Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	**Physical Layer Proposal for the 802.16.1 Air Interface Specification**
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Re:	This contribution is a proposed draft based on both proposals as submitted to the IEEE 802.16.1
Abstract	This draft presents a single document containing both PHY proposals. It does not delete any core idea of the original proposals yet it combines them both to a single formatted document
Purpose	To serve as the first 802.16.1 PHY draft.
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Physical Layer Proposal for the 802.16.1 Air Interface Specification

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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 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.

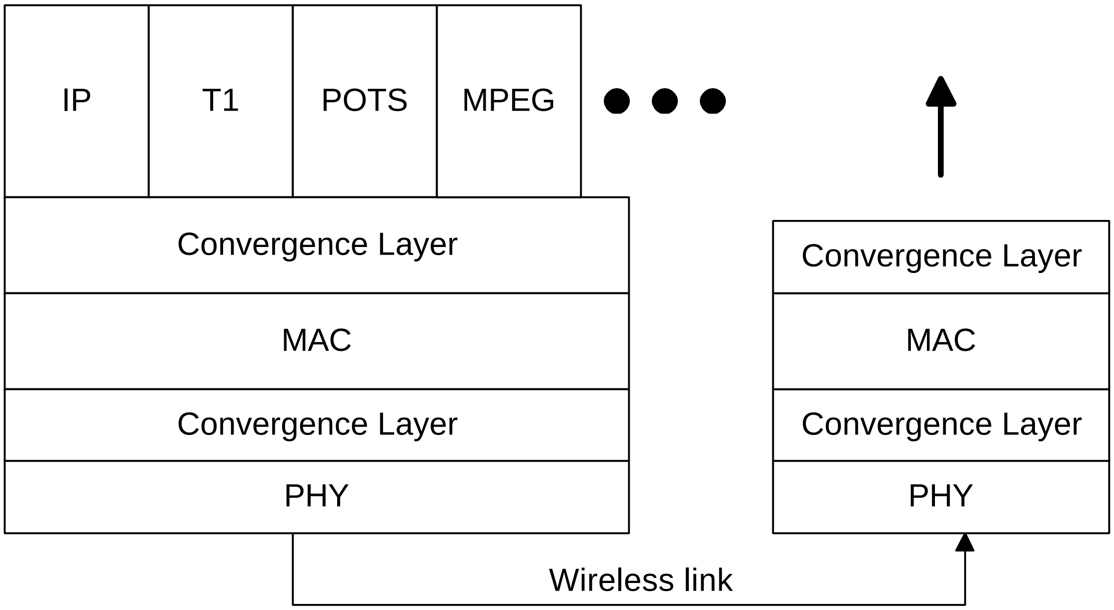


Figure 1: Reference Configuration

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 (polling, contention, guard, or reserved) 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, half-duplex FDD terminals, or time division duplexing (TDD). The primary difference between the two modes of operation 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 modulation level can be chosen on a subscriber level basis.

3.5 Modes of Operation - Philosophy

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 half-duplex FDD terminals 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.

3.5.1 Mode A

3.5.1.1 Downstream Coding, Interleaving, Scrambling & Modulation

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 ½, 2/3, ¾, 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.

3.5.1.2 Upstream Coding, Interleaving, Scrambling & Modulation

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 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 or 16-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.

3.5.2 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 or 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. For the upstream an additional modulation scheme would be considered to allow for terminal cost reduction.

4 Mode A

4.1 Downstream Physical Layer

4.1.1 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.

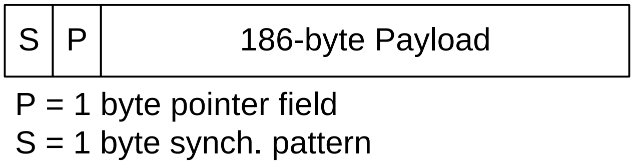


Figure 2: Format of the Convergence Layer Packet

4.1.2 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.

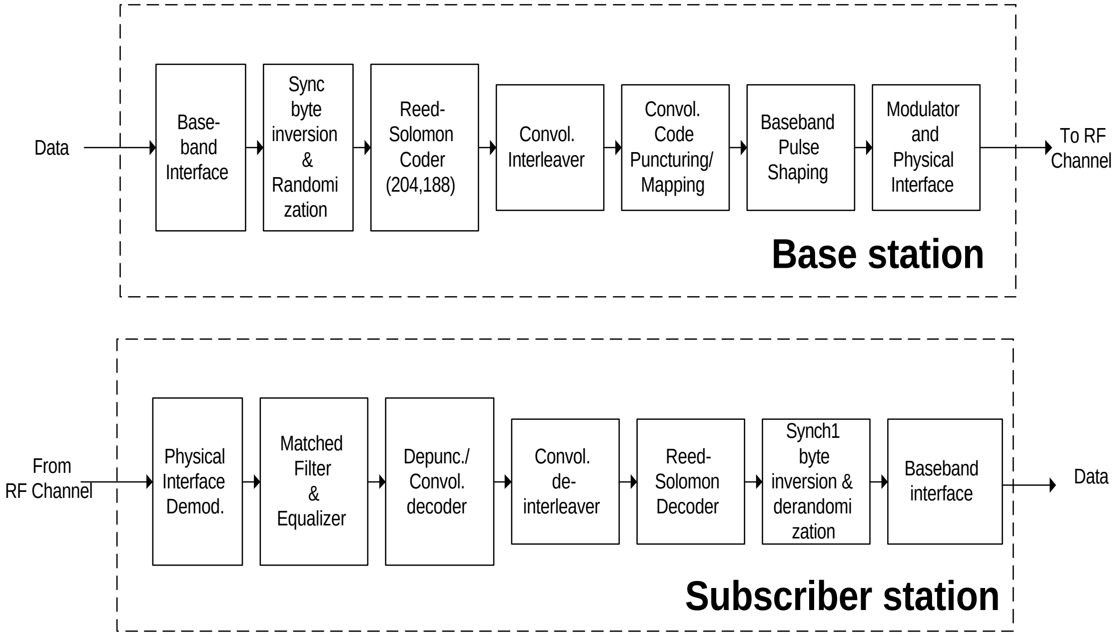


Figure 3: Conceptual Block diagram of the Mode A Downstream Physical Layer

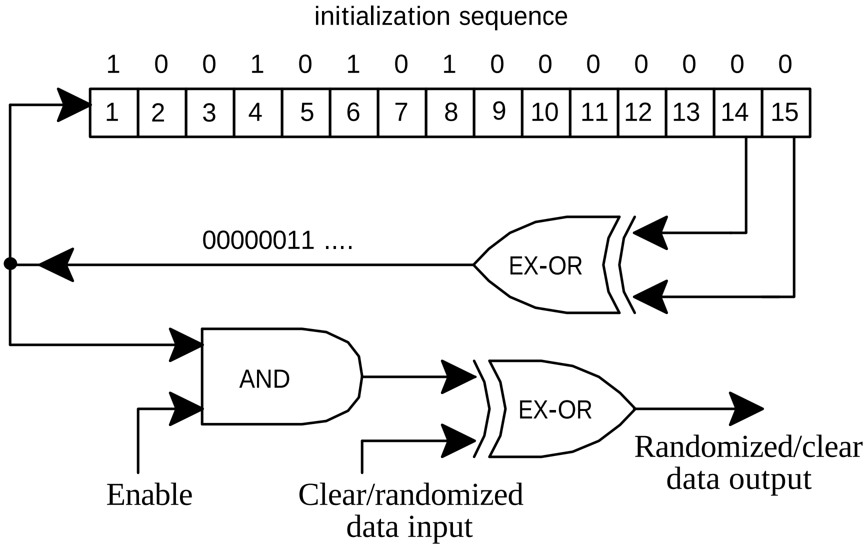
4.1.2.1 Baseband interfacing

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

4.1.2.2 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.



Data input (MSB first): 1 0 1|1 1 0 0 0 x x x|x x x x x .... |
PRBS sequence: | 0 0 0|0 0 0 1 1 .... |

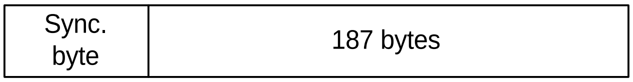
Figure 4: Randomizer logic diagram.

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.

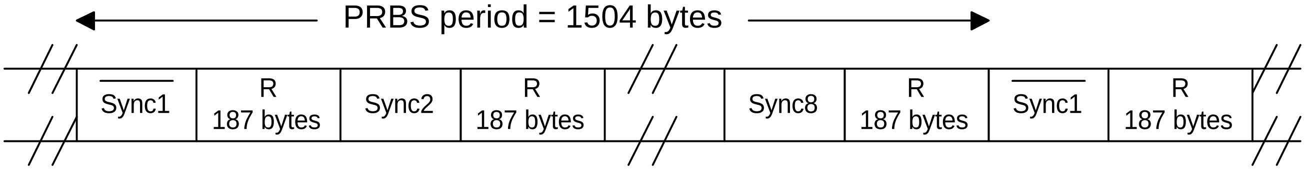
The generator polynomial for the PRBS shall be:

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

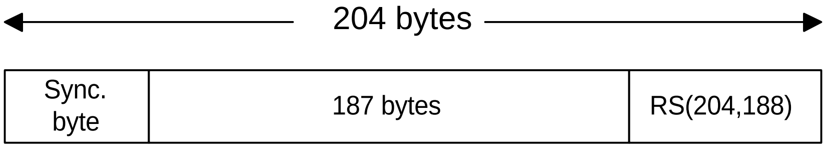
Following initialization, the first PRBS generator output bit shall be added to the first bit following the inverted synch. byte. Over subsequent synch. bytes, the PBRS generator shall continue to step its internal shift register state but the PBRS output addition to the synch. byte bits shall be disabled.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



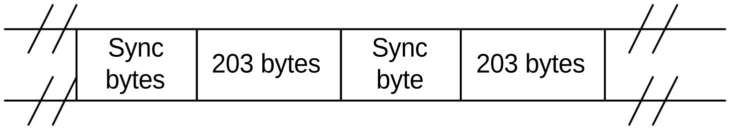
(a) Transmission convergence sublayer packet



(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 5: Framing structure based on transmission convergence sublayer.

4.1.2.3 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.

4.1.2.4 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.

