Project	**IEEE 802.16 Broadband Wireless Access Working Group**
Title	**PHY Proposal for 802.16 based on cable modem standards**
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Re:	802.16 PHY Task Group Call for Contributions 802.16p-99/01 dated 9/16/1999.
Abstract	This proposal addresses the PHY protocol for 802.16 BWA systems based on enhanced DOCSIS (Data over Cable Systems Interface Specification). The improvements are mainly due to the development of more powerful ECC algorithms based on Soft in/Soft out algorithms designed to transmit MPEG-2, ATM and IP frame formats through the BWA channel.
Purpose	This document is submitted for acceptance as a PHY recommendation at session #4 of IEEE 802.16 Broadband Wireless Access Working Group.
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PHY Proposal for 802.16

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1.0 PHY Overview

1.1 Introduction

This proposal addresses PHY protocol for the IEEE 802.16 Broadband Wireless Access (BWA) systems based on cable modem standards. In particular, this proposal follows the lines of Annex B of ITU-T Recommendation J.112 "Data over Cable Radio Frequency Interface" [2] and the ITU-R 8A-9B draft for Fixed BWA [2a]. In order to comply with 802.16 system requirements (see [1]) several necessary improvements to existing cable modem standards [2]-[10] are recommended. The commonality to DOCSIS is maximized to achieve economies of scale.

1.2 Reference Configuration

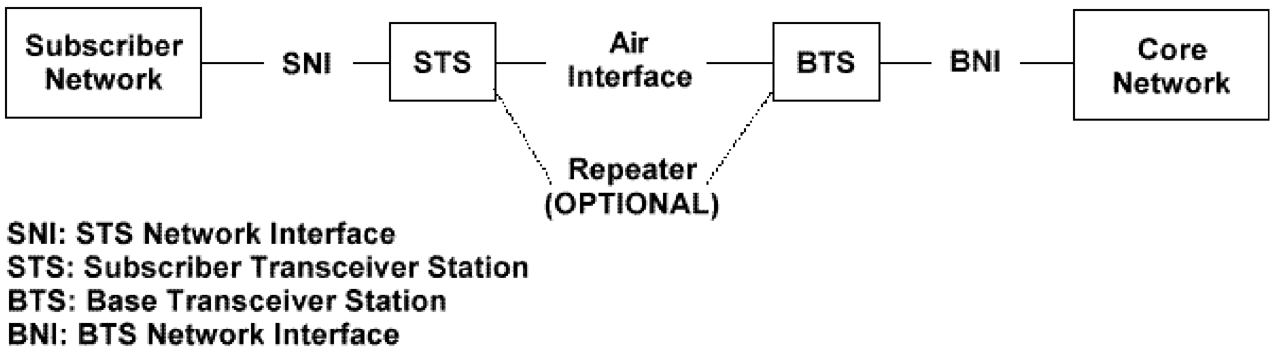


FIG 1.1: System reference points

The Air Interfaces defined in this proposal are the following:

- between the BTS radio and the STS radio in the downstream direction.
- between the BTS radio and the STS radio in the upstream direction.

The network interfaces BNI and SNI are beyond the scope of this document. We adopt the methodology of [2a] to define IF interfaces between the radio\IF Module and baseband Modem of an STS. Similarly, an IF interface between BTS radio\IF Module and BTS modems. The details of these IF interfaces will be specified in the final proposal.

RF interface points are defined as follows:

- ❑ downstream output on the BWA BTS Modem
- ❑ upstream input on the BWA BTS Modem
- ❑ STS modem in/out at the BWA STS Modem

We focus our attention on PHY layer of the air interface. Key radio transmission technology considerations for the proposed PHY are:

1. Downstream uses contentionless broadcast TDM.
2. Upstream uses TDMA.
3. One or more upstream carriers may be supported for a single downstream carrier.
4. Frequency band between 10 - 66 GHz, BW: up to 40 MHz in the downstream direction and 26 MHZ in the upstream direction.
5. 2-way wireless transmission based on Frequency Division Duplexing (FDD).
6. Multiple cell reuse frequency topology with cell radius typically less then 15 km. A cell may be subdivided into sectors
7. BTS uses P-MP radio with shaped sector antenna; STS employs highly directional antenna pointed at BTS.

Most of the radio transmission technology features are the same as those contained in the draft recommendation of ITU-R for Fixed Broadband Wireless (F.BWA) [see 2a]. Modulation technology is, however, slightly modified and more powerful channel coding based on Soft in\Soft out decoding is recommended (see Fig 1.2 and Appendix 1).

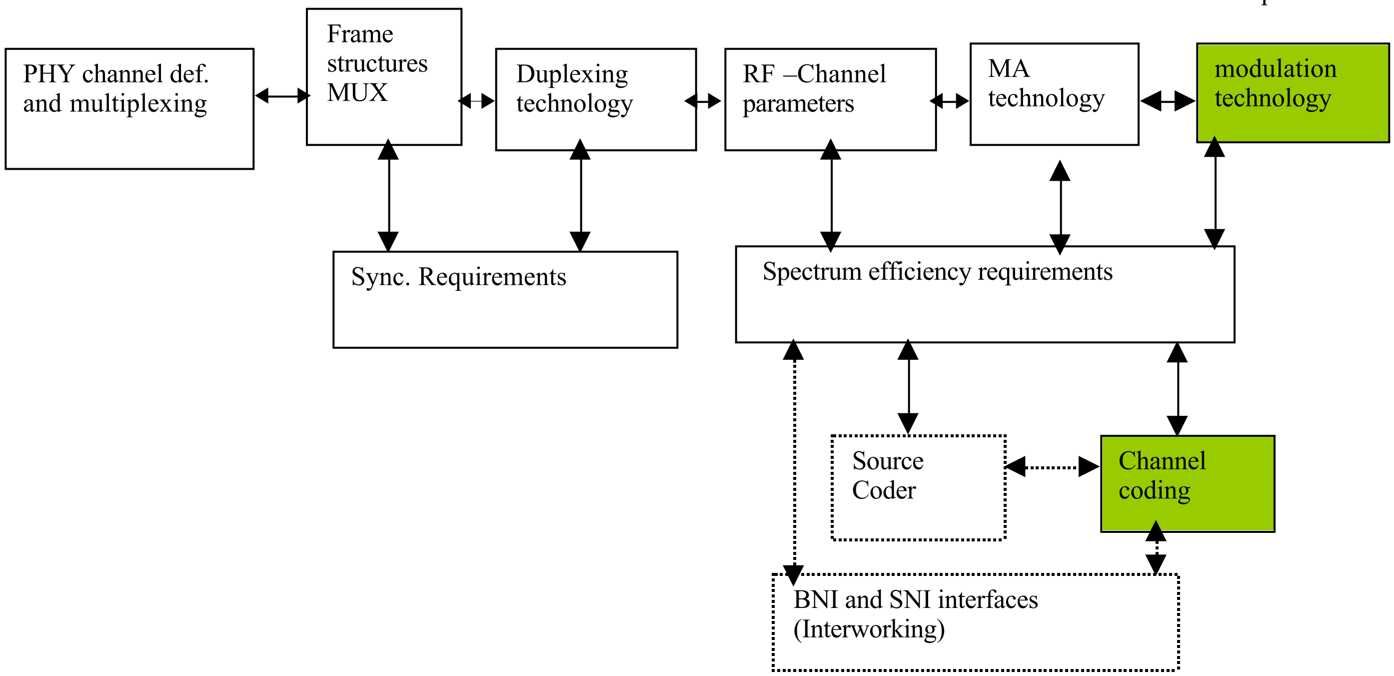


FIG 1.2: **Radio transmission technology Considerations for the proposed PHY**

1.3 Communications protocols

The PHY layer is comprised of two sublayers:

- Physical Media Dependent (PMD) sublayer. The PMD sublayer involves digitally modulated RF carriers over- the-air.
- Transmission Convergence (TC) sublayer (present in the downstream direction only). This sublayer is defined for applications such as Digital Audio/Video.

