Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**	
Title	**Draft Physical Layer Specification for the 802.16.1 Air Interface Standard**	
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Re:	This contribution incorporates the changes to the PHY draft specification that were agreed upon during the PHY task group meeting on 2000-07-11.	
Abstract	This contribution incorporates the changes to the PHY draft specification that were agreed upon during the PHY task group meeting on 2000-07-11.	
Purpose	The author would like the task group to consider adopting the revised physical layer specification contained in this contribution as the new working draft.	
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Draft Physical Layer Specification for the 802.16.1 Air Interface Standard

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1 Scope

This document describes the physical layer components that meet the functional requirements of the Broadband Wireless Access (BWA) system that has been defined by the 802.16 Working Group. Detailed electrical and signal processing specifications are presented that enable the production of interoperable equipment.

2 Normative References

[1] ETSI EN 300 421 V1.1.2 (1997-08), "Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for 11/112 GHz satellite services."

[2] ETSI EN 301 210 V1.1.1 (1999-03), "Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for Digital Satellite News Gathering (DSNG) and other contribution applications by satellite."

[3] ITU-T J.83 (04/97), Series J: Transmission of Television, Sound Programme and Other Multimedia Signals: Digital transmission of television signals, "Digital multi-programme systems for television, sound and data services for cable distribution."

[4] Data-Over-Cable Service Interface Specifications, "Radio Frequency Interface Specification," SP-RFIv1.1-I03-991103.

[5] ETSI EN 301 199 v1.2.1 (1999-06), "Digital Video Broadcasting (DVB); Interaction channel for Local Multi-point Distribution Systems (LMDS)."

[6] ITU-T draft Recommendation J.116, "Interaction channel for Local Multipoint Distribution services."

[7] ITU-R 9B/134-E, JRG 8A-9B, Draft New Recommendation ITU-R F.BWA, "Radio Transmission Systems for Fixed Broadband Wireless Access (BWA) Based on Cable Modem Standards (Annex B of ITU-T Rec. J.112)."

3 Physical Layer Overview

3.1 Introduction

The following physical layer specification was designed to meet the functional requirements that have been defined for Broadband Wireless Access (BWA) systems. It incorporates many aspects of existing standards [1]-[7] in order to leverage existing technology for reduced equipment cost and demonstrated robustness of implementation, with modifications to ensure reliable operation in the targeted 10-60 GHz frequency band. In addition, this physical layer was 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 considerations, radio capabilities, offered services, and capacity requirements. Two modes of operation have been defined for the downstream channel, one targeted to support a continuous transmission stream and one targeted to support a burst transmission stream. Having this separation allows each to be optimized according to their respective design constraints, while resulting in a standard that supports various system requirements and deployment scenarios.

3.2 Reference Configuration

Below is a simple reference model that is used to show the interface between the physical layer and the MAC layer, and to show how the MAC layer might interface with higher layers. The convergence layer between the MAC and higher layers is beyond the scope of this specification, but the convergence layer between the MAC and PHY is clearly defined in the following sections in order to ensure interoperation between the two entities.

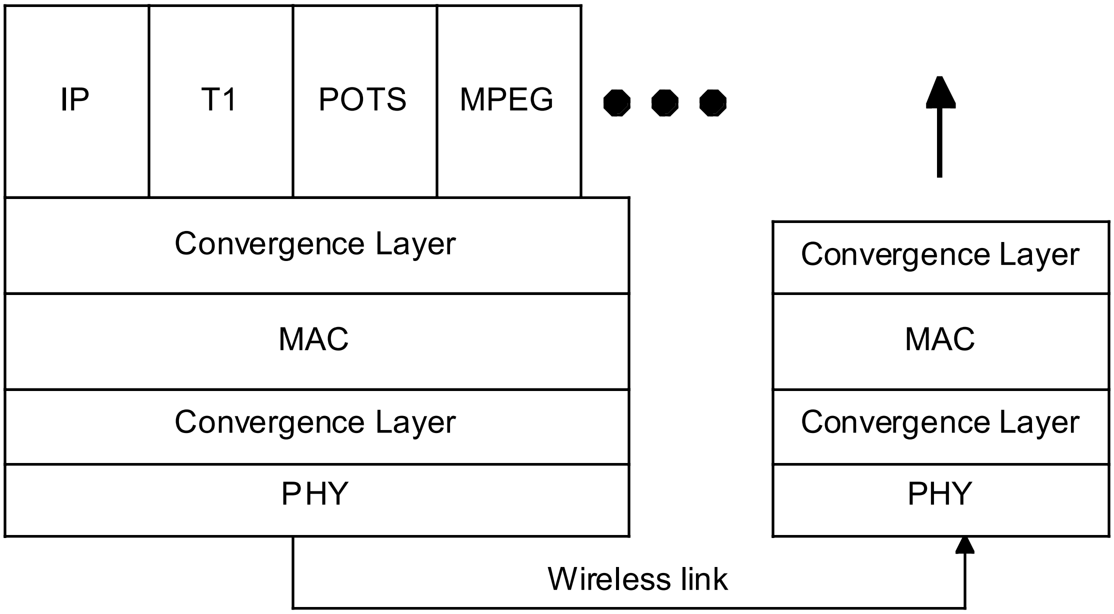


Figure 1: Reference Configuration

3.3 Multiplexing and Multiple Access Technique

The upstream physical layer is based on the use of a combination of time division multiple access (TDMA) and demand assigned multiple access (DAMA). In particular, the upstream 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 base station and can vary in time for optimal performance. The downstream channel can be either based upon continuous time division multiplexing (TDM), where the information for each subscriber station is multiplexed onto the same stream of data and is received by all subscriber stations located within the same sector or in an alternative method (defined for the burst mode of operation), which allows bursts to be transmitted to specific CPEs in a similar fashion to the TDMA upstream bursts.

3.4 Duplexing Technique

Several duplexing techniques are supported with this physical layer. The continuous transmission downstream mode that is defined supports frequency division duplexing (FDD) only, while the burst mode of operation supports FDD with adaptive modulation, frequency switch division duplexing (FSDD), or time division duplexing (TDD). The primary difference between the continuous mode and burst mode of operatoin for supporting FDD is the coding gain and how higher order modulation formats are supported. The continuous downstream mode has a higher coding gain due to the presence of a concatenated Reed-Solomon, interleaver, and convolutional code, and can support different orders of modulation on separate carriers. The burst mode supports the capability to have different modulation formats transmitted on the same carrier so that the modulation level can be chosen on a subscriber level basis.

3.5 Physical Layers

Two different downstream physical layers have been defined in this standard. A Mode A downstream physical layer has been designed for continuous transmission, while a Mode B physical layer has been designed to support a burst transmission format.

Mode A is based upon a continuous transmission stream supporting a concatenation of Reed Solomon coding, interleaving, and convolutional coding for use in an FDD only system. Mode B supports a burst format that allows systems to implement an adaptive modulation scheme for an FDD system as well as supporting FSDD and TDD configurations.

This approach to standardization allows for service providers the ability to pick the format which best allows them to meet their system requirements. Standards compliant subscriber stations are required to support at least one of the modes of operation as defined here.

A single upstream physical layer is also defined here to support a TDMA based burst upstream transmission.

3.5.1 Continuous Downstream Physical Layer (Mode A)

The Mode A downstream physical layer first encapsulates MAC packets into a convergence layer frame as defined by the transmission convergence sublayer. Then, the data is randomized and encoded using a (204,188) Reed-Solomon code over GF(256). Following the outer block encoder, the data goes through a convolutional interleaver with a depth of I=12. Then, the data must either pass through an inner, constraint length K=7, convolutional code with a rate of _, 2/3, _, 5/6, or 7/8, or pass through a differential encoder (*i.e.*, bypassing the convolutional encoder) as defined in the following sections. Code bits are then mapped to a QPSK, 16-QAM (optional), or 64-QAM (optional) signal constellation with symbol mapping as described here. Elements that are identified as optional need not be implemented in order to be standards compliant. However, if these options are supported, they shall be supported in the manner defined in this standard. Finally, symbols are Nyquist filtered using a square-root raised cosine filter with a roll-off factor of 0.15, 0.25 or 0.35.

3.5.2 Burst Downstream Physical Layer (Mode B)

The Mode B downstream physical layer has a framing mechanism associated with it that simplifies the support for TDD and FSDD systems, typically with a frame time of 1 msec. The frame can either be configured to support a TDM transmission format, which would typically be used in an FDD system supporting adaptive modulation or a TDD system, or a TDMA format, which is expected to be used in an FSDD system. One unique preamble is used to indicate the beginning of a frame, which is followed by QPSK data. A PHY control map is used to indicate the beginning of a 16-QAM burst, the beginning of a 64-QAM burst, and the end of a frame. Various frame configurations for FDD, TDD, and FSDD are supported, as will be discussed later. All user data is FEC block encoded allowing for a shortening of the last codeword of a burst. The Mode B downstream physical layer also goes through a transmission convergence sublayer that inserts a pointer byte at the beginning of the payload information bytes and terminates the packet with a 16 bit CRC to help the receiver identify the beginning of a MAC packet and preserve data integrity. Code bits out of the FEC encoder are then randomized and mapped, along with the preambles, to a QPSK, 16-QAM, or 64-QAM (optional) signal constellation and Nyquist filtered using a square-root raised cosine filter with a roll-off factor of 0.15, 0.25 and 0.35.

3.5.3 Upstream Physical Layer

The upstream physical layer has been designed to support burst modulation for a TDMA based system. Since many of the specific upstream channel parameters can be programmed by MAC layer messaging coming from the base station, several parameters can be left unspecified and configured by the base station in order to optimize performance for a particular deployment scenario. In this mode, each burst is designed to carry MAC messages of variable lengths, and first encodes the incoming MAC messages using a Reed-Solomon encoder based on GF(256) and an inner code to be selected by the MAC messages, and then randomizes the complete outgoing burst. The length of the codeword and the error correction capability of the code are programmable by the MAC messages coming from the basestation via a burst configuration message. Each burst also contains a variable length preamble and a variable length guard space at the end of the burst. The preamble and coded bits are mapped to QPSK, 16-QAM, or 64-QAM (optional) constellations. Nyquist pulse shaping using a square-root raised cosine filter is also employed with a roll-off factor of 0.15, 0.25, or 0.35.

4 Duplexing Techniques

Several duplexing techniques are supported in this standard in order to allow for greater flexibility in spectrum usage. The choice of duplexing technique may effect certain physical layer parameters, as will be discussed later.

4.1 Frequency Division Duplexing (FDD)

In a system employing FDD, the upstream and downstream channels are located on separate frequencies and all subscriber stations can transmit and receive simultaneously. The frequency separation between carriers is set either according to the target spectrum regulations or to some value sufficient for complying with radio channel transmit/receive isolation and desensitization requirements. In this type of system, the downstream channel is “always on” and all subscriber stations are always listening to it. Therefore, traffic is sent in a broadcast manner using time division multiplexing (TDM) in the downstream channel, while the upstream channel is shared using time division multiple access (TDMA), where the allocation of upstream bandwidth is controlled by a centralized scheduler.

4.2 Frequency Switched Division Duplexing (FSDD)

An FSDD system refers to a system in which the upstream and downstream channels are located on separate frequencies, but some or all subscriber stations can only transmit or receive at any particular instance in time (for simplicity, these users are referred to as half duplex capable). This mode of operation imposes a restriction on the bandwidth controller not to allocate upstream bandwidth for a subscriber at the same time is expected to receiver data on the downstream channel. Note that this type of system may also have some subscriber stations that can transmit and receive simultaneously (i.e., these users are referred to as full duplex capable).

The following figure describes the basics of the FSDD based mode of operation. In order to simplify the bandwidth allocation algorithms, the upstream and downstream channels are divided into 1 msec frames. During the time a user is not transmitting in the upstream channel, it must always listen to the downstream channel.

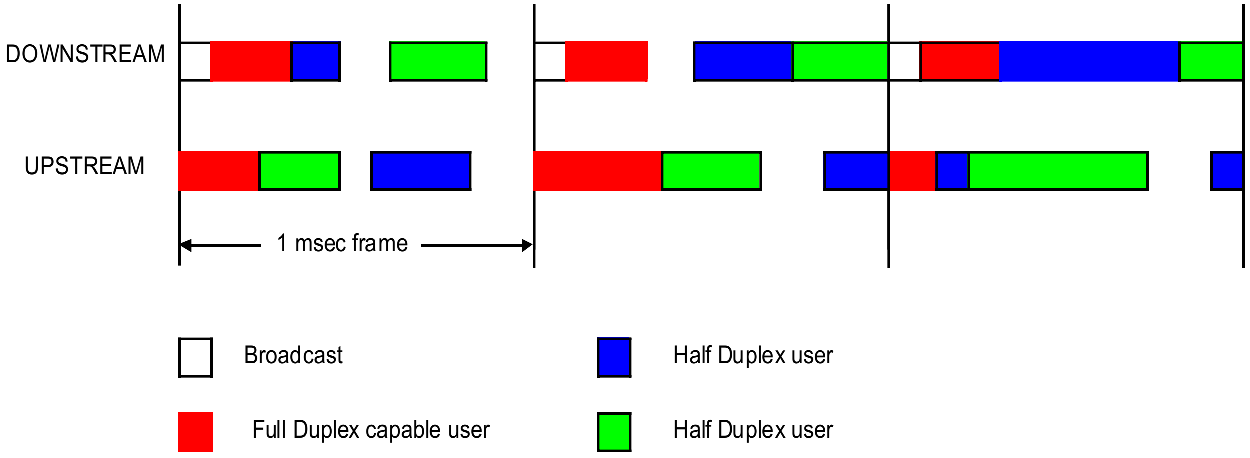


Figure 2: Example of FSDD Bandwidth Allocation

4.3 Time Division Duplexing (TDD)

In the case of TDD, the upstream and downstream transmissions share the same frequency, but are separated in time. A TDD frame also has a 1 msec duration and contains one downstream and one upstream subframe. The frame is divided into an integer number of physical slots (PS), which help to partition the bandwidth easily. The TDD framing is adaptive in that the bandwidth allocated to the downstream versus the upstream can vary. The split between upstream and downstream is a system parameter and is controlled at higher layers within the system.

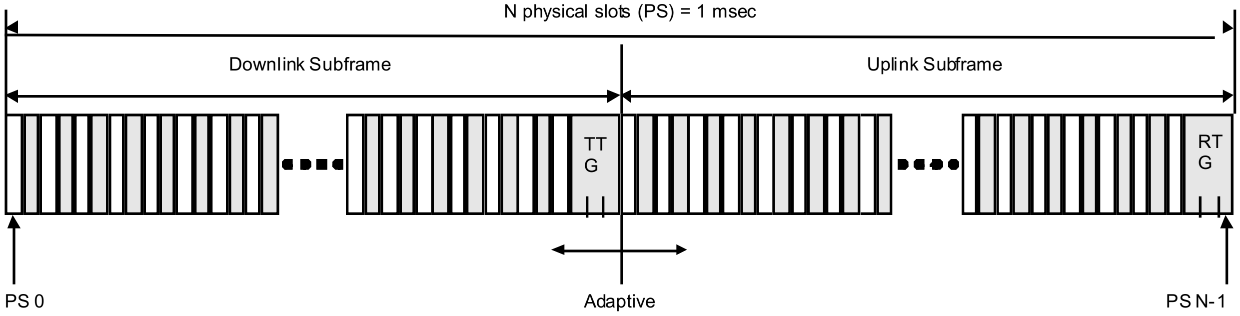


Figure 3: TDD Frame Structure

4.3.1 Tx / Rx Transition Gap (TTG)

The TTG is a gap between the Downstream burst and the Upstream burst. This gap allows time for the BS to switch from transmit mode to receive mode and CPEs to switch from receive mode to transmit mode. During this gap, BS and CPE are not transmitting modulated data but simply allowing the BS transmitter carrier to ramp down, the Tx / Rx antenna switch to actuate, and the BS receiver section to activate. After the TTG, the BS receiver will look for the first symbols of QPSK modulated data in the upstream burst. The TTG has a variable duration which is an integer number of PSs. The TTG starts on a PS boundary.

4.3.2 Rx / Tx Transition Gap (RTG)

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

5 Fixed/Adaptive Modulation and Framing

This standard provides the capability to efficiently support either a fixed modulation level per downstream carrier or an adaptively changing modulation level and FEC coding on each downstream carrier, where the modulation level and FEC scheme can be set on a per subscriber station basis. Depending on the deployment scenario, one may be preferred over the other. When a fixed modulation level is used, there is no explicit framing mechanism defined.

The adaptive modulation/FEC capability is supported on a frame by frame basis. In this case, the downstream channel is divided into 1 msec frame times, where each frame is subdivided into an integer number of physical slots (PSs). Each PS represents a multiple of 4 symbols. The structure of the downstream burst used by the BS to transmit to the CPEs, using time division multiplexing (TDM), is shown in the following figures. This structure is the preferred option for both FDD and TDD systems using adaptive modulation. This burst structure defines the single, downstream physical channel. It starts with a Frame Control Header that is always transmitted in QPSK. This frame header contains a preamble used by the PHY for synchronization and equalization. It also contains control sections for both the PHY and the MAC that is encoded with a fixed FEC scheme defined in this standard in order to ensure interoperability. Within the downstream subframe, transmissions are organized into different modulation and FEC groups, where the modulation type and FEC parameters are defined through MAC layer messaging. The PHY Control portion of the Frame Control Header contains fields stating the PSs at which the different modulation/FEC groups begin. Data is transmitted in modulation order QPSK, followed by 16-QAM, followed by 64-QAM. There is a Tx/Rx Transmission Gap (TTG) separating the downstream subframe from the upstream subframe in the case of TDD.

