Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	**Physical Layer Proposal for the 802.16 Air Interface Specification**
Date Submitted	**2000-04-14**
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Re:	This contribution is a response to the invitation to provide a detailed proposal for a physical layer specification, based upon the acceptance of the proposal presented at Session #6.
Abstract	This contribution provides a detailed description of a physical layer that incorporates many aspects of existing standards in order to leverage existing technology, with modifications to ensure reliable operation in the targeted 10-60 GHz frequency band. In addition, it was designed with a high degree of flexibility in order to optimize system deployments with respect to cell planning, cost considerations, radio capabilities, offered services, and capacity requirements.
Purpose	To provide a detailed description of a proposed physical layer specification for IEEE 802.16 WG.
Notice	
Release	

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1 Scope

This proposal 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. Both modes of operation have been designed with the intent to maximize the commonality between them in order to allow vendors to support both modes at a reasonable cost. The upstream physical layer has been designed to support a burst transmission stream for a time division multiple access (TDMA) system.

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.

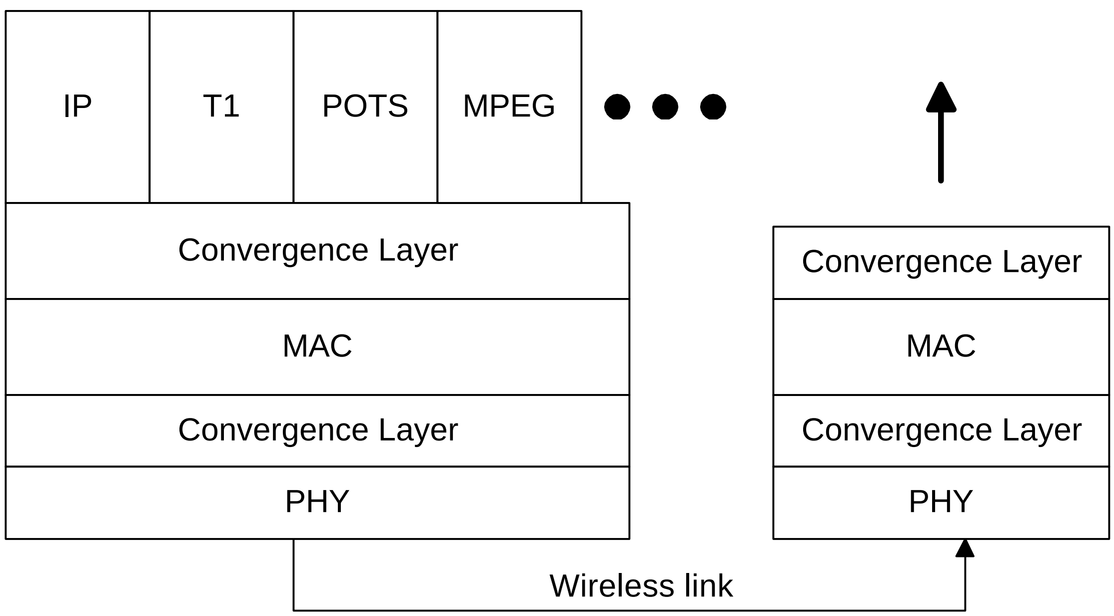


Figure 1: Reference Configuration

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 is based upon 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. An alternative method is also defined for the burst mode of operation, which allows bursts to be transmitted to specific CPEs in a TDMA type form, rather than a TDM form.

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, 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 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**.

3.6 Downstream Coding, Interleaving, Scrambling & Modulation

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. This approach to standardization allows for service providers the ability to pick the format which best allows them to meet their system requirements.

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, 8-PSK (optional), 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 or 0.35.

The Mode B downstream physical layer has a framing mechanism associated with it that simplifies the support for TDD and H-FDD systems, 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 H-FDD system. Five unique preambles are defined, which are used to indicate the beginning of a frame, the beginning of a QPSK burst, 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 H-FDD are supported, as will be discussed later. All user data is Reed Solomon encoded using a (192,164) code, 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 a 163 byte information packet to help the receiver identify the beginning of a MAC packet. Code bits out of the Reed Solomon 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 either 0.15 or 0.35.

3.7 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.

4 Downstream Physical Layer

The downstream physical layer has two modes of operation. 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 supporing half-duplex FDD and TDD configurations. Standards compliant subscriber stations are required to support at least one of the modes of operation as defined here.

4.1 Mode A Definition

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.

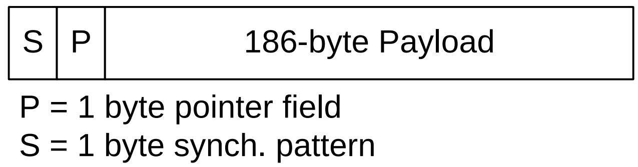


Figure 2: Format of the Convergence Layer Packet

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.

