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|---|---|
| Project | **IEEE 802.16 Broadband Wireless Access Working Group** |
| Title | **Physical Layer Proposal for the 802.16 Air Interface Specification** |
| Date Submitted | **2000-02-25** |
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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 #5. |
| 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 |  |
| IEEE Patent Policy |  |

See <http://ieee802.org/16/ipr> for details.

# Physical Layer Proposal for the 802.16 Air Interface Specification

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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 (DBV); 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. This proposed physical layer has been optimally designed to support a continuous transmission in the downstream channel and a burst transmission in the upstream channel, which is expected to meet the majority of BWA system requirements today and in the future. It should be noted that this proposal does not limit the possible future adoption of a complementary physical layer specification supporting burst transmission in the downstream by sharing many of the same elements present in this proposed physical layer specification.

Several optional implementations have been identified in this proposal in order to allow vendors the ability to add additional flexibility to both the upstream and downstream physical layers as needed. It is mandatory that an 802.16 standards compliant subscriber station support the basic physical layer components described here, while the elements that are identified as "optional" need not be implemented in order to be standards compliant. If the options are implemented, they shall be implemented as described here. This approach to the physical layer specification allows for rapid time to market for this standard, using existing and mature technology, while providing a migration path for more advanced coding and modulation schemes supporting different services, higher capacity links, and/or lower equipment cost following the market demands.

## 3.2 REFERENCE CONFIGURATION

The physical layer is designed to support both 802.16 MAC frames and native MPEG packets in the downstream channel. However, all traffic must still pass through the MAC for scheduling of the available bandwidth for both the upstream and downstream channels. The support of native MPEG video packets has been incorporated into the physical layer, so that they do not need to be encapsulated into 802.16 MAC frames for seamless integration into a video distribution network. 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.

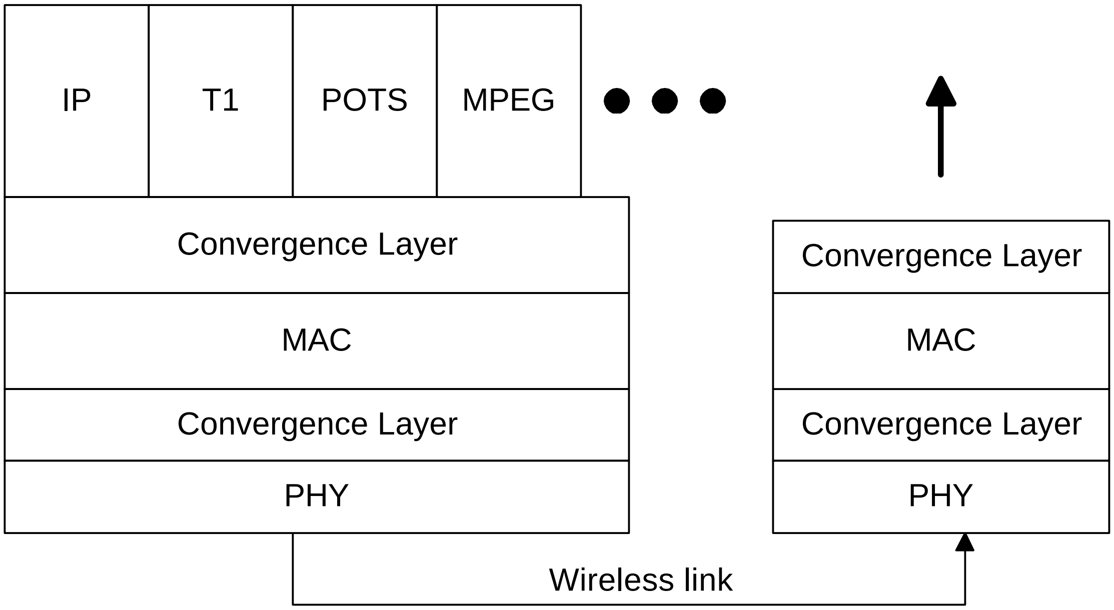



Figure 1: Reference Configuration

### 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 basestation 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.

### 3.4 DUPLEXING TECHNIQUE

This physical layer has been targeted to support frequency division duplexing (FDD), which provides a separate frequency assignment for the upstream and downstream channels. This approach to transmitter and receiver isolation is a proven technique that has been utilized by many other wireless systems, including cellular, PCS, and satellite communication systems. In addition, it allows for low cost modem receivers to be used in the subscriber station units that have been designed to demodulate signals with continuous transmission. There also exists several techniques, including the use of ortho-mode transducers (OMTs), which enables radio equipment to be designed to meet a wide variety of channelization plans as well as to meet various cost targets.

This proposal does not prevent the adoption of a separate, complementary physical layer specification that is better suited for burst transmission in the downstream channel in order to support time division duplexing (TDD). Due to interference considerations, it is not expected that frequency division duplexed and time division duplexed systems will coexist in the same geographical areas. In addition, continuous transmission systems and burst transmission systems have different design constraints and would be better served through different specifications. Thus, it is recommended that separate physical layers be adopted by the 802.16

working group in order to address the different requirements for continuous and burst transmission in the downstream channel. Maximizing the commonality between the two physical layer specifications will allow for cost effective silicon solutions in the future that can support both modes of operation.