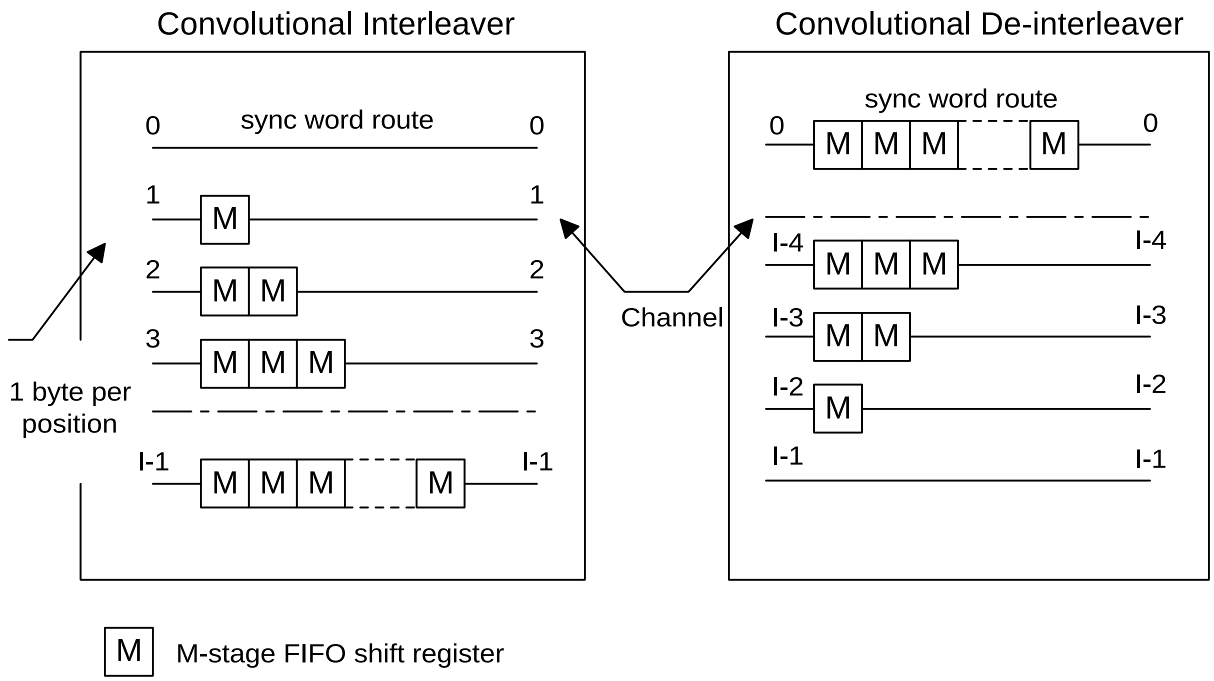


Figure 6: Conceptual diagram of the convolutional interleaver and de-interleaver.

4.1.2.5 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 1: 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	10	X=10 Y=11	6	X=101 Y=110	5	X=10101 Y=11010	4	X=1000101 Y=1111010	3

			I=X_1 Q=Y_1		I=$X_1Y_2Y_3$ Q=$Y_1X_3Y_4$		I=X_1Y_2 Q=Y_1X_3		I=$X_1Y_2Y_4$ Q=$Y_1X_3X_5$		I=$X_1Y_2Y_4Y_6$ Q=$Y_1Y_3X_5X_7$	
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:

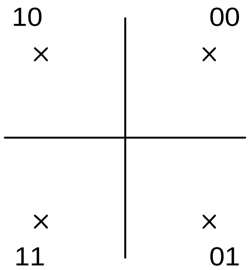


Figure 7: QPSK symbol mapping

4.1.2.6 Convolutional Coding with 16-QAM Modulation (optional)

16-QAM shall be supported using a rate ¾ or 7/8 punctured convolutional code with the inner coding and constellation mapping as described in [2].

4.1.2.7 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:

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

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

> 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.

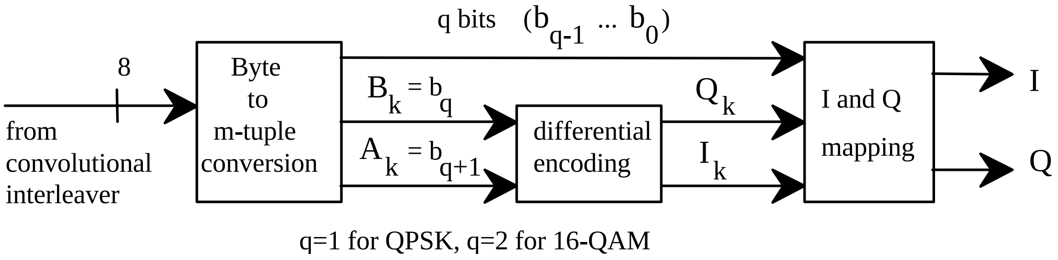


Figure 8: Example implementation of the byte to m-tuple conversion and the differential encoding of the two MSBs**.**

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 2: 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	+ π/2
3	11	+ π
4	01	+ 3π/2

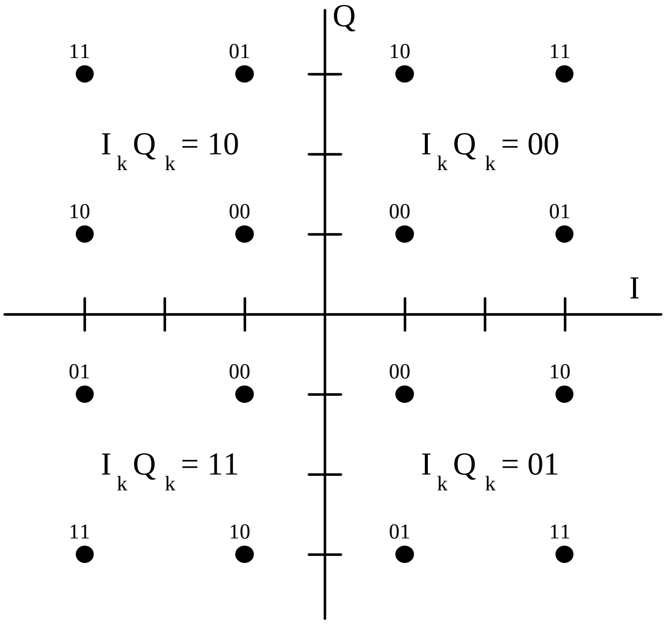


Figure 9: 16 QAM Constellation diagram

4.1.2.8 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:

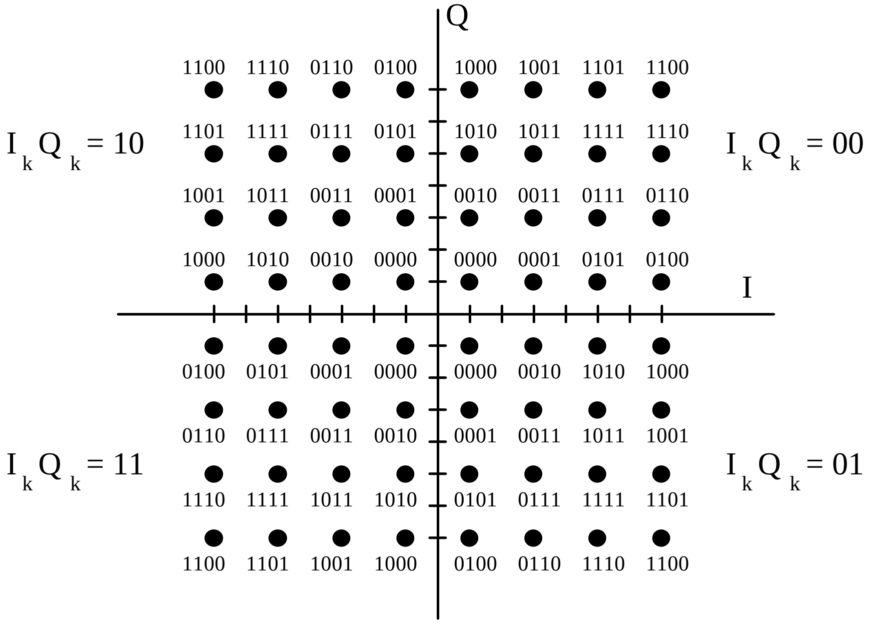


Figure 10: 64-QAM Constellation Diagram

4.1.2.9 Additional Modulation Schemes

TBD

4.1.2.10 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:

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

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 $|f|>f_N\,(1+a)$ should be $H(f) < 50\ dBc$ measured with respect to the passband.

4.1.3 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 ½, 2/3, ¾, 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

4.2 Upstream Physical Layer

4.2.1 Upstream Transmission Convergence (TC) Sublayer

MAC packets are carried directly within upstream bursts, so no convergence sublayer is used to delineate the packets.

4.2.2 Upstream Physical Media Dependent (PMD) Sublayer

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

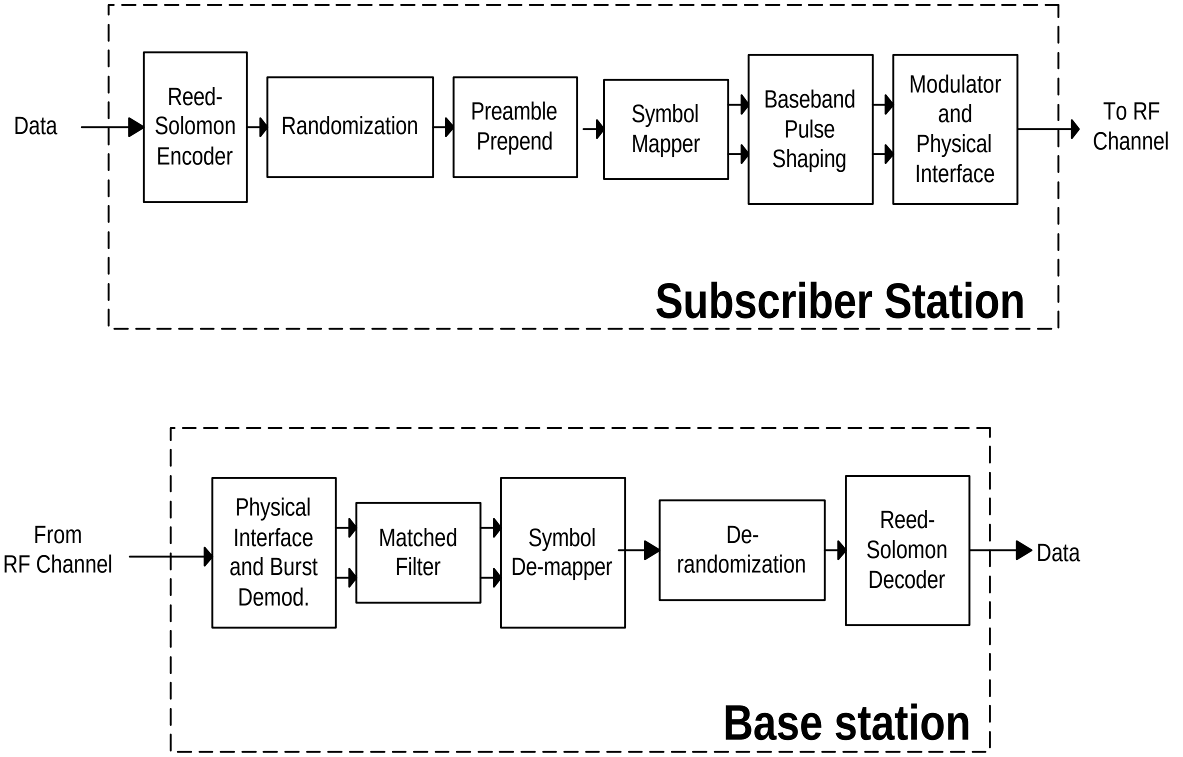


Figure 11: Conceptual Block diagram of the 802.16 Burst Transmission Upstream Physical Layer

