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Re:	TGd call for comments
Abstract	Proposed changes to WirelessMAN-SC PHY
Purpose	Harmonization with HiperACCESS
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8. PHY

8.1 PHY service specification

8.2 WirelessMAN-SC PHY specification

8.2.1 Overview

This PHY specification, targeted for operation in the 10–66 GHz frequency band, is designed with a high degree of flexibility in order to allow service providers the ability to optimize system deployments with respect to cell planning, cost, radio capabilities, services, and capacity.

In order to allow for flexible spectrum usage, both TDD and FDD configurations (8.2.4) are supported. Both cases use a burst transmission format whose framing mechanism (8.2.5.1) supports adaptive burst profiling in which transmission parameters, including the modulation and coding schemes, may be adjusted individually to each SS on a frame-by-frame basis. The FDD case supports full-duplex SSs as well as half-duplex SSs, which do not transmit and receive simultaneously.

The uplink PHY is based on a combination of TDMA and DAMA. In particular, the uplink channel is divided into a number of time slots. The number of slots assigned for various uses (registration, contention, guard, or user traffic) is controlled by the MAC ~~layer~~ in the BS and may vary over time for optimal performance. The downlink channel is TDM, with the information for each SS multiplexed onto a single stream of data and received by all SSs within the same sector. To support half-duplex FDD SSs, provision is also made for a TDMA portion of the downlink.

The downlink PHY includes a Transmission Convergence sublayer that inserts a pointer byte at the beginning of the payload to help the receiver identify the beginning of a MAC PDU. Data bits coming from the Transmission Convergence sublayer are randomized, FEC encoded, and mapped to a QPSK, 16 quadrature amplitude modulation (QAM), or 64-QAM (optional) signal constellation.

The uplink PHY is based upon TDMA burst transmission. Each burst is designed to carry variable-length MAC PDUs. The transmitter randomizes the incoming data, FEC encodes it, and maps the coded bits to a QPSK, 16-QAM (optional), or 64-QAM (optional) constellation.

8.2.2 PHY SAP parameter definitions

This subclause defines the PHY SAP parameters (8.1.3) used in this PHY specification.

8.2.2.1 SCHED_PARAM_VECTOR

The SCHED_PARAM_VECTOR parameters and values are shown in Table 111.

Table 111—SCHED_PARAM_VECTOR for 10–66 GHz PHY

Parameter	Value
Symbol Rate	16 to 40 (in MBd)
Modulation density	2, 4, or 6

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Table 111—SCHED_PARAM_VECTOR for 10–66 GHz PHY

FEC block size	~~0 to 511~~ 256 bytes
FEC payload	~~0 to 255~~ 239 bytes
Uplink Preamble length	16 or 32 Symbols
PHY Overhead	0 to 256 Symbols

8.2.2.2 DCD_PARAM_VECTOR

The DCD_PARAM_VECTOR parameters and values are shown in Table 112.

Table 112—DCD_PARAM_VECTOR for 10–66 GHz PHY

Parameter	Value
RF Channel number	0 to maximum number of channels allowed in the system
Symbol Rate	16 to 40 (in MBd)
Number of active PHY burst profiles	1-13
Start active region in frame	0-65535 (in symbols)
End active region in frame	0-65535 (in symbols)

8.2.2.3 UCD_PARAM_VEC

The UCD_PARAM_VEC parameters and values are shown in Table 113.

Table 113—UCD_PARAM_VEC for 10–66 GHz PHY

Parameter	Value
RF Channel number	0 to maximum number of channels allowed in the system
Symbol Rate	16 to 40 (in MBd)
Number of active PHY burst profiles	3-12
Start active region in frame	0-65535 (in symbols)
End active region in frame	0-65535 (in symbols)

~~8.2.2.4 RNG_REQ_VECTOR~~

~~The RNG_REQ_VECTOR parameters and values are shown in Table 114.~~

8.2.2.5 RNG_IND_VECTOR

The RNG_IND_VECTOR parameters and values are shown in Table 115.

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~~Table 114—RNG_REQ_VECTOR for 10–66 GHz PHY~~

~~Parameter~~	~~Value~~
~~Frequency change adjustment~~	~~(-1000…+1000) (in KkHz)~~
~~Time alignment~~	~~(-32768…+32767) in quarter symbols~~
~~Power adjust~~	~~(-128…+127) number of 0.5 dB~~

Table 115—RNG_IND_VECTOR for 10–66 GHz PHY

Parameter	Value
~~Frequency deviation~~	~~(-1000…+1000) In KkHz~~
RSSI	(0 to RSSI_MAX) (in dB)
Relative symbol time deviation	-16…15 (in quarter symbols)
Receiver failure	(0-OK, 1-failure)

8.2.2.6 TXVECTOR

The TXVECTOR parameters and values are shown in Table 116.

Table 116—TXVECTOR for 10–66 GHz PHY

Parameter	Value
Symbol Rate	16 to 40 (in MBd)
Burst profile used	0-15
Start transmit in frame	0-65535 (in symbols)
End transmit in frame	0-65535 (in symbols)
Actual number of bytes transmitted	0-65535 (in bytes)

8.2.2.7 TXSTATUS

The TXSTATUS parameters and values are shown in Table 117.

8.2.2.8 RXVECTOR

The RXVECTOR parameters and values are shown in Table 118.

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Table 117—TXSTATUS for 10–66 GHz PHY

Parameter	Value
Overrun	(0-65535) in symbols, 0 indicates no-overrun
Underrun	(0-65535) in symbols, 0 indicates no-underrun

Table 118—RXVECTOR for 10–66 GHz PHY

Parameter	Value
Symbol Rate	16 to 40 (in MBd)
Burst profile used	0-15
Start Receive in frame	0-65535 (in symbols)
End Receive in frame	0-65535 (in symbols)
Actual number of bytes expected	0-65535 (in bytes)

8.2.2.9 RXSTATUS

The RXSTATUS parameters and values are shown in Table 119.

Table 119—RXSTATUS for 10–66 GHz PHY

Parameter	Value
RSSI level	(0 to RSSI_MAX) in dB
Number of bytes received	(0-65535) in bytes
Relative symbol time deviation	-16…15 (in quarter symbols)
Estimated number of byte errors	(0-65535) in bytes
Overrun	(0-65535) in symbols, 0 indicates no-overrun
Underrun	(0-65535) in symbols, 0 indicates no-underrun
Integrity	0 (valid data), 1 (invalid data)

8.2.3 Framing

This PHY specification operates in a framed format (6.4.7). Within each frame are a downlink subframe and an uplink subframe. The downlink subframe begins with information necessary for frame synchronization and control. In the TDD case, the downlink subframe comes first, followed by the uplink subframe. In the FDD case, uplink transmissions occur concurrently with the downlink frame.

Each SS shall attempt to receive all portions of the downlink except for those bursts whose burst profile is either not implemented by the SS or is less robust than the SS's current operational downlink burst profile. Half-duplex SSs shall not attempt to listen to portions of the downlink coincident with their allocated uplink transmission, if any, adjusted by their Tx time advance.

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8.2.3.1 Supported frame durations

Table 120 indicates the supported frame durations.

Table 120—Frame durations and frame duration codes

Frame duration code	Frame duration (T_F)	Units
~~0x01~~	~~0.5~~	~~ms~~
0x02	1	ms
~~0x03~~	~~2~~	~~ms~~

8.2.4 Duplexing techniques and PHY Type parameter encodings

Both FDD and TDD are supported. The duplexing method shall be reflected in the PHY Type parameter (11.1.2.1) as shown in Table 121.

Table 121—PHY Type parameter encoding

PHY Type	Value
TDD	0
FDD	1

8.2.4.1 FDD operation

In FDD operation, the uplink and downlink channels are on separate frequencies. The capability of the downlink to be transmitted in bursts facilitates the use of different modulation types and allows the system to simultaneously support full-duplex SSs (which can transmit and receive simultaneously) and half-duplex SSs (which do not). Note that the downlink carrier may be continuous, as demonstrated in Figure 138 (third frame). Figure 138 describes the basics of the FDD operation.

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In the case of a half-duplex SS, transition gaps, as described in 8.2.4.2.1 and 8.2.4.2.2, apply.

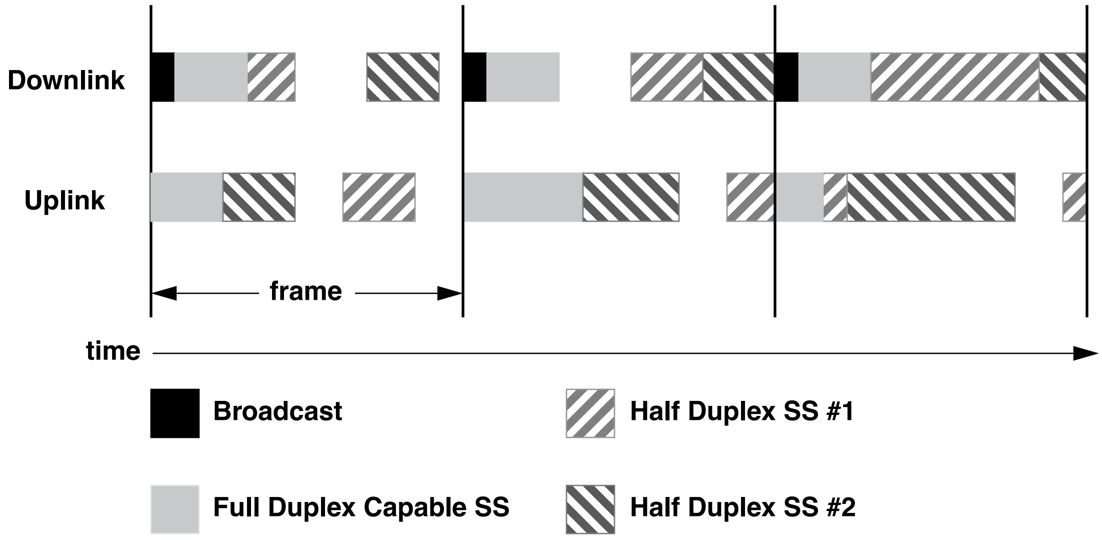

Figure 138—Example of FDD bandwidth allocation

8.2.4.2 TDD operation

In the case of TDD, the uplink and downlink transmissions share the same frequency but are separated in time, as shown in Figure 139. A TDD frame also has a fixed duration and contains one downlink and one uplink subframe. The TDD framing is adaptive in that the link capacity allocated to the downlink versus the uplink may vary.

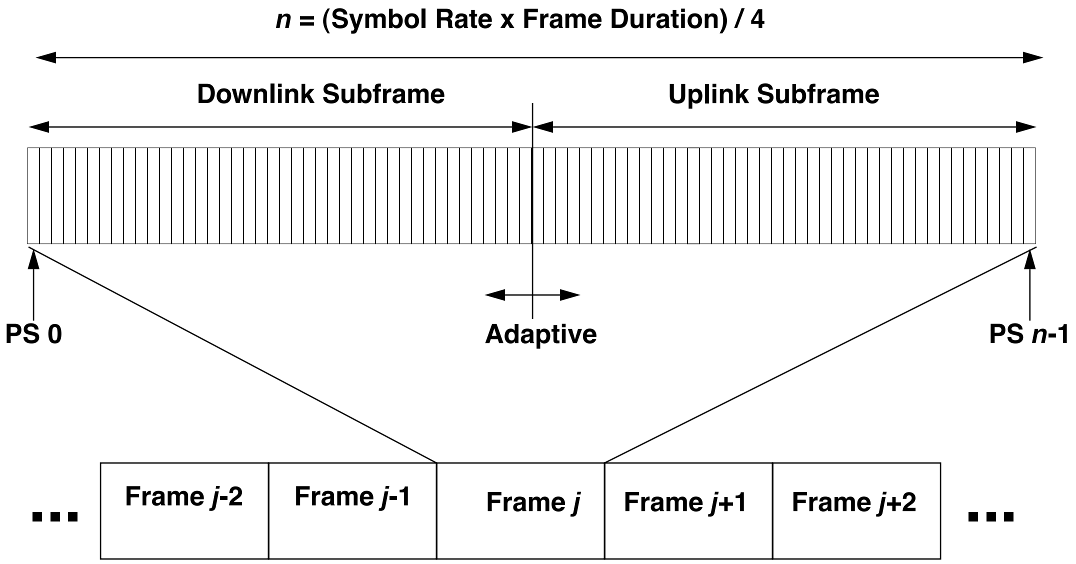

Figure 139—TDD frame structure

8.2.4.2.1 TTG

The TTG is a gap between the downlink burst and the subsequent uplink burst. This gap allows time for the BS to switch from transmit to receive mode and SSs to switch from receive to transmit mode. During this gap, the BS and SS are not transmitting modulated data but simply allowing the BS transmitter carrier to ramp down, the transmit/receive (Tx/Rx) antenna switch to actuate, and the BS receiver section to activate. After the gap, the BS receiver shall look for the first symbols of uplink burst. This gap is an integer number of PS durations and starts on a PS boundary.

8.2.4.2.2 RTG

The RTG is a gap between the uplink burst and the subsequent downlink burst. This gap allows time for the BS to switch from receive to transmit mode and SSs to switch from transmit to receive mode. During this gap, the BS and SS are not transmitting modulated data but simply allowing the BS transmitter carrier to ramp up, the Tx/Rx antenna switch to actuate, and the SS receiver sections to activate. After the gap, the SS receivers shall look for the first symbols of QPSK modulated data in the downlink burst. This gap is an integer number of PS durations and starts on a PS boundary.

8.2.5 Downlink PHY

The available bandwidth in the downlink direction is defined with a granularity of one PS. The available bandwidth in the uplink direction is defined with a granularity of one minislot, where the minislot length is 2^m PSs (m ranges from 0 through 7). The number of PSs with each frame is a function of the symbol rate. The symbol rate is selected in order to obtain an integral number of PSs within each frame. For example, with a 20 MBd symbol rate, there are 5000 PSs within a 1 ms frame.

8.2.5.1 Downlink subframe

The structure of the downlink subframe using TDD is illustrated in Figure 140. The downlink subframe begins with a Frame Start Preamble used by the PHY for synchronization and equalization. This is followed by the frame control section, containing DL-MAP and UL-MAP stating the PSs at which bursts begin. The following TDM portion carries the data, organized into bursts with different burst profiles and therefore different level of transmission robustness. The bursts are transmitted in order of decreasing robustness. For example, with the use of a single FEC type with fixed parameters, data begins with QPSK modulation, followed by 16-QAM, followed by 64-QAM. In the case of TDD, a TTG separates the downlink subframe from the uplink subframe.

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Each SS receives and decodes the control information of the downlink and looks for MAC headers indicating data for that SS in the remainder of the downlink subframe.

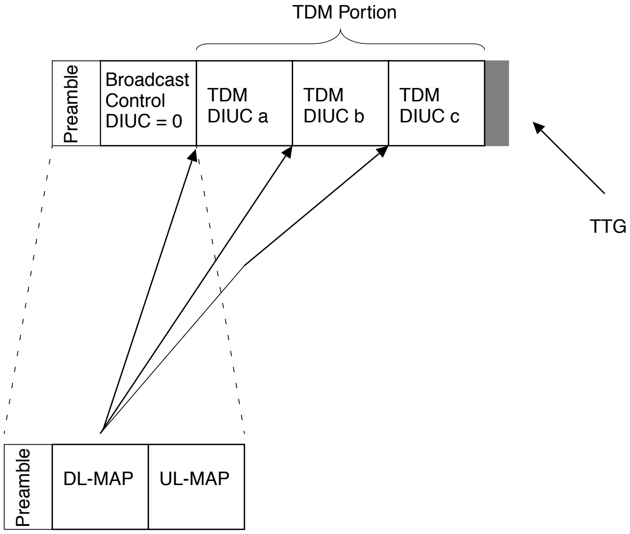

Figure 140—TDD downlink subframe structure

In the FDD case, the structure of the downlink subframe is illustrated in Figure 141. Like the TDD case, the downlink subframe begins with a Frame Start Preamble followed by a frame control section and a TDM portion organized into bursts transmitted in decreasing order of burst profile robustness. This TDM portion of the downlink subframe contains data transmitted to one or more of the following:

- full-duplex SSs
- half-duplex SSs scheduled to transmit later in the frame than they receive
- half-duplex SSs not scheduled to transmit in this frame.