### 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 continuous mode transmission and 5 Mbaud to 30 Mbaud for burst mode transmissions. 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

The downstream physical layer has been designed for a continuous transmission stream with added flexibility to enable system wide optimization for various deployment scenarios. First, MAC packets are encapsulated into an MPEG frame as defined by the transmission convergence sublayer, and 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. In order to ensure interoperability in different system configurations, a subscriber station must support both data paths. 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. Finally, symbols are 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 basestation, several parameters can be left unspecified and configured by the basestation 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 either 0.15, 0.25, or 0.35.

# 4 DOWNSTREAM PHYSICAL LAYER

## 4.1 DOWNSTREAM TRANSMISSION CONVERGENCE (TC) SUBLAYER

In order to improve demodulation robustness, facilitate common receiving hardware for both video and data, and provide an opportunity for the possible multiplexing of video and data over the physical layer, the following convergence sublayer between the MAC and PHY layer has been adopted.

The downstream bitstream is defined as a continuous series of 188-byte MPEG [ITU-T H.222.0] packets. These packets consist of a 4-byte header followed by 184 bytes of payload. The header identifies the payload as containing 802.16 MAC messages or other types of payloads, including digital video. The mixtures of the various services that are transported in the downstream are to be controlled by the basestation.

The format of the MPEG Packet carrying MAC messages is given below

| Header<br>4 bytes | P | Payload |
|---|---|---|

P=1 byte pointer field, not present in all packets

*Figure 2: Format of an MPEG Packet*

The format of the MPEG transport stream header is defined in Section 2.4 of [ITU-T H.222.0]. The particular field values that distinguish the 802.16 MAC message stream are defined in the following table, where the field names are from the ITU specification. The MPEG header consists of 4 bytes that begin the 188-byte MPEG packet. The format of the header for use on an 802.16 PID is restricted to that shown in the table. The header format conforms to the MPEG standard, but its use is restricted in this specification to NOT ALLOW inclusion of an adaptation_field in the MPEG packets.

Table 1: MPEG Header Format for 802.16 MAC packets

| **Field** | **Length (bits)** | **Description** |
|---|---|---|
| sync_byte | 8 | 0x47 or 0xB8; MPEG Packet sync byte |
| transport_error_indicator | 1 | Indicates an error has occurred in the reception of the packet. This bit is reset to zero by the sender, and set to one whenever an error occurs in the transmission of the packet. |
| payload_unit_start_indicator (PUSI) | 1 | A value of one indicates the presence of a pointer_field as the first byte of the payload (fifth byte of the packet). |
| transport_priority (frame_start_indicator) | 1 | This bit is set to 1 to indicate the beginning of a downstream frame, when framing is used. |
| PID | 13 | 802.16 well-known packet ID (TBD) |
| transport_scrambling_control | 2 | Reserved, set to '00' |
| adaptation_field_control | 2 | '01'; use of the adaptation_field is NOT ALLOWED on the 802.16 PID |

| | | |
|---|---|---|
| continuity_counter | 4 | cyclic counter within this PID |

The payload portion of the MPEG packet will carry the 802.16 MAC frames. The first byte of the MPEG payload will be a 'pointer_field' if the PUSI is set. A stuff_byte pattern having a value (0xFF) must be used within the MPEG 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 pointer_field is present as the fifth byte of the MPEG packet (first byte following the MPEG header) whenever the PUSI is set to one in the MPEG header. The interpretation of the pointer_field is as follows:

The pointer_field contains the number of bytes in the packet that immediately follow the pointer_field that the subscriber station decoder must skip past before looking for the beginning of an 802.16 MAC frame. A pointer field MUST be present if it is possible to begin an 802.16 MAC frame in the packet, and MUST point to either:

1. the beginning of the first MAC frame to start in the packet or
2. to any stuff_byte preceding the MAC frame.

MAC frames may begin anywhere within an MPEG packet, MAC frames may span MPEG packets, and several MAC frames may exist within an MPEG packet. The following figures show the format of the MPEG packets that carry 802.16 MAC frames. In all cases, the PUSI flag indicates the presence of the pointer_field as the first byte of the MPEG payload. The following figure shows a MAC frame that is positioned immediately after the pointer_field byte. In this case, pointer_field is zero, and the 802.16 decoder will begin searching for a valid MAC header byte at the byte immediately following the pointer_field.

| | | | |
|---|---|---|---|
| Header (PUSI=1) | P =0 | MAC frame (up to 183 bytes) | stuff_byte (0 or more) |

P=1 byte pointer field

*Figure 3: Packet Format Where a MAC Frame Immediately Follows the pointer_field*

The next figure shows the more general case where a MAC Frame is preceded by the tail of a previous MAC Frame and a sequence of stuffing bytes. In this case, the pointer_field still identifies the first byte after the tail of Frame #1 (a stuff_byte) as the position where the decoder should begin searching for a legal MAC header byte. This format allows the multiplexing operation in the basestation to immediately insert a MAC frame that is available for transmission if that frame arrives after the MPEG header and pointer_field has been transmitted.

