Project	**IEEE 802.16 Broadband Wireless Access Working Group**
Title	DVB and DOCSIS Based Physical Layer Proposal for the 802.16 Air Interface Specification
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Re:	This contribution is a response to the Call for Contributions from the 802.16 Physical Layer Task Group, dated 22 September, 1999, for a proposed PHY solution for Broadband Wireless Access (BWA) systems.
Abstract	This contribution provides a general description of a physical layer specification that is applicable to the work of the IEEE 802.16 Broadband Wireless Access Working Group. In short, this proposed physical layer specification combines several aspects of the ETSI based Digital Video Broadcasting (DVB) for Satellite physical layer components for the downstream channel (BTS to STS), DOCSIS based physical layer components for the upstream channel (STS to BTS), and other wireless components that enable reliable communication in the 10-60 GHz band.
Purpose	To provide a general description of a proposed physical layer specification that is applicable to BWA systems.
Notice	
Release	
IEEE Patent Policy	

DVB and DOCSIS Based Physical Layer Proposal for the 802.16 Air Interface Specification

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Overview

Following is a general description of a physical layer specification that is broadly applicable to the markets the IEEE 802.16 Broadband Wireless Access Group is trying to address. In order to leverage existing technology for demonstrated robustness of implementation as well as for reduced cost, this proposal uses many aspects of the ETSI based Digital Video Broadcasting (DVB) standards for satellite broadcasting in the downstream channel (base transceiver station (BTS) to subscriber transceiver station (STS)) and many aspects of the DOCSIS based cable modem standard in the upstream channel (STS to BTS). In addition, this proposal contains other physical layer elements that specifically address the challenges to operating reliably in the 10-60 GHz band. The following sections provide a general description of several aspects of the proposed physical layer.

Duplexing Technique

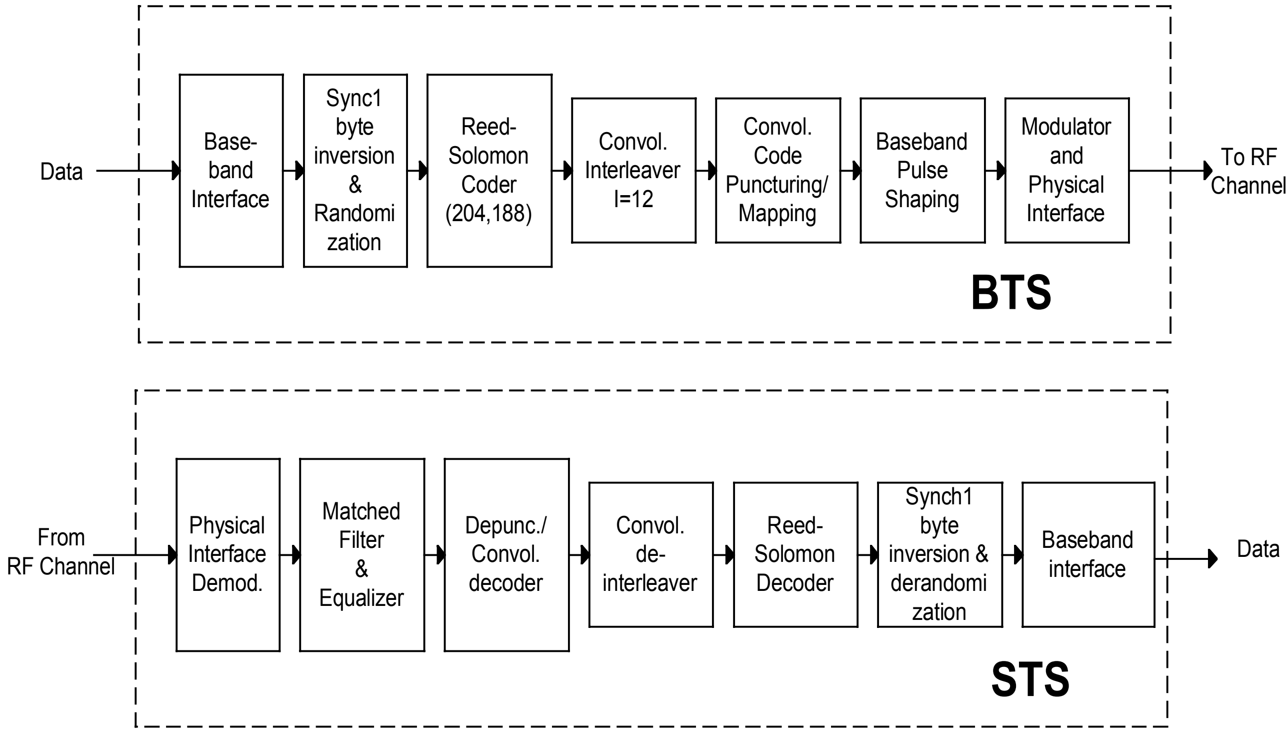
This proposed physical layer is based on frequency division duplexing (FDD), which provides a separate frequency assignment for the upstream and downstream channels. This approach to transmitter and receiver isolation is a proven technique that has been utilized for many other wireless systems, including cellular, PCS, and satellite communication systems. Since FDD provides continuous transmission in the downstream channel, advanced receiver and equalizer designs can be used to enable robust, high-order QAM modulation. In addition, the use of ortho-mode transducer (OMT) technology can be used to provide isolation between the upstream and downstream channels through antenna cross-polarization. This allows the FDD system to be designed with minimal guard band, which is typically required when using traditional diplexers.