4.2.2.1 Reed-Solomon coding

Reed-Solomon coding shall be applied to each MAC packet. The code shall be a shortened, systematic Reed-Solomon code generated from GF(256) with codeword lengths (N) variable from 18-255 bytes, and error correction capability able to correct from T=0-10 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.

4.2.2.2 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).

4.2.2.3 Preamble

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

4.2.2.4 Modulation

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

4.2.2.5 QPSK Symbol Mapping

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

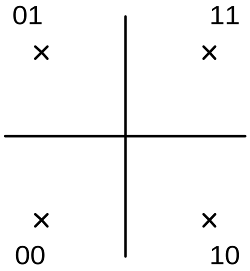


Figure 12: QPSK constellation mapping

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

4.2.2.6 Differentially encoded 16-QAM (optional)

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

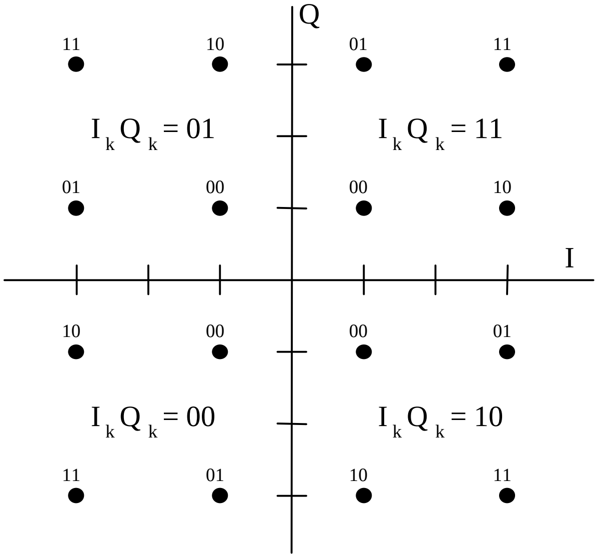


Figure 13: Differentially encoded 16-QAM Constellation diagram

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

4.2.2.7 Gray-coded 16-QAM (optional)

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

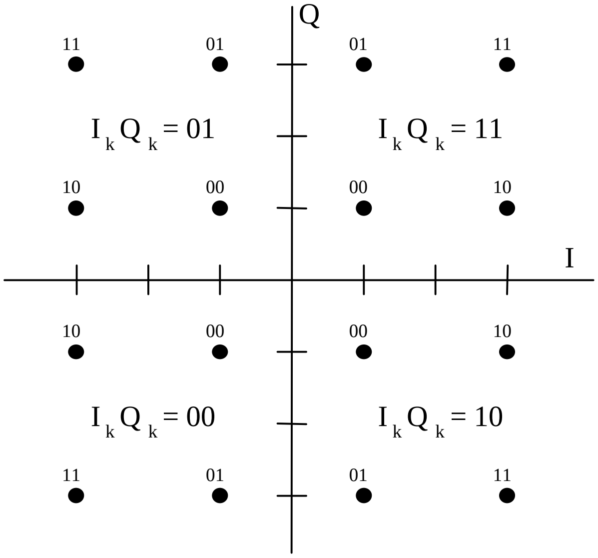


Figure 14: Gray-coded 16-QAM Constellation diagram

4.2.2.8 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 square-root raised cosine filter is defined by the following transfer function H:

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

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.

4.2.2.9 Summary of Mode A Upstream Physical Layer Parameters

Reed-Solomon Coding	Codeword lengths: 18-255 bytes

	T=0-10
Randomization	$x^{15}+x^{14}+1$ Initialization seed: 15-bit programmable
Preamble	Programmable length: 0-1024 bits Programmable value
Modulation	QPSK or 16-QAM (optional)
Differential encoding	Selectable on/off
Spectral shaping	α=0.15, 0.25, 0.35

4.2.3 Mode A Upstream channel description

The following parameters and their ranges can be used to configure the necessary upstream channel. It is expected that these parameters be sent in MAC messages from the base station.

Parameter description	**Parameter needed from MAC**	**Meaning**
Mini-slot size	0-255 (M)	Number of bytes per mini-slot, which is the smallest unit of time slot size
Spectrum inversion	0= inverted, 1=non-inverted	
Scrambler tap coefficients	16 bits	Each tap is either on (1) or off (0)
Upstream center frequency	0-60 GHz	in KHz

4.2.4 Mode A Burst profiles

The upstream transmitter should be able to save multiple burst profiles, each of which contain the following information:

Parameter description	**Parameter needed from MAC**

Modulation	2=QPSK, 4=16-QAM
Preamble length	0-1023 bits
Preamble pattern	0-1023 bits
RS information bytes	16-255 bytes
Error correction of codeword	0-10 bytes
Last codeword length	1=fixed; 2=shortened (**optional**)
Guard time	0-255 symbols
Scrambler seed	15 bits
Differential encoding	on/off
Maximum burst size	0-255 mini-slots
Scrambler	on/off

4.3 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 should be left very 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**.

5 Mode B

5.1 Multiple Access and Channel multiplexing

5.1.1 Introduction

This section defines the physical channels of the radio sub-system required to support the logical channels. It includes a description of the logical channels and the definitions of TDMA frames, physical slots and bursts. A Transmission Convergence (TC) Layer has been defined for the mapping of MAC channels to PHY layer resources. This section defines the interaction of the PHY layer and the TC sub-layer.

5.1.2 The physical resource

5.1.2.1 General

The physical resource available to the radio sub-system is an allocation of part of the radio spectrum. This resource is partitioned in time only. The total available spectrum for deployment shall be partitioned by RF channels. Timeslots and TDMA frames as defined in this subsection shall partition time. The access scheme shall be TDMA. The TDMA structure shall be composed of hyper-frames, multi-frames, frames, physical slots and symbols.

5.1.2.2 RF channels

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 of equal bandwidth, 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. The PHY layer is designed around a 1 mSec time base frame. Each frame is segmented into 5,000 Physical Slots (PSs). See Figure 5-1 for an illustration of a frame. Each Physical Slot is defined as 4 Symbols in the case QAM transmission.

5.1.2.3 Framing and Formatting

Downstream frames are structured according to modulation type into four groups: QPSK Frame Control Header, QPSK data block, 16-QAM data block, and 64-QAM data block. This structure is detailed in Section 5.1.4.2.1. A downstream TDMA option (similar to the upstream) where individual user data is not multiplexed with other user data is supported as well. Upstream frames are structured according to modulation type into five groups: QPSK Registration Request Contention slot, QPSK Bandwidth Request Contention slot, QPSK data bursts, 16-QAM data bursts, and 64-QAM data bursts. Each burst is separated by a transition gap for ramping down and ramping up transmissions. This structure is detailed in Section 5.1.4.2.1.

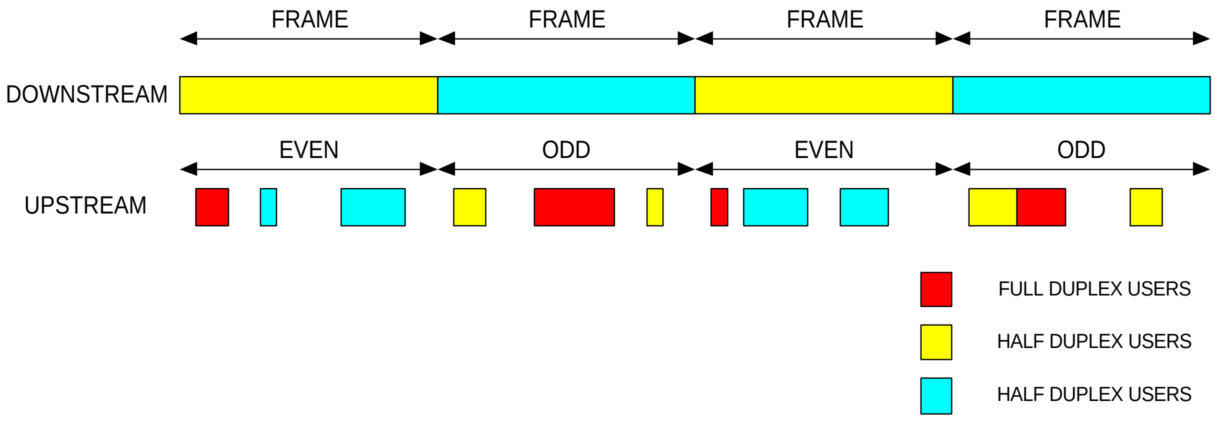
Addressing a specific starting point for a user upstream transmission is done by reference to a PS As pointed earlier the PS granularity is required to simplify radio time management over the frame. The FEC output bits are converted to modulation symbols according to the modulation scheme chosen. Although the FEC operation is block oriented (requires a specific information size to operate on) there would be cases where the FEC operates on a shorter block due to efficiency. In these cases, the information before the FEC operation is effectively prefixed with zero byte padding. The resulting FEC operation would contain a zero byte prefix padding which are discarded for transmission and are padded back at the receiver.

5.1.2.4 FDD

In this mode of operation the downstream and upstream are using 2 different carrier frequencies. Both carriers are equal in channel bandwidth *and* instantaneous baud rate. 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 the time domain both upstream and downstream are frame *synchronized*.