In order to facilitate multiplexing of the MPEG packet stream carrying 802.16 data with other MPEG-encoded data, the basestation SHOULD NOT transmit MPEG packets with the 802.16 PID which contain only stuff_bytes in the payload area. MPEG null packets SHOULD be transmitted instead. Note that there are timing relationships implicit in the 802.16 MAC sublayer which must also be preserved by any MPEG multiplexing operation.

| | | | | |
|---|---|---|---|---|
| Header (PUSI=1) | P =M | Tail of MAC frame #1 (M bytes) | stuff_byte (0 or more) | Start of MAC Frame 2 |

P=1 byte pointer field

*Figure 4: Packet Format with MAC Frame Preceded by Stuffing Bytes*

The next figure shows that multiple MAC frames may be contained within the MPEG packet. The MAC frames may be concatenated one after the other or be separated by an optional sequence of stuffing bytes.

| | | | | | |
|---|---|---|---|---|---|
| Header (PUSI=1) | P =0 | MAC Frame 1 | MAC Frame 2 | stuff_byte (0 or more) | Start of MAC Frame 3 |

P=1 byte pointer field

*Figure 5: Packet Format Showing Multiple MAC Frames in a Single Packet*

The next figure shows the case where a MAC frame spans multiple MPEG packets. In this case, the pointer_field of the succeeding frame points to the byte following the last byte of the tail of the first frame.

<table>
<tr><td>Header (PUSI=1)</td><td>P =0</td><td>stuff_byte (0 or more)</td><td colspan="2">Start of MAC Frame 1 (up to 183 bytes)</td></tr>
<tr><td>Header (PUSI=0)</td><td>P =0</td><td colspan="3">Continuation of MAC frame 1 (184 bytes)</td></tr>
<tr><td>Header (PUSI=1)</td><td>P =M</td><td>Tail of MAC frame 1 (M bytes)</td><td>stuff_byte (0 or more)</td><td>Start of MAC Frame 2</td></tr>
</table>

P=1 byte pointer field

*Figure 6: Packet Format Where a MAC Frame Spans Multiple Packets*

## 4.2 PHYSICAL MEDIA DEPENDENT (PMD) SUBLAYER

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

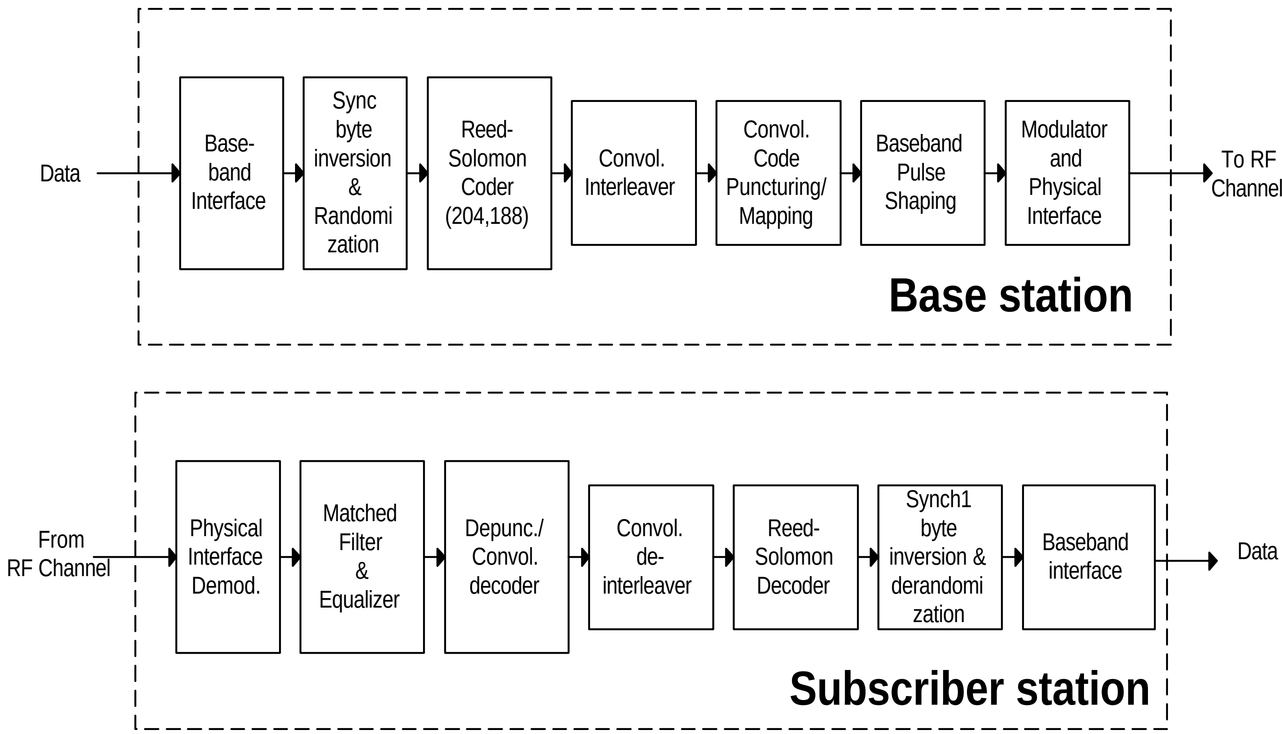



*Figure 7: Conceptual Block diagram of the 802.16 Continuous Transmission Downstream Physical Layer*