PMD and TC sublayers are strongly related to the draft the recommendations of [2a] and [10]. FEC in the up-stream /down-stream is changed to allow the use of Block Product code based on shortened Hamming codes (see Appendix 1).

1.4 Main features and benefits (unique features, scalability to various data formats)

- **ECC performance**: BER vs. E_b/N_o outperforms conventional Reed-Solomon (RS) by 2 to 3 dB over wide range of S/N ratio. Overcomes the weakness of non-concatenated RS code at BER between 10E-2 to 10E-4.
- **Scalability**: supporting ATM, MPEG-2, variable-length PDU.
- **Delay:** decoding delay is reduced due to block interleaver when compared to a two-stages coding scheme with large convolutional interleaver and feedback between the decoders.
- **Modulation formats**: Adaptive modulation based on channel information metrics.
- **Powerful tool for Quality of Service**: reliability per symbol based on channel information data.
- **Reduced STS Cost**: improved Coding gain adds 3 dB to reference system gain
  The design uses many features from well established cable modem standards.

1.5 Provisions for future capabilities

Existing MAC signaling provides for optional transmitter equalization. Other forms of upstream transmission manipulation, such as Tomlinson-Harashima precoding, may be developed in the future. Signaling to support such can be added as optional TLV-encoding for the Ranging Response message. This configuration setting can be phased into existing networks without placing new requirements on existing devices. When developing a new network, it may be necessary to know modem capabilities before coming to rely on a feature like this. The "Modem Capabilities" mask, exchanged as part of the BWA CPE Modem -to-BWA BTS Modem registration process is intended to provide this information.

Adding Upstream Channel and Burst Configuration Settings

In future, configuration settings may be provided for new upstream burst characteristics:

- trellis-coded modulation (2 bits/symbol and 4 bits/symbol);
- improved interleaving within a burst.

These are defined through new encoding of the Upstream Channel Descriptor. A BWA CPE Modem which finds characteristics which it does not implement is required to either abstain from that burst type, or to find a different upstream channel. This is also controllable by administrative policy if enough commonality is present to complete the registration process. As with transmission precoding, a modem-capabilities flag may be needed if the BWA BTS Modem is to choose least-common-denominator capability.

New Network Service Requirements

The types of network service expected on a BWA network are apt to change over the lifetime of equipment conforming to this specification. This specification anticipates use of ATM-style traffic parameters by giving the BWA BTS Modem centralized control over bandwidth allocation and jitter. Future networks may include classes of data other than those explicitly provided (802-like and ATM). These may be implemented by using the Reserved code point in the MAC FC field. Because this specification does not require a particular bandwidth allocation algorithm, future algorithms may be developed which take into account policies and traffic types that are not yet well-understood.

2.0 PMD Specifications of Enhanced DOCSIS

2.1 Scope

This specification defines the electrical characteristics and protocol for a BWA STS modem and BWA BTS modem. The intention of this specification is to define an interoperable BWA STS Modem and BWA BTS Modem such that any implementation of a BWA STS Modem can work with any BWA BTS Modem. It is not the intent of this specification to imply any specific implementation.

2.2 Upstream Channel

2.2.1 Overview

The upstream Physical Media Dependent (PMD) sublayer uses a FDMA/TDMA burst modulation format, which provides variable symbol rates and modulation formats (QPSK, 16 QAM and optionally 64 QAM). The modulation format includes pulse shaping for spectral efficiency, is carrier-frequency agile, and has selectable output power level. The PMD sublayer format includes a variable-length modulated burst with precise timing beginning at boundaries spaced at integer multiples of 6.25 msec apart. Each burst supports a flexible modulation, symbol rate, preamble, randomization of the payload, and programmable FEC encoding.

All of the upstream transmission parameters associated with burst transmission outputs from the BWA STS Modem are configurable by the BWA BTS Modem via MAC messaging. Many of the parameters are programmable on a burst-by-burst basis. Maximum timing error and guard time may vary with BWA BTS Modem from different vendors.

The upstream modulator is part of the BWA STS modem that interfaces with the BWA network. The modulator contains the actual electrical-level modulation function and the digital signal-processing function; the latter provides the FEC, preamble prepend, symbol mapping, and other processing steps. This specification is written with the idea of buffering the bursts in the signal processing portion, and with the signal processing portion (1) accepting the information stream a burst at a time, (2) processing this stream into a complete burst of symbols for the modulator, and (3) feeding the properly-timed bursted symbol stream to a memoryless modulator at the exact burst transmit time. The memoryless portion of the modulator only performs pulse shaping and quadrature upconversion.

At the Demodulator, similar to the Modulator, there are two basic functional components: the demodulation function and the signal processing function. Unlike the Modulator, the Demodulator resides in the BWA BTS Modem and the specification is written with the concept that there will be one demodulation function (not necessarily an actual physical demodulator) for each carrier frequency in use. The demodulation function would receive all bursts on a given frequency.

The demodulation function of the Demodulator accepts a varying-level signal centered around a commanded power level and performs symbol timing and carrier recovery and tracking, burst acquisition, and demodulation. Additionally, the demodulation function provides an estimate of burst timing relative to a reference edge, an estimate of received signal power, an estimate of signal-to-noise ratio, and may engage adaptive equalization to mitigate the effects of multipath and IF circuit distortion. ***In addition, the modulator provides "bit level metric computations" for each received symbol. These metrics based on channel measurement are required for the Soft Decision Decoding (SDD).***

The signal-processing function of the Demodulator performs the inverse processing of the signal-processing function of the Modulator. This includes accepting the demodulated burst data stream and decoding, etc., and possibly multiplexing the data from multiple channels into a single output stream. The signal-processing function also provides the edge-timing reference and gating-enable signal to the demodulators to activate the burst acquisition for each assigned burst slot. The signal-processing function may also provide an indication of successful decoding, decoding error, or fail-to-decode for each codeword and the number of corrected Reed-Solomon symbols in each codeword.

2.2.2 Modulation Formats
The upstream modulator/demodulator MUST provide both QPSK and 16 QAM and/or optionally 64 QAM modulation formats.