A subscriber capable of full duplex FDD operation, meaning it is capable of transmitting and receiving at the same instant, imposes no restriction on the base station controller regarding its upstream bandwidth allocation management. On the other hand, a subscriber that is limited to Frequency Switched Division Duplex operation imposes a restriction on such a controller not to allocate upstream bandwidth for the subscriber, which may force it to instantaneously transmit and receive. It is mandatory that both types of subscribers could co-exist in a FDD deployment, meaning that radio channels could address both type of subscribers instantaneously.

The following figure describes the basics of the FDD and FSDD based operation. Frames are either even numbered or odd numbered. A subscriber limited to FSDD operation is designated to operate either on even frames or odd frames. Those that are receiving downstream on even frames are using odd frames for upstream and vice versa. A user that is capable of full duplex FDD ignores the even/odd structure and may utilize the system on both even and odd frames.



In order to increase statistical gain a user may change its even-odd frame relationship according to traffic requirements. When a user has no upstream bandwidth it is required to receive all frames. When bandwidth is being allocated for it then the user limits itself by the frame assigning its bandwidth. If the frame assigning bandwidth on the downstream is even numbered than its upstream frames would be odd numbered and vice versa.

5.1.2.5 TDD and Supporting Varying Traffic Asymmetry Conditions

In the case of TDD, upstream and downstream share the same frequency in time. A TDD frame has a 1 mS duration and contains one downstream and one upstream subframe. Each frame contains 5,000 PS as shown in Figure 5-1. The TDD framing is adaptive in that the number of PS allocated to downstream versus upstream can vary. The split between upstream and downstream is a system parameter and is controlled at higher layers within the system.

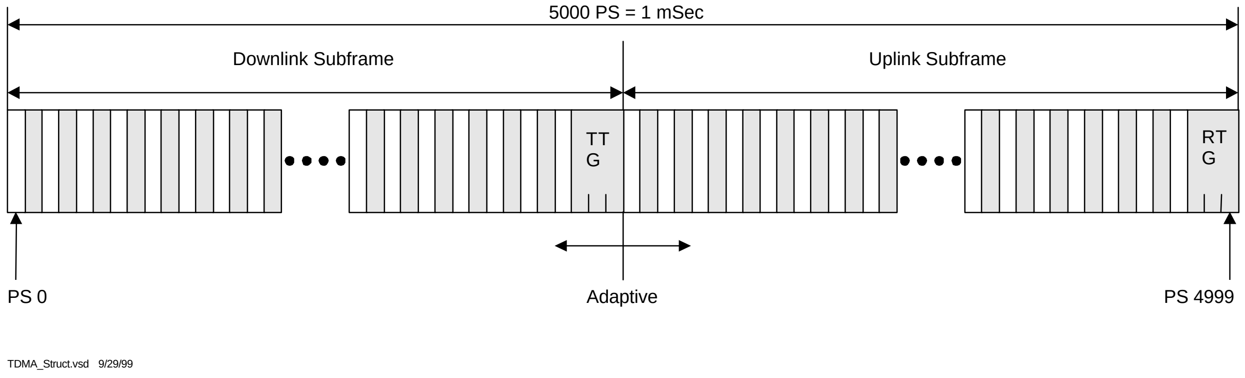


Figure 5-1 Frame Structure

5.1.2.5.1 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.

5.1.2.5.2 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 transmit 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.

5.1.2.5.3 CPE Transition Gap (CTG)

The CTG is a gap between Upstream bursts. This gap allows time for one CPE to ramp down its transmission while the next CPE is ramping up its transmission. The CTG consists of an integer number of physical slots. The CTG starts on a PS boundary.

5.1.3 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.

The definition of the logical channels supported by the radio subsystem is given below.

5.1.3.1 Logical channels hierarchy

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.

5.1.3.2 Traffic channels

The traffic channels shall carry user information. Three traffic channels are defined for four different modulation types. If the propagation environment allows, the BS assigns higher modulation types to CPEs on an individual basis independently on upstream and downstream. 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 burst and an upstream burst 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.

The downstream frame can operate either in a TDM burst mode or in TDMA mode. In the TDM burst mode channels are grouped by modulation type. The PHY Control portion of the Frame Control Header contains fields stating the PSs at which modulation will change. Data is transmitted in modulation order QPSK, followed by 16-QAM, followed by 64-QAM. The structure of the data sections are the same, the only difference is the modulation type.

If the downstream data does not fill the entire downstream subframe, the downstream subframe is padded with fill data (0x55). If one or more TC data units (TDUs) remain to be filled, the MAC performs the fill on a specific connection ID. If less than one TDU remains to be filled, the TC performs the fill.

In the case of FSDD filling is replaced by transmitter shut-down in order to allow parallel upstream allocations and preferably a TDMA burst mode of operation is used in this case for the downstream. Within the upstream subframe, bursts are of the modulation type assigned to the CPE. The first portion of each upstream burst is a preamble, followed by MAC data from 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 (0x55). If one or more TDUs remain to be filled, the MAC performs the fill on a specific connection ID. If less than one TDU remains to be filled, the TC performs the fill or shortening.

5.1.3.2.1 TCH4

The TCH4 QPSK data channels transport data at a rate of 2 bits per symbol.

5.1.3.2.1.1 QPSK Downstream Data

On the downstream, the most robust modulation scheme used is QAM-4 (QPSK). Data is transported at a rate of 2 bits per symbol.

5.1.3.2.1.2 QPSK Upstream Data

On the upstream, the most robust modulation scheme used is QAM-4 (QPSK). Data is transported at a rate of 2 bits per symbol.

5.1.3.2.2 16-QAM Data (TCH16)

The TCH16 16-QAM data channels transport data at a rate of 4 bits per symbol.

5.1.3.2.3 64-QAM Data (TCH64)

The TCH64 64-QAM data channels transport data at a rate of 6 bits per symbol.

5.1.3.3 Control CHannels (CCH)

5.1.3.3.1 General

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 burst has two categories of control channel defined:

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

These two channels are the first two sections of the DL burst and are not separate bursts from the DL traffic channels. The upstream burst has two 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.

5.1.3.3.2 PHY Control CHannel (PCCH)

The PCCH occupies the first bytes of the first TDU in the downstream burst following the preamble. 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 QPSK.

5.1.3.3.3 MAC Control CHannel (MCCH)

The MAC Control portion of the downstream subframe is used for MAC messages destined for multiple CPEs. 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. The MAC Control messages are FEC encoded. The information transmitted in this section is always transmitted in QPSK.

5.1.3.3.4 Registration Request Contention CHannel (RCCH)

Periodically, a portion of the upstream burst is allocated for registration request message contention. 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 QPSK modulation.

For more details of the Registration Request Contention slot, see Section 5.1.4.2.2.2.1.

5.1.3.3.5 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 QPSK modulation. For more details of the Registration Request Contention slot, see Section 5.1.4.2.2.2.2.

5.1.4 Types of Physical Channels

5.1.4.1 General

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

5.1.4.2 Types of Physical Channels

Three types of physical channels are defined:

- Downstream subframe burst
- Upstream subframe Control Channel bursts
- Upstream subframe Traffic Channel bursts

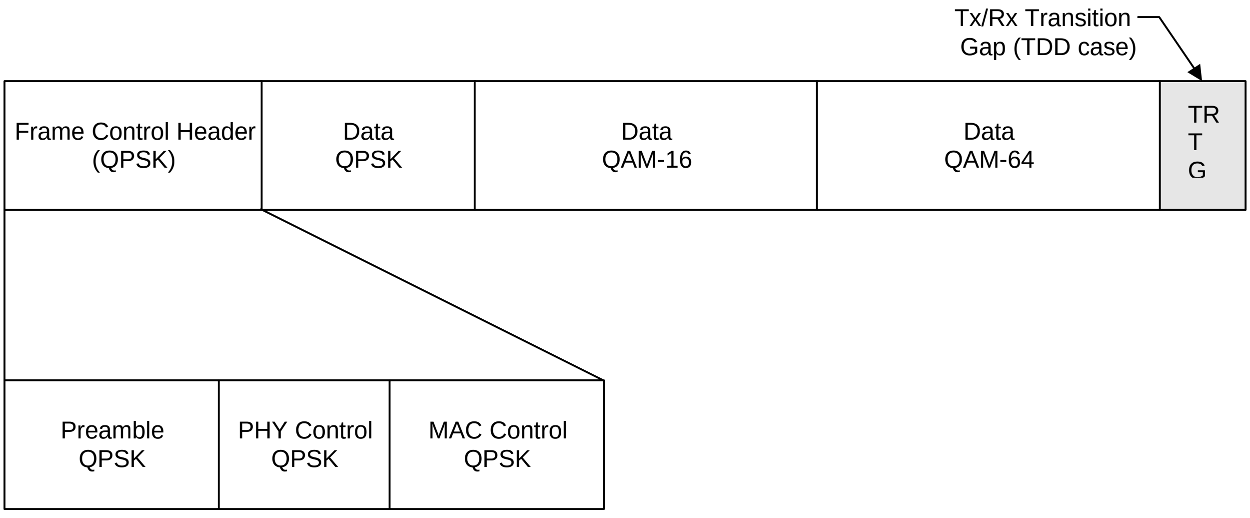
5.1.4.2.1 Downstream Burst

The structure of the downstream burst used by the BS to transmit to the CPEs is shown in Figure 5-2. 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. Within the downstream subframe, transmissions are grouped by modulation type. Preambles are not FEC. There is a Tx/Rx Transmission Gap (TTG) separating the downstream subframe from the upstream subframe in the case of TDD.

5.1.4.2.1.1 Downstream Traffic Channels

The downstream traffic channels are used for transmitting data and control messages to the CPEs. There are 2 options supported by the downstream traffic channels: TDM and TDMA. While using the TDM option, each CPE continuously receives the entire downstream burst. The CPE decodes the data in the DL burst and looks for MAC headers indicating data for that CPE. 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. 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. For TDD the preferred option is TDM and for FSDD the preferred option is TDMA.

This data is always FEC coded and is transmitted at the current operating modulation of the individual CPE. Data is transmitted in modulation order QPSK, followed by 16-QAM, followed by 64-QAM in the TDM case. The PHY Control portion of the Frame Control Header contains fields stating the PS at which modulation will change.