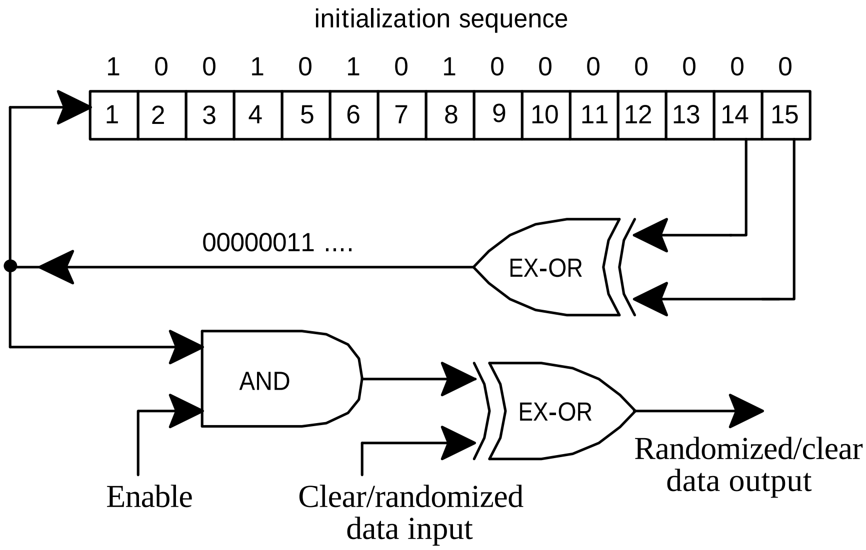
### 4.2.1 Baseband interfacing

This unit shall perform the transmission convergence sublayer function by adapting the data structure coming from the MAC layer to the format of the proposed physical layer transport stream based on the MPEG packet structure.

### 4.2.2 Sync byte inversion and randomization

This unit shall invert the Sync byte according to the MPEG framing structure, 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 sync 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 8: 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 sync byte (hex 47) shall be inverted (hex B8) every eight packets, starting at the beginning of the frame.

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 sync bit. Over subsequent sync bytes, the PBRS generator shall continue to step its internal shift register state but the PBRS output addition to the sync 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 MPEG transport stream.

