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**IEEE P802.11  
Wireless LANs**

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**WWiSE Proposal: High throughput extension to the 802.11  
Standard**

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**EXHIBIT**

**Cooklev 3**

exhibitstick.com

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**Abstract**

Changes and additions to IEEE Std. 802.11-1999 (Reaff 2003), as amended by published amendments IEEE802.11a, IEEE802.11g, IEEE802.11h and IEEE802.11i and by IEEE draft standard 802.11e/D9.0 are provided to support a new high throughput physical layer (PHY) for operation in the 2.4 and 5 GHz bands.

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**Draft Amendment to IEEE Standard for Information  
technology-  
Telecommunications and information exchange between  
systems -  
Local and metropolitan area networks -  
Specific Requirements -**

**Part 20: Wireless LAN Medium Access Control  
(MAC) and Physical Layer (PHY) specifications:**

**High throughput extension for the 2.4 GHz and  
5 GHz Bands**

[This amendment is based on IEEE Std 802.11™, 1999 Edition (Reaff 2003), as amended by IEEE Std 802.11a™-1999 and IEEE Std 802.11g™-2003, and Draft Amendment IEEE P802.11e/D9.0]

**3. Definitions**

*Insert the following new definitions in alphabetical order, renumbering as necessary:*

**20 MHz transmission:** A frame transmission in which the modulation spans only one of the 20 MHz channels of a 40 MHz Channel Pair.

**40 MHz channel pair:** A pair of 20 MHz channels whose centre frequencies are separated by 20 MHz and which can be treated as a single channel for 40 MHz transmissions by a BSS, and where one of the 20 MHz channels will also be used for (non-overlapping) 20 MHz transmissions by the BSS.

**40 MHz transmission:** A frame transmission in which the modulation spans both 20 MHz channels of a 40 MHz channel pair.

**aggregated MSDU (A-MSDU):** A MSDU that encapsulates one or more MSDUs to be transmitted to the same destination.

**aggregated PPDU (A-PPDU):** A PPDU that contains one or more pairs of PLCP headers and PSDUs.

**HTP burst transmission:** A sequence of frames transmitted by a single high-throughput station in a single medium access. The frames may be transmitted as part of an A-PPDU, or with reduced or zero interframe spacing to enhance medium efficiency.

## 20. High throughput PHY specification for the 2.4 and 5 GHz bands

### 20.1 Overview

This clause specifies the PHY entity for a multiple input multiple output orthogonal frequency division multiplexing (MIMO-OFDM) system and the additions that have to be made to the base standard to accommodate the MIMO-OFDM PHY. The radio frequency LAN system is aimed for both the 2.4 GHz band and the 5 GHz bands, as specified in subclause 20.3.8.3

#### 20.1.1 Introduction

The MIMO-OFDM system provides a wireless LAN with mandatory data payload communication capabilities of up to 135 Mbit/s and with optional modes capable of supporting data rates up to 540 Mbit/s. The MIMO-OFDM PHY draws from the basic OFDM PHY defined in Clause 17, and builds its extensions to two, three, and four transmit antenna modes (hereafter known as 2TX, 3TX, and 4TX, respectively), operating in 20 MHz bandwidth. Additionally, 1TX, 2TX, 3TX, and 4TX modes are also defined for operation in 40 MHz bandwidth.

#### 20.1.2 Operational Modes

The radio portion of all Clause 20 compliant MIMO-OFDM PHY systems shall implement all mandatory and optional data rates defined in Clause 17, all mandatory data rates defined in Clause 19, and all optional data rates of the OFDM-based ERP defined in Clause 19, in their respective bands of operation. In addition, support for transmitting and receiving data using the MIMO-OFDM PHY defined in this Clause is mandatory for all rates specified for the 2TX, 20 MHz mode. Support for 3TX and 4TX modes in 20 MHz, and 1TX, 2TX, 3TX, and 4TX modes in 40 MHz shall be optional.

#### 20.1.3 Scope

This subclause describes the PHY services provided to the IEEE 802.11 wireless LAN MAC by the MIMO-OFDM system. The MIMO-OFDM PHY layer consists of two protocol functions, defined as follows:

- a) A PHY convergence function, which adapts the capabilities of the physical medium dependent (PMD) system to the PHY service. This function is supported by the physical layer convergence procedure (PLCP), which defines a method of mapping the IEEE 802.11 PHY sublayer service data units (PSDU) into a framing format suitable for sending and receiving user data and management information between two or more stations using the associated PMD system.
- b) A PMD system whose function defines the characteristics and method of transmitting and receiving data through a wireless medium between two or more stations, each using the MIMO-OFDM PHY.

#### 20.1.4 MIMO-OFDM PHY functions

The architecture of the MIMO-OFDM PHY is depicted in the ISO/IEC basic reference model shown in Figure 141 of 18.4.1. The MIMO-OFDM PHY contains three functional entities: the PMD function, the PHY convergence function (PLCP), and the layer management function.

The MIMO-OFDM PHY service is provided to the MAC through the PHY service primitives defined in Clause 12. Interoperability is addressed by use of the carrier sense mechanism specified in 9.2.1 and the protection mechanism in 9.10. This mechanism allows non-MIMO-OFDM stations to know of MIMO-OFDM traffic that they cannot demodulate so they may defer the medium to that traffic.

### 20.2 PHY-specific service parameter list

The architecture of the IEEE 802.11 MAC is intended to be PHY independent. Some PHY implementations require PHY-dependent MAC state machines running in the MAC sublayer in order to meet certain PMD requirements. The PHY-dependent MAC state machine resides in a sublayer defined as the MAC sublayer management entity (MLME). In certain PMD implementations, the MLME may need to interact with the PLME as part of the normal PHY SAP primitives. These interactions are defined by the PLME parameter list currently defined in the PHY service primitives as TXVECTOR and

RXVECTOR. The list of these parameters, and the values they may represent, are defined in the specific PHY specifications for each PMD. This subclause addresses the TXVECTOR and RXVECTOR for the MIMO-OFDM PHY.

The parameters in Table 001 are defined as part of the TXVECTOR parameter list in the PHY-TXSTART.request service and PLME-TXTIME.request primitives.

**Table 001—TXVECTOR parameters**

| Parameter         | Value                                                                                                                                                                                                                                                                                   |
|-------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| DATARATE          | The rate used to transmit the PSDU in Mbit/s. Allowed value depends on the values of TRANSMISSION_MODE and NUM_STREAMS parameters<br><br>Values: 6.75, 10.125, 13.5, 20.25, 27, 40.5, 54, 60.75, 81, 108, 121.5, 135, 162, 182.25, 202.5, 216, 243, 270, 324, 364.5, 405, 432, 486, 540 |
| LENGTH            | The length of the PSDU in octets<br><br>Range: 1-8191                                                                                                                                                                                                                                   |
| TRANSMISSION_MODE | The mode used for transmission of the PPDU. Determines the preamble type used.<br><br>Enumerated type: 2TX20GF, 3TX20GF, 4TX20GF, 2TX20MM, 3TX20MM, 4TX20MM, 1TX40GF, 2TX40GF, 3TX40GF, 4TX40GF, 1TX40MM, 2TX40MM, 3TX40MM, 4TX40MM.                                                    |
| NUM_STREAMS       | The number of independent spatial streams transmitted.<br><br>Values: 1, 2, 3, 4.                                                                                                                                                                                                       |
| CODE_TYPE         | Convolutional or LDPC<br><br>Values: 0 (convolutional), 1 (LDPC)                                                                                                                                                                                                                        |
| SERVICE           | The scrambler initialization vector.<br><br>16 null bits                                                                                                                                                                                                                                |
| TXPWR_LEVEL       | The transmit power level. The definition of these levels is up to the implementer.<br><br>Range: 1-8                                                                                                                                                                                    |
| LPI               | Indicates that this is the last PSDU to be aggregated into the current PPDU<br><br>Values: true, false                                                                                                                                                                                  |
| BURST_DURATION    | The length in microseconds of the BURST_DURATION field in the mixed mode preamble. Only used when a mixed mode TRANSMISSION_MODE is selected.<br><br>Range: 0-4095                                                                                                                      |

The parameters in Table 002 are defined as part of the RXVECTOR parameter list in the PHY-RXSTART.indicate service primitive. When implementations require the use of these vectors, some or all of these parameters may be used in the vectors.

**Table 002—RXVECTOR parameters**

| Parameter         | Value                                                                                                                                                                                                                                                                                        |
|-------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| DATARATE          | The rate at which the PSDU was received in Mbit/s. Allowed value depends on the values of TRANSMISSION_MODE and NUM_STREAMS parameters<br><br>Values: 6.75, 10.125, 13.5, 20.25, 27, 40.5, 54, 60.75, 81, 108, 121.5, 135, 162, 182.25, 202.5, 216, 243, 270, 324, 364.5, 405, 432, 486, 540 |
| LENGTH            | The length of the PSDU in octets.<br><br>Range: 1-8191                                                                                                                                                                                                                                       |
| TRANSMISSION_MODE | The transmission type detected during reception of the PPDU                                                                                                                                                                                                                                  |

|                |                                                                                                                                                                                       |
|----------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                | Enumerated type: 2TX20GF, 3TX20GF, 4TX20GF, 2TX20MM, 3TX20MM, 4TX20MM, 1TX40GF, 2TX40GF, 3TX40GF, 4TX40GF, 1TX40MM, 2TX40MM, 3TX40MM, 4TX40MM.                                        |
| NUM_STREAMS    | The number of independent spatial streams transmitted.<br><br>Values: 1,2,3,4.                                                                                                        |
| CODE_TYPE      | Convolutional or LDPC<br><br>Values: 0 (convolutional), 1 (LDPC)                                                                                                                      |
| SERVICE        | Null                                                                                                                                                                                  |
| RSSI           | The RSSI is a measure of the RF energy received by the MIMO-OFDM PHY, averaged across all RX antennas. The 8-bit value is in the range of 0 to RSSI maximum as described in 17.2.3.2. |
| LPI            | Indicates that this is the last PSDU to be aggregated into the current PPDU<br><br>Values: true, false                                                                                |
| BURST_DURATION | The length in microseconds of the BURST_DURATION field in the mixed mode preamble. Only valid when a mixed mode TRANSMISSION_MODE is used.<br><br>Range: 0-4095                       |

## 20.3 MIMO-OFDM PLCP sublayer

### 20.3.1 Introduction

This subclause provides a convergence procedure by which PSDUs are converted to and from PPDU at the transmitter and receiver. During transmission, the PSDU shall be appended with a PLCP preamble and header to create the PPDU. At the receiver, the PLCP preamble and header are processed to aid in the demodulation and delivery of the PSDU.

Stations implementing the MIMO-OFDM PHY shall use one of two methods of access to the medium. The medium may be reserved solely via a MAC mechanism, as defined in subclause 9.13. Alternatively, a special PLCP frame format may be used to cause non-MIMO-OFDM stations to defer the medium to MIMO-OFDM traffic. Hereafter, these two methods of access shall be known as greenfield and mixed-mode, respectively.

### 20.3.2 PLCP frame format

Figure 001 shows the format of the PPDU used with greenfield access in the 1TX mode of operation in 40 MHz and the 2TX modes of operation in both 20 and 40 MHz. The PPDU consists of a MIMO-OFDM PLCP preamble, MIMO-OFDM PLCP header, PSDU, and may consist of appended tail bits and pad bits.

The MIMO-OFDM PLCP preamble is composed of a sequence of short and long training symbols. The format of the PLCP preamble is defined in subclause 20.3.3 for each mode of operation in the MIMO-OFDM PHY.

The MIMO-OFDM PLCP header is composed of the SIGNAL-N field and the SERVICE field. The SIGNAL-N field is defined in 20.3.4 and consists of 54 bits that specify all configuration and length-related parameters associated with PPDU transmission. The SERVICE field is composed of 16 bits and is defined in subclause 20.3.5.1.

The SERVICE field of the PLCP header and the PSDU (with tail and pad bits appended, if necessary) are denoted as DATA and may constitute multiple MIMO-OFDM symbols. These symbols are transmitted according to the configuration parameters specified in the SIGNAL-N field.

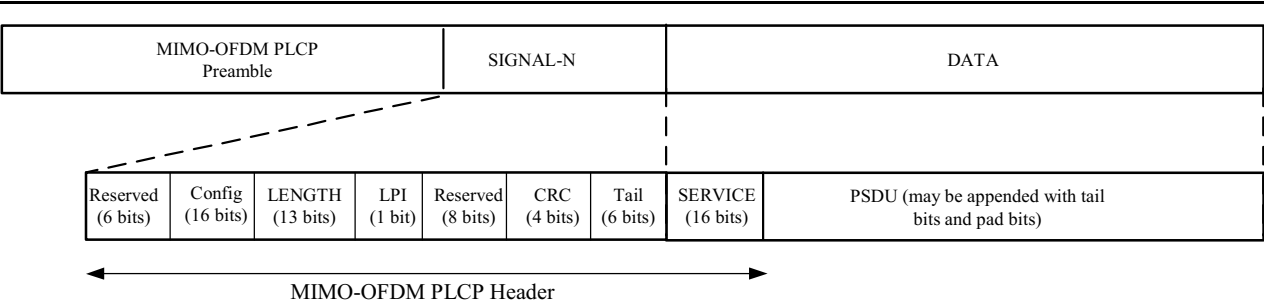


**Figure 001 – PPDU frame format: Greenfield access in the 1TX (40 MHz) and 2TX (20 and 40 MHz) modes**

Figure 002 shows the format of the PPDU used with greenfield access in the 3TX and 4TX modes of operation in both 20 and 40 MHz. In these modes the MIMO-OFDM PLCP preamble field is extended according to subclause 20.3.3 in order to provide training from the additional transmit antennas.

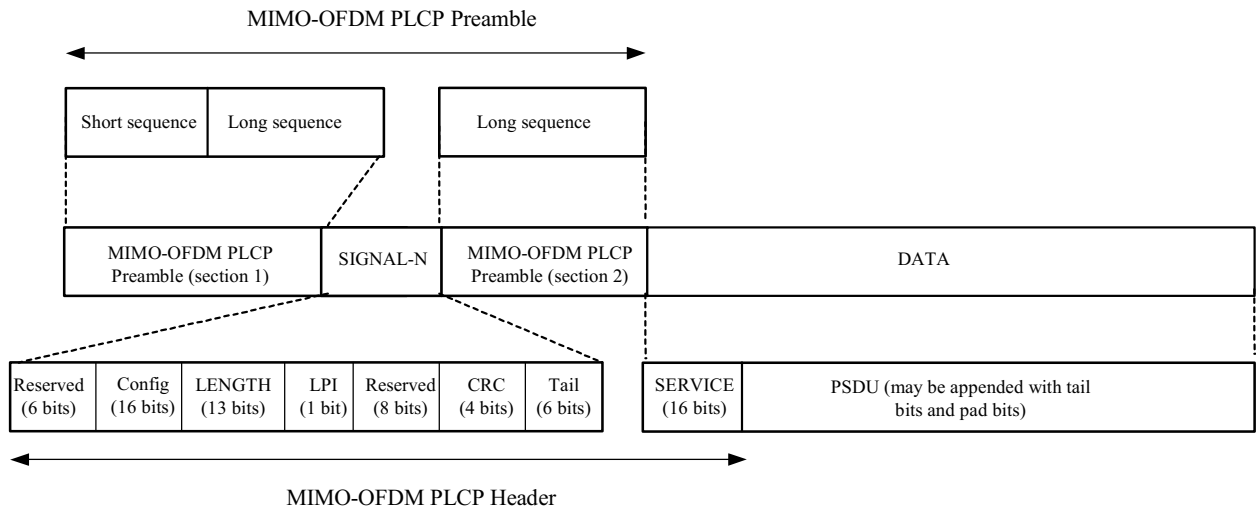


**Figure 002 – PPDU frame format: Greenfield access in the 3TX and 4TX modes (20 and 40 MHz)**

Figure 003 shows the format of the PPDU used with mixed-mode access in the 1TX mode of operation in 40 MHz and the 2TX modes of operation in both 20 and 40 MHz. The PLCP header in these modes consists of an additional SIGNAL-MM field that conveys information about the MIMO-OFDM PPDU transmission to non-MIMO-OFDM stations, causing them to defer the medium for the duration of the MIMO-OFDM transmission. The SIGNAL-MM field is defined in subclause 20.3.4.

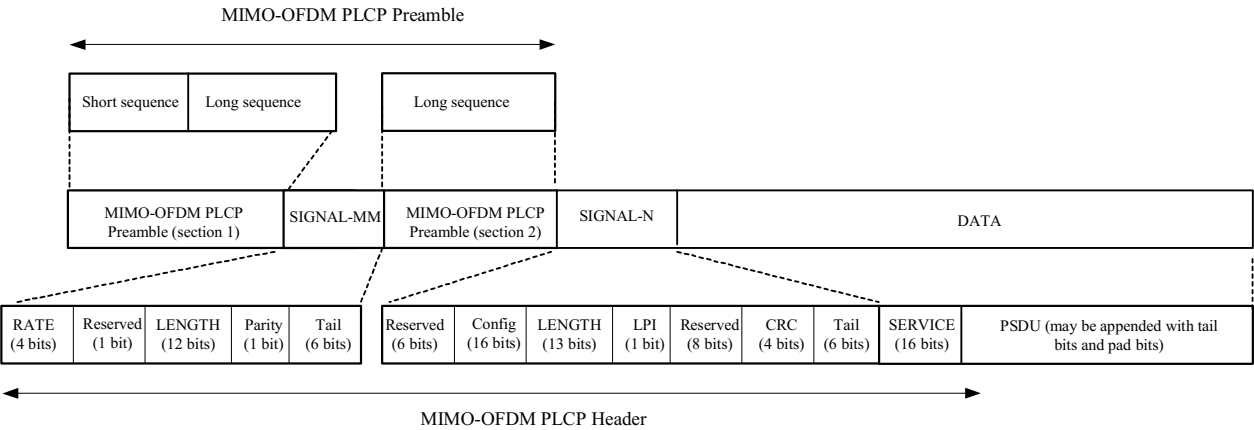


**Figure 003 – PPDU frame format: Mixed mode access in the 1TX (40 MHz) and 2TX (20 and 40 MHz) modes**

Figures 004 and 005 shows the format of the PPDU used with mixed mode access in the 3TX and 4TX modes, operating in 20 MHz and 40 MHz, respectively.