DLSubframe_Struct.vsd 9/7/99

Figure 5-2 Downstream Subframe Structure

5.1.4.2.2 Upstream Bursts

The structure of the upstream subframe used by the CPEs to transmit to the BS is shown in Figure 5-3. 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 QPSK modulation. 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.

5.1.4.2.2.1 CPE Transition Gaps (CTGs)

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.

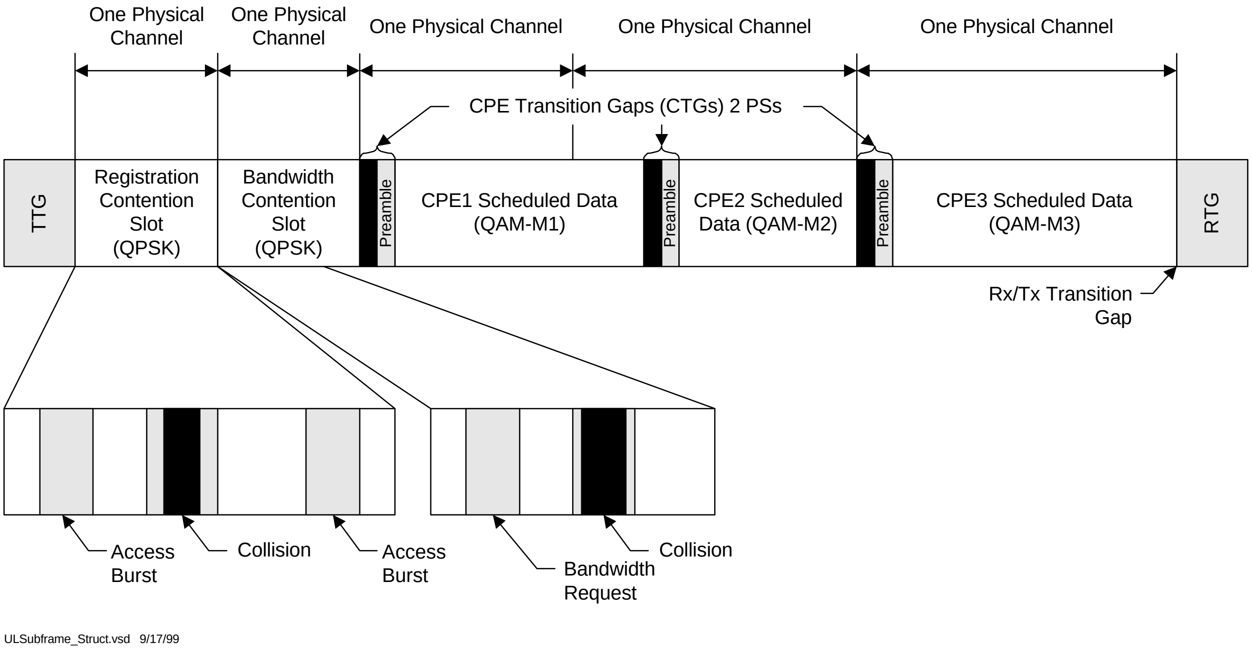


Figure 5-3 Upstream Subframe Structure

5.1.4.2.2.2 Upstream Control Channels

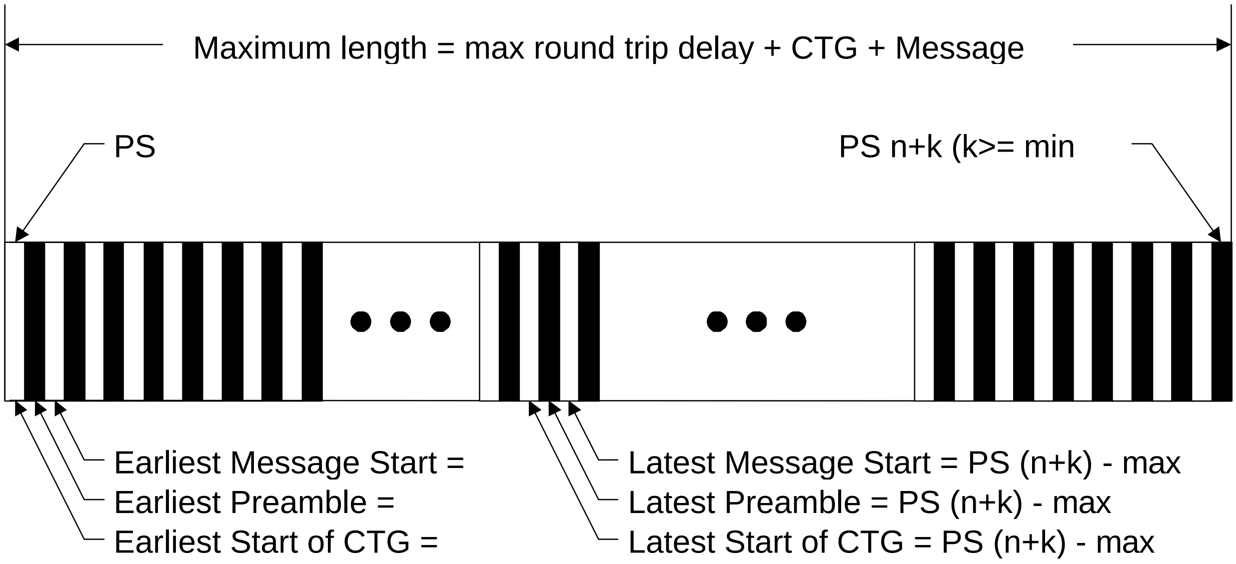
5.1.4.2.2.2.1 Registration Contention Slots

A portion of the upstream bandwidth is periodically be 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 ½ 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 round trip delay for a 5 km cell causes a CPE with no Tx timing advance to transmit up to 150 PSs late, not including delays through the modem. Therefore, the minimum length of the registration contention period is 150 + modem delay (in integer number of PSs) + n PS, where n is the number of PS required to transmit a registration or ranging message. More PSs may be allocated to reduce the likelihood of collision or to allow larger cells. Figure 5-4 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.



Regist_Slot.vsd 9/1/99

Figure 5-4 Registration Contention Slot Usage

5.1.4.2.2.2.2 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.

5.1.4.2.2.3 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 CPE UL bursts are preferably ordered by modulation. The bandwidth is requested by the CPE and granted by the BS. All bandwidth within a given frame, allocated to an individual CPE, is grouped into a contiguous block. 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 TDU packets transmitted are always FEC coded. As indicated previously, the pointer for the beginning of a scheduled transmission uses a PS number.

5.1.4.2.2.4 Scheduled Downstream Traffic Channels

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.

5.1.4.3 Bursts

5.1.4.3.1 General

A burst is a period of RF carrier that is modulated by a data stream. A burst therefore represents the physical content of a timeslot or subslot.

The description of a physical channel is made in terms of physical slots (PSs) and symbols. As described in section 5.1.2.2, each Physical Slot is defined as 4 Symbols for the QAM based modulation.

In general, the FEC is programmed to work on a N byte block prior to encoding. The FEC output is defined as the PHY Information Element (PI). Each PI provides the payload to the TC for transport of MAC messages, control information, and data. The TC provides to the MAC a data block defined as a TC Data Unit (TDU). The modulation within the frame may vary, and determines the number of PS and symbols required for transmission. A shortened PI is supported as well by zero padding prior to FEC and discarding the pads at transmission. The receiver pads back the discarded zeros prior to decoding.

5.1.4.3.2 Modulation symbol numbering

In the case of QAM a PS shall be divided into 4 modulation symbol durations, each one. A particular modulation symbol within a burst shall be referenced by a Symbol Number (SN), with the first modulation symbol numbered SN0 and the last modulation symbol numbered SNmax. Different types of bursts are defined, having different durations.

5.1.4.3.3 Modulation bit numbering

A particular modulation bit within a burst shall be referenced by a Bit Number (BN), with the first modulation bit numbered BN0 and the last modulation bit numbered BNmax.

At the modulator the modulation bits shall be grouped into groups of one, two, four, or six depending upon the modulation type (QPSK, 16-QAM, or 64-QAM) and each group shall be converted into one modulation symbol.

5.1.4.3.4 Burst timing

The symbol time is defined as the instant at which the transmitted symbol waveform is at a maximum for the symbol of interest. The beginning of a symbol is defined as one half a symbol period before the instant at which the transmitted symbol waveform is at a maximum for the symbol of interest.

5.1.4.3.5 Burst Preambles

Table 5-1 defines the preambles for the different burst types. The preamble is always at the first part of a burst. QPSK, 16-QAM use 24 symbol preambles. 64-QAM uses a 48 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 5-1 Burst Preamble Types

Burst type	Preamble Type	Modulation Type
Downstream burst, Frame begin	1	QPSK
Upstream Registration Request burst	1	QPSK
Upstream Bandwidth Request burst	1	QPSK
Upstream QPSK Data burst	2	QPSK
Upstream 16-QAM Data burst	3	16-QAM

Upstream 64-QAM Data burst	4	64-QAM
Downstream TDMA burst	5	QPSK

5.1.4.3.5.1 Burst Preamble 1

Table 5-2 defines the bit sequence for burst preamble 1 (TBD).

Table 5-2 Burst Preamble 1

Symbol	I	Q	B(1)	B(2)
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				

5.1.4.3.5.2 Burst Preamble 2

Table 5-4 defines the bit sequence for burst preamble 2 (TBD).

Table 5-4 Burst Preamble 2

Symbol	I	Q	B(1)	B(2)
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				

5.1.4.3.5.3 Burst Preamble 3

Table 5-5 defines the bit sequence for burst preamble 3 (TBD).

Table 5-5 Burst Preamble 3

Symbol	I	Q	B(1)	B(2)	B(3)	B(4)
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						

5.1.4.3.5.4 Burst Preamble 4

Table 5-6 defines the bit sequence for burst preamble 4 (TBD).

Table 5-6 Burst Preamble 4

Symbol	I	Q	B(1)	B(2)	B(3)	B(4)	B(5)	B(6)
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								
…								
45								
46								
47								
48								

5.1.4.3.5.5 Burst Preamble 5

Table 5-7 defines the bit sequence for burst preamble 5 (TBD).

Table 5-7 Burst Preamble 1

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

5.1.4.4 Types of bursts

5.1.4.4.1 General

8 types of bursts shall exist in the system. Figure 5-5 summarizes the description of the bursts and their timing with respect to the timeslot.