Each CPE continuously receives the entire downstream burst, decodes the data in the DL burst, and looks for MAC headers indicating data for that CPE.

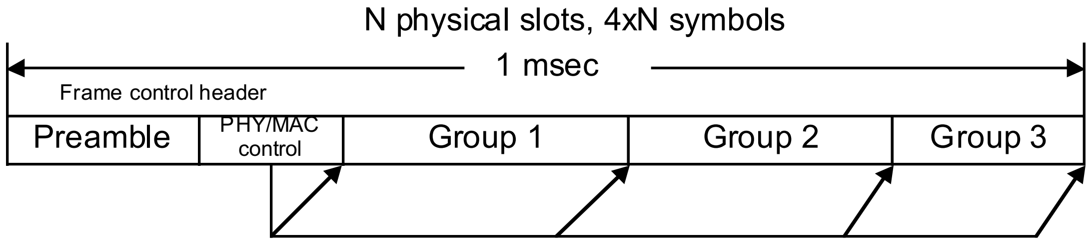


Figure 4: Frame format for an FDD system with Adaptive Modulation

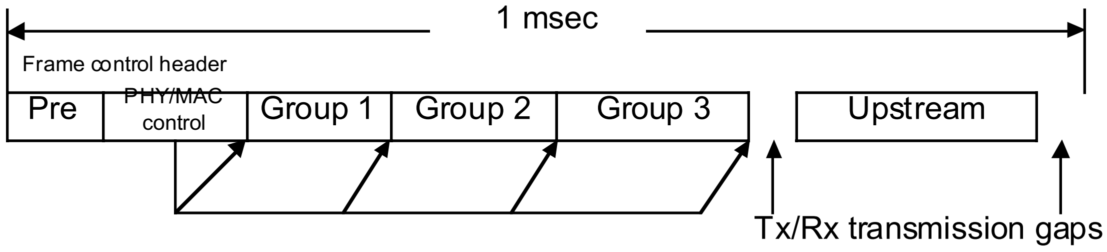


Figure 5: Frame format for a TDD system

An alternative structure is also supported in this standard, which allows for a TDMA downstream frame structure. This method is preferable when using an FSDD system. While using the TDMA option, an allocation map similar to the upstream allocation map (for scheduled upstream transmissions) is transmitted in the frame control header, as shown in the figure below. This allows an individual CPE to decode a specific portion of the downstream without the need to decode the whole DL burst. In this particular case, each transmission associated with different CPEs is required to start with a short preamble for phase re-synchronization. This data is always FEC coded and is transmitted at the current operating modulation of the individual CPE.

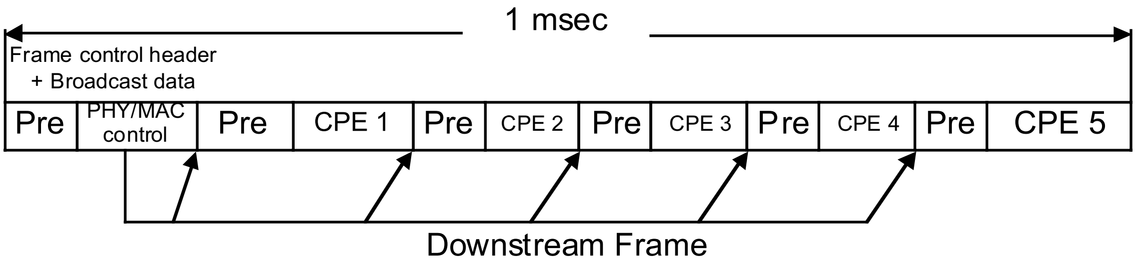


Figure 6: Downstream frame format for an FSDD system

6 Logical and Physical Channels

6.1 Logical channels

A logical channel is defined as a logical communication pathway between two or more parties. The logical channels represent the interface between the protocol and the radio subsystem. There are two categories of logical channels: the traffic channels carrying speech or data information and the control channels carrying signaling messages. The logical channels supported by the PHY and MAC are described here with their hierarchical relationship. The differentiation between the channel types and user destinations is determined through MAC header connection IDs (CIDs).

6.1.1 Traffic channels

The traffic channels shall carry user information. Three traffic channels are defined for three different modulation types. If the propagation environment allows, the BS may assign higher modulation types to CPEs on an individual basis independently on upstream and downstream, the Mode B downstream physical layer is supported. The Traffic CHannels are defined as follows:

- TCH4 – QPSK data;
- TCH16 - 16-QAM data;
- TCH64 - 64-QAM data.

The length of each type of traffic channel in a downstream transmission and an upstream transmission is dynamically assigned by the BS. A map of the assignments is included in the MAC Control Channel that is read and interpreted by the CPEs.

The downstream data sections are used for transmitting data and control messages to the CPEs. The upstream data sections are used for transmitting data and control messages to the BS. This data is always FEC coded and is transmitted at the current operating modulation.

In the case of FDD, when the downstream data does not fill the entire downstream subframe, the downstream subframe is padded with fill data according to the transmission convergence sublayer. In the case of TDD or FSDD filling is replaced by transmitter shut-down in order to allow parallel upstream allocations.

Within the upstream subframe, bursts are of the modulation type assigned to the CPE. The Upstream Map in the previous downstream burst regulates the length of the data section. If the upstream data does not fill the entire given upstream burst allocation, the burst is padded with fill data according to the transmission convergence sublayer.

6.1.2 Control CHannels (CCH)

The CCH shall carry signaling messages. Four categories of control channels are defined:

- PHY Control CHannel (PCCH);
- MAC Control CHannel (MCCH);
- Registration Request CHannel (RCCH);
- Bandwidth Request CHannel (BCCH).

The downstream channel has two categories of control channel defined:

- PHY Control CHannel (PCCH);
- MAC Control CHannel (MCCH).

When framing is used, these two channels are the first two sections of the DL burst and are not separate bursts from the DL traffic channels. When framing is not used, these channels are multiplexed with the downstream data. The upstream burst has two additional categories of control channel defined:

- Registration Request CHannel (RCCH);
- Bandwidth Request CHannel (BCCH).

Each message on these two channels is a separate burst from the UL traffic channels. Each channel can support multiple bursts per frame from multiple CPEs.

6.1.2.1 PHY Control CHannel (PCCH)

When framing is used, the PCCH occupies the first bytes following the preamble in the downstream burst. The PHY Control portion of the downstream subframe is used for physical information destined for all CPEs. The PHY Control information is FEC encoded. The information transmitted in this section is always transmitted in the lowest order modulation provisioned for the downstream channel.

6.1.2.2 MAC Control CHannel (MCCH)

The MAC Control portion of the downstream subframe is used for MAC messages destined for multiple CPEs. The MAC Control messages are FEC encoded. The information transmitted in this section is always transmitted in the lowest order modulation provisioned for the downstream channel. For information directed at an individual CPE, MAC messages are transmitted in the established control connection at the operating modulation of the CPE to minimize bandwidth usage.

6.1.2.3 Registration Request Contention CHannel (RCCH)

Periodically, a portion of the upstream channel is allocated for registration request messages on a contention basis. The Registration Request Contention Channel allows unregistered users a portion of the upstream frame to attempt transmission of registration requests without interfering with ongoing traffic. Registration request messages transmitted in the Registration Request Contention Channel are transmitted using the modulation order that has been defined for this message type, typically the lowest order modulation level provisioned for the channel.

6.1.2.4 Bandwidth Request Contention CHannel (BCCH)

Periodically, a portion of the upstream burst is allocated for bandwidth or connection requests. The Bandwidth Request Contention Channel allows registered users a portion of the upstream to attempt transmission of bandwidth requests without interfering with ongoing traffic. Bandwidth request messages transmitted in the Bandwidth Request Contention Channel are transmitted using the modulation order that has been defined for this message type, typically the lowest order modulation level provisioned for the channel.

6.2 Physical Channels

A physical channel is defined by a burst or transmission on a radio carrier frequency. There shall be one physical channel per radio frequency/burst.

Four types of physical channels are defined:

- Downstream continuous transmission channel
- Downstream TDM burst channel
- Downstream TDMA burst channel

- Upstream TDMA burst channel

6.2.1 Downstream continuous transmission channel

For an FDD system employing a fixed modulation level, the downstream channel can utilize a continuous transmission stream. In this case, all traffic, both user data traffic and MAC control messages, are multiplexed onto the same transmission stream in a Time Division Multiplexed (TDM) manner.

6.2.2 Downstream TDM burst channel

The structure of the downstream channel used to support FDD systems employing adaptive modulation or TDD systems, which is used by the BS to transmit to the CPEs, is shown Figure 4 and Figure 5. In this case, the downstream traffic is multiplexed onto a single burst that is received by all CPEs in the sector. The burst will begin with a preamble, followed by PHY control messages, MAC control messages, and then user data. The modulation level used to transmit the user data is determined on a subscriber by subscriber basis, and the burst format MUST transmit the QPSK data first, followed by 16-QAM, which is then followed by 64-QAM data.

6.2.3 Downstream TDMA burst channel

The structure of the downstream channel used to support FSDD systems uses a TDMA architecture, as shown in Figure 6. This mode of downstream operation (as mentioned previously) is advantageous in the case of supporting FSDD allowing the scheduling of individual users on the downstream. The reasoning for this approach is minimizing latency and controlling efficiently and tightly the allocation process for both upstream and downstream together as in the FSDD case users are forbidden to transmit and receive at the same instant.

Therefore scheduled downstream traffic bandwidth is allocated to specific CPEs for the transmission of control messages and user data. All bandwidth within a given frame, allocated to an individual CPE, is grouped into a contiguous block. In the downstream it is assumed that the user is capable of listening to the control portion at the beginning of the frame hence only a short preamble is required prior to the scheduled downstream transmission of an individual CPE, mainly for phase sync. In this case only a short 12 symbol preamble is used. There is no requirement for ramping power as downstream is assumed to be continuous within its subframe.

The existence of a downstream allocation map is identified in the control portion of each frame. There could be both TDM and TDMA downstream assignments. In this case, the TDM portion with all its modulation schemes would be transmitted first. In the case of FSDD, if a downstream map exists and the map does not address a specific user then this user is required to receive the TDM downstream portion if it exists. Only if the user has its upstream scheduled overlapping the TDM portion, it can assume that the base station MAC has not multiplexed any information for the user on the TDM portion and it can skip to the next frame.

6.2.4 Upstream TDMA burst channel

The structure of the upstream subframe used by the CPEs to transmit to the BS is shown in Figure 7. There are three main classes of MAC/TC messages transmitted by the CPEs during the upstream frame:

- Those that are transmitted in contention slots reserved for station registration;
- Those that are transmitted in contention slots reserved for response to multicast and broadcast polls for bandwidth needs;
- Those that are transmitted in bandwidth specifically allocated to individual CPEs.

The bandwidth allocated for contention slots is grouped together and is transmitted using the modulation defined for that message. The remaining, scheduled bandwidth is grouped by CPE. During its scheduled bandwidth, a CPE transmits with a fixed modulation, determined by the effects of environmental factors on transmission to and from that CPE. CPE Transition Gaps (CTG) separate the transmissions of the various CPEs during the upstream subframe. The CTG time length is an integer number of PSs sufficient for preamble (long) and ramp up time. The transmitting CPE transmits the preamble at the ending portion of the CTG ending where the CTG ends allowing the BS to synchronize to the new CPE. CTGs are considered part of the subsequent burst.

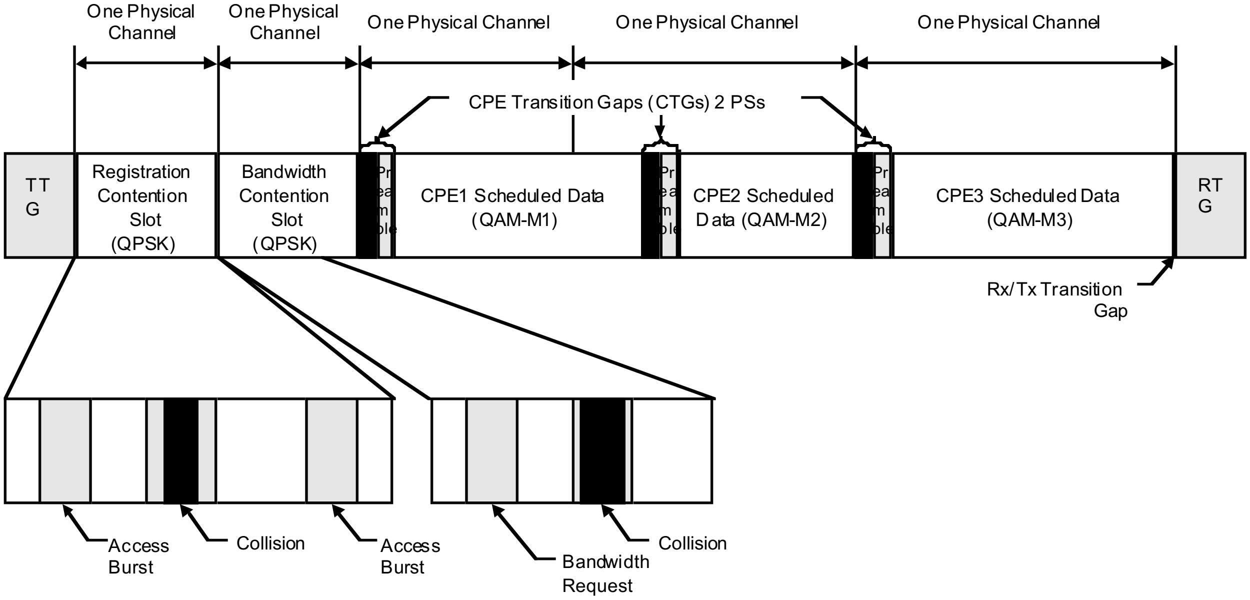


Figure 7: Example Upstream Subframe Structure

6.2.4.1 Upstream Control Channels

6.2.4.1.1 Registration Contention Slots

A portion of the upstream bandwidth is periodically allocated for registration contention slots. Registration contention slots are used to allow CPEs to register with the BS and to perform ranging. CPEs wishing to register and range must have acquired downstream synchronization with the BS, but do not know their Tx timing advance or an appropriate power level. Additionally, they do not yet have a basic connection ID assigned for direct communication with the BS. The registration contention slots allow access under these conditions, allowing CPEs to finalize their upstream physical synchronization with the BS and to establish a logical connection for control communication.

Due to propagation delays, the registration contention bursts from the CPEs are not aligned to the symbols or PSs of the downstream burst. The BS must use a sliding window to accurately detect the preamble of each request burst. The window is incremented in _ symbol increments.

Multiple CPEs may transmit in the registration contention period simultaneously, potentially causing collisions. When a collision occurs, the BS does not respond. If the BS successfully receives a registration message from a CPE, it responds with a registration results message in the QPSK portion of the downstream subframe.

The length of the registration contention period should account for the maximum expected propagation delay as well as any modem delays. Longer registration periods may be allocated to reduce the likelihood of collision or to allow for larger cells. Figure 8 shows the relationship between the registration contention slot window and the various parameters governing the timing of messages within the window. The registration contention slots must preserve PS boundary.

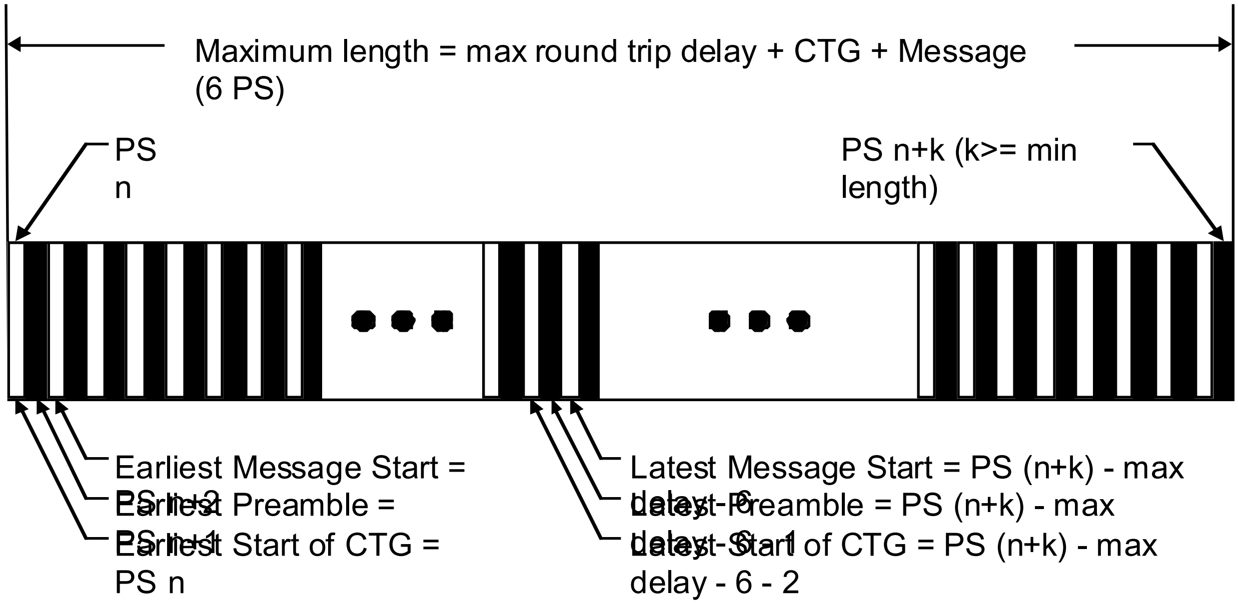


Figure 8: Registration Contention Slot Usage

6.2.4.1.2 Bandwidth Request Contention Slots

A portion of the upstream bandwidth is periodically allocated for bandwidth or connection requests. Since a CPE must be registered and have achieved upstream synchronization with the BS before it is allowed to request bandwidth, there is no Tx time uncertainty to be allowed for in the length of the bandwidth request contention period. Therefore, the bandwidth request contention period requires some number of PSs to transmit the request command, plus a CTG. As with registration requests, if a collision occurs, the BS does not respond. If the BS successfully receives a bandwidth request message, it responds by allocating the CPE (additional) bandwidth in the Upstream Map. Polling and piggybacking help to minimize the need to use bandwidth request contention slots.