Modulation Rates
The upstream modulator MUST provide QPSK and 16 QAM the symbol rate must be selected from the following list: 640, 1 280, 2 560, 5 120, 10 240, and 20 480 ksym/sec. The upstream modulator optionally should provide 64 QAM and the symbol rate must be selectable from the following list: 640, 1 280, 2 560, 5 120, 10 240, and 20 480 ksym/sec.

Symbol Mapping
The modulation mode (QPSK or 16 QAM or 64 QAM) should be programmable and Gray coded.

Spectral Shaping
The upstream PMD sublayer MUST support 25% Nyquist square root raised cosine shaping.

Upstream Frequency Agility and Range
The upstream PMD sublayer MUST support operation over the frequency range of 10– 66 GHz edge to edge. Offset frequency resolution MUST be supported having a range of ±350 kHz.

Spectrum Format
The upstream modulator MUST provide operation with the format $s(t) = I(t)*\cos(\omega t) \pm Q(t)*\sin(\omega t)$, where t denotes time and ω denotes angular frequency.

2.2.3 FEC Encode
The upstream modulator MUST be able to provide the following selections of codes:

- product codes based on shortened binary Hamming code:
  $(2^m - S1, 2^m-m-1-S1, 4)X(2^m - S2, 2^m-m-1-S2, 4)$ where m and S1 and S2 are configurable.
  For ATM format: m=5, S1=2, S2=7 (53+4 bytes for payload)
  m=5, S1=2, S2=8 (53+1 bytes for payload)
  For MPEG-2 format m= 6, S1= 25, S2= 10. (188 bytes for payload)
  For MPEG extended m=6, S1=25, S2=9 (188+4 bytes for payload)
- Product codes based on binary parity-check codes:
  (2k+1, 2k) X (2k+1, 2k) where k configurable.

(See Appendix 1)

2.2.4 Scrambler (Randomizer)
The upstream modulator MUST implement a scrambler where the 15-bit seed value MUST be arbitrarily programmable. The polynomial MUST be $x^{15} + x^{14} + 1$.

2.2.5 Preamble Prepend
The upstream PMD sublayer MUST support a variable-length preamble field that is prepended to the data after they have been randomized and FEC encoded. The value of the preamble that is prepended MUST be programmable and the length MUST be 0, 2,4, ..., or 1 024 bits for QPSK and 0, 4, 8, ..., or 1 024 bits for 16 QAM. Thus, the maximum length of the preamble is 512 QPSK symbols or 256 QAM symbols. The preamble length and value MUST be configured in response to the Upstream Channel Descriptor message transmitted by the BWA BTS Modem.

2.2.6 Burst Profiles
The burst profiles are separated into two portions: a) Channel Burst Parameters, which are common to all users assigned to a given channel using that burst type, and b) User Unique Parameters, which vary for each user even when using the same burst type on the same channel as another user (for example, Power Level). In addition to these parameters, the assigned center frequencies and mini-slot grants MUST also be provided by the BWA BTS Modem.
The upstream PMD sublayer MUST support a minimum of four distinct burst profiles, with variable parameters, to be stored within the BWA CPE Modem.

2.2.7 Transmit Power Requirements
The upstream PMD sublayer MUST support the variation of the amount of transmit power. Requirements are presented for 1) the range of commanded transmit power; 2) the step size of the power commands; and 3) the accuracy (actual output power compared to the commanded amount) of the response to the command.

Output Power Agility and Range

The output transmit power in the design bandwidth MUST be variable over the minimum range of –27 dBm to +17 dBm (16 QAM), -30 dBm to +20 dBm (QPSK), in 1-dB steps.

The absolute accuracy of the transmitted power MUST be ±2 dB, and step size accuracy ±0.4 dB. For example, the actual power increase resulting from a command to increase the power level by 1 dB in a BWA CPE modems next transmitted burst MUST be between 0.6 dB and 1.4 dB.

2.2.8 Fidelity Requirements

1) Spurious Emissions

The noise and spurious power MUST NOT exceed the levels given in table below. The measurement bandwidth is equal to the symbol rate (e.g. 160 kHz for 160 ksymbols/sec) for the requirements. The spurious emissions MUST meet local national and/or regional limits.

Parameter	Transmitting Burst	Between Bursts
Inband	-40 dBc	The greater of -72 dBc or -97 dBm
Adjacent Band	-45 dBc	The greater of -72 dBc or -97 dBm

2) Spurious Emissions During Burst On/Off Transients

Each transmitter MUST control spurious emissions, prior to and during ramp up and during and following ramp down, before and after a burst in the TDMA scheme.

On/off spurious emissions, such as the change in voltage at the upstream transmitter output due to enabling or disabling transmission, MUST be no more than 100 mV, and such a step MUST be dissipated no faster than 2 ms of constant slewing. This requirement applies when the BWA CPE is transmitting at +20 dBm or more; at backed-off transmit levels, the maximum change in voltage MUST decrease by a factor of 2 for each 6-dB decrease of power level from +20 dBm, down to a maximum change of 7 mV at -4 dBm and below. This requirement does not apply to BWA CPE Modem power-on and power-off transients.

3) Bit Error Rate (BER)

Overall modem performance MUST be within 1.5 dB of theoretical uncoded BER vs. C/N, at BER $=10^{-6}$ for QPSK and 16 QAM.

4) Filter Distortion

The following requirements assume that any pre-equalization is disabled.

Amplitude

The spectral mask MUST be the ideal square root raised cosine spectrum with alpha = 0.25, within the ranges given below:

$f_c - R_s/4$ Hz to $f_c + R_s/4$ Hz: -0.3 dB to +0.3 dB

$f_c - 3R_s/8$ Hz to $f_c - R_s/4$ Hz, and $f_c + R_s/4$ Hz to $f_c + 3R_s/8$ Hz: -0.5 dB to 0.3 dB

$f_c - R_s/2$ Hz and $f_c + R_s/2$ Hz: -3.5 dB to -2.5 dB

$f_c - 5R_s/8$ Hz and $f_c + 5R_s/8$ Hz: no greater than -30 dB

where f_c is the center frequency and R_s is the symbol rate.

Phase

$f_c - 5R_s/8$ Hz to $f_c + 5R_s/8$ Hz: Group Delay Variation MUST NOT be greater than 100 nsec.

5) Carrier Phase Noise

The upstream transmitter total integrated phase noise (including discrete spurious noise) MUST be less than or equal to -43 dBc summed over the spectral regions spanning 1 kHz to 1.6 MHz above and below the carrier.

6) Channel Frequency Accuracy

The BWA CPE MUST implement the assigned channel frequency within ± 5 parts per million over a temperature range of -40 to 75 degrees C up to five years from date of manufacture.