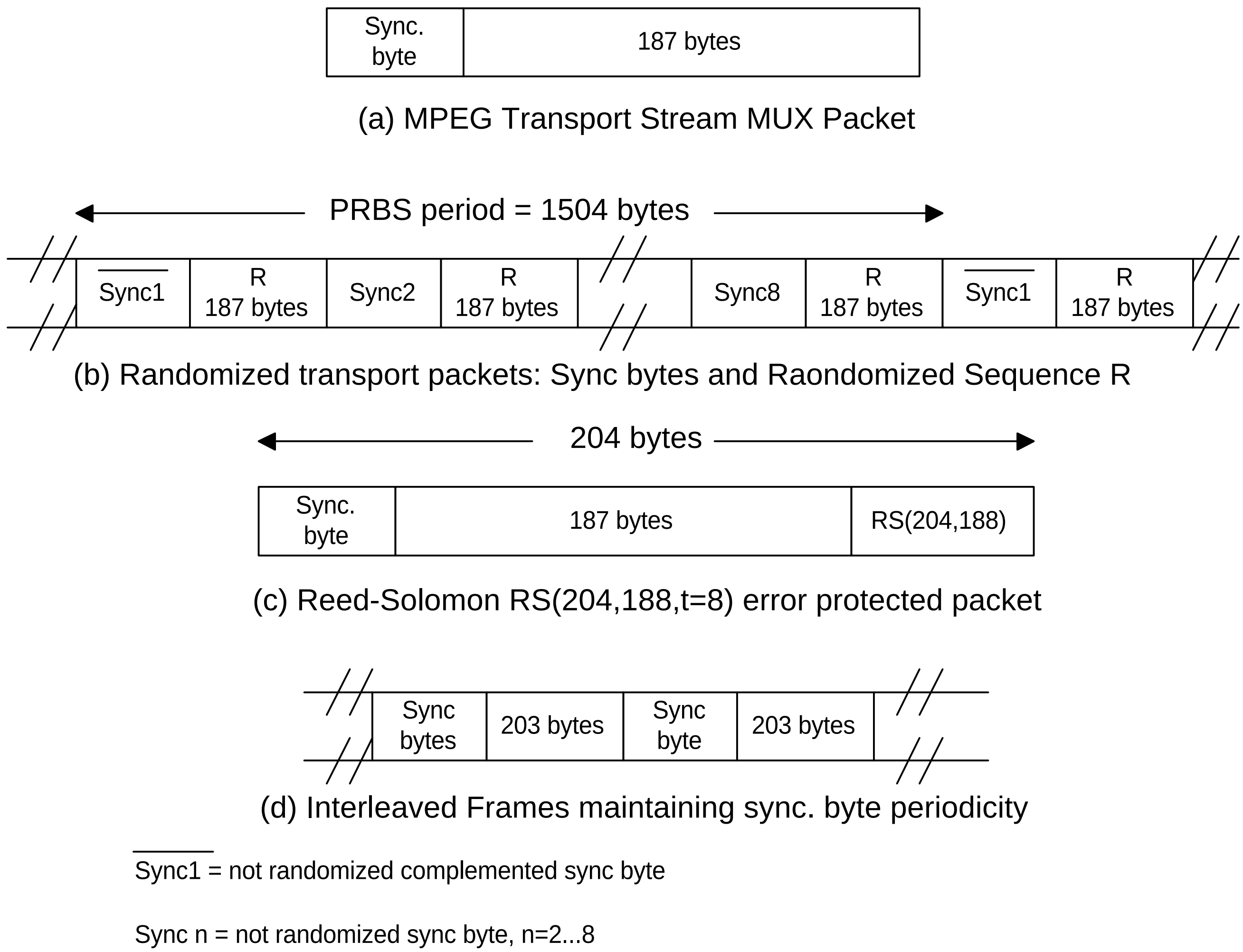



*Figure 9: Framing structure based on MPEG transport stream.*

### 4.2.3 Reed-Solomon coding

Following the energy dispersal randomization process, systematic shortened Reed-Solomon encoding shall be performed on each randomized MPEG 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 MPEG transport packet to give a codeword (204,188). RS coding shall also be applied to the packet sync 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 $\mu$= 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.

### 4.2.4 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 MPEG sync 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.

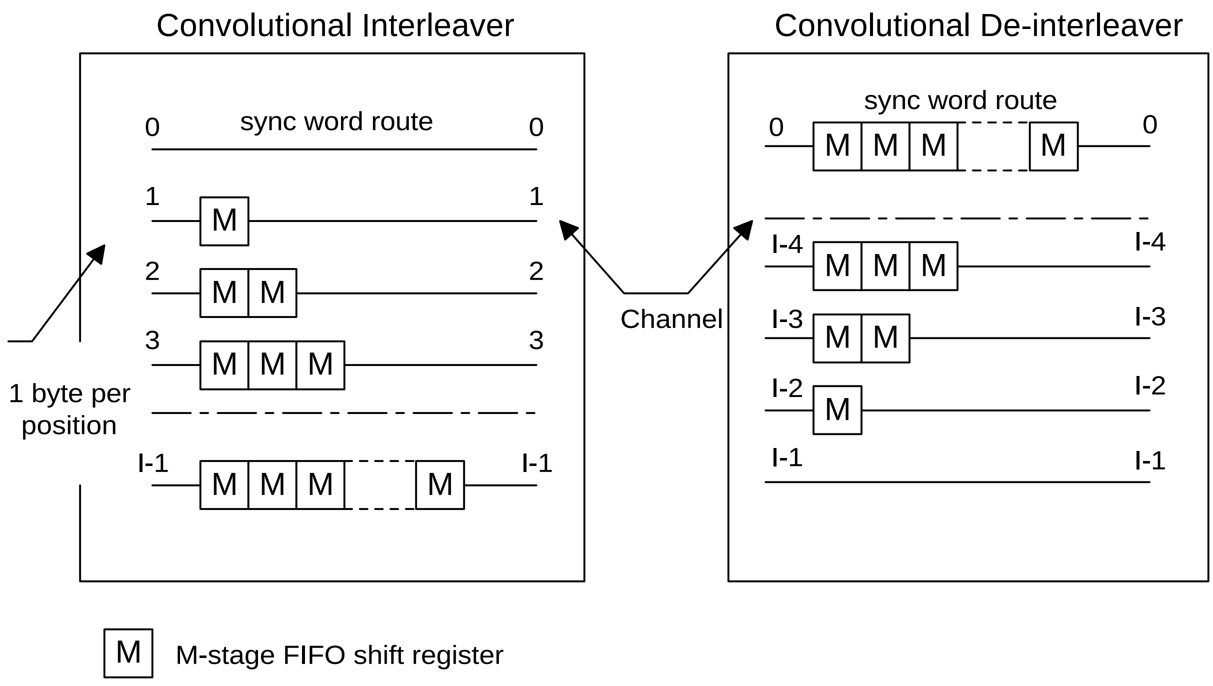



*Figure 10: Conceptual diagram of the convolutional interleaver and de-interleaver.*

### 4.2.5 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 2: 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<br>Y=1<br><br>$I=X_1$<br>$Q=Y_1$ | 10 | X=10<br>Y=11<br><br>$I=X_1Y_2Y_3$<br>$Q=Y_1X_3Y_4$ | 6 | X=101<br>Y=110<br><br>$I=X_1Y_2$<br>$Q=Y_1X_3$ | 5 | X=10101<br>Y=11010<br><br>$I=X_1Y_2Y_4$<br>$Q=Y_1X_3X_5$ | 4 | X=1000101<br>Y=1111010<br><br>$I=X_1Y_2Y_4Y_6$<br>$Q=Y_1Y_3X_5X_7$ | 3 |
| NOTE: 1=transmitted bit<br>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:

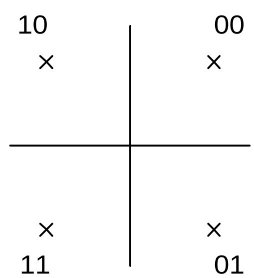



Figure 11: QPSK symbol mapping

### 4.2.6 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 code as described above with the inner coding and constellation mapping as described in [2].