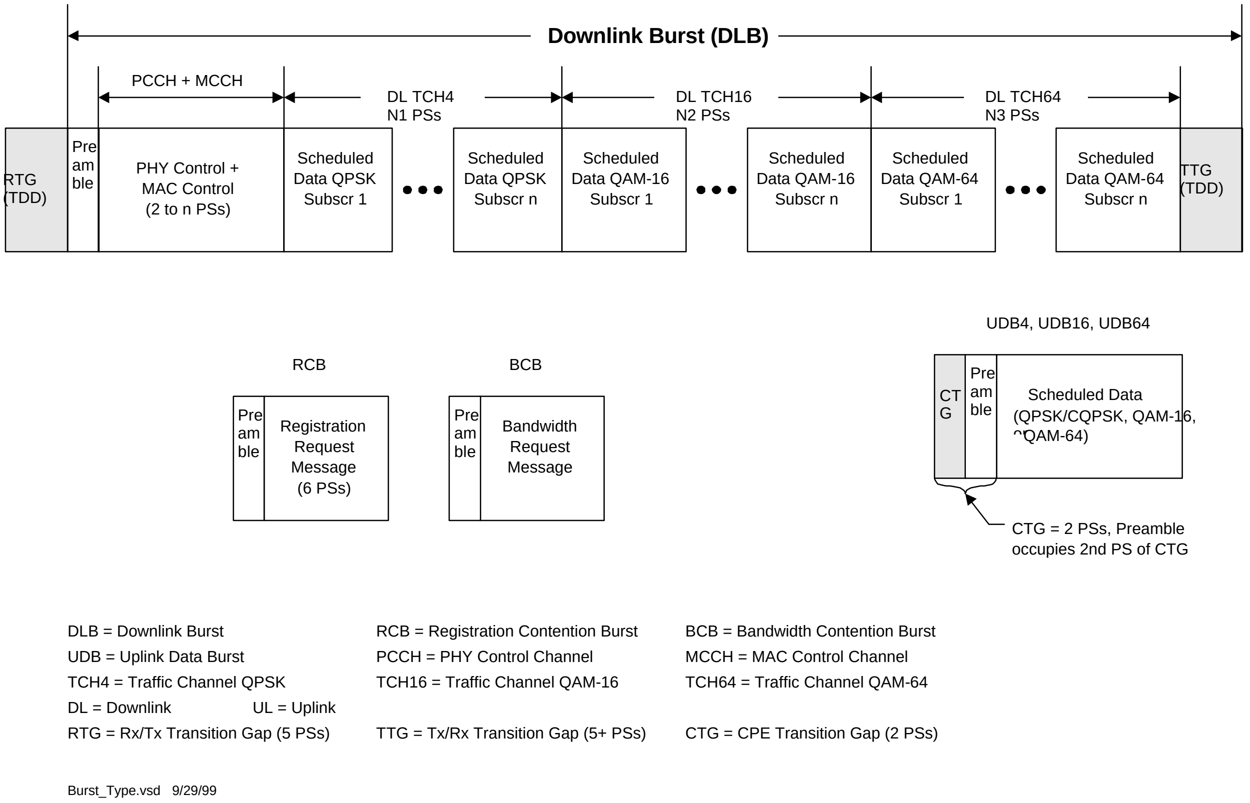


Figure 5-5 Types of Bursts

Table 5-3 Burst Types

Burst type	Channel ID	Logical Format	Definition
Downstream	DLB	Preamble, PCCH, MCCH DL TCH4, DL TCH16, DL TCH64	subsection 5.1.4.4.2
Upstream Registration Contention	RCB	Preamble, RCCH	subsection 5.1.4.4.3
Upstream Bandwidth Request Contention	BCB	Preamble, BCCH	subsection 5.1.4.4.4
Upstream Scheduled Traffic, QPSK	UDB4	Preamble, UL TCH4	subsection 5.1.4.4.5
Upstream Scheduled Traffic, 16-QAM	UDB16	Preamble, UL TCH16	subsection 5.1.4.4.5
Upstream Scheduled Traffic, 64-QAM	UDB64	Preamble, UL TCH64	subsection 5.1.4.4.5

5.1.4.4.2 Downstream Burst (DLB), TDM and TDMA modes

The downstream burst is composed of up to three sections: the QPSK section, the 16-QAM section, and the 64-QAM section. In the case of the TDMA option on the downstream each user data in the TCH logical channels are prefixed with a short preamble. If both TDM and TDMA options exist on a specific carrier, then the TDM traffic is transmitted first similar to the situation of being the only option supported. If only TDMA is supported there is no particular need to preserve the modulation order with the exception that PCCH and MCCH control channels are transmitted first at the beginning of each frame using QPSK. The following sections address the TDM mode.

5.1.4.4.2.1 QPSK

Every downstream burst always contains a QPSK section. This section contains at minimum the preamble, the PCCH and MCCH control channels. If present, the TDM stream using TCH4 QPSK user data section is transmitted immediately afterwards.

The preamble, PCCH, MCCH, and TCH4 logical channels are concatenated into one continuous QPSK symbol stream. The preamble shall be as defined in Section 5.1.4.3.5. The PHY Control message and MAC Control message are defined in the MAC Specification.

Downstream traffic packets consist of concatenated MAC control messages and MAC data packets.

5.1.4.4.2.2 16-QAM

The 16-QAM section is used to transport CPE user data with 16-QAM modulation. Downstream traffic packets consist of concatenated MAC control messages and MAC data packets. If 16-QAM data is present in the frame, the TCH16 channel will follow the TCH4 channel.

5.1.4.4.2.3 64-QAM

The 64-QAM section is used to transport CPE user data with 64-QAM modulation. Downstream traffic packets consist of concatenated MAC control messages and MAC data packets. If 64-QAM data is present in the frame, the TCH64 channel will follow the TCH16 channel.

5.1.4.4.3 Upstream Registration Request Contention Burst (RCB)

5.1.4.4.3.1 Preamble

The first portion of the Upstream Registration Request Message burst shall be a 24 symbol preamble as defined in Section 5.1.4.3.5.

5.1.4.4.3.2 Registration Request Burst

The registration burst is sent by CPEs in the registration contention slot when performing registration. The payload is FEC protected in a shortened format. QPSK modulation scheme is used.

5.1.4.4.4 Upstream Bandwidth Request Contention Burst (BCB)

5.1.4.4.4.1 Preamble

The first portion of the Upstream Bandwidth Request Message burst shall be a 24 symbol preamble as defined in Section 5.1.4.3.5.

5.1.4.4.4.2 Bandwidth Request Burst

The Bandwidth Request burst is sent by the CPE to the BS in the Bandwidth Contention Slot to request bandwidth in which to send data for a specific connection. The payload is FEC protected in a shortened format. QPSK modulation scheme is used.

5.1.4.4.5 Upstream Schedule Data Burst (UDB4, UDB16, & UDB64)

The upstream data packet bursts provide the physical channel for the upstream TCH4, TCH16, and TCH64 logical channels using, respectively, QPSK, 16-QAM, or 64-QAM modulation. Although the first scheduled upstream burst is assigned to a PS boundary, the latter may be assigned to a specific symbol location. When allocations using the same modulation level are ended, a PS boundary maybe forced for the next allocation.

5.1.4.4.5.1 Preamble

Upstream MAC data packets burst shall start with one of three preambles as defined in Section 5.1.4.3.5 depending on the type of modulation in use by the CPE.

5.1.4.4.5.2 Upstream Traffic Data Packets

The upstream traffic data packets are used to transport CPE user data to the BS using the appropriate modulation type. The data packets consist of concatenated MAC control messages and MAC data packets.

The CPE must fill the data packet so the burst uses all of its granted allocation as indicated in the Upstream Map.

5.1.4.5 Transmission modes

5.1.4.5.1 BS continuous transmission

When the BS is in continuous transmission mode, normal downstream bursts shall be transmitted on the main carrier. When the BS does not have enough downstream traffic to fill the downstream burst, the BS shall stop transmit for the remaining duration of that downstream subframe.

5.1.4.5.2 CPE discontinuous transmission

Each CPE may be granted a portion of the upstream spectrum for transmission of scheduled data traffic (UL TCHx). These upstream transmission bursts shall be transmitted on the main carrier.

5.1.4.5.3 BS discontinuous transmission

Similar to 5.4.5.2, supporting the TDMA downstream option.

5.1.5 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 5.1.4. These physical channels transport the logical channels defined in Section 5.1.3.

5.1.5.1 General mapping of logical channels

Table 5-4 defines the mapping in time of logical channels into physical channel types.

Table 5-4 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 5000-x
RTG	--	--	All (TDD only)	5000-x to 5000
DLB = Downstream Burst, **BCB** = Bandwidth Contention Burst, **RCB** = Registration Contention Burst, **UDB** = Upstream Data Burst				

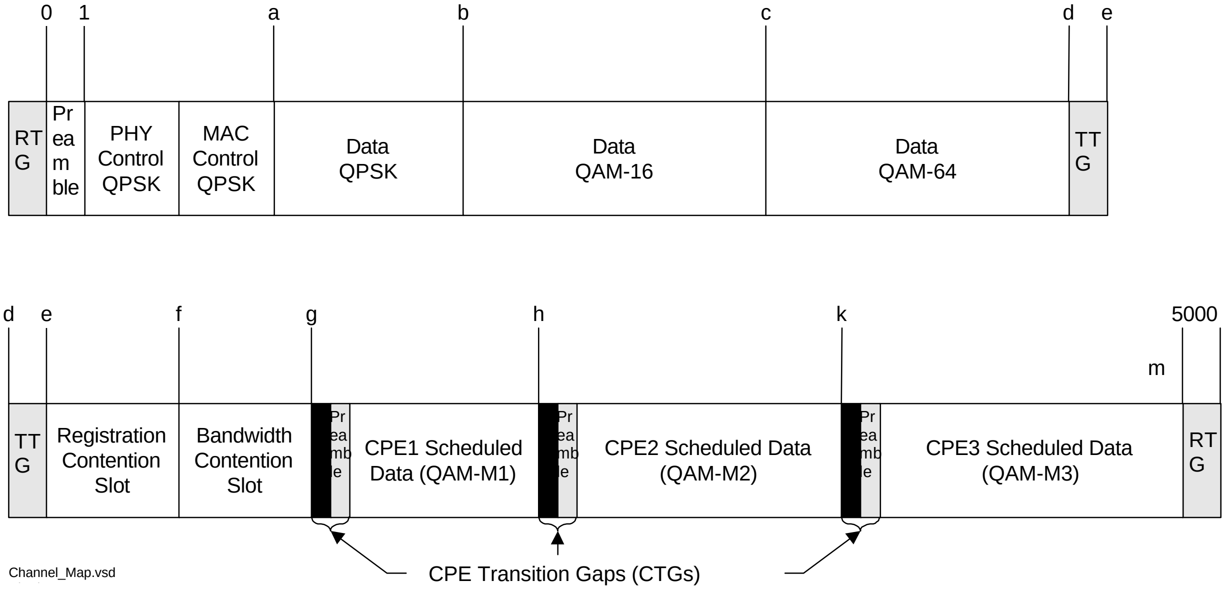
Table 5-5 Mapping of Logical Channel into Physical Channels - FDD

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 5000
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 5000

DLB = Downstream Burst, **BCB** = Bandwidth Contention Burst, **RCB** = Registration Contention Burst, **UDB** = Upstream Data Burst

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. Figure 5-6 depicts the division of the frame into logical sub-channels as listed in Table 5-4.