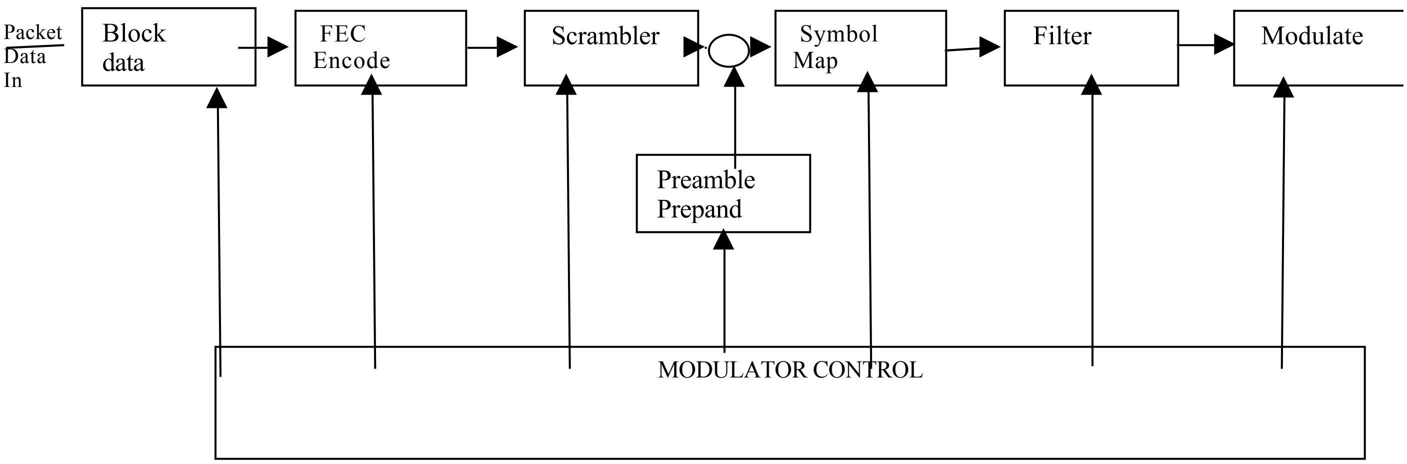
7) Symbol Rate Accuracy

The upstream modulator MUST provide an absolute accuracy of symbol rates ± 50 parts per million over a temperature range of 0 to 40 degrees C up to five years from date of manufacture.

8) 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. In other words, the difference between the maximum and the minimum symbol duration during the 2-sec
period shall be less than 0.02 of the nominal symbol duration for each of the upstream symbol rates. 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. In other words, the difference between the maximum and the minimum cumulative phase error during the 0.1-sec period shall be less than 0.04 of the nominal symbol duration for each of the eight upstream symbol rates. Factoring out a fixed symbol frequency offset is to be done by using the computed mean symbol duration during the 0.1 sec.

2.2.9 Signal Processing Requirements
The signal processing order for each burst packet type MUST be compatible with the sequence shown in Figure 2.2.9-1 .

FIG: 2-2.9-1: **Signal-Processing Sequence**



2.2.10 Upstream Receiver Input Power Characteristics
All CPEs MUST implement upstream power control so that the various bursts from different CPEs arrive at the BWA BTS with more or less the same power level. The objective receive signal at the BTS receiver depends upon the specific power control algorithm implemented. Once the objective receive signal level is defined, the demodulator MUST operate within its defined performance specifications with received bursts within ±6 dB of the nominal commanded received power.

2.2.11 Upstream Electrical Output from the BWA CPE Modem
The BWA CPE Modem MUST output an RF modulated signal with the characteristics as follows:

Parameter	**Value**
Frequency:	10 to 66 GHz
Minimum Level range (one channel):	-27 to +17 dBm (16 QAM) -30 to +20 dBm (QPSK)
Modulation Type:	QPSK and 16 QAM and/or optionally 64 QAM
Symbol Rate (nominal):	640, 1 280, 2 560, 5 120, 10 240, and 20 480 ksym/sec
Bandwidth	800, 1 600, 3 200, 6 400, 13 000, and 26 000 kHz
Output impedance:	50 ohms
Output Return Loss:	> 6 dB

2.3 Downstream

2.3.1 Downstream Protocol

The downstream PMD sublayer MUST support QPSK, 16QAM and optionally 64QAM modulations and symbol rates and bandwidth defined in Table 2.3-1. and Table 2.3-2

Table 2.3-1: **BWA BTS RF Output**

Parameter	Value
Center Frequency	(fc) 10 to 66 GHz ± 5 ppm
Transmit Power Level (at tx antenna flange)	>10 dBm
Modulation Type	QPSK, 16QAM and optionally 64 QAM
Symbol Rate (RS)	up to 34.78 Msym/sec
Nominal Channel Spacing	up to 40 MHz
Frequency response	12%~18% Square Root Raised Cosine shaping
Spurious and Noise Inband (fc ± RS/2) Adjacent channel (fc ± Rs/2) to (fc ± 1.25 * Rs/2) Adjacent channel (fc ± 1.25 * Rs/2) to (fc ± 3 * Rs/2) Next adjacent channel (fc ± 3 * Rs/2) to (fc ± 5 * Rs/2)	 < -50 dBc in symbol rate bandwidth (Rs) < -51 dBc in a bandwidth of Rs/8 < -55 dBc, in 1.75 * RS, excluding up to 3 spurs, each of which must be <-53 dBc when measured in a 10 kHz band < -58 dBc in symbol rate bandwidth (Rs)
Output Impedance	50 ohms
Output Return Loss	> 14 dB

Table 2.3-2: RF Input to BWA CPE

Center Frequency: 10 to 66 GHz ± 5 ppm
Level Range (one channel): -87 dBm to -32 dBm
Modulation Type: QPSK, 16QAM and optionally 64 QAM
Symbol Rate (nominal): up to 34.78 Msym / sec
Bandwidth: up to 40 MHz with 12%~18% Square Root Raised Cosine shaping
Input (load) Impedance: 50 ohms
Input Return Loss > 14 dB

2.3.2 Scalable Interleaving to Support Low Latency

The downstream PMD sublayer support a block interleaver embedded in the FEC Encoder (products block codes). BWA BTS may use helical interleaving to support variable depth interleaver. The interleaver depth, which is coded in a 4-bit control word contained in the FEC frame synchronization trailer, always reflects the interleaving in the immediately-following frame. In addition, errors are allowed while the interleaver memory is flushed after a change in interleaving is indicated.

2.3.3 Downstream Frequency Plan

The downstream frequency should be in the range 10 to 66 GHz with channel bandwidth up to 40 MHz.

2.3.4 BWA CPE Modem BER Performance

The bit-error-rate performance of a BWA CPE Modem MUST be as described in section 6 of [1].

QPSK

a) QPSK BWA CPE Modem BER Performance

Implementation loss of the BWA CPE Modem MUST be such that the BWA CPE Modem achieves a post-FEC BER less than or equal to 10^{-8} when operating at a carrier to noise ratio (C/N) of 9.8 dB or greater.

b) QPSK Adjacent Channel Performance

Performance as described in a) MUST be met with digital signal at 0 dBc in the adjacent channels.
Performance as described in a) with an additional 0.2-dB allowance, MUST be met with digital signal at +10 dBc in the adjacent channels.