6.2.4.1.3 Scheduled Upstream Traffic Channels

Scheduled upstream traffic bandwidth is allocated to specific CPEs for the transmission of control messages and user data. These scheduled bursts are the Traffic Channels (TCHs) for the CPEs. The bandwidth is requested by the CPE and granted by the BS. All bandwidth within a given frame, allocated to an individual CPE, can be grouped into a contiguous block, but is not required. The CTG PS count is included in the allocation to the CPE in the Upstream Map. The CPE transmits a preamble located at the CTG end. The preamble is not part of the FEC process. The data packets transmitted are always FEC coded. As indicated previously, the pointer for the beginning of a scheduled transmission uses a PS number.

6.2.5 Types of bursts

Figure 9 summarizes the description of the bursts and their timing with respect to the timeslot. Note that the downstream bursts are not applicable when a the Mode A downstream physical layer is used. In this case, there is no explicit framing mechanism, as mentioned earlier.

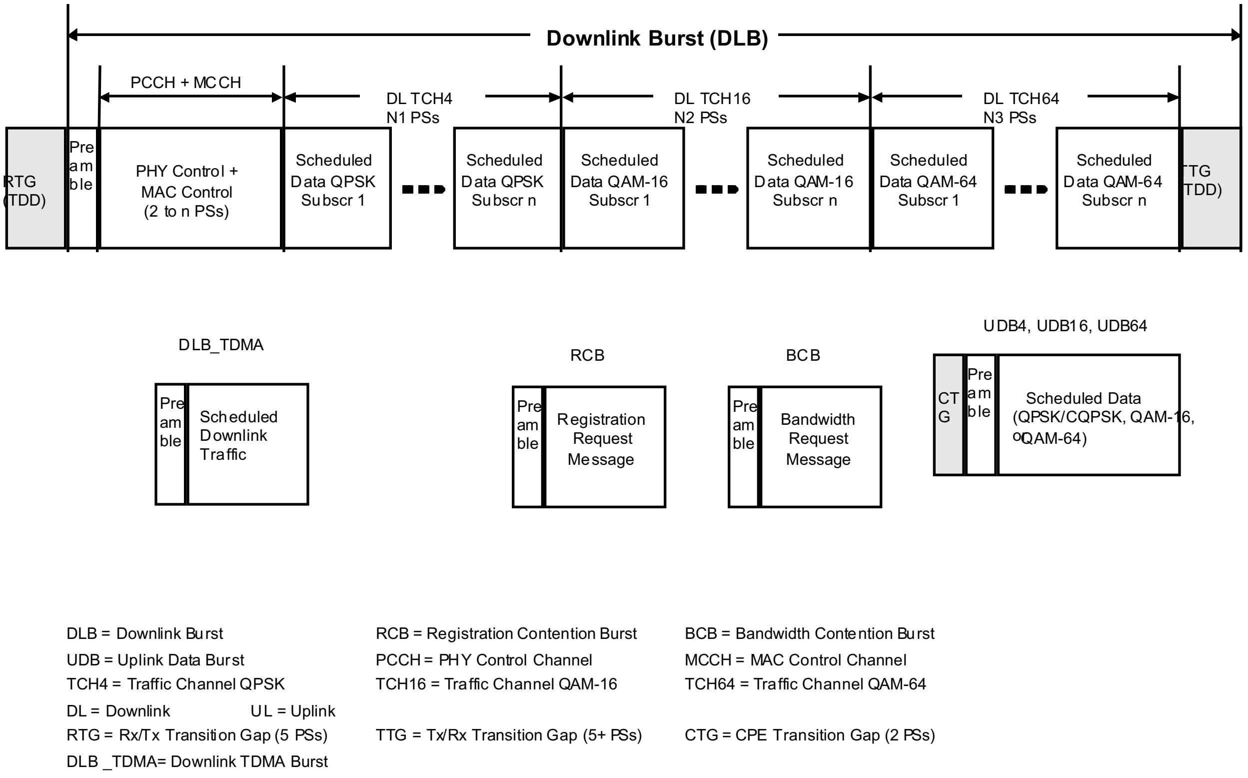


Figure 9: Types of Bursts

Table 1: Burst Types

Burst type	Channel ID	Logical Format	Definition (Section)
Downstream TDM burst	DLB	Preamble, PCCH, MCCH DL TCH4, DL TCH16, DL TCH64	6.2.2
Downstream TDMA burst	DLB_TDMA	Preamble, DL TCH(4, 16, or 64)	6.2.3
Upstream Registration Contention	RCB	Preamble, RCCH	6.2.4.1.1
Upstream Bandwidth Request Contention	BCB	Preamble, BCCH	6.2.4.1.2
Upstream Scheduled Traffic, QPSK	UDB4	Preamble, UL TCH4	6.2.4.1.3
Upstream Scheduled Traffic, 16-QAM	UDB16	Preamble, UL TCH16	6.2.4.1.3
Upstream Scheduled Traffic, 64-QAM	UDB64	Preamble, UL TCH64	6.2.4.1.3

6.3 Mapping of logical channels into physical channels

In the case of TDD, the PHY uses only one RF channel that carries both upstream and downstream traffic data and control data. In the case of FDD, the PHY uses a pair of RF channels, one for the upstream and one for the downstream. The RF channel is subdivided into physical channels as defined in Section 6.2. These physical channels transport the logical channels defined in Section 6.1.

6.3.1 General mapping of logical channels using continuous downstream format (Mode A)

When the continuous downstream format is used, all PHY and MAC control messages are time division multiplexed (TDM) with the rest of the users traffic. Therefore, it can be viewed as a single physical channel which multiplexes all logical channels onto it. It is left up to the scheduler residing in the base station to properly schedule the traffic to meet the required quality of services needed for the traffic as well as the physical layer control functions. As a result, there is no explicit framing mechanism defined here in order to allow for flexibility in the traffic scheduler design. In addition, the MAC is responsible for scheduling the bandwidth for the upstream channel for registration, bandwidth requests, and user traffic, where there exists no explicit time slots always assigned to particular functions. An example of a usage for the upstream bandwidth is shown in the following sections.

6.3.2 General mapping of logical channels using burst downstream format (Mode B)

Table 2 - Table 4 and Figure 10 - Figure 12 define the mapping in time of logical channels into physical channel types when the burst downstream format is used.

Table 2: Mapping of Logical Channel into Physical Channels - TDD

Logical Channel	Direction	Burst Type	FN	PSN
PCCH & MCCH	DL	DLB	All	1 to a
DL TCH4	DL	DLB	As Required	a to b
DL TCH16	DL	DLB	As Required	b to c
DL TCH64	DL	DLB	As Required	c to d
TTG	--	--	All (TDD only)	d to e
RCCH	UL	RCB	As Required	e to f
BCCH	UL	BCB	As Required	f to g
UL TCH4	UL	UDB4	As Required	g to h
UL TCH16	UL	UDB16	As Required	h to k
UL TCH64	UL	UDB64	As Required	k to N-x
RTG	--	--	All (TDD only)	N-x to N
DLB = Downstream Burst, **BCB** = Bandwidth Contention Burst, **RCB** = Registration Contention Burst, **UDB** = Upstream Data Burst, N = number of physical slots per frame				

Table 3: Mapping of Logical Channel into Physical Channels – FDD with burst downstream format

Logical Channel	Direction	Burst Type	FN	PSN
PCCH & MCCH	DL	DLB	All	1 to a
DL TCH4	DL	DLB	As Required	a to b
DL TCH16	DL	DLB	As Required	b to c
DL TCH64	DL	DLB	As Required	c to N
RCCH	UL	RCB	As Required	0 to f
BCCH	UL	BCB	As Required	f to g
UL TCH4	UL	UDB4	As Required	G to h
UL TCH16	UL	UDB16	As Required	H to k
UL TCH64	UL	UDB64	As Required	k to N
DLB = Downstream Burst, **BCB** = Bandwidth Contention Burst, **RCB** = Registration Contention Burst, **UDB** = Upstream Data Burst, N = number of physical slots per frame				

Table 4: Mapping of Logical Channel into Physical Channels - FSDD

Logical Channel	Direction	Burst Type	FN	PSN
PCCH & MCCH	DL	DLB	All	1 to a
DL TCH4	DL	DLB_TDMA	As Required	a to b
DL TCH16	DL	DLB_TDMA	As Required	b to c
DL TCH64	DL	DLB_TDMA	As Required	c to N
RCCH	UL	RCB	As Required	0 to f

BCCH	UL	BCB	As Required	f to g
UL TCH4	UL	UDB4	As Required	G to h
UL TCH16	UL	UDB16	As Required	H to k
UL TCH64	UL	UDB64	As Required	k to N
DLB = Downstream Burst, **DLB_TDMA** = Downstream TDMA Burst, **BCB** = Bandwidth Contention Burst, **RCB** = Registration Contention Burst, **UDB** = Upstream Data Burst, N = number of physical slots per frame				

Each frame may contain each type of logical channel. The allocation of PSs and symbols to each type of logical channel is based on current subscriber demands. The following figures depicts the division of the frame into logical sub-channels as listed above.

The Registration Control Channel (RCCH) and the Bandwidth Control Channel (BCCH) can be located any where within the upstream subframe. In practice, they are the first and second slots, respectively, in the upstream subframe.

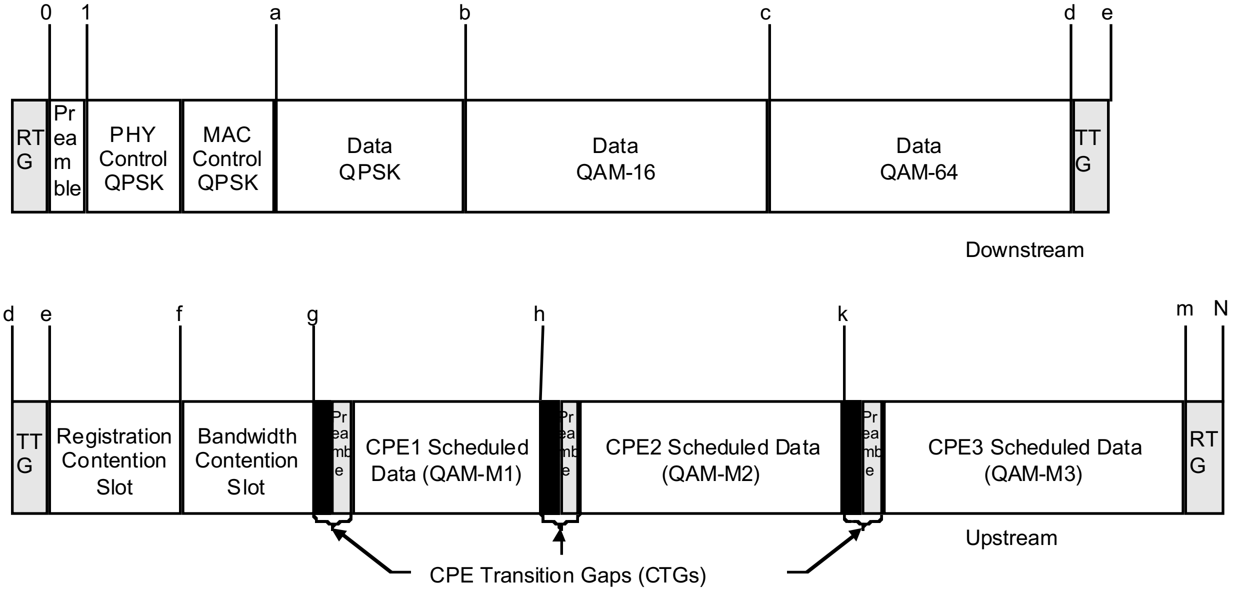


Figure 10: Logical Channel Mapping for TDD

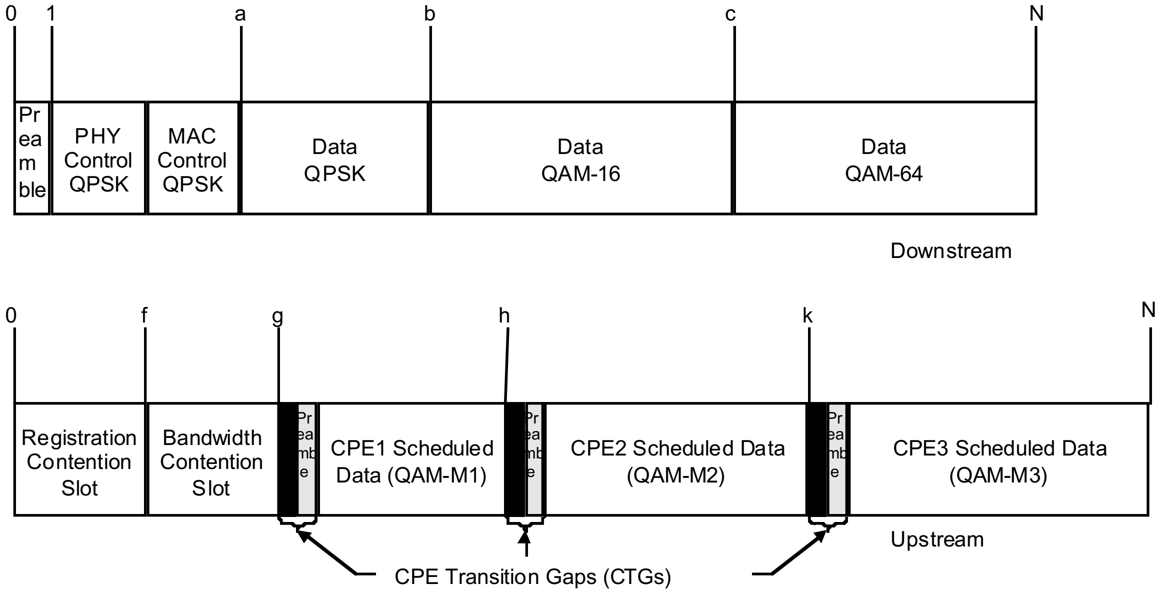


Figure 11: Logical Channel Mapping for FDD with adaptive modulation

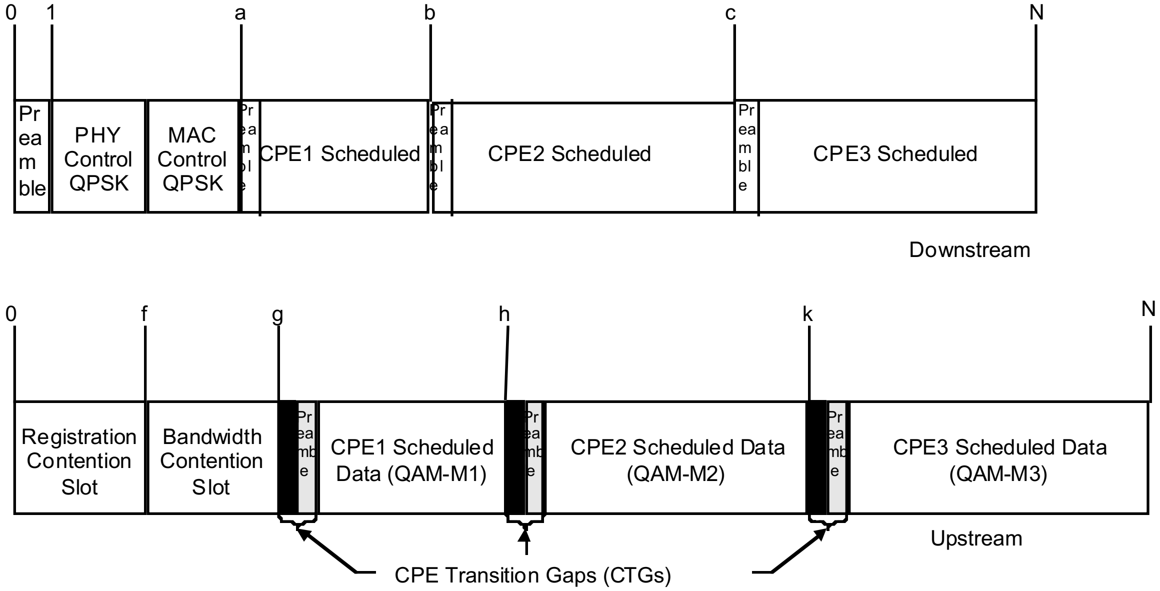


Figure 12: Logical Channel Mapping for FSDD

7 Downstream Physical Layer

7.1 Mode A: Continuous Downstream Transmission

This mode of operation has been designed for a continuous transmission stream, and does not allow for adaptive modulation on a single carrier or duplexing schemes requiring bursting on the downstream (FSDD or TDD). As a result, this architecture has no specific constraints on codeword lengths and no explicit frame times for greater flexibility in controlling and utilizing the physical layer resources. This physical layer may be more appropriate when there is a large amount of spectrum available to support multiple carriers, where each carrier can support different modulation levels if desired, or when system deployments favor a fixed modulation level (typically QPSK) in order to reduce radio design constraints and cost.