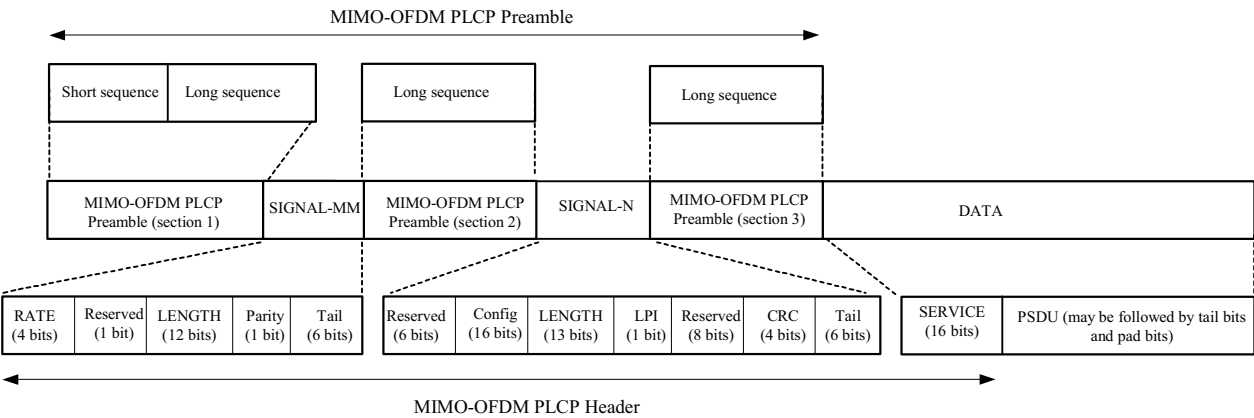


**Figure 004– PPDU frame format: Mixed mode access in the 3TX and 4TX modes (20 MHz)**

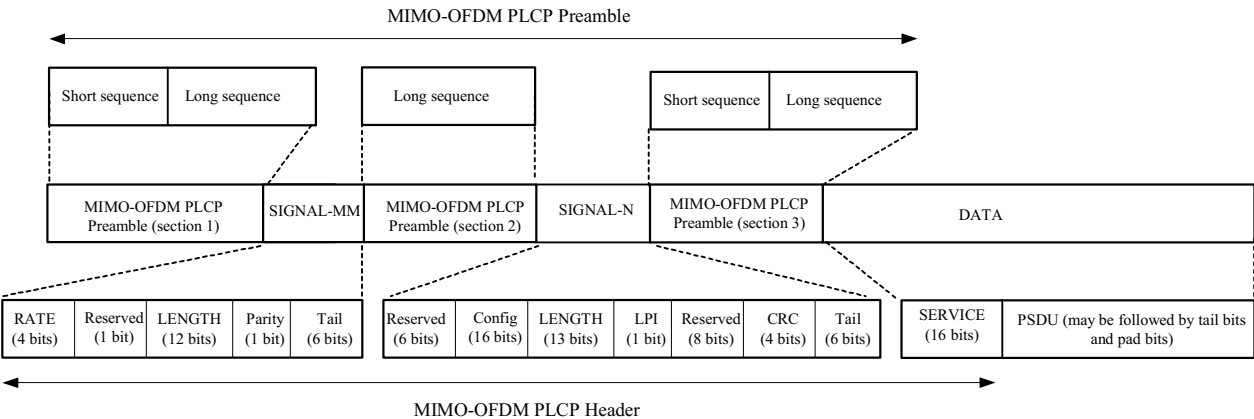


**Figure 005– PPDU frame format: Mixed mode access in the 3TX and 4TX modes (40 MHz)**

### 20.3.2.1 Overview of the PPDU encoding process

The encoding process is composed of many detailed steps, which are described fully in later subclauses, as noted below. The following overview intends to facilitate understanding the details described in these subclauses:

- a) Produce the PLCP preamble fields for each transmit antenna based on the TRANSMISSION\_MODE field of the TXVECTOR. Refer to 20.3.3 for details.
- b) Produce the PLCP header field from the LENGTH, DATARATE, TRANSMISSION\_MODE, NUM\_STREAMS, CODE\_TYPE, and SERVICE fields of the TXVECTOR by filling the appropriate bit fields, as described in subclause 20.3.4 and subclause 20.3.5.1.
- c) Calculate from the DATARATE, TRANSMISSION\_MODE, and NUM\_STREAMS fields of the TXVECTOR, the number of data bits per MIMO-OFDM symbol ( $N_{DBPS}$ ), the coding rate ( $R$ ), the number of bits in each OFDM subcarrier per antenna ( $N_{BPSC}$ ), the number of coded bits per MIMO-OFDM symbol ( $N_{CBPS}$ ), the number of spatial streams ( $N_{SS}$ ), and the number of encoding streams ( $N_{ES}$ ).
- d) Extend the data bit string with “zero” bits (at least 6 bits for each encoding stream) so that the resulting length will be a multiple of the number of data bits per OFDM symbol ( $N_{DBPS}$ ).
- e) Initiate the scrambler with a pseudorandom non-zero state; generate a sequence of scrambled data bits as defined in subclause 20.3.5.4.
- f) Demultiplex every other bit of the “data” to the  $N_{ES}$  encoding streams, with bit 0 directed to the first encoder.
- g) Replace the six scrambled “zero” bits following the “data” of each parallel encoding stream with six nonscrambled “zero” bits (These bits return the convolutional encoder to the “zero state” and are denoted as “tail bits.”).
- h) Encode each extended, scrambled parallel encoding stream data string with a convolutional encoder ( $R = 1/2$ ). Omit (puncture) some of the encoder output string (chosen according to “puncturing pattern”) to reach the desired “coding rate”, as defined in subclause 20.3.5.5.
- i) Divide the parallel encoded bit strings into groups of  $N_{CBPS} / N_{ES}$  bits and multiplex them alternately between the  $N_{ES}$  encoders’ outputs to obtain a single aggregated bit string.
- j) Divide the aggregated bit string into groups of  $N_{CBPS}$  bits. Within each group, perform an “interleaving” (reordering) of the bits according to the rule specified in subclause 20.3.5.6. The interleaving parameters are independent of  $N_{ES}$ .
- k) Divide the resulting coded and interleaved data string into groups of  $N_{BPSC}$  bits. For each of the bit groups, convert the bit group into a complex number according to the modulation encoding tables.
- l) Divide the complex number string into groups of  $N_{SD} \times N_{SS}$  complex numbers, where  $N_{SD}$  is the number of data subcarriers per OFDM symbol, and  $N_{SS}$  is the number of spatial streams to be transmitted. Map the complex numbers to antennas and subcarriers, as specified in subclause 20.3.5.8. The first  $N_{SD}$  complex numbers are modulated on the subcarriers of the first transmit antenna.
- m) Insert  $N_{SP}$  subcarriers as pilots on each transmit antenna, according to subclause 20.3.5.9.
- n) For each group of subcarriers, and on each TX antenna, convert the subcarriers to time domain using inverse Fourier transform. Prepend to the Fourier-transformed waveform a circular extension of itself thus forming a guard interval (GI), and truncate the resulting periodic waveform to a single OFDM symbol length by applying time domain windowing. Refer to 20.3.2.4 for details.
- o) Append the OFDM symbols for each antenna one after another, starting with the SIGNAL symbols defined in subclause 20.3.4, and with fields of the PLCP preamble inserted in between if necessary. Refer to 20.3.3 for details.
- p) Up-convert the resulting “complex baseband” waveform on each antenna to an RF frequency according to the center frequency of the desired channel and transmit. Refer to 20.3.2.4 and 20.3.8.1 for details.

### 20.3.2.2 RATE-dependent parameters

When the number of transmitted spatial streams  $N_{SS}$  is equal to the number of transmit antennas  $N_{TX}$ , the RATE-dependent modulation parameters shall be set according to the values defined in Tables 003, 004, and 005 respectively for the 2TX, 3TX, and 4TX modes in 20 MHz. The RATE-dependent parameters for the 1TX, 2TX, 3TX, and 4TX modes in 40 MHz shall be set according to the values defined in Tables 006, 007, 008, and 009, respectively.

The number of parallel encoding streams  $N_{ES}$  shall be 2 for all modes in 40 MHz in which the number of spatial streams  $N_{SS}$  is greater than two.  $N_{ES}$  shall be 1 for all other modes.

**Table 003—Rate-dependent parameters for 20 MHz,  $N_{SS} = 2$  ( $N_{ES} = 1$ )**

| Data rate (Mbits/s) | Modulation | Coding rate (R) | Coded bits per subcarrier per antenna ( $N_{BPSC}$ ) | Number of data subcarriers ( $N_{SD}$ ) | Number of pilots ( $N_{SP}$ ) | Coded bits per MIMO-OFDM symbol ( $N_{CBPS}$ ) | Data bits per MIMO-OFDM symbol ( $N_{DBPS}$ ) | Clause 10.4.4.2 rate code |
|---------------------|------------|-----------------|------------------------------------------------------|-----------------------------------------|-------------------------------|------------------------------------------------|-----------------------------------------------|---------------------------|
| 54                  | 16-QAM     | 1/2             | 4                                                    | 54                                      | 2                             | 432                                            | 216                                           | 73                        |
| 81                  | 16-QAM     | 3/4             | 4                                                    | 54                                      | 2                             | 432                                            | 324                                           | 74                        |
| 108                 | 64-QAM     | 2/3             | 6                                                    | 54                                      | 2                             | 648                                            | 432                                           | 75                        |
| 121.5               | 64-QAM     | 3/4             | 6                                                    | 54                                      | 2                             | 648                                            | 486                                           | 76                        |
| 135                 | 64-QAM     | 5/6             | 6                                                    | 54                                      | 2                             | 648                                            | 540                                           | 77                        |

**Table 004—Rate-dependent parameters for 20 MHz,  $N_{SS} = 3$  ( $N_{ES} = 1$ )**

| Data rate (Mbits/s) | Modulation | Coding rate (R) | Coded bits per subcarrier per antenna ( $N_{BPSC}$ ) | Number of data subcarriers ( $N_{SD}$ ) | Number of pilots ( $N_{SP}$ ) | Coded bits per MIMO-OFDM symbol ( $N_{CBPS}$ ) | Data bits per MIMO-OFDM symbol ( $N_{DBPS}$ ) | Clause 10.4.4.2 rate code |
|---------------------|------------|-----------------|------------------------------------------------------|-----------------------------------------|-------------------------------|------------------------------------------------|-----------------------------------------------|---------------------------|
| 81                  | 16-QAM     | 1/2             | 4                                                    | 54                                      | 2                             | 648                                            | 324                                           | 78                        |
| 121.5               | 16-QAM     | 3/4             | 4                                                    | 54                                      | 2                             | 648                                            | 486                                           | 79                        |
| 162                 | 64-QAM     | 2/3             | 6                                                    | 54                                      | 2                             | 972                                            | 648                                           | 80                        |
| 182.25              | 64-QAM     | 3/4             | 6                                                    | 54                                      | 2                             | 972                                            | 729                                           | 81                        |
| 202.5               | 64-QAM     | 5/6             | 6                                                    | 54                                      | 2                             | 972                                            | 810                                           | 82                        |

**Table 005—Rate-dependent parameters for 20 MHz,  $N_{SS} = 4$  ( $N_{ES} = 1$ )**

| Data rate (Mbits/s) | Modulation | Coding rate (R) | Coded bits per subcarrier per antenna ( $N_{BPSC}$ ) | Number of data subcarriers ( $N_{SD}$ ) | Number of pilots ( $N_{SP}$ ) | Coded bits per MIMO-OFDM symbol ( $N_{CBPS}$ ) | Data bits per MIMO-OFDM symbol ( $N_{DBPS}$ ) | Clause 10.4.4.2 rate code |
|---------------------|------------|-----------------|------------------------------------------------------|-----------------------------------------|-------------------------------|------------------------------------------------|-----------------------------------------------|---------------------------|
| 108                 | 16-QAM     | 1/2             | 4                                                    | 54                                      | 2                             | 864                                            | 432                                           | 83                        |
| 162                 | 16-QAM     | 3/4             | 4                                                    | 54                                      | 2                             | 864                                            | 648                                           | 84                        |
| 216                 | 64-QAM     | 2/3             | 6                                                    | 54                                      | 2                             | 1296                                           | 864                                           | 85                        |
| 243                 | 64-QAM     | 3/4             | 6                                                    | 54                                      | 2                             | 1296                                           | 972                                           | 86                        |
| 270                 | 64-QAM     | 5/6             | 6                                                    | 54                                      | 2                             | 1296                                           | 1080                                          | 87                        |

**Table 006—Rate-dependent parameters for 40 MHz,  $N_{SS} = 1$  ( $N_{ES} = 1$ )**

| Data rate (Mbits/s) | Modulation | Coding rate (R) | Coded bits per subcarrier per antenna ( $N_{BPSC}$ ) | Number of data subcarriers ( $N_{SD}$ ) | Number of pilots ( $N_{SP}$ ) | Coded bits per MIMO-OFDM symbol ( $N_{CBPS}$ ) | Data bits per MIMO-OFDM symbol ( $N_{DBPS}$ ) | Clause 10.4.4.2 rate code |
|---------------------|------------|-----------------|------------------------------------------------------|-----------------------------------------|-------------------------------|------------------------------------------------|-----------------------------------------------|---------------------------|
|---------------------|------------|-----------------|------------------------------------------------------|-----------------------------------------|-------------------------------|------------------------------------------------|-----------------------------------------------|---------------------------|

|       |        |     |   |     |   |     |     |    |
|-------|--------|-----|---|-----|---|-----|-----|----|
| 54    | 16-QAM | 1/2 | 4 | 108 | 4 | 432 | 216 | 88 |
| 81    | 16-QAM | 3/4 | 4 | 108 | 4 | 432 | 324 | 89 |
| 108   | 64-QAM | 2/3 | 6 | 108 | 4 | 648 | 432 | 90 |
| 121.5 | 64-QAM | 3/4 | 6 | 108 | 4 | 648 | 486 | 91 |
| 135   | 64-QAM | 5/6 | 6 | 108 | 4 | 648 | 540 | 92 |

**Table 007—Rate-dependent parameters for 40 MHz,  $N_{SS} = 2$  ( $N_{ES} = 1$ )**

| Data rate (Mbits/s) | Modulation | Coding rate (R) | Coded bits per subcarrier per antenna ( $N_{BPSC}$ ) | Number of data subcarriers ( $N_{SD}$ ) | Number of pilots ( $N_{SP}$ ) | Coded bits per MIMO-OFDM symbol ( $N_{CBPS}$ ) | Data bits per MIMO-OFDM symbol ( $N_{DBPS}$ ) | Clause 10.4.4.2 rate code |
|---------------------|------------|-----------------|------------------------------------------------------|-----------------------------------------|-------------------------------|------------------------------------------------|-----------------------------------------------|---------------------------|
| 108                 | 16-QAM     | 1/2             | 4                                                    | 108                                     | 4                             | 864                                            | 432                                           | 97                        |
| 162                 | 16-QAM     | 3/4             | 4                                                    | 108                                     | 4                             | 864                                            | 648                                           | 98                        |
| 216                 | 64-QAM     | 2/3             | 6                                                    | 108                                     | 4                             | 1296                                           | 864                                           | 99                        |
| 243                 | 64-QAM     | 3/4             | 6                                                    | 108                                     | 4                             | 1296                                           | 972                                           | 100                       |
| 270                 | 64-QAM     | 5/6             | 6                                                    | 108                                     | 4                             | 1296                                           | 1080                                          | 101                       |

**Table 008—Rate-dependent parameters for 40 MHz,  $N_{SS} = 3$  ( $N_{ES} = 2$ )**

| Data rate (Mbits/s) | Modulation | Coding rate (R) | Coded bits per subcarrier per antenna ( $N_{BPSC}$ ) | Number of data subcarriers ( $N_{SD}$ ) | Number of pilots ( $N_{SP}$ ) | Coded bits per MIMO-OFDM symbol ( $N_{CBPS}$ ) | Data bits per MIMO-OFDM symbol ( $N_{DBPS}$ ) | Clause 10.4.4.2 rate code |
|---------------------|------------|-----------------|------------------------------------------------------|-----------------------------------------|-------------------------------|------------------------------------------------|-----------------------------------------------|---------------------------|
| 162                 | 16-QAM     | 1/2             | 4                                                    | 108                                     | 4                             | 1296                                           | 648                                           | 102                       |
| 243                 | 16-QAM     | 3/4             | 4                                                    | 108                                     | 4                             | 1296                                           | 972                                           | 103                       |
| 324                 | 64-QAM     | 2/3             | 6                                                    | 108                                     | 4                             | 1944                                           | 1296                                          | 104                       |
| 364.5               | 64-QAM     | 3/4             | 6                                                    | 108                                     | 4                             | 1944                                           | 1458                                          | 105                       |
| 405                 | 64-QAM     | 5/6             | 6                                                    | 108                                     | 4                             | 1944                                           | 1620                                          | 106                       |

**Table 009—Rate-dependent parameters for 40 MHz,  $N_{SS} = 4$  ( $N_{ES} = 2$ )**

| Data rate (Mbits/s) | Modulation | Coding rate (R) | Coded bits per subcarrier per antenna ( $N_{BPSC}$ ) | Number of data subcarriers ( $N_{SD}$ ) | Number of pilots ( $N_{SP}$ ) | Coded bits per MIMO-OFDM symbol ( $N_{CBPS}$ ) | Data bits per MIMO-OFDM symbol ( $N_{DBPS}$ ) | Clause 10.4.4.2 rate code |
|---------------------|------------|-----------------|------------------------------------------------------|-----------------------------------------|-------------------------------|------------------------------------------------|-----------------------------------------------|---------------------------|
| 216                 | 16-QAM     | 1/2             | 4                                                    | 108                                     | 4                             | 1728                                           | 864                                           | 109                       |
| 324                 | 16-QAM     | 3/4             | 4                                                    | 108                                     | 4                             | 1728                                           | 1296                                          | 110                       |
| 432                 | 64-QAM     | 2/3             | 6                                                    | 108                                     | 4                             | 2592                                           | 1728                                          | 111                       |
| 486                 | 64-QAM     | 3/4             | 6                                                    | 108                                     | 4                             | 2592                                           | 1944                                          | 112                       |
| 540                 | 64-QAM     | 5/6             | 6                                                    | 108                                     | 4                             | 2592                                           | 2160                                          | 113                       |

**20.3.2.3 Timing related parameters**

Table 010 is a list of timing parameters associated with the MIMO-OFDM PLCP.

