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Title	**Physical Protocol Proposal based on DVB Satellite Receiver Modems for Continuous Transmissions and ETSI LMDS Modems for Upstream TDMA**
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Re:	802.16 Physical Layer Task Group CALL FOR CONTRIBUTIONS - Session #4, Document 80216p-99_01
Abstract	This PHY proposal is based on an implementation by DVB and ETSI
Purpose	The author desires that the 802.16 working group incorporate all or part of the proposal into the 802.16.1 standard.
Notice	
Release	
IEEE Patent Policy	

Physical Protocol Proposal based on DVB Satellite Receiver Modems for Continuous Transmissions and ETSI LMDS Modems for Upstream TDMA

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Introduction

This PHY proposal is based on standards from the Digital Video Broadcast (DVB) project and the Digital Audio Video Council (DAVIC). The approach defines the physical layer implementation for delivery of high-bandwidth voice, data, and video services. Services under consideration include telephony, ATM, video, video conferencing, T1/frame relay equivalent, Internet Protocol, and many others.

The intended service will allow transparent bi-directional transfer of ATM and Internet Protocol (IP) traffic, between network access points and customer locations, over a point-to-multipoint microwave radio system.

While the following proposal can be used in conventional channelized bandplans, the underlying assumption is that a licensee is issued a license to operate multiple stations throughout a metropolitan sized area and that the stations may transmit on any frequency within an assigned block of spectrum. These assumptions are reflected in the LMDS and LMCS policies by the U.S. and Canada, respectively[1]. While the equipment used to provide the service uses channels, the licensee is free to adjust the carrier frequency and channel bandwidth to provide the best mix of service to customer. For flexible delivery of service, the equipment must adjust carrier frequency and channel bandwidth on a monthly, hourly, and sometimes burst basis.

Overview and Reference Model

Include an overview and a reference model that describes functions, including interfaces to other layers.

Reference Model

The physical layer ("PHY") is between the media access layer (MAC) and the 802.16.1 air interface (Figure 1). The physical layer contains the functions that put a signal on the air with a prescribed modulation format (Figure 2). In point-to-multipoint radios, the PHY layers are normally different at the hub and at the subscriber terminal (sub). For the purposes of specifying an air interface, a minimum set of requirements are defined. Details of how to control and provision the PHY are outside the scope of the PHY portion of the standard.

Each hub downstream PHY and subscriber upstream PHY consists of a modulator and a transmitter. The modulator contains functions such as forward error correction encoding, spectral shaping, and modulation. The transmitter contains the conversion of the modulator output to an emission with a defined center frequency and functions necessary to radiate a signal, such as a power amplifier and an antenna.

Each sub downstream PHY and hub upstream PHY consists of a receiver and a demodulator. The receiver converts a radiated signal to an electrical signal. The demodulator performs demodulation, forward error correction, timing recovery, and data stream recovery.

[1] LMDS – Local Multipoint Distribution Service, LMCS – Local Multipoint Communications System.