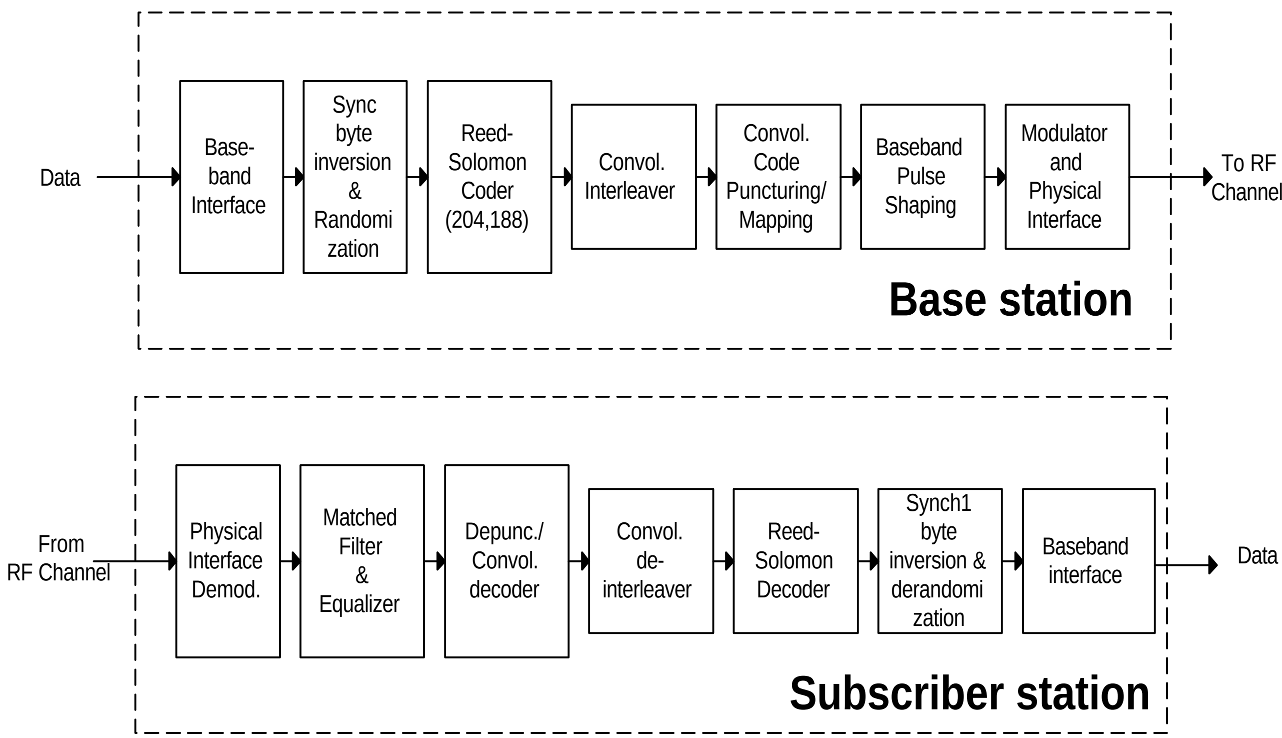


Figure 3: Conceptual Block diagram of the Mode A Downstream Physical Layer

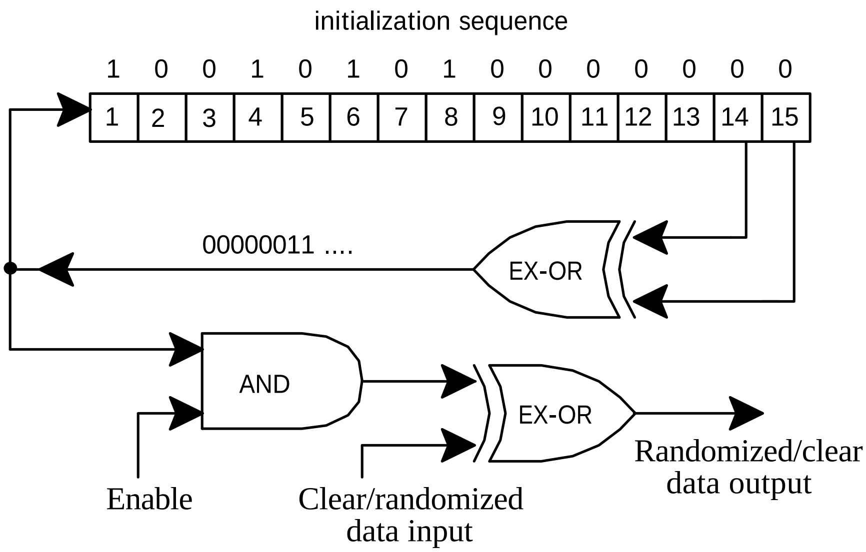
4.1.2.1 Baseband interfacing

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.