16 QAM

a) 16 QAM BWA CPE Modem BER Performance

Implementation loss of the BWA CPE Modem MUST be such that the BWA CPE Modem achieves a post-FEC BER less than or equal to 10^{-8} when operating at a carrier to noise ratio (C/N) of 16.8 dB or greater.

b) 16 QAM Adjacent Channel Performance

Performance as described in Section a) MUST be met with digital signal at 0 dBc in the adjacent channels.
Performance as described in Section a), with an additional 0.2-dB allowance, MUST be met with digital signal at +10 dBc in the adjacent channels.

64 QAM

a) 64 QAM BWA CPE Modem BER Performance

Implementation loss of the BWA CPE Modem MUST be such that the BWA CPE Modem achieves a post-FEC BER less than or equal to 10^{-8} when operating at a carrier to noise ratio (C/N) of 23.5 dB or greater.

b) QAM Adjacent Channel Performance

Performance as described in Section a) MUST be met with digital signal at 0 dBc in the adjacent channels.
Performance as described in Section a), with an additional 0.2-dB allowance, MUST be met with digital signal at +10 dBc in the adjacent channels.

3. Downstream Transmission Convergence Sublayer

3.1 Introduction

In order to improve demodulation robustness, facilitate common receiving hardware for both video and data, and provide an opportunity for the possible future multiplexing of video and data over the PMD sublayer bitstream defined in Section 2, a sublayer is interposed between the downstream PMD sublayer and the Data-Over-BWA MAC sublayer.
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 belonging to the Data-Over-BWA MAC. Other values of the header may indicate other payloads. The mixture of MAC payloads and those of other services is optional and is controlled by the BWA BTS Modem. Enlarged packet size of 188+4 bytes SHOULD also supported.

3.2 MPEG Packet Format

The format of an MPEG Packet carrying BWA data is shown in Figure 3-2. The packet consists of a 4-byte MPEG Header, a pointer_field (not present in all packets) and the BWA Payload.

MPEG Header	pointer_field	BWA Payload
(4 bytes)	(1 byte)	(183 or 184 bytes)

FIGURE 3-2: Format of an MPEG Packet

3.3 MPEG Header 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 Data-Over-BWA MAC streams are defined in Table 3-1. 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 BWA Data-Over-BWA PID is restricted to that shown in Table 3-1. 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 3.1: MPEG Header Format for BWA Data-Over-BWA Packets

Field	Length (bits)	Description
sync_byte	8	0x47; 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 transmission of the packet
payload_unit_start_indicator	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	1	Reserved; set to zero
PID (see NOTE)	13	Data-Over-BWA well-known PID (0x1FFE) NOTE - In the future, additional PIDs MAY be assigned to a BWA CPE Modem. E.g., additional 4 x 8 bits (4 bytes)
transport_scrambling_control	2	Reserved, set to "00"
adaptation_field_control	2	"01"; use of the adaptation_field is NOT ALLOWED on the BWA PID
continuity_counter	4	cyclic counter within this PID

3.4 MPEG Payload for BWA Data-Over-the-Air

The MPEG payload portion of the MPEG packet will carry the BWA MAC frames. The first byte of the MPEG payload will be a "pointer_field" if the payload_unit_start_indicator (PUSI) of the MPEG header is set.

stuff_byte

This standard defines a stuff_byte pattern having a value (0xFF) that is used within the BWA payload to fill any gaps between the BWA MAC frames. This value is chosen as an unused value for the first byte of the BWA MAC frame. The "FC" byte of the MAC Header will be defined to never contain this value. (FC_TYPE = "11" indicates a MAC-specific frame, and FC_PARM = "11111" is not currently used and, according to this specification, is defined as an illegal value for FC_PARM.)

pointer_field

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 this packet that immediately follow the pointer_field that the BWA CPE Modem decoder must skip past before looking for the beginning of an BWA MAC Frame. A pointer field MUST be present if it is possible to begin an BWA Frame in the packet, and MUST point to the beginning of the first MAC frame to start in the packet or to any preceding stuff_byte.

3.5 Interaction with the MAC Sublayer

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.

3.6 Interaction with the Physical Layer

The MPEG-2 packet stream MUST be encoded according to ITU-T J.83, including MPEG-2 transport framing using a parity checksum as described in ITU-T J.83.

3.7 MPEG Header Synchronization and Recovery

The MPEG-2 packet stream SHOULD be declared "in frame" (i.e. correct packet alignment has been achieved) when five consecutive correct parity checksums, each 188 bytes from the previous one, have been received.

The MPEG-2 packet stream SHOULD be declared "out of frame", and a search for correct packet alignment started, when nine consecutive incorrect parity checksums are received.

APPENDIX 1: Channel Coding and Error Performance Requirements

A1.1 Introduction

Iterative decoding of product codes or concatenated codes using Soft in/Soft out (SISO) decoders based on systematic block codes provides outstanding performance which outperform the standard concatenated RS-Viterbi decoders. The basic idea is to break up the optimal decoding of long codes into steps of decoding of component codes and iterate the decoding (see Fig A1-1) . In each iteration step a Bounded Distance (BD) or optimal Soft Decision Decoding (SDD) of the component codes is carried. The novelty in this approach is that a-priori knowledge related with each symbol is updated per iteration based on extrinsic information gained during computations. The underlying decision rule is symbol-by-symbol Maximum a Posteriori (MAP) rule. The resulted word is not necessarily a valid codeword and HDD decoder is usually applied on the final output.

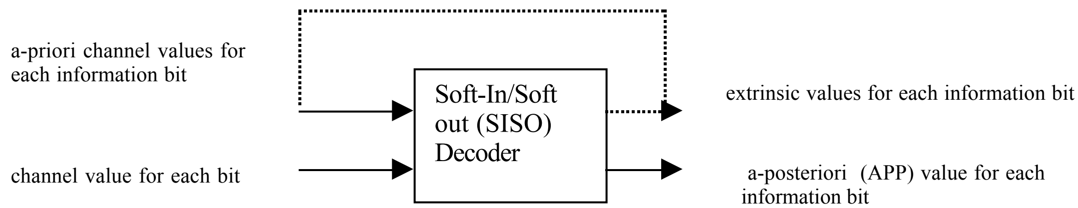


FIG.A1-1 SISO decoder concept

Two main problems are related with SISO decoders: the complexity and the decoding delay. Therefore, codes for which low complexity decoders exists are utilized.
Berrou [11] obtained in 1993 exceptional performances with recursive systematic convolutional (RSC) codes. These SISO decoders are known as Convolutional Turbo Codes (CTC). SISO decoders based on product of linear block codes, mainly binary Hamming codes, were also addressed [12]. This family of SISO decoders are named Block Turbo Codes (BTC).

A1.2 SDD for Fading Channels

Errors in wireless channels are characterized by bursts of errors as a direct result of the nonuniform propagation of radio signal through the channel. Generally, ECC schemes perform better against statistically independent errors than against burst of errors. A technique to reduce the statistical independence of errors is interleaving. SISO decoders based on product of block codes have inherent block-interleaver. Furthermore, simulations results show that very little is gained by making non-uniform interleaver with BTC.