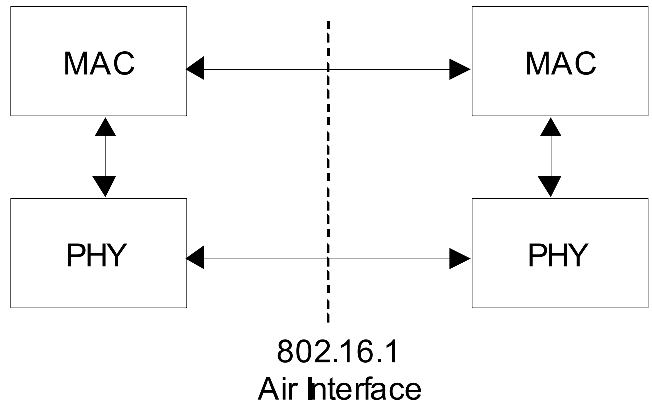

Figure 1, Simplified reference model for the 802.16.1 PHY

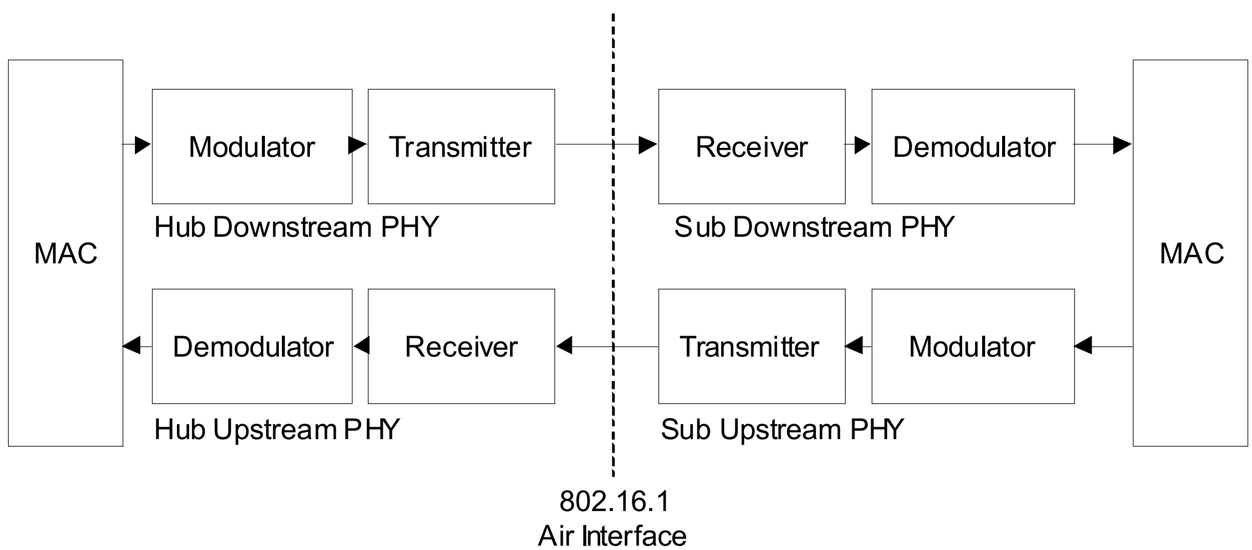

Figure 2, 802.16.1 PHY consists of four distinct physical layers: Hub and Sub, Upstream and Downstream.

The proposed PHY layer uses quadrature phase shift modulation (QPSK) for several reasons, including relatively low cost, relatively low transmit power (system gain), robustness to interference, enablement of frequency re-use between sectors, and dependable performance.

In the downstream direction, information rates vary from 10 to 50 Mbps, and the nominal rate is about 45 Mbps. The rate allows an efficient match at DS3 rates to network connections at the hub. Future data rates extend to 155 Mbps.

In the upstream direction, information rates vary from 2 to 20 Mbps. Two formats are supported: continuous and burst. For continuous and burst transmission QPSK modulation is used. With Trellis coding, the modulation may be extended to include QAM.

Frequency Plan

To minimize the separation distance between full duplex stations operating on opposite sides of license boundaries, the following frequency plan (Figure 3) is suggested for 802.16.1 systems operating in the U.S. LMDS Bands[2]. Note this is a recommendation and not a requirement. The 802.16.2 coexistence practice document is expected to show that the separation distance necessary to prevent harmful interference is simply increased if hubs and subs transmit in the same portion of a band[3]. Additional discussion and the basis for this band plan are given in a previous paper to IEEE 802.bwa[4].

The recommended band plan splits the band from 27.5 to 28.35 GHz in half. Hubs are assigned to transmit in the lower portion of the band and subs transmit in the upper portion of the band. The choice of which portion of the band hubs transmit is arbitrary, but at one time during the U.S. LMDS policy development process there was a preference for hub transmission in the lower portion of the band. Some full duplex systems may require a transition band to prevent unwanted emissions from transmitters at levels that become harmful interference with co-located receivers. The amount of transition band is left as a radio manufacturer's decision.

For the 29.1 to 29.25 GHz band, the U.S. regulations[5] prevent transmissions from subscriber locations. The proposed 802.16.1 band recommendation is to pair the 29.1-29.25 GHz band with the A-band block at 31.075-31.225 GHz. Hubs transmit in the 29.1-29.25 GHz band and subs transmit in the 31.075-31.225 GHz band.

For the B-band licenses, the proposed 802.16.1 band recommendation arbitrarily places hub transmissions in the 31.000-31.075 GHz band and sub transmissions in the 31.225-31.300 GHz band.