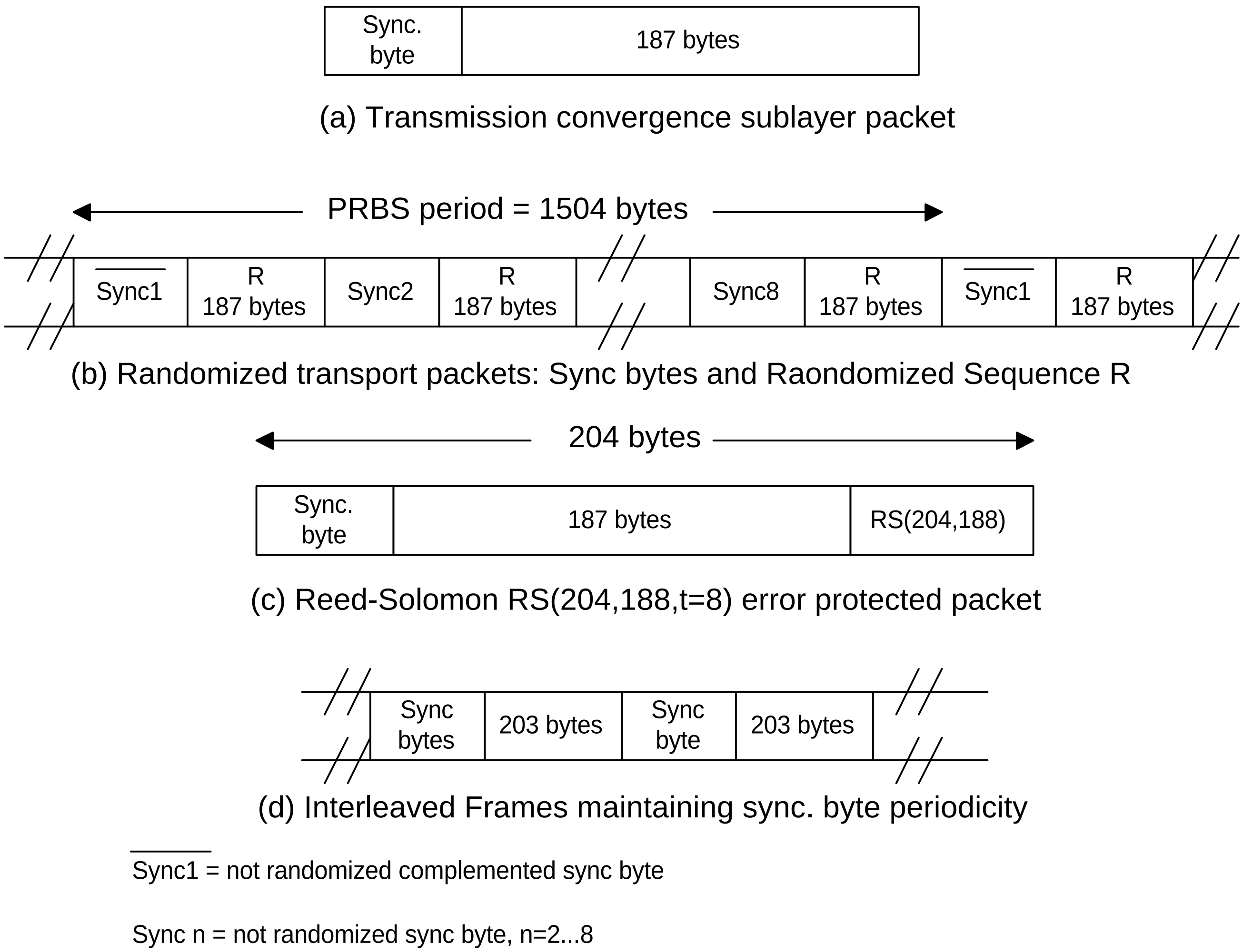


Figure 5: Framing structure based on transmission convergence sublayer.

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.

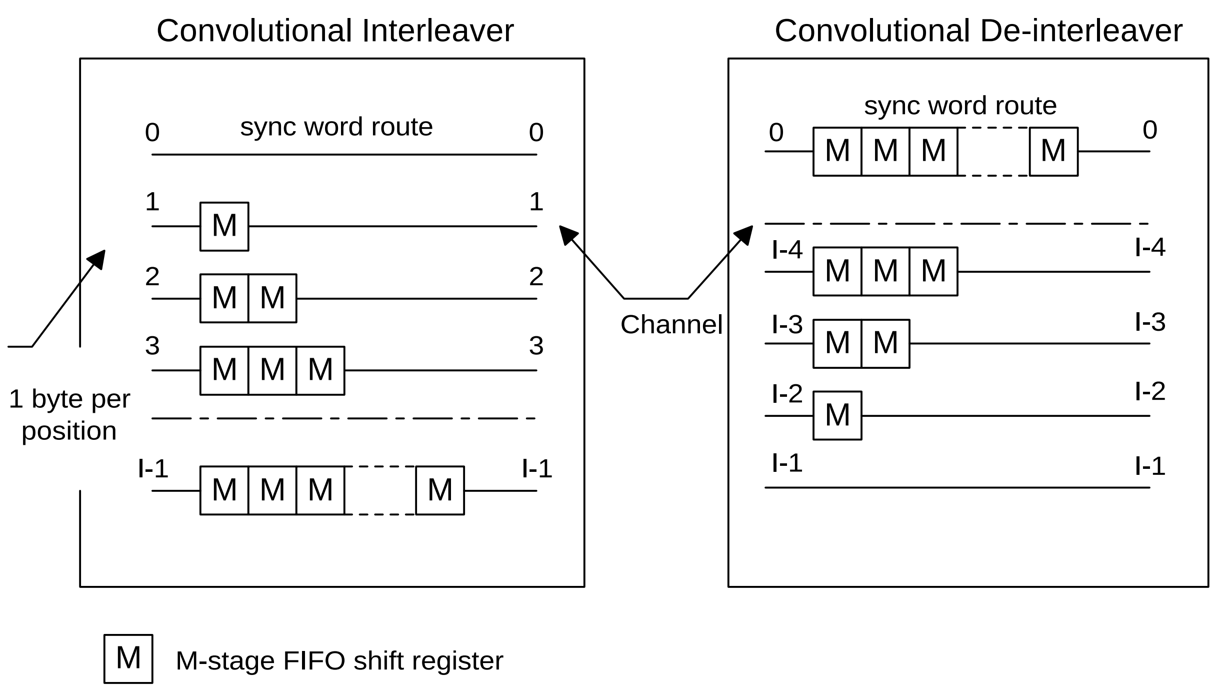


Figure 6: Conceptual diagram of the convolutional interleaver and de-interleaver.

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 $I=X_1$ $Q=Y_1$	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:

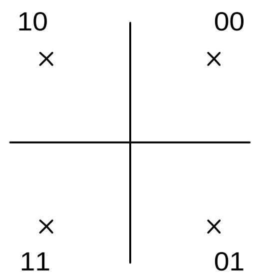


Figure 7: QPSK symbol mapping

4.1.2.6 Convolutional Coding with 8-PSK Modulation (optional)

8-PSK shall be optionally supported using a rate 2/3, 5/6, or 8/9 punctured convolutional with the inner coding and constellation mapping as described in [2].

4.1.2.7 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].

4.1.2.8 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.

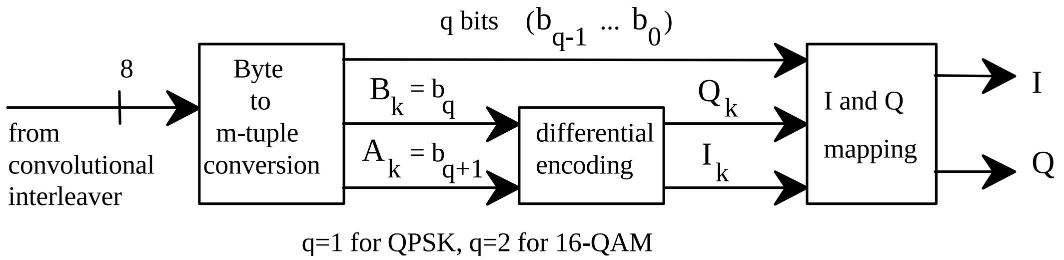


Figure 8: Example implementation of the byte to m-tuple conversion and the differential encoding of the two MSBs**.**