It is a key issue that SDD algorithms of any kind (either symbol-by-symbol iterative SISO decoders based on MAP criteria or direct SDD with minimum Euclidean distance criteria) are much more appropriate for fading channels than HDD algorithms. The reason for that is because channel information at the input to SDD is translated into reliability for each received symbol. Thus in fact, an instantaneous quality metric is provided for each received symbol. This "extra" information can be processed to improve performance via SDD schemes. Furthermore, higher layers in the communication model (MAC, LLC and system layer 3) can process this raw-data of reliabilities to derive a better metric of quality for disperssive channels.

A1.3 Approach to SISO Decoders for BWA Channels

The proposed demodulator and decoder is given in FIG. A1-2

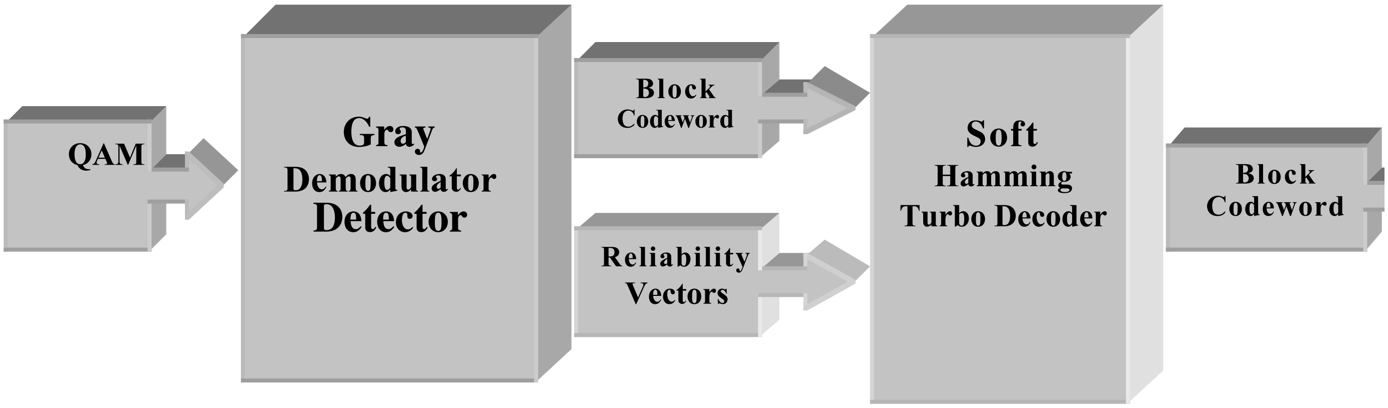


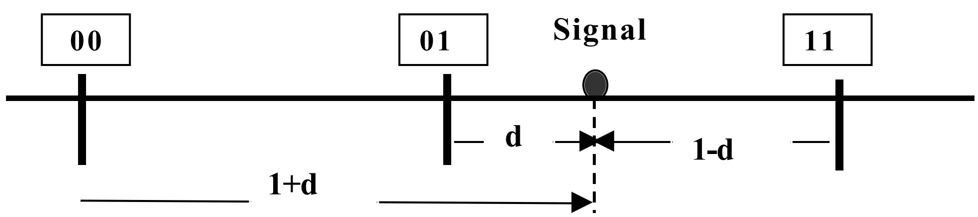
FIG. A1-2 : M-QAM demodulator and Iterative SISO decoder based on Hamming product code.

The Gray code demodulator

The Gray code demodulator accepts a sequence of noisy QAM symbols and produces two outputs:

- The bit pattern corresponding to the received symbol (HDD output).
- The reliability estimation of each of those bits (soft information per bit)

The bit reliability **(**called sometimes "the metric of the bit") is a non-negative real number**:** **r** $\in$ **[0,2],** and it is proportional to the energy difference between the energy associated with the decision for assigning some value to the bit and the energy for the opposite choice of the bit value. Where, "energy" stands for Square Euclidean Distance, SED.



To illustrate the above – consider a 4-PAM Gray code constellation, and assume some incoming symbols having a value just between the constellation points corresponding to bit patterns '01' and '11'. Now if **d** is the distance to the nearest point in the constellation **('01'),** and **1 – d** is the distance to the far point ('11') accordingly, then the resulting bit pattern is **'01'.**

Since the two bit patterns differ in the most significant bit, then the reliability of the decision to assign 0 to this bit is given by**:**

$$E_{01/11} = (1-d)^2 - d^2 = 1 - 2\cdot d + d^2 - d^2 = 1 - 2\cdot d$$

we take this value as the reliability of the most significant bit.

Similarly, the distance to the next far point *('00') is 1 + d*, because the bit patterns *'01'* and *'00'* differ in the least significant bit, then the reliability of the decision to assign **1** to this bit is given by**:**

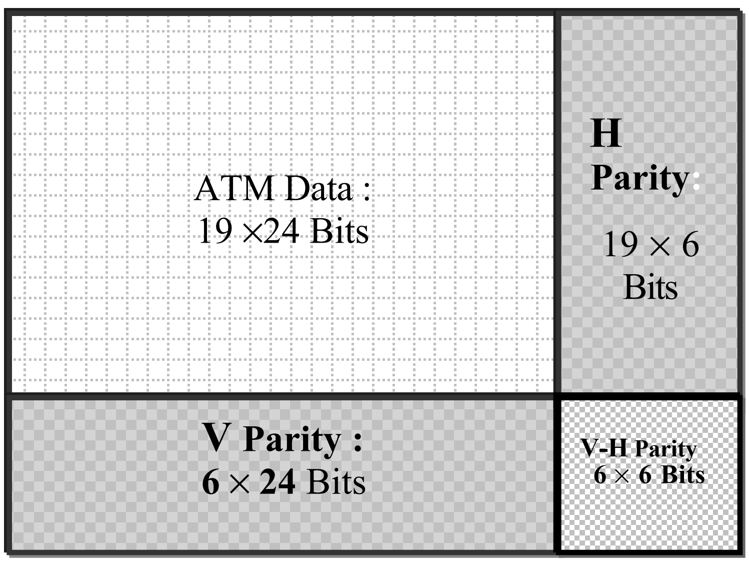
$$E_{01/00} = (1+d)^2 - d^2 = 1 + 2\cdot d + d^2 - d^2 = 1 + 2\cdot d$$

We take this value as the reliability of the least significant bit.

A1.4 ATM package format:

An ATM package contains 53 bytes of 8 bits each. If we add 4 additional data bytes – we get 57 bytes – which is 456 bits.

Those information bits are arranged in a 19 × 24 bit rectangle, and encoded as a block code of 25 × 30 bits using a shortened Hamming block encoder: (32-2 ,26-2)×(32-7 ,26-**7)** resulting a overall block codes of [750, 456, 16].