**Table 010—Timing-related parameters**

| Parameter                                          | Value (20 MHz modes) | Value (40 MHz modes) | Remarks                    |
|----------------------------------------------------|----------------------|----------------------|----------------------------|
| $N_{SD}$ : Number of data subcarriers              | 54                   | 108                  |                            |
| $N_{SP}$ : Number of pilot subcarriers             | 2                    | 4                    |                            |
| $N_{ST}$ : Number of subcarriers, total            | 56                   | 112                  | $N_{ST} = N_{SD} + N_{SP}$ |
| $N_{OT}$ : Index of outermost populated subcarrier | 28                   | 58                   |                            |

|                                            |             |             |                                 |
|--------------------------------------------|-------------|-------------|---------------------------------|
| $N_{TX}$ : Number of transmit antennas     | 2,3,4       | 1,2,3,4     |                                 |
| $\Delta_F$ : Subcarrier frequency spacing  | 0.3125 MHz  | 0.3125 MHz  | $\Delta_F = 20/64 = 40/128$ MHz |
| $T_{FFT}$ : IFFT/FFT period                | 3.2 $\mu$ s | 3.2 $\mu$ s | $T_{FFT} = 1/\Delta_F$          |
| $T_{GI}$ : GI duration                     | 0.8 $\mu$ s | 0.8 $\mu$ s | $(T_{FFT}/4)$                   |
| $T_{GI2}$ : Training symbol guard duration | 1.6 $\mu$ s | 1.6 $\mu$ s |                                 |
| $T_{SYM}$ : Symbol interval                | 4 $\mu$ s   | 4 $\mu$ s   | $(T_{GI} + T_{FFT})$            |

#### 20.3.2.4 Mathematical conventions in the signal descriptions

The transmitted signal will be described in a complex baseband signal notation. The RF (radio frequency) signal issued from the antenna is related to the complex baseband signal by the following relation:

$$r_{RF}(t) = \text{Re}\{r(t) \exp(j2\pi f_c t)\} \quad (1)$$

where  $\text{Re}(\cdot)$  represents the real part of the complex argument, and  $f_c$  denotes the carrier frequency. The actual RF signal over the air is the sum of RF signals emanated from each transmit antenna.

The transmitted baseband signal from any antenna is composed of contributions from several OFDM symbols, including preamble, signal, and data. Each symbol is constructed as an inverse Fourier transform of a set of coefficients  $C_k$ , with  $C_k$  defined later as data, pilots, or training symbols in subclause 20.3.3 through 20.3.5:

$$r_{SYMBOL}(t) = w_{SYMBOL}(t) \sum_{k=-N_{OT}}^{N_{OT}} C_k \exp(j2\pi k \Delta_F (t - T_{GUARD})). \quad (2)$$

The parameters  $\Delta_F$  and  $N_{OT}$  are defined in Table 010. The resulting waveform is periodic with a period of  $T_{FFT} = 1/\Delta_F$ . Shifting the time by  $T_{GUARD}$  creates the "cyclic prefix" used in OFDM to avoid ISI from the previous symbol. Three kinds of  $T_{GUARD}$  are defined: for the short training sequence ( $= 0\mu$ s), for the long training sequence ( $= T_{GI2}$ ), and for data OFDM symbols ( $= T_{GI}$ ). Informative considerations related to the windowing function  $w_{SYMBOL}(t)$  and other implementation aspects, as specified in subclause 17.3.2.4, may also apply on a per-antenna basis in the MIMO-OFDM PHY.

The common way to implement the inverse Fourier transform, as shown in Equation (2), is by an inverse Fast Fourier Transform (IFFT) algorithm. If, for example, a 128-point IFFT is used to implement the 40 MHz transmission modes, the coefficients 3 to 58 are mapped to the same numbered IFFT inputs, while the coefficients -58 to -3 are copied into IFFT inputs 70 to 125. The rest of the inputs, 59 to 69, 1, 2, 126, 127, as well as the 0 (dc) input, shall be set to zero. This mapping is illustrated in Figure 006. After performing an IFFT, the output is cyclically extended to the desired length.

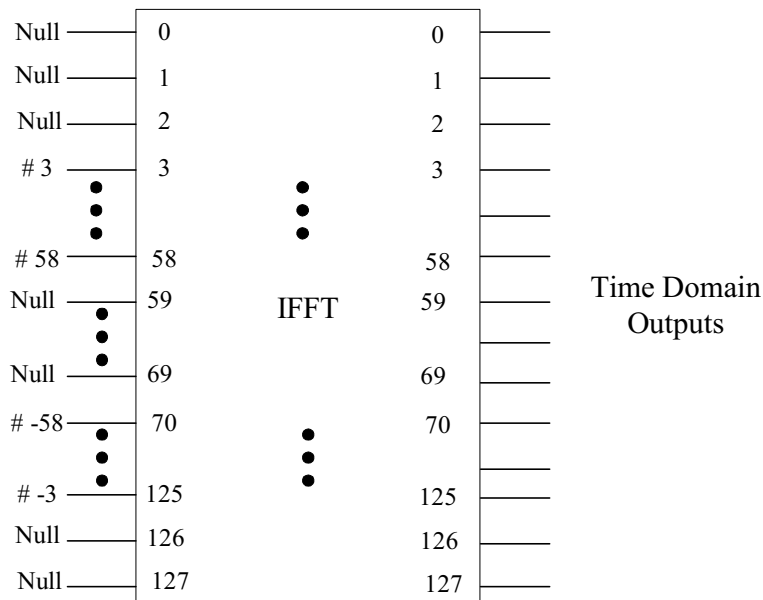


**Figure 006– Inputs and outputs of 128-point IDFT for 40 MHz data transmission**

### 20.3.3 PLCP preamble (SYNC)

The PLCP preamble field is used for synchronization. It consists of a sequence of short symbols and long symbols that are transmitted simultaneously from all transmit antennas, as described in this subclause.

Figure 007 shows the PLCP preamble format for greenfield 2TX mode in 20 MHz. The PLCP preamble is followed in this mode by the SIGNAL-N field and DATA. The total duration of the training symbols is 16  $\mu\text{s}$ . The short MIMO-OFDM training sequence transmitted from the first antenna consists of 12 subcarriers, which are modulated by elements of the sequence  $\text{SS}_{20}$ , given by

$$\begin{aligned} \text{SS}_{20}[-28,28] = \sqrt{7/3} \times \{ & 0, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, 0, 0, 0, 0, -1-j, \\ & 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 0, 0\}. \end{aligned} \quad (3)$$

The second antenna transmits a cyclically shifted version of the sequence transmitted from the first antenna, such that the first sample of the short sequence transmitted from the second antenna is the sample that is transmitted 400 nsec after the start of the short sequence on the first antenna. This is denoted by “(400 ns cs)” in Figure 007. More generally, an indicator “S (x ns cs)” in Figures 007 through 016 denotes that the transmitted sequence is obtained by cyclically shifting by x nsec, the time-domain sequence corresponding to frequency domain sequence S. The indicator “GI” or “GI2” in these figures denotes respectively the last  $T_{GI}$  or  $T_{GI2}$  duration of waveform of the immediately ensuing OFDM symbol, prepended to the OFDM symbol as a guard interval.

The short sequence is followed by a long OFDM training sequence which is generated by modulating the elements of the sequence

$$\text{LS}_{20}[-28..28] = \{1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 0, 1, -1, -1, 1, 1, -1, 1, -1, 1, -1, -1, -1, -1, 1, 1, -1, -1, 1, -1, 1, -1, 1, 1, 1, -1, -1\} \quad (4)$$

according to the equation

$$r_{LONG}(t) = w_{TLONG}(t) \sum_{k=-N_{cr}/2}^{N_{ST}/2} LS_{20}[k] \exp(j2\pi k \Delta_F (t - T_{GI2})) \quad (5)$$

where  $T_{GI2} = 1.6 \mu\text{sec}$ . Two periods of the long symbol are transmitted for improved channel estimation accuracy. The long training sequence is also transmitted simultaneously from both antennas. The second antenna transmits a 1600 nsec cyclically shifted version of the long training symbols transmitted from the first antenna.

The PLCP preamble format for 2TX mixed-mode operation in 20 MHz is shown in Figure 008. The definition of the long and short sequences, as well as relative cyclic shifts between transmit antennas in this mode shall follow the description provided in Figure 008. The first and second TX antennas simultaneously transmit the first and second rows respectively of the MIMO-OFDM training structure shown in the figure.

Figure 009 and 010 define the PLCP preamble format for the 3TX and 4TX modes in 20 MHz, with greenfield access and mixed-mode access respectively. In the 3TX modes, only the first three rows shown in the corresponding MIMO-OFDM training structure are transmitted.

Figures 011, 013, and 015 show the PLCP preamble format for the 1TX, 2 TX, and 3TX/4TX greenfield modes in 40 MHz. The short sequence in these modes are obtained by modulating the elements of the sequence

$$\text{SS}_{40\text{GF}}[-58,58] = \sqrt{2} \times \{0, 0, -1j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, \\ 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, \\ 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, \\ 0, -1-j, 0, 0\}$$

(6)

on the subcarriers of the OFDM signal. The ensuing long sequence for 40 MHz greenfield operation is defined by the sequence

$$\text{LS}_{40\text{GF}}[-58..58] = \{1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, -1, 1, -1, -1, 1, 1, -1, 1, -1, 1, -1, 1, -1, 1, 1, 1, -1, -1, -1, -1, 1, 1, -1, -1, 1, -1, 1, -1, 1, 1, 1, 1, 1, 1, 1, -1, -1, 1, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, -1, -1, -1, -1, 1, 1, -1, -1, 1, -1, 1, -1, 1, 1, 1, 1, -1, -1\}. \quad (7)$$

The mixed mode training structures for 1TX, 2TX, and 3TX/4TX modes in 40 MHz are defined in Figure 012, 014, and 016 respectively. The additional short and long sequences used in these modes are defined by the following frequency domain sequences:

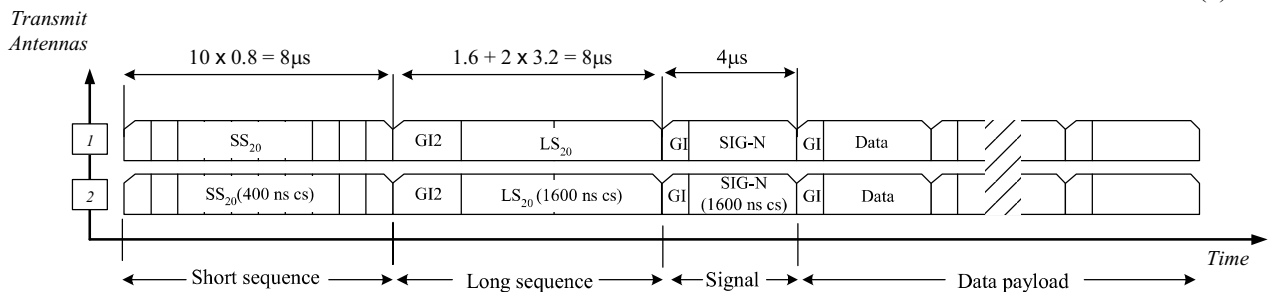
$$SS_{40MM}[-58..58] = \sqrt{7/3} \times \{0, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 0, 1+j, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 0\}, \quad (8)$$
$$\text{LS}_{40\text{MM}}[-58..58] = \{1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 0, 1, -1, -1, 1, 1, -1, 1, -1, 1, -1, -1, -1, 1, 1, -1, -1, 1, -1, 1, -1, 1, 1, 1, 1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 1, 1, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 1, -1, -1, 1, -1, 1, -1, 1, 1, 1, 1, 1, -1, -1, 1, -1, 1, -1, 1, -1, 1, -1, 1, -1, 1, -1, 1, 1, 0, 1, -1, -1, 1, 1, -1, 1, -1, -1, -1, -1, 1, 1, -1, -1, 1, -1, 1, -1, 1, 1, 1, -1, -1\}. \quad (9)$$