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

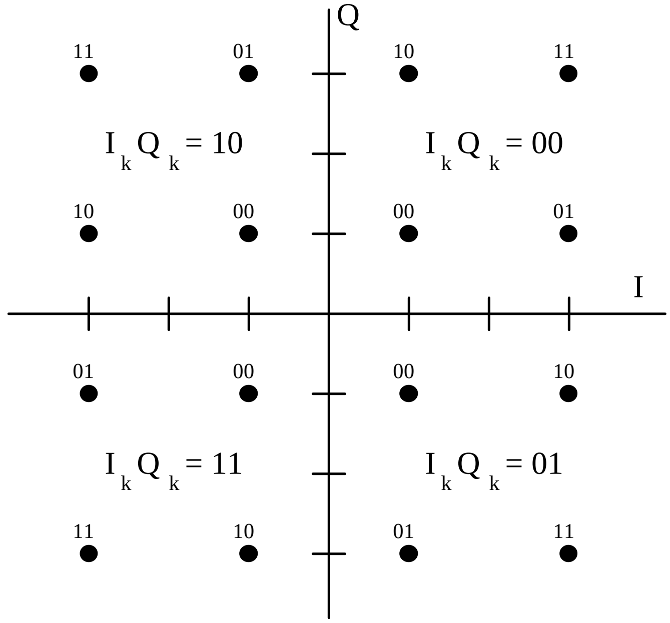


Figure 9: 16 QAM Constellation diagram

4.1.2.9 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:

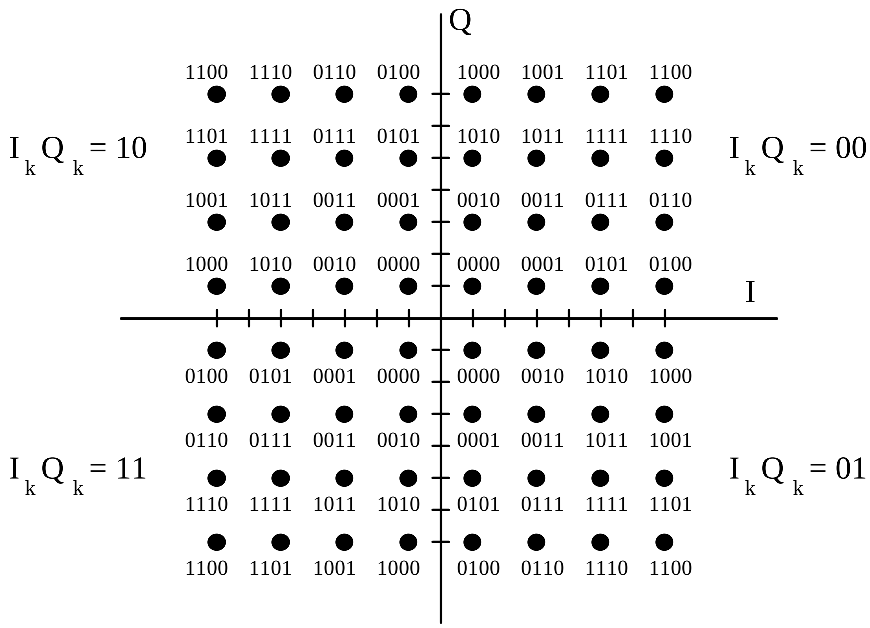


Figure 10: 64-QAM Constellation Diagram

4.1.2.10 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 or 0.35. The square-root raised cosine filter is defined by the following transfer function H:

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

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, 8-PSK (optional), 16-QAM (optional), or 64-QAM (optional)
Differential encoding	enabled/disabled (only enabled when convolutional coding is not employed)
Spectral shaping	α=0.15 or 0.35
Spectral inversion	inverted or non-inverted

4.2 Mode B Definition

4.2.1 Mode B Downstream Transmission Convergence (TC) Sublayer

The downstream bitstream is defined as a continuous series of 164-byte packets. These packets consist of a 1-byte pointer followed by 163 bytes of payload. 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. At the end of a transmission, corresponding to the end of a modulation level, when adaptive modulation is used, or the end of a burst, when H-FDD or TDD is employed, these stuff bytes are used to ensure the codeword length is a multiple of 2 for 16-QAM modulated packets, or a multiple of 3 for 64-QAM modulated packets, as will be discussed in the next section. The following figure illustrates the format of the packet leaving the convergence layer.

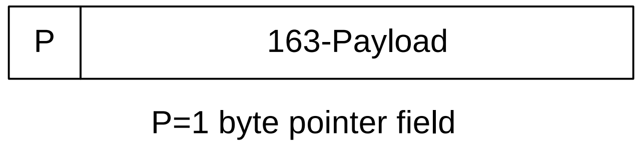


Figure 11: Format of the Convergence Layer Packet

4.2.2 Mode B Physical Media Dependent (PMD) Sublayer

The Mode B physical layer has been designed to support adaptive modulation, where modulation may change dynamically within a short time frame, in an FDD system. In addition, this mode of operation can also support H-FDD and TDD operation. The physical layer requirements to support these configurations leads to a burst type architecture for the PMD sublayer, since the receiver will not necessarily be able to demodulate all of the data on the downstream channel. As a result, preambles are utilized to help the receiver track frequency, phase, symbol timing, and equalizer tap changes. The following sections detail the structure of this mode of operation.

4.2.2.1 Framing

The downstream channel is divided into a sequence of 1 msec. frames. Each frame is also divided into an integer number of physical slots (PS), where each PS consists of 4 symbols. This number was chosen since it results in physical slots consisting of an integer number of bytes. In particular, each physical slot consists of 1 byte with QPSK modulation, 2 bytes with 16-QAM modulation, and 3 bytes with 64-QAM modulation. Bursts must begin and end at a physical slot boundary, which results in relatively simple constraints that preambles must be a multiple of 4 symbols, codeword lengths used with 16-QAM modulation must be divisible by 2, and codeword lengths used with 64-QAM modulation must be divisible by 3. The following figure illustrates how the frame is utilized in an FDD system supporting adaptive modulation.

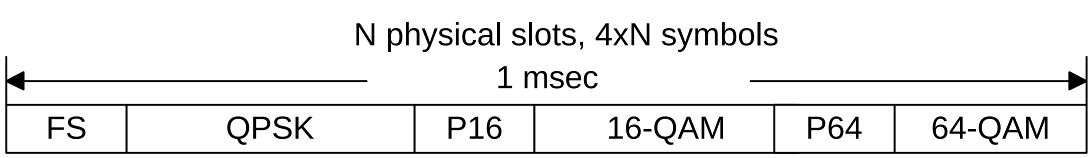


Figure 12: Frame format for an FDD system with adaptive modulation

The beginning of the frame is denoted by the presence of the frame start (FS) preamble. The preambles are used to help delineate the modulation levels, and therefore are unique. The end of the QPSK portion of the frame is denoted by the preamble for the next modulation format. For an FDD system, the N physical slots in the above frame will occupy the full 1 msec frame. If the base station has no data to send, the convergence layer inserts stuff bytes in order to enable a continuous transmission stream.