Multiple Access Technique

The proposed 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 assumed to be divided into a number of "time slots" to be defined by the MAC layer. The number of slots assigned for various uses (polling, contention, guard, or reserved) is controlled by the MAC layer in the BTS and can vary in time for optimal performance. This initial proposal focuses on the efficient transport of ATM cells in both the upstream and downstream channels. This results in an upstream "time slot" that encapsulates a single ATM cell. The downstream channel is based upon time division multiplexing (TDM), where the information for each STS is multiplexed onto the same stream of data and is received by all STSs located within the same sector. Multiplexing of the traffic is based on ATM QoS definitions in order to meet the various system requirements defined for the 802.16 BWA system.

Downstream Physical Layer

To leverage existing physical layer ASIC technology, the coding and modulation of the downstream carrier waveform is suggested to be compatible with the Digital Video Broadcasting by Satellite standard [EN 300 421 and EN 301 210]. This standard is based on the transmission of packetized digital video corresponding to the Motion Pictures Experts Group Standard 2 (MPEG-2). However, the downstream packets are not restricted to carrying only MPEG-2 data. In particular, a transmission convergence layer can be designed to efficiently transport seven ATM cells in groups of two MPEG-2 packets. The encoding and decoding functions for the DVB physical layer are summarized in the following block diagram.