The FDD downlink subframe continues with a TDMA portion used to transmit data to any half-duplex SSs scheduled to transmit earlier in the frame than they receive. This allows an individual SS to decode a specific portion of the downlink without the need to decode the entire downlink subframe. In the TDMA portion, each burst begins with the Downlink TDMA Burst Preamble for phase resynchronization. Bursts in the TDMA portion need not be ordered by burst profile robustness. The FDD frame control section includes a map of both the TDM and TDMA bursts.

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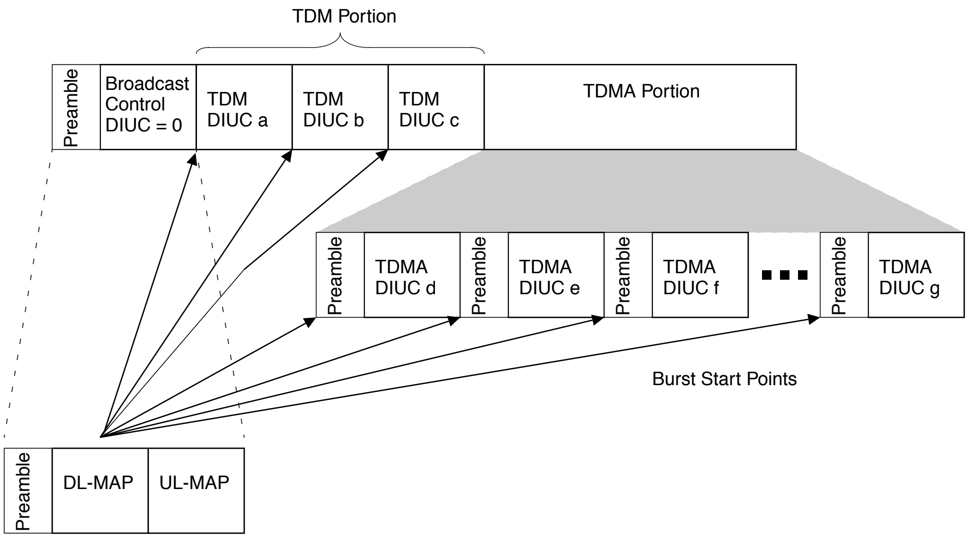

Figure 141—FDD downlink subframe structure

The TDD downlink subframe, which inherently contains data transmitted to SSs that transmit later in the frame than they receive, is identical in structure to the FDD downlink subframe for a frame in which no half-duplex SSs are scheduled to transmit before they receive.

8.2.5.1.1 Downlink burst preambles

As shown in Table 122, two downlink burst preambles are used. The Frame Start Preamble shall begin each downlink frame. The Downlink TDMA Burst Preamble shall begin each TDMA burst in the TDMA portion of the downlink subframe.

Table 122—Downlink burst preambles

Preamble name	Burst profile	Preamble Type	Modulation Type
Frame Start Preamble	TDM Burst	1	QPSK
Downlink TDMA Burst Preamble	TDMA Burst	2	QPSK

Both preambles use QPSK modulation and are based upon +45 degrees rotated constant amplitude zero autocorrelation (CAZAC) sequences (Milewski [B37]). The amplitude of the preamble shall depend on the downlink power adjustment rule (8.2.5.4.7). In the case of the constant peak power scheme (power adjustment rule=0), the preamble shall be transmitted such that its constellation points coincide with the outermost constellation points of the modulation(s) scheme in the burst. In the case of the constant mean power scheme (power adjustment rule=1), it shall be transmitted with the mean power of the constellation points of the modulation scheme(s) in the burst.

The Frame Start Preamble (Table 123) consists of a 32-symbol sequence generated by repeating a 16 symbol CAZAC sequence. The Downlink TDMA Burst Preamble (Table 124) consists of a 16 symbol sequence generated by repeating an 8-symbol CAZAC sequence.

Table 123—Frame start preamble

Symbol	I	Q	B(1)	B(2)
1 and 17	1	1	0	0
2 and 18	~~–1~~ 1	1	~~1~~ 0	0
3 and 19	–1	~~–1~~ 1	1	~~1~~ 0
4 and 20	~~1~~ -1	–1	~~0~~ 1	1
5 and 21	~~1~~ -1	1	~~0~~ 1	0
6 and 22	~~–1~~ 1	–1	~~1~~ 0	1
7 and 23	~~1~~ -1	1	~~0~~ 1	0
8 and 24	~~–1~~ 1	~~–1~~ 1	~~1~~ 0	~~1~~ 0
9 and 25	~~1~~ -1	~~1~~ -1	~~0~~ 1	~~0~~ 1
10 and 26	~~1~~ -1	–1	~~0~~ 1	1
11 and 27	–1	~~–1~~ 1	1	~~1~~ 0
12 and 28	–1	~~1~~ -1	1	~~0~~ 1
13 and 29	1	~~1~~ -1	0	~~0~~ 1
14 and 30	~~1~~ -1	1	~~0~~ 1	0
15 and 31	~~1~~ -1	1	~~0~~ 1	0
16 and 32	1	1	0	0

Table 124—Downlink TDMA burst preamble

Symbol	I	Q	B(1)	B(2)
1 and 9	~~1~~ -1	~~1~~ -1	~~0~~ 1	~~0~~ 1
2 and 10	~~1~~ -1	1	~~0~~ 1	0
3 and 11	~~1~~ -1	~~1~~ -1	~~0~~ 1	~~0~~ 1
4 and 12	~~–1~~ 1	1	~~1~~ 0	0
5 and 13	~~–1~~ 1	~~–1~~ 1	~~1~~ 0	~~1~~ 0
6 and 14	~~1~~ -1	1	~~0~~ 1	0
7 and 15	~~–1~~ 1	~~–1~~ 1	~~1~~ 0	~~1~~ 0
8 and 16	~~–1~~ 1	1	~~1~~ 0	0

8.2.5.1.2 Frame control section

The frame control section is the first portion of the downlink frame following the preamble. It is used for control information destined for all SSs. This control information shall not be encrypted. The information transmitted in this section always uses the well-known downlink burst profile with DIUC=0.

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The frame control section shall contain a DL-MAP message (6.4.2.3.2) for the channel followed by one UL-MAP message (6.4.2.3.4) for each associated uplink channel. In addition, it may contain DCD and UCD messages (6.4.2.3.1 and 6.4.2.3.3) following the last UL-MAP message. No other messages shall be sent in the frame control section.

8.2.5.1.2.1 DL-MAP elements

The IEs as defined in Table 125 follow the Number of DL-MAP Elements field of the DL-MAP message, as described in 6.4.2.3.2. The Map IEs shall be in chronological order. Note that this is not necessarily DIUC order (as DIUC numbering does not necessarily reflect robustness of the burst profile) or CID order.

Table 125—DL_MAP_~~Information_Element~~IE

Syntax	Size	Notes
DL_MAP_~~Information_Element~~IE() {		
DIUC	4	
StartPS	16	the starting point of the burst, in units of PS where the first PS in a given frame has StartPS=0
}		

8.2.5.1.2.2 DL-MAP PHY synchronization field definition

The format of the PHY Synchronization Field of the DL-MAP message, as described in 6.4.2.3.2, is given in Table 126. The Frame Duration Codes are given in Table 120. The Frame Number is incremented by 1 each frame and eventually wraps around to zero.

Table 126—PHY synchronization field

Syntax	Size	Notes
PHY Synchronization Field() {		
Frame Duration Code()	8 bits	
Frame Number	24 bits	
}		

8.2.5.1.2.3 UL-MAP allocation start time definition

The allocation start time (Alloc Start Time) is the effective start time of the uplink allocation defined by the UL-MAP in units of minislots. The start time is relative to the start of the frame in which the UL-MAP message is transmitted.

8.2.5.1.2.4 Required DCD parameters

The following parameters shall be included in the DCD message:

- BS Transmit Power [Note: to be used by SSs to validate radio link conditions]
- PHY type
- FDD/TDD frame duration

8.2.5.1.2.5 Downlink_Burst_Profile

Each Downlink_Burst_Profile in the DCD message (6.4.2.3.1) shall include the following parameters:

- Modulation type
- FEC Code Type
- Last codeword length
- DIUC mandatory exit threshold
- DIUC minimum entry threshold
- Preamble Presence

If the FEC Code Type is 1~~, 2, or 3 (RS codes)~~, the Downlink_Burst_Profile shall also include

- RS information bytes (*K*)
- ~~RS parity bytes (*R*)~~ convolutional code rate (r).

~~If the FEC Code Type is 2, the Downlink_Burst_Profile shall also include~~

- ~~BCC code type~~

If the FEC Code Type is 42, the Downlink_Burst_Profile shall also include

- Block Turbo Code (BTC) row code type
- BTC column code type
- BTC interleaving type

The mapping between Burst Profile and DIUC is given in Table 127.

Table 127—Mapping of burst profile to DIUC

Burst profile	DIUC
Downlink Burst Profile 1	0
Downlink Burst Profile 2	1
Downlink Burst Profile 3	2
Downlink Burst Profile 4	3
Downlink Burst Profile 5	4
Downlink Burst Profile 6	5
Downlink Burst Profile 7	6
Downlink Burst Profile 8	7
Downlink Burst Profile 9	8
Downlink Burst Profile 10	9

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Table 127—Mapping of burst profile to DIUC *(continued)*

Burst profile	DIUC
Downlink Burst Profile 11	10
Downlink Burst Profile 12	11
Downlink Burst Profile 13	12
Reserved	13
Gap	14
End of DL-MAP	15

The Downlink Burst Profile 1 (DIUC=0) parameters defined in 8.2.5.4.5 shall be stored in the SS and shall not be included in the DCD message.

The Gap Downlink Burst Profile (DIUC=14) indicates a silent interval in downlink transmission. It is well-known and shall not be defined in the DCD message.

The End of DL-MAP Burst Profile (DIUC=15) indicates the first PS after the end of the ~~DL~~downlink subframe. It is well known and shall not be included in the DCD message.

Table 128 defines the format of the Downlink_Burst_Profile, which is used in the DCD message (6.4.2.3.1). The Downlink_Burst_Profile is encoded with a Type of 1, an 8 bit length, and a 4 bit DIUC. The DIUC field is associated with the Downlink Burst Profile and Thresholds. The DIUC value is used in the DL-MAP message to specify the Burst Profile to be used for a specific downlink burst.

Table 128—Downlink_Burst_Profile format

Syntax	Size	Notes
Type=1	8 bits	
Length	Variable	
reserved	4 bits	shall be set to zero
DIUC	4 bits	
TLV encoded information	Variable	TLV Specific

8.2.5.2 Downlink burst allocation

The downlink data sections are used for transmitting data and control messages to the specific SSs. The data are always FEC coded and are transmitted at the current operating modulation of the individual SS. In the TDM portion, data shall be transmitted in order of decreasing burst profile robustness. In the case of a TDMA portion, the data are grouped into separately delineated bursts that need not be in robustness order (see 8.2.5.1). The DL-MAP message contains a map stating at which PS the burst profile changes occur. In case of TDMA, if the downlink data does not fill the entire downlink subframe, the transmitter is shut down. FEC codewords within a burst are arranged in a compact form aligned to bit-level boundaries. This implies that, while the first FEC codeword shall start on the first PS boundary, succeeding FEC codewords may start even within a modulation symbol or within a PS if the succeeding FEC codeword ended within a modulation symbol or within a PS. The exact alignment conditions depend on the burst profile parameters.

In the case of shortening the last FEC block within a burst (optional, see 11.1.2.2), the DL-MAP provides an implicit indication.

In general, the number of PSs *i* (which shall be an integer) allocated to a particular burst can be calculated from the DL-MAP, which indicates the starting position of each burst as well as the burst profiles. Let *n* denote the minimum number of PSs required for one FEC codeword of the given burst profile (note that *n* is not necessarily an integer). Then $i=kn+j+q$, where *k* is the number of whole FEC codewords that fit in the burst, *j* (not necessarily an integer) is the number of PSs occupied by the largest possible shortened codeword, and *q* ($0 \le q < 1$) is the number of PSs occupied by pad bits inserted at the end of the burst to guarantee that *i* is an integer. In Fixed Codeword Operation ~~0~~, *j* is always 0. Recall that a codeword can end partway through a modulation symbol as well as partway through a PS. When this occurs, the next codeword shall start immediately, with no pad bits inserted. At the end of the burst (i.e., when there is no next codeword), then $4q$ symbols are added as padding (if required) to complete the PS allocated in the DL-MAP. The number of padding bits in these padding symbols is $4q$ times the modulation density, where the modulation density is 2 for QPSK, 4 for 16-QAM, and 6 for 64-QAM. Note that padding bits may be required with or without shortening. Either *k* or *j*, but not both, may be zero. The number *j* implies some number of bits *b*. Assuming *j* is nonzero, it shall be large enough such that *b* is larger than the number of FEC bits, *r*, added by the FEC scheme for the burst. The number of bits (preferably an integral number of bytes) available for user data in the shortened FEC codeword is $b–r$. Any bits that may be left over from a fractional byte are encoded as binary 1 to ensure compatibility with the choice of 0xFF for pad. A codeword cannot have less than 6 information bytes. This is illustrated in Figure 142.

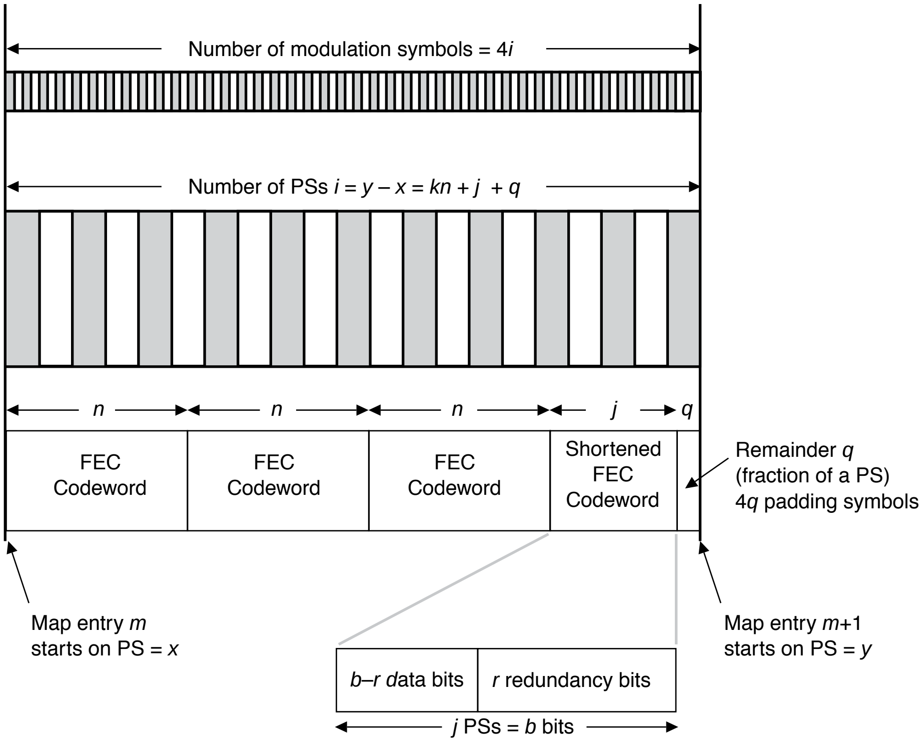


Figure 142—DL-MAP usage with shortened FEC blocks—TDM case

In the case of TDMA downlink, a burst includes the Downlink TDMA Burst Preamble of length *p* PSs, and the DL-MAP entry points to its beginning (Figure 143).