An example frame structure used to support H-FDD operation is shown in the following figure.

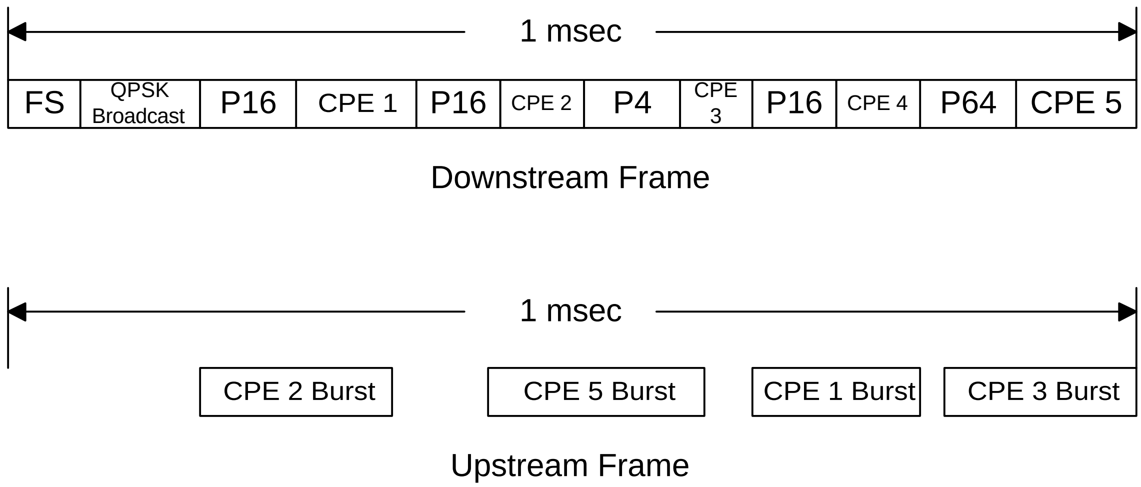


Figure 13: Frame format for an H-FDD system

In this configuration, the downstream channel is operated in a TDMA type fashion, where each burst is destined to a particular CPE. The downstream scheduler is responsible for ensuring that the upstream and downstream transmissions to particular CPEs do not coincide, since CPEs, in this case, are not able to transmit and receive at the same time. The upstream transmissions are controlled by the base station through upstream allocation maps. When the CPE is not transmitting, it must be listening to the downstream channel and demodulating the data it is capable of detecting. The only restriction on the frame is that it begin with an FS preamble and a QPSK burst. If broadcast packets need to be transmitted, then these should occupy the first burst. Otherwise, data destined to QPSK capable users should occupy the first burst.

The following frame structure can be used in a TDD system configuration.

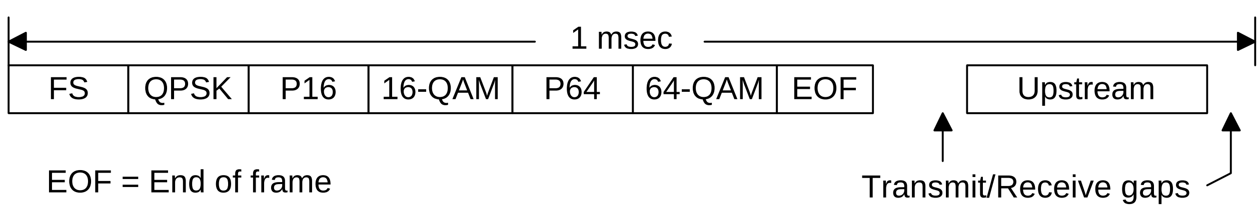
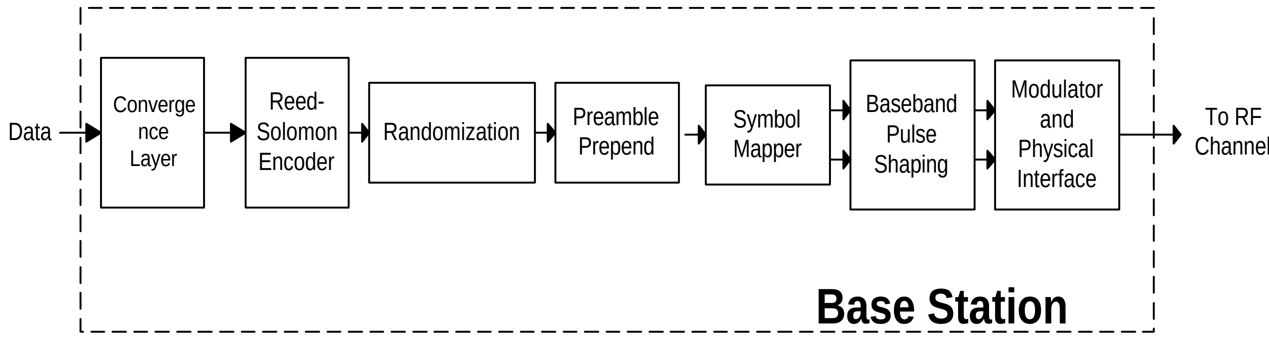


Figure 14: Frame format for a TDD system

For a TDD system, the downstream channel occupies one portion of the frame, while the upstream channel occupies the other portion of the frame, separated by any required transmit or receive gaps necessary in order to prevent any transmission overlap. The EOF sequence is a QPSK sequence that is used to designate the end of the transmitted frame so that the length of the last codeword can be determined.