**Figure 007 – MIMO-OFDM Training structure for  $N_{TX} = 2$ , 20 MHz, greenfield operation**

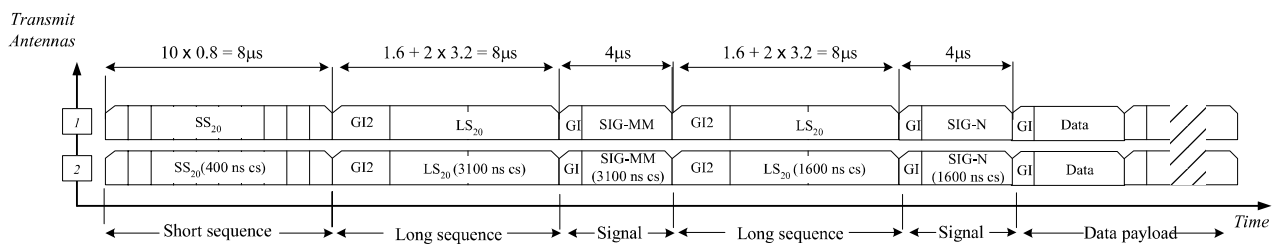


**Figure 008 – MIMO-OFDM Training structure for  $N_{TX} = 2$ , 20 MHz, mixed mode operation**

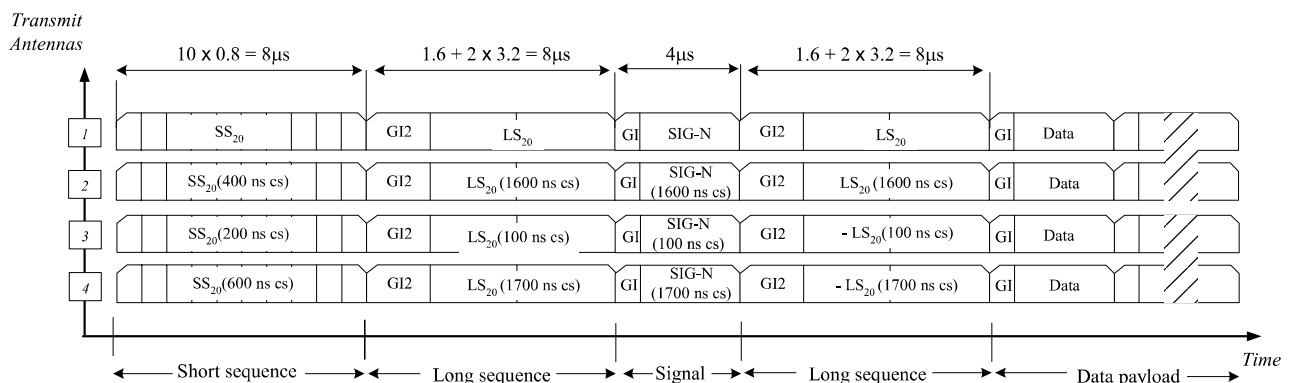


**Figure 009 – MIMO-OFDM Training structure for  $N_{TX} = 3$  and 4, 20 MHz, greenfield operation**

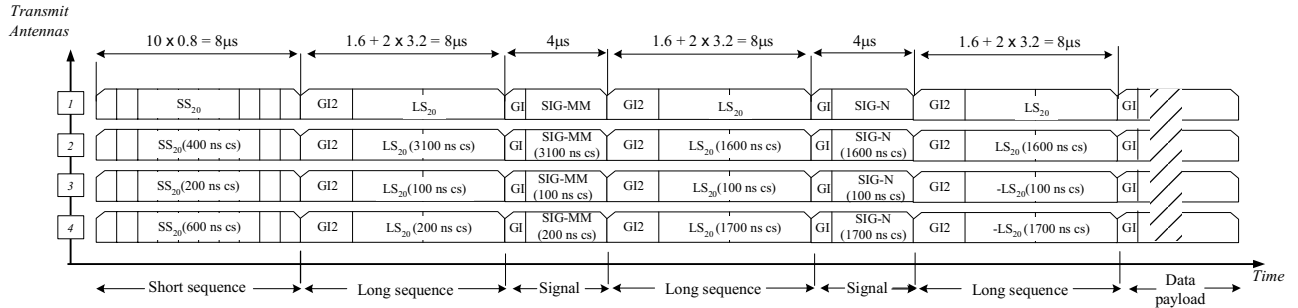


**Figure 010 – MIMO-OFDM Training structure for  $N_{TX} = 3, 4, 20$  MHz, mixed mode operation**

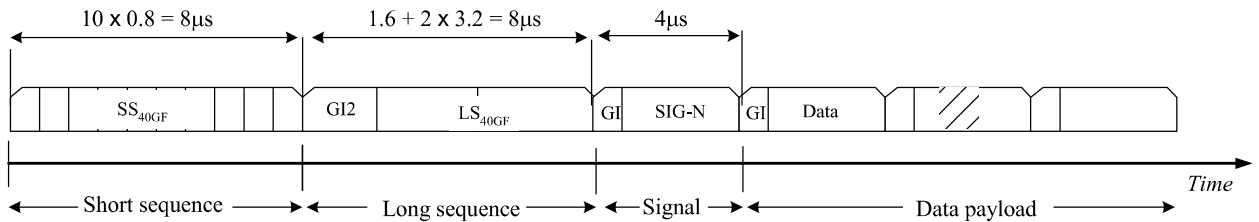


**Figure 011 – MIMO-OFDM Training structure for  $N_{TX}=1$ , 40 MHz, greenfield operation**

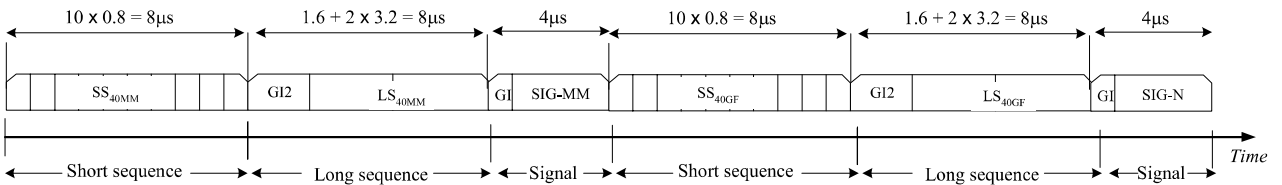


**Figure 012 – MIMO-OFDM Training structure for  $N_{TX}=1$ , 40 MHz, mixed mode operation**

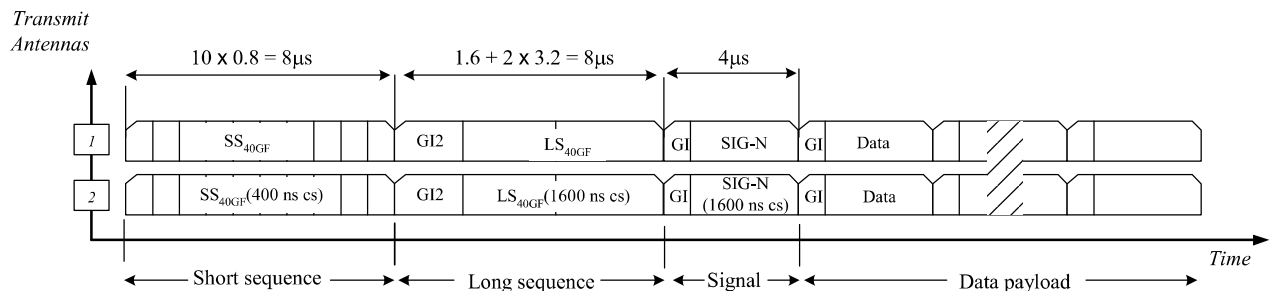


**Figure 013 – MIMO-OFDM Training structure for  $N_{TX} = 2$ , 40 MHz, greenfield operation**

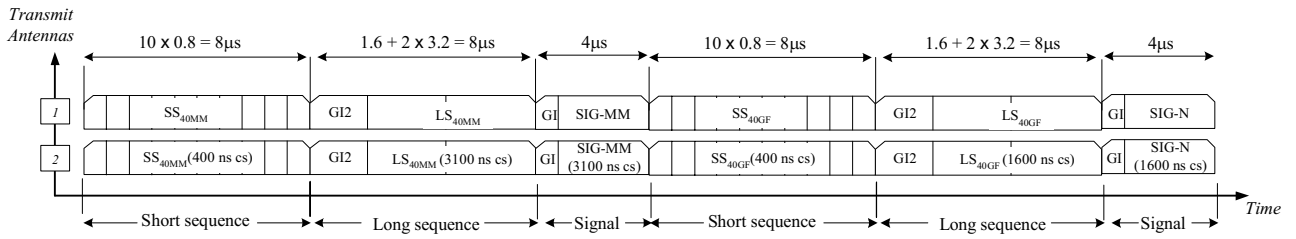


**Figure 014 – MIMO-OFDM Training structure for  $N_{TX} = 2$ , 40 MHz, mixed mode operation**

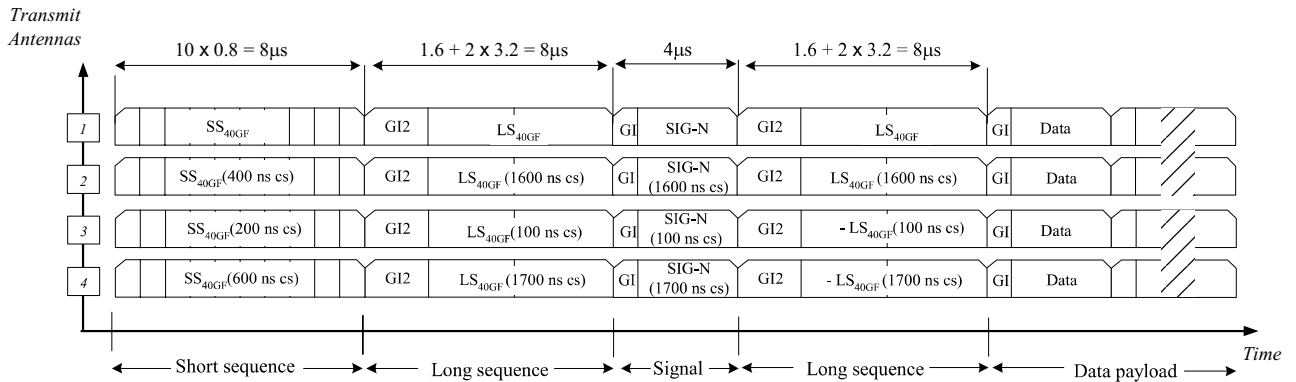


**Figure 015 – MIMO-OFDM Training structure for  $N_{TX} = 3$  and 4, 40 MHz, greenfield operation**

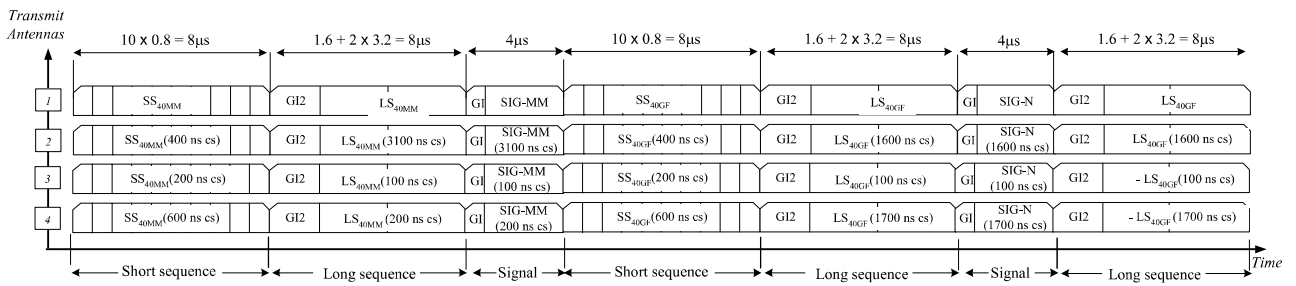


**Figure 016 – MIMO-OFDM Training structure for  $N_{TX} = 3, 4$ , 40 MHz, mixed mode operation**

### 20.3.4 Signal fields (SIG-N and SIG-MM)

The SIGNAL-N field (SIG-N) is composed of a single MIMO-OFDM symbol that provides all length and configuration parameters associated with a MIMO-OFDM PPDU. The SIGNAL-N field is composed of 54 bits, which shall be interpreted according to the bit assignment specified in Figure 017 and Table 011.

**Table 011—SIG-N field bit assignment**

| Bits      | Field  | Subfield | Parameter                   | Values                                        |
|-----------|--------|----------|-----------------------------|-----------------------------------------------|
| b0 : b5   | RSVD   |          | Reserved bits               | 111111, Bits shall be ignored at the receiver |
| b6 : b21  | CONFIG |          | Configuration               |                                               |
| b6: b8    |        | NSS      | Number of spatial streams   | 000: 1, 001: 2, 010: 3, 011: 4                |
| b9 : b11  |        | NTX      | Number of transmit antennas | 000: 1, 001: 2, 010: 3, 011: 4                |
| b12 : b13 |        | BW       | Bandwidth                   | 00: 20 MHz, 01: 40 MHz                        |
| b14: b16  |        | CR       | Code rate                   | 000: 1/2, 001: 2/3, 010: 3/4, 011: 5/6        |

|           |      |     |                         |                                                                               |
|-----------|------|-----|-------------------------|-------------------------------------------------------------------------------|
| b17 : b18 |      | CT  | ECC type                | 00 : convolutional, 01 : LDPC                                                 |
| b19 : b21 |      | CON | Constellation type      | 000: BPSK, 001: QPSK, 010: 16-QAM, 011: 64-QAM                                |
| b22 : b34 | LEN  |     | Length                  | Number of bytes in the payload                                                |
| b35       | LPI  |     | Last PSDU indicator     | 1 indicates that this is the last PSDU to be aggregated into the current PPDU |
| b36 : b43 | RSVD |     | Reserved                | 00000000, Bits shall be ignored at the receiver                               |
| b44 : b47 | CRC  |     | Cyclic Redundancy Check | CRC calculated on bits 0-43 using generator polynomial $x^4+x+1$              |
| b48 : b53 | TAIL |     |                         | 000000                                                                        |

In all 20 MHz modes, the encoding of the single SIG-N MIMO-OFDM symbol shall be performed with QPSK modulation of the subcarriers of the first antenna and shall use convolutional coding at  $R = 1/2$ . In all 40 MHz modes, the encoding of the single SIG-N MIMO-OFDM symbol shall be performed with BPSK modulation of the subcarriers of the first antenna and shall use convolutional coding at  $R = 1/2$ . The contents of the SIG-N field are not scrambled.

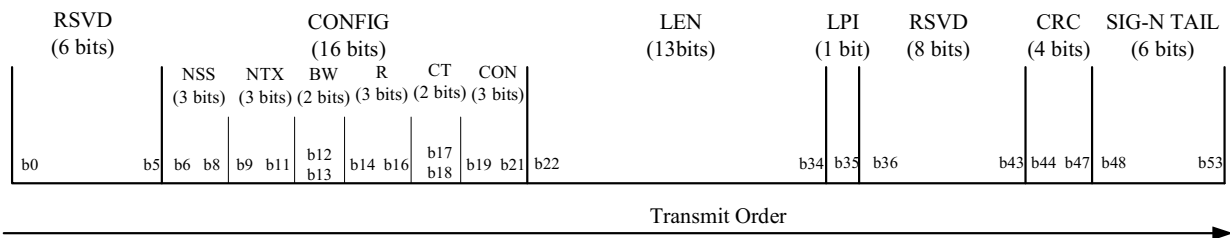


**Figure 017 – SIG-N field bit assignment**

The SIG-N MIMO-OFDM symbol is transmitted simultaneously from all TX antennas in all modes, with the same values of relative cyclic shift between antennas as are used to transmit the long training symbol preceding the SIG-N symbol. The value of the cyclic shift in each operating mode is specified in Figures 007 through 016 in subclause 20.3.3.

With mixed-mode access, another symbol, denoted as SIGNAL-MM (SIG-MM) is sent in the PLCP header. The SIG-MM field is encoded and transmitted from the first antenna as per IEEE 802.11a-1999 subclause 17.3.4. The remaining antennas simultaneously transmit the same OFDM symbol, with relative cyclic shifts defined in subclause 20.3.3. The reserved bit in the SIG-MM field shall be set to signal a MIMO-OFDM PPDU transmission. The duration for which the medium will be used by the MIMO-OFDM PPDU transmission is signaled to non MIMO-OFDM stations via the LENGTH and RATE fields of the SIG-MM symbol.

In 40 MHz mixed-mode operation, the SIG-MM field shall be transmitted such that it can be decoded by non-MIMO-OFDM stations operating in either the upper or the lower 20 MHz band.

### 20.3.5 DATA field

The DATA field contains the SERVICE field, the PSDU, the TAIL bits, and the PAD bits, if needed, as described in 20.3.5.2 and 20.3.5.4. All bits in the DATA field except the TAIL bits are scrambled, as described in 20.3.5.4.

#### 20.3.5.1 Service field (SERVICE)

The IEEE 802.11 SERVICE field has 16 bits, which shall be denoted as bits 0-15. The bit 0 shall be transmitted first in time. The bits 0-6 of the SERVICE field, which are transmitted first, are set to zeros and are used to synchronize the descrambler in the receiver. The remaining 9 bits (7-15) of the SERVICE field shall be reserved for future use. All reserved bits shall be set to zero. Refer to Figure 112, IEEE 802.11a-1999 subclause 17.3.5.1.

#### 20.3.5.2 PPDU tail bits

The PPDU tail bits shall follow IEEE 802.11a-1999 subclause 17.3.5.2.

### 20.3.5.3 PAD bits

The number of bits in the DATA field shall be a multiple of  $N_{CBPS}$ , the number of coded bits in an OFDM symbol. To achieve that, the length of the message is extended so that it becomes a multiple of  $N_{DBPS}$ , the number of data bits per OFDM symbol. At least 6 bits per encoding stream ( $N_{ES}$ ) are appended to the message, in order to accommodate the TAIL bits, as described in 20.3.5.2. The number of MIMO-OFDM symbols,  $N_{SYM}$ ; the number of bits in the DATA field,  $N_{DATA}$ ; and the number of pad bits,  $N_{PAD}$ , are computed from the length of the PSDU (LENGTH) as follows:

$$N_{SYM} = \text{Ceiling}((16 + 8 \times \text{LENGTH} + 6 \times N_{ES})/N_{DBPS}) \quad (10)$$

$$N_{DATA} = N_{SYM} \times N_{DBPS} \quad (11)$$

$$N_{PAD} = N_{DATA} - (16 + 8 \times \text{LENGTH} + 6 \times N_{ES}) \quad (12)$$

The appended bits ("pad bits") are set to "zeros" and are subsequently scrambled with the rest of the bits in the DATA field.

### 20.3.5.4 PLCP data scrambler and descrambler

The PPDU data scrambler and descrambler shall follow IEEE 802.11a-1999 subclause 17.3.5.4.

### 20.3.5.5 Convolutional encoder

The DATA field, composed of SERVICE, PSDU, tail, and pad parts, shall be coded with a convolutional encoder that conforms to IEEE 802.11a-1999 subclause 17.3.5.5 for code rates of  $R = 1/2$ ,  $2/3$ , and  $3/4$ . Additionally, the code rate of  $R = 5/6$  shall be implemented according to the puncturing pattern illustrated in Figure 018.

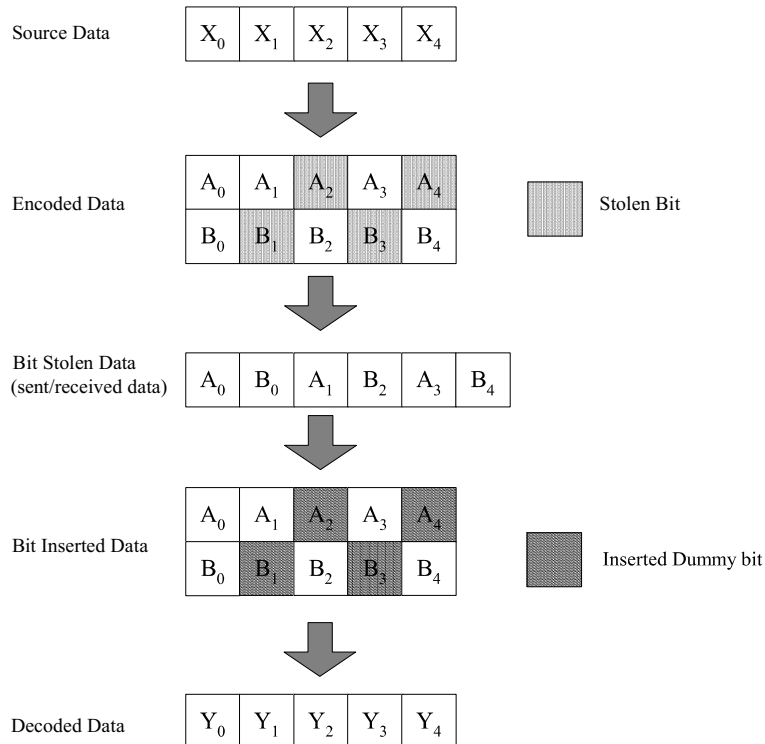


**Figure 018 – An illustration of the bit stealing and bit insertion procedure for  $R = 5/6$**

### 20.3.5.6 Interleaver

All encoded bits shall be interleaved by a block interleaver with a block size equal to the number of bits in a single MIMO-OFDM symbol,  $N_{CBPS}$ . The interleaver is defined by the following series of permutations.

We shall denote by  $k$  the index of the coded bits before interleaving,  $k = 0, 1 \dots N_{CBPS}-1$ .  $n = 0, 1 \dots N_{SS}-1$  denotes the index of the spatial streams. The bits are first distributed across spatial streams by inputting the bit with index  $k_n \times N_{SS} + n$  into the  $n$ th spatial stream. This is illustrated in Figure 019.

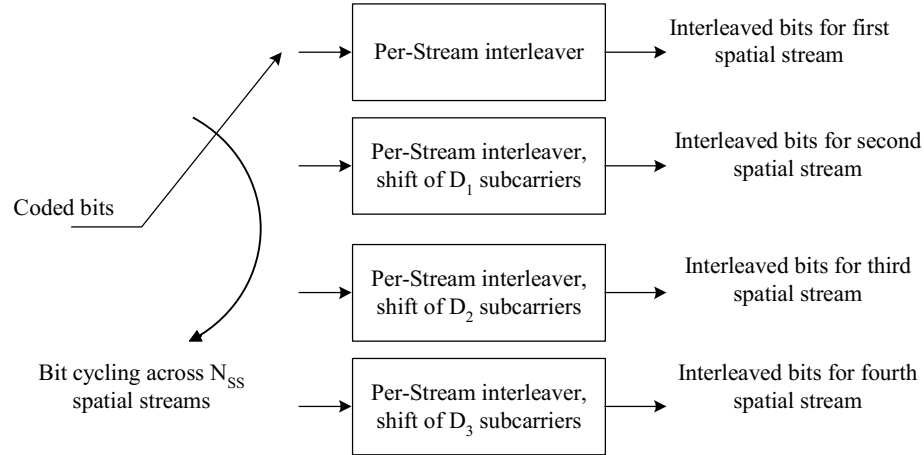


**Figure 019 – Illustration of the interleaver function**

The interleaver for spatial stream  $n$  within its block of  $N_{CBPS}/N_{SS}$  bits is defined by the following relations.

$$k = k_n \times N_{SS} + n$$

$$i = ((N_{CBPS}/N_{SS})/I_{DEPTH}) (k_n \bmod I_{DEPTH}) + \text{floor}(k_n/I_{DEPTH})$$

$$k_n = 0, 1 \dots (N_{CBPS}/N_{SS})-1$$

$$j = s \times \text{floor}(i/s) + (i + N_{CBPS}/N_{SS} - \text{floor}(I_{DEPTH} \times i / (N_{CBPS}/N_{SS}))) \bmod s$$

$$s = \max(N_{BPS}/2, 1)$$

$$j_n = (j + N_{CBPS}/N_{SS} - 2sD_n) \bmod (N_{CBPS}/N_{SS}). \quad (13)$$

The parameter  $D_n$  which denotes the shift in subcarriers for spatial stream  $n$  is given by

$$D_n = 5n. \quad (14)$$

The interleaving depth  $I_{DEPTH}$  shall conform to the values given in Table 012.

**Table 012—Interleaving parameters**

| $N_{SS}$   | $N_{SD}$ | $I_{DEPTH}$ |
|------------|----------|-------------|
| 1, 2, 3, 4 | 54       | 6           |
| 2,3,4      | 108      | 6           |
| 1          | 108      | 12          |

The deinterleaver, which performs the inverse relation, is defined by the following series of permutations.

$$k_d = \text{mod}(k_n + N_{CBPS}/N_{SS} + 2sD_n) \bmod (N_{CBPS}/N_{SS})$$

$$i_d = s \text{ floor}(k_d/s) + (k_d + \text{floor}(I_{DEPTH} \times k_d / (N_{CBPS}/N_{SS}))) \bmod s$$

$$j_{dn} = I_{DEPTH} \times i_d - ((N_{CBPS}/N_{SS}) - 1) \times \text{floor}(I_{DEPTH} \times i_d / (N_{CBPS}/N_{SS})). \quad (15)$$

where  $s$  and  $D_n$  are as defined for the interleaver.

### 20.3.5.7 Low density parity check codes (optional ECC)

This subclause describes the LDPCCs to be optionally used in the MIMO-OFDM system as high-performance ECC technique, instead of the convolutional code (20.3.5.5). The rate-dependent parameters in subclause 20.3.2.2 shall still apply.

When this subclause applies, the following clauses are to be considered no more applicable:

- 20.3.2.1: changes needed, as described in 20.3.5.7.3;
- 20.3.5.2: not used;
- 20.3.5.3: replaced by 20.3.5.7.3;
- 20.3.5.5: replaced by 20.3.5.7.4;
- 20.3.5.6: not used.

#### 20.3.5.7.1 LDPC Code Rates and Block Sizes

The supported code rates, information block size, and coded block size are described in Table 013.