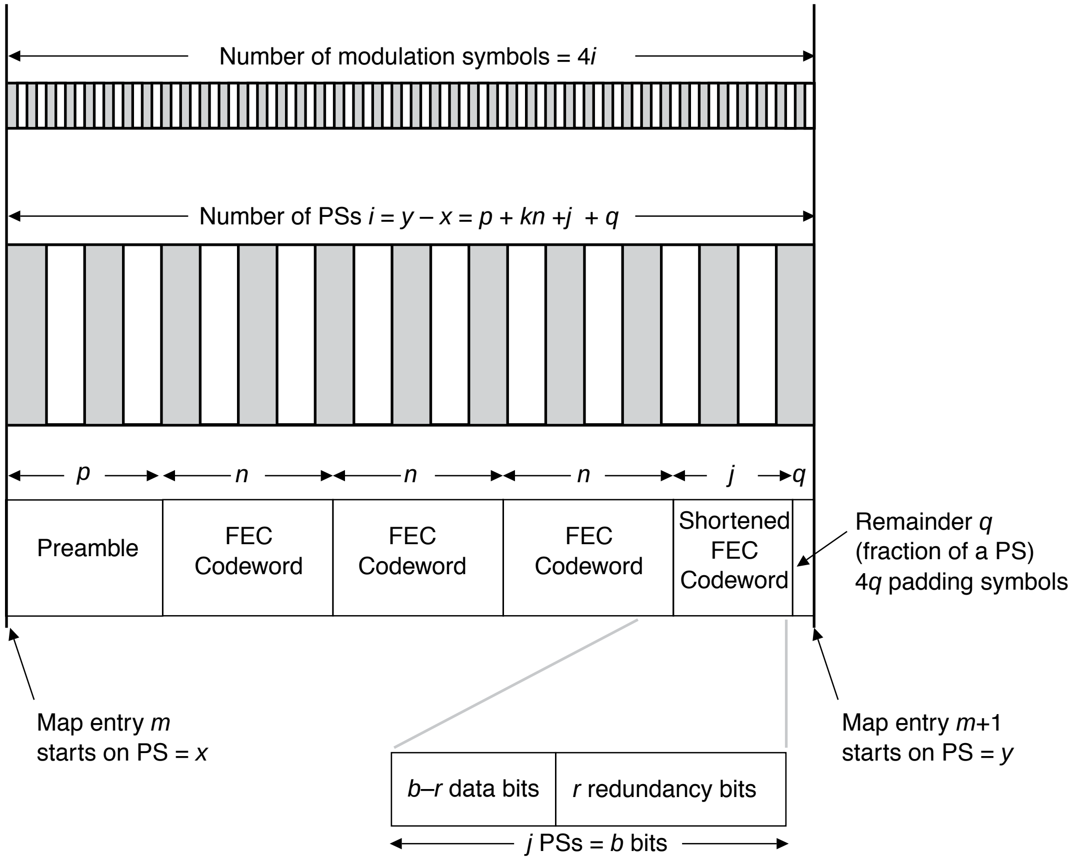
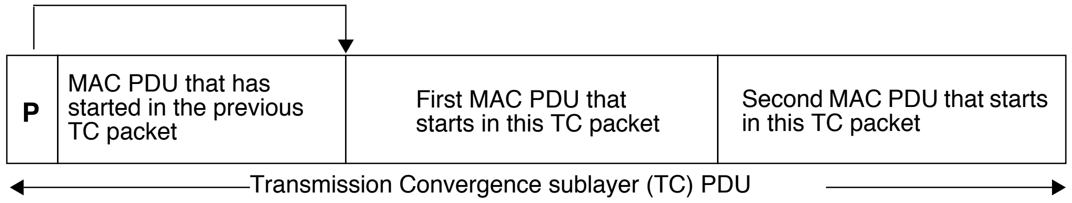


Figure 143—DL-MAP usage with shortened FEC blocks—TDMA case

8.2.5.3 Downlink Transmission Convergence sublayer

The downlink payload shall be segmented into blocks of data designed to fit into the proper codeword size after the CS pointer byte is added. Note that the payload length may vary, depending on whether shortening of codewords is allowed or not for this burst profile. A pointer byte shall be added to each payload segment, as illustrated in Figure 144.



P = 1 byte pointer field

Figure 144—Format of the downlink Transmission Convergence sublayer PDU

The pointer field identifies the byte number in the packet which indicates either the beginning of the first MAC PDU to start in the packet or the beginning of any stuff bytes that precede the next MAC PDU. For reference, the first byte in the packet is referred to as byte number 1. If no MAC PDU or stuff bytes begin in the CS packet, then the pointer byte is set to 0. When no data is available to transmit, a stuff_byte pattern having a value (0xFF) shall be used within the payload to fill any gaps between the IEEE Std 802.16~~-2001~~ MAC PDUs. This value is chosen as an unused value for the first byte of the IEEE Std 802.16~~-2001~~ MAC PDU, which is designed to never have this value.

8.2.5.4 Downlink PMD sublayer

The downlink PHY coding and modulation for this mode is summarized in the block diagram in Figure 145.

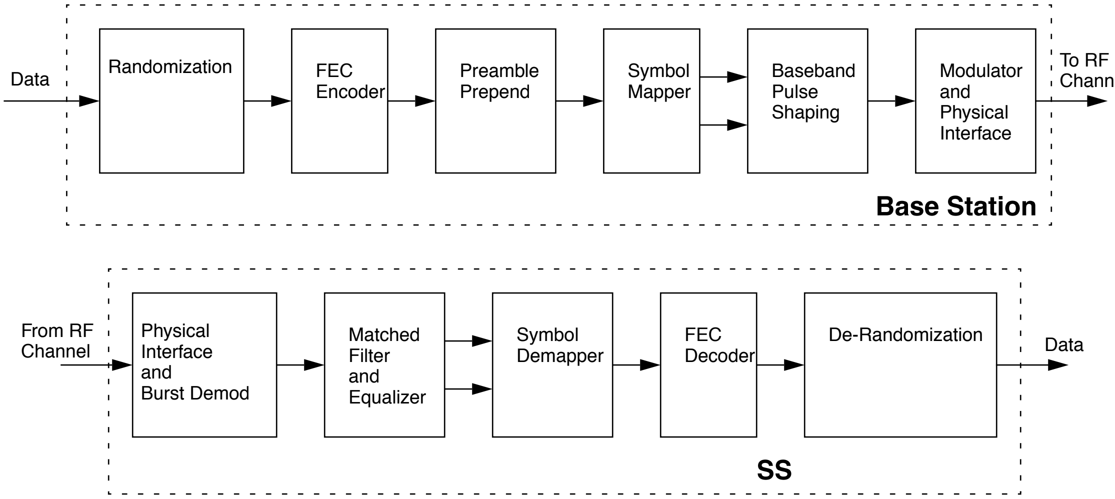


Figure 145—Conceptual block diagram of the downlink PMD sublayer

8.2.5.4.1 Burst profile definitions

The downlink channel supports adaptive burst profiling on the user data portion of the frame. Up to twelve burst profiles can be defined. The parameters of each are communicated to the SSs via MAC messages during the frame control section of the downlink frame (see 8.2.5.1). The downlink channel and burst profiles are communicated to the SSs via the MAC messages described in 6.4.2.3.1.

The use of DIUCs shall be constrained as shown in Table 129.

Table 129—DIUC allocation

DIUC	Usage
0	frame control (well known, not in DCD message)
1-6	TDM Burst Profiles (no preamble)
7-12	TDMA Burst Profiles (preamble prefixed)
13	*Reserved*
14	Gap (well known, not in DCD message)
15	End of Map

8.2.5.4.2 Downlink PHY SS capability set parameters

Since there are optional modulation and FEC schemes that can be implemented at the SS, a method for identifying the capability to the BS is required (i.e., including the highest order modulation supported, the optional FEC coding schemes supported, and the minimum shortened last codeword length supported). This information shall be communicated to the BS during the subscriber registration period.

8.2.5.4.3 Randomization

Randomization shall be employed to minimize the possibility of transmission of an unmodulated carrier and to ensure adequate numbers of bit transitions to support clock recovery. The stream of downlink packets shall be randomized by modulo-2 addition of the data with the output of the pseudo-random binary sequence (PRBS) generator, as illustrated in Figure 146. The generator polynomial for the PRBS shall be $c(x) = x^{15} + x^{14} + 1$.

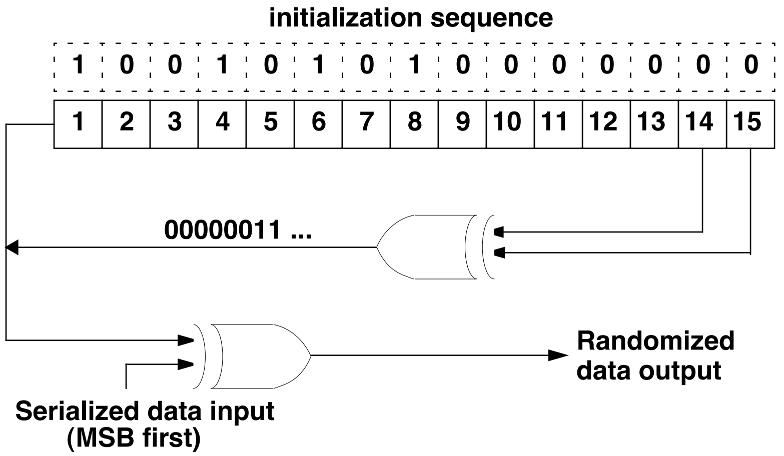


Figure 146—Randomizer logic diagram

At the beginning of each burst, the PRBS register is cleared and the seed value of 100101010000000 is loaded. A burst corresponds to either a TDM burst beginning with the Frame Start Preamble or a TDMA burst beginning with a Downlink TDMA Burst Preamble (8.2.5.1.1). The seed value shall be used to calculate the randomization bits, which are combined in an XOR operation with the serialized bit stream of each burst. The randomizer sequence is applied only to information bits.

8.2.5.4.4 Downlink FEC

Two channel coding schemes are adopted for forward error correction. The first one, being mandatory is based on a concatenated Reed-Solomon with convolutional coding. The second optional coding scheme is based on Turbo code. Both coding schemes can provide different code-rates.

The FEC schemes are selectable from the types in Table 130.

Implementation and use of Code Types 2~~3 and 4~~ is optional. Code Types 1 ~~and 2~~ shall be implemented by all BSs and SSs. ~~Code Type 2 shall not be used except in the case of QPSK modulation. In the case of QPSK, any of the four Code Types may be used, with one exception: Code Type 2 shall always be used for the control channel (DIUC=0).~~

Table 130—FEC Code Types

Code Type	Outer Code	Inner Code
~~1~~	~~Reed–Solomon over Galois field (GF) (256)~~	~~None~~
~~2~~ 1	Reed–Solomon over GF(256), T=8	(~~24,16~~) ~~Block~~ Convolutional code, Memory 8 with mother code rate 1/2. The following code rate r shall be supported: - 1/2 (only for QPSK, and DL-control portion)) - 2/3 (only for QPSK) - 5/6 (only for 64-QAM) - 7/8 (only for 16-QAM) r=1, no inner coding (for all modulations)
~~3 (Optional)~~	~~Reed–Solomon over GF(256)~~	~~(9,8) Parity check code~~
~~4~~ 2(Optional)	BTC	—

Following is a summary of the two ~~four~~ Code Types:

a) ***Code Type 1:*** ~~*Reed–Solomon only:* This case is useful either for a large data block or when high coding rate is required. The protection could vary between *t*=0 to *t*=16.~~ *Reed–Solomon + convolutional code (soft decodable):* This case is useful for low to moderate coding rates providing good carrier-to-noise ratio (C/N) enhancements. The mother code rate of the inner convolutional code is 1/2. By punctring, from the mother code, several high rate codes can be derived.

~~b)~~ ~~***Code Type 2:*** *Reed–Solomon + Block convolutional code (soft decodable):* This case is useful for low to moderate coding rates providing good carrier-to-noise ratio (C/N) enhancements. The coding rate of the inner block convolutional code (BCC) is 2/3. Note: The number of information bytes shall be even in this case.~~

~~c)~~ ~~***Code Type 3:*** *Reed–Solomon + Parity check:* This optional code is useful for moderate to high coding rates with small to medium size blocks (i.e., *K* = 16, 53 or 128). The code itself is a simple bit wise parity check operating on byte (8-bit) level. The parity code can be used for error correction, preferably employing a soft decoder.~~

d) ***Code Type 2~~4:~~*** *BTC:* This optional code is used to significantly lower the required carrier-to-interference ratio (C/I) level needed for reliable communication, and can be used to either extend the range of a BS or increase the code rate for greater throughput.

8.2.5.4.4.1 Concatenated Coding Scheme

The mandatory FEC coding scheme is based on a concatenated coding scheme. The outer code shall be a shortened Reed-Solomon (RS) code and the inner code shall be a punctured convolutional code (CC) (see figure 153). The coding scheme is flexible. It provides different outer and inner code rates (from1/2 to 1, where 1 means no use of inner CC, i.e. only outer RS code).

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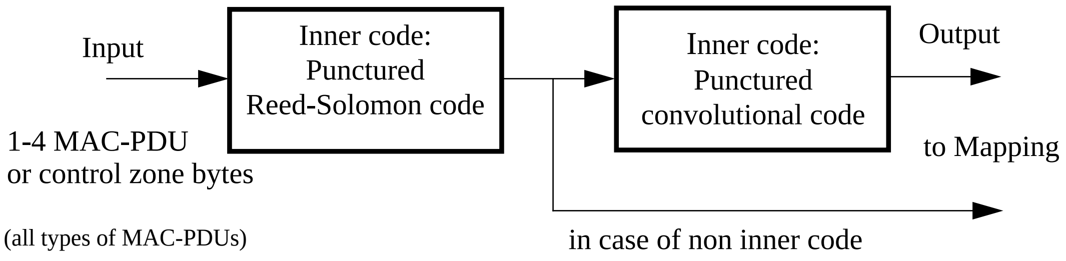

Figure 147—Mandatory channel coding scheme

8.2.5.4.4.1.1 Outer Reed Solomon code

The outer Reed Solomon block code ~~for Code Types 1-3~~ shall be a shortened, systematic Reed–Solomon code RS (K + 16, K, T=8) generated from GF(256) with information block length *K* variable from 6-~~255~~239 bytes and error correction capability *T* ~~able to correct~~ = 8 ~~from 0 to 16~~ bytes ~~errors~~. The specified code generator polynomials are given by:

$$\textit{Code Generator Polynomial: } g(\mathrm{x}) = (x+\mu^0)(x+\mu^1)(x+\mu^2)\ \ldots\ (x+\mu^{\cancel{2T-1}\underline{15}}),\ \text{where } \mu = 02_{\mathrm{hex}}$$

$$\textit{Field Generator Polynomial: } p(x) = x^8 + x^4 + x^3 + x^2 + 1$$

~~The specified code has a block length of 255 bytes and is shall be configured as an RS(K+16, K255-*R*) code with information bytes preceded by (255-*N*) zero symbols, where *N* is the codeword length and *R* the number of redundancy bytes (*R* = 2**T* ranges from 0 to 32, inclusive).~~

The value of *K* ~~and *T* are~~ is specified for each burst profile by the MAC. Both Fixed Codeword Operation and Shortened Last Codeword Operation, as defined below, are allowed.

~~When using Code Type 2, the number of information bytes *K* shall always be an even number so that the total codeword size (*K*+*R*) is also an even number. This is due to the fact that the BCC code requires a pair of bytes on which to operate.~~

a) Fixed Codeword Operation

In Fixed Codeword Operation, the number of information bytes *K* is the same in each Reed–Solomon codeword. If the MAC messages in a burst require fewer bytes than are carried by an integral number of codewords, stuff bytes ($\mathrm{FF}_{\mathrm{hex}}$) shall be added between MAC messages or after the last MAC message so that the total message length is an integral multiple of *K* bytes.

The SS determines the number of codewords in its downlink burst from the DL-MAP message, which defines the beginning point of each burst, and hence the length. The BS determines the number of codewords in the downlink as it scheduled this transmission event and is aware about its length. Using the burst length, both the SS and the BS calculate the number of full-length RS codewords that can be carried by each burst.

