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Revision History

Version	Date
A/322:2024-04 Amendment No. 1 approved	13 September 2024
Numbering inconsistency in Annex O corrected	24 September 2024
Reference in Section O.12.1 to “Section L.11.12” corrected to read “Section L.11.2”	8 October 2024

ATSC Standard:
A/322;2024-04 Amendment No. 1, "ATSC 3.0 MIMO Extension"

1. OVERVIEW

1.1 Definition

An Amendment is generated to document an enhancement, an addition or a deletion of functionality to previously agreed technical provisions in an existing ATSC document. Amendments shall be published as attachments to the original ATSC document. Distribution by ATSC of existing documents shall include any approved Amendments.

1.2 Scope

This document specified MIMO, Channel Bonding, LDM, and their combinations in the physical layer, in order to support a significant throughput increase or spectral flexibility. This amendment also adds TxID signal generation complying with MIMO signals. This amendment is in response to New Project Proposal N-074r0, "ATSC 3.0 MIMO Extension".

1.3 Rationale for Changes

In A/322, optional technologies MIMO and Channel Bonding nearly double the capacity by introducing additional spatial and frequency resources; LDM in A/322 enables enhanced performance based on spectrum reuse multiplexing. Despite these advantages, combining LDM, MIMO, and Channel Bonding is precluded or limited in A/322. The changes described in this document are being proposed in order to enable the combinations among LDM, MIMO, and Channel Bonding. This amendment also adds necessary descriptions lacking in the currently published version of the standard, regarding MIMO and Channel Bonding operations. Descriptions for TxID are additionally revised to enable related functionality in MIMO transmission.

1.4 Compatibility Considerations

The changes described in this document are backward-compatible to the currently published version of the standard to which this Amendment pertains and any previously approved Amendments for that standard; however, currently deployed receivers would not have the capability of decoding the signal generated by this amendment. These changes would not affect any receiver's ability to demodulate signals not encoded using MIMO or CB.

2. LIST OF CHANGES

Change instructions are given below in *italics*. Unless otherwise noted, inserted text, tables, and drawings are shown in blue; deletions of existing text are shown in ~~red~~. The text "[ref]" indicates that a cross reference to a cited referenced document should be inserted. Yellow highlighted references indicate the document editor should insert the appropriate internal document references.

2.1 Change Instructions

Add the following entries in alphabetical order to Section 3.4, Terms:

Layered MIMO – The combination of LDM and MIMO.

MIMO (Multiple-Input Multiple-Output) – A technique that allows a higher spectral efficiency and/or a higher transmission robustness, when compared to a single-path (SISO) system, through addition of spatial diversity and multiplexing over two distinct paths between antennas at a transmitter and a receiver (See Annex L).

MIMO mode – A transmission mode in which a PLP is configured to create two transmitter signal paths that ultimately feed a pair of cross-polarized transmitting antennas (See Annex X).

Layered MIMO Type A – A mode of operation in which MIMO and LDM both are active and MIMO is applied to both the Core and Enhanced Layers (See Annex O).

Layered MIMO Type B – A mode of operation in which MIMO and LDM both are active and MIMO is applied only to the Enhanced Layer, meaning that the associated Core Layer operates in a SISO configuration (See Annex O).

Polarization – The orientation of the electric field vector of a radiated electromagnetic (radio) wave with respect to the horizon as seen from the antenna, the orientation of the wave emitted from which is described. Such orientation can be fixed linear (i.e., planar) or rotating with time (i.e., circular).

SISO (Single-Input Single-Output) – A transmission system configuration in which only a single path is created between a transmitting antenna and a receiving antenna (as opposed to MIMO, in which two or more paths are created between antennas).

Modify Section 4.2 as follows:

4.2 System Architecture

A block diagram of the main data flow for the total transmitter system architecture is shown in Figure 4.1. The system architecture consists of four main parts: Input Formatting, Bit-Interleaved Coded Modulation (BICM), Framing and Interleaving, and Waveform Generation. For simplicity, control and signaling information flow is not shown in this diagram.

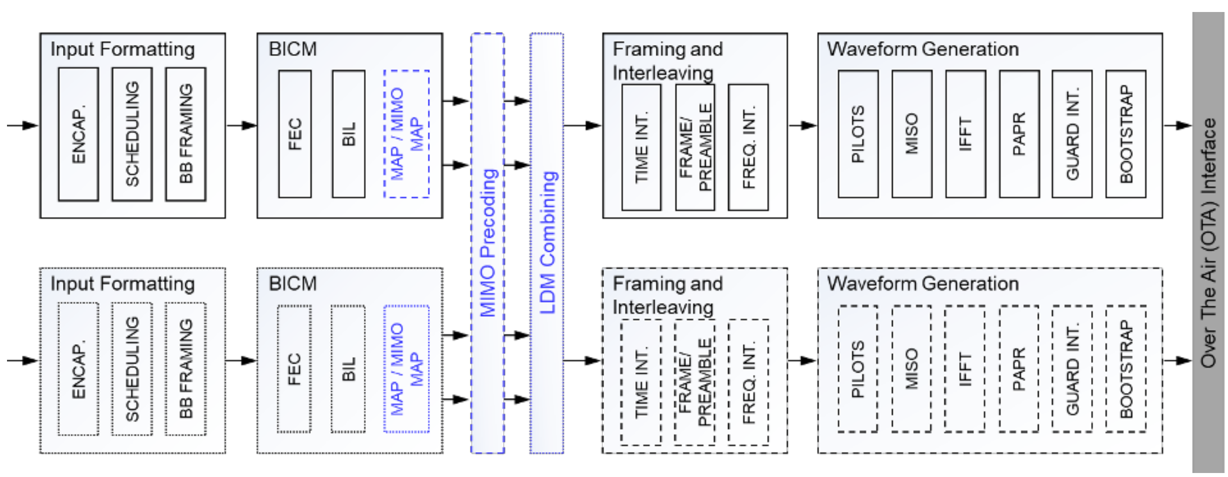

Figure 4.1 Block diagram of the system architecture for one RF channel.

In this specification, Input Formatting is described in Section 5, BICM is described in Section 6, LDM Combining in Section 6.4, Framing and Interleaving in Section 7, and Waveform Generation in Section 8. The signaling required to configure all of the blocks is described in Section 9. MIMO Precoding is described in Annex L.

Not all blocks are used in each configuration. In Figure 4.1 the solid lines show blocks common to all configurations, dotted lines show blocks specific to LDM ~~(MIMO blocks are not used)~~ and dashed lines show blocks specific to MIMO ~~(LDM blocks are not used)~~.

If LDM and MIMO are used together (i.e., in a Layered MIMO configuration), MIMO Precoding shall precede LDM Combining. The combined use of LDM and MIMO is described in Annex O.

Modify Section 9.2 as follows:

9.2 Syntax for L1-Basic Data

The syntax and field semantics of the L1-Basic signaling fields shall be as defined in Table 9.2 and the following subsections. The names of signaling fields in L1-Basic are always prefixed with '**L1B_**'.

Table 9.2 L1-Basic Signaling Fields and Syntax

Syntax	No. of Bits	Format
L1_Basic_signaling() {		
L1B_version	3	uimsbf
L1B_mimo_scattered_pilot_encoding	1	uimsbf
L1B_lls_flag	1	uimsbf
L1B_time_info_flag	2	uimsbf
L1B_return_channel_flag	1	uimsbf
L1B_papr_reduction	2	uimsbf
L1B_frame_length_mode	1	uimsbf
if (**L1B_frame_length_mode**=0) {		
L1B_frame_length	10	uimsbf
L1B_excess_samples_per_symbol	13	uimsbf
} else {		
L1B_time_offset	16	uimsbf
L1B_additional_samples	7	uimsbf
}		
L1B_num_subframes	8	uimsbf
L1B_preamble_num_symbols	3	uimsbf
L1B_preamble_reduced_carriers	3	uimsbf
L1B_L1_Detail_content_tag	2	uimsbf
L1B_L1_Detail_size_bytes	13	uimsbf
L1B_L1_Detail_fec_type	3	uimsbf
L1B_L1_Detail_additional_parity_mode	2	uimsbf
L1B_L1_Detail_total_cells	19	uimsbf
L1B_first_sub_mimo	1	uimsbf
L1B_first_sub_miso	2	uimsbf
L1B_first_sub_fft_size	2	uimsbf
L1B_first_sub_reduced_carriers	3	uimsbf
L1B_first_sub_guard_interval	4	uimsbf
L1B_first_sub_num_ofdm_symbols	11	uimsbf
L1B_first_sub_scattered_pilot_pattern	5	uimsbf
L1B_first_sub_scattered_pilot_boost	3	uimsbf

L1B_first_sub_sbs_first	1	uimsbf
L1B_first_sub_sbs_last	1	uimsbf
L1B_first_sub_mimo_mixed	1	uimsbf
L1B_reserved	47 ~~48~~	uimsbf
L1B_crc	32	uimsbf
}		

Modify Section 9.2.1 as follows:

9.2.1 L1-Basic System and Frame Parameters

The following parameters provide information related to the entire frame.

L1B_version – This field shall indicate the version of the L1-Basic signaling structure that is used for the current frame. For the current version of the specification **L1B_version** shall be set to ~~0~~1. It is envisaged that when new L1-Basic signaling fields are introduced into an updated L1-Basic signaling structure in such a manner that the presence or absence of at least one of those new L1-Basic signaling fields cannot be otherwise deduced, **L1B_version** would be incremented by 1. New L1-Basic signaling fields that are introduced into an L1-Basic signaling structure corresponding to a particular **L1B_version** should be added in such a manner that they do not interfere with the parsing of L1-Basic signaling fields by receivers that have been provisioned only up to an earlier **L1B_version**.

Modify Section 9.2.3 as follows:

9.2.3 L1-Basic Parameters for First Subframe

L1B_first_sub_sbs_last – This field shall indicate whether or not the last symbol of the first subframe of the current frame is a subframe boundary symbol. **L1B_first_sub_sbs_last** =0 shall indicate that the last symbol of the first subframe of the current frame is not a subframe boundary symbol. **L1B_first_sub_sbs_last** =1 shall indicate that the last symbol of the first subframe of the current frame is a subframe boundary symbol.

L1B_first_sub_mimo – This field shall indicate whether MIMO (see Annex L and Annex O) is used for all PLPs in the first subframe of the current frame. A value of 1 shall indicate that MIMO processing is applied to all PLPs in the first subframe. ~~used, and a~~ A value of 0 shall indicate that ~~MIMO is not used.~~ the first subframe includes one or more PLPs to which MIMO processing is not applied. See Table 9.8 and note that the setting of this field to 1 is mutually exclusive with the setting of **L1B_first_sub_mimo_mixed** to 1, as shown on the last line of the table.

L1B_first_sub_mimo_mixed – This field shall indicate whether the first subframe of the current frame multiplexes PLPs using MIMO with other PLPs not using MIMO. A value of 1 shall indicate that PLPs using and not using MIMO are multiplexed within the subframe, and a value of 0 shall indicate that all PLPs in the subframe either use MIMO (i.e., **L1B_first_sub_mimo** =1) or do not use MIMO (i.e, **L1B_first_sub_mimo** =0).

When LDM is applied to the first subframe in a frame (i.e., when PLPs having **L1D_plp_layer** values > 0 are present in the subframe), the values of **L1B_first_sub_mimo_mixed** indicate the following: When set to 1, MIMO processing shall be applied to all Enhanced PLPs (i.e., **L1D_plp_layer** >0) in the described subframe, and MIMO processing shall not be applied to all Core PLPs (i.e., **L1D_plp_layer** =0) in the described subframe. See Table 9.8, and note that the setting of this field to 1 is mutually exclusive with the setting of **L1D_first_sub_mimo** to 1, as shown on the last line of the table.

Table 9.8 Use Cases and Indications Related to MIMO: Signaling Format for **L1B_first_sub_mimo_mixed** in Conjunction with **L1B_first_sub_mimo**

MIMO Configurations	**Related L1-Basic Signaling Assignment**	
	L1B_first_sub_mimo	**L1B_first_sub_mimo_mixed**
All PLPs in first subframe use SISO	0	0
PLPs of both types in first subframe	0	1
All PLPs in first subframe use MIMO	1	0
Invalid Combination	1	1

Note: In cases of all-SISO and all-MIMO PLPs within the first subframe, any of the available multiplexing types (i.e., TDM, FDM, LDM, and combinations thereof) can be applied. In cases in which MIMO is to be applied differently to the PLPs on the respective layers (i.e., Core and Enhanced) within a subframe, LDM multiplexing is required to be applied to the subframe (potentially along with TDM, FDM, and combinations thereof on either or both of the layers).

Modify Section 9.3 as follows:

9.3 Syntax and Semantics for L1-Detail Data

The syntax and field semantics of the L1-Detail signaling fields shall be as defined in Table 9.~~8~~9 and the following subsections. The names of signaling fields in L1-Detail are always prefixed with '**L1D_**'.

In Table 9.9, there are a nested pair of 'for' loops, having outer and inner loops denoted as 'i' and 'j', which process the subframes within a physical layer frame and the PLPs within each subframe, respectively. This nested pair of 'for' loops appears twice in the table. The ordering of the subframes and the PLPs within each subframe is given in full in the first appearances of the 'i' and 'j' 'for' loops in Table 9.9, and the same ordering of the subframes and the PLPs within them shall be applied in the second appearances of those loops in the table.[1]

Table 9.~~8~~9 L1-Detail Signaling Fields and Syntax

Syntax	**No. of Bits**	**Format**
L1_Detail_signaling() {		
L1D_version	4	uimsbf
L1D_num_rf	3	uimsbf
for (**L1D_rf_id=1 .. L1D_num_rf**) {		
L1D_bonded_bsid	16	uimsbf
reserved	3	bslbf
}		
if (**L1B_time_info_flag** != 00) {		
L1D_time_sec	32	uimsbf

1 The splitting of the 'i' and 'j' 'for' loops into two sections each was necessitated by the evolution of functions described in the table to enable simultaneous use of multiple signal processing methods while maintaining backward compatibility.