7.1.1 Mode A Downstream Transmission Convergence (TC) Sublayer

The downstream bitstream is defined as a continuous series of 188-byte packets. These packets consist of a 1-byte synch. pattern and a one byte pointer followed by 186 bytes of payload. The synch. byte shall be set to hex 47 and shall be inverted to hex B8 every eight packets in order to reset the randomization function. The pointer field identifies the byte number in the packet which indicates either the beginning of the first MAC frame to start in the packet, or indicates the beginning of any stuff bytes that precede the next MAC frame. If no MAC frame begins in the packet, then the pointer byte is set to 0. When no data is available to transmit, a stuff_byte pattern having a value (0xFF) must be used within the payload to fill any gaps between the 802.16 MAC frames. This value is chosen as an unused value for the first byte of the 802.16 MAC frame, which is designed to NEVER have this value. The following figure illustrates the format of the packet leaving the convergence layer.

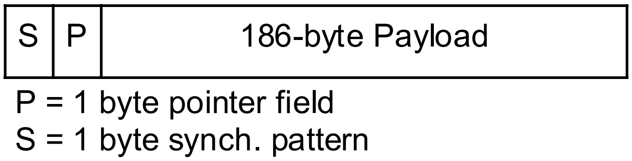


Figure 13: Format of the Convergence Layer Packet

7.1.2 Mode A Physical Media Dependent (PMD) Sublayer

The encoding and decoding functions for the Mode A downstream physical layer are summarized in the following block diagram.

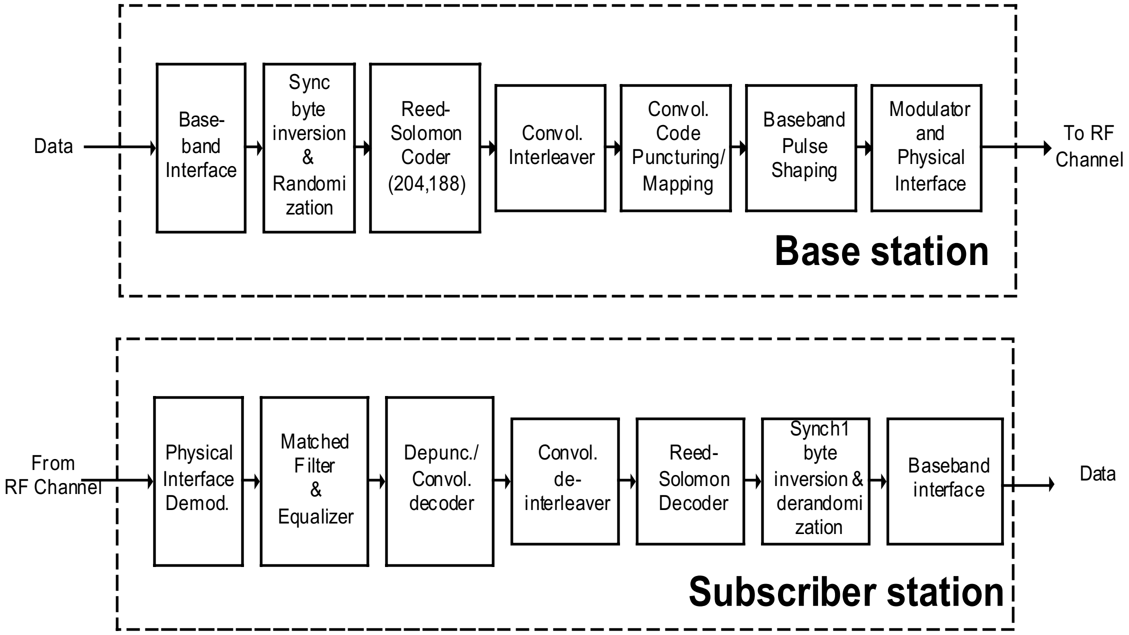


Figure 14: Conceptual Block diagram of the Mode A Downstream Physical Layer

7.1.2.1 Baseband interfacing

This unit shall adapt the data structure coming from the MAC layer to the format defined by the transmission convergence sublayer defined above.

7.1.2.2 Synch. byte inversion and randomization

This unit shall invert the synch. byte according to the transmission convergence sublayer function, and randomizes the data stream for spectrum shaping purposes. 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 uncoded downstream packets, excluding synch. bytes, shall be randomized by modulo-2 addition of the data with the output of the pseudo random binary stream (PBRS) generator, as illustrated in the following diagram.

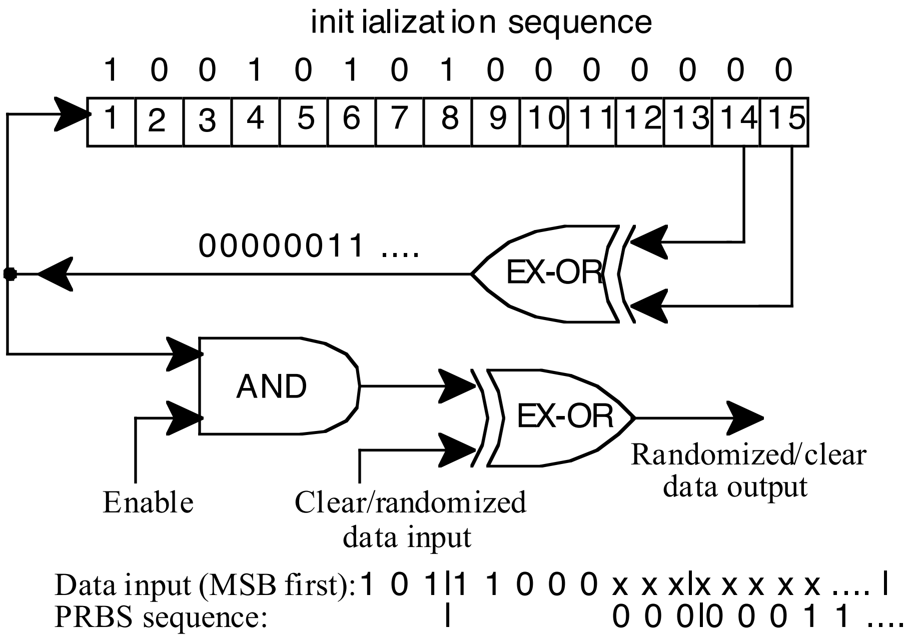


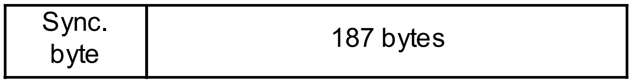
Figure 15: Randomizer logic diagram.

The PBRS shall be initialized at each inverted sync byte by the sequence 100101010000000 in the manner depicted in the figure. The synch. byte (hex 47) shall be inverted (hex B8) every eight packets, starting at the beginning base station powerup.

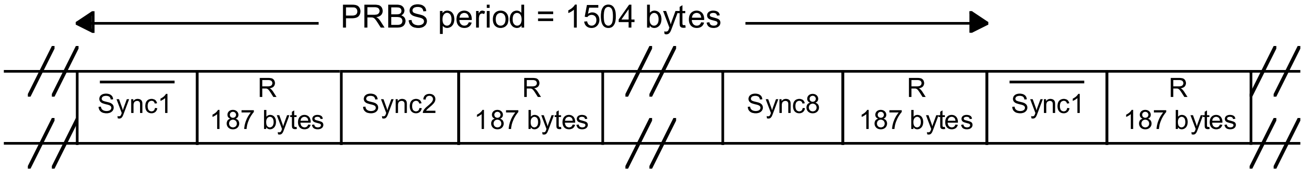
The generator polynomial for the PRBS shall be:

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

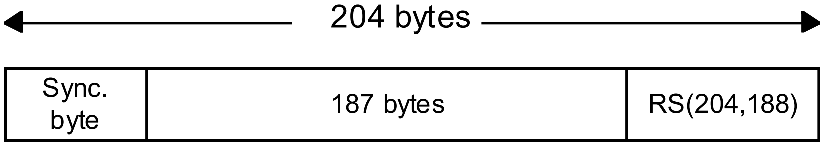
Following initialization, the first PRBS generator output bit shall be added to the first bit following the inverted synch. byte. Over subsequent synch. bytes, the PBRS generator shall continue to step its internal shift register state but the PBRS output addition to the synch. byte bits shall be disabled. Thus, the period of the PRBS sequence shall be 1504 bytes. The following diagram illustrates the framing structure of the transport stream.



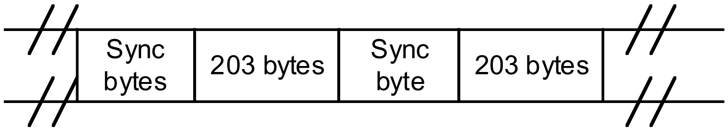
(a) Transmission convergence sublayer packet



(b) Randomized transport packets: Sync bytes and Raondomized Sequence R



(c) Reed-Solomon RS(204,188,t=8) error protected packet



(d) Interleaved Frames maintaining sync. byte periodicity

$\overline{\text{Sync1}}$ = not randomized complemented sync byte

Sync n = not randomized sync byte, n=2...8

Figure 16: Framing structure based on transmission convergence sublayer.

7.1.2.3 Reed Solomon Coding

Following the energy dispersal randomization process, systematic shortened Reed-Solomon encoding shall be performed on each randomized transport packet, with T = 8. This means that 8 erroneous bytes per transport packet can be corrected. This process adds 16 parity bytes to the transport packet to give a 204 byte codeword. RS coding shall also be applied to the packet synch byte, either non-inverted (i.e. 47hex) or inverted (i.e. B8hex).

The Reed-Solomon code shall have the following generator polynomials:

Code Generator Polynomial: $g(x) = (x+\mu^0)(x+\mu^1)(x+\mu^2) \ldots (x+\mu^{15})$, where μ= 02hex

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

The shortened Reed-Solomon code shall be implemented by appending 51 bytes, all set to zero, before the information bytes at the input of a (255,239) encoder; after the coding procedure these bytes are discarded.

7.1.2.4 Convolutional interleaving

The convolutional interleaving process shall be based on the Forney approach, with a depth of I=12. The interleaved frame shall be composed of overlapping error protected packets and shall be delimited by synch. bytes (preserving the periodicity of 204 bytes).

The interleaver is composed of I branches, cyclically connected to the input byte-stream by the input switch. Each branch shall be a First In First Out (FIFO) shift register, with depth (M) cells (where $M = N/I$, $N = 204$ = error protected frame length, $I = 12$ = maximum interleaving depth, j = branch index). The cells of the FIFO shall contain 1 byte, and the input and output switches shall be synchronized, as shown in the diagram below.

For synchronization purposes, the sync bytes and the inverted sync bytes shall be always routed into the branch "0" of the interleaver (corresponding to a null delay).

The deinterleaver is similar, in principle, to the interleaver, but the branch indexes are reversed (i.e. $j = 0$ corresponds to the largest delay). The de-interleaver synchronization is achieved by routing the first recognized sync byte into the "0" branch.

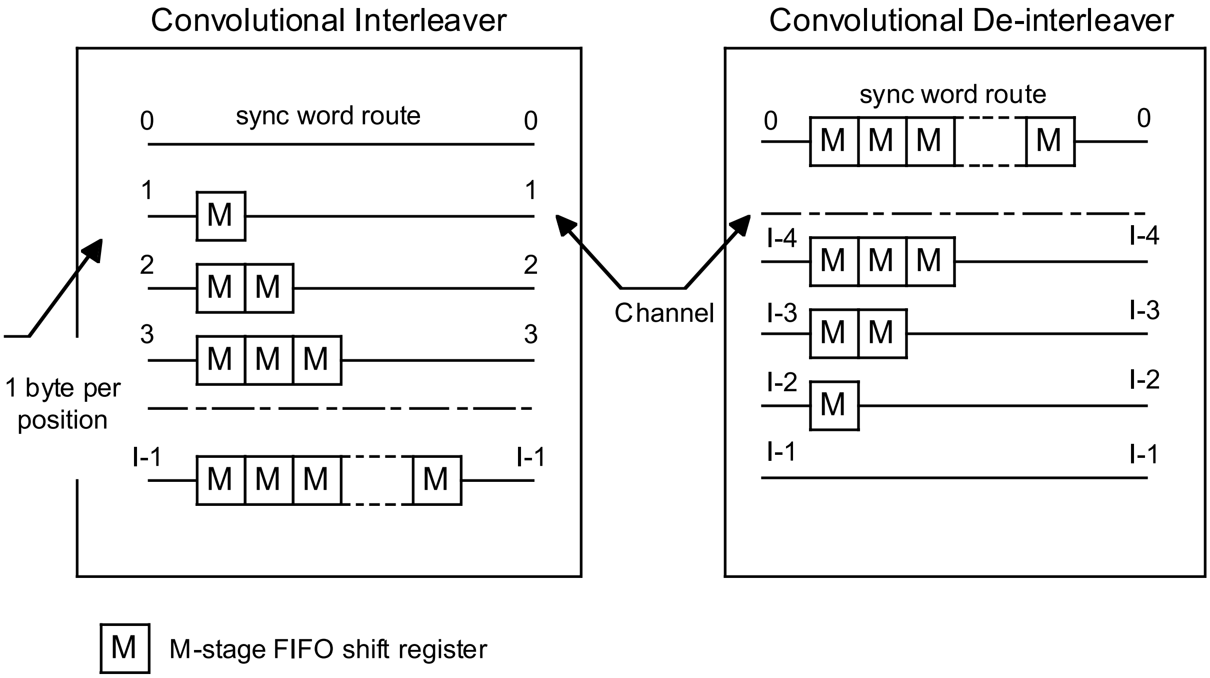


Figure 17: Conceptual diagram of the convolutional interleaver and de-interleaver.

7.1.2.5 Convolutional Coding with QPSK Modulation

When convolutional encoding is employed, the convolutional code shall be chosen from the following table of code rates, which are obtained by puncturing a rate 1/2 constraint length K = 7 code having the following generator vectors G, and puncturing patterns P (0 denotes punctured (deleted) bit).

Table 5: Convolutional Code Puncture Patterns

Original code			**Code rates**									
			1/2		2/3		3/4		5/6		7/8	
K	G_1	G_2	P	d_{free}	P	d_{free}	P	d_{free}	P	d_{free}	P	d_{free}

7	171_{oct}	133_{oct}	X=1 Y=1 $I=X_1$ $Q=Y_1$	10	X=10 Y=11 $I=X_1Y_2Y_3$ $Q=Y_1X_3Y_4$	6	X=101 Y=110 $I=X_1Y_2$ $Q=Y_1X_3$	5	X=10101 Y=11010 $I=X_1Y_2Y_4$ $Q=Y_1X_3X_5$	4	X=1000101 Y=1111010 $I=X_1Y_2Y_4Y_6$ $Q=Y_1Y_3X_5X_7$	3
NOTE: 1=transmitted bit 0 = non transmitted bit												

The QPSK symbols will use gray-coded direct mapping of (I,Q) from bit pairs out of the convolutional encoder as follows:

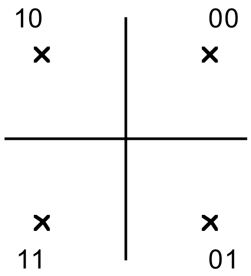


Figure 18: QPSK symbol mapping

7.1.2.6 Convolutional Coding with 16-QAM Modulation (optional)

16-QAM shall be supported using a rate _ or 7/8 punctured convolutional code with the inner coding and constellation mapping as described in [2].

7.1.2.7 Differential encoding with QPSK or 16-QAM Modulation (16-QAM is optional)

In this mode, the inner convolutional code is disabled, and the mapping of bits to symbols shall use the following differential encoder and mapper as defined in [3, ITU-T J.83 Annex A]. The two most significant bits (MSBs) of each symbol shall be differentially coded in order to obtain a π/2 rotation-invariant QAM constellation. The differential encoding of the two MSBs shall be given by the following Boolean expression:

$$I_k = \left(\overline{A_k \oplus B_k}\right).\left(A_k \oplus I_{k-1}\right) + \left(A_k \oplus B_k\right).\left(A_k \oplus Q_{k-1}\right)$$

$$Q_k = \left(\overline{A_k \oplus B_k}\right).\left(B_k \oplus Q_{k-1}\right) + \left(A_k \oplus B_k\right).\left(B_k \oplus I_{k-1}\right)$$

Note: For the above Boolean expression " " denotes the EXOR function, "+" denotes the logical OR function, "." denotes the logical AND function and the overstrike denotes inversion.

The following figure gives an example of implementation of byte to symbol conversion.

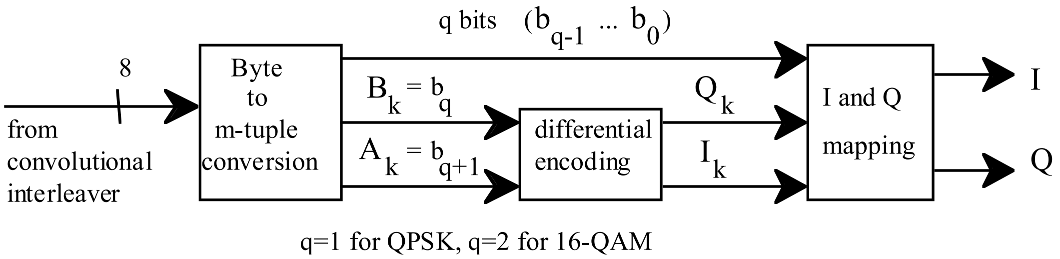


Figure 19: Example implementation of the byte to m-tuple conversion and the differential encoding of the two MSBs.

For QPSK, the output of the differential encoder shall map directly to the QPSK signal constellation based on the Quadrant to MSB mapping shown in the following table. The mapping of bits to symbols for 16-QAM, when implemented as an option, is given by the following figure.

Table 6: Conversion of constellation of quadrant 1 to other quadrants of the constellation diagrams given in the following diagrams.