The process used by the BS to encode each burst is described below:

When the number of randomized MAC message bytes (*M*) entering the FEC process is less than *K* bytes, Operation A shall be performed:

A1) Add (~~*K*~~*239*-*M*) stuff bytes (FFhex) **to the *M* byte block as a ~~suffix~~ prefix.**

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A2) RS encode the ~~*K*~~*239* bytes and append the *R=16* parity bytes.
A3) Serialize the bytes and transmit them to the inner coder or the modulator ~~MSB~~most significnat bit first.

When the number of randomized MAC message bytes (M) entering the FEC process is greater than or equal to K bytes, Operation B shall be performed:

B1) RS encode the first K bytes and append the R parity bytes.
B2) Subtract K from M (Let $M=M–K$).
B3) If the new M is greater than or equal to K, then repeat with the next set of bytes (go to B1).
B4) If the new M is zero, then stop; otherwise go to step A1 above and process the $M<K$ case.

b) Shortened Last Codeword Operation

In the Shortened Last Codeword Operation, the number of information bytes in the final Reed–Solomon block of each burst is reduced from the normal number K, while the number of parity bytes R remains the same. The BS tailors the number of information bytes in the last codeword in order to minimize the number of stuff bytes to add to the end of the MAC message. The length of the burst is then set to the minimum number of PSs required to transport all of the burst's bytes, which include preamble, information, and parity bytes. The BS implicitly communicates the number of bytes in the shortened last codeword to the SS via the DL-MAP message, which defines the starting PS of each burst. The SS uses the DL-MAP information to calculate the number of full-length RS codewords and the length of the shortened last codeword that can be carried within the specified burst size. The BS performs a similar calculation as the SS for its encoding purposes.

To allow the receiving hardware to decode the previous Reed–Solomon codeword, no Reed–Solomon codeword shall have less than 6 information bytes. The number of information bytes carried by the shortened last codeword shall be between 6 and K bytes, inclusive. If the number of information bytes needing to be sent by the BS is less than 6 bytes of data, stuff bytes (FF_{hex}) shall be appended to the end of the data to bring the total number of information bytes up to the minimum of 6.

~~When using Code Type 2, the number of information bytes in the shortened last codeword shall always be an even number so that the total codeword size is also an even number. If an odd number of information bytes needs to be sent, a stuff byte (~~FF_{hex}~~) shall be appended to the end of the message to obtain an even number of bytes.~~

The process used by the BS to encode each burst is described below:

First, the full-sized Reed–Solomon codewords that precede the burst's final codeword are encoded as in the Fixed Codeword Mode above. The number of bytes allocated for the shortened last codeword by the UL-MAP is k' bytes, which shall be between 6 and K bytes. The remaining M bytes of the message are then encoded into these k' bytes using the following procedure:

A1) Add (~~*K*~~ *239*-*k´*) zero bytes to the *M* byte block as a prefix.
A2) RS encode the ~~*K*~~ *239* bytes and append the *R=16* parity bytes.
A3) Discard all of the (~~*K*~~ *239*-*k´*) zero RS symbols.
A4) Serialize the bytes and transmit them to the inner coder or the modulator ~~msb~~most significnat bit first.
A5) Perform the inner coding operation (if applicable).

~~8.2.5.4.4.2 Inner code for Code Type 2, downlink~~

8.2.5.4.4.1.2 Inner convolutional code

The inner code shall be a punctured convolutional code that shall provide from the mother code memory 6 (64 states), rate 1/2, a wide range of higher inner code rates r, e.g. r = 2/3, 5/6 and 7/8. The generator polynomial of the mother convolutional code shall be: $G_1 = 171_{oct}$, $G2 = 133_{oct}$.

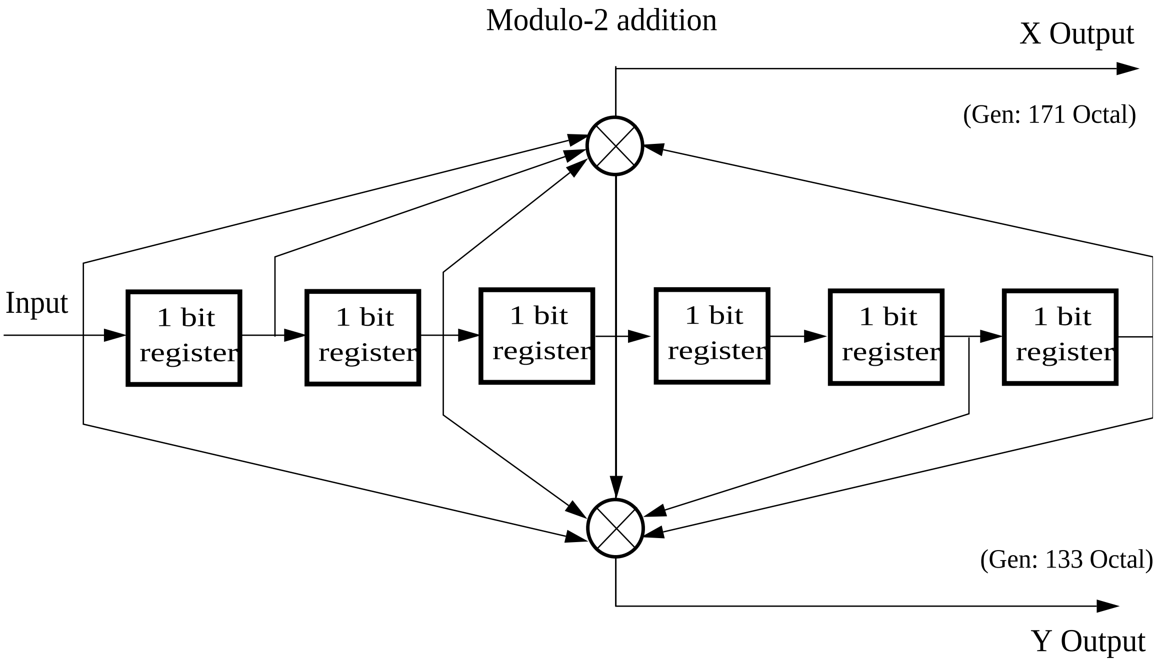

Figure 148—Inner mother convolutional code of rate 1/2 with memory 6

The puncturing patterns of the convolutional code for different inner code rates r are given in table 131. In this table "0" means that the coded bits shall not be transmitted (i.e. punctured) and "1" means that the coded bits shall be transmitted. Note that each matrix has two rows and several columns; where the puncturing vector for each row corresponds to the outputs of the encoder X- and Y, respectively (see figure 154).

Table 131—The puncturing patterns of the inner convolutional code (X_1 is sent first)

Inner code rate, r	**Puncturing patterns**	**Transmitted sequences (after parallel to serial conversion)**
1/2	X: 1 Y: 1	$X_1 Y_1$
2/3	X: 1 0 Y: 1 1	$X_1 Y_1 Y_2$
5/6	X: 1 0 1 0 1 Y: 1 1 0 1 0	$X_1 Y_1 Y_2 X_3 Y_4 X_5$
7/8	X: 1 0 0 0 1 0 1 Y: 1 1 1 1 0 1 0	$X_1 Y_1 Y_2 Y_3 Y_4 X_5 Y_6 X_7$

Coding Procedure:

Due to the use of adaptive coding and modulation for the UL and DL (see Figure 155) except for the DL-control portion which is specified later, the channel coding operation is performed as follows:

A byte stream of K bytes shall be mapped to the information part, yielding K bytes of the outer code RS(255,239, T=8).

Since K could be not longer than 239 bytes, 239-K bytes shall be filled by zero bytes at the beginning of the information part of the RS-codeword. The systematic RS (255, 239, T=8) Reed-Solomon coding shall be applied. After RS coding, the systematic structure of RS code allows to shorten the code, i.e. remove the inserted 239-K zero bytes before transmission. Then, each shortened RS codeword of length K + 16 bytes shall be serial bit converted (MSB first). If inner coding is not used, the shortened RS codeword containing [(K + 16) / 8] bits shall be submitted directly to the modulation by inserting padding bits (depending on the used coding and modulation) in order to guarantee an integer number of modulated symbol.

In case of inner coding, at the end of each serial bit converted RS-codeword 6 zero tailbits shall be inserted for inner code trellis termination purposes.

Then each [(K + 16) / 8 + 6 Tailbits] bits shall be encoded by the inner convolutional mother binary code of rate 1/2. After convolutional coding, the puncturing operation shall be applied following the used inner code rate r for a given PHY mode, that results in a total of [(K + 16) / 8 + 6 Tailbits] / r bits. Finally, the punctured bits shall be parallel-serial converted and shall be submitted to the modulation/Mapping unit. However, before modulation, some padding bits (depending on the used coding and modulation) shall be inserted in order to provide an integer number of modulated symbol.

Figure 149—Channel Coding Procedure per FEC-Block

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By shortening the systematic RS code, the RS codeword length can be adapted to transmit different number of bytes. For the downlink operation with fixed size PDU DLC, 4 x MAC PDUs per codeword shall be transmitted, where the RS code will be shortened to transmit one data MAC-PDU of 54 Bytes using RS(70,54, T=8) or up to four MAC-PDUs using RS(232, 216, T=8) code.

In addition, as the uplink frame structure will be governed by the BS, then for each terminal different number of bytes could be reserved by the MAC-layer. In this case the RS code may be adapted to transmission of a given number of bytes and, in the case of fixed size PDU, only one or several MAC PDUs per codeword can be transmitted, where the RS code will be shortened to transmit one data MAC PDU of 55 Bytes using RS(71,55, T=8) code.

Note that in case of only RS coding, the FEC block is equivalent to a RS codeword and some additional padding bits. In case of concatenated coding scheme (outer RS and inner convolutional code), the FEC block will contain the redundancy of one RS codeword, the inner code redundancy, the 6 trellis termination bits and the padding bits, where the trellis termination bits are inserted before inner coding at the end of the RS codeword.

~~The inner code in Code Type 2 consists of short block codes derived from a 4-state, nonsystematic, punctured convolutional code (7,5). The trellis shall use the tail-biting method, where the last 2 bits of the message block are used to initialize the encoder memory, in order to avoid the overhead required for trellis termination. Thus, the encoder has the same initial and ending state for a message block.~~

~~For this concatenated coding scheme, the inner code message block is selected to be 16 bits. The puncturing pattern is described in Table 132 for the (24,16) case.~~

~~Table 132—Parameters of the inner codes for the BCC~~

~~**Inner code rate**~~	~~**Puncture pattern**~~ ~~**G1 = 7, G2 = 5**~~
~~2/3~~	~~11, 10~~

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~~Figure 150 describes the exact encoding parity equations.~~

~~**Figure 150—Inner code for Code Type 2 in the downlink**~~

~~The number of information bytes shall be even since the BCC code operates on byte pairs.~~

~~8.2.5.4.4.3 Inner code for Code Type 3, downlink~~

~~For Code Type 3, a parity check bit is added to each Reed–Solomon (RS) symbol individually and inserted as the LSB of the resulting 9 bit word. The parity is an XOR operation on all 8 bits within the symbol.~~

8.2.5.4.4.4 Code Type 2 4, downlink

Code Type 2 4, the BTC, is a Turbo decoded Product Code (TPC). The idea of this coding scheme is to use extended Hamming block codes in a two-dimensional matrix. The two-dimensional code block is depicted in Figure 151. The k_x information bits in the rows are encoded into n_x bits, by using an extended Hamming binary block (n_x,k_x) code. Likewise, k_y information bits in the columns are encoded into n_y bits, by using the same or possibly different extended Hamming binary block (n_y,k_y) code. The resultant code block is comprised of multiple rows and columns of the constituent extended Hamming block codes.

For this standard, the rows shall be encoded first. After encoding the rows, the columns are encoded using another block code (n_y,k_y), where the check bits of the first code are also encoded. The overall block size of such a product code is $n = n_x \text{ x } n_y$, the total number of information bits $k_x \text{ x } k_y$, the code rate is $R = R_x \text{ x } R_y$, where $R_i = k_i/n_i$ and $i=x$ or y.

Table 133 provides the generator polynomials of the constituent Hamming codes used in this specification.

The composite extended Hamming code specified requires addition of an overall even parity check bit at the end of each codeword.

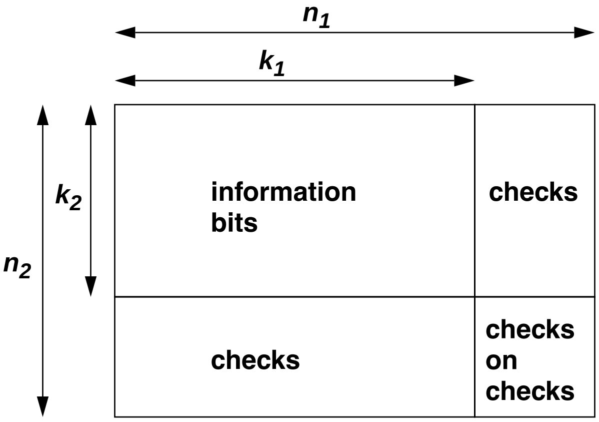

Figure 151—Two-dimensional product code matrix

Table 133—Hamming code generator polynomials

n	k	Generator polynomial
31	26	$x^5 + x^2 + 1$
63	57	$x^6 + x + 1$

The encoder for a BTC is composed of linear feedback shift registers (LFSRs), storage elements, and control logic. An example row (or column) encoder is shown here for clarification. The order of transmission is important so that the decoder may match for proper decoding. This specification mandates that the resultant code block be transmitted row by row, left to right, top to bottom, for the case when no interleaving is used (Interleaver Type 1 described below).

Figure 152 shows a sample LFSR based on a $x^4 + x + 1$ Hamming code polynomial to encode a (15,11) Hamming code. Also shown is an even parity computation register that results in an extended Hamming code. Note that encoders for the required (64,57) and (32,26) codes follow the same design concept. This figure is shown for clarification of the BTC encoder design and does not depict an actual design implementation.

The example circuit begins with all toggle switches in position A. Data to be encoded is fed as input one bit per clock (LSB first) to both the Hamming error correction code (ECC) computation logic and the overall even parity computation logic. Extended Hamming codes are systematic codes, so this data is also fed through as output on the encoded bit output. After all *k* bits are input, the toggle switches are moved to position B. At this point, data from the Hamming ECC logic is shifted out on the encoded bits bus. Finally, the overall parity bit is shifted out when the output select switch is moved to position C.

In order to encode the product code, each data bit is fed as input both into a row LFSR and a column LFSR. Note that only one row LFSR is necessary for the entire block, since data is written as input in row order. However, each column of the array shall be encoded with a separate LFSR. Each column LFSR is clocked for only one bit of the row, so a more efficient method of column encoding is to store the column LFSR states in a k_x x $(n_y – k_y)$ storage memory. A single LFSR can then be used for all columns of the array. With each bit input, the appropriate column LFSR state is read from the memory, clocked, and written back to the memory.