**Table 013— LDPC parameters**

| Coding rate (R) | LDPC information bits (bits) | LDPC codeword length (bits) |
|-----------------|------------------------------|-----------------------------|
| 1/2             | 972                          | 1944                        |
| 2/3             | 1296                         | 1944                        |
| 3/4             | 1458                         | 1944                        |
| 5/6             | 1620                         | 1944                        |

#### 20.3.5.7.3 LDPC PPDU encoding process

a) Produce the PLCP preamble fields for each transmit antenna based on the TRANSMISSION\_MODE field of the TXVECTOR. Refer to 20.3.3 for details.

b) Produce the PLCP header field from the LENGTH, DATARATE, and SERVICE fields of the TXVECTOR by filling the appropriate bit fields, as described in subclause 20.3.4 and subclause 20.3.5.1.

c) Compute the integer number of LDPC codewords to be transmitted,  $L_1$ , and the possible remainder  $K_1$ .

$$L_1 = \text{ceil}((\text{LENGTH} \times 8 + 16)/1944/R),$$

$$K_1 = \text{rem}((\text{LENGTH} \times 8 + 16), 1944 \times R). \quad (16)$$

d) If  $K_1 > 0$  compute the number of zeros for padding in order to encode the last codeword as

$$N_{PI} = 1944 \times R - K_1. \quad (17)$$

These bits will not be transmitted nor scrambled. If  $K_1 > 0$ , the last frame has an effective information frame (i.e. information frame excluding padded zeros) of size  $K_1$ , generally less than  $k$ . The last codeword includes a fixed number of parity bits equal to  $p = (1944 - k)$ . This implies the code rate for the last codeword is different from the overall target code rate and is given by:

$$\frac{K_1}{K_1 + (1944 - k)}. \quad (18)$$

e) Compute the number of coded bits to be transmitted (including the shortened codeword) as

$$L_2 = \begin{cases} 1944 \times L_1, & K_1 = 0 \\ 1944 \times L_1 + 1944 \times (1 - R) + K_1, & K_1 \neq 0 \end{cases} \quad (19)$$

f) Compute the integer number of MIMO-OFDM symbols  $N_{S1}$  and the possible reminder  $R_{S1}$ :

$$N_{S1} = \text{ceil}(L_2 / N_{CBPS}),$$

$$R_{S1} = \text{rem}(L_2, N_{CBPS}). \quad (20)$$

g) If  $R_{S1} > 0$  append  $N_{P2}$  zeros to info bits in order to fill an integer number of MIMO-OFDM symbols

$$N_{P2} = N_{CBPS} - R_{S1}. \quad (21)$$

h) The service field at the beginning of the resulting sequence is used to initialize a scrambler, which is then used to scramble the rest of the sequence including the zeros appended in step g).

k) The resulting PSDU is then coded by the LDPC at the proper code rate ( $R$ ) and block size (i.e. 1944 bits for all frames). The last codeword is encoded extending the info bits with  $N_{P1}$  zeros; these  $N_{P1}$  bits are not transmitted. The last  $N_{P2}$  bits are not encoded.

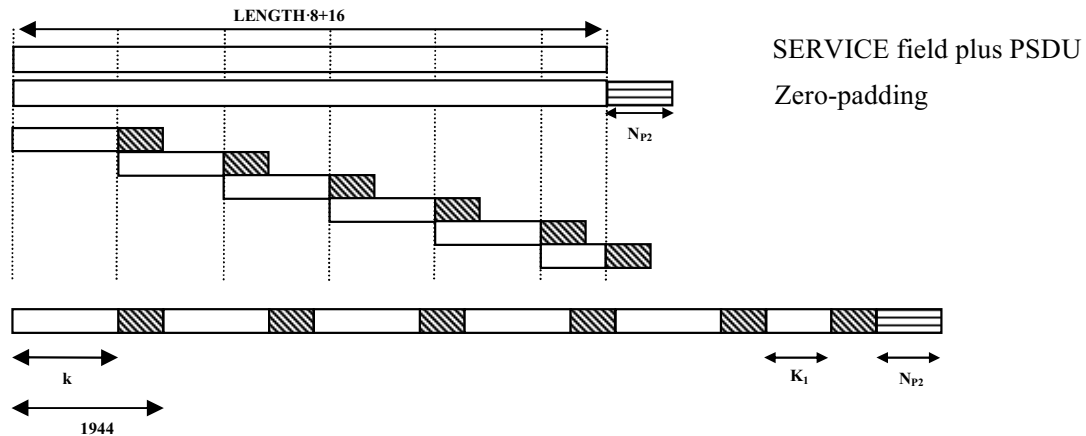


Figure 020 – LDPC PPDU encoding

#### 20.3.5.7.4 LDPC Encoder

A characteristic feature of the considered LDPCs is that combining rows of the parity-check matrix ( $\mathbf{H}$ ) for the lowest rate code produces  $\mathbf{H}$  for higher rates. This is equivalent to replacing a group of check nodes with a single check node that sums all the edges coming into each of the original check nodes. Direct consequences are that all code rates have the same block length and the same variable node degree distribution.

The LDPC encoder is systematic, i.e. encodes an information block of size  $k$ ,  $\mathbf{I}=(i_0, i_1, \dots, i_{(k-1)})$  into a codeword  $\mathbf{C}$  of size  $n$   $\mathbf{C}=(i_0, i_1, \dots, i_{(k-1)}, p_0, p_1, \dots, p_{(n-k-1)})$  by adding  $n-k$  parity bits obtained so that  $\mathbf{H} \cdot \mathbf{c}^T = \mathbf{0}$ .

$k$  and  $n$  are defined in Table 013 according to the selected rate.

The parity check matrix used to generate all the code rates is rate 1/2 (i.e. number of rows  $n-k = 972$ , number of columns  $n = 1944$ ). This belongs to the class of the so-called structured parity check matrices (compared to “random” generated codes). More specifically, the matrix can be partitioned into square sub-blocks of size  $27 \times 27$  which are either cyclic permutations of the diagonal identity matrix or null sub-matrices. A few of them – specifically 2 in the rate 1/2 matrix described in Table A.1 – may contain two (cyclically shifted) diagonals.

In addition, in order to enable a simple encoding process, the parity-check matrices include a block lower triangular structure at the right-hand side. This allows a linear-complexity encoder (based on back substitution). More precisely, the parity-check matrix is of the type:

$$H_{(n-k) \times n} = [A_{(n-k) \times k} \ B_{(n-k) \times (n-k)}] \quad (22)$$

where  $B$  is block lower triangular, i.e. has the structure reported in Fig. 021.

$$B_{(n-k) \times (n-k)} = \begin{pmatrix} b_{11} & 0 & \cdots & 0 \\ b_{21} & b_{22} & 0 & \\ & b_{32} & \ddots & \vdots \\ \vdots & & \ddots & 0 \\ & & & \ddots & 0 \\ b_{(n-k)1} & \cdots & & & b_{(n-k)(n-k)} \end{pmatrix},$$

$b_{ij}$  = circulant permutation matrix;  $(i,j)$  sub-matrix indexes.

**Figure 021 – lower triangular part of the parity check matrix**

In order to generate variable rate LDPCs, the following criteria apply:

- Row-combining of rows who do not have a '1' in the same position (this implies a same resulting variable node degree distribution for all the code rates).
- The selection of rows to be summed preserves the lower triangular structure of the right-hand side of the matrix through all the rates.

Taking into account above-mentioned criteria, the code rates are obtained as follows:

- Code rate 2/3:

row  $i$  (the rows are enumerated from top to bottom) is generated by summing row  $i$  of  $\mathbf{H}$  of rate 1/2 code and the row with index  $i+M/2$  where  $M$  is the total number of check equations in rate 1/2 code, for all the rows where  $i < M/3$ .

- Code rate 3/4:

row  $i$  is generated by summing row  $i$  of  $\mathbf{H}$  of rate 1/2 code and the row with index  $i+M/2$  where  $M$  is the total number of  $\mathbf{H}$  rows (i.e. check equations) in rate 1/2 code.

- Code rate 5/6:

Rows are summed three at a time as: row  $i$  plus the row with index  $i+M/3$  plus the row with index  $i+2M/3$ .

The codes are designed to avoid length 4 cycles and to avoid small stopping sets.

#### 20.3.5.7.5 Parity check matrix

In Table A.1 in Annex A the rate 1/2 parity check matrix is reported. All the other rates can be derived by properly combining its rows as explained in 20.3.5.7.4.

The table describes the "matrix prototype", i.e. a structure of size 36x72 where the basic elements are squared sub-matrices whose size is 27x27. Each sub matrix is either a null matrix or a cyclic permutation of the identity matrix (or the lower bidiagonal matrix at the right hand bottom of the matrix).

Figure 022 illustrates some examples (for a 10x10 matrix) of the basic circular permutation matrix  $S_i$ , clarifying how cyclic shift indexes  $i$  are to be interpreted. The last line in Table A.1, indicated as "st", indicates the staircase (or bi-diagonal) structure ( $S_d$  in Fig. 021).

$$S_0 = \begin{bmatrix} 1 & & & & \\ & 1 & & & \\ & & 1 & & \\ & & & 1 & \\ & & & & 1 \end{bmatrix} \quad S_3 = \begin{bmatrix} & 1 & & & \\ & & 1 & & \\ & & & 1 & \\ & & & & 1 \\ 1 & & & & \end{bmatrix} \quad S_7 = \begin{bmatrix} & & 1 & & \\ & & & 1 & \\ & 1 & & & \\ & & 1 & & \\ & & & 1 & \end{bmatrix} \quad S_d = \begin{bmatrix} 1 & & & & \\ & 1 & & & \\ & & 1 & & \\ & & & 1 & \\ & & & & 1 \end{bmatrix}$$

**Figure 022 – Structure of the cyclic permutations of the identity matrix. Matrix  $S_i$  is produced by cyclically shifting the columns of the identity matrix to the right  $i$  places.**

Table A.1 follows the following format: Row number - Column number - Cyclic shift to the right (of columns). Rows are enumerated from top to bottom, columns from left to right.

### 20.3.5.8 Subcarrier modulation mapping

The subcarrier modulation mapping shall follow IEEE 802.11a-1999 clause 17.3.5.7 for each transmit antenna.

### 20.3.5.9 Pilot tones

The subcarriers with index -21 and +21 are dedicated in all 20 MHz modes to transmit pilot signals during each OFDM symbol, in order to increase robustness against frequency offsets and phase noise. In the 40 MHz modes, 4 subcarriers are dedicated to transmitting pilots. These subcarriers have indexes -42, -14, +14, and +42.

The relative polarity of the pilots transmitted from various antennas shall be determined using the following relations. We shall number the MIMO-OFDM symbols transmitted in a PSDU sequentially, with  $n = 0$  denoting the first symbol that follows the PLCP preamble. We shall use  $p_n$  to denote the  $n$ th element of the sequence  $p_{0...126v}$  specified in equation (25) of IEEE 802.11a-1999 subclause 17.3.5.9. We define the following matrices:

$$A = \begin{bmatrix} +1 & +1 & +1 & -1 \\ +1 & -1 & +1 & +1 \end{bmatrix}$$

$$B = \begin{bmatrix} +1 & +1 & -1 & -1 \\ +1 & -1 & +1 & -1 \\ -1 & +1 & +1 & -1 \end{bmatrix}$$

$$C = \begin{bmatrix} +1 & +1 & +1 & -1 \\ +1 & +1 & -1 & +1 \\ +1 & -1 & +1 & +1 \\ -1 & +1 & +1 & +1 \end{bmatrix} \quad (23)$$

Furthermore, we define  $a_{i,j}$ ,  $b_{i,j}$ , and  $c_{i,j}$  as the element on the  $i$ th row and  $j$ th column of the matrices A, B, and C, respectively. For example,  $i = 0, 1, 2; j = 0, 1, 2, 3$  for matrix B. Then the pilot values sent from the  $m$ th antenna ( $m = 1, 2, \dots, 4$ ) during the  $n$ th OFDM symbol in the 20 MHz modes shall be given by the corresponding value in Table 014, multiplied with  $p_{n \bmod 127}$ .

The pilot value in the 40 MHz modes shall be given by the corresponding value in Table 015, multiplied with  $p_{n \bmod 127}$ . The value of the pilot signals sent during the SIG-N symbol defined in 20.3.4 shall be obtained by setting  $n = 0$  in this subclause.

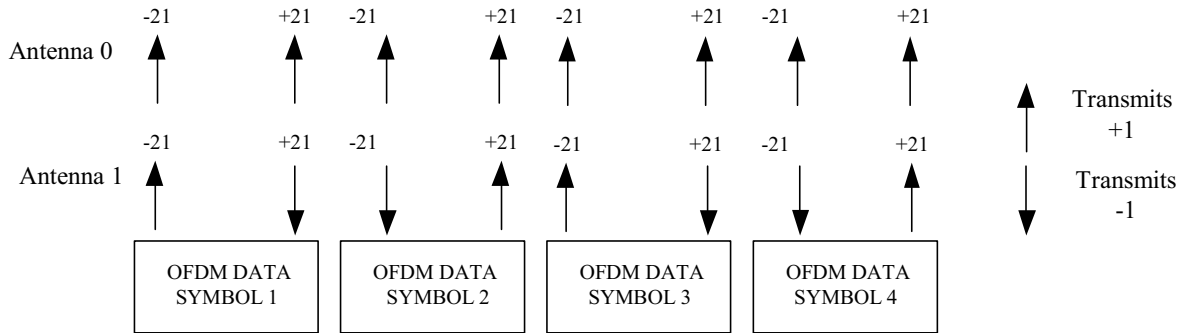
**Table 014—Pilot value sent from  $m$ th antenna during  $n$ th OFDM symbol in 20 MHz modes**

| Subcarrier index | 2TX mode                 | 3TX mode                 | 4TX mode                 |
|------------------|--------------------------|--------------------------|--------------------------|
| -21              | $a_{m-1, n \bmod 2}$     | $b_{m-1, n \bmod 4}$     | $c_{m-1, n \bmod 4}$     |
| +21              | $a_{m-1, (n+1) \bmod 2}$ | $b_{m-1, (n+1) \bmod 4}$ | $c_{m-1, (n+1) \bmod 4}$ |

**Table 015—Pilot value sent from  $m$ th antenna during  $n$ th OFDM symbol in 40 MHz modes**

| Subcarrier index | 1TX mode | 2TX mode                 | 3TX mode                 | 4TX mode                 |
|------------------|----------|--------------------------|--------------------------|--------------------------|
| -42              | +1       | $a_{m-1, n \bmod 4}$     | $b_{m-1, n \bmod 4}$     | $c_{m-1, n \bmod 4}$     |
| -14              | +1       | $a_{m-1, (n+1) \bmod 4}$ | $b_{m-1, (n+1) \bmod 4}$ | $c_{m-1, (n+1) \bmod 4}$ |
| +14              | +1       | $a_{m-1, (n+2) \bmod 4}$ | $b_{m-1, (n+2) \bmod 4}$ | $c_{m-1, (n+2) \bmod 4}$ |
| +42              | -1       | $a_{m-1, (n+3) \bmod 4}$ | $b_{m-1, (n+3) \bmod 4}$ | $c_{m-1, (n+3) \bmod 4}$ |

Figure 023 provides an illustration of the relative polarity of pilot signals transmitted in the 2TX, 20 MHz mode of operation

**Figure 023 – An illustration of the relative polarity of pilot signals in the 2TX, 20 MHz mode. “-21” and “+21” indicate the subcarrier indexes on which pilot signals are sent**

### 20.3.5.10 Space-time block coding (STBC)

This subclause defines a set of robust transmission rates which are applicable when  $N_{TX}$ , the number of TX antennas, is greater than  $N_{SS}$ , the number of transmitted spatial streams. These rates are based on space time block coding.

Implementation of all rates specified in Table 016 for  $N_{TX}=2$ ,  $N_{SS}=1$  in 20 MHz is mandatory. Implementation of all other modes defined in this subclause is optional.

The space time block encoding scheme for  $N_{TX}=2$ ,  $N_{SS}=1$  in 20 MHz and 40 MHz is defined as follows. The bits output from the interleaver of the (single) spatial stream are mapped to the subcarriers of the first antenna, according to subclause 20.3.5.8. We denote the pair of complex numbers transmitted on subcarrier  $k$  from this antenna during the  $j$ -th and  $j$ th OFDM symbol as  $s_{j-1}$  and  $s_j$  respectively. Then the corresponding transmission from the second antenna, on the same subcarrier index and during the same OFDM symbols, shall be  $-s_j^*$  and  $s_{j-1}^*$  where  $*$  denotes complex conjugate. This encoding scheme shall hereafter be referred to as the “STBC encoding rule”.

Since encoding takes place across pairs of MIMO-OFDM symbols in this subclause, the number of pad bits inserted in subclause 20.3.5.3 shall be sufficient to ensure that an even number of MIMO-OFDM symbols are transmitted in the PPDU.

**Table 016—Rate-dependent parameters for 20 MHz,  $N_{TX} = 2$ ,  $N_{SS} = 1$** 

| Data rate (Mbits/s) | Modulation | Coding rate (R) | Coded bits per subcarrier per antenna | Number of data subcarriers ( $N_{SD}$ ) | Number of pilots ( $N_{SP}$ ) | Coded bits per MIMO-OFDM symbol | Data bits per MIMO-OFDM symbol | Clause 10.4.4.2 rate code |
|---------------------|------------|-----------------|---------------------------------------|-----------------------------------------|-------------------------------|---------------------------------|--------------------------------|---------------------------|
|---------------------|------------|-----------------|---------------------------------------|-----------------------------------------|-------------------------------|---------------------------------|--------------------------------|---------------------------|

|        |        |     | (N <sub>BPSK</sub> ) |    |   | (N <sub>CBPS</sub> ) | (N <sub>DBPS</sub> ) |     |
|--------|--------|-----|----------------------|----|---|----------------------|----------------------|-----|
| 6.75   | BPSK   | 1/2 | 1                    | 54 | 2 | 54                   | 27                   | 114 |
| 10.125 | BPSK   | 3/4 | 1                    | 54 | 2 | 54                   | 40.5                 | 115 |
| 13.5   | QPSK   | 1/2 | 2                    | 54 | 2 | 108                  | 54                   | 116 |
| 20.25  | QPSK   | 3/4 | 2                    | 54 | 2 | 108                  | 81                   | 117 |
| 27     | 16-QAM | 1/2 | 4                    | 54 | 2 | 216                  | 108                  | 118 |
| 40.5   | 16-QAM | 3/4 | 4                    | 54 | 2 | 216                  | 162                  | 119 |
| 54     | 64-QAM | 2/3 | 6                    | 54 | 2 | 324                  | 216                  | 120 |
| 60.75  | 64-QAM | 3/4 | 6                    | 54 | 2 | 324                  | 243                  | 121 |

The RATE-dependent parameters for 20 MHz,  $N_{TX} = 3$ ,  $N_{SS} = 2$  are defined in Table 003. In this configuration, the STBC encoding rule shall be applied on the first and second antennas using bits from the first spatial stream. Bits from the second spatial stream shall be mapped to subcarriers of the third transmit antenna, according to subclause 20.3.5.8.

The RATE-dependent parameters for 20 MHz,  $N_{TX} = 4$ ,  $N_{SS} = 2$  are defined in Table 003. In this configuration, the STBC encoding rule shall be applied on the first and second antennas using bits from the first spatial stream, and on the third and fourth antennas using bits from the second spatial stream.

The RATE-dependent parameters for 20 MHz,  $N_{TX} = 4$ ,  $N_{SS} = 3$  are defined in Table 004. In this configuration, the STBC encoding rule shall be applied on the first and second antennas using bits from the first spatial stream. Bits from the second spatial stream shall be mapped to subcarriers of the third transmit antenna, according to subclause 20.3.5.8. Bits from the third spatial stream shall be mapped to subcarriers of the fourth transmit antenna, according to subclause 20.3.5.8.