L1D_time_msec	10	uimsbf
if (**L1B_time_info_flag** != 01) {		
L1D_time_usec	10	uimsbf
if (**L1B_time_info_flag** != 10) {		
L1D_time_nsec	10	uimsbf
}		
}		
}		
for (**i=0 .. L1B_num_subframes**) {		
if (i > 0) {		
L1D_mimo	1	uimsbf
L1D_miso	2	uimsbf
L1D_fft_size	2	uimsbf
L1D_reduced_carriers	3	uimsbf
L1D_guard_interval	4	uimsbf
L1D_num_ofdm_symbols	11	uimsbf
L1D_scattered_pilot_pattern	5	uimsbf
L1D_scattered_pilot_boost	3	uimsbf
L1D_sbs_first	1	uimsbf
L1D_sbs_last	1	uimsbf
}		
if (**L1B_num_subframes**>0) {		
L1D_subframe_multiplex	1	uimsbf
}		
L1D_frequency_interleaver	1	uimsbf
if (((i=0)&&(**L1B_first_sub_sbs_first || L1B_first_sub_sbs_last**)) || ((i>0)&&(**L1D_sbs_first | L1D_sbs_last**))) {		
L1D_sbs_null_cells	13	uimsbf
}		
L1D_num_plp	6	uimsbf
for (j=0 .. **L1D_num_plp**) {		
L1D_plp_id	6	uimsbf
L1D_plp_lls_flag	1	uimsbf
L1D_plp_layer	2	uimsbf
L1D_plp_start	24	uimsbf
L1D_plp_size	24	uimsbf
L1D_plp_scrambler_type	2	uimsbf
L1D_plp_fec_type	4	uimsbf
if (**L1D_plp_fec_type**∈{0,1,2,3,4,5}) {		
L1D_plp_mod	4	uimsbf
L1D_plp_cod	4	uimsbf
}		
L1D_plp_TI_mode	2	uimsbf
if (**L1D_plp_TI_mode**=00) {		
L1D_plp_fec_block_start	15	uimsbf
} else if (**L1D_plp_TI_mode**=01) {		

L1D_plp_CTI_fec_block_start	22	uimsbf
}		
if (**L1D_num_rf**>0) {		
L1D_plp_num_channel_bonded	3	uimsbf
if (**L1D_plp_num_channel_bonded**>0) {		
L1D_plp_channel_bonding_format	2	uimsbf
for (k=0..**L1D_plp_num_channel_bonded**){		
L1D_plp_bonded_rf_id	3	uimsbf
}		
}		
}		
if (i=0 && **L1B_first_sub_mimo**=1) || (i >0 && **L1D_mimo**=1) {		
L1D_plp_mimo_stream_combining	1	uimsbf
L1D_plp_mimo_IQ_interleaving	1	uimsbf
L1D_plp_mimo_PH	1	uimsbf
}		
if (**L1D_plp_layer**=0) {		
L1D_plp_type	1	uimsbf
if (**L1D_plp_type**=1) {		
L1D_plp_num_subslices	14	uimsbf
L1D_plp_subslice_interval	24	uimsbf
}		
if (((**L1D_plp_TI_mode**=01) || (**L1D_plp_TI_mode**=10))&&(**L1D_plp_mod**=0000)) {		
L1D_plp_TI_extended_interleaving	1	uimsbf
}		
if (**L1D_plp_TI_mode**=01) {		
L1D_plp_CTI_depth	3	uimsbf
L1D_plp_CTI_start_row	11	uimsbf
}else if (**L1D_plp_TI_mode**=10) {		
L1D_plp_HTI_inter_subframe	1	uimsbf
L1D_plp_HTI_num_ti_blocks	4	uimsbf
L1D_plp_HTI_num_fec_blocks_max	12	uimsbf
if (**L1D_plp_HTI_inter_subframe**=0) {		
L1D_plp_HTI_num_fec_blocks	12	uimsbf
}else {		
for (k=0..**L1D_plp_HTI_num_ti_blocks**) {		
L1D_plp_HTI_num_fec_blocks	12	uimsbf
}		
}		
L1D_plp_HTI_cell_interleaver	1	uimsbf
}		
}else {		
L1D_plp_ldm_injection_level	5	uimsbf
}		
}		
}		
L1D_bsid	16	uimsbf

<table>
<tr><td>for (i=0 .. L1B_num_subframes) {</td><td></td><td></td></tr>
<tr><td>if (i > 0) {</td><td></td><td></td></tr>
<tr><td>L1D_mimo_mixed</td><td>1</td><td>uimsbf</td></tr>
<tr><td>}</td><td></td><td></td></tr>
<tr><td>if (i = 0 && L1B_first_sub_mimo_mixed = 1) || (i >0 && L1D_mimo_mixed = 1) {</td><td></td><td></td></tr>
<tr><td>for (j = 0 .. L1D_num_plp) {</td><td></td><td></td></tr>
<tr><td>L1D_plp_mimo</td><td>1</td><td>uimsbf</td></tr>
<tr><td>If (L1D_plp_mimo = 1) {</td><td></td><td></td></tr>
<tr><td>L1D_plp_mimo_stream_combining</td><td>1</td><td>uimsbf</td></tr>
<tr><td>L1D_plp_mimo_IQ_interleaving</td><td>1</td><td>uimsbf</td></tr>
<tr><td>L1D_plp_mimo_PH</td><td>1</td><td>uimsbf</td></tr>
<tr><td>}</td><td></td><td></td></tr>
<tr><td>}</td><td></td><td></td></tr>
<tr><td>}</td><td></td><td></td></tr>
<tr><td>}</td><td></td><td></td></tr>
<tr><td>L1D_reserved</td><td>as needed</td><td>uimsbf</td></tr>
<tr><td>L1D_crc</td><td>32</td><td>uimsbf</td></tr>
<tr><td>}</td><td></td><td></td></tr>
</table>

Modify Section 9.3.1 as follows:

L1-Detail Miscellaneous Parameters

The following miscellaneous parameters are included in L1-Detail.

L1D_version – This field shall indicate the version of the L1-Detail signaling structure that is used for the current frame. For the current version of the specification **L1D_version** shall be set to ~~1~~2. It is envisaged that when new L1-Detail signaling fields are introduced into an updated L1-Detail signaling structure in such a manner that the presence or absence of at least one of those new L1-Detail signaling fields cannot be otherwise deduced, **L1D_version** would be incremented by 1. New L1-Detail signaling fields that are introduced into an L1-Detail signaling structure corresponding to a particular **L1D_version** are added in such a manner that they do not interfere with the parsing of L1-Detail signaling fields by receivers that have been provisioned only up to an earlier **L1D_version**. New L1-Detail signaling fields can be added immediately before **L1D_reserved** such that these new L1-Detail signaling fields immediately follow all of the previously existing L1-Detail signaling fields with the exception of **L1D_reserved** and **L1D_crc**. With this approach, a parser built to a previous version of this standard would consider any new L1-Detail signaling fields to be part of **L1D_reserved**. The length of **L1D_reserved** for a particular frame is calculated by subtracting the aggregate lengths of all known and included L1-Detail signaling fields from **L1B_L1_Detail_size_bytes**, and thus a parser built to a previous version of this standard would be able to parse the known portions of L1-Detail successfully without requiring knowledge of the structure or contents of any new fields added to what that parser would perceive as **L1D_reserved**.

Modify Section 9.3.3 as follows:

9.3.3 L1-Detail Subframe Parameters

L1-Detail parameters related to subframe configuration are as follows.

L1D_mimo – This ~~flag~~field shall indicate whether MIMO (see Annex L and Annex O) is used for all PLPs in the current subframe. A value of 1 shall indicate that MIMO processing is applied to all PLPs in the current subframe. ~~used, and a~~ A value of 0 shall indicate that ~~MIMO is not used.~~ the subframe includes one or more PLPs to which MIMO processing is not applied. See Table 9.10, and note that the setting of this field to 1 is mutually exclusive with the setting of **L1D_mimo_mixed** to 1, as shown on the last line of the table.

L1D_mimo_mixed – This field shall indicate whether the current subframe multiplexes PLPs using MIMO with other PLPs not using MIMO. A value of 1 shall indicate that PLPs using and not using MIMO are multiplexed within the subframe, and a value of 0 shall indicate that all PLPs in the subframe either use MIMO (i.e., **L1D_mimo** =1) or do not use MIMO (i.e., **L1D_mimo** =0).

When LDM is applied to a subframe (i.e., when PLPs having **L1D_plp_layer** values >0 are present in the subframe), the values of **L1D_mimo_mixed** indicate the following: When set to 1, MIMO processing shall be applied to all Enhanced PLPs (i.e., **L1D_plp_layer** >0) in the described subframe, and MIMO processing shall not be applied to all Core PLPs (i.e., L1D_plp_layer =0) in the described subframe. See Table 9.10, and note that the setting of this field to 1 is mutually exclusive with the setting of L1D_mimo to 1, as shown on the last line of the table.

Table 9.10 Use Cases and Indications Related to MIMO: Signaling Format for **L1D_mimo_mixed** in Conjunction with **L1D_mimo**

MIMO Configurations	**Related L1-Detail Signaling Assignment**	
	L1D_mimo	**L1D_mimo_mixed**
All PLPs in subframe use SISO	0	0
PLPs of both types in subframe	0	1
All PLPs in subframe use MIMO	1	0
Invalid Combination	1	1

Note: In cases of all-SISO and all-MIMO PLPs within a subframe, any of the available multiplexing types (i.e., TDM, FDM, LDM, and combinations thereof) can be applied. In cases in which MIMO is to be applied differently to the PLPs on the respective layers (i.e., Core and Enhanced) within a subframe, LDM multiplexing is required to be applied to the subframe (potentially along with TDM, FDM, and combinations thereof on either or both of the layers).

Modify Section 9.3.5 as follows:

9.3.5 L1-Detail LDM Parameters

The following L1-Detail signaling fields are related to Layered Division Multiplexing (LDM).

L1D_plp_layer – This field shall be set equal to the layer index of the current PLP. **L1D_plp_layer** =0 shall correspond to the Core Layer, while **L1D_plp_layer** >0 shall correspond to an Enhanced Layer. For the current version of the specification, **L1D_plp_layer** shall ~~only~~ be set only to values of 0 or 1. Presence in a subframe of any PLP having **L1D_plp_layer** >0 shall indicate that the subframe is to be configured for operation with LDM applied; subframes having no PLPs present with **L1D_plp_layer** >0 shall be configured for operation with LDM not applied. These conditions with respect to the value of the **L1D_plp_layer** field are the sole indicator of LDM operation in the related subframe.

L1D_plp_ldm_injection_level – This field shall indicate the Enhanced PLP's injection level relative to the Core PLP. The correspondence between a signaled value of **L1D_plp_ldm_injection_level** and a particular injection level shall be as given in Table 9.~~22~~24. Injection levels are defined in

Table 6.15. This field shall ~~only~~ be included only when the index of the current layer is greater than 0 (i.e., when **L1D_plp_layer** >0). When LDM and MIMO are used simultaneously, the value of the injection level may take on a different meaning with respect to the two Polarization cases. The definitions for this scenario are provided in Section O.6.

Modify Section 9.3.7 as follows:

9.3.7 L1-Detail MIMO Parameters (PLP)

The following L1-Detail signaling fields are related to MIMO on a PLP-by-PLP basis. ~~These signaling fields shall not be included when L1B_first_sub_mimo or L1D_mimo (as appropriate for the current subframe) has a value of 0.~~

L1D_plp_mimo – This field shall indicate whether MIMO (see Annex L and Annex O) is used for a given PLP when the current subframe contains PLPs both using and not using MIMO. This field shall be signaled when **L1B_first_sub_mimo_mixed** or **L1D_mimo_mixed** (as appropriate for the current subframe) has a value of 1. A value of 1 shall indicate that MIMO is used, and a value of 0 shall indicate that MIMO is not used. When LDM is applied to the subframe identified by **L1B_first_sub_mimo_mixed** =1 or **L1D_mimo_mixed** =1, only Enhanced PLP(s) shall use MIMO.

Annex K, "Channel Bonding"

Modify Section K.1 as follows:

K.1 INTRODUCTION

In channel bonding, data of a single PLP connection is spread over two or more different RF channels. Primarily channel bonding enables total service data rates that exceed the net capacity of a single RF channel, but it can also be used to exploit the frequency diversity among multiple RF channels. In this Annex the description is of channel bonding for two channels. The two RF channels may be located at any channel frequency, not necessarily adjacent to each other. The use of channel bonding is optional, but when it is used it shall conform to the description in this Annex.

~~Channel bonding shall not be used with MIMO. Other features are compatible with channel bonding, including but not limited to LDM, PAPR reduction, MISO, and so on.~~

Channel bonding is compatible with other features including MIMO, LDM, PAPR reduction, MISO, and so on.

Channel bonding is processed transparently, such that the output stream on the receiver side is equal to the corresponding input stream on the transmitter side.

Figure K.1.1 shows a simple block diagram of a channel bonded system.

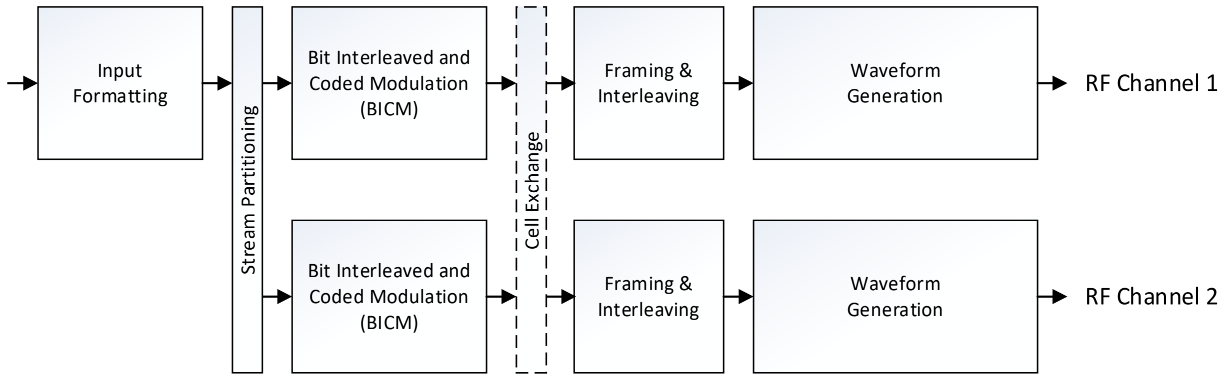

Figure K.1.1 Simple block diagram of channel bonding.