Quadrant	**MSBs**	**LSBs rotation**
1	00	0
2	10	+ _/2
3	11	+ _
4	01	+ 3_/2

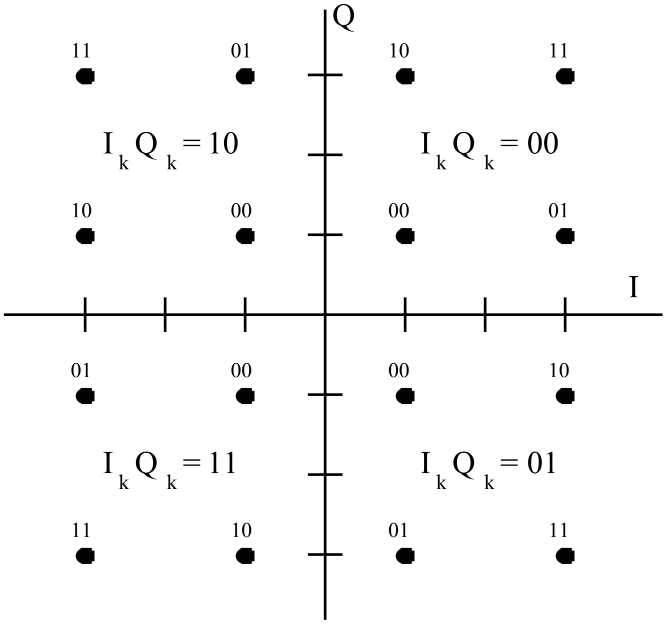


Figure 20: 16 QAM Constellation diagram

7.1.2.8 Differential encoding with 64-QAM Modulation (optional)

The support for 64-QAM modulation shall be optionally supported in this specification in order to allow for the future support for higher capacity links. This option uses the same differential encoding structure described above, with q=4 in the differential encoder, and the following mapping of bits to symbols:

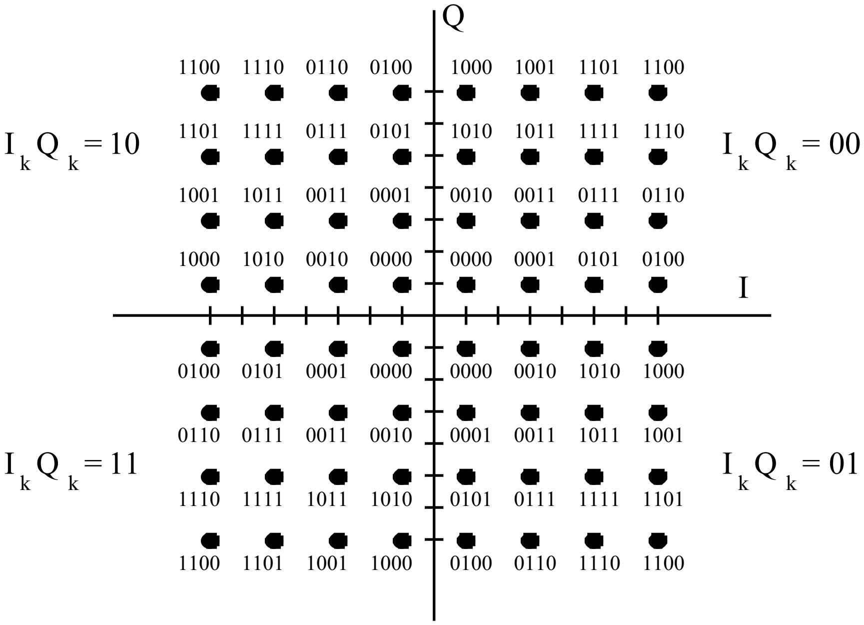


Figure 21: 64-QAM Constellation Diagram

7.1.2.9 Additional Modulation Schemes

TBD

7.1.2.10 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 either 0.15, 0.25 or 0.35. The square-root raised cosine filter is defined by the following transfer function H:

$$\begin{cases} H(f) = 1 & \text{for } |f| < f_N(1-\alpha) \\ H(f) = \left\{ \frac{1}{2} + \frac{1}{2}\sin\frac{\pi}{2f_N}\left[\frac{f_N - |f|}{\alpha}\right]\right\}^{1/2} & \text{for } f_N(1-\alpha) \le |f| \le f_N(1+\alpha) \\ H(f) = 0 & \text{for } |f| > f_N(1+\alpha) \end{cases}$$

where $f_N = \frac{1}{2T_s} = \frac{R_s}{2}$ is the Nyquist frequency. Since $H(f)=0$ is impossible to realize in practice, the actual response in the range $|f|>f_N(1+\alpha)$ should be $H(f) < 50$ *dBc* measured with respect to the passband.

7.1.3 Summary of Mode A Downstream Physical Layer Parameters

Randomization	$1 + X^{14} + X^{15}$ Initialization: 100101010000000
Reed-Solomon Coding	(204,188) with T=8 byte errors corrected
Interleaving	Convolutional with depth I=12.
Convolutional coding	Selectable: rate _, 2/3, _, 5/6, 7/8, or 1 (disabled)
Modulation	QPSK, 16-QAM (optional), or 64-QAM (optional)
Differential encoding	enabled/disabled (only enabled when convolutional coding is not employed)
Spectral shaping	α=0.15, 0.25 or 0.35
Spectral inversion	inverted or non-inverted

7.2 Mode B: Burst Downstream Transmission

This mode of operation has been designed to support burst transmission in the downstream channel. In particular, this mode is applicable for systems using adaptive modulation in an FDD system, or for systems using FSDD or TDD, all of which require a burst type capability in the downstream channel. Operating with a burst capability puts some constraints on several aspects of the physical layer, primarily with respect to phase recovery and allowable codeword lengths, which are taken into account in this mode of operation. In order to simplify phase recover and channel tracking, a 1 msec frame is used. At the beginning of every frame, a preamble is transmitted in order to allow for phase recover and equalization training. A description of the framing mechanism and the structure of the frame is further described in Section 5.

7.2.1 Mode B Downstream Transmission Convergence (TC) Sublayer

First, the downstream payload is segmented into blocks of data designed to fit into the proper codeword size after the convergence layer bytes are added. Note that the payload length may vary, depending on whether shortening of codewords is allowed or not for this burst type. A pointer byte and 2 CRC bytes are then added to each payload segment, as shown in the following figure.

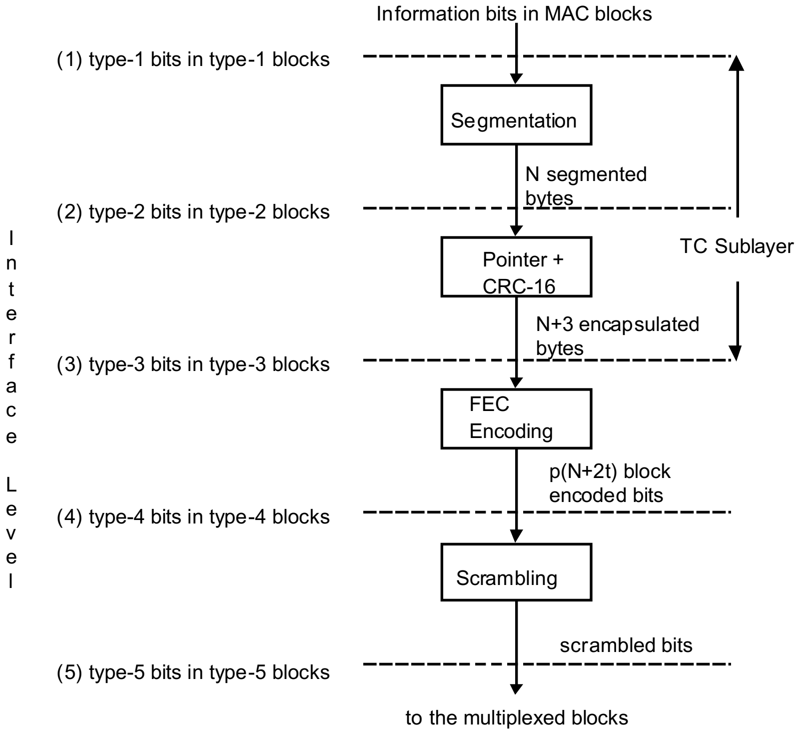


Figure 22: Transmission convergence sublayer segmentation process

The pointer field identifies the byte number in the packet which indicates either the beginning of the first MAC frame to start in the packet, or indicates the beginning of any stuff bytes that precede the next MAC frame. If no MAC frame begins in the packet, then the pointer byte is set to 0. When no data is available to transmit, a stuff_byte pattern having a value (0xFF) must be used within the payload to fill any gaps between the 802.16

MAC frames. This value is chosen as an unused value for the first byte of the 802.16 MAC frame, which is designed to NEVER have this value. The CRC bytes are used for detecting errors in the packet.

Each burst shall have its own, independent error correction. For each one, the information bits (eventually including a MAC header) are referred to as type-1 bits. The type-1 bits are packed in MAC blocks, which are referred to as type-1 blocks, this defines interface (1) in Figure 22.

The processing in the transmit part shall be as follows:

- The type-1 bits shall be segmented into type-2 blocks of N byte length which. The N segmented bytes are referred to as type-2 bytes and shall be packed in a type-2 block, this defines interface (2);
- The type-2 bits shall be processed into type-3 blocks by adding a 1 byte header and appending a 16 bit CRC (2 byte). The header, payload and CRC (N+3, total) bytes are referred to as type-3 bytes and shall be packed in a type-3 block, this defines interface (3);
- the type-3 bits shall be encoded by a FEC block code. The block-encoded bits and are referred to as type-4 bits and shall be packed in a type-4 block, this defines interface (4); These bits shall then be mapped into multiplexed blocks.
- the type-4 bits shall be scrambled, into type-5 bits, which compose type-5 blocks, this defines the interface (5).

  Remark:

  > *The CRC issue would be revisited according to MAC recommendations and to other invited contributions.*

All these operations are made on a per type-1 block basis. The sizes of type-1 blocks and of type-3 blocks and multiplexed blocks depend on the logical channel with which they are associated.

7.2.2 Mode B Physical Media Dependent (PMD) Sublayer

The downstream physical layer coding and modulation for this mode is summarized in the block diagram shown below.

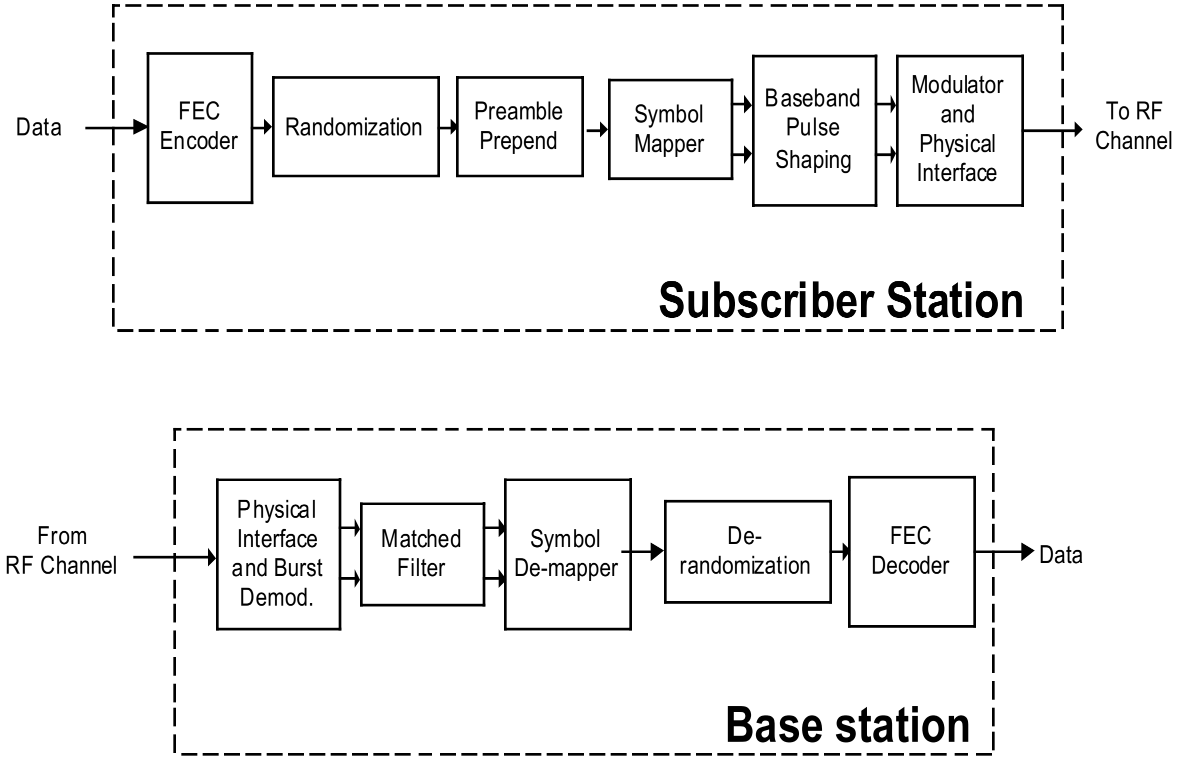


Figure 23: Conceptual Block diagram of the Mode B Downstream Physical Layer

7.2.2.1 Downstream Modulation/FEC Group Definitions

The downstream channel supports flexible modulation type and FEC coding on the user data portion of the frame. Up to 16 modulation/FEC groups can be defined, each having the following parameters that are communicated to the subscriber stations via MAC messages.

Parameter description	**Parameter needed from MAC**
Modulation	1=QPSK 2=16-QAM 3=64-QAM (Optional)

FEC code type	1 = Reed-Solomon only 2 = Reed-Solomon + Inner (9,8) Parity Check Code 3 = Reed-Solomon + Inner Block Convolutional Code 4 = Block Turbo Code (Optional) 5-255 = Reserved
RS information bytes (K)	K=6-255
RS error correction capability (T)	T=0-16
BCC code type	1 = (24,16) 2-255 = Reserved
BTC Row code type	1 = (64,57) Extended Hamming 2 = (32,26) Extended Hamming 3-255 = Reserved
BTC Column code type	1 = (64,57) Extended Hamming 2 = (32,26) Extended Hamming 3-255 = Reserved
BTC Row code shortening	0-255 columns
BTC Column code shortening	0-255 rows
BTC Product code shortening bits	0-255 bits
Last codeword length	1=fixed; 2=shortened (**optional**). This allows for the transmitter to shorten the last codeword, based upon the allowable shortened codewords for the particular code type.

The MAC section of the standard defines the exact message format of the management messages used to carry this information.

Note: The use of modulation/FEC groups must be accounted for in the Downstream Allocation MAPs that are defined in the MAC section.

7.2.2.2 Downlink Physical Layer Terminal Capability Set Parameters

Since there exists some optional modulation and FEC schemes that can be implemented at the subscriber station, there must exist some method for identifying the capability to the base station. The following information shall be communicated to the base station during the subscriber registration period.

Standard Version Number	
Highest Modulation Order	1 = 16-QAM 2 = 64-QAM
Optional FEC Type	00000000 = None xxxxxxx1 = BTC1: (32,26) Extended Hamming xxxxxx1x = BTC2: (64,57) Extended Hamming other = Reserved
Minimum shortened last codeword size and capability	TBD

7.2.2.3 Forward Error Correction (FEC)

The forward error correction schemes for the Mode B downstream channel is selectable from the following types:

Code Type	Outer Code	Inner Code
1	Reed Solomon over GF(256)	None
2	Reed Solomon over GF(256)	(9,8) Parity check code
3	Reed Solomon over GF(256)	(24,16) Block convolutional code
4 (Optional)	Block Turbo Code	---

Note that the first three code types MUST be implemented by all subscriber stations, while code type 4 is optional.

Following is a summary of the four coding options:

(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=1 to t=16.

(2) Reed-Solomon + Parity check: This case is useful for moderate to high coding rates with small to medium size blocks (i.e., P=16, 53 or 128). The code itself is a simple bit wise parity check operating on byte (8 bit) level.

(3) Reed-Solomon + Block convolutional code (soft decodable): This case is useful for low to moderate coding rates providing good C/N enhancements. The coding rate is 2/3.

(4) Block Turbo Code: This code is used to significantly lower the required C/I level need for reliable communication, and can be used to either extend the range of a base station or increase the code rate for greater throughput.

7.2.2.3.1 Reed Solomon Encoding (for code types 1-3)

Reed-Solomon coding shall be applied to each packet. The code shall be a shortened, systematic Reed-Solomon code generated from GF(256) with information block lengths (P) variable from 6-255 bytes and error correction capability able to correct from t=0-16 byte errors. The specified code generator polynomials are given by

Code Generator Polynomial: $g(x) = (x+\mu^0)(x+\mu^1)(x+\mu^2) \ldots (x+\mu^{2T-1})$, where μ= 02hex

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 shall be configured as a RS(255,255-2t, t) code with information bytes preceded by (255-N) zero symbols, where N is the codeword length.

When the number of bytes entering the FEC process M is less than P bytes, the following operation is performed:

(1) (P-M) zero bytes are added to the M byte block as a prefix

(2) RS Encoding is performed

(3) The (P-M) zero RS symbols not associated with the original data are discarded

(4) Inner coding is performed on remaining symbols

(5) The resulting byte block is converted to bit block

When the number of bytes entering the FEC process M is greater than P bytes, the following operation is performed:

(1) Let K=M

(2) Next P bytes entering the FEC are encoded

(3) Subtract P from K, meaning Let K=K-P

(4) If K<P go to (5) otherwise go to (2)

(5) Shortened FEC is applied to the remaining bytes

It is expected that the receiver having knowledge of the expected data length, would properly zero pad the received block and decode it afterwards.