### 4.2.7 Convolutional Coding with 16-QAM Modulation (optional)

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

### 4.2.8 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 $\pi/2$ 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.

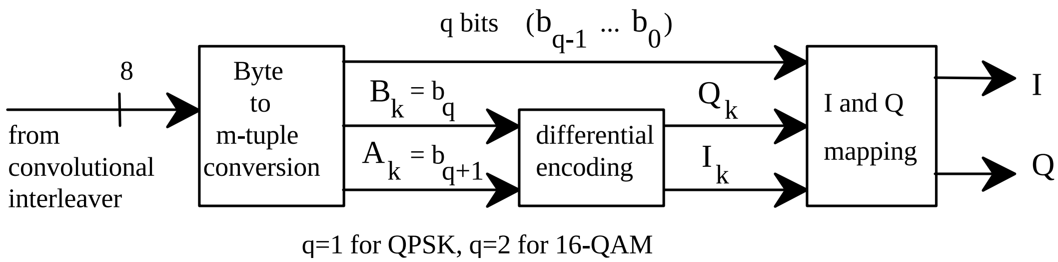



*Figure 12: Example implementation of the byte to m-tuple conversion and the differential encoding of the two MSBs.*

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 3: 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 |

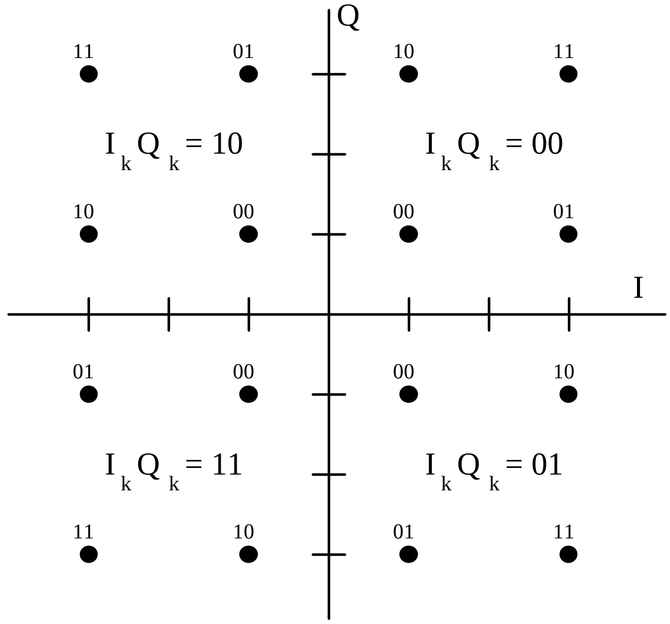



*Figure 13: 16 QAM Constellation diagram*

4.2.9 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:

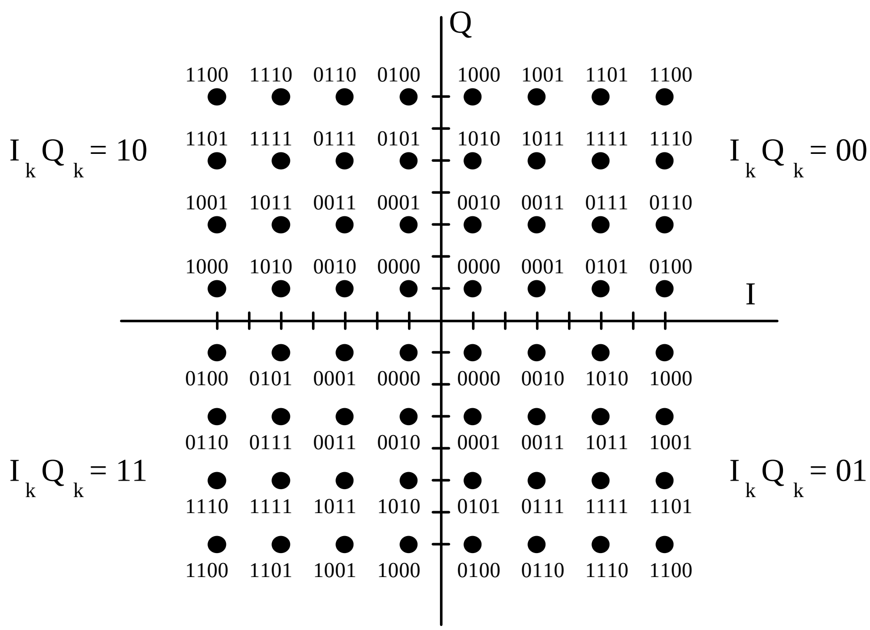



*Figure 14: 64-QAM Constellation Diagram*

### 4.2.10 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:

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

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

### 4.2.11 Summary of Downstream Physical Layer Parameters

| | |
|---|---|
| Randomization | $1 + X^{14} + X^{15}$<br>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 or 0.35 |
| Spectral inversion | inverted or non-inverted |
| Achievable symbol rates | 10-40 Mbaud |

# 5 UPSTREAM PHYSICAL MEDIA DEPENDENT (PMD) SUBLAYER

## 5.1 PHYSICAL MEDIA DEPENDENT (PMD) SUBLAYER

The upstream physical layer coding and modulation for this mode is summarized in the block diagram shown below. Note that, in this mode, the MAC packets are transported directly over the air and require no additional convergence sublayer encapsulation.