All data packets of a PLP transmitted in channel bonding mode shall pass through a common input formatting block (i.e., utilizes same **L1D_plp_id** value on all RF channels), where the Baseband Header of the Baseband Packet is inserted. **L1D_rf_id** can be used in combination with **L1D_plp_id** to uniquely identify the partitioned stream for each RF channel. When channel bonding is used, the Baseband Header extension **counter** shall always be used (see Section 5.2.2.3.1 for details). This allows for correct reordering of the packets from different RF channels at the receiver side even in the presence of different delays on each RF channel. The ordering of Baseband Packets shall be maintained. At the output of the stream partitioning block, the Baseband Packets of the bonded PLP for each of the two partitioned streams shall be FEC encoded, bit-interleaved and modulated individually and transmitted on different RF channels. The use of channel bonding does not depend on the cell multiplexing method, channel bonding may be used with any valid multiplexing method, including LDM.

Since there are two BICM chains used in channel bonding, the total required TI memory will be twice that of a single chain. When channel bonding is used with MIMO, the total required TI memory will be four times of that required for a single transmitter chain engaged with a single Polarization.

Figure K.1.2 shows the transmitter side processing for channel bonding, with the joint input formatting stage showing Baseband Header insertion followed by stream partitioning.

Modify Section K.3 as follows:

K.3 CHANNEL BONDING WITH SNR AVERAGING

To enable low-complexity cell re-exchange on the receiver side, the framing of both RF channels shall be synchronized. This includes time synchronicity for bootstrap, Preamble, same OFDM waveform parameters as well as the same scheduling of the PLP in the payload frame. In this mode, the PLP of each RF channel shall use the same ModCod setting, same Inner Code and Outer Code, same MIMO setting, number of FEC Blocks per subframe as well as TI mode and configuration.

Add a new Section K.4 as follows:

K.4 CELL/PLP MULTIPLEXING

At least one RF channel of channel-bonded RF channels may be composed of multiple PLPs that are multiplexed within the RF channel by FDM, LDM, TDM, and their combination manners as described in Section 7.2. In this case, channel-bonded PLP(s) can be multiplexed with other PLPs not using channel bonding. LDM combines two cells belonging to different PLPs in the same RF channel, and the combined cell is treated as and mapped to a single cell within a subframe in Framing. In addition, since channel bonding combines two PLPs of different RF channels and is independently applied to each PLP, LDM Combining shall be done after cell exchange. Therefore, whether to use channel bonding for Core PLP and Enhanced PLP can be determined independently.

Figure K.4.1 shows a simple block diagram of channel bonding with use of LDM. Dashed lines show blocks specific to channel bonding with SNR averaging, and dotted lines show blocks enabled by the inclusion of layered division multiplexed PLP(s) in channel bonding process.

When plain channel bonding is used, two PLPs in different RF channels can be bonded while having different scheduling parameters including layer setting, multiplexing scheme, and framing information such as PLP size, PLP start, PLP type, and so on. When channel bonding with SNR averaging is used, the two mutually bonded PLPs shall be configured with the same scheduling parameters, including the layer indices of PLPs, in order to achieve low complexity. This means that Core PLP shall be channel-bonded only with Core PLP, and Enhanced PLP shall be channel-bonded only with Enhanced PLP, respectively.

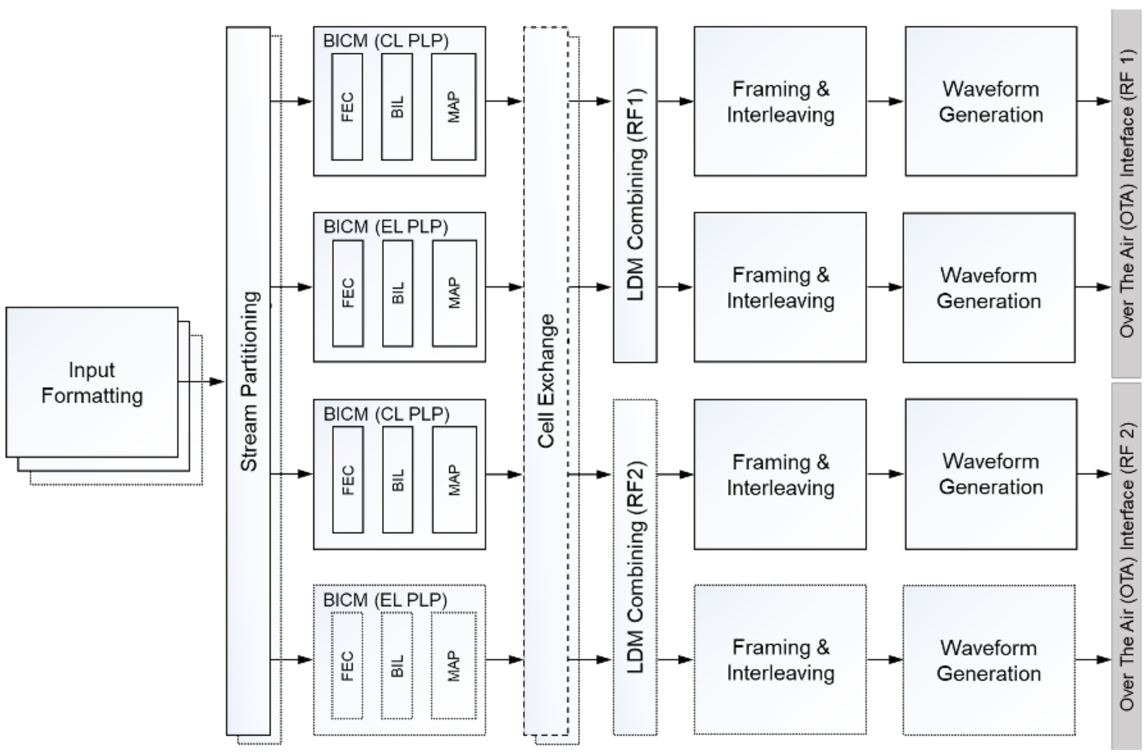

Figure K.4.1 Block diagram of channel bonding with LDM.

Annex L, “MIMO”

Modify Section L.1 as follows:

L.1 OVERVIEW

MIMO (Multiple-Input Multiple-Output) improves robustness via additional spatial diversity and/or increases capacity by sending two data streams in a single RF channel (spatial multiplexing). The spatial multiplexing gain is achieved only in the case of MIMO~~,~~ and allows overcoming the capacity limit of single-antenna wireless communications in a given channel bandwidth~~. without increasing the total transmission power~~. Note that, to obtain the increase in channel capacity that can be provided with use of MIMO, a higher total transmission power than in the single-antenna case will be required if the same service area and S/N threshold are to be maintained. For SIMO (Single-Input Multiple-Output) and MISO (Multiple-Input Single-Output) only ~~the~~ spatial diversity gain is achieved. MIMO is an optional technology, but when adopted, shall conform to the requirements of this Annex.

In this version of the specification, MIMO processing is restricted to a 2×2 antenna system, with the two antennas orthogonally polarized with respect to one another. This means that at least two effective antennas, operating with different radiation Polarizations, and thereby creating independent propagation paths, ~~aerials are~~ must be present at both transmitter and receiver~~-side~~ locations. In practice, cross-polarized MIMO antennas (~~i.e.~~e.g., having horizontally and vertically polarized~~ation~~ elements or possibly having elements rotated 45 degrees in the same direction from horizontal and vertical) should be used. ~~The~~Transmitters should include individually fed cross-polar antennas, and ~~the~~ receivers should include individually connected cross-polar pairs of antennas in order to receive and decode ~~the~~ MIMO signals.

Figure L.1.1 depicts ~~the~~ a MIMO transmission chain. Two new blocks can be identified~~:~~, providing MIMO ~~demultiplexer~~ mapping and MIMO Precoding functions~~ block~~. The MIMO transmission chain re-uses as many blocks as possible from SISO, including FEC codes, bit interleavers, constellations, and frequency and time interleavers. Additional pilot patterns have been defined for MIMO such that the same echo tolerance/Doppler performance as for SISO is achieved. All blocks not specifically mentioned in this Annex, such as ~~the~~ input formatting,~~ inverse Fast Fourier transform,~~ guard interval, etc. shall follow their specifications for SISO.

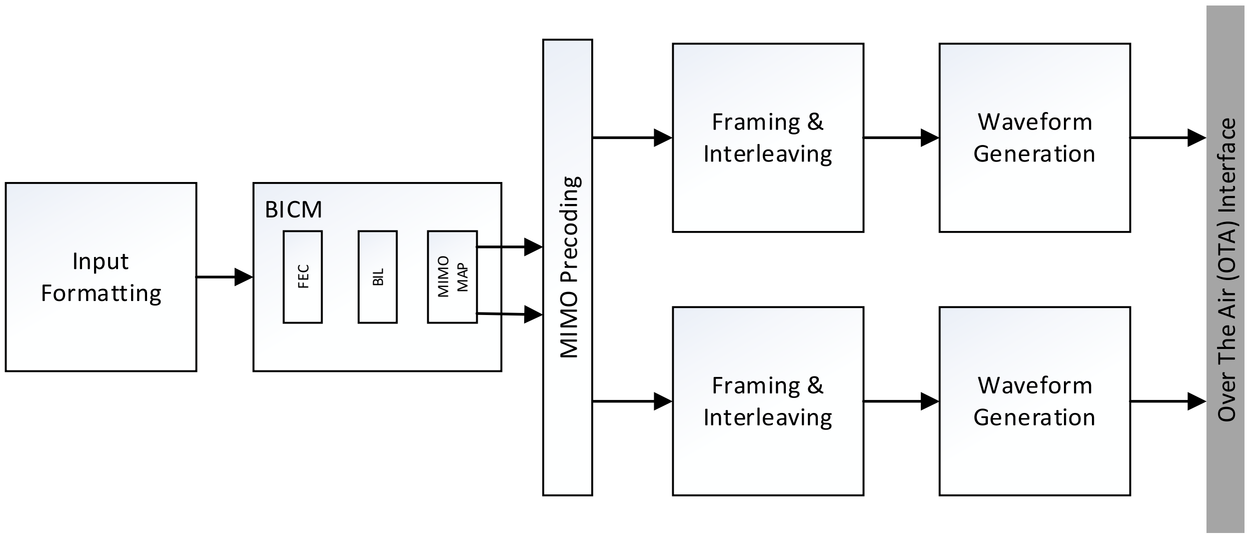

Figure L.1.1 MIMO block diagram.

The MIMO MAP function consists of a Demultiplexer block followed by bit-to-IQ-mapping blocks. A block diagram of the MIMO MAP is shown in Figure L.1.2.

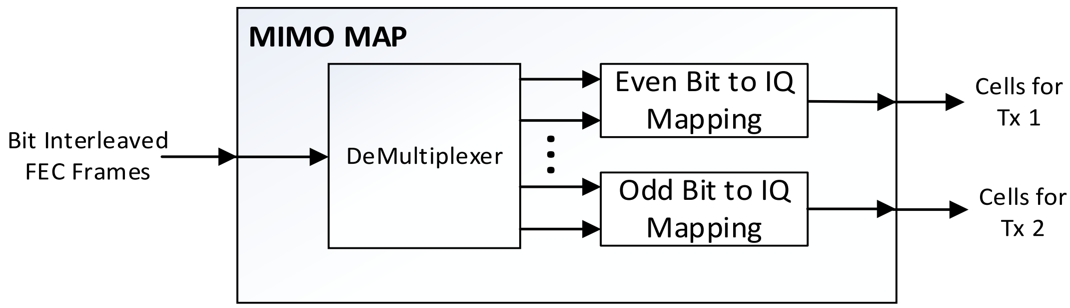

Figure L.1.2 MIMO MAP block diagram.

MIMO processing shall not be applied to ~~the~~ Bootstraps or Preambles. MIMO processing shall ~~only~~ be applied only to subframes. ~~MIMO shall not be applied to signaling elements.~~

~~MIMO shall not be used with ACE nor LDM nor Channel Bonding, however the remaining features of the specification are compatible with MIMO.~~

MIMO shall not be used with ACE, however the remaining features of the specification, including LDM and channel bonding, are compatible with MIMO. This Annex describes the specifications for MIMO not combined with LDM. The combination of MIMO and LDM is described in Annex O.

Modify Section L.4.1 as follows:

L.4.1 Demultiplexer

The MIMO demultiplexer is composed of two stages. The first stage is exactly the same as the SISO demultiplexing described in Section 6.3.3. The second stage evenly spreads the output vectors of the first stage SISO demultiplexer into two constellation mappers, one for each transmitting ~~antenna~~ Polarization.

At the second stage, the even vector ($y_{0,2n}$, ..., $y_{\eta MOD-1,2n}$) and the odd vector ($y_{0,2n+1}$, ..., $y_{\eta MOD-1,2n+1}$) are input to the mappers of transmitting ~~antenna~~ Polarizations #1 and #2, respectively, where n is the value for indexing each vector:

$$n = (0, 1, 2, \ldots, N - 1), \qquad N = \left\lfloor \frac{N_{cell}}{2} \right\rfloor$$

N_{cell} is the number of the output data cells for each FEC Frame input to the demultiplexer, as shown in Table 6.14.

Modify Section L.4.2 as follows:

L.4.2 Constellations

The same constellations as in Section 6.3 shall be used for MIMO. The same modulation order shall be transmitted ~~from~~ in both ~~antennas~~ Polarizations.