The RATE-dependent parameters for 40 MHz,  $N_{TX} = 2$ ,  $N_{SS} = 1$  are defined in Table 006. In this configuration, the STBC encoding rule shall be applied on the first and second antennas.

The RATE-dependent parameters for 40 MHz,  $N_{TX} = 3$ ,  $N_{SS} = 2$  are defined in Table 007. In this configuration, the STBC encoding rule shall be applied on the first and second antennas using bits from the first spatial stream. Bits from the second spatial stream shall be mapped to subcarriers of the third transmit antenna, according to subclause 20.3.5.8.

The RATE-dependent parameters for 40 MHz,  $N_{TX} = 4$ ,  $N_{SS} = 2$  are defined in Table 007. In this configuration, the STBC encoding rule shall be applied on the first and second antennas using bits from the first spatial stream, and on the third and fourth antennas using bits from the second spatial stream.

The RATE-dependent parameters for 40 MHz,  $N_{TX} = 4$ ,  $N_{SS} = 3$  are defined in Table 008. In this configuration, the STBC encoding rule shall be applied on the first and second antennas using bits from the first spatial stream. Bits from the second spatial stream shall be mapped to subcarriers of the third transmit antenna, according to subclause 20.3.5.8. Bits from the third spatial stream shall be mapped to subcarriers of the fourth transmit antenna, according to subclause 20.3.5.8.

### 20.3.6 Clear channel assessment

PLCP shall provide the capability to perform CCA and report the result to the MAC. The CCA mechanism shall detect a "medium busy" condition with a performance specified in 20.3.10.5. This medium status report is indicated by the primitive PHY\_CCA.indicate.

### 20.3.7 PLCP data modulation and modulation rate change

The PLCP preamble shall be transmitted using a set of OFDM-modulated fixed waveforms, specified in subclause 20.3.3 for each transmit antenna for each mode of operation defined in the MIMO-OFDM PHY. The SIG-N field, composed of 54 bits, shall indicate the bandwidth, modulation, code rate, code type, number of TX antennas, and number of spatial streams that shall be used to transmit the MPDU. The transmitter (receiver) shall initiate the modulation constellation, code rate, code type, and other configuration parameters according to the CONFIG indicated in the SIG-N field. The MPDU transmission rate shall be set by the DATARATE parameter in the TXVECTOR, issued with the PHY-TXSTART.request primitive described in 20.2.

### 20.3.8 PMD operating specifications

Subclauses 20.3.8.1 through 20.3.8.8 provide general specifications for the various modes and options defined in the MIMO-OFDM PMD sublayer. These specifications apply to both the receive and transmit functions and general operation of the MIMO-OFDM PHY.

#### 20.3.8.1 TX Block diagram

The general block diagram of the transmitter for the MIMO-OFDM PHY is shown in Figure 024. The blocks that are shaded in the figure may be replicated  $N_{TX}$  times in a MIMO-OFDM system with  $N_{TX}$  transmit antennas.

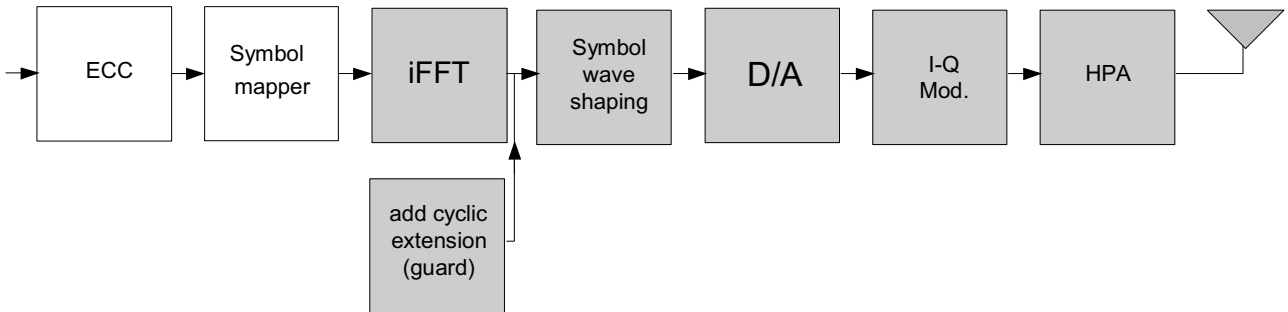


Figure 024 – Transmitter block diagram for the MIMO-OFDM PHY

#### 20.3.8.2 Regulatory requirements

All systems shall comply with the local regulatory requirements for operation in the band in which they are implemented. For 2.4 GHz operation, refer to FCC 15.247, 15.249, 15.205, and 15.209 for the USA; ETS 300-328 for Europe; and MPHPT article 49-20 for Japan. For 5 GHz operation in the USA, refer to FCC CFR47, Part 15, sections 15.205 and 15.209; and Subpart E, sections 15.401-15.407.

The documents listed here are provided for information only, and are subject to change or revision at any time.

#### 20.3.8.3 Operating channel frequencies

The range of operating frequencies for the MIMO-OFDM PHY shall be 2400-2497 MHz and 4920-5805 MHz. The channel numbering shall be as defined in IEEE 802.11b-1999 clause 18.4.6.2, and clause 17.3.8.3.2 of IEEE P802.11j/D1.5, May 2004. The relationship between center frequency and channel number is given by the following equations:

$$\text{Channel center frequency} = 5000 + (\text{channel number}) \times 5 \text{ (MHz) for center frequency} > 5000 \text{ MHz} \quad (24)$$

$$\text{Channel center frequency} = 4000 + (\text{channel number}) \times 5 \text{ (MHz) for } 4900 \leq \text{center frequency} \leq 5000 \text{ MHz} \quad (25)$$

40 MHz operation shall be restricted to the 5 GHz band only. Each 40 MHz channel shall occupy two 20 MHz channels, with the center frequency of the 40 MHz transmission selected to be midway between the center frequencies of the two occupied 20 MHz channels. For example, if the two occupied 20 MHz channels are centered at channel number 149 and 153, then the 40 MHz transmission shall be centered at channel number 151.

#### 20.3.8.4 Spurious emissions

The spurious emissions shall conform to IEEE 802.11a-1999 subclause 17.3.8.4

#### 20.3.8.5 TX RF delay

The TX RF delay shall follow IEEE 802.11a-1999 subclause 17.3.8.5.

### 20.3.8.6 Slot time

The slot time shall follow IEEE 802.11a-1999 subclause 17.3.8.6 for 5 GHz bands and IEEE 802.11g-1999 subclause 19.4.4 for 2.4 GHz bands.

### 20.3.8.7 Transmit and receive antenna port impedance

The transmit and receive antenna port impedance for each transmit and receive antenna shall follow IEEE 802.11a-1999 subclause 17.3.8.7.

### 20.3.8.8 Transmit and receive operating temperature range

The transmit and receive temperature range shall follow IEEE 802.11a-1999 subclause 17.3.8.8.

## 20.3.9 PMD TX specifications

Subclauses 20.3.9.1 through 20.3.9.7 describe the transmit specifications associated with the PMD sublayer. In general, these are specified by primitives from the PLCP, and the transmit PMD entity provides the actual means by which the signals required by the PLCP primitives are imposed into the medium.

### 20.3.9.1 TX power levels

The maximum allowable output power shall conform to national regulatory constraints on the maximum radiated power allowed in any frequency band.

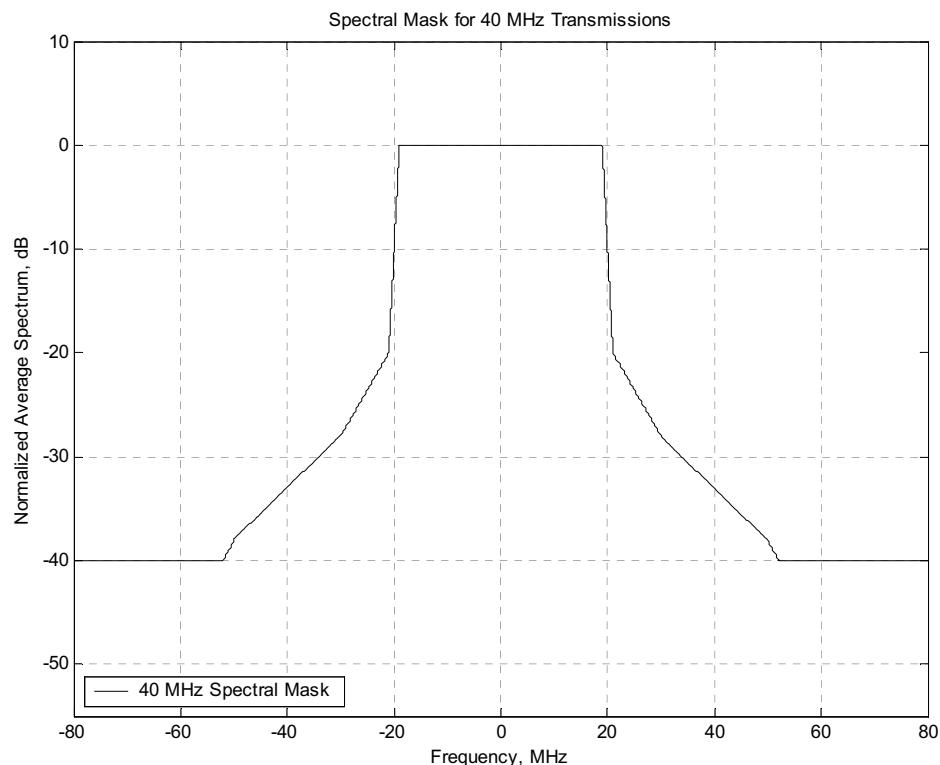


**Figure 025 –Transmit spectrum mask for 40 MHz transmissions**

### 20.3.9.2 TX spectrum mask

The transmitted spectral density of the transmitted signal shall conform to subclause IEEE 802.11a-1999 17.3.9.2 for all 20 MHz transmissions. The transmitted spectrum for 40 MHz transmissions shall have a 0 dBm bandwidth not exceeding 38

1 MHz, -20 dBr at 21 MHz frequency offset, -28 dBr at 30 MHz frequency offset, -38 dBr at 50 MHz frequency offset, and -40 dBr at 52 MHz frequency offset and above. The transmitted spectral density of the 40 MHz transmitted signal shall fall within the spectral mask shown in Figure 025. The measurements shall be made using a 100 kHz resolution bandwidth and a 30 kHz video bandwidth.

### 20.3.9.3 TX spurious

Spurious transmissions from Clause 20 compliant devices shall conform to national regulations.

### 20.3.9.4 TX center frequency tolerance

The transmitted center frequency tolerance shall be  $\pm 20$  ppm maximum for 5 GHz bands and  $\pm 25$  ppm for 2.4 GHz bands. The transmit center frequency and the symbol clock frequency for all transmit antennas shall be derived from the same reference oscillator.

### 20.3.9.5 TX symbol clock frequency tolerance

The symbol clock frequency tolerance shall be  $\pm 20$  ppm maximum for 5 GHz bands and  $\pm 25$  ppm for 2.4 GHz bands. The transmit center frequency and the symbol clock frequency for all transmit antennas shall be derived from the same reference oscillator.

### 20.3.9.6 Modulation accuracy

Transmit modulation accuracy specifications are described in this subclause. The test method is described in 20.3.9.7.

#### 20.3.9.6.1 TX center frequency leakage

TX center frequency leakage shall follow IEEE 802.11a-1999 subclause 17.3.9.6.1 for all 20 MHz modes of transmission. For 40 MHz modes, the center frequency leakage shall not exceed -18 dB relative to overall transmitted power, or, equivalently, +2 dB relative to the average energy of the rest of the subcarriers.

#### 20.3.9.6.2 TX spectral flatness

For 20 MHz transmissions, the average energy of the constellation in each of the spectral lines -16...-1 and +1...+16 will deviate no more than  $\pm 2$  dB of their average energy. The average energy of the constellations in each of the spectral lines -28...-17 and +17...+28 will deviate no more than  $\pm 2/4$  dB from the average energy of the spectral lines -16...-1 and +1...+16.

For 40 MHz transmissions, the average energy of the constellation in each of the spectral lines -32...-3 and +3...+32 will deviate no more than  $\pm 2$  dB of their average energy. The average energy of the constellations in each of the spectral lines -58...-33 and +33...+58 will deviate no more than  $\pm 2/4$  dB from the average energy of the spectral lines -32...-3 and +3...+32.

#### 20.3.9.6.3 TX constellation error

The relative constellation RMS error, averaged over subcarriers, transmit spatial streams, OFDM frames, and packets, shall not exceed a constellation and code rate dependent value according to Table 017 for the all modes in which the number of spatial streams is equal to the number of transmit antennas.

**Table 017—Allowed relative constellation error versus constellation type and code rate**

| Constellation size | Code Rate | Relative constellation error (dB) |
|--------------------|-----------|-----------------------------------|
| 16-QAM             | 1/2       | -17                               |
| 16-QAM             | 3/4       | -20                               |
| 64-QAM             | 2/3       | -24                               |
| 64-QAM             | 3/4       | -26                               |
| 64-QAM             | 5/6       | -27                               |

### 20.3.9.7 TX modulation accuracy (EVM) test

The transmit modulation accuracy test shall be performed by instrumentation capable of converting the transmitted signals into a stream of complex samples at 20 Msamples/s or more for 20 MHz modes, and 40 Msamples/s or more for 40 MHz modes, with sufficient accuracy in terms of I/Q arm amplitude and phase balance, DC offsets, phase noise, etc. A possible embodiment of such a setup is converting the signals to a low IF frequency with a microwave synthesizer, sampling the signals with a digital oscilloscope and decomposing them digitally into quadrature components.

The test procedure for this requirement is as follows: Matrices  $H_{1TX}$ ,  $H_{2TX}$ ,  $H_{3TX}$ , and  $H_{4TX}$  are defined to give the connections from the transmit antennas to the receive antennas for the 1TX, 2TX, 3TX, and 4TX cases respectively. They are specified as follows:

$$H_{1TX} = \alpha \cdot 1$$

$$H_{2TX} = \alpha \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$$

$$H_{3TX} = \alpha \begin{bmatrix} -1 & 2 & 2 \\ 2 & -1 & 2 \\ 2 & 2 & -1 \end{bmatrix}$$

$$H_{4TX} = \alpha \begin{bmatrix} -1 & 1 & 1 & 1 \\ 1 & -1 & 1 & 1 \\ 1 & 1 & -1 & 1 \\ 1 & 1 & 1 & -1 \end{bmatrix} \quad (25)$$

The elements of the above matrices  $h_{ij}$  specify the connection from the  $j^{\text{th}}$  transmitter to the  $i^{\text{th}}$  receiver, where  $h_{ij}$  is the element of the  $i^{\text{th}}$  row and  $j^{\text{th}}$  column where  $i=1,\dots,N_{RX}$  and  $j=1,\dots,N_{TX}$ . The attenuation  $\alpha$  is chosen to ensure an appropriate received signal power at the test equipment. Figure 026 shows an example test setup for a 2TX mode.

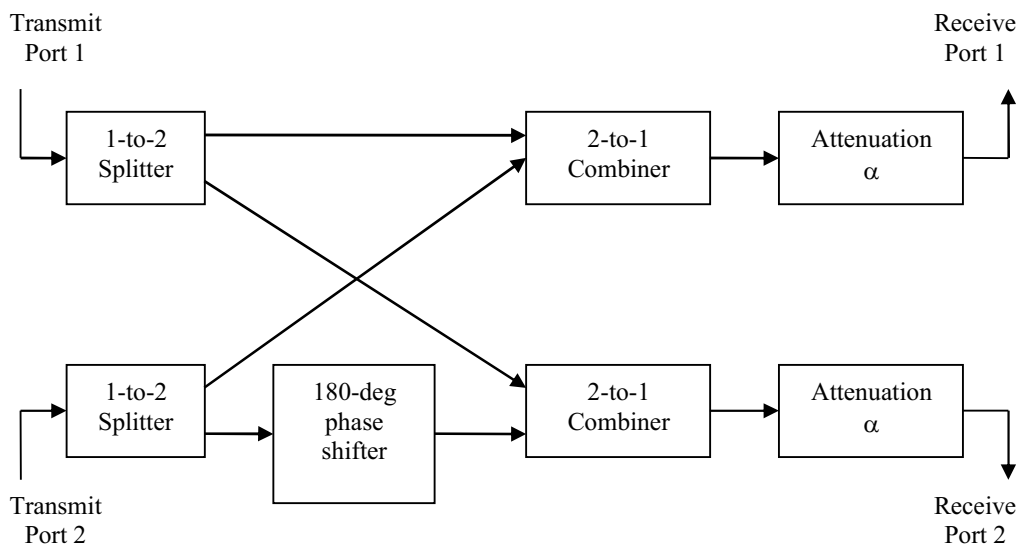


**Figure 026 –EVM test setup**

The 180 degree phase shifter shall be 180 +/- 10 degrees. The relative amplitudes of the connections  $h_{ij}$  shall be within +/-1 dB of the relative values specified in the H matrices above.

The sampled signals shall be processed in a manner similar to an actual receiver, according to the following steps, or an equivalent procedure:

- a) Start of frame shall be detected.
- b) Transition from short sequences to channel estimation sequences shall be detected, and fine timing (with one sample resolution) shall be established.
- c) Coarse and fine frequency offsets shall be estimated.
- d) The packet shall be derotated according to estimated frequency offset.
- e) The complex channel response coefficients shall be estimated for each of the subcarriers.
- f) For each of the data OFDM symbols: transform the symbol into subcarrier received values, estimate the phase from the pilot subcarriers, derotate the subcarrier values according to estimated phase, and apply an MMSE channel equalizer to each vector of received subcarrier values based on complex estimated channel response coefficients found in (e).
- g) For each data-carrying subcarrier of each transmitted stream, find the closest constellation point and compute the Euclidean distance from it.
- h) Compute the RMS average of all errors in a packet. It is given by:

$$Error_{RMS} = \frac{\sum_{i=1}^{N_f} \sqrt{\frac{\sum_{l=1}^{N_{SS}} \sum_{j=1}^{L_P} \sum_{k=1}^{N_{ST}} \{ (I(i,j,k,l) - I_0(i,j,k,l))^2 + (Q(i,j,k,l) - Q_0(i,j,k,l))^2 \}}{N_{ST} L_P P_0 N_{SS}}}}{N_f} \quad (26)$$

where

- $L_P$  is the length of the packet;
- $N_{SS}$  is the number of spatial streams;
- $N_f$  is the number of frames for the measurement;
- $N_{ST}$  is the total number of subcarriers (data and pilots) per OFDM symbol;
- $(I_0(i,j,k,l), Q_0(i,j,k,l))$  denotes the ideal symbol point of the  $i^{\text{th}}$  frame,  $j^{\text{th}}$  OFDM symbol of the frame,  $k^{\text{th}}$  subcarrier, and  $l^{\text{th}}$  spatial stream of the OFDM symbol in the complex plane;
- $(I(i,j,k,l), Q(i,j,k,l))$  denotes the observed point of the  $i^{\text{th}}$  frame,  $j^{\text{th}}$  OFDM symbol of the frame,  $k^{\text{th}}$  subcarrier, and  $l^{\text{th}}$  spatial stream of the OFDM symbol in the complex plane;
- $P_0$  is the average power of the constellation.