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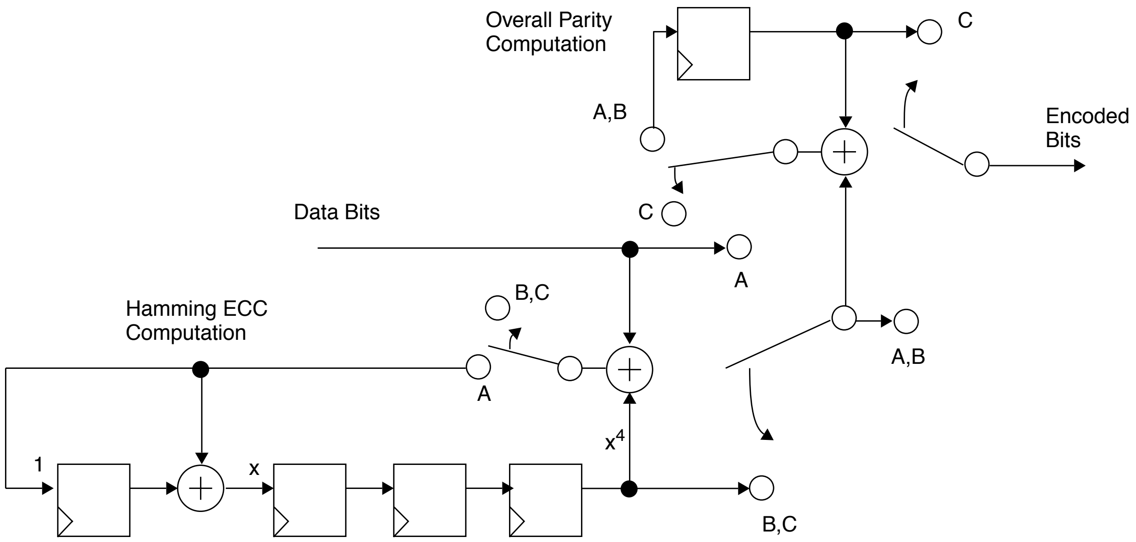

Figure 152—Example encoder for a (16,11) extended Hamming Code

The encoding process is demonstrated here with an example. Assume a two-dimensional (8,4)x(8,4) extended Hamming product code is to be encoded. This block has 16 data bits, and 64 total encoded bits. Table 134 shows the original 16 data bits denoted by D_{yx}, where y corresponds to a column and x corresponds to a row.

Table 134—Original data for encoding

D_{11}	D_{21}	D_{31}	D_{41}
D_{12}	D_{22}	D_{32}	D_{42}
D_{13}	D_{23}	D_{33}	D_{43}
D_{14}	D_{24}	D_{34}	D_{44}

The first four bits of the array are fed into the row encoder input in the order D_{11}, D_{21}, D_{31}, D_{41}. Each bit is also fed as input into a unique column encoder. Again, a single column encoder may be used, with the state of each column stored in a memory. After the fourth bit is fed into the input, the first row encoder ECC bits are shifted out.

This process continues for all four rows of data. At this point, 32 bits have been taken as output from the encoder, and the four column encoders are ready to shift out the column ECC bits. This data is shifted out at the end of the row. This continues from the remaining 3 rows of the array. Table 135 shows the final encoded block with the 48 generated ECC bits denoted by E_{yx}.

Table 135—Encoded block

D_{11}	D_{21}	D_{31}	D_{41}	E_{51}	E_{61}	E_{71}	E_{81}
D_{12}	D_{22}	D_{32}	D_{42}	E_{52}	E_{62}	E_{72}	E_{82}

Table 135—Encoded block

D_{13}	D_{23}	D_{33}	D_{43}	E_{53}	E_{63}	E_{73}	E_{83}
D_{14}	D_{24}	D_{34}	D_{44}	E_{54}	E_{64}	E_{74}	E_{84}
E_{15}	E_{25}	E_{35}	E_{45}	E_{55}	E_{65}	E_{75}	E_{85}
E_{16}	E_{26}	E_{36}	E_{46}	E_{56}	E_{66}	E_{76}	E_{86}
E_{17}	E_{27}	E_{37}	E_{47}	E_{57}	E_{67}	E_{77}	E_{87}
E_{18}	E_{28}	E_{38}	E_{48}	E_{58}	E_{68}	E_{78}	E_{88}

Transmission of the block over the channel occurs in a linear manner; all bits of the first row are transmitted left to right, followed by the second row, etc. This allows for the construction of a near zero-latency encoder, since the data bits can be sent immediately over the channel, with the ECC bits inserted as necessary. For the (8,4)x(8,4) example, the output order for the 64 encoded bits is D_{11}, D_{21}, D_{31}, D_{41}, E_{51}, E_{61}, E_{71}, E_{81}, D_{12}, D_{22}, … ,E_{88}.

For easier readability, the following notation is used:

— The codes defined for the rows (*x*-axis) are binary (n_x,k_x) block codes.
— The codes defined for the columns (y-axis) are binary (n_y,k_y) block codes.
— Data bits are noted D_{yx} and parity bits are noted E_{yx}.

a) *Shortened BTC:* To match packet sizes, removing symbols from the array shortens a product code. In general, rows or columns are removed until the appropriate size is reached. Codes selected shall have an integral number of information bytes. Different shortening approaches are applicable for BTC. In one method, rows and columns are deleted completely from an initial BTC array. For example, a 253 byte code is generated by starting with (64,57) constituent codes and deleting thirteen rows and eleven columns. Another method uses a more systematic two-dimensional shortening. For example, a 128 byte BTC code is composed of (64,57) constituent codes which are shortened by 25 rows and 25 columns, as described in Figure 153. The end result is a (39,32)x(39,32) array which is capable of encoding 32x32=1024 bits (128 bytes) of data. Table 136 summarizes these example codes. A method for determining codes for payload sizes different than these examples is given at the end of this subclause.

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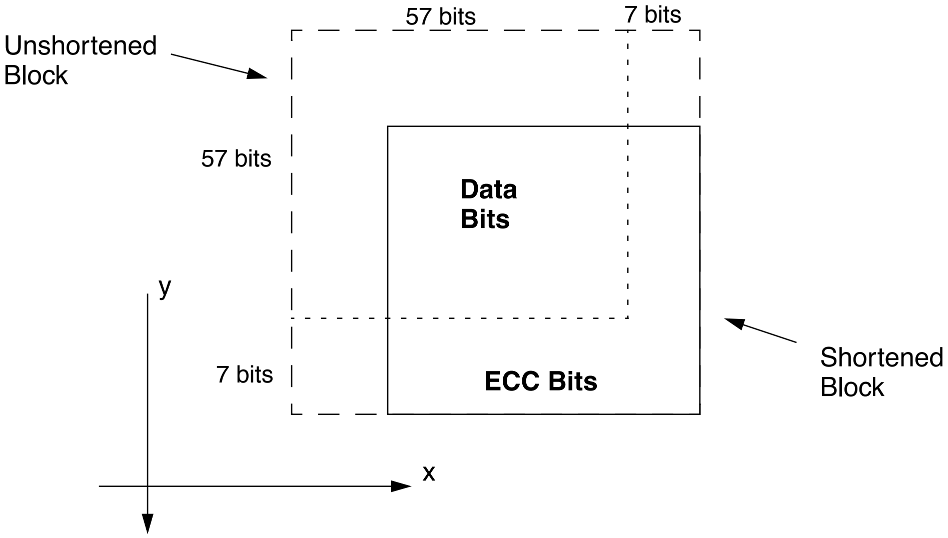

Figure 153—Structure of shortened 2 D block

Modifications to the encoder to support shortening are minimal. Since shortened bits are always zero, and zeros input to the encoder LFSR result in a zero state, the shortened bits can simply be ignored for the purpose of encoding. The encoder simply needs to know how many bits per row to input to the row LFSR before shifting out the result. Similarly, it must know the number of columns to input to the column encoders.

Transmission of the resultant code block shall start with the first data bit in the first row, proceed left to right and then row by row from top to bottom.

Table 136—Required block codes for the BTC option for the downlink channel

Code	(39,32)**x**(39,32)	(53,46)**x**(51,44)
Aggregate Code Rate	0.673	0.749
Uplink/Downlink/Both	Downlink	Downlink
Block size (payload bits)	1024 (128 bytes)	3136 (392 bytes)

b) *Interleaving:* When using the Block Turbo Coding, two modes of bit interleaving shall be supported. The interleaver mechanism shall be implemented by writing information bits into the encoder memory and reading out the encoded bits as follows:

  1) *Interleaver type 1:* No interleaver. In this mode the encoded bits are read from the encoder row by row, in the order that they were written.

  2) *Interleaver type 2:* Block interleaver. In this mode, the encoded bits are read from the encoder after the first *k*2 rows (Figure 151) are written into the encoder memory. The bits are read column by column, proceeding from the top position in the first column.

  3) *Interleaver type 3:* Reserved. It is expected that other interleaving methods may yield better performance in some cases. So, this Interleaver type 3 has been reserved for future definition.

c) *Block mapping to the signal constellation:* The first encoded bit out shall be the LSB, which is the first bit written into the encoder.

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d) *Method for determining codes for payload size different than the listed examples:* The following text describes a method for performing additional codeword shortening when the input block of data does not match exactly the codeword information size.

   1) Take the required payload as specified in bytes and convert it to bits (i.e., multiply by 8).
   2) Take the square root of the resultant number.
   3) Round the result up to the next highest integer.
   4) Select the smallest base constituent code from the available list that has a *k* value equal to or greater than the value determined in step 3.
   5) Subtract the value determined in step 3 from the *k* value selected in step 4. This value represents the number of rows and columns that need to be shortened from the base constituent code selected in step 4.

This method will generally result in a code block whose payload is slightly larger than required in step 1 above. In order to address the residual bits, the column dimension (n_y,k_y) should be shortened as needed and, as needed, zero bits may be stuffed into the last bits of the last row of the resulting code matrix. The zero bits in the last row should be discarded at the receiver.

Example: If a 20 byte payload code is desired, a (32,26)x(32,26) code is shortened by 13 rows and by 13 columns, resulting in a (19,13)x(19,13) code. There are 9 bits left over which are stuffed with zeros. Data input to the defined encoder is 160 data bits followed by 9 zero bits. The code block is transmitted starting with the bit in row 1 column 1 (the LSB), then left to right, and then row by row.

8.2.5.4.5 Definition of parameters for burst profile (DIUC=0)

The burst profile with DIUC=0 shall be configured with the parameters in Table 137.

Table 137—Parameters for burst profile (DIUC=0)

Parameter	Value	Comment
Modulation type	1	QPSK
FEC Code Type	~~2~~ 1	RS+~~B~~CC
RS information bytes (*K*)	~~26~~ 30	
RS parity bytes (*R*)	~~20~~ 16	
~~B~~CC Code Type	1	~~(24,16)~~ 1/2
Last codeword length	1	fixed

8.2.5.4.6 Coding of the control portion of the frame

The frame control section of the downlink frame (as defined in 8.2.5.1) shall be encoded with a fixed set of parameters known to the SS at initialization in order to ensure that all SSs can read the information. The modulation shall be QPSK, and the data shall be encoded with an outer (46,~~26~~ 30) Reed–Solomon code and an inner (~~24,16~~ 1/2) convolutional code. There shall be a minimum of ~~2~~3 codewords per control portion of the frame when a downlink allocation map is present. ~~When a~~ The UL-MAP ~~is present, it~~ shall be concatenated with the DL-MAP~~Downlink Allocation map to increase efficiency~~. This operation mode shall be designated as TDM Burst Profile 1 (DIUC = 0). Stuff bytes (FF_{hex}) shall be appended as necessary to the end of the control messages to fill up the minimum number of codewords.

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8.2.5.4.7 Downlink modulation

To maximize utilization of the airlink, the PHY uses a multilevel modulation scheme. The modulation constellation can be selected per subscriber based on the quality of the RF channel. If link conditions permit, then a more complex modulation scheme can be utilized to maximizing airlink throughput while still allowing reliable data transfer. If the airlink degrades over time, possibly due to environmental factors, the system can revert to the less complex constellations to allow more reliable data transfer.

In the downlink, the BS shall support QPSK and 16-QAM modulation and, optionally, 64-QAM.

The sequence of modulation bits shall be mapped onto a sequence of modulation symbols $S(k)$, where k is the corresponding symbol number. The number of bits per symbol depends on the modulation type. For QPSK, $n = 2$; for 16-QAM, $n = 4$; and for 64-QAM, $n = 6$. $B(m)$ denotes the modulation bit of a sequence to be transmitted, where m is the bit number (m ranges from 1 through n). In particular, $B(1)$ corresponds to the first bit entering the modulator, $B(2)$ corresponds to the second bit entering the modulation, and so on.

In changing from one burst profile to another, the BS shall use one of two power adjustment rules: maintaining constant constellation peak power (power adjustment rule=0), or maintaining constant constellation mean power (power adjustment rule=1). In the constant peak power scheme, corner points are transmitted at equal power levels regardless of modulation type. In the constant mean power scheme, the signal is transmitted at equal mean power levels regardless of modulation type. The power adjustment rule is configurable through the DCD Channel Encoding parameters (11.1.2.1).

At the end of each burst, the final FEC-encoded message might not end exactly on a PS boundary. If this is the case, the end of the encoded message to the start of the next burst shall be filled with zero bits.

The complex modulation symbol $S(k)$ shall take the value $I + jQ$. The following subsections apply to the base-band part of the transmitter.

Figure 154 and Table 138 describe the bit mapping for QPSK modulation.

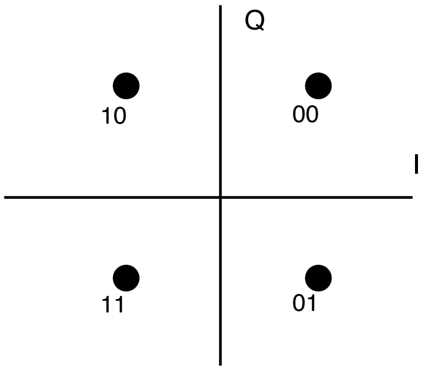

Figure 154—QPSK constellation

Table 138—QPSK bits to symbol mapping

B(1)	B(2)	I	Q
0	0	1	1
0	1	1	–1
1	0	–1	1
1	1	–1	–1

Figure 155 and Table 139 describe the bit mapping for 16-QAM modulation.

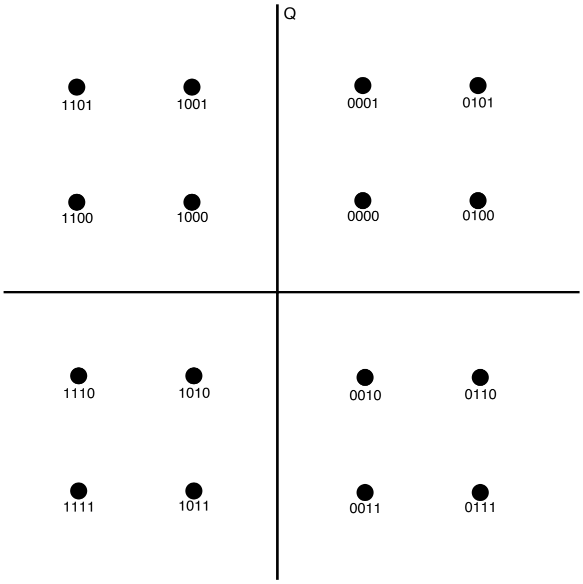

Figure 155—16-QAM constellation (gray-coded)

Table 139—16-QAM bits to symbol mapping

B(1)	B(2)	B(3)	B(4)	I	Q
0	1	0	1	3	3
0	1	0	0	3	1
0	1	1	0	3	–1
0	1	1	1	3	–3
0	0	0	1	1	3
0	0	0	0	1	1
0	0	1	0	1	–1
0	0	1	1	1	–3
1	0	0	1	–1	3

Table 139—16-QAM bits to symbol mapping *(continued)*

B(1)	B(2)	B(3)	B(4)	I	Q
1	0	0	0	–1	1
1	0	1	0	–1	–1
1	0	1	1	–1	–3
1	1	0	1	–3	3
1	1	0	0	–3	1
1	1	1	0	–3	–1
1	1	1	1	–3	–3

Figure 156 and Table 140 describe the bit mapping for 64-QAM modulation.