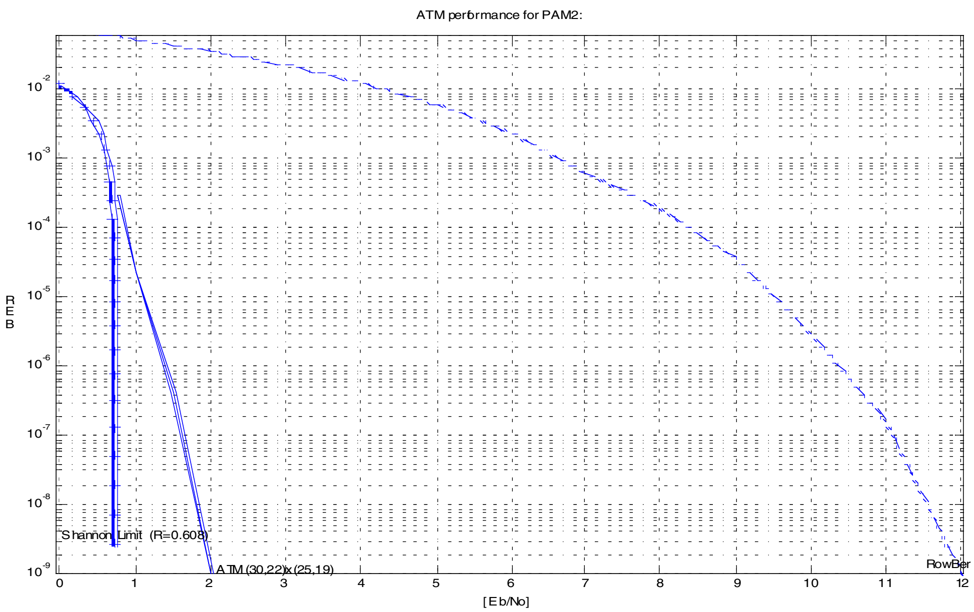
Such a code have a rate R=0.608 and its performance is bounded theoretically by the Shannon Limit corresponding to this rate $[Eb/No]_{Shannon}$ (0.608) = 0.724 dB**.**

Note: constructing user block containing only 54 bytes based on this construction is rather direct. Omitting one column in data area part resulted in block of 18x24 = 432 bits. The parity check area is unchanged since the components codes are Hamming [32,26,4] codes with redundancy n-k=6. Thus the product code is [18+6, 18] x [24+6,24] rate of this code is exactly 0.6.

Performance for AGWN channel are listed below for 2-**PAM** modulation

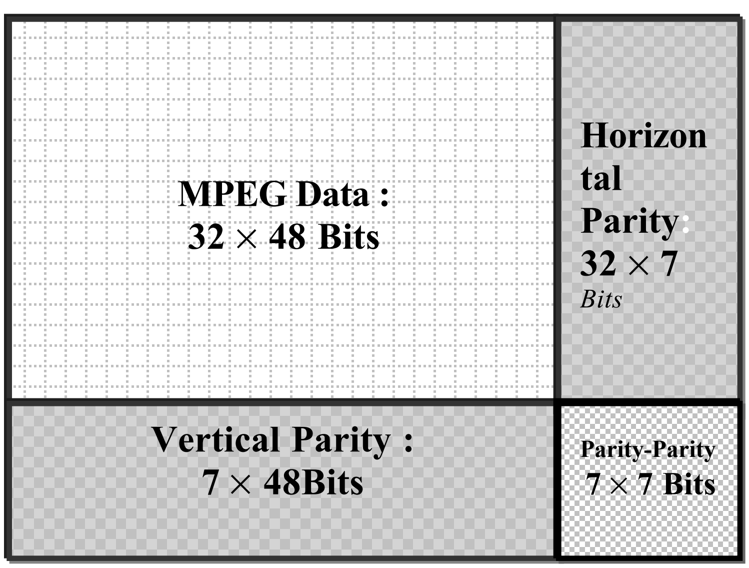
[Eb/No]	***RowBer***	***CorBer***
0.5 dB	6.39E-2	3.05E-4
1.0 dB	5.30E-2	2.25E-5
1.5 dB	4.33E-2	4.50E-7
2.0 dB	3.48E-2	1.07E-9

FIG.A1-3 BER vs. E_b/N_0 for ATM cell based on [750,456,16] code



4.2 The MPEG package format:

An MPEG package contains 188 bytes of 8 bits each. If we add 4 additional data bytes – we get 192 bytes – which is 1536 bits. Those (data) bits are arranged in a 32×48 bit rectangle, and encoded as a block code of **39** $\times$ **55** bits using a shortened Hamming block encoder (64-25 , 57-25)×(64-9 , 57-9) resulting a overall block of 2145 bits.

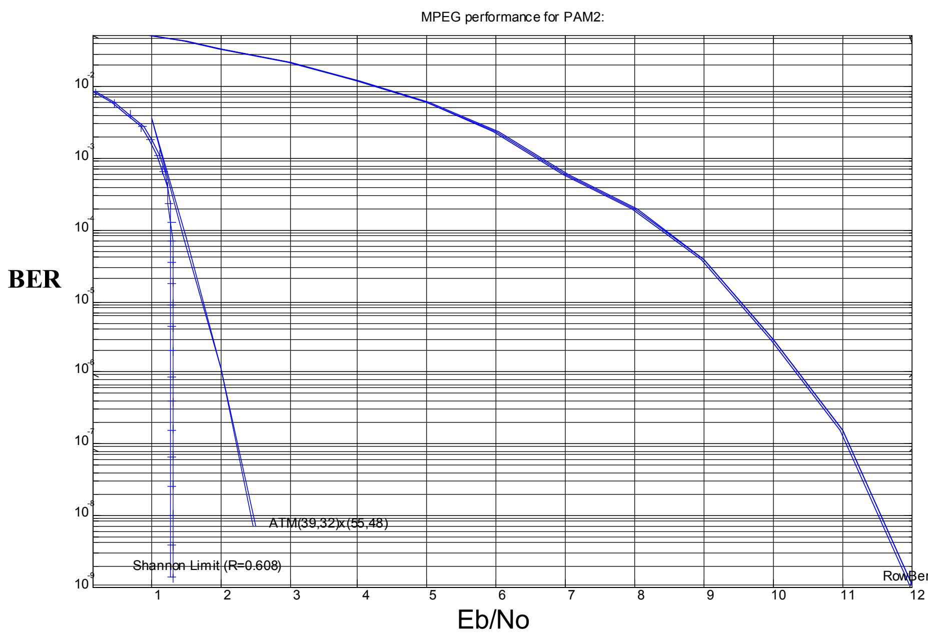


Such a code have a data rate R=0.716 and its performance is bounded theoretically by the Shannon Limit corresponding to this rate $[Eb/No]_{Shannon}$ *(0.716) = 1.3804 dB***.**

Simulation results for additive Gaussian white noise (AGWN) channel are listed below for 2-PAM modulation:

[Eb/No]	**RowBer**	**CorBer**
1.0 dB	5.30E-2	3.57E-3
1.5 dB	4.33E-2	7.81E-5
2.0 dB	3.48E-2	1.07E-6
2.5 dB	2.97E-2	7.05E-9