The combination of 256QAM and FEC codes with length N_{inner}=16200 bits shall not be allowed, since it does not yield an integer number of modulated cells per ~~antenna~~ Polarization per FEC Block. All remaining ModCod combinations are feasible for MIMO.

For MIMO, L1 signaling does not signal the modulation order, as for SISO, but rather the bits per cell unit (bpcu), which defines the overall spectrum efficiency per cell for the two ~~antennas~~ Polarizations, as shown in Table L.4.1.

Remove Section L.4.3 as follows:

~~L.4.3 Constellation Superposition for LDM~~

~~The use of constellation superposition for LDM with MIMO is not defined in this version of the specification.~~

Modify Section L.5 as follows:

L.5 PRECODING

MIMO precoding acts on a pair of input constellation symbols (X_{2i}, X_{2i+1}), where i is the index of the cell pair within the FEC Block, and creates a pair of output constellation symbols as depicted in Figure L.5.1. Encoded cell pairs (S_{2i}, S_{2i+1}) shall be transmitted on the same OFDM symbol and carrier from transmitting ~~antenna~~ Polarization #1 (Tx1) and transmitting ~~antenna~~ Polarization #2 (Tx2), respectively.

MIMO precoding is never applied to ~~the~~ Bootstraps or ~~the~~ Preambles, only to ~~data symbols~~ subframes.

Modify Section L.5.2 as follows:

L.5.2 I/Q Polarization Interleaving

The I/Q ~~p~~Polarization interleaver is simply a switching interleaving operation, such that the output cells consist of the real (i.e., In-phase) component of one input symbol and the imaginary (i.e., Quadrature) component of the other input symbol. The I/Q polarization interleaving shall be described by the following equations:

Modify Section L.5.3 as follows:

L.5.3 Phase Hopping

The phase hopping consists of a phase rotation to the symbols of the second transmitting Polarization ~~antenna~~. The phase hopping operation shall be mathematically expressed as follows:

$$\begin{bmatrix} S_{2i}(Tx1) \\ S_{2i+1}(Tx2) \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & e^{j\phi(i)} \end{bmatrix} \begin{bmatrix} Z_{2i}(Tx1) \\ Z_{2i+1}(Tx2) \end{bmatrix}$$

where ϕ is the phase rotation angle, defined by the following equation:

$$\phi(i) = \frac{2\pi}{N} i, (N = 9), i = 0, \dots, \frac{N_{cells}}{2} - 1$$

where N_{cells} is the number of cells per FEC Block. The phase rotation is initialized to 0 radians at the beginning of each FEC Block and is incremented by 2π/9 radians for every cell pair.

Modify Section L.6 as follows:

L.6 TIME INTERLEAVER

The same time interleavers as in Section 7.1 shall be used for MIMO. 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 shall be identical. The total memory requirement as described in Section 7.1.2, applies ~~for~~ to each time interleaver ~~of~~ for each ~~antenna~~ Polarization. Hence, time interleaving for MIMO requires twice the memory as is required for SISO. When MIMO is used with channel bonding, the total memory requirement is proportional to the number of combined RF channels compared to the memory required for MIMO transmission within a single RF channel. In this version of the specification, the total memory requirement for MIMO with channel bonding is twice and four times that of MIMO and SISO transmissions within a single RF channel, respectively.

Modify Section L.7 as follows:

L.7 FRAMER

MIMO frames shall be built according to Section 7.2.

The specific multiplexing techniques allowed for MIMO shall be the following:

- Time division multiplexing (TDM), as described in Section 7.2.7.3.
- Frequency division multiplexing (FDM), as described in Section 7.2.7.5.
- Time and frequency division multiplexing (TFDM), as described in Section 7.2.7.6.

The number of available data cells for cell multiplexing can be obtained from tables in Section 7.2.6. Equivalent SISO pilot patterns that have the same number and position as those of MIMO scattered pilot patterns shall be used for a table lookup. Equivalent SISO scattered pilot patterns are shown in Table L.9.2.

This version of the specification specifies the multiplexing between MIMO and SISO PLPs as follows: TDM between MIMO and SISO PLPs is allowed; LDM of MIMO and SISO PLPs is allowed as described in Annex O.

Modify Section L.9 as follows:

L.9 PILOT PATTERNS

L.9.1 Pilot ~~Antenna~~ Polarization Encoding

MIMO pilots fall on exactly the same positions as for SISO, but the amplitudes and/or phases of the scattered, continual, edge, and subframe boundary pilots may be modified compared to SISO. Two MIMO pilot Polarization ~~antenna~~ encoding algorithms are defined, namely:

- Walsh-Hadamard encoding.
- Null pilot encoding.

Only one MIMO pilot encoding algorithm shall be configured for a given frame.

Table L.9.1 gives an overview of the different types of pilots and the corresponding MIMO pilot encoding mechanism per Polarization ~~antenna~~, where SISO indicates that the pilots are not modified compared to SISO, WH indicates Walsh-Hadamard encoding and NP indicates null pilot encoding. Both Polariztions ~~antennas~~ shall transmit in all pilot positions, although the amplitudes of some transmitted pilots for null pilot encoding will be zero.

Note: Those cells which would be both an additional continual pilot and a scattered pilot shall be treated as scattered pilots, and they shall be encoded using Walsh-Hadamard encoding (for Polarization ~~antenna~~ #2) or using null pilot encoding (for both Polarizations ~~antennas~~) depending upon the configured MIMO pilot encoding algorithm. The additional continual pilots that do not fall on scattered-pilot-bearing cells shall be treated similarly to common continual pilots and shall not be modified compared to SISO.

Table L.9.1 MIMO Pilot Polarization ~~Antenna~~ Encoding Overview

Pilot Encoding Algorithm	Polarization ~~Antenna~~	Scattered Pilot	Subframe Boundary Pilot	Common Continual Pilot	Additional Continual Pilot	Edge Pilot
Walsh-Hadamard	#1	SISO	SISO	SISO	SISO	SISO
	#2	WH	WH	SISO	SISO/WH	WH
Null Pilot	#1	NP	SISO	SISO	SISO/NP	SISO
	#2	NP	WH	SISO	SISO/NP	WH

MIMO pilots are divided into two groups, namely group 1 and group 2, depending on the pilot encoding scheme used, as described in Section L.9.2. Both pilot groups are transmitted ~~from~~ in each Polarization ~~antenna~~. However, each pilot encoding algorithm applies a specific signal processing method to each pilot group for each Polarization ~~antenna~~.

9.1.1 Walsh-Hadamard

With Walsh-Hadamard encoding, the phases of the scattered, additional continual, edge, and subframe boundary pilots for group 2 are inverted in the signal transmitted ~~from~~ in Polarization ~~antenna~~ #2. The phases of both the group 1 and group 2 pilots transmitted ~~from~~ in Polarization ~~antenna~~ #1 and of the group 1 pilots transmitted ~~from~~ in Polarization ~~antenna~~ #2 shall not be modified.

The scattered pilots transmitted ~~from~~ in Polarization ~~antenna~~ #2 shall be inverted compared to Polarization ~~antenna~~ #1 on alternate scattered-pilot-bearing carriers. These inverted scattered pilots represent the group 2 scattered pilots for Polarization ~~antenna~~ #2. Both group 1 and group 2 scattered pilots for Polarization ~~antenna~~ #2 shall be calculated using the following equations:

$$\mathrm{Re}\{c_{m,l,k}\} = 2 \cdot (-1)^{\frac{k}{D_X}} \cdot A_{\mathrm{SP}} \cdot (\frac{1}{2} - r_k)$$

$$\mathrm{Im}\{c_{m,l,k}\} = 0$$

Common continual pilots and additional continual pilots on non-scattered-pilot-bearing cells shall not be inverted for either transmit Polarization ~~antenna~~. The few additional continual pilots which fall on scattered-pilot-bearing cells for which the scattered pilot transmitted ~~from~~ in Polarization ~~antenna~~ #2 would be inverted shall be inverted. Both group 1 and group 2 additional continual pilots for Polarization ~~antenna~~ #2 shall be calculated using the following equations:

$$\mathrm{Re}\{c_{m,l,k}\} = 2 \cdot (-1)^{\frac{k}{D_X}} \cdot A_{\mathrm{SP}} \cdot (\tfrac{1}{2} - r_k) \qquad \text{for } k \bmod D_X = 0$$

$$\mathrm{Re}\{c_{m,l,k}\} = 2 \cdot A_{\mathrm{SP}} \cdot (\tfrac{1}{2} - r_k) \qquad \text{otherwise}$$

$$\mathrm{Im}\{c_{m,l,k}\} = 0$$

Note: Those cells which would be both an additional continual pilot and a scattered pilot are treated as scattered pilots as described above. All additional continual pilots shall have the amplitude A_{SP} as in SISO.

The edge pilots ~~from~~ in Polarization ~~antenna~~ #2 shall be inverted compared to Polarization ~~antenna~~ #1 on odd-numbered OFDM symbols. Both group 1 and group 2 edge pilots ~~for~~ in Polarization ~~antenna~~ #2 shall be calculated using the following equations:

$$\mathrm{Re}\{c_{m,l,k}\} = 2 \cdot (-1)^{l} \cdot A_{\mathrm{SP}} \cdot \left(\frac{1}{2} - r_k\right)$$

$$\mathrm{Im}\{c_{m,l,k}\} = 0$$

The subframe boundary pilots ~~from~~ in Polarization ~~antenna~~ #2 shall be inverted compared to Polarization ~~antenna~~ #1 on alternate scattered-pilot-bearing carriers. Both group 1 and group 2 subframe boundary pilots ~~for~~ in Polarization ~~antenna~~ #2 shall be calculated using the following equations:

$$\mathrm{Re}\{c_{m,l,k}\} = 2 \cdot (-1)^{\frac{k}{D_X}} \cdot A_{\mathrm{SP}} \cdot \left(\frac{1}{2} - r_k\right)$$

$$\mathrm{Im}\{c_{m,l,k}\} = 0$$

L.9.1.2 Null Pilot

With null pilot encoding, the amplitudes of the scattered pilots of both group 1 and group 2 are modified in the signals transmitted ~~from~~ in Polarizations ~~antennas~~ #1 and #2. With null pilot encoding, Polarization ~~antenna~~ #1 shall transmit group 1 scattered pilots with 3 dB increased transmit power (amplitude of $\sqrt{2}A_{\text{SP}}$) and group 2 scattered pilots with null power (zero amplitude). Similarly, Polarization ~~antenna~~ #2 shall transmit group 2 scattered pilots with 3 dB increased transmit power (amplitude of $\sqrt{2}A_{\text{SP}}$) and group 1 scattered pilots with null power (zero amplitude).

Both group 1 and group 2 scattered pilots ~~for~~ in Polarization ~~antenna~~ #1 shall be calculated using the following equations:

$$\text{Re}\{c_{m,l,k}\} = \sqrt{2} \cdot \left(1 + (-1)^{\frac{k}{D_X D_Y} + \frac{(D_Y - 1)l}{D_Y}}\right) \cdot A_{\text{SP}} \cdot (\frac{1}{2} - r_k)$$

$$\text{Im}\{c_{m,l,k}\} = 0$$

The scattered pilots transmitted ~~from~~ in Polarization ~~antenna~~ #2 shall be as given in the following equations:

$$\text{Re}\{c_{m,l,k}\} = \sqrt{2} \cdot \left(1 + (-1)^{\frac{k}{D_X D_Y} + \frac{(D_Y - 1)l}{D_Y} + 1}\right) \cdot A_{\text{SP}} \cdot (\frac{1}{2} - r_k)$$

$$\text{Im}\{c_{m,l,k}\} = 0$$

Common continual pilots and additional continual pilots on non-scattered-pilot-bearing cells shall not be modified compared to SISO for either transmit Polarization ~~antenna~~. The few additional continual pilots falling on scattered-pilot-bearing carriers shall be encoded using the null pilot encoding for scattered pilots.

Note: Those cells which would be both an additional continual pilot and a scattered pilot shall be treated as scattered pilots and therefore shall have the amplitude $\sqrt{2}A_{\text{SP}}$ or 0. The additional continual pilot cells which do not fall on scattered pilot positions shall have the amplitude A_{SP} as in SISO.

With null pilot encoding, the edge pilots and subframe boundary pilots shall be encoded using Walsh-Hadamard encoding. The phases of the group 2 edge and subframe boundary pilots shall be inverted in the signal transmitted ~~from~~ in Polarization ~~antenna~~ #2 using Walsh-Hadamard encoding as described in the previous section.

L.9.2 Pilot Schemes

This section illustrates the scattered pilot patterns for MIMO following the same model used for the SISO scattered pilot patterns in Annex E.

Twelve MIMO scattered pilot patterns are defined for Walsh-Hadamard pilot encoding and are illustrated from Figure L.9.1 to Figure L.9.12. Sixteen MIMO scattered pilot patterns are defined for null pilot encoding and are illustrated from Figure L.9.13 to Figure L.9.28.

The terminology employed for the MIMO pilot patterns is MP**a**_**b**, where **a** = D_X and **b** = D_Y are defined taking into account the two transmit Polarizations ~~antennas~~, such that each MIMO pilot pattern has pilots in exactly the same positions as the equivalent SISO pilot pattern.

Table L.9.2 lists each MIMO pilot scheme, the corresponding equivalent SISO pilot scheme, and the values of D_X and D_Y. Note that the equivalent values of D_X and D_Y per transmit ~~antenna~~

Polarization for the two available MIMO pilot encoding schemes are not shown in the table. The last four rows of the table are only allowed for null pilot encoding.

Modify Section L.10 as follows:

L.10 MISO

The use of MISO, as described in Section 8.2 may be optionally added to MIMO with a unique MISO code applied per station or per Polarization ~~antenna~~.

Add a new Section L.11 as follows:

L.11 IFFT

The same OFDM structures as in Section 8.3 shall be used for each Polarization stream in MIMO transmission.