4.2.2.2 Overview of PMD sublayer

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



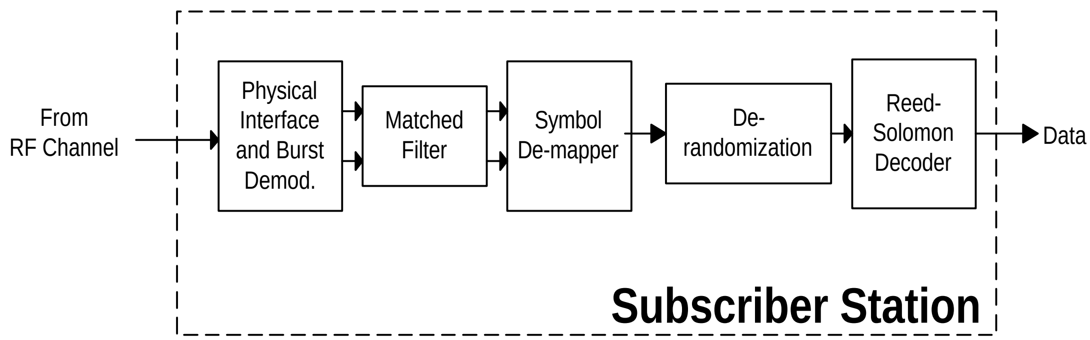


Figure 15: Conceptual Block diagram of the Mode B Downstream Physical Layer

4.2.2.3 Reed-Solomon coding

Reed-Solomon coding shall be applied to each convergence layer packet. The code shall be based upon a systematic Reed-Solomon code generated from GF(256). The Reed Solomon encoder shall take the 164 bytes from the convergence layer and append 28 error correction bytes for a resulting codeword length of 192 and capability of correcting T=14 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(255,227, T=14) code with information bytes preceded by 63 zero symbols. When the last codeword is shortened, corresponding to a modulation change boundary or end of burst, the information bytes coming from the convergence layer shall be preceded by 63 + (164-K) zeros, where K is the number of information bytes. The minimum number of information bytes per codeword is **TBD** bytes.

4.2.2.4 Randomization for spectrum shaping

The upstream modulator must implement a scrambler using the polynomial $x^{15}+x^{14}+1$ with a 15-bit seed set to 100101010000000. 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).

4.2.2.5 Preambles

The following preambles are defined for the downstream channel:

Preamble	**Sequence (in bits)**
FS	**TBD**
P4	**TBD**
P16	**TBD**
P64	**TBD**
EOF	**TBD**

4.2.2.6 Modulation

The modulation used on the downstream channel shall support the following formats.

4.2.2.6.1 QPSK Symbol Mapping

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

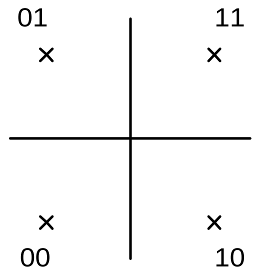


Figure 16: QPSK constellation mapping

4.2.2.6.2 Gray-coded 16-QAM Symbol Mapping

The following mapping of bits to symbols shall be supported for 16-QAM modulation:

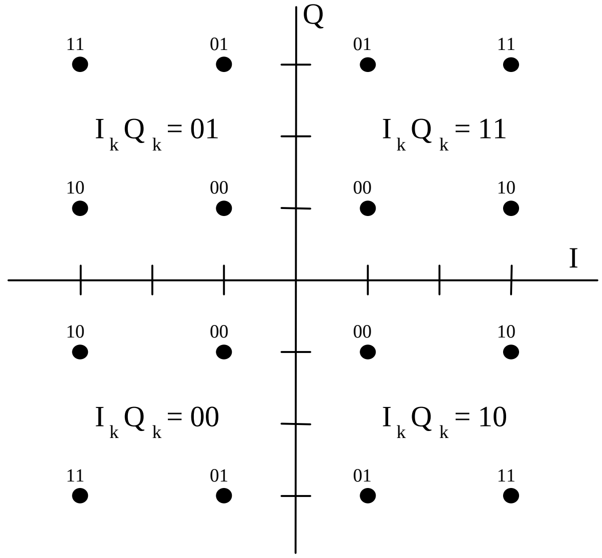


Figure 17: Gray-coded 16-QAM Constellation diagram

4.2.2.6.3 Gray-coded 64-QAM Symbol Mapping (optional)

The following mapping of bits to symbols shall be supported for 64-QAM modulation:

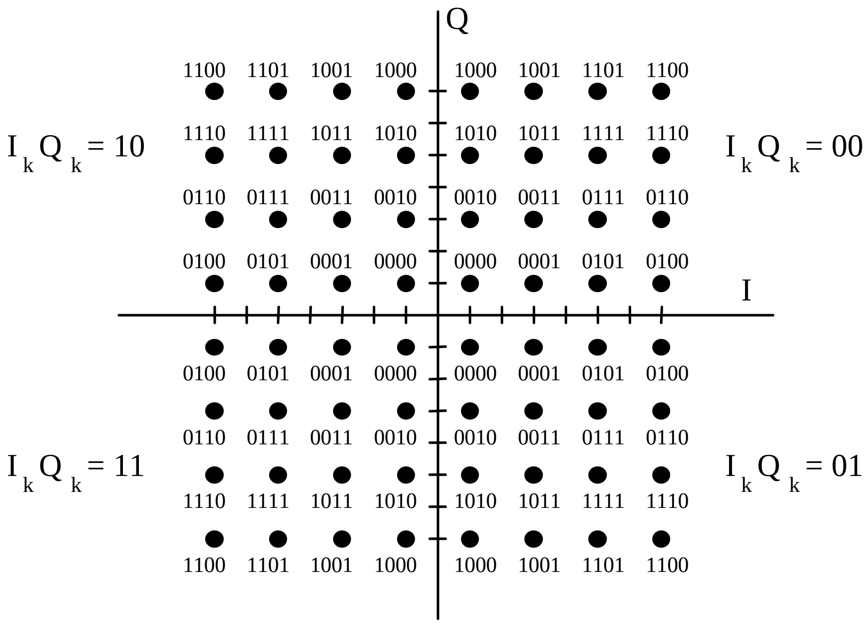


Figure 18: Gray-coded 64-QAM Constellation diagram

4.2.2.7 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 or 0.35. The square-root raised cosine filter is defined by the following transfer function H:

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

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.