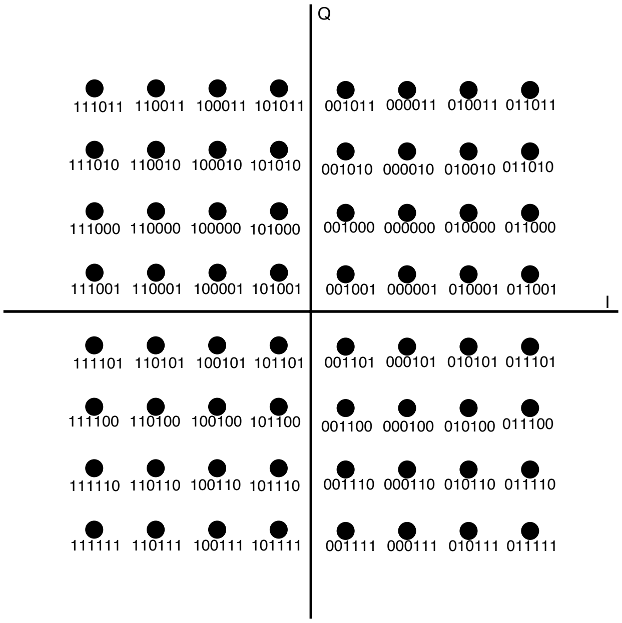

Figure 156—64-QAM constellation (gray-coded)

Table 140—64-QAM bits to symbol mapping

B(1)	B(2)	B(3)	B(4)	B(5)	B(6)	I	Q
0	1	1	0	1	1	7	7
0	1	1	0	1	0	7	5
0	1	1	0	0	0	7	3
0	1	1	0	0	1	7	1
0	1	1	1	0	1	7	–1
0	1	1	1	0	0	7	–3

Table 140—64-QAM bits to symbol mapping *(continued)*

B(1)	B(2)	B(3)	B(4)	B(5)	B(6)	I	Q
0	1	1	1	1	0	7	–5
0	1	1	1	1	1	7	–7
0	1	0	0	1	1	5	7
0	1	0	0	1	0	5	5
0	1	0	0	0	0	5	3
0	1	0	0	0	1	5	1
0	1	0	1	0	1	5	–1
0	1	0	1	0	0	5	–3
0	1	0	1	1	0	5	–5
0	1	0	1	1	1	5	–7
0	0	0	0	1	1	3	7
0	0	0	0	1	0	3	5
0	0	0	0	0	0	3	3
0	0	0	0	0	1	3	1
0	0	0	1	0	1	3	–1
0	0	0	1	0	0	3	–3
0	0	0	1	1	0	3	–5
0	0	0	1	1	1	3	–7
0	0	1	0	1	1	1	7
0	0	1	0	1	0	1	5
0	0	1	0	0	0	1	3
0	0	1	0	0	1	1	1
0	0	1	1	0	1	1	–1
0	0	1	1	0	0	1	–3
0	0	1	1	1	0	1	–5
0	0	1	1	1	1	1	–7
1	0	1	0	1	1	–1	7
1	0	1	0	1	0	–1	5
1	0	1	0	0	0	–1	3
1	0	1	0	0	1	–1	1
1	0	1	1	0	1	–1	–1
1	0	1	1	0	0	–1	–3
1	0	1	1	1	0	–1	–5

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Table 140—64-QAM bits to symbol mapping *(continued)*

B(1)	B(2)	B(3)	B(4)	B(5)	B(6)	I	Q
1	0	1	1	1	1	–1	–7
1	0	0	0	1	1	–3	7
1	0	0	0	1	0	–3	5
1	0	0	0	0	0	–3	3
1	0	0	0	0	1	–3	1
1	0	0	1	0	1	–3	–1
1	0	0	1	0	0	–3	–3
1	0	0	1	1	0	–3	–5
1	0	0	1	1	1	–3	–7
1	1	0	0	1	1	–5	7
1	1	0	0	1	0	–5	5
1	1	0	0	0	0	–5	3
1	1	0	0	0	1	–5	1
1	1	0	1	0	1	–5	–1
1	1	0	1	0	0	–5	–3
1	1	0	1	1	0	–5	–5
1	1	0	1	1	1	–5	–7
1	1	1	0	1	1	–7	7
1	1	1	0	1	0	–7	5
1	1	1	0	0	0	–7	3
1	1	1	0	0	1	–7	1
1	1	1	1	0	1	–7	–1
1	1	1	1	0	0	–7	–3
1	1	1	1	1	0	–7	–5
1	1	1	1	1	1	–7	–7

8.2.5.4.8 Baseband pulse shaping

Prior to modulation, the I and Q signals shall be filtered by square-root raised cosine filters. The excess bandwidth factor α shall be 0.25. The ideal square-root raised cosine filter is defined by the following transfer function H:

$$H(f) = 1 \qquad \text{for } |f| < f_N(1-\alpha)$$

$$H(f) = \sqrt{\frac{1}{2} + \frac{1}{2}\sin\left[\frac{\pi}{2f_N}\left(\frac{f_N - |f|}{\alpha}\right)\right]} \qquad \text{for } f_N(1-\alpha) \le |f| \le f_N(1+\alpha)$$

$$H(f) = 0 \qquad \text{for } |f| > f_N(1+\alpha)$$

where $f_N = \frac{1}{2T_S} = \frac{R_S}{2}$ is the Nyquist frequency.

8.2.5.4.9 Transmitted waveform

The transmitted waveform at the antenna port $S(t)$ shall be:

$$S(t) = I(t)\cos(2\pi f_c t) - Q(t)\sin(2\pi f_c t)$$

where $I(t)$ and $Q(t)$ are the filtered baseband (pulse-shaped) signals of the I_k and Q_k symbols, k is the discrete symbol index, and f_c is the carrier frequency.

8.2.5.4.10 Summary of downlink PHY parameters

The downlink PHY parameters are summarized in Table 141.

Table 141—Summary of downlink PHY Parameters

Transmission Convergence sublayer	**Includes 1 pointer byte**
Outer Coding	Reed–Solomon over GF(256) Information byte lengths: 6~~–255~~239 bytes Error correction capability R = ~~0-32~~ 16 (T=~~0-16~~8) ~~BTC (optional)~~ ~~NOTE—There is no inner code selected in this case.~~
Randomization	$1 + X^{14} + X^{15}$ Initialization: 100101010000000 at the beginning of each burst
Inner convolutional Coding	Selectable from the following options: ~~None~~ ~~(24,16) block convolutional code~~ ~~(9,8) parity check code (optional)~~ r=1/2 (only for QPSKand used only for DL control portion) r=2/3 (only for QPSK) r=5/6 (only for 64-QAM) r=7/8 (only for 16-QAM) r=1, no inner coding (for all modulations)
Preamble	Frame Start Preamble (32 symbols) Downlink TDMA Burst Preamble (16 symbols)
Modulation	QPSK (mandatory), 16-QAM (mandatory), 64-QAM (optional)
Spectral shaping	α=0.25

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8.2.6 Uplink PHY

8.2.6.1 Uplink subframe

The structure of the uplink subframe used by the SS to transmit to the BS is shown in Figure 157. Three classes of bursts may be transmitted by the SS during the uplink subframe:

a) Those that are transmitted in contention opportunities reserved for Initial ~~Maintenance~~Ranging.

b) Those that are transmitted in contention opportunies defined by Request Intervals reserved for response to multicast and broadcast polls.

c) Those that are transmitted in intervals defined by Data Grant IEs specifically allocated to individual SSs.

Any of these burst classes may be present in any given frame. They may occur in any order and any quantity (limited by the number of available PSs) within the frame, at the discretion of the BS uplink scheduler as indicated by the UL_MAP in the frame control section (part of the downlink subframe).

The bandwidth allocated for Initial ~~Maintenance~~Ranging and Request contention opportunies may be grouped together and is always used with the uplink burst profiles specified for Initial ~~Maintenance~~Ranging Intervals (UIUC=2) and Request Intervals (UIUC=1), respectively. The remaining transmission slots are grouped by SS. During its scheduled bandwidth, an SS transmits with the burst profile specified by the BS.

SSTGs separate the transmissions of the various SSs during the uplink subframe. The gap allows for ramping down of the previous burst, followed by a preamble allowing the BS to synchronize to the new SS. The preamble and gap lengths are broadcast periodically in the UCD message.

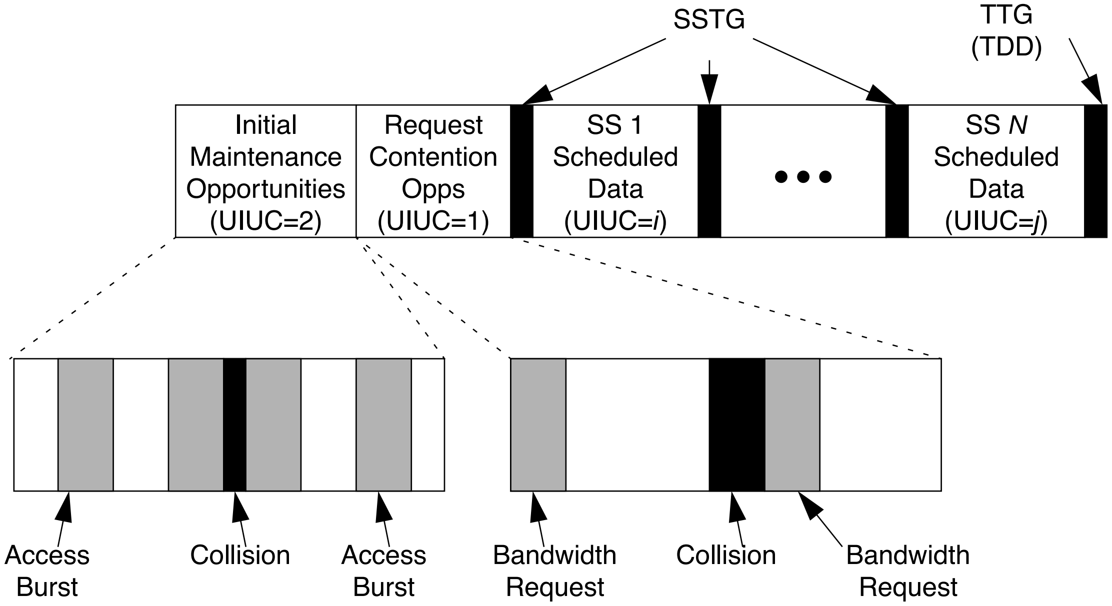

Figure 157—Uplink subframe structure

8.2.6.1.1 Uplink burst preamble

Each uplink burst shall begin with an uplink preamble. This preamble is based upon a repetition of a +45 degrees rotated constant amplitude zero auto-correlation (CAZAC) sequence (Milewski [B37]). The preamble length is either 16 symbols or 32 symbols. In the 16-symbol preamble (whose sequence is specified in Table 142), the CAZAC sequence is of length 8 and repeated once. In the 32-symbol preamble (whose sequence is specified in Table 143), the CAZAC sequence is of length 16 and repeated once.

Table 142—16-symbol uplink preamble sequence

Symbol	I	Q	B(1)	B(2)
1 and 9	1	1	0	0
2 and 10	–1	~~1~~ -1	1	~~0~~ 1
3 and 11	~~1~~ -1	1	~~0~~ 1	0
4 and 12	1	1	0	0
5 and 13	~~–1~~ 1	~~–1~~ 1	~~1~~ 0	~~1~~ 0
6 and 14	~~–1~~ 1	1	~~1~~ 0	0
7 and 15	–1	~~–1~~ 1	1	~~1~~ 0
8 and 16	~~1~~ -1	~~1~~ -1	~~0~~ 1	~~0~~ 1

Table 143—32-symbol uplink preamble sequence

Symbol	I	Q	B(1)	B(2)
1 and 17	~~1~~ -1	~~1~~ -1	~~0~~ 1	~~0~~ 1
2 and 18	~~1~~ -1	~~1~~ -1	~~0~~ 1	~~0~~ 1
3 and 19	1	~~–1~~ 1	0	~~1~~ 0
4 and 20	~~–1~~ 1	~~–1~~ 1	~~1~~ 0	~~1~~ 0
5 and 21	–1	–1	1	1
6 and 22	1	1	0	0
7 and 23	1	~~1~~ -1	0	~~0~~ 1
8 and 24	~~–1~~ 1	1	~~1~~ 0	0
9 and 25	1	~~1~~ -1	0	~~0~~ 1
10 and 26	~~1~~ -1	~~1~~ -1	~~0~~ 1	~~0~~ 1
11 and 27	–1	~~1~~ -1	1	~~0~~ 1
12 and 28	1	1	0	0
13 and 29	~~–1~~ 1	~~–1~~ 1	~~1~~ 0	~~1~~ 0
14 and 30	1	1	0	0

Table 143—32-symbol uplink preamble sequence *(continued)*

Symbol	I	Q	B(1)	B(2)
15 and 31	–1	~~–1~~ 1	1	~~1~~ 0
16 and 32	1	~~–1~~ 1	0	~~1~~ 0

The amplitude of the preamble shall depend on the uplink power adjustment rule (8.2.6.3.7). In the case of the constant peak power scheme (power adjustment rule=0), the preamble shall be transmitted such that its constellation points coincide with the outermost constellation points of the modulation scheme in use. In the case of the constant mean power scheme (power adjustment rule=1), it shall be transmitted with the mean power of the constellation points of the modulation scheme in use.

The BS defines the preamble length through the UCD message.

8.2.6.1.2 UL_MAP_~~Information_Element~~IE definition

The format of UL_MAP_~~Information_Element~~IEs shall be as defined in Table 144 and utilized according to 6.4.2.3.4. The UIUC shall be one of the values defined in Table 145. The Offset indicates the start time, in units of minislots, of the burst relative to the Allocation Start Time given in the UL-MAP message. The end of the last allocated burst is indicated by allocating ~~a NULL~~an End of map burst (CID = 0 and UIUC = 10) with zero duration. The time instants indicated by the offsets are the transmission times of the first symbol of the burst, including the preamble.

Table 144—UL_MAP_~~Information_Element~~IE

Syntax	Size	Notes
UL_MAP_~~Information_Element~~IE() {		
CID	16 bits	
UIUC	4 bits	
Offset	12 bits	offset, in units of minislots, of the preamble relative to the Allocation Start Time
}		

Table 145—UL-MAP IE

IE name	UIUC	Connection ID	Description
Reserved	0	NA	Reserved for future use.
Request	1	any	Starting offset of request region.
Initial ~~Maintenance~~Ranging	2	broadcast	Starting offset of maintenance region (used in Initial Ranging).

Table 145—UL-MAP IE *(continued)*

IE name	UIUC	Connection ID	Description
~~Station Maintenance~~*Reserved*	3	~~unicast~~N/A	~~Starting offset of maintenance region (used in Periodic Ranging).~~ Reserved for future use.
Data Grant Burst Type 1	4	unicast	Starting offset of Data Grant Burst Type 1 assignment.
Data Grant Burst Type 2	5	unicast	Starting offset of Data Grant Burst Type 2 assignment.
Data Grant Burst Type 3	6	unicast	Starting offset of Data Grant Burst Type 3 assignment.
Data Grant Burst Type 4	7	unicast	Starting offset of Data Grant Burst Type 4 assignment.
Data Grant Burst Type 5	8	unicast	Starting offset of Data Grant Burst Type 5 assignment.
Data Grant Burst Type 6	9	unicast	Starting offset of Data Grant Burst Type 6 assignment.
~~Null IE~~End of map	10	zero	Ending offset of the previous grant. Indicates the first minislot after the end of the ~~UL~~uplink allocation. The burst profile is well known and shall not be included in the UCD message. Used to bound the length of the last actual interval allocation.
~~Empty~~Gap	11	zero	Used to schedule gaps in transmission.
Reserved	12-15	N/A	Reserved.

8.2.6.1.3 Required UCD parameters

The following parameters shall be included in the UCD message:

- Preamble Length

The following parameters may be included in the UCD message and if absent shall have their default values:

- SSTG
- Roll-off Factor

Uplink Symbol Rate and Frequency are implied by the downlink symbol rate and frequency.

8.2.6.1.4 Uplink channel

Since SSs do not transmit in the uplink channel until they have received some minimal configuration information from the BS, it is possible to support several different configurations that can be adjusted on an uplink channel basis or on a burst by burst basis. These parameters, and their ranges, are supported through MAC ~~sublayer~~ signaling, as described in 6.4.2.3.3.