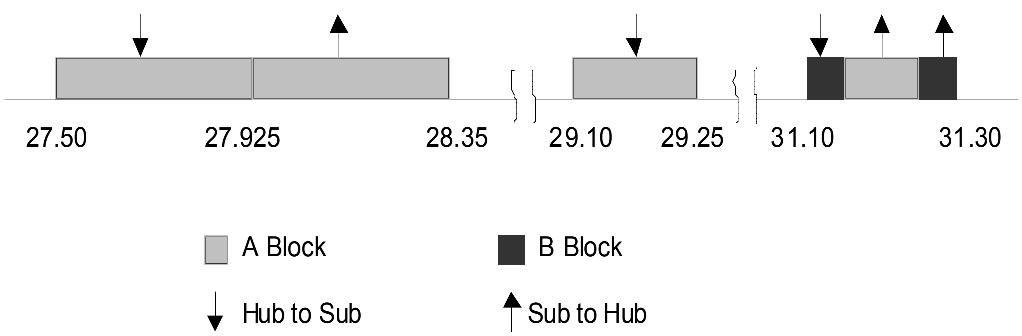

Figure 3. Recommended Bandplan for LMDS Systems in the United States

Hub channel frequencies and bandwidths are unspecified. A sub receiver searches for and locks to a carrier.

RF Channel Assumptions

The proposed center frequency resolution is 1 MHz with a tolerance of +/- 0.001% (10 ppm).

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2 The U.S. LMDS bands are defined in the U.S. Code of Federal Regulations, Title 47, Part 101, "Fixed Microwave Service", 10/1/98 Edition available at http://www.fcc.gov/wtb/rule.html.

3 Scott Marin, "Interference Consideration at LMDS/LMCS License Boundaries", http://grouper.ieee.org/groups/802/16/study_group/coexistence.html, paper #3.

4 Scott Marin, "Recommended LMDS Bandplan for Systems in the United States," http://grouper.ieee.org/groups/802/16/study_group/coexistence.html, paper #2.

5 CFR 47, Part 101, para 101.133d

Approach – Continuous Transmission

The specific approach for continuous transmission mode for both upstream and downstream is to use modems that are compliant with ETSI EN 300 421.

The reference model for the PHY Layer for the continuous PHY transmitter is shown in Figure 4.

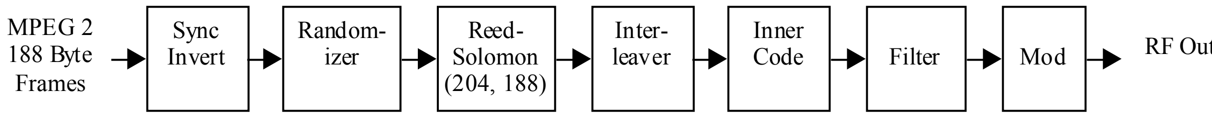

Figure 4, Continuous Mode Modulator

The reference diagram for the receiver PHY layer is the reverse of the above one, except that an additional adaptive equalizer can be inserted if desired. The specifics of this adaptive equalizer are not specified within this document, and are left up to each manufacturer.

The modems accept an MPEG-2 transport stream (ISO/IEC DIS 12818-1)[6], which has a packet size of 188 bytes. Data is randomized by a pseudo random binary sequence. Outer forward error correction code bytes are added using a Reed-Solomon RS(204, 188, T=8) shortened code. Inner coding is added using convolution codes with rates 1/2, 2/3, 3/4, 5/6, and 7/8. Phase ambiguity in the demodulator is resolved by decoding the MPEG-2 sync bytes delimiting the interleaved frame.

To accomplish baseband shaping the modem employs Gray-coded QPSK. The roll-off factor, α, is 0.35.

The error performance of the modem is very good. A bit error ratio (BER) of less than 2×10^{-4} is met after the inner code with a signal having an E_b/N_o of at least 5.5 dB. After the outer code, the BER is quasi error free for a signal having an E_b/N_o of at least 5.5 dB.

Modems built to EN 300 421 are in their fourth generation of implementation. Two-chip implementations (tuner, demodulator) are now commonly installed in satellite TV receivers.