IFFT for MIMO follows the definitions and descriptions in Section 8.3 but includes a partial augmentation. Since MIMO introduces an extra transmission path in addition to a SISO setup, the waveform expression for MIMO shall render the following two framing scenarios explainable:

- Case 1: Pure MIMO frame consisting solely of MIMO subframe(s)
- Case 2: Coexistence of MIMO and SISO subframes based on TDM

If MIMO is in use, the baseband time domain signal after IFFT shall be described in a Polarization-specific fashion as follows:

$$\sum_{l=0}^{L_{Fp}-1} \frac{1}{\sqrt{P_{preamble,l}}} \sum_{k=0}^{NoC_{P,l}-1} c_{l,k} \times \psi_{l,k}(t) + \sum_{\substack{m=0,\\ m \in S_{M,a}}}^{N_{SF}-1} \frac{1}{\sqrt{P_{data,m}}} \sum_{l=0}^{L_{SFm}-1} \sum_{k=0}^{NoC_m-1} c_{a,m,l,k} \times \psi_{m,l,k}(t)$$

where $\psi_{l,k}(t)$ and $\psi_{m,l,k}(t)$ shall follow the same definitions as in Section 8.3 and:

a denotes the Polarization index, where $a = 0$ and $a = 1$ indicates Polarizations #1 and #2, respectively;

k denotes the carrier number;

l denotes the OFDM symbol number starting from 0 for the first Preamble symbol of a frame and being reset at the first OFDM symbol of each subframe;

m denotes the subframe number, $0 \leq m < N_{SF}$;

$c_{l,k}$ is the complex modulation value for carrier k of the Preamble symbol number l;

$c_{a,m,l,k}$ is the complex modulation value for carrier k of the OFDM symbol number l in subframe number m associated with Polarization a;

$S_{M,a}$ denotes the set of subframe numbers, for which Polarization a is active during the corresponding transmission;

$NoC_{P,l}$ denotes the number of carriers in the $(l + 1)^{\text{th}}$ Preamble symbol. The first Preamble symbol ($l = 0$) always has the minimum NoC and the following Preamble symbols ($0 < l < L_{\text{Fp}}$) share the same NoC value that is signaled in L1-Basic as explained in Sections 7.2.5.1 and 9.2.2;

NoC_m denotes the number of carriers of subframe m as defined in Table 8.8;

L_{SFm} is the number of data and subframe boundary symbols in subframe m;

L_{Fp} is the number of OFDM symbols in the Preamble;

N_{SF} is the number of subframes in a frame;

$P_{preamble,l}$ is the per-Polarization frequency domain total power of $(l + 1)^{th}$ Preamble symbol summarized in Table I.1.1;

$P_{data,m}$ is the per-Polarization frequency domain total power of each data and subframe boundary symbol in subframe m. Allowed values of $P_{data,m}$ are summarized in Table I.2.1 to Table I.2.5.

The MIMO transmitter shall transmit the same Preamble symbols over Polarizations #1 and #2. The presented signal expression shares a common value $c_{l,k}$ irrespective of the Polarization index a. Carrier signals in data and subframe boundary symbols can differ between Polarization, and hence the corresponding carrier modulation value $c_{a,m,l,k}$ is defined as Polarization-specific.

IFFT power normalization for MIMO shall be applied to each Polarization stream. For the use of MIMO, the definitions of $P_{preamble,l}$ and $P_{data,m}$ are specified to be the frequency domain total power per Polarization. Evaluation of $P_{preamble,l}$ and $P_{data,m}$ for MIMO applies the same with the SISO processing. The same lookup tables as in Table I.1.1 and Table I.2.1 to I.2.5 shall be used for $P_{preamble,l}$ and $P_{data,m}$, respectively.

The presented MIMO-version post-IFFT signal expression is compatible with the framing scenarios of Case 1 and 2, where the subframe indicator set $S_{M,a}$ shall vary depending thereon. The corresponding specifications related to each framing scenario are defined below.

L.11.1 Case 1: Pure MIMO Frame

If every subframe in the frame of interest uses MIMO, $S_{M,a}$ shall satisfy the following condition:

$S_{M,a}$ shall consist of every integer within the range $0 \le m < N_{SF}$, regardless of the value of a. That is, $S_{M,a} = \{0, \ldots, N_{SF} - 1\}$.

L.11.2 Case 2: Coexistence with SISO Subframes

TDM of MIMO and SISO subframes involves transmission of SISO signals at MIMO transmitters. In the current version of the specification, transmission of SISO signals from MIMO transmitters can take one of the following forms:

- Polarization #1 transmits SISO subframes and Polarization #2 is inactive during then.
- Polarizations #1 and #2 transmit the same signal copies of SISO subframes.

If only Polarization #1 is active during the subframe duration using SISO and Polarization #2 is inactive during then, $S_{M,a}$ shall be defined accordingly as follows:

$S_{M,a}$ shall be determined as follows. If $a = 0$, $S_{M,a} = \{0, \ldots, N_{SF} - 1\}$. If $a = 1$, $S_{M,a}$ consists of the subframe numbers that use MIMO.

For example, if subframe 2 and subframe 3 apply MIMO processing out of total $N_{SF} = 4$ subframes, $S_{M,1}$ equals $\{2, 3\}$, while $S_{M,0}$ equals $\{0, 1, 2, 3\}$.

If Polarizations #1 and #2 are both active during the subframe duration using SISO, the notions $S_{M,a}$ and $c_{a,m,l,k}$ shall satisfy the following:

$S_{M,a}$ shall consist of every subframe number within $0 \le m < N_{SF}$, regardless of the value of a. That is, $S_{M,a} = \{0, \ldots, N_{SF} - 1\}$;

$c_{a,m,l,k}$ shall satisfy $c_{0,m,l,k} = c_{1,m,l,k}$ if m indicates a SISO subframe.

Change the order of Section L.11 into Section L.12 as follows:

~~L.11~~ L.12 PAPR REDUCTION

The Tone Reservation Peak to Average Power Ratio reduction technique, as described in Section 8.4.1, may be used with MIMO. The Active Constellation Extension (ACE) technique, as described in Section 8.4.2, shall not be used with MIMO.

Change the order of Section L.12 into Section L.13 and modify the content as follows:

~~L.12~~ L.13 CHANNEL BONDING

~~The use of Channel Bonding with MIMO is not defined in this version of the specification, and Channel Bonding shall not be used together with MIMO.~~

Channel bonding (see Annex K) may be used with MIMO and shall conform to this section when used. Channel bonding described in this section is defined for two RF channels. A block diagram in Figure L.13.1 shows the system architecture when channel bonding is used with MIMO. Following the stream partitioning process described in Section K.1, a single input data packet stream is partitioned into two separate Baseband Packet streams, each fed into the BICM chain for each RF channel. MIMO with channel bonding can also operate in two modes, plain channel bonding and SNR averaging, which can be selected by **L1D_plp_channel_bonding_format**. Dashed lines in Figure L.13.1 show blocks enabled by MIMO precoding setting, and dotted lines indicate blocks activated only when SNR averaging is applied.

Channel bonding with MIMO is not restricted to a bonding between MIMO PLPs but allows a bonding between SISO and MIMO PLPs. When plain channel bonding is used, a channel-bonded PLP can consist of a MIMO PLP and a SISO PLP, each transmitted onto different RF channels. In this case, the BICM chain encoding the engaged SISO PLP operates with MAP (see Section 6.3), while the MIMO PLP within the other RF channel applies MIMO MAP. If channel bonding with SNR averaging is used, a MIMO PLP shall not be channel-bonded with SISO PLP, thereby enabling low-complexity cell re-exchange on the receiver side as described in Section K.3.

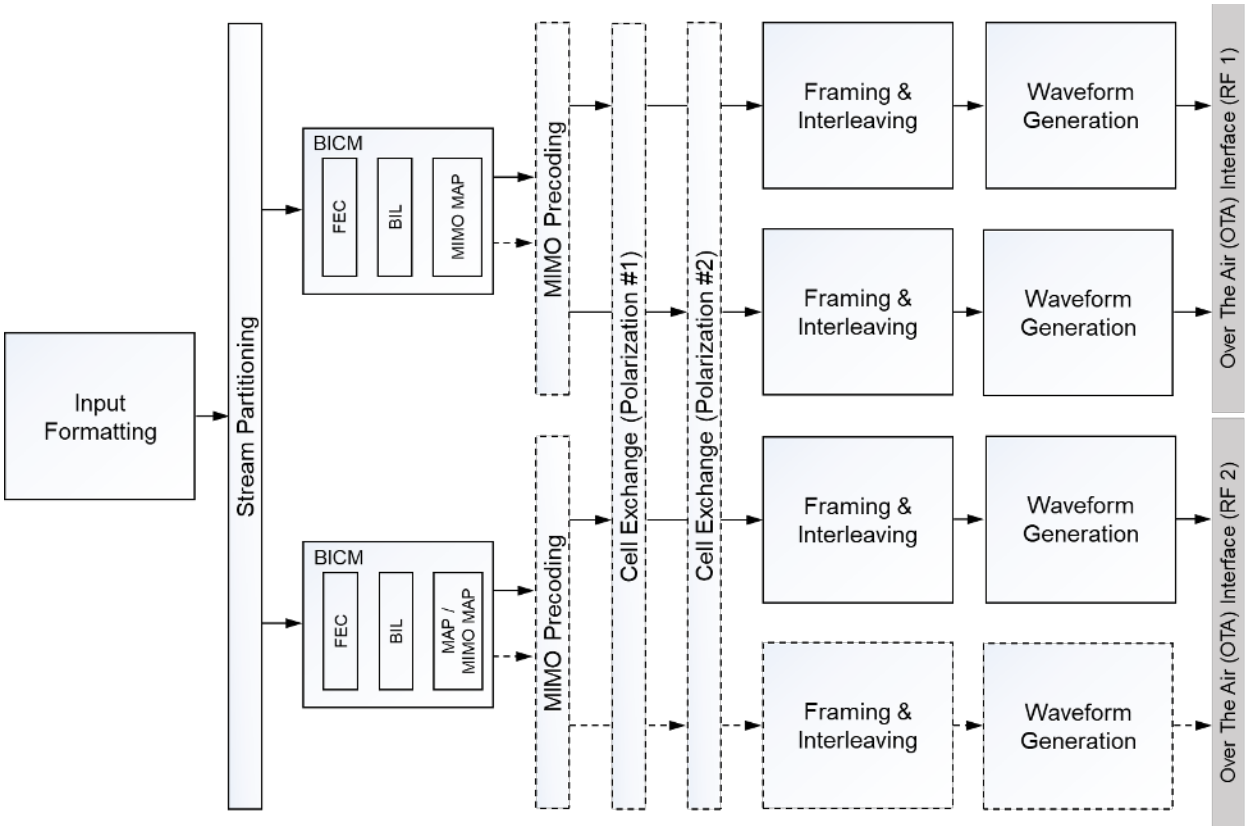

Figure L.13.1 Block diagram of the channel bonding with MIMO system architecture.

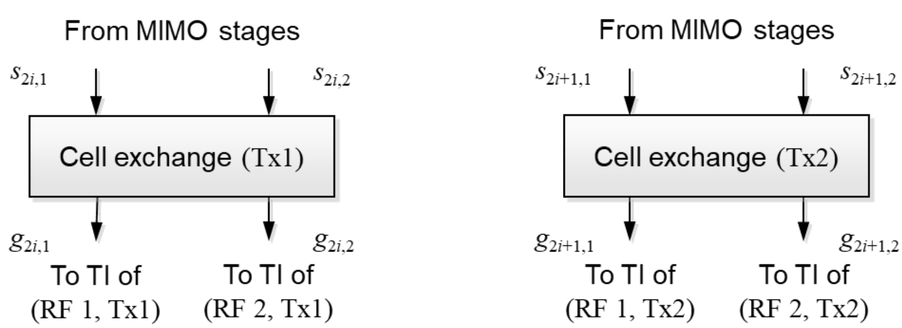

Figure L.13.2 Cell exchange block for each Polarization, Tx1 and Tx2.

When channel bonding with SNR averaging is used, the cell exchange block shall be applied Polarization-wise as shown in Figure L.13.2. A cell exchange matrix, defined for each Polarization, shall be multiplied to the vector including both cells for each input path at index i ($i = 0 \ldots \lfloor N_{cells}/2 \rfloor$-1):

$$\begin{pmatrix} g_{2i,1} \\ g_{2i,2} \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} s_{2i,1} \\ s_{2i,2} \end{pmatrix} \text{ for } i \text{ even, with respect to the cells for Tx1}$$

$$\begin{pmatrix} g_{2i,1} \\ g_{2i,2} \end{pmatrix} = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \cdot \begin{pmatrix} s_{2i,1} \\ s_{2i,2} \end{pmatrix} \text{ for } i \text{ odd, with respect to the cells for Tx1}$$

$$\begin{pmatrix} g_{2i+1,1} \\ g_{2i+1,2} \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} s_{2i+1,1} \\ s_{2i+1,2} \end{pmatrix} \text{ for } i \text{ even, with respect to the cells for Tx2}$$

$$\begin{pmatrix} g_{2i+1,1} \\ g_{2i+1,2} \end{pmatrix} = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \cdot \begin{pmatrix} s_{2i+1,1} \\ s_{2i+1,2} \end{pmatrix} \text{ for } i \text{ odd, with respect to the cells for Tx2,}$$

where the meaning of variables are as follows. The input cells fed into the cell exchange block for Tx1, $s_{2i,1}$ and $s_{2i,2}$, are associated with RF channels RF 1 and RF 2, respectively; the input cells fed into the cell exchange block for Tx2, $s_{2i+1,1}$ and $s_{2i+1,2}$, are associated with RF channels RF 1 and RF 2, respectively. The output cells produced from the cell exchange block for Tx1, $g_{2i,1}$ and $g_{2i,2}$, are associated with RF 1 and RF 2, respectively; the output cells produced from the cell exchange block for Tx2, $g_{2i+1,1}$ and $g_{2i+1,2}$, are associated with RF 1 and RF 2, respectively. The output cells are fed into the dedicated time interleaving blocks located on each corresponding path.