The vector error on a phase plane is shown in Figure 121 in IEEE 802.11a-1999 subclause 17.3.9.7.

The test shall be performed over at least 20 frames ( $N_f$ ), and the RMS average shall be taken. The packets under test shall be at least 16 OFDM symbols long. Random data shall be used for the symbols.

### 20.3.10 PMD RX specifications

Subclauses 20.3.10.1 through 20.3.10.5 describe the receive specifications associated with the PMD sublayer.

#### 20.3.10.1 RX minimum input level sensitivity

The packet error rate (PER) shall be less than 10% at a PSDU length of 1000 bytes for rate-dependent input levels shall be the numbers listed in Table 018 or less. The minimum input levels are measured at the antenna connectors and are referenced as the average power per receive antenna.

**Table 018—Receiver minimum input level sensitivity**

| Constellation size | Code Rate     | Minimum sensitivity (dBm) |
|--------------------|---------------|---------------------------|
| BPSK               | $\frac{1}{2}$ | -82                       |
| BPSK               | $\frac{3}{4}$ | -81                       |
| QPSK               | $\frac{1}{2}$ | -79                       |
| QPSK               | $\frac{3}{4}$ | -77                       |
| 16-QAM             | $\frac{1}{2}$ | -74                       |
| 16-QAM             | $\frac{3}{4}$ | -70                       |
| 64-QAM             | $\frac{2}{3}$ | -66                       |
| 64-QAM             | $\frac{3}{4}$ | -65                       |
| 64-QAM             | $\frac{5}{6}$ | -64                       |

**20.3.10.2 RX maximum input level**

The RX maximum input level shall be defined as the maximum at any or all antennas, and shall follow IEEE 802.11a-1999 subclause 17.3.10.4 for the 4920-5805 MHz band, and follow IEEE 802.11g-2003 subclause 19.5.3 for the 2400-2497 MHz band.

**20.3.10.3 CCA sensitivity**

The CCA sensitivity of all Clause 20 compliant devices shall conform to IEEE 802.11a-2003 subclause 17.3.10.5.

**20.3.11 PLCP TX procedure**

The transmit PLCP is shown in Figure 029. In order to transmit data, PHY-TXSTART.request shall be enabled so that the PHY entity shall be in the transmit state. Further, the PHY shall be set to operate at the appropriate frequency through station management via the PLME. Other transmit parameters, such as DATARATE, TRANSMISSION\_MODE, NUM\_STREAMS, and TXPWR\_LEVEL, are set via the PHY-SAP with the PHY-TXSTART.request(TXVECTOR), as described in 20.2.

A clear channel shall be indicated by PHY-CCA.indicate(IDLE). The MAC considers this indication before issuing the PHY-TXSTART.request. Transmission of the PPDU or A-PPDU shall be initiated after receiving the PHYTXSTART.request(TXVECTOR) primitive. The TXVECTOR elements for the PHY-TXSTART.request are the PLCP header parameters LENGTH, DATARATE, TRANSMISSION\_MODE, NUM\_STREAMS, CODE\_TYPE, SERVICE, LPI, and BURST\_DURATION, and the PMD parameter TXPWR\_LEVEL.

The PLCP shall issue PMD\_TXPWRLVL, PMD\_RATE, PMD\_NUM\_STREAMS, and PMD\_TRANSMISSION\_MODE, primitives to configure the PHY. The PLCP shall then issue a PMD\_TXSTART.request, and transmission of the PLCP preamble and PLCP header, based on the parameters passed in the PHY-TXSTART.request primitive will begin. Once PLCP preamble transmission is started, the PHY entity shall immediately initiate data scrambling and data encoding. The scrambled and encoded data shall then be exchanged between the MAC and the PHY through a series of PHYDATA.request(DATA) primitives issued by the MAC, and PHY-DATA.confirm primitives issued by the PHY. The modulation rate change, if any, shall be initiated from the SERVICE field data of the PLCP header, as described in 20.3.2. The PHY proceeds with PSDU transmission through a series of data octet transfers from the MAC. The PLCP header parameter, SERVICE, and PSDU are encoded by the convolutional encoder with the bit-stealing function described in 20.3.5.5. At the PMD layer, the data octets are sent in bit 0–7 order and presented to the PHY through PMD\_DATA.request primitives. In the PMD, the GI shall be inserted in every OFDM symbol as a countermeasure against severe delay spread.

Transmission of a PSDU can be prematurely terminated by the MAC through the primitive PHY-TXEND.request. PHY-TXSTART shall be disabled by the issuance of the PHY-TXEND.request. Normal transmission of a PSDU occurs after the transmission of the final bit of the last PSDU octet, according to the number of bytes supplied in the PLCP header LENGTH.

Each PHY-TXEND.request is acknowledged with a PHY-TXEND.confirm primitive from the PHY. If the coded PSDU (C-PSDU) is not multiples of the OFDM symbol, bits shall be stuffed to make the C-PSDU length multiples of the OFDM symbol.

1  
2 If an aggregated PPDU (A-PPDU) is being transmitted as indicated by the TXVECTOR LPI parameter, the PHY will wait  
3 for the next PHY\_TXSTART.request from the MAC. The process of transmitting the subsequent MPDUs as part of the A-  
4 PPDU is identical to the first MPDU except that the PLCP will not issue PMD primitives to configure the PHY.

5  
6 Normal termination of the A-PPDU occurs at the termination of the transmission of the last PSDU, indicated by the PHY  
7 PLCP header LPI field. A prematurely terminated PSDU transmission from the MAC will prematurely terminate the  
8 transmission of the A-PPDU.

9  
10 The A-PPDU transmission shall be completed and the PHY entity shall enter the receive state (i.e., PHY-TXSTART shall be  
11 disabled).

12  
13 A typical state machine implementation of the transmit PLCP is provided in Figure 027. Requests (.req) and  
14 confirmations(.confirm) are issued once with designated states.  
15

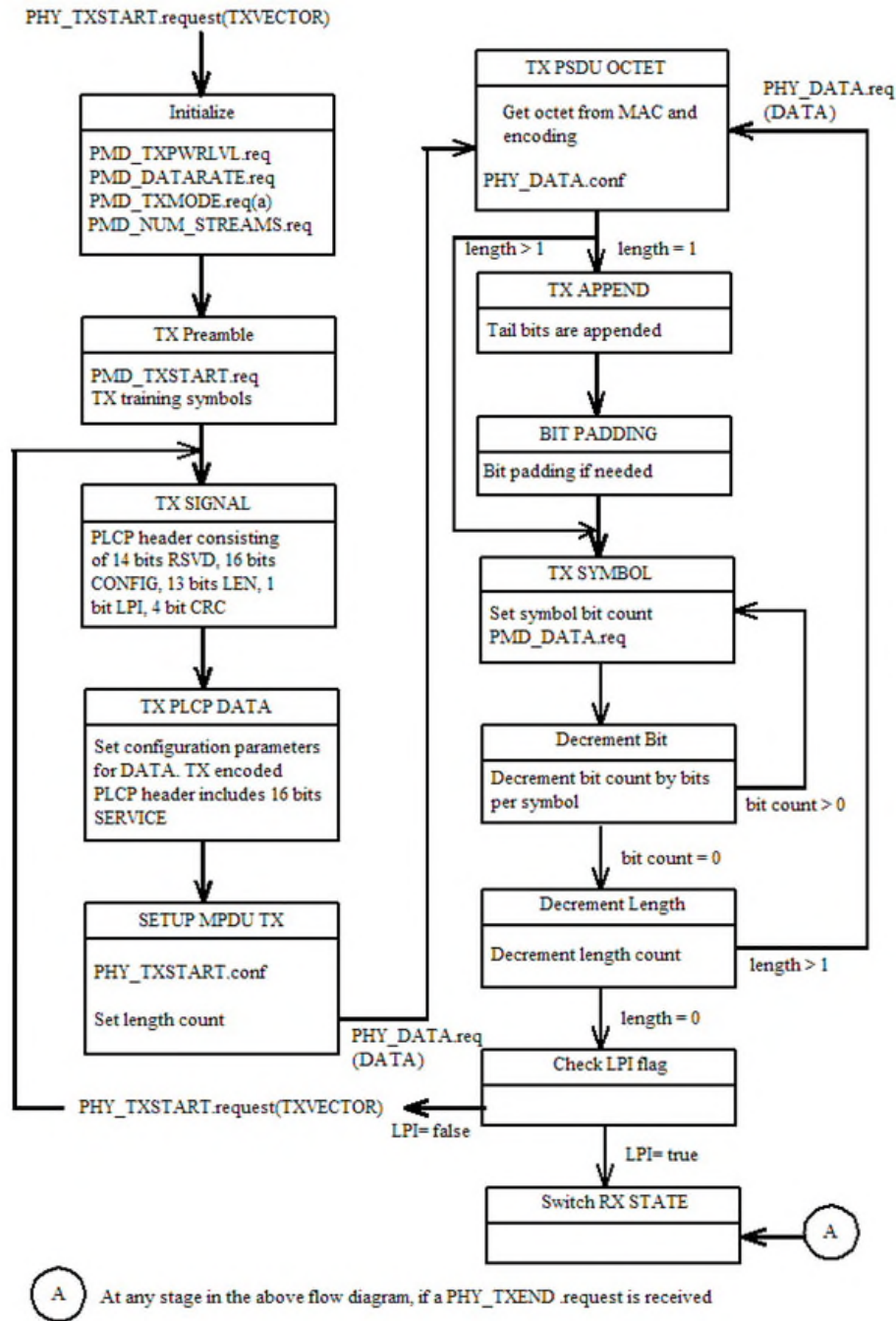


Figure 027 –PLCP transmit state machine

### 20.3.12 PLCP RX procedure

The receive PLCP is shown in Figure 030. In order to receive data, PHY-TXSTART.request shall be disabled so that the PHY entity is in the receive state. Further, through station management (via the PLME) the PHY is set to the appropriate frequency. Other receive parameters, such as RSSI and indicated DATARATE, TRANSMISSION\_MODE, NUM\_STREAMS, CODE\_TYPE, LPI, and BURST\_DURATION may be accessed via the PHY-SAP.

Upon receiving the transmitted PLCP preamble, PMD\_RSSI.indicate shall report a significant received signal strength level to the PLCP. This indicates activity to the MAC via PHY\_CCA.indicate. PHY\_CCA.indicate(BUSY) shall be issued for

reception of a signal prior to correct reception of the PLCP frame. The PMD primitive PMD\_RSSI is issued to update the RSSI and parameter reported to the MAC.

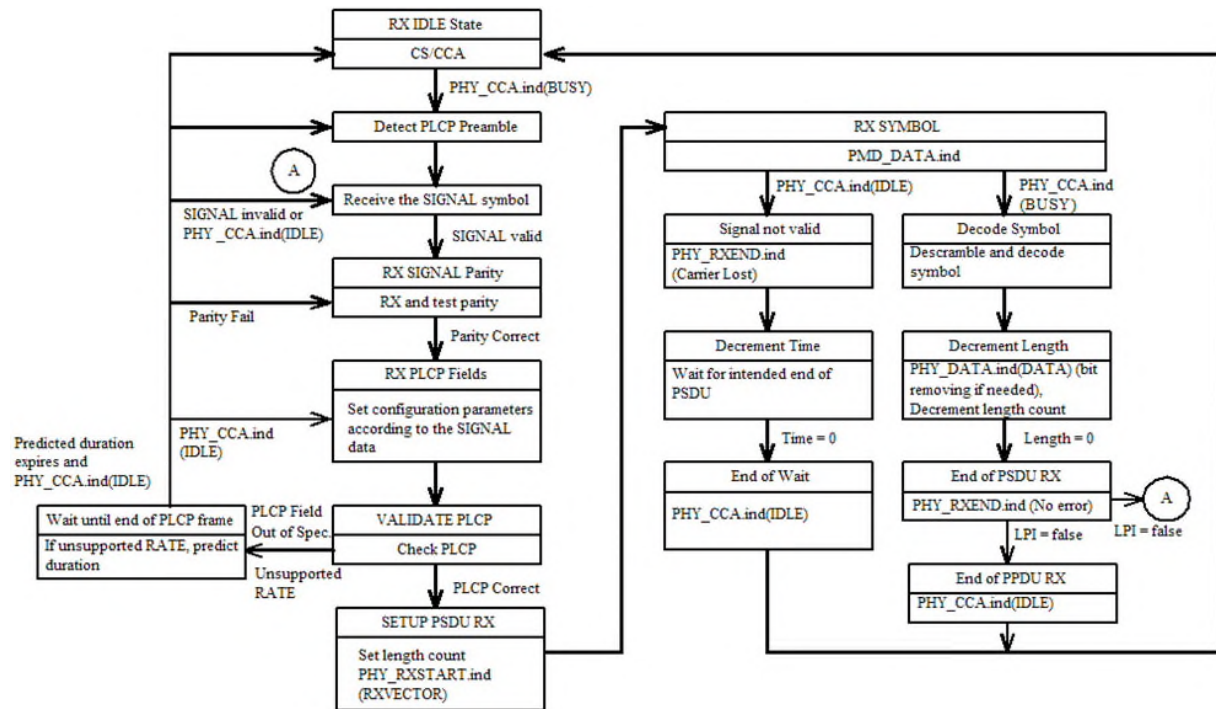
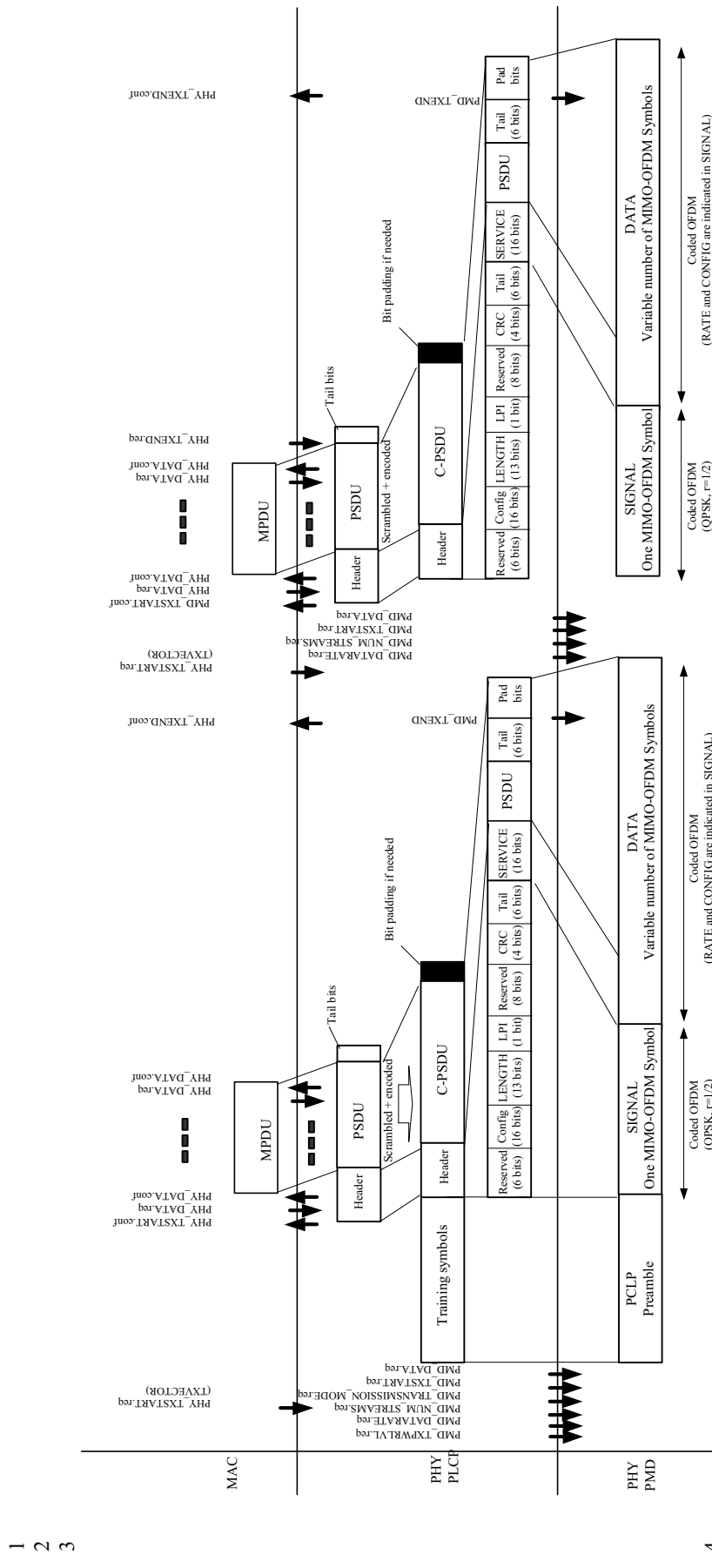


Figure 028 – PLCP receive state machine

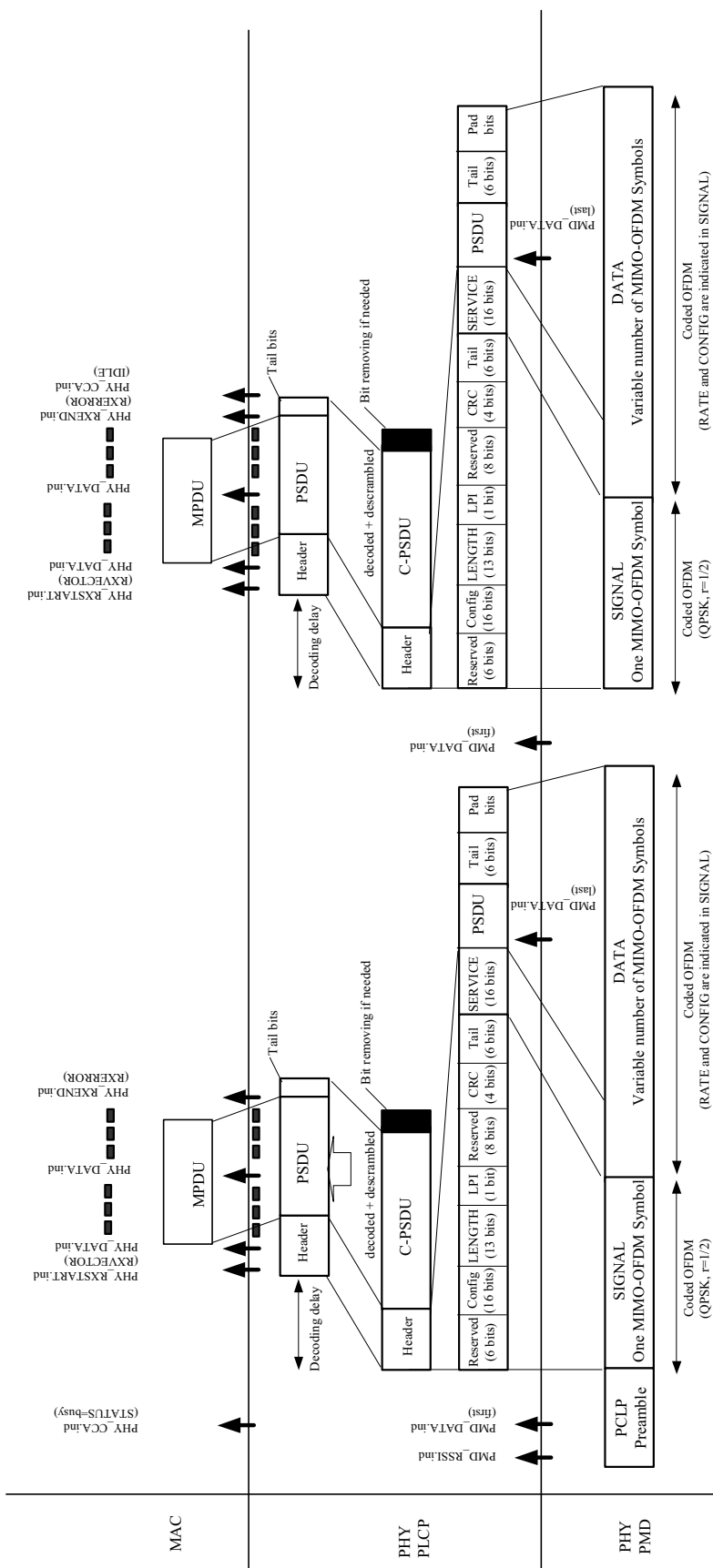
After PHY-CCA.indicate is issued, the PHY entity shall begin receiving the training symbols and searching for the SIGNAL in order to set the length of the data stream, the demodulation type, and the decoding rate. Once the SIGNAL is detected without any errors detected by the CRC checker, FEC decode shall be initiated and the PLCP SERVICE fields and data shall be received, and decoded. Should the status of CCA return to the IDLE state during reception prior to completion of the full PLCP processing, the PHY receiver shall return to the RX IDLE state.