8.2.6.1.5 Uplink_Burst_Profile

Each Uplink_Burst_Profile in the UCD message (6.4.2.3.3) shall include the following parameters:

- Modulation type
- FEC Code Type
- Last codeword length
- Preamble Length
- ~~Scrambler Seed~~

If the FEC Code Type is 1, ~~2, or 3~~ (~~RS codes~~), the Uplink_Burst_Profile shall also include

- RS information bytes (*K*)
- ~~RS parity bytes (*R*)~~ inner convolutional code rate (r)

~~If the FEC Code Type is 2, the Uplink_Burst_Profile shall also include~~

- ~~BCC code type~~

If the FEC Code Type is 42, the Uplink_Burst_Profile shall also include

- BTC row code type
- BTC column code type
- BTC interleaving type

Table 146 illustrates the format of the Uplink_Burst_Profile, which is encoded with a Type of 1.

Table 146—Uplink_Burst_Profile format

Syntax	Size	Notes
Type=1	8 bits	
Length	Variable	
reserved	4 bits	shall be set to zero
UIUC	4 bits	
TLV encoded information	Variable	TLV specific

Within each Uplink_Burst_Profile is an unordered list of PHY attributes, encoded as TLV values (see 11.1.1.2).

8.2.6.2 Uplink Transmission Convergence sublayer

The uplink Transmission Convergence sublayer operation shall be identical to the downlink Transmission Convergence sublayer operation, as described in 8.2.5.3.

8.2.6.3 Uplink PMD sublayer

The uplink PHY coding and modulation are summarized in the block diagram shown in Figure 158.

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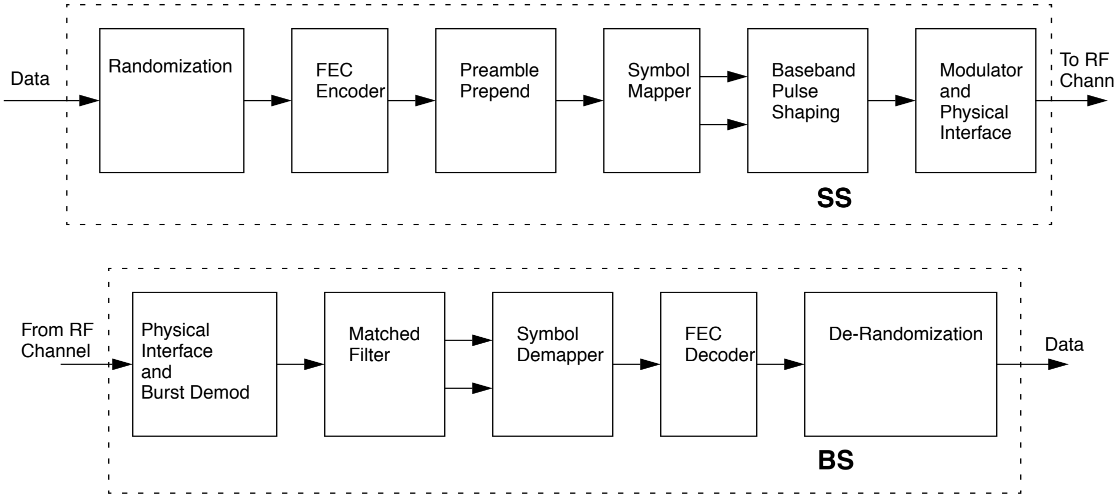

Figure 158—Conceptual block diagram of the uplink PHY

8.2.6.3.1 Randomization for spectrum shaping

The uplink modulator shall implement a randomizer using the polynomial $x^{15}+x^{14}+1$ ~~with the 15 bit programmable Scrambler Seed~~. At the beginning of each burst, the register is cleared and the Scrambler Seed value 100101010000000 is loaded. The Scrambler Seed value shall be used to calculate the scrambler bit, which is combined in an XOR with the first bit of data of each burst [which is the MSB of the first symbol following the last symbol of the preamble].

8.2.6.3.2 Uplink FEC

The uplink FEC schemes are as described in 8.2.5.4.4, including Table 130.

8.2.6.3.2.1 Outer code for Code Types 1~~-3~~, uplink

The Outer Code~~s~~ for Code Type~~s~~ 1~~-3~~ ~~are nearly~~ is identical to those of the downlink ~~(.1),~~ with the following exceptions:

a) **Fixed Codeword Operation**

In the Fixed Codeword Operation, the number of information bytes in each codeword is always the same (K). If the MAC messages in a burst require fewer bytes than are carried by an integral number of Reed–Solomon codewords, stuff bytes (FF_{hex}) shall be added between MAC messages or after the last MAC message so that the total message length is an integral multiple of K bytes.

The SS determines the number of codewords in its uplink burst from the UL-MAP message, which defines the beginning point of each burst, and hence the length. The BS determines the number of codewords in the received uplink burst as it scheduled this transmission event and is aware about its length. Using the burst length, both the SS and the BS calculate the number of full-length RS codewords that can be carried by each burst.

The process used by the SS to encode each burst is identical to the process performed by the BS in Downlink Fixed Codeword Operation ~~()~~.

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b) Shortened Last Codeword Operation

In the Shortened Last Codeword Operation, the number of information bytes in the final Reed–Solomon block of each burst is reduced from the normal number *K*, while the number of parity bytes *R* remains the same. The BS tailors the number of information bytes in the last codeword, allowing the SS to transport as many information bytes as possible in each uplink burst. The BS implicitly communicates the number of bytes in the shortened last codeword to the SS via the UL-MAP message, which defines the starting minislot of each burst. The SS uses the UL-MAP information to calculate the number of full-length RS codewords and the length of the shortened last codeword that can be carried within the specified burst size. This calculation shall take into account the number of bytes in the burst used for the preamble and coding bytes as well as the guard time. The BS performs a similar calculation as the SS for its decoding purposes.

To allow the receiving hardware to decode the previous Reed–Solomon codeword, no Reed–Solomon codeword shall have less than 6 information bytes. The number of information bytes carried by the shortened last codeword shall be between 6 and *K* bytes inclusive. In this mode, the BS shall only allocate bursts that result in shortened last codewords of the proper length.

~~When using Code Type 2, the number of information bytes in the shortened last codeword shall always be an even number so that the total codeword size is also an even number. Both BS and SS shall take this into account when calculating the number of information bytes in the last codeword.~~

The process used by the SS to encode each burst is identical to the process used by the BS in Downlink Shortened Last Codeword Operation ().

8.2.6.3.2.2 Inner code for Code Type 1 ~~2~~, uplink

See 8.2.5.4.4.2.

~~8.2.6.3.2.3 Inner code for Code Type 3, uplink~~

~~See 8.2.5.4.4.3.~~

8.2.6.3.2.4 Code Type 2 4, uplink

Code Type 2 4 in the uplink is similar to the downlink case (8.2.5.4.4.4). Some exceptions apply to the uplink due to the smaller payload expected within a burst. For example, using a similar two-dimensional shortening process, a 57 byte code is composed of (32,26) constituent codes which have been shortened by seven rows and two columns as described in Figure 159. The end result is a (30,24)x(25,19) array which is capable of encoding 24x19=456 bits (57 bytes). Table 147 summarizes this code example.

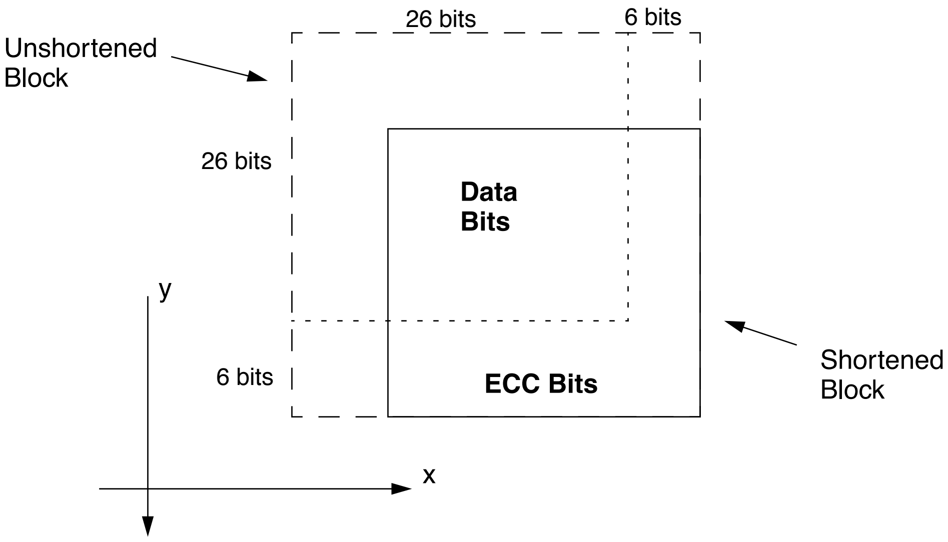

Figure 159—Structure of shortened 2 D block

Table 147—Required block codes for the BTC option for the uplink channel

Code	(30,24)**x**(25,19)
Aggregate Code Rate	0.608
Uplink/Downlink/Both	Uplink
Block size (payload bits)	456 (57 bytes)

8.2.6.3.3 Shortening of FEC blocks in uplink

Shortening of FEC blocks in the uplink is identical to the handling in the downlink as described in 8.2.5.2 or .

8.2.6.3.4 Number of scheduled uplink bursts per frame

Only one scheduled burst (UIUC 4-9) per SS shall be included in the UL-MAP for any given frame.

8.2.6.3.5 Coding of the Request IE Uplink_Burst_Profile

The uplink burst profile associated with the Request IE (UIUC = 1) shall use Modulation Type = 1 (QPSK) and shall use FEC Code Type = 1 or 2. The other parameters of the Uplink_Burst_Profile encoding shall be chosen such that the resulting uplink burst profile is no less robust than the most robust uplink burst profile associated with any of the Data Grant Burst Type IEs.

8.2.6.3.6 Coding of the Initial ~~Maintenance~~Ranging Uplink_Burst_Profile

The burst profile for the Initial ~~Maintenance~~Ranging UIUC shall be the same as for the frame control section, as defined in 8.2.5.4.6.

8.2.6.3.7 Uplink modulation

The modulation used on the uplink channel shall be variable and set by the BS. QPSK shall be supported, while 16-QAM and 64-QAM are optional, with the mappings of bits to symbols identical to those described in 8.2.5.4.7.

In changing from one burst profile to another, the SS shall use one of two power adjustment rules: maintaining constant constellation peak power (power adjustment rule=0), or maintaining constant constellation mean power (power adjustment rule=1). In the constant peak power scheme, corner points are transmitted at equal power levels regardless of modulation type. In the constant mean power scheme, the signal is transmitted at equal mean power levels regardless of modulation type. The power adjustment rule is configurable through the UCD Channel Encoding parameters (11.1.1.1).

In changing from one modulation scheme to another (i.e., during burst profile change), sufficient RF power amplifier margins should be maintained to prevent violation of emissions masks.

8.2.6.3.8 Baseband pulse shaping

Prior to modulation, the *I* and *Q* signals shall be filtered by square-root raised cosine filters as specified~~discussed~~ in 8.2.5.4.8.

8.2.6.3.9 Transmitted waveform

The transmitted waveform shall be as described in 8.2.5.4.9.

8.2.6.3.10 Summary of uplink PHY parameters

Table 148 summarizes the uplink PHY parameters.

Table 148—Summary of uplink PHY parameters

Outer Coding	Reed–Solomon over GF(256) Information byte lengths: 6~~–255~~239 bytes Error correction capability *R* = ~~0-32~~ 16 (*T*=~~0-16~~8) ~~BTC (optional)~~ ~~NOTE—There is no inner code selected in this case.~~
Inner convolutional Coding	Selectable from the following options: ~~None~~ ~~(24,16) block convolutional code~~ ~~(9,8) parity check code (optional)~~ r=2/3 (only for QPSK) r=5/6 (only for 64-QAM) r=7/8 (only for 16-QAM) r=1, no inner coding (for all modulations)
Randomization	$1 + X^{14} + X^{15}$ Initialization: 100101010000000 at the beginning of each burst
Preamble	Based on repetition of 8 symbol or 16 symbol CAZAC sequences
Modulation	QPSK (mandatory);16-QAM (optional); 64-QAM (optional)
Spectral shaping	$\alpha = 0.25$

8.2.7 Baud rates and channel bandwidths

A large amount of spectrum is potentially available in the 10–66 GHz range for PMP systems. Although regulatory requirements vary between different regions, sufficient commonality exists for a default RF channel bandwidth to be specified for each major region. This is necessary in order to ensure that products built to this standard have interoperability over the air interface.

Systems shall use Nyquist square-root raised cosine pulse shaping with a roll-off factor of 0.25 and shall operate on the default RF channel arrangement shown in Table 149. Note that baud rates are chosen to provide an integer number of PSs per frame. The frame duration choice compromises between transport efficiency (with lower frame overhead) and latency.

Table 149—Baud rates and channel sizes for a roll-off factor of 0.25

Channel size (MHz)	Symbol rate (MBd)	Bit rate (Mbit/s) QPSK	Bit rate (Mbit/s) 16-QAM	Bit rate (Mbit/s) 64-QAM	Recommended Frame Duration (ms)	Number of PSs/frame
20	16	32	64	96	1	4000
25	20	40	80	120	1	5000
28	22.4	44.8	89.6	134.4	1	5600

Due to wide variations in local regulations, no frequency plan is specified in this standard. No single plan can accommodate all cases. For example, the 24.5-26.5 GHz band in Europe is regulated by CEPT requirements concerning specific duplex spacing and rasters. This does not match a similar spectrum allocation in North America.

8.2.8 Radio subsystem control

8.2.8.1 Synchronization technique

The downlink demodulator typically provides an output reference clock that is derived from the downlink symbol clock. This reference can then be used by the SS to provide timing for rate critical interfaces when the downlink clock is locked to an accurate reference at the BS.

Accurate uplink time slot synchronization is supported through a ranging calibration procedure defined by the MAC ~~sublayer~~ to ensure that uplink transmissions by multiple users do not interfere with each other. Therefore, the PHY needs to support accurate timing estimates at the BS, and the flexibility to finely modify the timing at the SS according to the transmitter characteristics specified in 8.2.9.

8.2.8.2 Frequency control

~~Frequency control is also a critical component of the PHY. Frequency errors, varying with age and temperature, will exist in radio units, particularly so due to the high carrier frequencies. In order to minimize the complexity of the radio-frequency elements at the SS, the uplink and downlink carrier frequencies shall reference each other. Note that there also exists an initial ranging process for frequency and power calibration. After the initial frequency has been calibrated, periodic measurements of the frequency offset value at the BS shall be made by the PHY and sent to the SS via a MAC message, if required.~~

In order to meet more stringent coexistence requirements in place today the transmitted RF centre frequency for both the BS and at each SS shall have an absolute accuracy better than ±10 ppm. The value shall be guaranteed over the complete temperature range and time of operation, i.e. ageing for FWA equipment. In order to meet this main requirement, following other requirements have been derived for both BS and SS. The absolute carrier frequency accuracy for the BS shall be better than ±8 ppm. Therefore:

- The carrier frequency accuracy for the BS shall be ±8 ppm.
- The SS shall be locked in frequency to the BS.
- The relative accuracy of the SS shall be ±1 ppm with respect to the BS.

8.2.8.3 Power control

~~As with frequency control~~, ~~a~~ The power control algorithm shall be supported for the uplink channel with both an initial calibration and periodic adjustment procedure without loss of data. The BS should be capable of providing accurate power measurements of the received burst signal. This value can then be compared against a reference level, and the resulting error can be fed back to the SS in a calibration message coming from the MAC ~~sublayer~~. The power control algorithm shall be designed to support power attenuation due to distance loss or power fluctuations at rates of at most ~~10~~ 20 dB/second with depths of at least 40 dB. The exact algorithm implementation is vendor-specific. The total power control range consists of both a fixed portion and a portion that is automatically controlled by feedback. The power control algorithm shall take into account the interaction of the RF power amplifier with different burst profiles. For example, when changing from one burst profile to another, margins should be maintained to prevent saturation of the amplifier and to prevent violation of emissions masks.

8.2.9 Minimum performance

This subclause details the minimum performance requirements for proper operation of systems in the frequency range of 24–32 GHz. The values listed in this subclause apply over the operational environmental ranges of the system equipment.