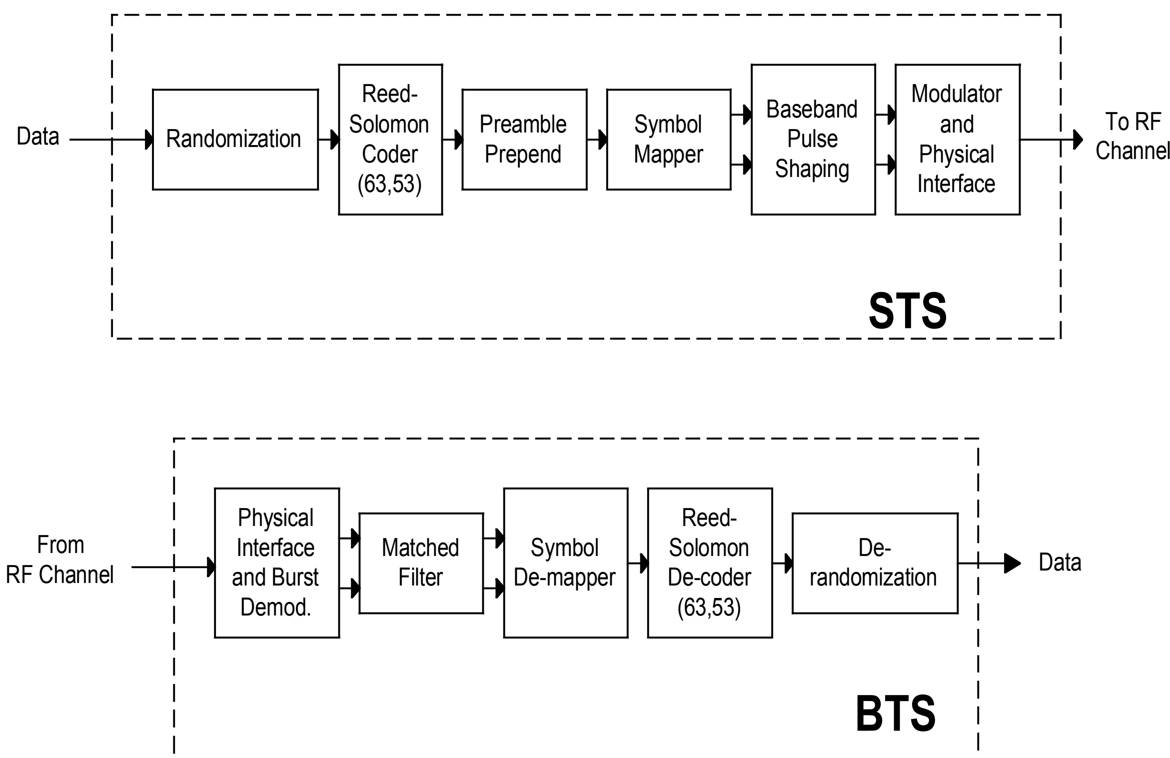


Conceptual Block diagram of a DVB based LMDS Physical layer

The baseband interface performs the transmission convergence sublayer function by adapting the data structure coming from the MAC layer to the format of the MPEG-2 Transport Stream (including sync bytes, but not necessarily requiring the additional 3 MPEG-2 control bytes). The Sync 1 inversion and randomization unit randomizes the data stream for spectrum shaping purposes. Then, systematic shortened Reed-Solomon encoding shall be performed on each randomized MPEG-2 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-2 transport packet to give a codeword size of 204 bytes. The convolutional interleaving process shall be based on the Forney approach, with I=12. The interleaved frame shall be composed of overlapping error-protected packets and shall be delimited by MPEG-2 sync bytes (preserving the periodicity of 204 bytes). The convolutional code shall be selectable from one of the following rates: _, 2/3, _, 5/6, or 7/8, which is obtained by puncturing a rate 1/2 constraint length K = 7 code. QPSK modulation is recommended initially, with gray-coded direct mapping (no differential encoding) of (I,Q) from bit pairs out of the convolutional encoder. Prior to modulation, the I and Q signals shall be filtered by square-root raised cosine filters with a nominal excess bandwidth factor α of about 0.35. Note that this design places more importance on power efficiency and robustness rather than spectral efficiency. If greater spectral efficiency is desired (at the cost of power efficiency and/or robustness), an optional configuration, based on "pragmatic" trellis codes with 8-PSK or 16-QAM constellations and a roll-off factor of 0.35 or 0.25, can be supported with the same basic physical layer elements described above (as defined in EN 301 210 V1.1.1).

Upstream Physical Layer

The recommended upstream physical layer is a subset of that described by DOCSIS 1.1. In particular, the recommended coding and modulation of upstream packets is summarized in the block diagram shown below. Since the upstream channel is TDMA based, the channel can be modeled as a continuous sequence of "time slots" that can be used by different STS terminals. Based on the DAMA scheme developed by the MAC group, these "time slots" can be assigned for particular uses by a "bandwidth manager" located in the BTS. In this initial proposal, these "time slots" are designed to encapsulate a single ATM cell. In general, the length of these "time slots" may want to be a programmable parameter that can be set by the BTS. However, in order to meet the QoS requirements defined by the System Requirements document for the 802.16 Air Interface Specification, efficient segmentation of the upstream packets must be supported, which will have an impact on the degree of programmability of the transmitted packet sizes. The upstream packets are first randomized for spectral shaping. Then, the randomized packet shall be encoded for forward error correction using a shortened Reed Solomon encoder (63,53), which can correct up to 5 byte errors. The synchronization preamble shall be prepended to each packet and the resultant coded packet is mapped into I/Q baseband pulses based on QPSK or 16-QAM modulation (supporting either differential encoding or Gray code mapping). The baseband modulation pulses shall be filtered with root-raised cosine filters having a nominal excess bandwidth factor α of about 0.25, and the packet data shall be burst modulated onto the upstream RF waveform in the assigned "time slot".