4.2.2.8 Summary of Mode B Downstream Physical Layer Parameters

Reed-Solomon Coding	(192,164) + shortened last codeword based on GF(256)
Randomization	$x^{15}+x^{14}+1$ Initialization seed per burst: 100101010000000
Preambles	**TBD**
Modulation	QPSK, 16-QAM, or 64-QAM (optional)
Spectral shaping	α=0.15 or 0.35

5 Upstream Physical Layer

5.1 Upstream Transmission Convergence (TC) Sublayer

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

5.2 Upstream Physical Media Dependent (PMD) Sublayer

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

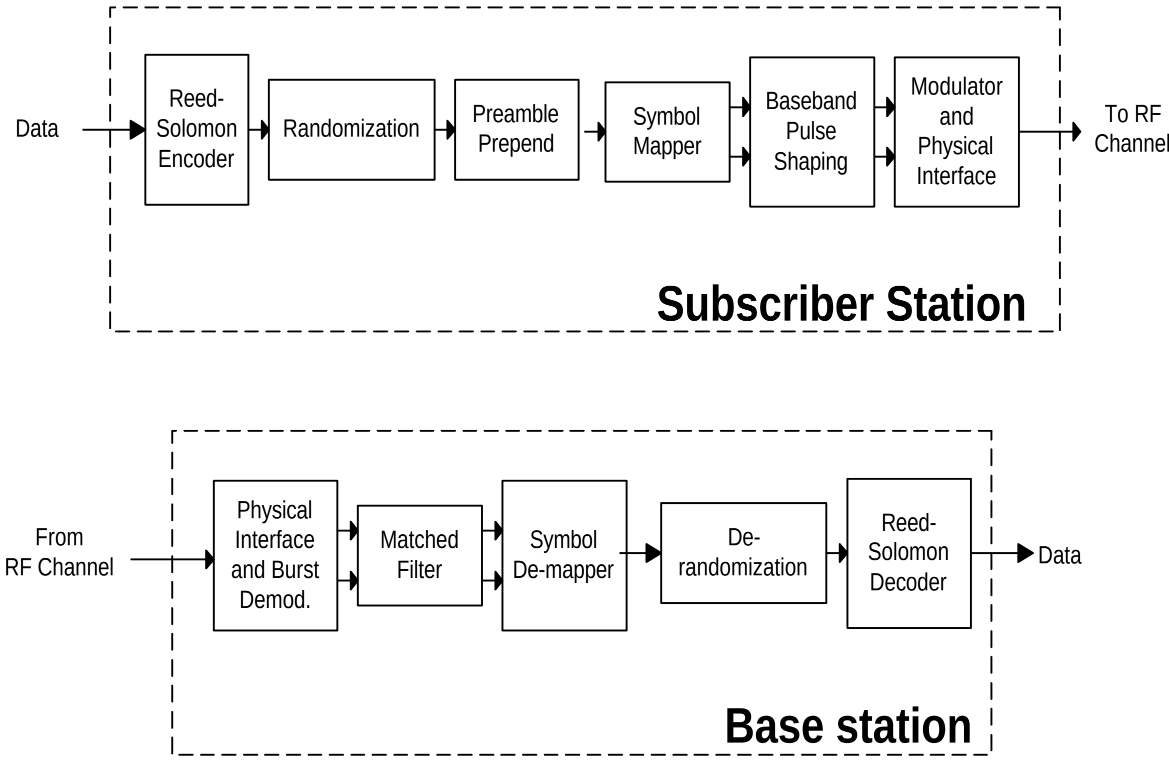


Figure 19: Conceptual Block diagram of the 802.16 Burst Transmission Upstream Physical Layer

5.2.1 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.

5.2.2 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).

5.2.3 Preamble

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

5.2.4 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.

5.2.5 QPSK Symbol Mapping

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

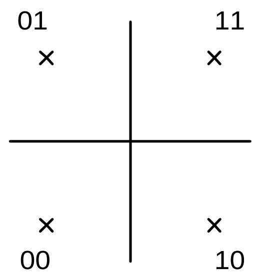


Figure 20: QPSK constellation mapping

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

5.2.6 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).

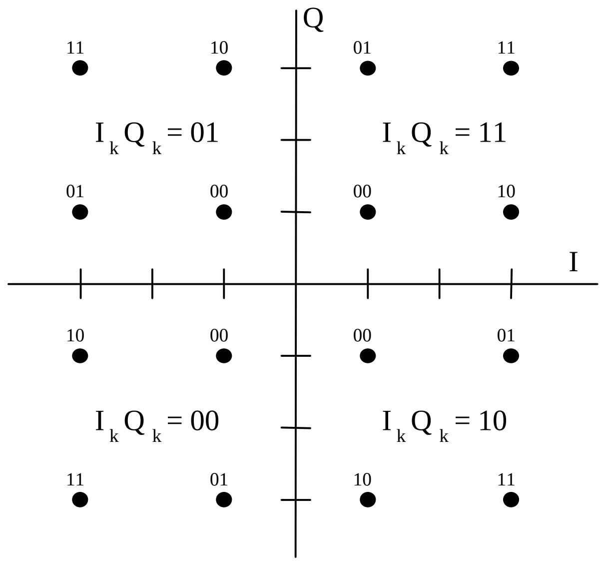


Figure 21: Differentially encoded 16-QAM Constellation diagram

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

5.2.7 Gray-coded 16-QAM (optional)

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

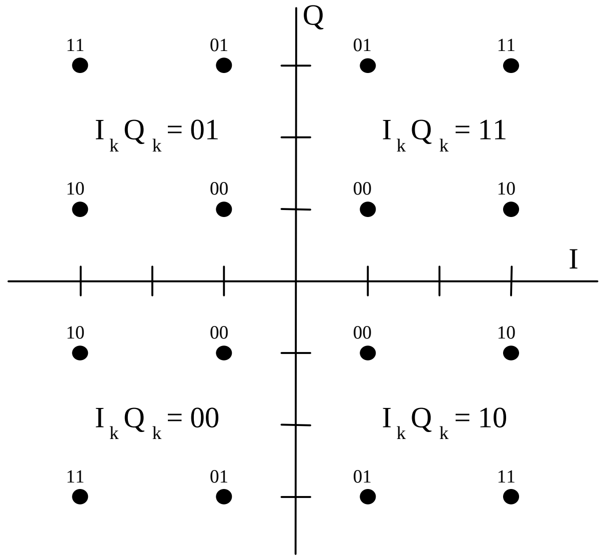


Figure 22: Gray-coded 16-QAM Constellation diagram

5.2.8 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:

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

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.