7.2.2.3.2 Code 2: Parity Check

A parity check bit is added to each RS symbol individually as the MSB. The parity is an exclusive-or operation on all 8 bits within the symbol. Each RS symbol is translated into a 9 bits. The result is a 9(P+2t) block of bits, symbol after symbol, MSB first. It is recommended to soft decode the parity check code at the receiver.

7.2.2.3.3 Code 3: Rate 2/3 Block Convolutional Code

The inner code in this concatenated coding scheme consists of short block codes derived from 4-state, nonsystematic, punctured and un-punctured convolutional code $(7,5)_8$. The technique of trellis tail-biting (where the last K-1 bits of the block is used to initialize the encoder memory, K is the constraint length of the code) is used to avoid the overhead required otherwise for trellis termination.

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

Table 7: **The Parameters of the Inner Codes**

Inner Code Rate	**Puncture pattern** **G1 = 7, G2 = 5**
1/2	NA
2/3	11, 10

7.2.2.3.4 Code 4: Block Turbo Code

The BTC based on Hamming Product Codes (HPC) is a two dimensional array of bits where, the lines are encoded using systematic extended Hamming encoder (n_2, k_2) and the columns by using another extended Hamming encoder (n_1, k_1). The overall product code $(n_1, k_1)x(n_2, k_2)$ has length n_1xn_2, dimension k_1xk_2 and minimum Hamming distance 16. The code rate is $k_{1*} k_2 /n_{1*} n_2$.

The generator polynomial for the shortened Hamming component codes shall be based on the following primitive binary polynomial.

Table 1 Generator Polynomials of Hamming Codes

N	**K**	**Generator**
31	26	$x^5 + x^2 + 1$
63	57	$x^6 + x + 1$

The general product code based on shortened extended Hamming codes is given by

$HPC(m1,S1,m2,S2,S)=(2^{m1} - S1, 2^{m1} – m1 - 1 - S1, 4) \text{ x } (2^{m2} - S2, 2^{m2} – m2 - 1 - S2, 4) - S$

where,

$n_1=2^{m1}$ is the length of column encoder

$n_2=2^{m2}$ is the length of line encoder

$k_1= 2^{m1} – m1 - 1 - S1$ is the dimension of the extended Hamming column code

$k_2= 2^{m2} – m2 - 1 – S2$ is the dimension of the extended Hamming row code

S1= number of shortened bits in column encoder (i.e. number of lines preset to zero)

S2= number of shortened bits in row encoder (i.e. number of columns preset to zero)

S = number of shortened bits from the 2-D array.

These parameters can be adjusted to fit data block size up to 392bytes.

The case where m1=m2=m is called symmetric HPC. The current draft consider this case for m=5 or 6. However, provision for the general case of Hamming Product Code is done to allow future enhancements of these cases as well as allowing shortening of S bits from the 2-D array along the first line to simplify realization.

The block encoder for Hamming Product Code accepts S1 bits of zeros followed by $k_1= 2^m - m - 1 - S1$ bits of data. Those k_1 bits are written in columns of the array where last bit is regarded as the MSB. A sequence of m parity check bits are computed based on g(x) followed by an overall parity check bit. This procedure is repeated column by column until the first $k_2 = 2^m - m -1 - S2$ columns of the encoder array. When this process, called column encoding, is finished a row encoding process starts by appending S2 bits of zero followed by a sequence of m parity check bits for the first row followed by overall parity check bit. This process is repeated until all n_1 rows are encoded.

Four codes are currently specified, with provision for additional codes to be added as the PHY standard matures and if system level simulations suggest that additional codes are needed.

The following codes are based on (64,57) constituent codes for both axis with shortening as noted:

Row Code (x axis)	Column Code (y axis)	Additional short bits from 1st row of the composite code	Payload (bytes)	Code Rate
39,32	39,32	0	128	0.673
46,39	46,39	17	188	0.717
63,56	63,56	0	392	0.790

The following code is based on 32,26 constituent codes for both axis with shortening as noted:

Row Code (x axis)	Column Code (y axis)	Additional short bits from 1st row of the composite code	Payload (bytes)	Code Rate
30,24	25,19	0	57	0.608

Additional future codes may also be based on parity only constituent codes such as (32,31) and/or on larger or smaller constituent Extended Hamming codes such as (128,120) or (16,11).

7.2.2.3.4.1 Codeword Shortening

1-D shortening HPC means stuffing fixed bits (usually zero's) instead of information bits in each of the components code. The following sequence of operations is performed:

1. S1 zero bits are added as a prefix to each column followed by $k_1 - S1$ information bits.
2. S2 zero bits are added as a prefix to each row followed by k_2 - S2 information bits.
3. Encoding the columns by Hamming code (n_1,k_1) and the rows by Hamming code (n_2,k_2).
4. Discarding the S1 rows and S2 columns with fixed bits before transmission.

The decoder properly inserts zero's padding to the received block and attached very high soft metric value to each restored fixed bit

This procedure applies for any binary linear product codes and does not change the minimum Hamming distance of the code. Shortening reduces both length (i.e., n) and dimension (i.e., k) of the mother code. The resulted code is an $(n_1 - S1, k_1 - S1, d_1) * (n_2 - S2, k_2 - S2, d_2)$ product code.

The method for shortening the product code by an additional S bits is TBD.

7.2.2.3.5 Coding for the PHY/MAC control message portion of the frame

The PHY/MAC control portion of the upstream frame shall be encoded using one of the following code types 1-3 with a fixed set of parameters in order to ensure that all subscriber stations can read the information. The modulation shall be QPSK, but the other FEC parameters are TBD.

7.2.2.3.6 PHY Information Element block (PI)

One FEC block is called PHY Information Element block (PI). The data unit presented to the FEC encoder is called a TC Data Unit (TDU). Depending on modulation, the PI requires a different number of PSs.

The following tables lists the number of PSs required per PI for the parity check case and for the RS only case.

Modulation	PSs required per PI
QPSK	N+3+2t
16-QAM	Ceil[(N+3+2t)/2]
64-QAM	Ceil[(N+3+2t)/3]

Remark: Ceil is a ceiling function returning the highest integer closest to the argument

Modulation	PSs required per PI
QPSK	Ceil[9(N+3+2t)/8]
16-QAM	Ceil[9(N+3+2t)/16]
64-QAM	Ceil[3(N+3+2t)/8]

7.2.2.4 Scrambling

The scrambling sequence is constructed from the primitive polynomial:

$$P(x) = \text{TBD} \qquad (1)$$

Figure 24 shows a block diagram of a typical Scrambler. The Scrambler is essentially a Linear Feedback Shift Register with a few taps. Each tap corresponds to an element of the primitive polynomial P(x). Data is fed to the scrambler from the Transmit FIFO interface.

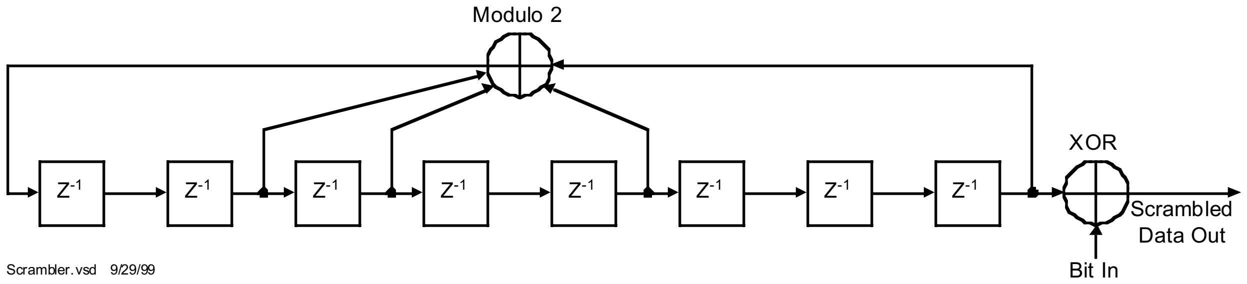


Figure 24: Example of a Scrambling Sequence Generator

7.2.2.5 Burst Preambles

Table 8 - Table 10 define the preambles for the different burst types. The preamble is always at the first part of a downstream frame and consists of a 24 symbol preamble. In the case of the TDMA mode on a downstream, user bursts are transmitted with a shortened preamble of 12 symbols for QPSK, 16-QAM and 64-QAM.

Table 8: Burst Preamble Types

Burst type	Preamble Type	Modulation Type
Downstream burst, Frame begin	1	QPSK
Downstream TDMA burst	2	QPSK

7.2.2.5.1 Burst Preamble 1

Table 9 defines the bit sequence for burst preamble 1 (TBD).

Table 9: Burst Preamble 1

Symbol	I	Q	B(1)	B(2)
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				

Symbol	I	Q	B(1)	B(2)
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				

7.2.2.5.1.1 Burst Preamble 2

Table 10 defines the bit sequence for burst preamble 2 (TBD).

Table 10: Burst Preamble 2

Symbol	I	Q	B(1)	B(2)
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				

7.2.2.6 Modulation

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

The modulation used by the BS in the downstream shall be QPSK, 16-QAM (both mandatory) and 64-QAM (optional). In the case of the reduced cost terminal a TBD scheme is used.

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 is result from the modulation type, for QPSK n=2, for 16-QAM n=4, for 64-QAM n=6. B(m) denotes the modulation bit of a sequence to be transmitted, where m is the bit number (m=1..n).

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

7.2.2.6.1 Bits to Symbol Mapping for QPSK

Figure 25 and Table 11 describe the bit mapping for QPSK modulation.

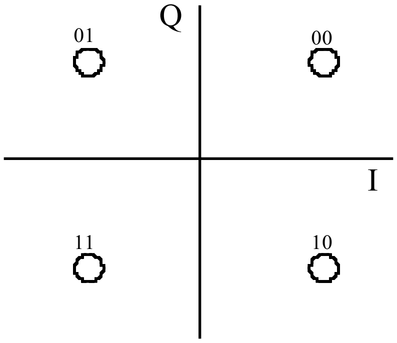


Figure 25: QPSK Constellation

Table 11: 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

7.2.2.6.2 Bits to Symbol Mapping for 16-QAM

Figure 26 and Table 12 describe the bit mapping for 16-QAM modulation.

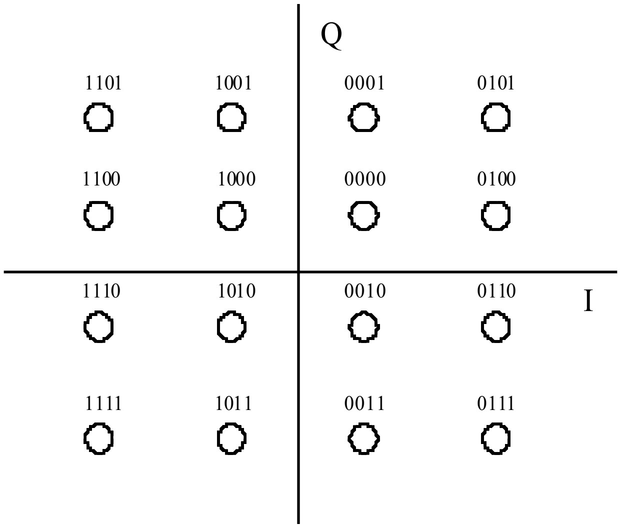


Figure 26: 16-QAM Constellation

Table 12: 16-QAM Bits to Symbol Mapping

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

7.2.2.6.3 Bits to Symbol Mapping for 64-QAM

Figure 27 and Table 13 describe the bit mapping for 64-QAM modulation.

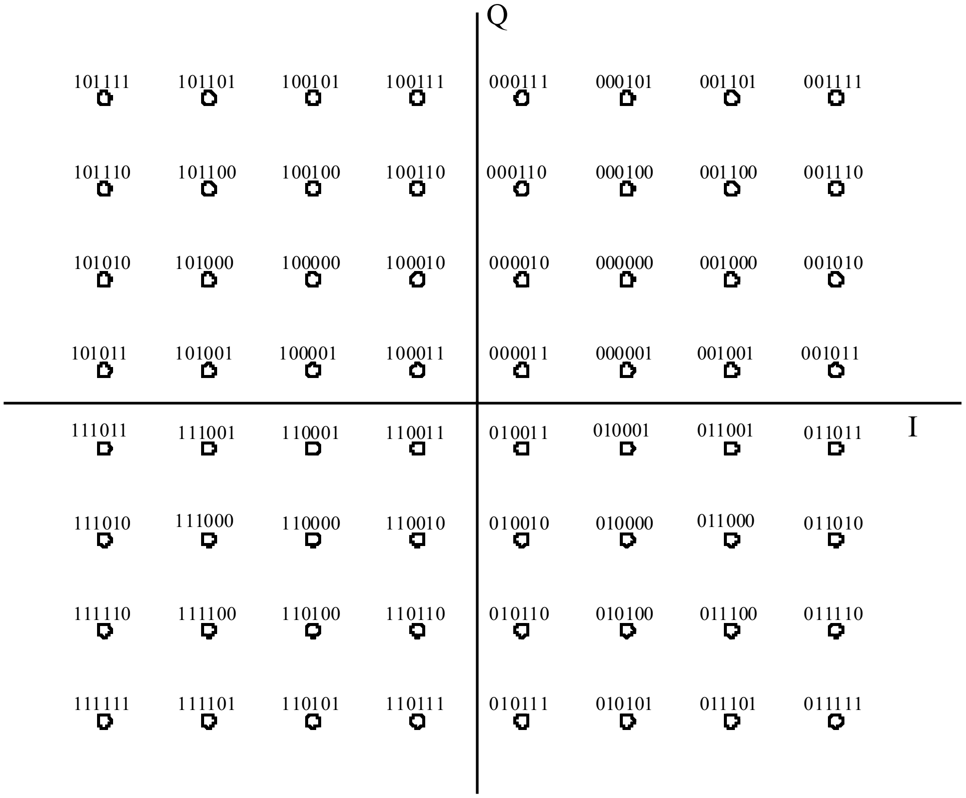


Figure 27: 64-QAM Constellation

Table 13: 64-QAM Bits to Symbol Mapping

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

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

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

7.2.2.7 Additional modulation schemes

TBD

7.2.2.8 QAM signal definition and Baseband Pulse Shaping

A block diagram of the modulation process is shown on the following figure. This diagram is for explanatory purposes and does not prescribe a specific implementation. The modulation filter excited by the complex Dirac impulse function $S(k)\delta(t-t_k)$ ideally has an impulse response $g(t)$.

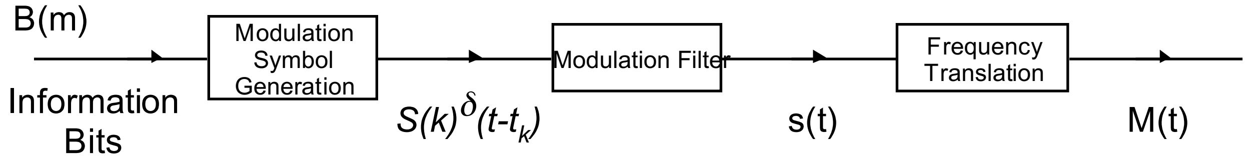


Figure 28: Block Diagram of the Modulation Process

The modulated signal, at carrier frequency f_c, shall be given by:

$$M(t) = \mathrm{Re}\{s(t)\exp(j(2\pi f_c T+\phi))\} \tag{2}$$

where:

ϕ = an arbitrary phase;

$s(t)$ = the complex envelope of the modulated signal defined as:

$$s(t) = \sum_{k=0}^{K} S(k)g(t-t_k) \tag{3}$$

where:

K = the maximum number of symbols;

T = the symbol duration;

$t_k = kT$ = is the symbol time corresponding to modulation symbol S(k);

g(t) = the ideal symbol waveform, obtained by the inverse Fourier transform of a square root raised cosine spectrum G(f), defined as follows:

$$\begin{aligned} G(f) &= 1 && \text{for } |f| \le \frac{1-\alpha}{2T} \\ G(f) &= \sqrt{0.5(1-\sin(\pi(2|f|T-1)/2\alpha))} && \text{for } \frac{1-\alpha}{2T} \le |f| \le \frac{1+\alpha}{2T} \\ G(f) &= 0 && \text{for } |f| \le \frac{1+\alpha}{2T} \end{aligned} \tag{4}$$

where:

α = the roll-off factor, which determines the width of the transmission band at a given symbol rate. The value of α shall be 0.15, 0.25 and 0.35.

8 Upstream Physical Layer

8.1 Upstream Channel Description

The following parameters and their ranges can be used to configure the necessary upstream channel for all subscriber stations transmitting on the designated upstream frequency. These parameters shall be sent in MAC type-length-value (TLV) type messages from the base station.

Parameter description	**Parameter needed from MAC**	**Meaning**
Upstream center frequency	0-60 GHz	in KHz
Symbol Rate	TBD	
Physical Slot (PS) size	0-252	Number of symbols per PS (must be a multiple of 4 symbols)
Spectrum inversion	0= inverted, 1=non-inverted	
Scrambler tap coefficients	16 bits	Each tap is either on (1) or off (0)
Roll-off Factor	0=0.15, 1=0.25, 2=0.35	
Framing	0=enabled, 1=disabled	
Convergence layer[1]	0=enabled, 1=disabled	

[1] The need for different convergence layers should be re-visited in the future based upon further MAC and PHY discussions.