Upstream Data Flow

Other Physical Layer Functions

Synchronization Technique/Timing Control

In order to avoid highly accurate and costly frequency sources (*e.g.*, OCXO) at the STS, and satisfy timing requirements for telephony or other CBR applications (T1/E1), it is recommended to have the STS clocks be derived from the downstream symbol clock, which is coherently related to a master clock coming from a telephone central office or backbone ATM network, for example. This can be accomplished by having the downstream symbol rate coherently related to the reference clock through a phase locked loop implementation at the BTS. This clock can then be derived by the STS, having a phase locked loop locked to the downstream symbol clock, and turned around to generate the upstream symbol clock and other clocking circuitry. Since this clock is coherently related to the reference clock there is no need for bit stuffing at the BTS. In addition, this clocking approach is simple and introduces no additional jitter or unnecessary delay. In order to provide a time slot reference for the upstream channel, the upstream and downstream channels are divided into equal and fixed length frames. The beginning of the downstream frame is identified by the receipt of a "frame start" message from the MAC layer that arrives on a periodic basis. 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 BTS, and the flexibility to finely modify the timing at the STS.

Frequency Control

Frequency control is also a critical component of the physical layer. Due to the large carrier frequencies proposed for BWA systems, frequency errors will exist in the radio units, and will vary with age and temperature. Note that the initial ranging process described above for timing adjustment will 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 BTS will be made by the physical layer and sent to the STS via a MAC message, enabling low cost frequency references to be used in the radio units.

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 BTS 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 STS in a calibration message coming from the MAC layer. The power control algorithm should be designed to support rain fade rates of at least 5 dB/second with depths on the order of 30 dB.

Benefits of Proposed Physical Layer

- **Time to market**: The proposed physical layers for both the upstream and downstream borrow from existing technology, which allows for rapid deployment of systems in the near term, and allows for sharing of technology advancements in the long term.
- **Cost**: Leveraging existing technology used in other applications allows for higher volume productions, which directly relates to lower cost chip solutions.

- **Robustness**: This proposal contains aspects to address certain system and channel impairments, such as power control to combat rain fades, frequency control for radio oscillator drift, powerful coding for operation in noisy environments, and robust modulation for less sensitivity to interference. This physical layer has been demonstrated to provide reliable operation, satisfying stringent T1/E1 timing requirements, in several LMDS based trial and deployed systems. The DVB based downstream physical layer has also been proven to provide reliable communication for satellite channels, and the DOCSIS based upstream physical layer has been proven to provide reliable communications over a cable channel. The following table illustrates the theoretical performance of some possible configurations of the downstream and upstream code rates:

Downstream

Inner code rate	**Required Eb/No for BER = 10^(-10) after RS decoder**
1/2	3.7 dB
2/3	4.2 dB
3/4	4.7 dB
5/6	5.2 dB
7/8	5.6 dB

Upstream

Reed-Solomon code	**Required Eb/No for BER = 10^(-10) after RS decoder with differential encoding/decoding**
RS (63,53,T=5)	9 dB

- **Flexibility**: The downstream channel has the capability of choosing from several different code rates to optimally design a system, based on desired availability, cell size, fade margin, antenna gains, etc. In addition, the method of synchronizing the upstream symbol rate from the downstream symbol rate enables a wide range of possible symbol rates for both the upstream and downstream channels. This aspect of the system is important, since this standard is desired to be broadly applicable for the 10-60 GHz region and the fact that different countries have different size blocks of available spectrum.
- **Supports QoS requirements**: The TDMA based architecture allows for a dynamic allocation of resources to efficiently transport bursty traffic, like data or Internet applications, while having the capability to also support fixed allocations to satisfy constant and variable bit rate applications, such as voice or video. In addition, the synchronization method described here minimizes delay and bit losses due to relative clock rate variations at the STS and BTS, allowing for T1/E1 based services to be cost effectively supported.

Drawbacks of Proposed Physical Layer

- This proposal focused on the efficient transport of fixed size packets in the upstream channel (nominally set to support single ATM cell transport). However, nothing in this proposal prohibits the adoption of supporting variable length packets over-the-air. In particular, it may be desirable to have the flexibility to transmit smaller sized packets for contention based messages (*i.e.*, bandwidth requests). In addition, it may be desirable to support larger sized packets over-the-air to reduce the physical layer overhead. However, the benefits of implementing variable length frames over-the-air needs to take into account the following issues: fragmentation efficiency (fragmentation will be required for virtually all packets when supporting multi-service based QoS), the ability to implement rapid filtering of data in both the upstream and downstream channels for high data rate implementations, and the simplicity of the bandwidth allocation mechanism residing in the BTS.

Statement on Intellectual Property Rights

Stanford Telecom and Newbridge Networks have patents, either accepted or pending, which may be relevant to this proposal. Both companies have read the IEEE patent policy and agree to abide by its terms.