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Title	Initial PHY Layer System Proposal for Sub 11 GHz BWA	
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Source(s)	Anader Benyamin-Seeyar Harris Corporation Inc. 3 Hotel de Ville Dollard-des-Ormeaux, Quebec, Canada. H9B 3G4	Voice: (514) 822-2014 Fax: (514) 421-3756 mailto:abenyami@harris.com
Re:	This contribution is submitted in response to “Call for Contributions: Session #10” by 802.16.3 Task Group chair on Sept. 15 th , 2000 for submission of “Initial PHY Proposals” for Sub 11 GHz BWA.	
Abstract	This document provides an initial PHY system proposal of a low frequency (Sub 11 GHz) wireless access PHY for point-to-multipoint voice, video and data applications. The submission is for consideration of the Task Group to develop a PHY standard for BWA system.	
Purpose	This contribution will be presented and discussed within the Task Group in Session #10 for possible adoption as baseline for a PHY standard Sub 11 GHz BWA systems.	
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Initial PHY Layer Proposal for Sub 11 GHz BWA Systems

Anader Benyamin-Seeyar
Harris Corporation Inc.

1.0 Background:

Fixed broadband wireless access (BWA) is a communication system that provides digital two-way voice, data, and video services. The BWA market targets wireless multimedia services to home offices, small- and medium-sized businesses and residences. The BWA system shall be a point-to-multipoint architecture comprising of Subscriber Stations and Base Stations (Hub station).

2.0 Introduction:

The proposed PHY system adopts TDM/TDMA bandwidth sharing scheme. The signal is transmitted downstream from the Base Station to all Subscriber Stations assigned to a frequency carrier in Time Division Multiplex (TDM) mode. The upstream signal is burst from the Subscriber Station sharing the same RF carrier with other Subscriber Stations to the Base Station in Time Division Multiple Access (TDMA) mode. This access scheme can be applied to either FDD or TDD. Both duplexing schemes have intrinsic advantages and disadvantages, so the optimum duplexing scheme to be applied depends on deployment-specific characteristics, i.e., bandwidth availability, Tx-to-Rx spacing, traffic models, and cost objectives.

Operating frequency band will be 2 to 11 GHz and the Base Station uses multiple sectors and will support smart antenna for future.

The PHY layer shall use optionally a single carrier modulation or Orthogonal Frequency Division Modulation (OFDM) technology to combat the Non-line of Sight (NLOS) problem that may arise in 2.5 and 3.5 GHz bands.

3.0 Proposed PHY Layer Reference model

Figures 1 and 2 illustrate block diagram of the proposed PHY layer and the PHY Layer Protocol with upper layers stack respectively.