If the PLCP header reception is successful (and the SIGNAL field is completely recognizable and supported), a PHY-RXSTART.indicate(RXVECTOR) shall be issued. The RXVECTOR associated with this primitive includes the SIGNAL fields, the SERVICE field, the PSDU length in bytes, and the RSSI. Also, in this case, the HT PHY will ensure that the CCA shall indicate a busy medium for the intended duration of the transmitted frame, as indicated by the LENGTH field. The received PSDU bits are assembled into octets, decoded, and presented to the MAC using a series of PHY-DATA.indicate(DATA) primitive exchanges. The rate change indicated in the SIGNAL field shall be initiated from the SERVICE field data of the PLCP header, as described in 20.3.2. The PHY shall proceed with PSDU reception. After the reception of the final bit of the last PSDU octet indicated by the PLCP header LENGTH field, the receiver shall transition to the RX IDLE state if LPI is 1 or to the RX SIGNAL state if LPI is 0 in the RXVECTOR associated with this primitive, as shown in Figure 030. If the LPI is 1 in the RXVECTOR, a PHY-RXEND.indicate(NoError) primitive shall also be issued.

In the event that a change in the RSSI causes the status of the CCA to return to the IDLE state before the complete reception of the PSDU, as indicated by the PLCP LENGTH field, the error condition PHYRXEND.indicate(CarrierLost) shall be reported to the MAC. The HT PHY will ensure that the CCA indicates a busy medium for the intended duration of the transmitted packet. If the indicated rate in the SIGNAL field is not receivable, a PHY-RXSTART.indicate will not be issued. The PHY shall issue the error condition PHY-RXEND.indicate(UnsupportedRate). If the PLCP header is receivable, but the FCS check of the PLCP header is not valid, a PHY-RXSTART.indicate will not be issued. The PHY shall issue the error condition PHY-RXEND.indicate(FormatViolation). Any data received after the indicated data length are considered pad bits (to fill out an OFDM symbol) and should be discarded. A typical state machine implementation of the receive PLCP is given in Figure 028.



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Fig. 030 PLCP receive procedure for A-PPDU reception in greenfield 20 MHz modes

## 20.4 MIMO-OFDM PMD operating specifications

### 20.4.1 PLME\_SAP sublayer management primitives

Table 20.4.2T1 lists the MIB attributes that may be accessed by the PHY entities and the intralayer of higher level LMEs. These attributes are accessed via the PLME-GET, PLME-SET, PLME-RESET, and PLME-CHARACTERISTICS primitives defined in 10.4.

### 20.4.2 MIMO-OFDM management information base

All MIMO-OFDM PHY MIB attributes are defined in Clause 13, with specific values defined in Table 20.4.2.T1. The column titled “Operational semantics” in Table 20.4.2.T1 contains two types: static and dynamic. Static MIB attributes are fixed and cannot be modified for a given PHY implementation. Dynamic MIB attributes can be modified by some management entity.

**Table 20.4.2T1 MIB attribute default values/ranges**

| Managed Object                             | Default Value / Range                                                 | Operational Semantics |
|--------------------------------------------|-----------------------------------------------------------------------|-----------------------|
| <b>dot11 PHY Operation Table</b>           |                                                                       |                       |
| dot11PHYtype                               | HTP (Value to be assigned)                                            | Static                |
| dot11CurrentRegDomain                      | Implementation dependent                                              | Static                |
| dot11TempType                              | Implementation dependent                                              | Static                |
| <b>dot11 PHY Antenna Table</b>             |                                                                       |                       |
| dot11CurrentTxAntenna                      | Implementation dependent                                              | Dynamic               |
| dot11DiversitySupport                      | Implementation dependent                                              | Static                |
| dot11CurrentRxAntenna                      | Implementation dependent                                              | Dynamic               |
| <b>Dot11 PHY Tx Power Table</b>            |                                                                       |                       |
| dot11NumberSupportedPowerLevels            | Implementation dependent                                              | Static                |
| dot11TxPowerLevel1                         | Implementation dependent                                              | Static                |
| dot11TxPowerLevel2                         | Implementation dependent                                              | Static                |
| dot11TxPowerLevel3                         | Implementation dependent                                              | Static                |
| dot11TxPowerLevel4                         | Implementation dependent                                              | Static                |
| dot11TxPowerLevel5                         | Implementation dependent                                              | Static                |
| dot11TxPowerLevel6                         | Implementation dependent                                              | Static                |
| dot11TxPowerLevel7                         | Implementation dependent                                              | Static                |
| dot11TxPowerLevel8                         | Implementation dependent                                              | Static                |
| dot11CurrentTxPowerLevel                   | Implementation dependent                                              | Dynamic               |
| <b>dot11 Phy DSSS Table</b>                |                                                                       |                       |
| dot11CurrentChannel                        | Implementation dependent                                              | Dynamic               |
| <b>dot11 Reg Domains Supported Table</b>   |                                                                       |                       |
| dot11RegDomainsSupportedValue(s)           | Implementation dependent                                              | Static                |
| <b>dot11 PHY Antennas List Table</b>       |                                                                       |                       |
| dot11SupportedTxAntenna                    | Implementation dependent                                              | Static                |
| dot11SupportedRxAntenna                    | Implementation dependent                                              | Static                |
| dot11DiversitySelectionRx                  | Implementation dependent                                              | Dynamic               |
| <b>dot11 Supported Data Rates Tx Table</b> |                                                                       |                       |
| dot11SupportedDataRatesTxValue             | See Clause 10.4.4.2 rate code columns of Tables 003-009 and Table 016 | Static                |
| <b>dot11 Supported Data Rates Rx Table</b> |                                                                       |                       |
| dot11SupportedDataRatesRxValue             | See Clause 10.4.4.2 rate code columns of Tables 003-009 and Table 016 | Static                |
| <b>dot11 PHY HTP Table</b>                 |                                                                       |                       |

|                                 |                                                                                                                                                     |         |
|---------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------|---------|
| dot11CurrentFrequency           | Implementation dependent                                                                                                                            | Dynamic |
| dot11SupportedTransmissionModes | Assign optional types in TRANSMISSION_MODE of Table 001 to bits in bit mask                                                                         | Static  |
| dot11SupportedNumStreams        | X'0' = Support 1 and 2 streams<br>X'1' = Support 1, 2, and 3 streams<br>X'2' = Support 1, 2, and 4 streams<br>X'3' = Support 1, 2, 3, and 4 streams | Static  |
| dot11SupportedCodeTypes         | X'0' = convolutional only<br>X'1' = convolutional and LDPC                                                                                          | Static  |

### 20.4.3 MIMO-OFDM TXTIME calculation

The value of the TXTIME parameter returned by the PLME-TXTIME.confirm primitive shall be calculated according to the following equation:

$$\text{TXTIME} = \text{TXTIME}_{\text{CONV}} \text{ if CODE\_TYPE is convolutional and } \text{TXTIME}_{\text{LDPC}} \text{ if CODE\_TYPE is LDPC}$$

where

$$\text{TXTIME}_{\text{CONV}} = T_{\text{MIXED}} + T_{\text{PREAMBLE}} + T_{\text{SIGNAL}} + T_{\text{SYM}} \cdot \text{Ceiling}((16 + 8 \cdot \text{LENGTH} + 6)/N_{\text{DBPS}})$$

$$\text{TXTIME}_{\text{LDPC}} = T_{\text{MIXED}} + T_{\text{PREAMBLE}} + T_{\text{SIGNAL}} + T_{\text{SYM}} \cdot N_{\text{S1}}$$

$T_{\text{MIXED}}$  is 20 $\mu\text{s}$  if TRANSMISSION\_MODE is a mixed mode and 0 $\mu\text{s}$  if it is a greenfield mode

$T_{\text{PREAMBLE}}$  is 16 $\mu\text{s}$  if TRANSMISSION\_MODE specifies  $N_{\text{TX}} = 2$  and 28 $\mu\text{s}$  if TRANSMISSION\_MODE specifies  $N_{\text{TX}} = 3$  or 4

$T_{\text{SIGNAL}}$  is 4 $\mu\text{s}$

$N_{\text{DBPS}}$  is derived from the DATARATE parameter (Ceiling is a function that returns the smallest integer value greater than or equal to its argument value)

$N_{\text{S1}}$  is defined in subclause 20.3.5.7.3.

### 20.4.4 MIMO-OFDM PHY characteristics

**Table 20.4.4.1—MIMO-OFDM PHY characteristics**

| Characteristic      | Value                                                                                |
|---------------------|--------------------------------------------------------------------------------------|
| aSlotTime           | 9 $\mu\text{s}$                                                                      |
| aSIFSTime           | 16 $\mu\text{s}$                                                                     |
| aRIFSTime           | 2 $\mu\text{s}$                                                                      |
| aCCATime            | <4 $\mu\text{s}$                                                                     |
| aRxTxTurnaroundTime | Implementation dependent as long as the requirements of aSIFSTime are met.           |
| aTxRxTurnaroundTime | Implementation dependent as long as the requirements of aSIFSTime are met.           |
| aTxPLCPDelay        | Implementation dependent as long as the requirements of aRxTxTurnaroundTime are met. |
| aRxPLCPDelay        | Implementation dependent as long as the requirements of                              |

|                     |                                                                                        |
|---------------------|----------------------------------------------------------------------------------------|
|                     | aSIFSTime and aCCATime are met                                                         |
| aRxTxSwitchTime     | Implementation dependent                                                               |
| aTxRampOnTime       | Implementation dependent as long as the requirements of aRxTxTurnaroundTime are met    |
| aTxRampOffTime      | Implementation dependent as long as the requirements of aSIFSTime are met              |
| ATxRFDelay          | Implementation dependent as long as the requirements of aRxTxTurnaroundTime are met    |
| ARxRFDelay          | Implementation dependent as long as the requirements of aSIFSTime and aCCATime are met |
| aAirPropagationTime | $\ll 1 \mu\text{s}$                                                                    |
| aMACProcessingDelay | $< 2 \mu\text{s}$                                                                      |
| aPreambleLength     | $16 \mu\text{s}$                                                                       |
| aPLCPHeaderLength   | $4 \mu\text{s}$                                                                        |
| aMPDUMaxLength      | 8191                                                                                   |
| aCWmin              | 15                                                                                     |
| aCWmax              | 1023                                                                                   |

## 20.5 MIMO-OFDM operating specifications

### 20.5.1 Scope and field of application

This subclause describes the PMD services provided to the PLCP for the MIMO-OFDM PHY.

### 20.5.2 Overview of service

The MIMO-OFDM sublayer accepts PLCP sublayer service primitives and provides the actual means by which data is transmitted or received from the medium. The combined functions of the MIMO-OFDM PMD sublayer primitives and parameters for the receive function result in a data stream, timing information, and associated received signal parameters being delivered to the PLCP sublayer. A similar functionality is provided for data transmission.

### 20.5.3 Overview of interactions

The primitives associated with the PLCP sublayer to the MIMO-OFDM fall into two basic categories

- a) Service primitives that support PLCP peer-to-peer interactions;
- b) Service primitives that have local significance and that support sublayer-to-sublayer interactions.

### 20.5.4 Basic services and options

All of the service primitives described in this subclause are considered mandatory, unless otherwise specified.

#### 20.5.4.1 PMD\_SAP peer-to-peer service primitives

Table 20.5.4.1 indicates the primitives for peer-to-peer interactions.

**Table 20.5.4.1 PMD\_SAP peer-to-peer services**

| Primitive | Request | Indicate | Confirm | Response |
|-----------|---------|----------|---------|----------|
| PMD Data  | X       | X        |         |          |

#### 20.5.4.2 PMD\_SAP sublayer-to-sublayer service primitives

Table 19.9.4.2 indicates the primitives for sublayer-to-sublayer interactions.

Table 19.9.4.2 PMD\_SAP sublayer-to-sublayer services

| Primitive             | Request | Indicate | Confirm | Response |
|-----------------------|---------|----------|---------|----------|
| PMD_TXSTART           | X       |          |         |          |
| PMD_TXEND             | X       |          |         |          |
| PMD_ANTSEL            | X       |          |         |          |
| PMD_TXPWRLVL          | X       |          |         |          |
| PMD_TRANSMISSION_MODE | X       |          |         |          |
| PMD_NUM_STREAMS       | X       |          |         |          |
| PMD_DATARATE          | X       |          |         |          |
| PMD_RSSI              |         | X        |         |          |

### 20.5.4.3 PMD\_SAP service primitive parameters

Table 19.9.4.3 shows the parameters used by one or more of the PMD\_SAP service primitives.

Table 20.5.4.3 List of parameters for the PMD primitives

| Parameter         | Associated primitive          | Value                                                                                                                                                                                                                           | Description                                                                                                                                               |
|-------------------|-------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------|
| TXD_UNIT          | PMD_DATA.request              | 0 to $(2^n)-1$ , where n is the number of bits per symbol for the transmission mode, number of streams, and data rate specified in PMD_TRANSMISSION_MODE.request, PMD_NUM_STREAMS.request, and PMD_DATARATE.request primitives. | This parameter represents a single block of data, which, in turn, is used by the PMD to be encoded into a transmitted symbol.                             |
| RXD_UNIT          | PMD_DATA.indicate             | 0 to $(2^n)-1$ , where n is the number of bits per symbol for the transmission mode, number of streams, and data rate specified in PMD_TRANSMISSION_MODE.request, PMD_NUM_STREAMS.request, and PMD_DATARATE.request primitives. | This parameter represents a single symbol that has been demodulated by the PMD entity.                                                                    |
| TRANSMISSION_MODE | PMD_TRANSMISSION_MODE.request | See Table 001 in 20.2                                                                                                                                                                                                           | This parameter specifies to the PMD layer, which transmission mode is used.                                                                               |
| ANT_STATE         | PMD_ANTSEL.request            | 1 to 256                                                                                                                                                                                                                        | ANT_STATE selects which of the available antennas is used for transmission. The number of available antennas is determined from the MIB table parameters. |
| TXPWR_LEVEL       | PMD_TXPWRLVL.request          | 1-8                                                                                                                                                                                                                             | TXPWR_LEVEL selects which of the optional transmit power levels should be                                                                                 |

|          |                      |                                                                       |                                                                                                                                   |
|----------|----------------------|-----------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------|
|          |                      |                                                                       | used for the current PPDU transmission. The number of available power levels is determined from the MIB table parameters.         |
| DATARATE | PMD_DATARATE.request | See Clause 10.4.4.2 rate code columns of Tables 003-009 and Table 016 | DATARATE selects which of the data rates is used for PSDU transmission.                                                           |
| RSSI     | PMD_RSSI.indicate    | 8 bits of RSSI (256 levels)                                           | The RSSI is a measure of the RF energy received. Mapping of the RSSI values to actual received power is implementation dependent. |

## 20.5.5 PMD\_SAP detailed service specification

The following subclauses describe the services provided by each PMD primitive.

### 20.5.5.1 PMD\_DATA.request

This primitive is the same as that defined in 17.5.5.1 and 18.4.5.1 except that the parameter TXD\_UNIT is expanded in scope to reflect the supported transmission formats defined in 20.5.4.3.

### 20.5.5.2 PMD\_DATA.indicate

This primitive is the same as that defined in 17.5.5.2 and 18.4.5.2 except that the parameter RXD\_UNIT is expanded in scope to reflect the supported transmission formats defined in 20.5.4.3.

### 20.5.5.3 PMD\_TRANSMISSION\_MODE.request

This primitive is the same as that defined in 18.4.5.3 except that the parameter MODULATION of that section is expanded in scope to reflect the supported transmission formats defined in 20.5.4.3.

### 20.5.5.4 PMD\_TXSTART.request

This primitive is the same as that defined in 17.5.5.3 and 18.4.5.6.

### 20.5.5.5 PMD\_TXEND.request

This primitive is the same as that defined in 17.5.5.4 and 18.4.5.7.

### 20.5.5.6 PMD\_ANTSEL.request

This primitive is the same as that defined in 18.4.5.8, including the definition of the parameter ANT\_STATE.

**20.5.5.7 PMD\_TXPRWLVL.request**

This primitive is the same as that defined in 17.5.5.5, including the definition of the parameter TXPWR\_LEVEL.

**20.5.5.8 PMD\_DATARATE.request**

This primitive is the same as that defined in 17.5.5.6 and 18.4.5.10, except that the parameter DATARATE is expanded in scope to reflect the supported MIMO-OFDM transmission modes as defined in 20.5.4.3.

**20.5.5.9 PMD\_RSSI.indicate**

This primitive is the same as that defined in 17.5.5.7 and 18.4.5.11, including the parameter RSSI. This primitive is used to aid in link optimization algorithms such as roaming decisions.