The symbol rate is unspecified in EN 300 421. Most vendors supply modems with programmable symbol rates that range from about 1 Msps to 25 Msps. Demodulator control software searches over the frequency, symbol rates, and inner code rate choices until the demodulator locks to a carrier. With search capability, it is unnecessary to specify symbol rates or carrier frequencies in the 802.16.1 standard. Downstream Timing is as defined in-band operations of ETSI EN 301 199.

Approach – Upstream Burst Transmission

The specific approach for upstream burst transmission is to use modems compliant with ETSI EN 301 199.

The slot format contains a 4 byte Unique word, 53 byte payload, 6 byte Reed-Solomon Parity, and 1 byte guard band. For more robust performance, the Reed-Solomon is expanded to include from 6 bytes to 16 bytes.

The reference model for the PHY Layer for the upstream path transmitter is shown in Figure 5. The adaptive equalizer at the transmitter is optional, and is considered to be used to equalize only slowly changing multipath signals.

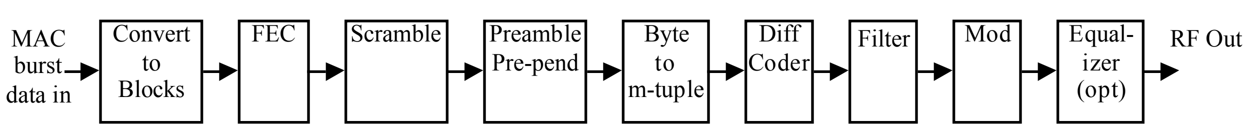

Figure 5, Sub Upstream Burst Modulator

The reference model for the upstream receiver is the same sequence in reverse, except that an additional adaptive equalizer can be inserted if desired. The specifics of this adaptive equalizer are not specified within this document, and are left up to each manufacturer.

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[6] ISO/IEC DIS 13818-1 (June 1994): "Coding of moving pictures and associated audio."

Upstream sychnronization is derived from synchronization bytes in the downstream signal.

Benefits

Describe the benefits of the proposed PHY, including any unique features.

The approach works well at 28 GHz. The approach enables frequency re-use between sectors to maximize the bits/cell spectrum capacity.

The approach operates in large amounts of interference.

The approach is low cost for both the PHY components (modems) and the associated system components like antennas, local oscillators, power amplifiers, and filters.

The approach has relatively low latency (msecs) suitable for voice and video applications transported by ATM.

The use of QPSK modulation enables frequency re-use between sectors. For a four sector hub, the effective spectral efficiency of the hub approaches four times the efficiency of the modulation method.

Drawbacks

Describe any drawbacks of the proposed PHY.

Spectral efficiency (bits per second per Hz) is less than can be attained with higher-level modulation formats such as 16-QAM or 64-QAM. But the higher-level formats are more costly to implement and have less coverage area (as measured by the area in which the C/(N+I) ratio is greater than the respective thresholds).

When spectrum efficiency per cell is considered, QPSK with frequency reuse between sectors, the bits/cell efficiency is maximized.

Relationship to Existing Standards

Explain how the submitted PHY relates to existing standards, such as ITU-R JRG 8A-9B, DAVIC, DVB, AF-WATM or others. If it is based on an existing standard, what differences occur due to BWA characteristics?

The downstream and continuous upstream approach uses an established standard for satellite video distribution.[7]

Scalability

Emphasize the scalability of the proposed PHY to deal efficiently with various data types (as IP, ATM, MPEG).

The proposed PHY allows optimum implementation of ATM mid-layer protocols. The frame structure fits well in the 53 byte format of ATM. IP runs well on top of ATM.

Intellectual Property

Include a statement on intellectual property rights and how 802.16 may utilize the proposed PHY in a standard.

The proposed ETSI specs conform to ETSI policy on intellectual property.

Evaluation Table

The evaluation table is included in Appendix A.

[7] European Telecommunications Standards Institute, “Digital Video Broadcasting (DVB); Frame Structure, Channel Coding, and Modulation for 11/12 GHz Satellite Services, EN 300 421 v1.1.2, 1997-08.

Conclusion

The proposed PHY for the 802.16.1 Air Interface Standard is based on ETSI DVB/DAVIC satellite modem specifications. Modems that are compliant to these specifications have been widely deployed in satellite receiver applications for video distribution. The modems have gone through several generations of implementation. Two-chip (tuner, demodulator) units are commonly sold.