5.2.9 Summary of 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

5.3 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

5.4 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

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 > 30 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 0.5 dB +/- 0.25 dB 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 +/- 10 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 Evaluation Table

#	Criterion	Discussion
1	**Meets system requirements**	This physical layer meets the Functional Requirements by having a general structure that supports any MAC layer residing above it and the services that it supports.

<table>
<tr><td>2</td><td>Spectrum efficiency</td><td>Following are some configuration examples:

Downstream: assuming α=0.15 and 0.35 and a payload of 186 bytes.
<table>
<tr><th>Modulation</th><th>Inner Code Rate</th><th>bps/Hz (0.15)</th><th>bps/Hz (0.35)</th></tr>
<tr><td>Mode A</td><td></td><td></td><td></td></tr>
<tr><td>QPSK</td><td>0.5</td><td>0.792838875</td><td>0.675381264</td></tr>
<tr><td></td><td>0.666666667</td><td>1.0571185</td><td>0.900508351</td></tr>
<tr><td></td><td>0.75</td><td>1.189258312</td><td>1.013071895</td></tr>
<tr><td></td><td>0.833333333</td><td>1.321398124</td><td>1.125635439</td></tr>
<tr><td></td><td>0.875</td><td>1.387468031</td><td>1.181917211</td></tr>
<tr><td></td><td>1</td><td>1.585677749</td><td>1.350762527</td></tr>
<tr><td>8-PSK*</td><td>0.666666667</td><td>1.585677749</td><td>1.350762527</td></tr>
<tr><td>*</td><td>0.833333333</td><td>1.982097187</td><td>1.688453159</td></tr>
<tr><td>*</td><td>0.888888889</td><td>2.114236999</td><td>1.801016703</td></tr>
<tr><td>16-QAM*</td><td>0.75</td><td>2.378516624</td><td>2.026143791</td></tr>
<tr><td>*</td><td>0.875</td><td>2.774936061</td><td>2.363834423</td></tr>
<tr><td>*</td><td>1</td><td>3.171355499</td><td>2.701525054</td></tr>
<tr><td>64-QAM*</td><td>1</td><td>4.757033248</td><td>4.052287582</td></tr>
<tr><td>Mode B</td><td></td><td></td><td></td></tr>
<tr><td>QPSK</td><td>1</td><td>1.485507246</td><td>1.265432099</td></tr>
<tr><td>16-QAM</td><td>1</td><td>2.971014493</td><td>2.530864198</td></tr>
<tr><td>64-QAM*</td><td>1</td><td>4.456521739</td><td>3.796296296</td></tr>
</table>
*=optional configuration

Upstream: Depends on a number of variables that are configured by the basestation, including preamble length, code rate (R), and guard time. As an example: 4 byte preamble, 1 byte guard time, roll-off of 0.25, QPSK modulation, and a RS(63,53) code.

bps/Hz=1.247</td></tr>
<tr><td>3</td><td>Simplicity of implementation</td><td>This physical layer uses elements from several existing standards, many components of which exist in silicon form today.</td></tr>
<tr><td>4</td><td>CPE cost optimization</td><td>Leveraging existing technology results in lower cost chip sets due to maturity of technology and increased volume of sales.</td></tr>
<tr><td>5</td><td>Spectrum resource flexibility</td><td>This proposal contains several flexible parameters including symbol rates, roll-off factors, modulation, and coding, so that efficient spectrum resource and power planning can be done based on services required and deployment scenarios. In addition, the ability to support different downstream modes of operation allows vendors to optimize system deployments for their specific system requirements.</td></tr>
<tr><td>6</td><td>System diversity flexibility</td><td>The proposed physical layer is relatively MAC independent, except for certain programmable variables that need to be defined by the MAC, so it is amenable to any future services that may reside above the MAC.</td></tr>
<tr><td>7</td><td>Protocol interfacing complexity</td><td>The proposed physical layer is MAC independent with simple mapping of MAC packets to physical layer frames.</td></tr>
</table>

8	**Implications on other network interfaces**	The proposed physical layer is relatively MAC independent, except for certain programmable variables that need to be defined by the MAC, so it is amenable to any network interfaces that may reside above the MAC.
9	**Reference system gain**	Assumptions: BER=10^(-10), 40 MHz DS channel, 10 MHz US channel, DS assumes a 0 dBW transmitter, 0 dB NF LNA, noise floor = -174 dBm + 10log(BW). See table below for results.
10	**Robustness to interference**	QPSK modulation is very robust against interference. Coding is flexible and can be changed to accommodate channel conditions.
11	**Robustness to channel impairments**	QPSK modulation is very robust against interference. Coding is flexible and can be changed to accommodate channel conditions.

8.1 Reference System Gain

Modulation	**Inner Code**	**Eb/No (dB)** [(1)]	**C/N (dB)**	**Backoff (dB)**	**RSG (dB)**
Mode A Downstream					
QPSK	½	4.5	4.13	4	119.84
	2/3	5	5.88	4	118.10
	¾	5.5	6.90	4	117.08
	5/6	6	7.85	4	116.13
	7/8	6.4	8.47	4	115.51
	1(differential)	9.3	11.9	4	112.08
8-PSK*	2/3	6.9	9.55	5	113.43
*	5/6	8.9	12.52	5	110.46
*	8/9	9.4	13.30	5	109.68
16-QAM*	¾	9	13.4	7	107.58
*	7/8	10.7	15.77	7	105.21
*	1(differential)	14.35	20.0	7	100.98
64-QAM*	1(differential)	19.25	26.68	9	92.3
Mode B Downstream					
QPSK	1	7.9	10.2	4	113.78
16-QAM	1	12.85	18.1	7	102.88
64-QAM	1	17.5	24.5	9	94.48
Upstream	**Code rate**	**Eb/No (dB)**	**C/N (dB)**	**Backoff (dB)**	**RSG (dB)**

QPSK (differential encoding)	53/63	11	13.25	4	116.75

*=optional configuration

(1) Note that the above numbers calculated for Eb/No include an implementation loss in the downstream of 0.8 dB for QPSK; 1, 1.4, and 1.5 dB for 8-PSK with rates 2/3, 5/6, and 8/9, respectively; 1.5, 2.1, and 2.1 dB for 16-QAM with rates ¾, 7/8, and 1, respectively; 2.5 dB for 64-QAM with differential encoding; and in the upstream of 2 dB.