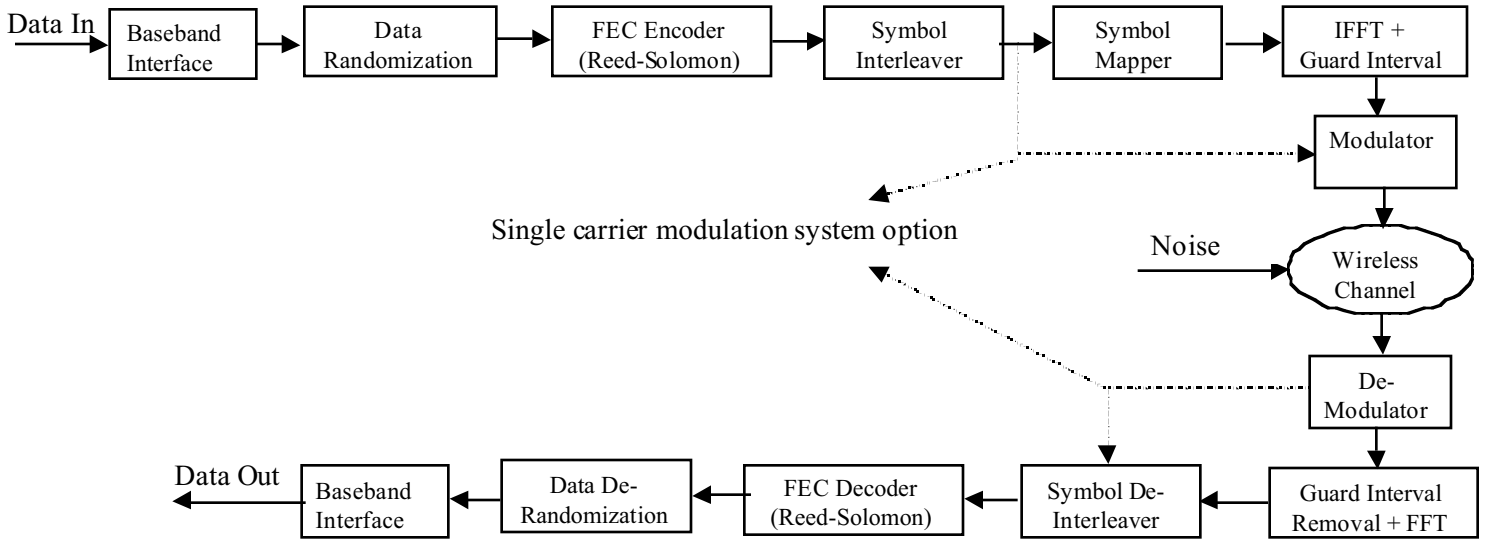


Figure 1: The Proposed PHY Layer Block Diagram.

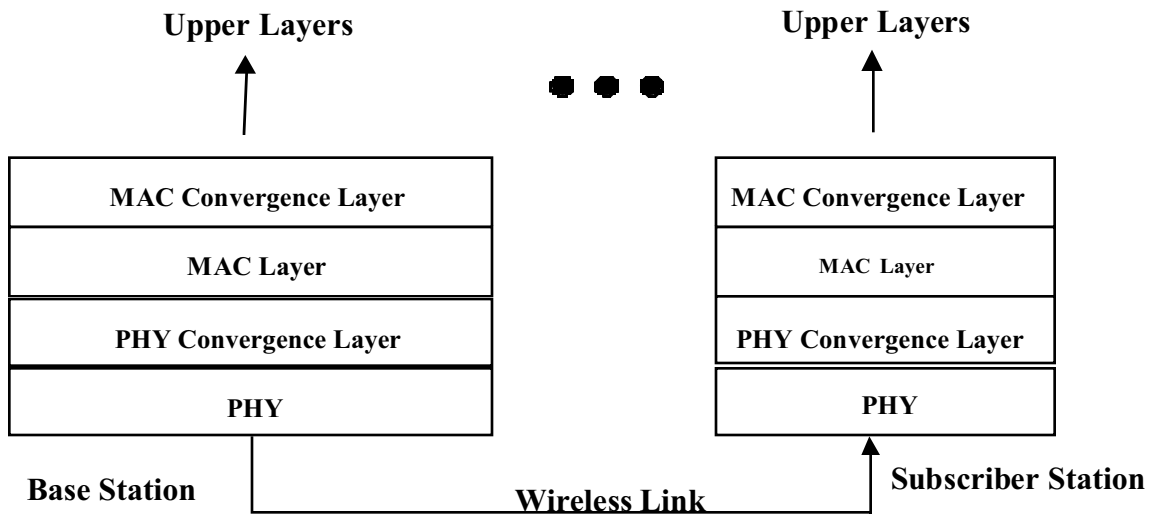


Figure 2: The proposed PHY Layer with upper layers protocol stack.

4.0 The PHY Layer Proposal

This section describes the main functions of the PHY layer. The PHY is a broadband wireless Point-to-Multipoint communication system that provides digital two-way voice, data, Internet and video services. Proposed PHY shall offer an effective “last mile” alternative to traditional wire line services.

The BWA system will support various services; such as packet data and Constant Bit Rate (CBR) services as well as T1, E1, POTS, wideband audio and video.

To maximize the utilization of limited spectrum resources in the low frequency bands (2 to 11 GHz), the air-interface supports statistical multiplexing over the air-interface using Time Division Multiple Access (TDMA) technology.

The main features of the proposal are the following:

- Multiple access Scheme is TDMA.
- Duplex schemes are both the TDD and FDD.
- Base Station uses multiple sector antenna.
- Support for future use of smart antenna.
- High capacity single carrier transmission.
- Addition of OFDM for the PHY robustness against various channel impairments.
- A flexible PHY for coverage, in the use of frequency band, and capacity allocation.
- Obtain a low cost Subscriber Station and the Base Station solution.

4.1 WHY TDMA?

- CDMA is best-suited access scheme for mobile cellular communications where the user behavior will change dynamically. CDMA systems simplify frequency planning and hand-over in mobile environments, but it places demands on the frequency bandwidth. CDMA is well suitable in unregulated ISM band. But for Fixed wireless application, where it is expected to deliver high data rates (tenths of Mb/s) within a limited bandwidth allocation, the benefit of CDMA becomes minimal mainly due to too much bandwidth requirements.
- FDMA systems are best suited for fixed capacity allocation, and therefore, FDMA is not optimal solution for bursty type traffic. Today, FDMA systems may require expensive Base Stations with multiple number of modem banks.
- TDMA systems can be designed to handle very fast, dynamic-capacity allocation, which is the requirement for statistical multiplexing of bursty traffic sources.