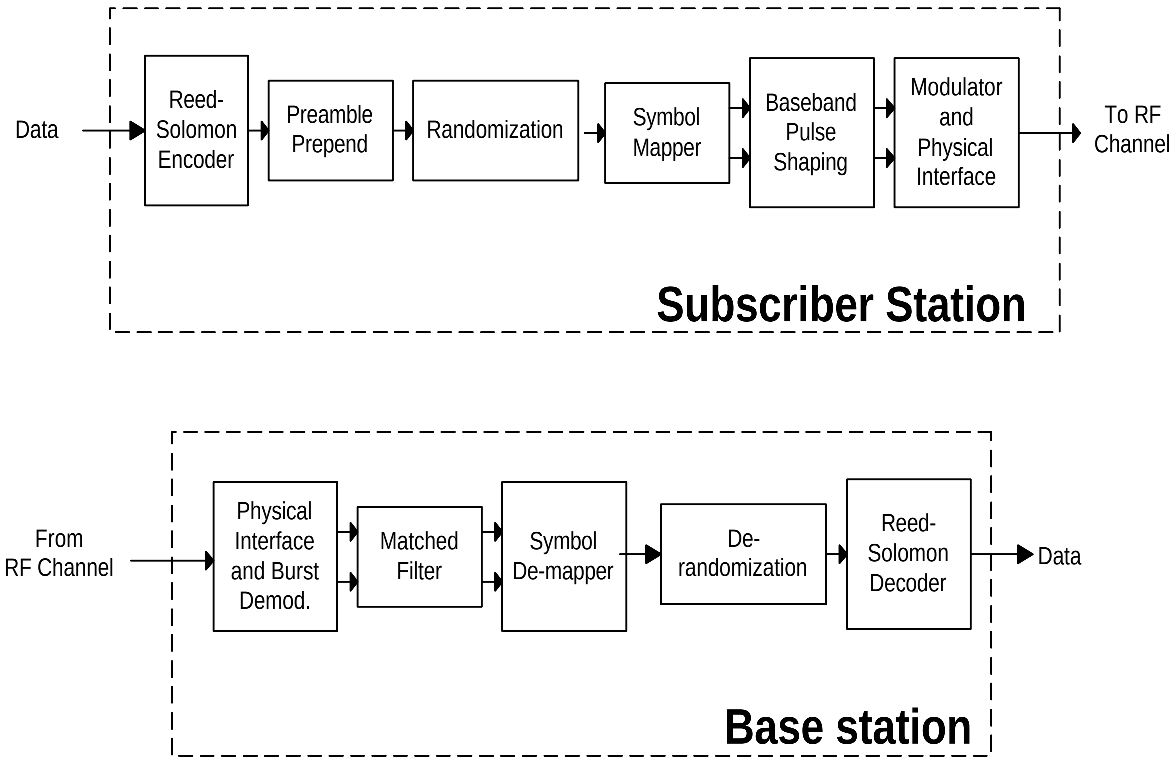



*Figure 15: Conceptual Block diagram of the 802.16 Burst Transmission Upstream Physical Layer*

### 5.1.1 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 $\mu$= 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.