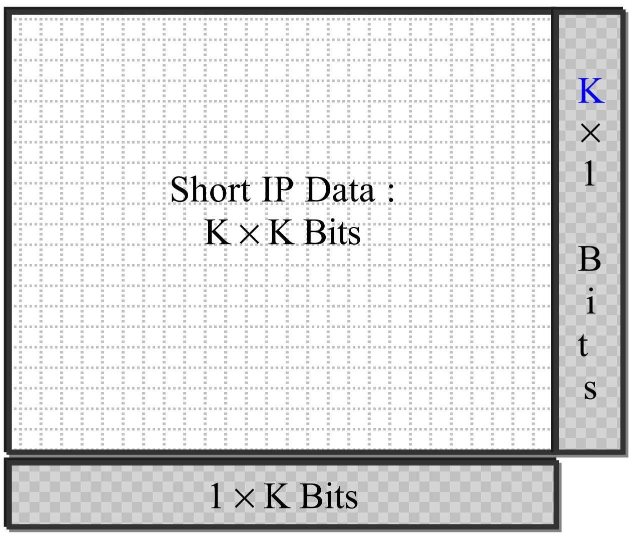
FIG. A1-4 BER vs. E_b/N_0 for MPEG-2 based on [39,32,4]x[55,48,4] shortened Hamming codes



4.3 Short IP packages :

Applications of BTC to variable length and relatively short IP packages can be realized quite simply with the aid of parity check block codes (PCB). Consider two examples of short package: 8 **bytes,** 32 **bytes**.

Information bits are arranged in a bit rectangle, and encoded as a **parity check block codes : PCB(9,8)^2 and PCB(17,16)^2** respectively.



A PCB(9,8)^2 code have a data rate R=0.8 and its Shannon Limit is : *$[Eb/No]_{Shannon}$ (0.8) = 2.04 dB***.**

Simulation results for additive Gaussian white noise (AGWN) channel are listed below for 2-**PAM**:

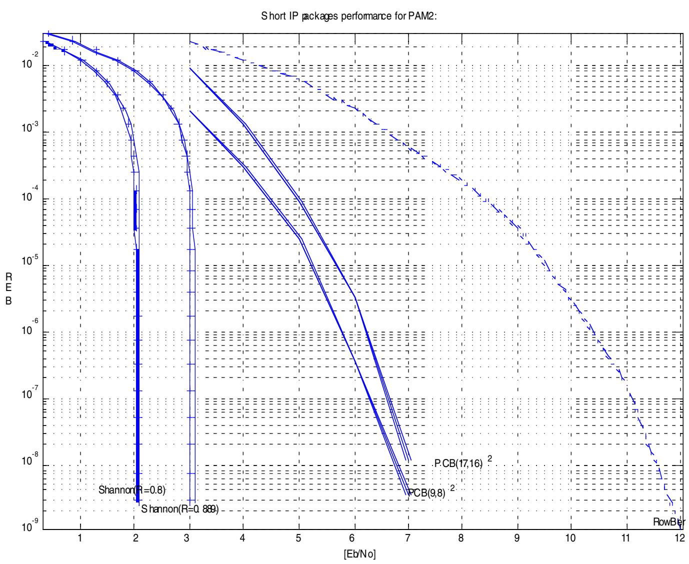
[Eb/No]	***RowBer***	***CorBer***
3.0 dB	2.30E-2	2.26E-3
4.0 dB	1.25E-2	3.19E-4
5.0 dB	5.94E-3	2.48E-5
6.0 dB	2.40E-3	3.58E-7
7.0 dB	7.71E-4	5.05E-9

A PCB(17,16)^2 code have a data rate R=0.889 and its *Shannon Limit* is **:** $[Eb/No]_{Shannon}$ (0.889) = 3.026 dB**.**

Our product has performance results for additive Gaussian white noise (AGWN) channel are listed below for 2-PAM:

[Eb/No]	***RowBer***	***CorBer***
3.0 dB	2.30E-2	9.62E-3
4.0 dB	1.25E-2	1.31E-3
5.0 dB	5.94E-3	9.62E-5
6.0 dB	2.40E-3	3.40E-6
7.0 dB	7.71E-4	1.42E-8

FIG. A1-5 BER vs. E_b/N_0 for short IP packets based on products of parity check



Appendix 2: 64QAM LMDS down link budget

Doubling the receiver antenna beam width reduces the gain by 6 dB
16QAM signal will give additional 5 dB of system gain
QPSK signal will give additional 10 dB of system gain

Transmit Peak Power	30	dBm		
Output Back Off P/A=7dB	-9	dB		
Transmit Antenna gain, 90 deg.	21	dBi		
Transmit EIRP			**42**	**dBm**
Path Loss 2 Km @ 28GHz	127	dB		
Received signal level			**-85**	**dBm**
Receiver Antenna Gain, 1.5 deg.	42	dBi		
Signal level input			**-43**	**dBm**
Noise level of 40 MHz channel	-98	dBm		
Receiver Noise Figure	0	dB		
Noise level input			**-98**	**dBm**
SNR			**55**	**dB**
Rain Fade Margin	30	dB		
SNR required for 10-9 BER w/FEC	16	dB		
Additional System Margin			**9**	**dB**

64QAM LMDS up link budget

Transmit Peak Power	30	dBm		
Output Back Off P/A=7dB	-9	dB		
Transmit Antenna gain	42	dBi		
Transmit EIRP			**63**	**dBm**
Path Loss 2 Km @ 28GHz	127	dB		
Received signal level			**-64**	**dBm**
Receiver Antenna Gain, 90 deg.	21	dBi		
Signal level input			**-43**	**dBm**
Noise level of 26 MHz channel	-100	dBm		
Receiver Noise Figure	0	dB		
Noise level input			**-100**	**dBm**
SNR			**57**	**dB**
Rain Fade Margin	30	dB		
SNR required for 10-9 BER w/FEC	16	dB		
Additional System Margin			**11**	**dB**

APEENDIX 3: Meeting evaluation criteria of PHY task group

Number	Category	Referenced section
1	**Meets System Requirements**	1.0 - 3.0, Appendix.1, Appendix.2
2	**Spectrum Efficiency**	2.2.2, 2.2.11, 2.3.1
3	**Simplicity of Implementation**	DOCSIS based, simple and powerful ECC adapted for BWA channels
4	**STS cost optimization**	simplified STS structure based on DOCSIS, reducing STS PA cost due to 2-3dB improved coding gain
5	**Spectrum Resource Flexibility**	2.2 variable symbol rates and modulation formats
6	**System diversity flexibility**	1.6
7	**Protocol Interfacing complexity**	3
8	**Implication to other networks interfaces**	Appendix 1: ECC optimized to ATM, MPEG-2, and variable IP packets. Efficient transport of telecomm and datacomm based on DOCSIS 1.1
9	**Reference System Gain**	Appendix. 2
10	**Robustness to Interference**	CCI will be handled by proper freq. planning
11	**Robustness to channel impairments**	2.2.1:variable symbol rate and modulation format 2.2.3: powerful FEC with simple block interleaving 2.2.7: support variation of the amount of Tx power Multipath - if necessary use TH precoding as DOCSIS.

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[11] C. Berrou, A. Glavieux and Thitimajshima, "Near Shannon Limit Error-Correcting Coding and Decoding: Turbo Codes," in Proc. ICC'93, May 1993, pp.1064-1070.

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