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.



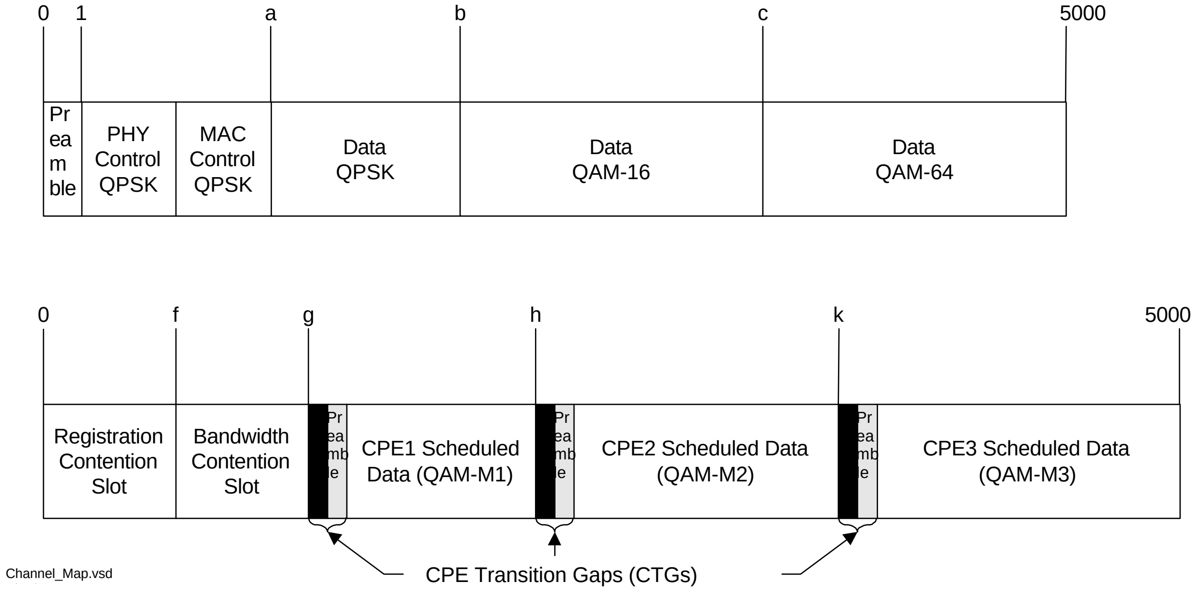


Figure 5-6 Logical Channel Mapping (TDD/FDD)

5.2 Channel Coding and Scrambling

5.2.1 Introduction

This section includes the specification of encoding but does not specify any data processing on the receive part. A definition of the error control process is provided for each kind of logical channel. The definition of logical channels is given in Section 5.1.

5.2.2 General

5.2.2.1 Interfaces in the error control structure

The definition of interfaces within the error control structure is given by Figure 5-7.

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 5-7.

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 scrambled, into type-4 bits, which compose type-4 blocks, this defines the interface (4).
- the type-4 bits shall be encoded by a FEC block code. The block-encoded bits and are referred to as type-5 bits and shall be packed in a type-5 block, this defines interface (5); These bits shall then be mapped into multiplexed blocks.

  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.

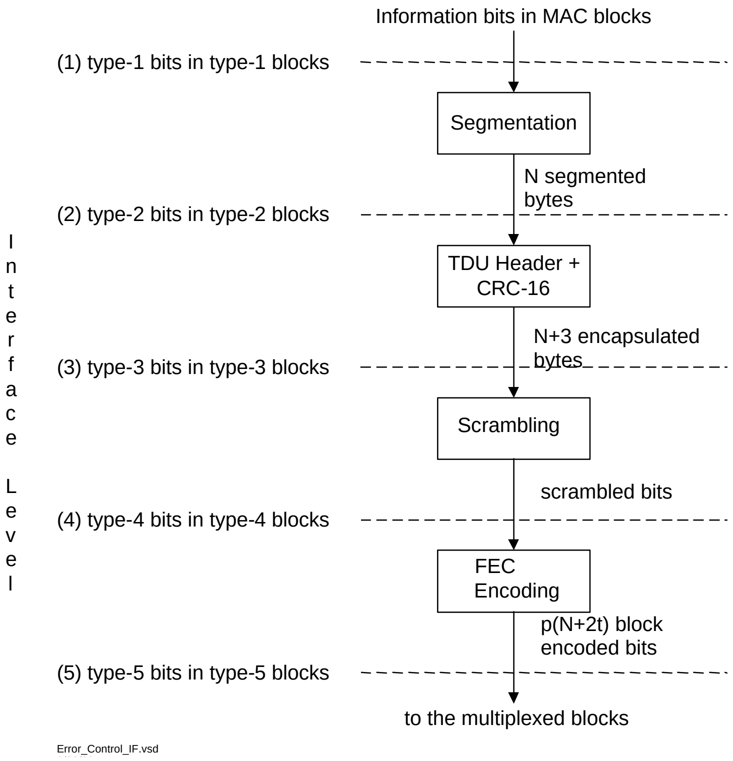


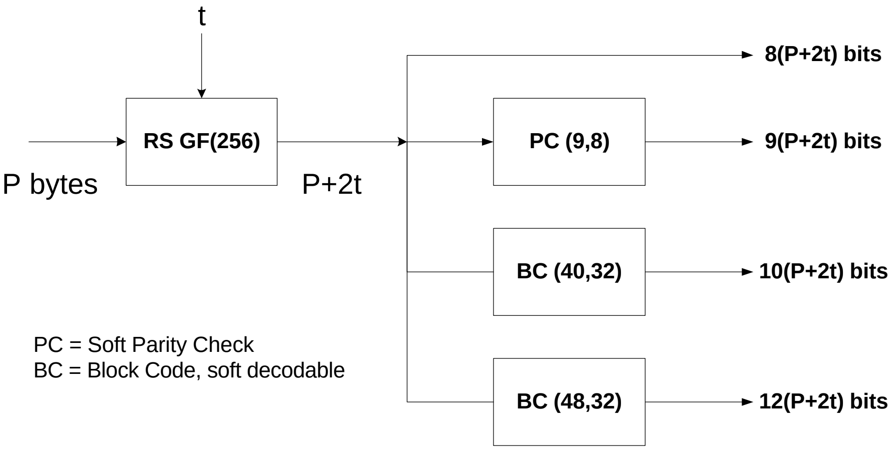
Figure 5-7 Interfaces in the Error Control Structure

5.2.2.2 Definition of error control codes

The FEC is based on a concatenation of 2 codes. A Reed Solomon GF(256) code (similar to mode A) is used as the outer code. An inner code is chosen to expose the decoding process to soft input without a requirement of interleaving which is essential for burst communications. The FEC code is used on all control channel and traffic channel data but not on the burst preambles.

5.2.2.2.1 FEC Code

The input to the FEC is a P byte block of data. A Reed Solomon code is applied first. The inner code is applied afterwards.



There are actually 4 options:

(1) No inner code, RS only: This case is useful either for a large data block or when high coding rate is required (i.e., P=188). The protection could vary between t=1 to t=16.

(2) 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) Block code (soft decodable): This case is useful for low to moderate coding rates providing good C/N enhancements. The coding rate is 4/5.

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

5.2.2.2.1.1 RS Encoding

A shortened code RS(P+2t,P) GF(256) is applied to the block resulting in a P+2t RS symbol block. The code is systematic and the redundant symbols are appended to the end of the entering block prior to encoding. The RS code could be used without an inner code.

5.2.2.2.1.2 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.

5.2.2.2.1.3 Block Code (Option 1)

A (40,32) block code capable of soft decoding is applied over 4 bytes of the RS output resulting in 40 bits (5 bytes).

5.2.2.2.1.4 Block Code (Option 2)

A (48,32) block code capable of soft decoding is applied over 4 bytes of the RS output resulting in 48 bits (6 bytes).

5.2.2.2.1.5 Shortening

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

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

5.2.2.2.1.6 Variable Length FEC

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 as described by 6.2.2.1.3

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

5.2.2.2.1.7 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]

5.2.2.2.1.8 Scrambling

The scrambling sequence is constructed from the primitive polynomial:

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

Figure 5-8 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.

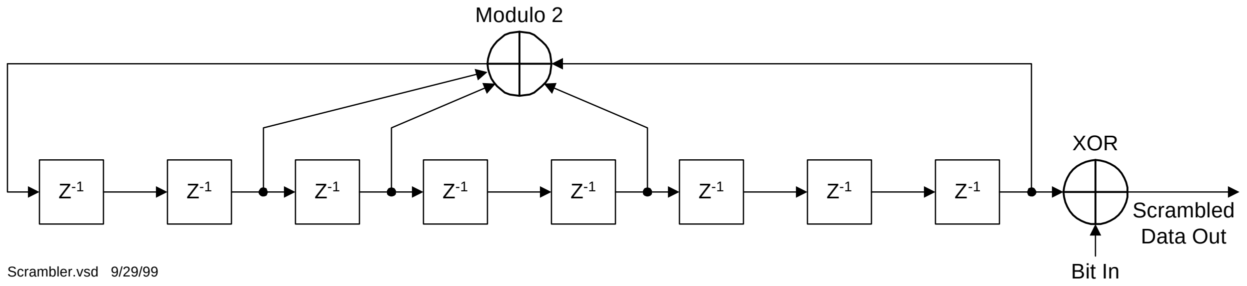


Figure 5-8 Example of a Scrambling Sequence Generator

5.2.2.3 FEC Parameters

The FEC has 2 parameters: P – the block size in bytes prior to encoding and t – the number of correctable byte errors. Fixed configuration parameters are:

(1) The PHY and MAC control portions and data transport (downstream, TDM) use P=128, t=6.