As packet –switched traffic is becoming more predominant in the small and medium-sized business sector, which will benefit from the advantages of statistical multiplexing of TDMA system [2]. The TDMA scheme seems to be the only access scheme that best suited to comply with the Functional requirements (IEEE802.16.3 FRD).

4.2 Why TDD or FDD?

- **TDD:** In Time division duplex (TDD) systems, the radio frame is divided into a downlink and an uplink section, offering flexible allocation of the upstream and downstream capacity. In BWA system, where the delay between transmission and reception can consist of a few time slots, a guard time between the downlink and uplink sections of the frames has to be introduced in order to avoid collision between time slots. However, the guard time reduces system throughput, especially if the system is designed for low latency.
- **FDD:** In Frequency division duplex (FDD) systems, on the other hand, allocate a fixed proportion between uplink and downlink capacity. Residential users are likely to request asymmetrical uplink and downlink capacity, while in a business-user scenario, more symmetrical traffic behavior is likely to be the rule. The current Harris BWA system is designed as an FDD system with full flexibility for instantaneous capacity allocation in the uplink and downlink for each access terminal and connection and is primarily addressing the business market segment.

In order to comply with the IEEE802.16.3 functional requirement [1], we propose the support of TDD and FDD systems and leave the selection of each system to the vendors /operators decision on implementation complexity, traffic scenario and cost objectives.

4.3 Modulation Scheme and System Capacity

4.3.1 Modulation:

The proposed BWA system shall use 16QAM or 64 QAM modulation for the downstream transmission, and QPSK or 16 QAM modulation for the upstream transmission.

4.3.2 OFDM:

Multi-carrier techniques like OFDM split a high-rate data-stream into number of lower rate streams that are transmitted simultaneously over several sub-carriers. That is, creating several parallel narrow-band sub-channels. Therefore, the symbol duration increases for the lower rate parallel subcarriers, the relative amount of dispersion in time caused by multipath delay spread is decreased. Intersymbol interference (ISI) is eliminated almost completely by introducing a guard time in every OFDM symbol. In the guard time, the OFDM symbol is cyclically extended to avoid Intercarrier interference (ICI) [3].

With OFDM a number of parameters are up for consideration, such as;

- the number of subcarriers,
- guard time,
- symbol duration, subcarrier spacing modulation type per carrier, and
- the type of FEC coding.

It is proven OFDM to be superior in performance than single carrier modulation techniques when the channels of communication suffer from deep multi-path fading in addition to the usual AWGN noise. In a single-carrier system, the implementation complexity is dominated by the requirement of equalisation, which is necessary when the delay spread is larger than about 10% of the symbol duration. OFDM does not require an equaliser. Instead, the complexity of an OFDM system is largely determined by the FFT, which is used to demodulate the various subcarriers. Another complexity advantage of OFDM is the fact that the FFT does not really require full multiplication, but rather phase rotations, which can be efficiently implemented by the CORDIC algorithm [3]. In fact, the technology is advancing rather rapidly in this area.

Though OFDM out performs single carrier modulation systems, we should emphasise that OFDM imposes stricter constraints on the analog blocks due to its large Peak-to-Average power (PAP) ratio characteristics and its sensitivity to carrier frequency offset and phase noise. Thus, for alleviate the frequency offsets between transmitter and receiver must use an accurate AFC circuitry, otherwise the sub-carriers will no longer be **orthogonal**. Synchronisation of multi-carrier scheme is much more difficult than single carrier. In addition, OFDM with large number of sub-carriers, the combined signal has a very large PAP and to maintain linearity over the range, the power amplifier will require back-off as much as 10dB.

The Proposed OFDM System:

- It seems natural to use OFDM based PHY protocol to get the best performance from BWA systems. In addition, the use of several code rates and different symbol sets like QPSK, 16QAM and 64 QAM provides the capability to scale the data rates without changing the signalling rate.
- Number of Subcarriers = TBD
- Length of Guard interval (GI) = TBD
- Number of pilot carriers per OFDM symbol = TBD

4.3.3 Capacity:

Table 1 shows the BWA PHY with Downstream and Upstream modulation schemes and the corresponding system capacity. The aggregate transmission bit rate is optimised based on several constraints. These are:

- The allocated channel bandwidth;
- The modulation level;
- The spectrum shaping filter bandwidth with roll factor of $\beta = 0.15$ to 0.25 ;
- The FEC coding scheme(Reed-Solomon (n, k) over $GF(2^8)$);
- The requirement of upstream time tick for the Mini-slots burst duration; and
- Processing power limitation of available chips to be used.