Annex N, "Transmitter Identification (TxID)"

Add a new Section N.5 as follows:

N.5 MIMO

When MIMO is used, TxID can identify not only individual transmitters but also each transmitting Polarization within the transmitter. The value of **txid_address** and TxID injection level can be independently assigned to each transmitting Polarization within the MIMO transmitter.

Add a new Annex O as follows:

Annex O: Combination of LDM and MIMO

O.1 OVERVIEW

The combination of LDM and MIMO, referenced as Layered MIMO, increases spectral efficiency by integrating two different multiplexing gains from independent domains: (1) LDM gain from spectrum reuse, and (2) MIMO gain from spatial multiplexing. Layered MIMO is an extension of the MIMO technology described in Annex L specific to multiplexing scenarios with multiple PLPs in which at least one MIMO PLP is included. Layered MIMO is an optional technology but, when adopted, shall conform to the requirements in this Annex.

In this version of the specification, the Layered MIMO system is restricted to a two-layer LDM with a MIMO-encoded Enhanced Layer. The Core Layer can be either SISO or MIMO. Depending on the form of the Core Layer, one of two types of Layered MIMO is applied as follows:

- Layered MIMO Type A: Both Core and Enhanced PLPs use MIMO.
- Layered MIMO Type B: Core PLPs use SISO, and Enhanced PLPs use MIMO.

MIMO processing in Layered MIMO uses 2×2 cross-polarized antenna systems (e.g., having horizontally and vertically polarized elements or possibly having elements rotated 45 degrees in the same direction from horizontal and vertical) (see Annex L). At least two effective antenna units must be present at transmitter locations, while antenna requirements for receivers can vary depending on the signals intended to be received. If a service carried by a MIMO PLP is to be received, receivers should include cross-polar pairs of antennas or more. If a SISO-carried service is to be received, receivers may operate with single antennas or sets of diversity antennas. Receivers capable of decoding MIMO PLPs also must support SISO decoding. In cases when Layered MIMO Type B is applied, compatibility with MIMO operations determines a receiver's capability to decode each signal layer.

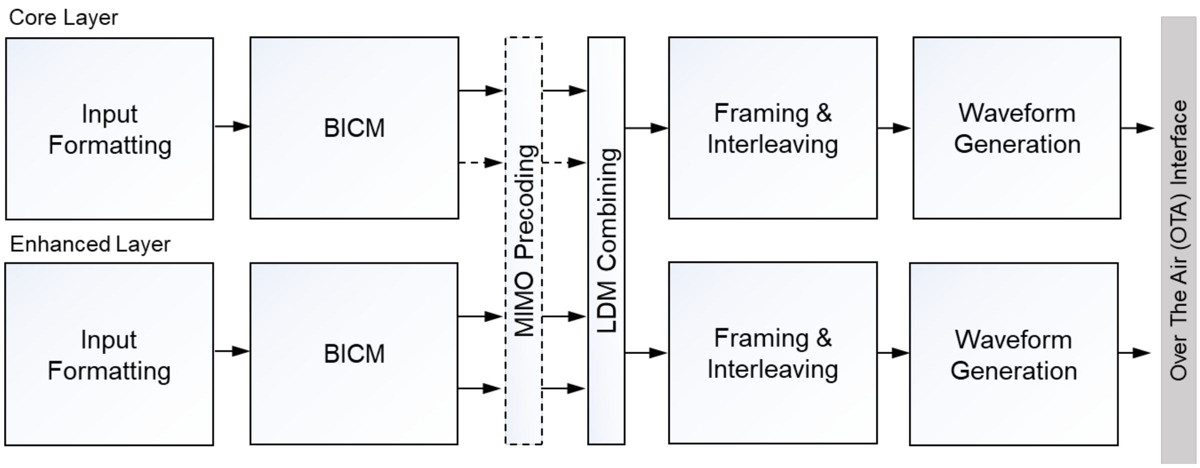

Figure O.1.1 Comprehensive block diagram for Layered MIMO.

Figure O.1.1 depicts a comprehensive block diagram for a Layered MIMO system. The Layered MIMO transmission chain reuses as many blocks as possible from SISO, including FEC codes, bit interleavers, constellations, and frequency and time interleavers. All blocks not specifically mentioned in this Annex, such as input formatting and guard interval, shall follow their specifications for SISO.

Not all blocks are used in every configuration. In Figure O.1.1, solid lines represent blocks common to all configurations, while dashed lines indicate blocks that can be disabled or partly applied, depending on whether the configuration is Type A or B. Solid arrows depict signal flows common to all configurations, and dashed arrows show signal flows specific to Layered MIMO Type A. The structure realization for each Layered MIMO type is specified in Figures O.1.2 and O.1.3.

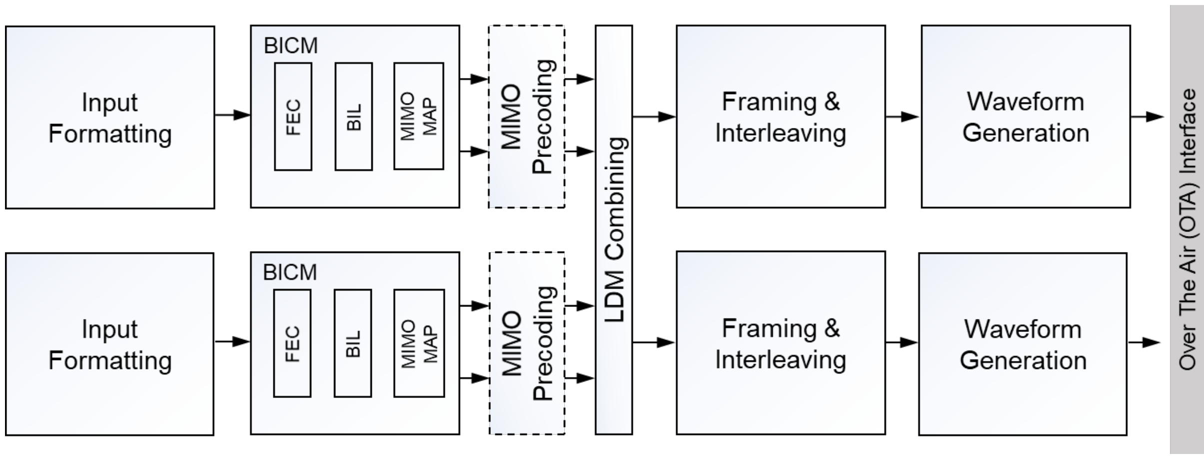

Figure O.1.2 Block diagram of Layered MIMO Type A.

Figure O.1.2 depicts a block diagram of Layered MIMO specific to Type A. Layered MIMO Type A is a simple combining between MIMO PLPs. The constellation superposition in this configuration shall be applied with respect to Polarization, i.e., the Core PLP's constellation symbol associated with Polarization #1 shall be superposed with the Enhanced PLP's constellation symbol associated with Polarization #1, and the same applies to Polarization #2.

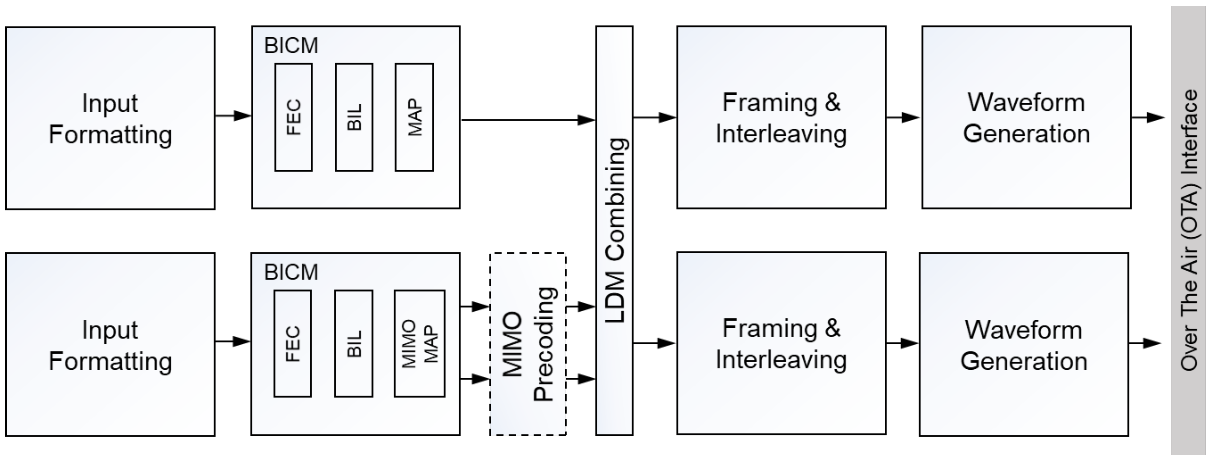

Figure O.1.3 Block diagram of Layered MIMO Type B.

Figure O.1.3 depicts a block diagram of Layered MIMO specific to Type B. Layered MIMO Type B multiplexes SISO and MIMO PLPs within a subframe. This multiplexing scheme allows receivers compatible only with SISO to receive Core PLP(s) without being impacted by the presence of Enhanced PLP(s) using MIMO.

In a Layered MIMO Type B system, such as shown in Figure O.1.3, MIMO precoding can be applied exclusively to Enhanced PLPs.

Layered MIMO processing shall not be applied to Bootstraps or to Preambles. Layered MIMO processing shall be applied to subframes individually according to the **L1D_mimo**, **L1D_mimo_mixed** (or **L1B_first_sub_mimo**, **L1B_first_sub_mimo_mixed**), and **L1D_plp_layer** settings carried in the Preamble of each frame (see Section O.14 for details).

O.2 FEC CODING

The same FEC codes as in Section 6.1 shall be used for Layered MIMO.

O.3 BIT INTERLEAVING

The same bit interleavers as in Section 6.2 shall be used for Layered MIMO.

O.4 CONSTELLATION MAPPING

The same MIMO mappers as in Section L.4 shall be used for Layered MIMO. For SISO PLPs in Layered MIMO Type B, the same constellation mappers as in Section 6.3 shall be used.

In the case of Layered MIMO Type A, both the Core Layer and Enhanced Layer apply MIMO mapping, producing two data cell streams each.

In the case of Layered MIMO Type B, the SISO constellation mapper within the Core Layer BICM chain is situated in the same position as the MIMO mapper within the Enhanced Layer BICM chain.

O.5 PRECODING

MIMO precoding in Layered MIMO shall be applied according to Section L.5.

For Layered MIMO Type A, both Core and Enhanced PLPs undergo MIMO precoding procedures. For Layered MIMO Type B, only Enhanced PLP(s) undergo the MIMO precoding process.

For reduced complexity at the receiver, Layered MIMO Type A shall apply to an Enhanced PLP the same I/Q Polarization Interleaving and Phase Hopping parameters as the associated Core PLP(s). That is, if a Core PLP enables I/Q Polarization, the associated Enhanced PLP(s) shall also enable I/Q Polarization, and vice versa. The same constraint applies to Phase Hopping.

O.6 LDM COMBINING: CONSTELLATION SUPERPOSITION FOR LDM

LDM Combining for Layered MIMO is carried out according to Section 6.4, while the detailed application differs between Type A and Type B.

O.6.1 Constellation Superposition for Layered MIMO Type A

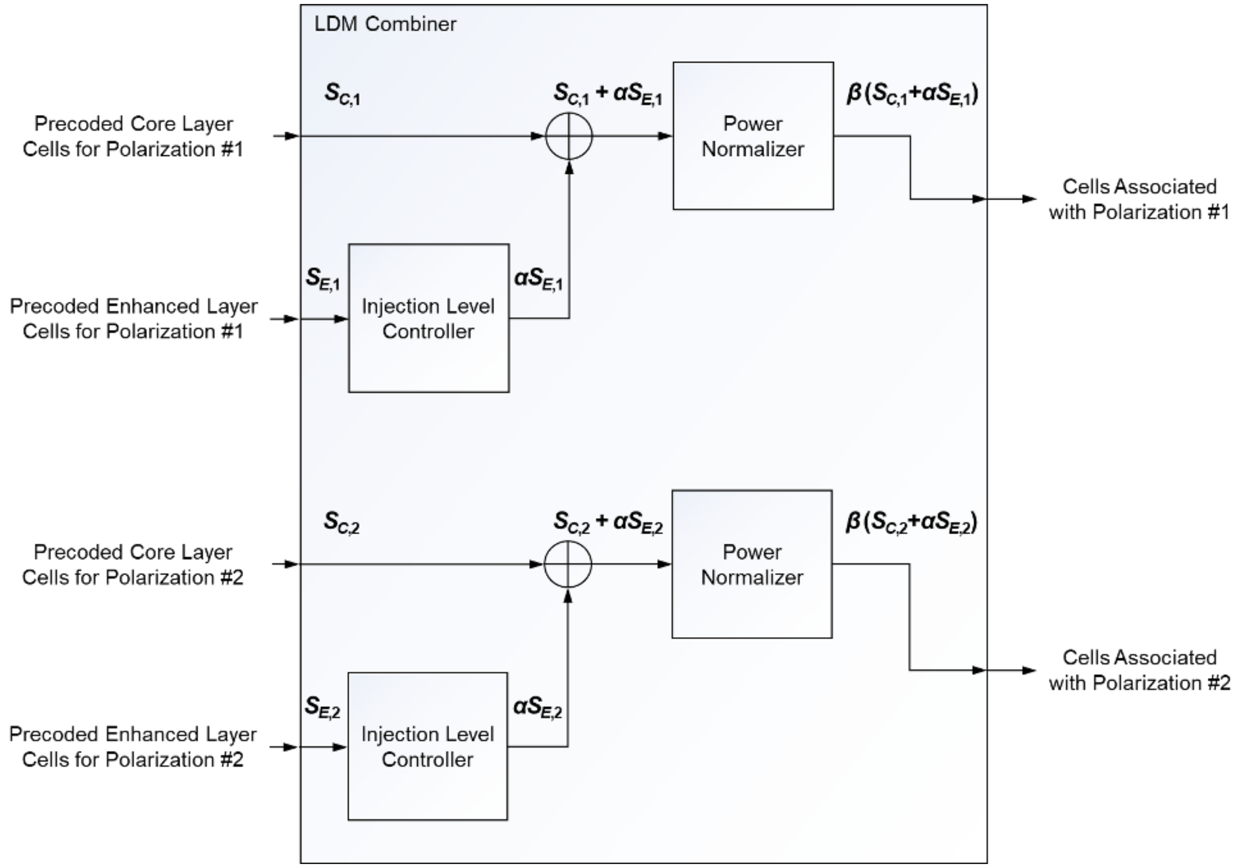

Figure O.6.1 Constellation superposition for Layered MIMO Type A.