(2) The PHY and MAC control portions and data transport (TDMA) use P=64, t=5.

(3) The Registration portion uses P=14, t=2.

(4) The Contention based access portion uses P=5, t=3.

In all options the parity check code is used as the inner code. Only for data transmission, FEC parameters ***may*** be programmable. In all cases the TC operation adds a 16 bit CRC for reducing the probability of miss detected errors to a minimal value.

5.3 Modulation

5.3.1 Introduction

To maximize utilization of the air-link, the PHY proposes to use a multi-level modulation scheme. The modulation constellation is selected based on the quality of the RF channel per subscriber, independently on upstream and downstream. 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 following subsections apply to the base-band part of the transmitter.

5.3.2 Modulation type

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

5.3.3 Modulation rate

For LMDS the following a 25 MHz channelization scheme is proposed:

Modulation	Symbol or Bit Rate
QPSK, 16-QAM, 64-QAM	20 MS/s

5.3.4 Modulation symbol definition

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.

5.3.4.1 Bits to Symbol Mapping for QPSK

Figure 5-9 and Table 5-6 describe the bit mapping for QPSK modulation.

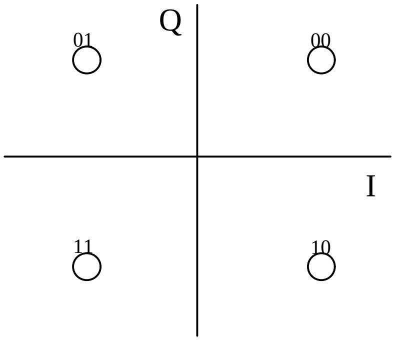


Figure 5-9 QPSK Constellation

Table 5-6 QPSK Bits to Symbol Mapping

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

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

5.3.4.2 Bits to Symbol Mapping for 16-QAM

Figure 5-10 and Table 5-7 describe the bit mapping for 16-QAM modulation.

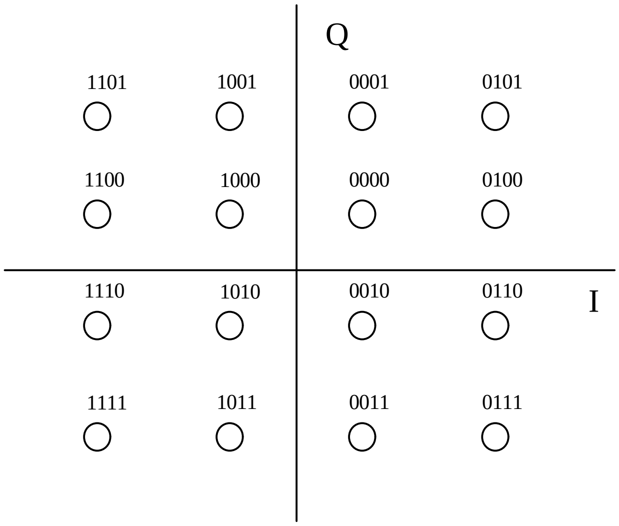


Figure 5-10 16-QAM Constellation

Table 5-7 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

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

5.3.4.3 Bits to Symbol Mapping for 64-QAM

Figure 5-11 and Table 5-8 describe the bit mapping for 64-QAM modulation.

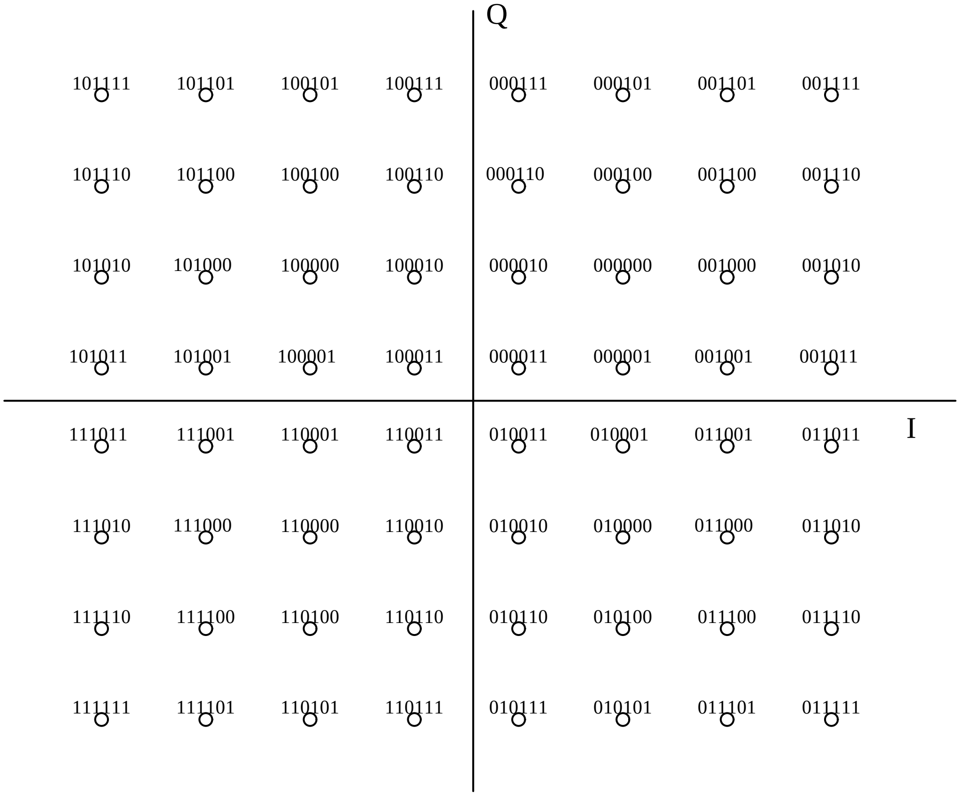


Figure 5-11 64-QAM Constellation

Table 5-8 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
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

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

5.3.4.4 QAM signal definition

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:

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

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:

$$G(f) = 1 \qquad \text{for } |f| \le \frac{1-a}{2T}$$

$$G(f) = \sqrt{0.5(1-\sin(p(2|f|T-1)/2a))} \qquad \text{for } \frac{1-a}{2T} \le |f| \le \frac{1+a}{2T} \qquad (4)$$

$$G(f) = 0 \qquad \text{for } |f| \le \frac{1+a}{2T}$$

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.

5.3.4.5 Additional upstream modulation

TBD

5.3.5 QAM Modulation filter definition

The ideal modulation filter shall be a linear phase filter which is defined by the magnitude of its frequency response | *H(f)* | = *G(f)*.

5.3.6 QAM Modulation block diagram

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 $S(k)d(t-t_k)$ ideally has an impulse response *g(t)*.

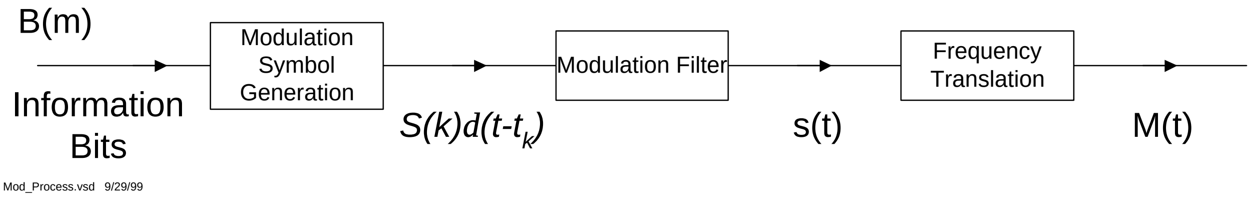


Figure 5-12 Block Diagram of the Modulation Process

5.3.7 Mandatory and Optional Modulation Schemes

For the downstream QAM-4 and 16-QAM modulation schemes are mandatory while 64-QAM is optional. For the upstream modulation schemes depend on the target cost and capabilities of the end user. For high end users both QPSK and 16-QAM are mandatory while 64-QAM is optional.

5.4 Channel Arrangement

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

6 Radio Sub-system Control

6.1 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.

6.2 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.

6.3 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.

7 Physical Layer Transmitter Characteristics

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 +/- ½ of a symbol and a resolution of +/- ¼ 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.

8 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.

Table 8-1 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

PHY Layer Requirement	Specification Section
- 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
– 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

8.1 Reference test planes

TBD

8.2 Propagation Conditions

TBD

8.2.1 Propagation Models

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

Table 8-2 Propagation Models

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

8.3 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 5.4.

8.3.1 Output Power

In the following subsections, power is defined as the average power, measured through the square root raised cosine filter defined in Section 5.3 over the scrambled bits of one transmitted burst as defined in Section 5.1.

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

8.3.1.1 BS

The BS transmitter maximum output power shall be as defined in Table 8-3.

Table 8-3 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.

8.3.1.2 CPE

The CPE maximum power shall be as defined in Table 8-4.

Table 8-4 Maximum CPE Transmitter Power

Power class	Maximum power
1	

TBD

Table 8-5 CPE Power Control Levels

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

8.3.2 Emissions Spectrum

TBD

8.3.3 Unwanted Conducted Emissions

TBD

8.3.4 Unwanted radiated emissions

TBD

8.3.5 Intermodulation Attenuation

TBD

8.3.6 Power Stability

TBD

8.3.7 RF Output Power Time Mask

TBD

8.3.8 Tx / Rx Carrier Switching Time Requirements

TBD

8.3.9 CPE Channel Switching Time

TBD

8.3.10 Special Co-Location Requirements – Transmitter

TBD

8.4 Receiver Characteristic

TBD

8.4.1 Blocking Characteristics

TBD

8.4.2 Spurious Response Rejection

TBD

8.4.3 Intermodulation Response Rejection

TBD

8.4.4 Unwanted Conducted Emissions

TBD

8.4.5 Unwanted Radiated Emissions

TBD

8.4.6 Received Signal Strength Indication (RSSI)

TBD

8.4.7 Special Co-Location Requirements – Receiver

TBD

8.5 Transmitter / Receiver Performance

TBD

8.5.1 Modulation Accuracy

TBD

8.5.2 Receiver Performance

TBD