8.2 Upstream Burst Description

The upstream transmitter should be able to save at least 16 burst profiles. The following tables lists some exptected types of burst profiles that can be defined and their expected use:

Burst Type	**Description**
Request	Used for requesting bandwidth in contention intervals
REQ/Data	Used for sending either a bandwidth request or a small data packet in a contention interval
Initial Maintenance	Used for sending the initial ranging message for entering the network.
Station Maintenance	Used for periodic ranging and calibration

Data Grant	Used for transmitting data (there could be multiple data grant types for different burst sizes, modulation levels, etc., if desired)

Each burst profile can be configured with the following information:

Parameter description	**Parameter needed from MAC**
Modulation	1=QPSK, 2=16-QAM, 3=64-QAM (optional)
Preamble pattern	0-1023 bits
FEC code type	1 = Reed-Solomon only 2 = Reed-Solomon + Inner (9,8) Parity Check Code 3 = Reed-Solomon + Inner Block Convolutional Code 4 = Block Turbo Code (Optional) 5-255 = Reserved
RS information bytes (K)	K=6-255
RS error correction capability (T)	T=0-16
BCC code type	1 = (24,16) 2-255 = Reserved
BTC Row code type	1 = (64,57) Extended Hamming 2 = (32,26) Extended Hamming 3-255 = Reserved
BTC Column code type	1 = (64,57) Extended Hamming 2 = (32,26) Extended Hamming 3-255 = Reserved
BTC Row code shortening	0-255 columns
BTC Column code shortening	0-255 rows
BTC Product code shortening bits	0-255 bits

Last codeword length	1=fixed; 2=shortened (**optional**). This allows for the transmitter to shorten the last codeword, based upon the allowable shortened codewords for the particular code type.
Guard time	0-255 symbols
Scrambler seed	15 bits
Scrambler	on/off
Differential encoding	on/off
Maximum burst size	0-65,535 Physical Slots (PS)

8.3 Uplink Physical Layer Terminal Capability Set Parameters

Since there exists some optional modulation and FEC schemes that can be implemented at the subscriber station, there must exist some method for identifying the capability to the base station. The following information shall be communicated to the base station during the subscriber registration period.

Standard Version Number	
Highest Modulation Order	1 = 16-QAM 2 = 64-QAM
Optional FEC Type	00000000 = None xxxxxxx1 = BTC1: (32,26) Extended Hamming xxxxxx1x = BTC2: (64,57) Extended Hamming other = Reserved

8.4 Upstream Framing and Scheduling Burst Intervals

The upstream channel is viewed as a contiguous series of physical slots and the transmissions within those slots are controlled by the base station through an allocation map, which identifies where each subscriber station is allowed to transmit. The scheduled burst interval is the interval that defines when a subscriber station is allowed to transmit and is identified by the beginning physical slot number at which a burst begins as well as the length of the ensuing burst. When framing is enabled, the upstream channel is divided into 1 msec frames, which is done to simplify bandwidth allocation algorithms as well as other MAC related functions. Each frame contains an integer number of physical slots (PS). In this case, the beginning physical slot number is identified by the beginning frame number plus the beginning physical slot number within the frame. When framing is disabled, the beginning physical slot number is identified by a count number on a 32 bit counter. This counter is clocked at a rate of four times the upstream symbol rate in order to allow for accurate symbol rate adjustments by the subscriber stations. In order to ensure the base station and all subscriber stations maintain accurate synchronization of this counter, periodic updates to this counter are sent by the base station.

8.5 Upstream Transmission Convergence (TC) Sublayer

When the transmission convergence layer is disabled, MAC packets are carried directly within upstream bursts. When the transmission convergence layer is enabled, the payload shall be partitioned in the following manner. First, the upstream payload is segmented into blocks of data designed to fit into the proper codeword size after the convergence layer bytes are added. Note that the payload length may vary, depending on whether shortening of codewords is allowed or not for this burst type. A pointer byte and 2 CRC bytes are then added to each payload segment. The pointer field identifies the byte number in the packet which indicates either the beginning of the first MAC frame to start in the packet, or indicates the beginning of any stuff bytes that precede the next MAC frame. If no MAC frame begins in the packet, then the pointer byte is set to 0. When no data is available to transmit, a stuff_byte pattern having a value (0xFF) must be used within the payload to fill any gaps between the 802.16 MAC frames. This value is chosen as an unused value for the first byte of the 802.16 MAC frame, which is designed to NEVER have this value. The CRC bytes are used for detecting errors in the packet. The following figure illustrates the format of the packet leaving the convergence layer.

P = 1 byte pointer field
CRC = 2 byte checksum on the payload + pointer

Figure 29: Format of the Convergence Layer Packet

8.6 Upstream Physical Media Dependent (PMD) Sublayer

The upstream physical layer coding and modulation for this mode is summarized in the block diagram shown below.

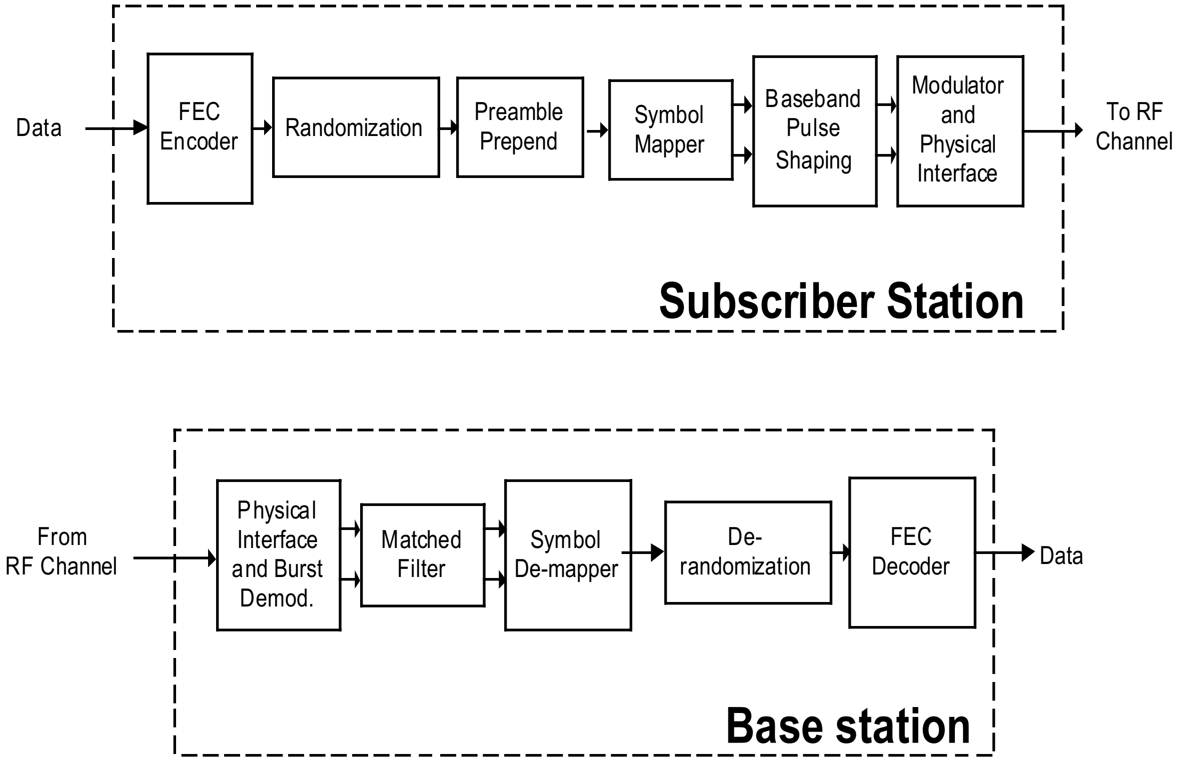


Figure 30: Conceptual Block diagram of the 802.16 Burst Transmission Upstream Physical Layer

8.6.1.1 Forward Error Correction

The forward error correction scheme for the upstream channel is selectable from the following types:

Code Type	Outer Code	Inner Code
1	Reed Solomon over GF(256)	None
2	Reed Solomon over GF(256)	(9,8) Parity check code
3	Reed Solomon over GF(256)	(24,16) Block convolutional code
4 (Optional)	Block Turbo Code	---

Note that the first three code types MUST be implemented by all subscriber stations, while code type 4 is optional.

Following is a summary of the four coding options:

(5) 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=1 to t=16.

(6) Reed-Solomon + Parity check: This case is useful for moderate to high coding rates with small to medium size blocks (i.e., P=16, 53 or 128). The code itself is a simple bit wise parity check operating on byte (8 bit) level.

(7) Reed-Solomon + Block convolutional code (soft decodable): This case is useful for low to moderate coding rates providing good C/N enhancements. The coding rate is 2/3.

(8) Block Turbo Code: This code is used to significantly lower the required C/I level need for reliable communication, and can be used to either extend the range of a base station or increase the code rate for greater throughput.

8.6.1.1.1 Reed Solomon Encoding (for code types 1-3)

Reed-Solomon coding shall be applied to each packet. The code shall be a shortened, systematic Reed-Solomon code generated from GF(256) with information block lengths (P) variable from 6-255 bytes and error correction capability able to correct from t=0-16 byte errors. The specified code generator polynomials are given by

Code Generator Polynomial: $g(x) = (x+\mu^0)(x+\mu^1)(x+\mu^2) \ldots (x+\mu^{2T-1})$, where μ= 02hex

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 shall be configured as a RS(255,255-2t, t) code with information bytes preceded by (255-N) zero symbols, where N is the codeword length.

When the number of bytes entering the FEC process M is less than P bytes, the following operation is performed:

(1) (P-M) zero bytes are added to the M byte block as a prefix

(2) RS Encoding is performed

(3) The (P-M) zero RS symbols not associated with the original data are discarded

(4) Inner coding is performed on remaining symbols

(5) The resulting byte block is converted to bit block

When the number of bytes entering the FEC process M is greater than P bytes, the following operation is performed:

(1) Let K=M

(2) Next P bytes entering the FEC are encoded

(3) Subtract P from K, meaning Let K=K-P

(4) If K<P go to (5) otherwise go to (2)

(5) Shortened FEC is applied to the remaining bytes

It is expected that the receiver having knowledge of the expected data length, would properly zero pad the received block and decode it afterwards.

8.6.1.1.2 Code 2: Parity Check

A parity check bit is added to each RS symbol individually as the MSB. The parity is an exclusive-or operation on all 8 bits within the symbol. Each RS symbol is translated into a 9 bits. The result is a 9(P+2t) block of bits, symbol after symbol, MSB first. It is recommended to soft decode the parity check code at the receiver.

8.6.1.1.3 Code 3: Rate 2/3 Block Convolutional Code

The inner code in this concatenated coding scheme consists of short block codes derived from 4-state, nonsystematic, punctured and un-punctured convolutional code $(7,5)_8$. The technique of trellis tail-biting (where the last K-1 bits of the block is used to initialize the encoder memory, K is the constraint length of the code) is used to avoid the overhead required otherwise for trellis termination.

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

Table 14: **The Parameters of the Inner Codes**

Inner Code Rate	**Puncture pattern** **G1 = 7, G2 = 5**
1/2	NA
2/3	11, 10

8.6.1.1.4 Code 4: Block Turbo Code

The BTC based on Hamming Product Codes (HPC) is a two dimensional array of bits where, the lines are encoded using systematic extended Hamming encoder (n_2, k_2) and the columns by using another extended

Hamming encoder (n_1, k_1). The overall product code (n_1, k_1)x(n_2, k_2) has length n_1xn_2, dimension k_1xk_2 and minimum Hamming distance 16. The code rate is $k_1 * k_2 / n_1 * n_2$.

The generator polynomial for the shortened Hamming component codes shall be based on the following primitive binary polynomial.

Table 1 Generator Polynomials of Hamming Codes

N	**K**	**Generator**
31	26	$x^5 + x^2 + 1$
63	57	$x^6 + x + 1$

The general product code based on shortened extended Hamming codes is given by

$$HPC(m1,S1,m2,S2,S)=(2^{m1} - S1, 2^{m1} - m1 - 1 - S1, 4) \times (2^{m2} - S2, 2^{m2} - m2 - 1 - S2, 4) - S$$

where,

$n_1=2^{m1}$ is the length of column encoder

$n_2=2^{m2}$ is the length of line encoder

$k_1= 2^{m1} - m1 - 1 - S1$ is the dimension of the extended Hamming column code

$k_2= 2^{m2} - m2 - 1 - S2$ is the dimension of the extended Hamming row code

S1= number of shortened bits in column encoder (i.e. number of lines preset to zero)

S2= number of shortened bits in row encoder (i.e. number of columns preset to zero)

S = number of shortened bits from the 2-D array.

These parameters can be adjusted to fit data block size up to 392bytes.

The case where m1=m2=m is called symmetric HPC. The current draft consider this case for m=5 or 6. However, provision for the general case of Hamming Product Code is done to allow future enhancements of these cases as well as allowing shortening of S bits from the 2-D array along the first line to simplify realization.

The block encoder for Hamming Product Code accepts S1 bits of zeros followed by $k_1= 2^m - m - 1 - S1$ bits of data. Those k_1 bits are written in columns of the array where last bit is regarded as the MSB. A sequence of m parity check bits are computed based on g(x) followed by an overall parity check bit. This procedure is repeated column by column until the first $k_2 = 2^m - m - 1 - S2$ columns of the encoder array. When this process, called column encoding, is finished a row encoding process starts by appending S2 bits of zero followed by a sequence of m parity check bits for the first row followed by overall parity check bit. This process is repeated until all n_1 rows are encoded.

Four codes are currently specified, with provision for additional codes to be added as the PHY standard matures and if system level simulations suggest that additional codes are needed.

The following codes are based on (64,57) constituent codes for both axis with shortening as noted:

Row Code (x axis)	Column Code (y axis)	Additional short bits from 1st row of the composite code	Payload (bytes)	Code Rate
39,32	39,32	0	128	0.673
46,39	46,39	17	188	0.717
63,56	63,56	0	392	0.790

The following code is based on 32,26 constituent codes for both axis with shortening as noted:

Row Code (x axis)	Column Code (y axis)	Additional short bits from 1st row of the composite code	Payload (bytes)	Code Rate
30,24	25,19	0	57	0.608

Additional future codes may also be based on parity only constituent codes such as (32,31) and/or on larger or smaller constituent Extended Hamming codes such as (128,120) or (16,11).

8.6.1.1.4.1 Codeword Shortening

1-D shortening HPC means stuffing fixed bits (usually zero's) instead of information bits in each of the components code. The following sequence of operations is performed:

5. S1 zero bits are added as a prefix to each column followed by $k_1 – S1$ information bits.
6. S2 zero bits are added as a prefix to each row followed by $k_2 - S2$ information bits.
7. Encoding the columns by Hamming code (n_1,k_1) and the rows by Hamming code (n_2,k_2).
8. Discarding the S1 rows and S2 columns with fixed bits before transmission.

The decoder properly inserts zero's padding to the received block and attached very high soft metric value to each restored fixed bit

This procedure applies for any binary linear product codes and does not change the minimum Hamming distance of the code. Shortening reduces both length (i.e., n) and dimension (i.e., k) of the mother code. The resulted code is an $(n_1 - S1, k_1- S1, d_1) * (n_2 – S2, k_2- S2, d_2)$ product code.

The method for shortening the product code by an additional S bits is TBD.

8.6.1.2 Randomization for spectrum shaping

The upstream modulator must implement a scrambler using the polynomial $x^{15}+x^{14}+1$ with a 15-bit programmable seed. At the beginning of each burst, the register is cleared and the seed value is loaded. The seed value must 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).

8.6.1.3 Preamble

The preamble should be programmable in length from 0-1024 bits and have a value that is also programmable.

8.6.1.4 Modulation

The modulation used on the upstream channel should be programmable with the following options. Both QPSK and 16-QAM must be supported, while 64-QAM is optional, with the following mappings of bits to symbols.

8.6.1.4.1 QPSK Symbol Mapping

The following mapping of bits to symbols shall be support for QPSK modulation:

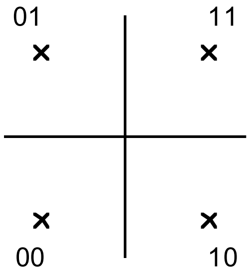


Figure 31: QPSK constellation mapping

If differential encoding is employed, the encoder shall accept bits A and B in sequence and generate phase changes as follows:

A	B	Phase Change
0	0	none
0	1	+90 degrees
1	1	180 degrees
1	0	-90 degrees

8.6.1.4.2 Differentially encoded 16-QAM

If differential encoding is desired for 16-QAM, then the following signal constellation should be supported (I1 Q1 I0 Q0 represent the bits identifying the 16-QAM symbol).