Layered MIMO Type A shall combine Core and Enhanced PLPs that both use MIMO. In this configuration, the Core Layer and Enhanced Layer constellations associated with each Polarization are superposed in an LDM Combiner block. The constellation superposition shall be applied to MIMO-precoded cells (regardless of whether the MIMO precoding functions are active or not), as the LDM Combining block depicted in Figure O.1.2 resides after MIMO precoding blocks. The LDM Combiner block for LDM MIMO Type A is depicted in Figure O.6.1.

Two parallel injection level controllers shall be used for each associated Polarization. The Layered MIMO system assigns the same injection level to each stream for the two Polarization streams involved. The allowed values for per-Polarization injection level and the corresponding power distributions between layers shall conform to the lookup table in Table 6.15.

In Layered MIMO Type A, descriptions for CL power, EL power, total power, and their ratios in Table 6.15 shall be interpreted as quantities confined to each Polarization transmission.

The correspondence between the allowed injection level values and scaling/normalizing parameters (i.e., α and β) shall conform to the lookup table in Table 6.16.

O.6.2 Constellation Superposition for Layered MIMO Type B

Layered MIMO Type B shall transmit the Core Layer signal over Polarization #1 alone.

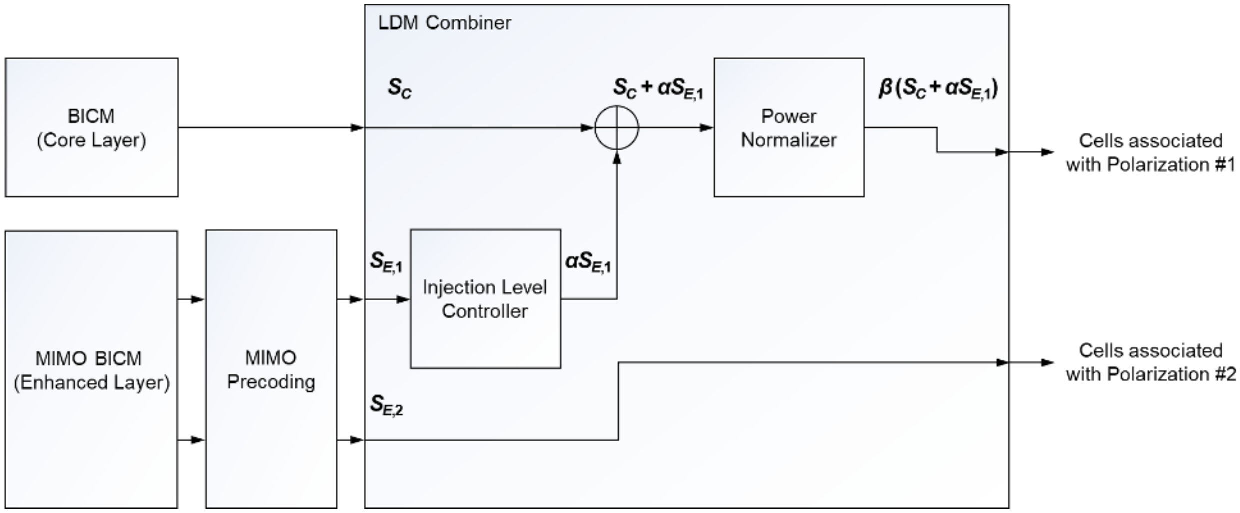

Figure O.6.2 Constellation superposition for Layered MIMO Type B.

In Layered MIMO Type B, the constellation-superposed signals shall be transmitted only in Polarization #1, while Polarization #2 shall carry the dedicated MIMO stream consisting solely of the Enhanced Layer cells.

If Layered MIMO Type B is used, constellation superposition is applied between the following two: The output of SISO BICM chain and Polarization #1 part of the output from MIMO precoder. The post-MIMO precoder cells associated with Polarization #2 bypass the LDM Combining block transparently. The LDM Combiner block for LDM MIMO Type B is depicted in Figure O.6.2.

LDM Combiner for Layered MIMO Type B shall use a single pair of injection level controller and power normalizer. The injection level controller and power normalizer associated with Polarization #1 stream operate the same as which described in Section O.6.1.

The scaling factor for the injection level controller, α, and the normalizing factor for the power normalizer, β, depend on the injection level of the Enhanced Layer. Values allowed and the correspondence among the parameters shall conform with the same lookup tables as in Table 6.15 and Table 6.16. For the use of Layered MIMO Type B, descriptions for CL power, EL power, total power, and their ratios in Table 6.15 and Table 6.16 shall be interpreted as the quantities confined to each dedicated Polarization transmission.

Layered MIMO Type B assigns an identical Enhanced Layer injection level to both Polarization streams but the interpretation shall differ between the Polarization streams. For Layered MIMO Type B, the injection level for Polarization #1 shall denote the power of Enhanced Layer component relative to that of the Core Layer component, specifically confining the meaning of layer components to the Polarization #1 stream. The injection level for Polarization #2 shall represent the power of Polarization #2 signal relative to that of the Core Layer component transmitted in Polarization #1.

The LDM Combiner shall output the Polarization #2 stream with unity power. The power scaling for Polarization #2 stream depending on the corresponding injection level shall be applied in the IFFT stage.

O.7 TIME INTERLEAVER

The same time interleavers as in Section 7.1 shall be used for Layered MIMO.

In both Layered MIMO Type A and B, time interleaving mode is defined for Core PLPs. The Enhanced PLP(s) follows the same time interleaving as defined for the associated Core PLP(s). The total memory requirement conforms to the description in Section L.6. Overall, time interleaving for Layered MIMO requires twice the total memory as is required for SISO.

O.8 FRAMING

Layered MIMO frames shall be built in the same manner with MIMO frames, according to Section 7.2. The LDM-combined cells in Layered MIMO are treated identically to cells in SISO or non-LDM MIMO systems.

Every data cell in a Layered MIMO PLP shall not be allocated to any cells in Preamble symbol(s), even if there are available parts remaining in the last Preamble symbol.

The cell multiplexing in Layered MIMO shall follow the same process as MIMO cell multiplexing described in Section L.7. The number of available data cells for cell multiplexing can be obtained from tables in Section 7.2.6. Equivalent SISO pilot patterns that have the same number and position as those of MIMO scattered pilot patterns shall be used for table lookup. Equivalent SISO scattered pilot patterns are shown in Table L.9.2.

O.9 FREQUENCY INTERLEAVING

The same frequency interleavers as in Section 7.3 shall be used for Layered MIMO.

O.10 PILOT PATTERNS

O.10.1 Pilot Polarization Encoding

Pilot encoding for Layered MIMO shall be organized according to Section L.9.1.

For Layered MIMO Type A, either Walsh-Hadamard encoding or null pilot encoding can be used. Pilot signals shall be shared Polarization-wise between the Core Layer and Enhanced Layer.

For Layered MIMO Type B, only Walsh-Hadamard encoding is allowed. If superposed by means of Layered MIMO Type B, SISO PLP(s) and MIMO PLP(s) shall share the pilot cells transmitted in Polarization #1. Pilot schemes using Walsh-Hadamard encoding achieve such pilot compatibility, as summarized in Table 9.1. The L1 signaling parameter **L1B_mimo_scattered**_pilot_encoding shall hence be identified as 0, indicating both the MIMO pilot pattern with Walsh-Hadamard encoding and the SISO pilot pattern simultaneously (see Table 9.3). This indication may be interpreted differently depending on which PLP(s) is being received.

O.10.2 Pilot Schemes

The same scattered pilot patterns as in Section L.9.2 shall be applied to Layered MIMO.

O.11 MISO

The use of MISO, as described in Section 8.2 may be optionally added to Layered MIMO with a unique MISO code applied per station or per Polarization.

If Layered MIMO Type B and MISO are used together, a MIMO transmitter shall apply different MISO code indices to Polarizations #1 and #2.

O.12 IFFT

IFFT in Layered MIMO follows the definitions and descriptions in Sections 8.3 and L.11 but with a partial modification. The same OFDM structures as in Section 8.3 shall be used for each Polarization stream in MIMO transmission.

To embrace MIMO formulation and different types of LDM Combining, Layered MIMO uses a post-IFFT signal description modified from that in Section 8.3. In a Layered MIMO system, the baseband time domain signal after IFFT shall be described for each Polarization by the following expression:

$$\sum_{l=0}^{L_{Fp}-1} \frac{K_0[a]}{\sqrt{P'_{preamble,a,l}}} \sum_{k=0}^{NoC_{P,l}-1} c_{l,k} \times \psi_{l,k}(t) + \sum_{m=0}^{N_{SF}-1} \frac{K_m[a]}{\sqrt{P'_{data,a,m}}} \sum_{l=0}^{L_{SFm}-1} \sum_{k=0}^{NoC_m-1} c_{a,m,l,k} \times \psi_{m,l,k}(t)$$

where $\psi_{l,k}(t)$ and $\psi_{m,l,k}(t)$ follow the definitions in Section 8.3, and:

a denotes the Polarization index, where $a = 0$ and $a = 1$ indicates Polarizations #1 and #2, respectively;

k denotes the carrier number;

l denotes the OFDM symbol number starting from 0 for the first Preamble symbol of a frame and being reset at the first OFDM symbol of each subframe;

m denotes the subframe number, $0 \le m < N_{SF}$;

$K_m[a]$ is the scaling coefficient subject to subframe number m and Polarization index a. The value of $K_m[a]$ is related to the injection level information as summarized in Table O.12.1;

$c_{l,k}$ is the complex modulation value for carrier k of the Preamble symbol number l;

$c_{a,m,l,k}$ is the complex modulation value for carrier k of the OFDM symbol number l in subframe number m associated with Polarization a;

$NoC_{P,l}$ denotes the number of carriers in the $(l + 1)^{th}$ Preamble symbol. The first Preamble symbol ($l = 0$) always has the minimum NoC and the following Preamble symbols ($0 < l < L_{Fp}$) share the same NoC value that is signaled in L1-Basic as explained in Sections 7.2.5.1 and 9.2.2;

NoC_m denotes the number of carriers of subframe m as defined in Table 8.8;

L_{SFm} is the number of data and subframe boundary symbols in subframe m;

L_{Fp} is the number of OFDM symbols in the Preamble;

N_{SF} is the number of subframes in a frame;

$P'_{preamble,a,l}$ is the frequency domain total power of the $(l + 1)^{th}$ Preamble symbol, derived from the input to the IFFT block associated with Polarization a;

$P'_{data,a,m}$ is the frequency domain total power of each data and subframe boundary symbol in subframe m, derived from the input to the IFFT block associated with Polarization a.

Two parallel IFFT functional blocks shall generate baseband time domain signals for each Polarization stream.

Given the complex modulation values $c_{l,k}$ and $c_{a,m,l,k}$ as input, the IFFT blocks for Layered MIMO shall perform a power scaling dependent on scalar coefficients $K_m[a]$. Allowed values of $K_m[a]$ and the correspondence to the injection level are listed in Table O.12.1. This scaling gives $K_m[1] < 1$ to the Polarization #2 stream in Layered MIMO Type B, while $K_m[a]$ shall be given as unity otherwise. The IFFT power normalization in Layered MIMO shall normalize the symbol-by-symbol average power of the baseband time domain signal to $(K_m[a])^2$ for subframe m subject to Polarization a. For the Preamble, the average power shall be normalized to $(K_0[a])^2$. This power normalization is achieved by applying the IFFT power normalization factor $1/\sqrt{P'_{preamble,a,l}}$ to the Preamble and $1/\sqrt{P'_{data,a,m}}$ to data and subframe boundary symbols. The frequency domain power parameters $P'_{\text{preamble},a,l}$ and $P'_{\text{data},a,m}$ are derived from the carrier signals unscaled by $K_m[a]$, i.e., the values $c_{l,k}$ and $c_{a,m,l,k}$. The frequency domain power parameter for the Preamble, $P'_{\text{preamble},a,l}$, shall share the same lookup table with $P_{\text{preamble},l}$ described in Table I.1.1. The frequency domain power parameter for data and subframe boundary symbols, $P'_{\text{data},a,m}$, shall share the same lookup table with $P_{\text{data},m}$ described in Table I.2.1 to Table I.2.5.

The same elementary period and OFDM parameters as in Section 8.3 shall be used for Layered MIMO, using the lookup Table 8.7 and Table 8.8.