### 5.1.2 Preamble

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

### 5.1.3 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).

### 5.1.4 Modulation

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

#### 5.1.4.1 QPSK Symbol Mapping

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

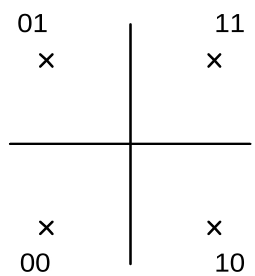



*Figure 16: QPSK constellation mapping*

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 |

#### 5.1.4.2 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).

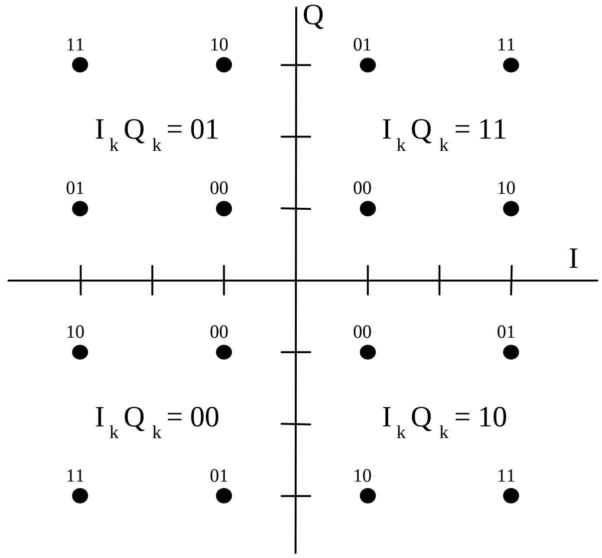



*Figure 17: Differentially encoded 16-QAM Constellation diagram*

| 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 |

### 5.1.4.3 Gray-coded 16-QAM (optional)

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

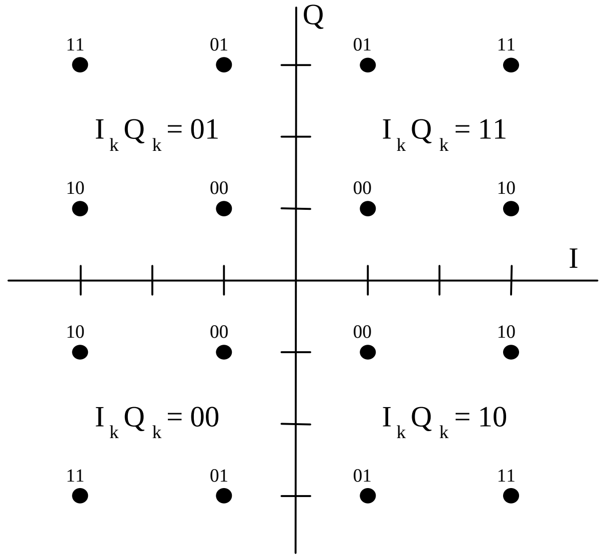



*Figure 18: Gray-coded 16-QAM Constellation diagram*

### 5.1.5 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:

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

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.

### 5.1.6 Summary of Upstream Physical Layer Parameters

| | |
|---|---|
| Reed-Solomon Coding | Codeword lengths: 18-255 bytes<br>T=0-10 |
| Randomization | $x^{15}+x^{14}+1$<br>Initialization seed: 15-bit programmable |
| Preamble | Programmable length: 0-1024 bits<br>Programmable value |
| Modulation | QPSK or 16-QAM (optional) |
| Differential encoding | Selectable on/off |

| | |
|---|---|
| Spectral shaping | $\alpha$=0.15, 0.25, or 0.35 |
| Achievable symbol rates | 5- 30 Mbaud |

### 5.2 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 |
| Framing mode | 0 or 1 | enabled/disabled |
| Frame time | 0-255 (N) | Frame time is Nx125 usec<br>N=0 indicates framing is disabled |
| Mini-slots per frame | 0-65,535 (P) | Number of mini-slots per frame |
| Symbols per mini-slot | 0-1024 (Q) | Integer number of symbols per mini-slot period (independent of modulation used for transmission) |
| 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 |

### 5.3 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.

In order to provide a time slot reference for the upstream channel, the upstream and downstream channels can be divided into equal and fixed length frames. The beginning of the downstream frame can be identified by the frame start indicator bit in the downstream MPEG Header. The beginning of the upstream frame could simply be a fixed offset from the downstream frame start message, programmed via a MAC message. 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 +14 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 +30 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

<table>
<tr><th>#</th><th>Criterion</th><th>Discussion</th></tr>
<tr><td>1</td><td>Meets system requirements</td><td>This physical layer meets the Functional Requirements by having a general structure that allows any MAC layer to reside above it. It has components which allow accurate synchronization of clocks at the subscriber station to support T1/E1 services and accurate determination of burst timing.</td></tr>
<tr><td>2</td><td>Spectrum efficiency</td><td>Following are some configuration examples:<br><br>Downstream: assuming α=0.25 and a payload of 183 bytes.<br><br>
<table>
<tr><th>Modulation</th><th>Inner Code Rate</th><th>bps/Hz</th></tr>
<tr><td>QPSK</td><td>0.5</td><td>0.717647</td></tr>
<tr><td></td><td>0.666666667</td><td>0.956863</td></tr>
<tr><td></td><td>0.75</td><td>1.076471</td></tr>
<tr><td></td><td>0.833333333</td><td>1.196078</td></tr>
<tr><td></td><td>0.875</td><td>1.255882</td></tr>
<tr><td></td><td>1</td><td>1.435294</td></tr>
<tr><td>8-PSK*</td><td>0.666666667</td><td>1.435294</td></tr>
<tr><td>*</td><td>0.833333333</td><td>1.794118</td></tr>
<tr><td>*</td><td>0.888888889</td><td>1.913725</td></tr>
<tr><td>16-QAM*</td><td>1</td><td>2.870588</td></tr>
<tr><td>*</td><td>0.75</td><td>2.152941</td></tr>
<tr><td>*</td><td>0.875</td><td>2.511765</td></tr>
<tr><td>64-QAM*</td><td>1</td><td>4.305882</td></tr>
</table>
<br>*=optional configuration<br><br>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, and QPSK modulation.<br><br>bps/Hz=1.247 (RS(63,53) code with differential encoding)</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.</td></tr>
<tr><td>6</td><td>System diversity flexibility</td><td>The proposed physical layer is 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>
<tr><td>8</td><td>Implications on other</td><td>The proposed physical layer is MAC independent, except for certain</td></tr>
</table>

| | | |
|---|---|---|
| | **network interfaces** | 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)** | **C/N (dB)** | **Backoff (dB)** | **RSG (dB)** |
|---|---|---|---|---|---|
| **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 |
| **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

Note that the above numbers 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.