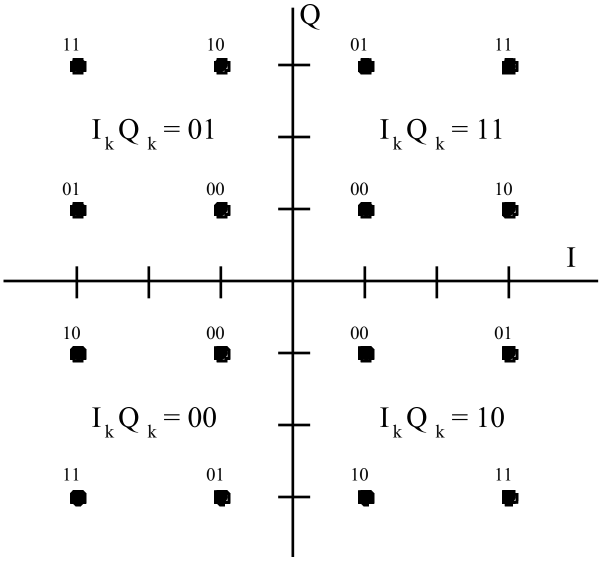


Figure 32: Differentially encoded 16-QAM Constellation diagram

Current Input Bits **I1 Q1**	**Quadrant Phase change**	**MSBs of Previously Transmitted Symbol**	**MSBs for Currently Transmitted Symbol**
00	0°	11	11
00	0°	01	01
00	0°	00	00
00	0°	10	10
01	90°	11	01
01	90°	01	00
01	90°	00	10
01	90°	10	11
11	180°	11	00
11	180°	01	10
11	180°	00	11
11	180°	10	01
10	270°	11	10
10	270°	01	11
10	270°	00	01
10	270°	10	00

8.6.1.4.3 Gray-coded 16-QAM

If differential encoding is not desired, then the following signal constellation shall be optionally supported:

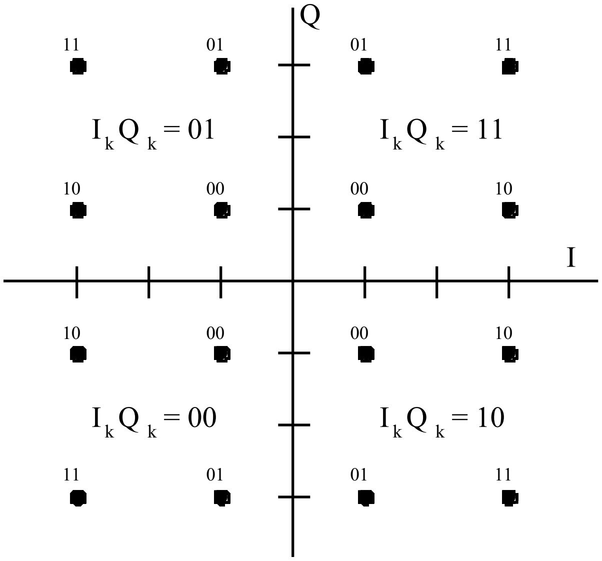


Figure 33: Gray-coded 16-QAM Constellation diagram

8.6.1.4.4 Gray-coded 64-QAM

The following figure and table describe the bit to symbol mapping for Gray-coded 64-QAM modulation.

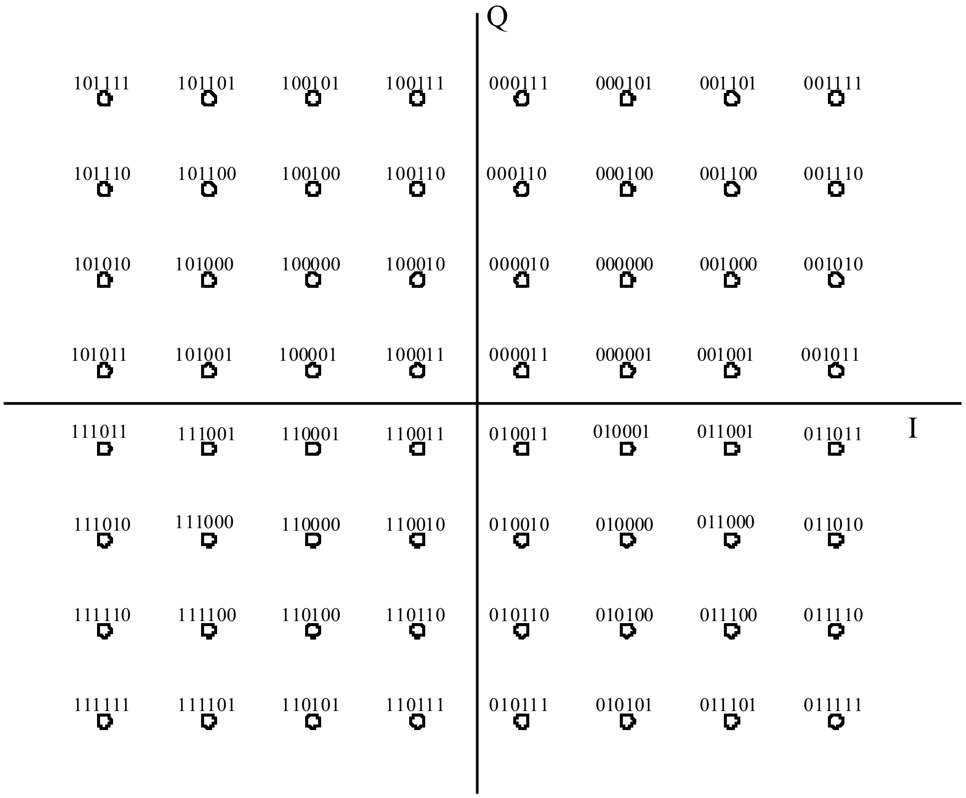


Figure 34: 64-QAM Constellation

Table 15: 64-QAM Bits to Symbol Mapping

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

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

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

111011-7-1□111100-5-5□111101-5-7□111110-7-□
5□111111-7-7□

Baseband Pulse Shaping

Prior to modulation, the I and Q signals shall be filtered by square-root raised cosine filters. The excess roll-off factor α shall be either 0.15, 0.25, or 0.35. The ideal square-root raised cosine filter is defined by the following transfer function H:

$$\begin{cases} H(f) = 1 & \text{for } |f| < f_N(1-\alpha) \\ H(f) = \left\{ \dfrac{1}{2} + \dfrac{1}{2}\sin\dfrac{\pi}{2f_N}\left[\dfrac{f_N - |f|}{\alpha}\right] \right\}^{1/2} & \text{for } f_N(1-\alpha) \le |f| \le f_N(1+\alpha) \\ H(f) = 0 & \text{for } |f| > f_N(1+\alpha) \end{cases}$$

where $f_N = \dfrac{1}{2T_s} = \dfrac{R_s}{2}$ is the Nyquist frequency. Since *H(f)=0* is impossible to realize in practice, the actual response in the range $|f| > f_N(1+\alpha)$ should be $H(f) < 50$ *dBc* measured with respect to the passband.

8.6.1.5 Summary of Upstream Physical Layer Parameters

Transmission convergence layer	Selectable on/off. When enable, the TC layer includes 1 pointer byte and 2 CRC checksum bytes for error detection.
Outer Coding	Reed Solomon over GF(256) Information byte lengths: 6-255 bytes Error correction capability t=0-16

Inner Coding	Selectable from the following options: (1) None (2) (9,8) parity check code (3) Rate 2/3 block convolutional code (4) Block Turbo Code (optional)
Randomization	$x^{15}+x^{14}+1$ Initialization seed: 15-bit programmable
Preamble	Programmable length: 0-1024 bits Programmable value
Modulation	QPSK, 16-QAM, or 64-QAM (optional)
Differential encoding	Selectable on/off
Spectral shaping	α=0.15, 0.25, 0.35

9 Baud Rates and Channel Bandwidths

Due to the large amount of spectrum available in the 10-60 GHz region for point-to-multipoint operation, and the different regulatory requirements in various countries around the world, the baud rates and RF channel bandwidths have been left somewhat flexible in order to allow service providers the ability to maximize capacity for a given spectrum allocation. Subscriber station equipment should support symbol rates that lie in the interval 10 Mbaud to 40 Mbaud for the downstream and 5 Mbaud to 30 Mbaud for the upstream. The granularity of the baud rates and/or channel sizes, and specific recommendations for interoperability testing is **TBD**.

A RF channel is defined as a specified portion of the RF spectrum. In the case of FDD, there is actually a pair of RF carriers, one for upstream and one for downstream communications. In the case of TDD a single channel is used by sharing it in time by upstream and downstream. The Downstream (DL) is defined as RF bursts used in the BS to CPE direction. The Upstream (UL) is defined as RF bursts used in the CPE to BS direction.

IEEE 802.16.1 is considering millimeter wave frequencies as the target operational frequency band, specifically those above 10 GHz. Line of Sight (LOS) communications is mandatory at these frequencies. Typical cell radius in a PMP deployment is limited to a few kilometers due to radio technology (i.e., power amplifiers) and susceptibility to rain attenuation. One outcome of these conditions is the fact that channel bandwidth could be large, hence enabling high bit rates with low to moderate modulation schemes.

The vast amount of available spectrum options worldwide points out additional requirements:

- There are frequency bands that historically follow ETSI recommendations. Recommended relevant channel bandwidths for BWA are 14 MHz, 28 MHz and 56 MHz.

- Other frequency bands and new worldwide spectrum allocations favor channel bandwidths of either 20 MHz and 40 MHz or 25 MHz and 50 MHz.

- Both FDD and TDD are supported.

For IEEE 802.16.1 we do not consider smaller channels due to the fact that it would require complex modulation schemes to enable very high bit rates. Complex modulation schemes are much more susceptible to co-channel interference, which is a major problem in PMP deployments.

The following table recommends modem baud rates and channel sizes. The pulse shape being used in this example is Nyquist Root-Raised Cosine with a roll-off factor of 0.25.

Baud Rate (MBaud)	**US Channel Size [MHz]**	**Recommended Frame size (mSec)**	**Number of PSs/Frame**
40	50	0.5	5000
32	40	0.5	4000
20	25	1	5000
16	20	1	4000
10	12.5	2	5000

10 Radio Sub-system Control

10.1 Synchronization Technique (Frame and Slot)

In order to satisfy timing requirements for telephony or other CBR applications (T1/E1), the downstream demodulator should provide an output reference clock that is derived from the downstream symbol clock. This reference can then be used by the subscriber station to provide timing for rate critical interfaces when the downstream clock is locked to an accurate reference at the base station. A time-stamp based method could be used if the desired clock accuracy is sufficient for the services provided, but it should at least be an option to choose to derive subscriber station timing from the downstream symbol clock or an internal oscillator with time stamps coming from the MAC layer at the base station. Accurate upstream time slot synchronization should be supported through a ranging calibration procedure defined by the MAC layer to ensure that upstream transmissions by multiple users do not interfere with each other. Therefore, the physical layer needs to support accurate timing estimates at the base station, and the flexibility to finely modify the timing at the subscriber station according to the transmitter characteristics specified in table below.

10.2 Frequency Control

Frequency control is also a critical component of the physical layer. Due to the large carrier frequencies proposed for Broadband Wireless Access systems, frequency errors will exist in the radio units, and will vary with age and temperature. In order to allow for cost effective radio units at the subscriber station, the upstream and downstream RF sources should reference each other. Note that the initial ranging process described above for timing adjustment should also be applicable for initial frequency and power calibration. After the initial frequency has been calibrated, it is expected that periodic measurements of the frequency offset value at the basestation will be made by the physical layer and sent to the subscriber station via a MAC message, enabling low cost frequency references to be used in the radio units.

10.3 Power Control

As with frequency control, a power control algorithm should be supported for the upstream channel with both an initial calibration and periodic adjustment procedure. The base station should be able to provide 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 subscriber station in a calibration message coming from the MAC layer. The power control algorithm should be designed to support dynamic power fluctuations at rates of at least **TBD** dB/second with depths at least **TBD** dB. Static power attenuation due to distance loss should be compensated for up to **TBD** dB.

11 Minimum Performance

This section details the minimum performance requirements for proper operation of the system for the LMDS A Band frequencies. The values listed in this section apply over the operational environmental ranges of the system equipment and measured per subsection 7.1.

Basestation transmitter	
Tx power level/accuracy	Tx power shall not exceed **TBD** dBW/MHz.
Max. Tx phase noise	TBD at a later date
Tx symbol Timing accuracy	Peak-to-peak symbol jitter, referenced to the previous symbol zero crossing, of the transmitted waveform, MUST be less than 0.02 of the nominal symbol duration over a 2-sec. period. The peak-to-peak cumulative phase error, referenced to the first symbol time and with any fixed symbol frequency offset factored out, MUST be less than 0.04 of the nominal symbol duration over a 0.1 sec period.

Tx RF frequency/accuracy	10-60 GHz/ +- 5 ppm (including aging and temperature variations)
Spectral Mask (OOB)	TBD by Coexistence group
Spectral mask (in-band)	TBD at a later date
Filter distortion	
Group delay variation	TBD at a later date
Amplitude ripple	TBD at a later date
Adjacent channel interference	TBD by coexistence
Co-channel interference	TBD by coexistence
Spurious	TBD by coexistence
Subscriber Station transmitter	
Tx power level and range	Tx power not to exceed **TBD** dBW/MHz with a range > TBD dB.
Tx power level adjustment steps and accuracy	The subscriber station shall adjust its Tx power level, based on feedback from the basestation via MAC messaging, in steps of TBD dB +/- TBDdB in a monotonic fashion.
Max. Tx phase noise	TBD at a later date.
Tx symbol timing jitter	Peak-to-peak symbol jitter, referenced to the previous symbol zero-crossing, of the transmitted waveform, MUST be less than 0.02 of the nominal symbol duration over a 2-sec. period. The peak-to-peak cumulative phase error, referenced to the first symbol time and with any fixed symbol frequency offset factored out, MUST be less than 0.04 of the nominal symbol duration over a 0.1 sec period.
Tx burst timing accuracy	Must implement corrections to burst timing with an accuracy of +/- _ of a symbol and a resolution of +/- _ of a symbol.
Tx RF frequency/accuracy	10-60 GHz +/- TBD ppm
Tx frequency range	TBD at a later date.

Spectral Mask (OOB)	TBD by Coexistence group.
Spectral mask (in-band)	TBD at a later date.
Filter distortion	
Group delay variation	TBD at a later date.
Amplitude ripple	TBD at a later date.
Adjacent channel interference	TBD by Coexistence group.
Co-channel interference	TBD by Coexistence group.
Spurious	TBD by Coexistence group.

Table 16: PHY Layer Requirements

PHY Layer Requirement	**Specification Section**
Reference Test Planes	**7.1**
Transmitter Minimum Requirements	**7.2**
- Introduction	7.2.1
- Tap-Gain Process Types	7.2.2
- Propagation Models	7.2.3
Transmitter Minimum Requirements	**7.3**
– Output Power	7.3.1
– Emission Spectrum	7.3.2
- Unwanted Conducted Emissions	7.3.3
- Unwanted Radiated Emissions	7.3.4
- RF Tolerance	7.3.5
- Required Oscillator Performance	7.3.5.1
- Frequency Stability	7.3.5.2
- Power Stability	7.3.6
- RF Output Power Time Mask	7.3.7
- Intermodulation attenuation	7.3.8
- CPE Channel Switching Time	7.3.9
- Tx / Rx Carrier Switching Time	7.3.10
- Off to On Carrier Switching Time	7.3.11
- On to Off Carrier Release Time	7.3.12

PHY Layer Requirement	Specification Section
– Special Co-Location Requirements - Transmitter	7.3.13
Receiver Minimum Requirements	**7.4**
- Blocking Characteristics	7.4.1
– Spurious Response Rejection	7.4.2
- Intermodulation Response Rejection	7.4.3
- Unwanted Conducted Emissions	7.4.4
- Unwanted Radiated Emissions	7.4.5
- Received Signal Strength Indication	7.4.6
- Special Co-Location Requirements - Receiver	7.4.7
Transmitter / Receiver Performance	**7.5**
- Modulation Accuracy	7.5.1
– Receiver Performance	7.5.2
- Nominal Error Rates	7.5.2.1
- Static Reference Sensitivity Performance	7.5.2.2
- Dynamic Reference Sensitivity Performance	7.5.2.3
- Reference Interference Performance	7.5.2.4
- CPE receiver performance for synchronization acquisition	7.5.2.5

11.1 Reference test planes

TBD

11.2 Propagation Conditions

TBD

11.2.1 Propagation Models

In this subsection, the propagation models that are referred to in this PHY Specification are defined.

Table 17: Propagation Models

Propagation model	Tap number	Relative delay (ηs)	Average relative power (dB)	Tap-gain process
Static				
Dynamic				

11.3 Transmitter characteristics

Unless stated otherwise, the transmitter requirements are referenced to the antenna output port and apply with the transmitter tuned to any channel in Section **Error! Reference source not found.**.

11.3.1 Output Power

In the following subsections, power is defined as the average power, measured through the square root raised cosine filter defined in Section **Error! Reference source not found.** over the scrambled bits of one transmitted burst as defined in Section **Error! Reference source not found.**.

The power at which CPEs or BSs may operate are specified in the following subsections.

11.3.1.1 BS

The BS transmitter maximum output power shall be as defined in **Error! Reference source not found.**.

Table 18: Maximum BS Transmitter Power

Power class	Maximum power per carrier
1	

The output power shall be adjustable over the range +20 dBm to -30 dBm via a configurable software parameter.

11.3.1.2 CPE

The CPE maximum power shall be as defined in **Error! Reference source not found.**.

Table 19: Maximum CPE Transmitter Power

Power class	Maximum power
1	

TBD

Table 20: CPE Power Control Levels

Step Level	Power
0	
1	
2	
* * *	
98	
99	
100	

11.3.2 Emissions Spectrum

TBD

11.3.3 Unwanted Conducted Emissions

TBD

11.3.4 Unwanted radiated emissions

TBD

11.3.5 Intermodulation Attenuation

TBD

11.3.6 Power Stability

TBD

11.3.7 RF Output Power Time Mask

TBD

11.3.8 Tx / Rx Carrier Switching Time Requirements

TBD

11.3.9 CPE Channel Switching Time

TBD

11.3.10 Special Co-Location Requirements – Transmitter

TBD

11.4 Receiver Characteristic

TBD

11.4.1 Blocking Characteristics

TBD

11.4.2 Spurious Response Rejection

TBD

11.4.3 Intermodulation Response Rejection

TBD

11.4.4 Unwanted Conducted Emissions

TBD

11.4.5 Unwanted Radiated Emissions

TBD

11.4.6 Received Signal Strength Indication (RSSI)

TBD

11.4.7 Special Co-Location Requirements – Receiver

TBD

11.5 Transmitter / Receiver Performance

TBD

11.5.1 Modulation Accuracy

TBD

11.5.2 Receiver Performance

TBD