Table O.12.1 Scaling Factors According to Enhanced Layer Injection Level in Layered MIMO

(Per-Polarization) Injection Level of EL below CL [dB]	Km[a]		
	Type A	Type B	
	a = 0, 1	a = 0	a = 1
0.0	1.0000000	1.0000000	0.7071068
0.5	1.0000000	1.0000000	0.6864761
1.0	1.0000000	1.0000000	0.6653483
1.5	1.0000000	1.0000000	0.6438178
2.0	1.0000000	1.0000000	0.6219832
2.5	1.0000000	1.0000000	0.5999458
3.0	1.0000000	1.0000000	0.5778067
3.5	1.0000000	1.0000000	0.5556652
4.0	1.0000000	1.0000000	0.533617
4.5	1.0000000	1.0000000	0.5117528
5.0	1.0000000	1.0000000	0.4901561
6.0	1.0000000	1.0000000	0.4480625
7.0	1.0000000	1.0000000	0.4078450
8.0	1.0000000	1.0000000	0.3698742
9.0	1.0000000	1.0000000	0.3343887
10.0	1.0000000	1.0000000	0.3015114
11.0	1.0000000	1.0000000	0.2712703
12.0	1.0000000	1.0000000	0.2436204
13.0	1.0000000	1.0000000	0.2184644
14.0	1.0000000	1.0000000	0.1956693
15.0	1.0000000	1.0000000	0.1750812
16.0	1.0000000	1.0000000	0.1565355
17.0	1.0000000	1.0000000	0.1398653
18.0	1.0000000	1.0000000	0.1249066
19.0	1.0000000	1.0000000	0.1115021
20.0	1.0000000	1.0000000	0.0995037
21.0	1.0000000	1.0000000	0.0887732

22.0	1.0000000	1.0000000	0.0791834
23.0	1.0000000	1.0000000	0.0706179
24.0	1.0000000	1.0000000	0.0629705
25.0	1.0000000	1.0000000	0.0561454

The expression above shall be used when the entire frame uses Layered MIMO. If a Layered MIMO subframe is time division multiplexed with subframes not using Layered MIMO, the IFFT processing shall conform to Section O.12.1.

O.12.1 Coexistence with SISO or MIMO Subframes

Layered MIMO subframes can be time division multiplexed with other types of subframes not using Layered MIMO. In this TDM case, the baseband time domain signal after IFFT shall be described by the following per-Polarization expression:

$$\sum_{l=0}^{L_{Fp}-1} \frac{K_0[a]}{\sqrt{P'_{preamble,a,l}}} \sum_{k=0}^{NoC_{P,l}-1} c_{l,k} \times \psi_{l,k}(t) + \sum_{\substack{m=0 \\ m \in S_{M,a}}}^{N_{SF}-1} \frac{K_m[a]}{\sqrt{P'_{data,a,m}}} \sum_{l=0}^{L_{SFm}-1} \sum_{k=0}^{NoC_m-1} c_{a,m,l,k} \times \psi_{m,l,k}(t)$$

where:

$S_{M,a}$ denotes the set of subframe numbers, for which Polarization a is active during the corresponding transmission;

and the other related parameters share definitions in the previous expression in Section O.12.

To clarify the processing on SISO and non-LDM MIMO elements, the following conditioned descriptions for related parameters are specified:

$K_m[a]$ satisfies $K_m[a] = 1$ if subframe m is not Layered MIMO;

For each Polarization, the power of Preamble symbol references the data symbol power of the first subframe activating the corresponding Polarization.

Transmission of pure SISO subframes at the Layered MIMO transmitter can choose between two different Polarization selection schemes summarized in Section L.11.2. The possible options for Polarization selection are as follows:

- Option 1: Polarization #1 transmits SISO subframes while Polarization #2 is inactive during then.
- Option 2: Polarizations #1 and #2 transmit identical signal copies of SISO subframes.

The realization of $S_{M,a}$ shall vary depending on the selected Polarization mapping option. If Option 1 is applied, $S_{M,a}$ shall be determined as follows:

$S_{M,0}$ consists of every integer within $0 \leq m < N_{SF}$, i.e., $S_{M,a} = \{0, \ldots, N_{SF} - 1\}$;

$S_{M,1}$ consists of the subframe numbers that use MIMO or Layered MIMO.

If Option 2 is applied, $S_{M,a}$ and $c_{a,m,l,k}$ shall be determined as follows:

$S_{M,a}$ consists of every integer within $0 \leq m < N_{SF}$, i.e., $S_{M,a} = \{0, \ldots, N_{SF} - 1\}$, irrespective to the value of a.

$c_{a,m,l,k}$ satisfies $c_{0,m,l,k} = c_{1,m,l,k}$ if subframe m is SISO.

O.13 CHANNEL BONDING

When used, channel bonding with Layered MIMO shall conform to the description in this section. The same Input Formatting, Stream Partitioning, and Cell Exchange operations as defined in Annex K and Section L.13 shall be applied, while details specific to Layered MIMO are added in this Section. A block diagram in Figure O.13.1 illustrates the system architecture applying channel bonding and Layered MIMO simultaneously.

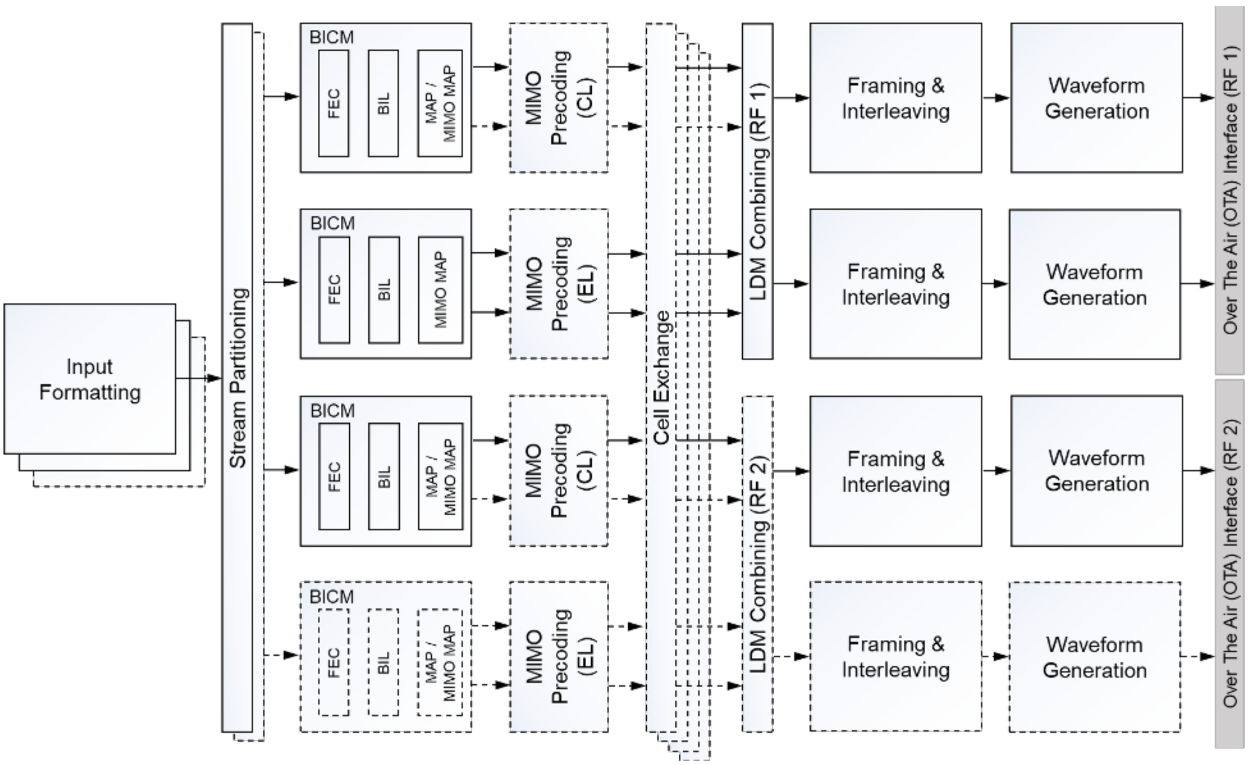

Figure O.13.1 Comprehensive block diagram of Layered MIMO with channel bonding.

Not all blocks are used in every configuration. In Figure O.13.1, solid lines denote blocks common to all configurations, while dashed lines indicate blocks that can be disabled depending on configurations related to LDM, MIMO, and channel bonding. Solid arrows represent signal flows common to all configurations, whereas dashed arrows denote optional signal flows that may be absent depending on the configuration.

For a channel-bonded PLP, all data packets engaged shall pass through a common Input Formatting block (utilizing the same **L1D_plp_id** value on every associated RF channel), as described in Section K.1. Baseband Packets generated by the Input Formatting block dedicated to a channel-bonded PLP shall be divided into two parallel streams at the Stream Partitioning block. Baseband Packets unrelated to channel bonding shall bypass Stream Partitioning.

Plain channel bonding and SNR averaging are both available for channel bonding with Layered MIMO. The related cell/PLP multiplexing shall follow Section K.4. Whenever channel bonding with SNR averaging is used, the bonded streams originating in the same Input Formatting block shall be contained in the same LDM layer.

If enabled, cell exchange processing shall be applied over the cells produced at the end of the MIMO precoding stage: MIMO-precoded (regardless of whether the MIMO precoding functions are active or not) cells for MIMO PLP(s) and post-BICM cells for SISO PLP(s). The cell exchange processing described in Section L.13 and Section K.3 shall be applied to MIMO PLP's and SISO PLP's cells, respectively.

The output streams from cell exchange blocks shall go through LDM Combining between each coupled stream pair, i.e., Core and Enhanced Layer cells that belong to the same Polarization. The LDM Combining process shall conform to the specifications in Sections 6.4 and O.6.

When a channel-bonded PLP with SNR averaging is included, Layered MIMO configurations for the bonded RF channels shall be identical between the corresponding subframes (each in a different RF channel). The type of Layered MIMO (i.e., whether Type A or B), injection level, and MIMO parameters shall be identical. Other configuration constraints under the use of SNR averaging shall follow the same specification in Section K.3.

Plain channel bonding with Layered MIMO does not restrict channel bonding to a homogeneous PLP pair. A channel-bonded PLP may comprise a SISO PLP and a MIMO PLP, and part of a Layered MIMO subframe may be bonded with one not using Layered MIMO.

O.14 L1 SIGNALLING FOR LAYERED MIMO

This section highlights the L1 signaling data specific to Layered MIMO defined in Section 9.

L1B_first_sub_mimo indicates whether MIMO is applied to every Core PLP in the first subframe of the current frame.

L1D_mimo indicates whether MIMO is applied to every Core PLP in the current subframe, which is the second or later in the given frame.

For the first subframe of the current frame, the type of Layered MIMO is signaled by **L1B_first_sub_mimo_mixed** in conjunction with **L1B_first_sub_mimo** when PLP(s) with **L1D_plp_layer** >0 are present in the subframe. Layered MIMO Type A is indicated when the two parameters are signaled as **L1B_first_sub_mimo_mixed** =0, **L1B_first_sub_mimo** =1. Layered MIMO Type B is indicated when the two parameters are signaled as **L1B_first_sub_mimo_mixed** =1, **L1B_first_sub_mimo** =0.

For subframes that are not the first in the current frame, the type of Layered MIMO is signaled by **L1D_mimo_mixed** in conjunction with **L1D _mimo** when PLP(s) with **L1D_plp_layer** >0 are present in the subframe. Layered MIMO Type A is indicated when the two parameters are signaled as **L1D_mimo_mixed** =0, **L1D _mimo** =1. Layered MIMO Type B is indicated when the two parameters are signaled as **L1D_mimo_mixed** =1, **L1D _mimo** =0.

Note: This version of the specification allows only LDM-based mixing of SISO and MIMO PLPs for subframes with **L1B_first_sub_mimo_mixed** =1 and **L1B_first_sub_mimo** =0, or **L1D_mimo_mixed** =1 and **L1D _mimo** =0 (as appropriate for the given subframe). Future versions may specify additional multiplexing options for mixed use of MIMO mode (e.g., all PLPs having **L1D_plp_layer** =0) within a subframe (see Table 9.8 and Table 9.10).

In subframes using Layered MIMO Type B, **L1D_plp_mimo** indicates whether each PLP is in MIMO mode. For the current version of the specification, Layered MIMO Type B shall assign **L1D_plp_mimo** =0 to Core PLPs and **L1D_plp_mimo** =1 to Enhanced PLPs.

The layer index of each PLP is signaled by **L1D_plp_layer**. Core and Enhanced PLPs are identified by **L1D_plp_layer** =0 and **L1D_plp_layer** >0, respectively. The use of Layered MIMO involves the presence of PLP(s) having **L1D_plp_layer** >0 in the corresponding subframe.

The choice of scattered pilot encoding scheme is signaled by **L1B_mimo_scattered_pilot_encoding**, which applies to every subframe in the current frame. The interpretation of this field is defined in Table 9.3. If Layered MIMO Type A is used, **L1B_mimo_scattered_pilot_encoding** can either be 0 or 1. If Layered MIMO Type B is used, **L1B_mimo_scattered_pilot_encoding** shall be signaled as 0.

The configuration of MIMO precoding is signaled by a set of L1-Detail parameters, **L1D_plp_mimo_stream_combining**, **L1D_plp_mimo_IQ_interleaving**, and **L1D_plp_mimo_PH**.

The choice of Enhanced Layer injection level is signaled by **L1D_plp_ldm_injection_level**. For Layered MIMO Type A, the injection level denotes the relative power ratio between the Enhanced Layer and Core Layer signals within each Polarization stream. For Layered MIMO Type B, the interpretation shall differ between Polarization streams as follows: The injection level in the context of Polarization #1 refers to the relative power ratio between the Enhanced Layer and Core Layer within Polarization #1 signal; the injection level with respect to Polarization #2 refers to the power of Polarization #2 signal relative to that of the Core Layer signal transmitted in Polarization #1.

The choice of scattered pilot pattern is signaled by **L1B_first_sub_scattered_pilot_pattern** for the first subframe and by **L1D_scattered_pilot_pattern** for other subframes in the current frame. These signaling parameters should be interpreted differently in SISO and MIMO contexts. When Layered MIMO Type B is used, two different interpretations are simultaneously intended by a single use of this signaling parameter. In the case of Layered MIMO Type B, the Core Layer receivers may interpret these signaling parameters in a SISO-related manner, while the Enhanced Layer receivers shall interpret them in a MIMO-related manner.

The choice of the bits per cell use for MIMO PLP(s) is signaled by **L1D_plp_mod**. This signaling parameter is also used for SISO but with a different interpretation.

The L1-Detail parameters **L1D_num_rf**, **L1D_rf_id**, **L1D_bonded_bsid**, **L1D_bsid**, **L1D_plp_num_channel_bonded**, **L1D_plp_bonded_rf_id**, and **L1D_plp_channel_bonding_format** shall signal the configuration related to channel bonding when channel bonding is used with Layered MIMO.

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