The proposed PHY meets all of the 802.16.1 system requirements and is, arguably, the best solution for P-MP radio implementations at 28 GHz.

Appendix A, PHY Task Group: Session #4 Evaluation Table

#	Criterion	Discussion
1	*Meets system requirements*	*How well does the proposed PHY protocol meet the requirements described in the current version of the 802.16 System Requirements (Document IEEE 802.16s0-99/n)? This document can be found at: < http://grouper.ieee.org/groups/802/16/sysreq/contributions/80216s0.pdf >* The proposed PHY implementation is believed to meet all system requirements. The frame structure, which is tailored to transport of ATM cells, allows ATM protocols to be efficiently transported. The ATM approach allows implementation of all services required in the system requirements specification at the required QoS values.
2	*Spectrum efficiency*	*Defined in terms of single sector capacity assuming all available spectrum is being utilized (either in terms of Gbps/Available Spectrum or in terms of Mbps/MHz)* The proposed PHY uses QPSK, which has an over-the-air efficiency of 2 bits/sec/Hz and an extremely low E_b/N_0 level, which enables frequency reuse between sectors. With an 88% frequency reuse per sector in a four sector node, the effective spectral efficiency is 7 bits per second/Hz/cell.
3	*Simplicity of implementation*	*How well does the proposed PHY allow for simple implementation or how does it leverage on existing technologies?* QPSK is one of the simplest digital modulation methods that can be used. QPSK is also highly tolerant to amplifier non-linearity, amplitude distortions, phase-distortion, and phase noise, which makes implementation of many parts in the transmitter and receiver relatively simple. QPSK also tolerates the smallest C/(N+I) ratio for a given BER when compared with other digital modulation methods. The low ratio allows lower power transmitters and lower gain antennas to be used. The low ratio also allows higher cross-polarization and operation in more interference, which enables frequency re-use.
4	*CPE cost optimization*	*How does the proposed PHY affect CPE cost?* The proposed PHY results in a relatively low CPE cost because modems are readily available and are being manufactured in high volumes for the European Satellite TV distribution systems.
5	*Spectrum resource flexibility*	*Flexibility in the use of the frequency band (i.e., minimum frequency band required to operate and migration capabilities)* Maximum flexibility is maintained by the proposed approach. Channel frequencies and Channel bandwidths are left unspecified. The only recommended limitation for full duplex systems is to designate sub-bands for hub and sub transmissions.
6	*System diversity flexibility*	*How flexible is the proposed PHY to any other system variations and future technology improvements or new services?* The proposed PHY is essentially independent of applications. The frame structure for the PHY is sized to efficiently support ATM cells.

#	Criterion	Discussion
7	*Protocol Interfacing complexity*	*Interaction with other layers of the protocol, specifically MAC and NMS* A MAC layer is expected to control the PHY. The PHY is expected to communicate directly with the NMS for such operations as provisioning, maintenance, and diagnostics. However, the NMS interface to the PHY is outside the scope of the 802.16.1 Air Interface Standard.
8	*Implication on other network interfaces*	*Intrinsic transport efficiency of telecomm and datacomm services* The transport efficiency is optimized for transport of ATM mid-layer protocols. IP and voice applications run efficiently on top of ATM using methods defined in IETF recommendations.
9	*Reference system gain**	*Sector coverage performance for a typical BWA deployment scenario (supply, reference system gain)* Because of the relatively low E_b/N_0 of QPSK, the proposed approach works with a relatively low E_b. System gain is directly proportional to E_b; therefore, the proposed approach requires the least system gain.
10	*Robustness to interference*	*Resistance to intra-system interference (i.e., frequency re-use) and external interference cause by other systems* Because of the relatively low E_b/N_0 (equivalent C/(N+I)) of QPSK, the proposed approach is about the most robust approach that can be selected.
11	*Robustness to channel impairments*	*Rain fading, multipath, atmospheric effects* Because of the relatively low E_b/N_0 of QPSK, the proposed approach is about the most robust approach that can be selected.

** In order to compare between PHY proposals, we define the reference system gain (RSG) as the output power of the transmitter minus the receiver threshold at a given working point, including back-off required for proper transmission. We will assume a 0 dBW transmitter (prior to back-off), and an ideal LNA (0 dB NF) and BER of* 10^{-6} *post coding.*