The philosophy taken in this subclause is to guarantee SS interoperability. Hence, the BS is described only in terms of its transmitter (Table 150), while the SS is described in terms of both its transmitter (Table 151) and receiver (Table 152). It is expected that BS manufacturers will use SS transmitter performance coupled with typical deployment characteristics (e.g., cell size, channel loading, near-far users, etc.) to profile their receiver equipment emphasizing specific performance issues as they require.

Table 150—Minimum BS transmitter performance

Tx symbol timing accuracy	Peak-to-peak symbol jitter, referenced to the previous symbol zero crossing, of the transmitted waveform, shall be less than 0.02 of the nominal symbol duration over a 2 s period. The peak-to-peak cumulative phase error, referenced to the first symbol time and with any fixed symbol frequency offset factored out, shall be less than 0.04 of the nominal symbol duration over a 0.1 s period. The Tx symbol timing accuracy shall be within ± ~~15~~ 8ppm of its nominal value (including aging and temperature variations).
Tx RF frequency/accuracy	10–66 GHz/ ± ~~10~~ 8ppm (including aging and temperature variations)
Tx RMS power	At least 15dBm measured at antenna port
Spectral mask (out of band/block)	Per relevant local regulation requirements (see 8.2.9.2.2 for more details)
Spurious	Per relevant local regulatory requirements

Table 150—Minimum BS transmitter performance

Maximum Ramp Up/Ramp Down Time	~~24~~ 8 symbols (~~6~~ 2 PSs)
Modulation accuracy (expressed in EVM, as in 8.2.9.2.3)	12% (QPSK); 6% (16-QAM) (Measured with an Ideal Receiver without Equalizer, all transmitter impairments included), and 10% (QPSK); 3% (16-QAM), 1.5% (64-QAM) (Measured with an Ideal Receiver with an Equalizer, linear distortion removed) Note: Tracking loop bandwidth is assumed to be between 1% to 5% optimized per phase noise characteristics. The tracking loop bandwidth is defined in the following way. A lowpass filter with unity gain at DC and frequency response $H(f)$, has a tracking loop (noise) bandwidth (B_L), defined as the integral of $\vert H(f)\vert$ squared from 0 to the sampling frequency. The output power of white noise passed through an ideal brick wall filter of bandwidth B_L shall be identical to that of white noise passed through any lowpass filter with the same tracking loop (noise) bandwidth.

Table 151—Minimum SS transmitter performance

Tx Dynamic range	40 dB
Tx RMS Power Level at Maximum Power Level setting for QPSK	At least +15 dBm (measured at antenna port)
Tx power level adjustment steps and accuracy	The SS shall adjust its Tx power level, based on feedback from the BS via MAC messaging, in steps of 0.5 dB in a monotonic fashion. [This required resolution is due to the small gap in sensitivities between different burst profiles (3–4 dB typical).]
Tx symbol timing jitter	Peak-to-peak symbol jitter, referenced to the previous symbol zero crossing, of the transmitted waveform, shall be less than 0.02 of the nominal symbol duration over a 2 s period. The peak-to-peak cumulative phase error, referenced to the first symbol time and with any fixed symbol frequency offset factored out, shall be less than 0.04 of the nominal symbol duration over a 0.1 s period.
Symbol clock	Shall be locked to BS symbol clock.
Tx burst timing accuracy	Shall implement corrections to burst timing in steps of up to ±0.~~2~~5 of a symbol with step accuracy of up to ±0.~~1~~25 of a symbol.
Tx RF frequency/accuracy	SS frequency locking to BS carrier required. 10–66 GHz/ ± 1 ppm (including aging and temperature variations)
Spectral Mask (out of band/block)	Per relevant local regulation requirements (see 8.2.9.2.2 for more details).
Maximum Ramp Up/Ramp Down Time	~~24~~ 8 symbols (2 ~~6~~ PSs)
Maximum output noise power spectral density when Tx is not transmitting information	–80 dBm/MHz (measured at antenna port)
Modulation accuracy (expressed in EVM, as in 8.2.9.2.3)	As specified in Table 150.

Note—The interfering source shall be a continuous signal of the same modulation type as the primary signal. The spectral mask of the interfering signal shall depend on local regulatory requirements. ~~For example, where ETSI regulations apply, the 1st and 2nd Adjacent Channel Interference test shall be performed with the interfering signal~~

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Table 152—Minimum SS receiver performance

Bit error rate (BER) performance threshold	For BER = 1×10^{-3}: QPSK: –984 + $10\log_{10}(B)$ 16-QAM: ~~–87~~ 91 + $10\log_{10}(B)$ 64-QAM: ~~–79~~ 82+ $10\log_{10}(B)$ For BER = 1×10^{-6}: QPSK: ~~–90~~ 96+ $10\log_{10}(B)$ 16-QAM: ~~–83~~89 + $10\log_{10}(B)$ 64-QAM: ~~–74~~ 80+ $10\log_{10}(B)$ NOTE: Measured ~~un~~coded in dBm, where B denotes carrier symbol rate in MBd. Propagation models of Type 0, 1, or 2 (Table 153) are used.
Maximum Transition time from Tx to Rx and from Rx to Tx	2 µs (TDD) 20 µs (FDD, half-duplex terminal)
1st Adjacent Channel Interference	At BER 10^{-3}, for 3 dB degradation: C/I = –9 (QPSK), –2 (16-QAM), and +5 (64-QAM) At BER 10^{-3}, for 1 dB degradation: C/I = –5 (QPSK), +2 (16-QAM), and +9 (64-QAM) At BER 10^{-6}, for 3 dB degradation: C/I = –5 (QPSK), +2 (16-QAM), and +9 (64-QAM) At BER 10^{-6}, for 1 dB degradation: C/I = –1 (QPSK), +6 (16-QAM), and +13 (64-QAM) NOTE: Measured uncoded, in dB.
2nd Adjacent Channel Interference	At BER 10^{-3}, for 3 dB degradation: C/I = –34 (QPSK), –27 (16-QAM), and –20 (64-QAM) At BER 10^{-3}, for 1 dB degradation: C/I = –30 (QPSK), –22 (16-QAM), and –16 (64-QAM) At BER 10^{-6}, for 3 dB degradation: C/I = –30 (QPSK), –23 (16-QAM), and –16 (64-QAM) At BER 10^{-6}, for 1 dB degradation: C/I = –26 (QPSK), –20 (16-QAM), and –12 (64-QAM) NOTE: Measured uncoded, in dB.

~~conforming to the ETSI Type C spectral mask. Where alternative masks are permitted, the interfering signal shall conform to the ETSI Type B spectral mask.~~

8.2.9.1 Propagation conditions

LOS radio propagation conditions between BS and SSs are required, to achieve high quality and availability service. Also, the SSs need highly directional antennas, which minimize the number of multipaths and interference from unexpected sources. The intersymbol interference may occur as a consequence of multipaths.

8.2.9.1.1 Propagation models

In this subclause, the propagation models referred to in this specification are defined. No further BER performance degradation should be expected with all propagation model types.

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The channel model is expressed as follows:

$$H(j\omega) = C_1*\exp(-j*\omega T_1) + C_2*\exp(-j*\omega T_2) + C_3*\exp(-j*\omega T_3)$$

Here C_1,C_2, and C_3 are the complex tap amplitudes and T_1,T_2, and T_3 are the tap delays. These parameters are provided in Table 153, where B is the channel ~~baud~~symbol rate in MBd and the resulting tap delay is in ns. For example, if B=20 MBd, then the resulting Type 2 tap delays will be 0, 20, and 40 ns.

Table 153—Propagation models

Propagation model	Tap number *i*	Tap amplitude C_i	Tap delay T_i
Type 0	1	1.0	0
Type 1	1	0.995	0
	2	0.0995 exp(–*j* 0.75)	400/B
Type 2	1	0.286 exp(–*j* 0.75)	0
	2	0.953	400/B
	3	–0.095	800/B

Note: Propagation path parameters are valid for B from 15 to 25 MBd.

Type 0 represents a clear LOS scenario. Type 1 and Type 2 represent typical deployment scenarios with weak multipath components, Type 1 being with better conditions.

8.2.9.1.2 Rain fades

For 10–66 GHz frequencies of operation, the predominant fade mechanism is that resulting from rain attenuation. Fade depths are geographically dependent by rain rate region and are also conditioned by both frequency of operation and link distance. For a given set of equipment transmission parameters and a specified link availability requirement, the rain rate criteria establish the maximum cell radius appropriate to system operation.

An internationally accepted method for computation of rain fade attenuation probability is that defined by ITU-R P.530-8 [B33]. As an example, typical 28 GHz equipment parameters result in a maximum cell radius of about 3.5 km in ITU rain region K. This criteria applies for a link BER = 10^{-6} at a link availability of 99.995%. Further details on this example system model may be found in IEEE Std 802.16.2-2001.

Another important issue is the impact of uncorrelated rain fading between an interference transmission link and a victim transmission link. Under rain fading conditions, the differential rain fading loss between the two transmission paths may have a significant impact on both intrasystem and intersystem link availability. At operational frequencies around 28 GHz, the estimated rain cell diameter is approximately 2.4 km (ITU-R P.452 [B32]). The effect of rain decorrelation may be estimated based on cell sector size and the specified frequency re-use plan.

A significant mitigation technique for the control of both intrasystem and intersystem interference is the angular discrimination provided by system antennas. The antenna radiation pattern envelope (RPE) discrimination has significance for both clear sky and rain faded propagation conditions. The RPE requirements for aggressive intrasystem frequency reuse plans may exceed the RPE requirements for the control of inter-system coexistence. Recommended antenna RPE characteristics are described in IEEE Std 802.16.2-2001.

8.2.9.2 Transmitter characteristics

Unless stated otherwise, the transmitter requirements are referenced to the transmitter output port and apply with the transmitter tuned to any channel.

8.2.9.2.1 Output power

In the following subclause, power is defined as the time-averaged power when emitting a signal (excluding off-time between bursts), measured over the scrambled bits of one transmitted burst.

The power at which SS or BSs shall operate is specified in the following subclause.

8.2.9.2.1.1 BS

A BS shall not produce an effective isotropic radiated power (EIRP) spectral density exceeding either ~~+14~~ 28,5 dBmi ~~W~~/MHz or local regulatory requirements.~~ The recommendations in 6.1.1.1 of IEEE Std 802.16.2-2001 should be followed.~~

8.2.9.2.1.2 SS

An SS shall not produce an EIRP spectral density exceeding either ~~+30~~ 3~~5~~9,5dBmi ~~W~~/MHz or local regulatory requirements. ~~The recommendations in 6.1.1.2 of IEEE Std 802.16.2-2001 should be followed.~~

8.2.9.2.2 Emission mask and adjacent channel performance (NFD)

Transmit parameters shall comply with existing ETSI standards having more stringent requirements, in particular:

- frequency band 40,5 GHz to 43,5 GHz: EN 301 997-1
- frequency band 24,25 GHz to 29,5 GHz: EN 301 213-3

In the downlink channel the transmitted spectrum shall not exceed the spectrum mask defined by table 154 which specifies more stringent requirements than System Type C spectrum mask defined in EN 301 213-3.

In the uplink channel the transmitted spectrum shall not exceed the spectrum mask defined by table 155 which is derived from the requirements given by System Type B spectrum mask defined in EN 301 213-3.

Downlink and Uplink spectrum masks are also shown in figure 166 .

~~Local regulation requirements typically dictate emission mask requirements. For example, in its territories, ETSI currently specifies the use of Type A (QPSK), Type B (16-QAM) and Type C (64-QAM) masks (ETSI EN 301 213-3). These masks are presented in Figure 162, Figure 163, and Figure 164.~~

~~In the case of mixed modulation systems (e.g., adaptive modulation), ETSI currently specifies the most stringent mask associated with the highest modulation complexity in the adjacent channels.~~

~~NOTE—This requirement is under review by ETSI.~~

Figure 160—Spectrum mask @ 28MHz

Figure 161—NFD mask for 28MHz channel

The Net-Filter-Discriminator (NFD) mask which shall be guaranteed by the system, is defined by table fUL.

Table 154—Downlink spectrum mask @ 28MHz channel

Frequency offset (MHz)	13	14	14.4	14.8	22.4	28	56	70
Relative attenuation (dB)	0	-15	-20	-28	-34	-42	-52	-52

Table 155—Uplink spectrum mask @ 28MHz channel

Frequency offset (MHz)	11.2	13.5	14.5	22.4	28	56	70
Relative attenuation (dB)	0	-7	-17	-32	-37	-52	-52

Table 156—Downlink and uplink NFD mask

Offset (MHz)	FD - DL (dB)	FD - UL (dB)
28	35,5	29
31,5	39	34,5
35	42	38,5
38,5	45	41
42	46,5	43
49	49	46,5
56	51	50
59,5	51,5	51
63	52	51,5
70	52	52
77	52	52
84	52	52

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In cases where alternative masks are permitted, the emission mask specified shall be the ETSI Type B mask [ETSI EN 301 213-3] (Figure 163).

~~Figure 162—ETSI Type A spectrum mask~~

~~Figure 163—ETSI Type B spectrum mask~~

~~Figure 164—ETSI Type C spectrum mask~~

8.2.9.2.3 Modulation accuracy and error vector magnitude (EVM)

The EVM defines the average constellation error with respect to the farmost constellation point power, as illustrated in Figure 165 and defined by the following equation:

$$EVM = \sqrt{\frac{\frac{1}{N}\sum_{1}^{N}(\Delta I^2 + \Delta Q^2)}{S_{\max}^2}}$$

where N is the number of symbols in the measurement period and $S_{\max}$ the maximum constellation amplitude.

The EVM shall be measured over the continuous portion of a burst occupying at least 1/4 of the total transmission frame at maximum power settings.

The required EVM can be estimated from the transmitter implementation margin if the error vector is considered noise which is added to the channel noise.

The implementation margin means the excess power needed to keep the C/N constant when going from the ideal to the real transmitter. EVM cannot be measured at the antenna connector but should be measured by

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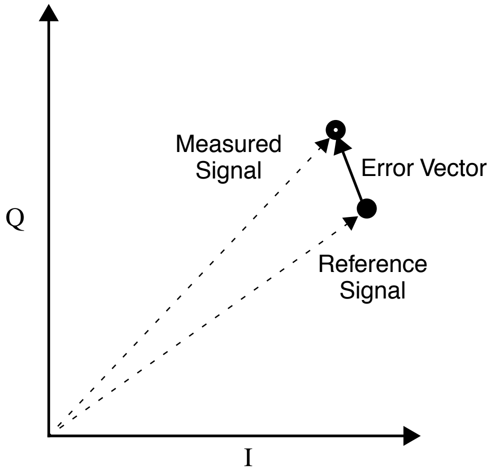

Figure 165—Illustration of EVM

an "ideal" receiver with a certain carrier recovery loop bandwidth specified in % of the symbol rate. In table 157 the EVM-values for different modulation schemes are specified using parameters relevant tothr system.

Based on the values in table 157 the EVM values shall be the following:

- EVM 12 % and 6 % for 4QAM, 16QAM respectively when measured by an "ideal" receiver without an equalizer with a carrier recovery loop bandwidth of 1 % to 5 %; and

- EVM 10 %, 3 % and 1,5 % for 4QAM, 16QAM and 64QAM respectively when measured by an "ideal" receiver with an equalizer with a carrier recovery loop bandwidth of 1 % to 5 %.

The above EVM measured will include the transmit filter accuracy, D/A-converter, modulator imbalances, untracked phase noise and PA (power amplifier) non-linearity.

Table 157—EVM values vs. modulation scheme

Modulation	**Tx implementation margin**	**Rx-AWGN C/N (dB)** **BER = 10E-6** **4 MAC-PDUs**	**Peak-to-average**	**EVM (%) Without equalization**	**EVM (%) With equalization**
4QAM + RS	0,5 dB	10	0 dB	12	10
16QAM + RS	1,0 dB	17	2,55 dB	6	3
16QAM + RS	1,5 dB	23	3,68 dB	n.a.	1,5

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