Table 1 presents an example of achievable system capacity.

Table 1: An example of System Capacity Objectives.

Channel Spacing	Downstream Transmission		Upstream Transmission	
	Rate (Mb/s)		Rate (Mb/s)	
	(16 QAM)	(64 QAM)	(QPSK)	(16 QAM)
3.5 MHz	11.84 Mb/s	17.76 Mb/s	5.12 Mb/s	10.24 Mb/s
5 MHz	16.90 Mb/s	25.34 Mb/s	8.00 Mb/s	16.00 Mb/s
6 MHz	20.22 Mb/s	30.34 Mb/s	9.60 Mb/s	19.20 Mb/s
7 MHz	23.68 Mb/s	35.52 Mb/s	10.24 Mb/s	20.48 Mb/s

1) UpStream TDMA Channels

The Upstream Channel is characterised by many transmitters (Subscriber Stations, SS) and one receiver (Base Station, BS). Time in the upstream channel is slotted, providing for Time Division Multiple Access (TDMA) at regulated time ticks.

A single carrier for each TDMA channel is used. All Subscriber Stations will communicate with their respective Base Station for bandwidth allocations. Each Subscriber Station will be allowed to use one or more of the TDMA time slots for their channel requests and data transmissions. The received TDMA signals at the Base Station will be bandpass-filtered to reject out of band interference signal (3.5, 5, 6, or 7 MHz). The gain of the Upstream link at the Base Station will be trimmed by amplification and/or attenuation in order to meet the dynamic range interface of the demodulators.

2) DownStream TDM Modulation Path

Each downstream RF channel (e.g., 6 MHz wide) is subdivided into fixed frames and size time slots and each RF carrier is suitability modulated (e.g., 16 QAM or 64 QAM) to provide a digital bit stream (e.g., 30 to 40 Mbps). Within each RF channel a frame structure is used to organise and schedule the transmission of voice, video and data traffic.

4.4: The frequency range and the channel bandwidth

The frequency range and the channel bandwidth of the Proposed PHY system are given below.

Table 2: Frequency Bands and Channel Bandwidth

Frequency Bands	Channel Bandwidth	Reference
a) 2.5 GHz	6 MHz	FCC 47 CFR 21.901 (MDS) FCC 47 CFR 74.902 (ITFS, MMDS) Industry Canada SRSP-302.5 (Fixed Services operating in the 2500 to 2686 MHz band)
b) 3.5 GHz	5, 7 MHz	EN 301 021, CEPT/ERC Rec. 14-03 E, CEPT/ERC Rec. 12-08 E, Others: TBD
c) 10.5 GHz	3.5, 5 and 7 MHz	EN 301 021, CEPT/ERC Rec. 12-05 E

Smart Antenna:

The PHY layer shall support future application of smart antenna for primary feature of providing the ability to track the line of sight target within a predetermined angle of uncertainty. Typically, one would expect 3 or more degrees of tracking. This active tracking capability of smart antenna will potentially provide better coexistence and will optimise the antenna pattern (transmit where the subscriber are located).

Benefits of the Proposed PHY:

The main advantage of the proposed PHY is its flexibility covering current and developing technologies. In addition, it fulfils are the functional requirements of the TG3 document.

Similarity with other standards:

The proposed PHY is similar to some extend with TG1 PHY (supporting TDMA multiple access, both TDD and FDD, QPSK/m-QAM, and FEC coding), to some degree with DOCSIS (supporting TDMA multiple access, QPSK/m-QAM, and FEC coding), and to some degree with IEEE802.11 (for supporting OFDM).

Table 3: Compliance with the Evaluation Criteria Table:

Meets system requirements	This proposal is believed to meet the requirements described in the current version of TG3 FRD.
Channel spectrum efficiency	The average of bps /Hz in a typical deployment (TDD or FDD) is about 3 bps/Hz. In FDD mode, the spectrum efficiency of the system ranges from 1.46 for QPSK and to 2.9 bps/Hz for 16 QAM modulation for the Uplink. For the Downlink, 3.38 for 16-QAm and to 5.0 bps/Hz for 64 QAM modulation.
Simplicity of implementation	The major functions of the proposed PHY (i.e., QAM, FEC and OFDM) are well known or they are becoming available technologies and do require complex implementations.
SS cost optimization	Similarity that exists between this proposal with other standards mentioned above, will facilitate the availability of chip-sets to be used for the SS with lower cost.
BS cost optimization	The use of OFDM at the BS can be a drawback from the complexity and PA Back-off requirements, but this feature will be advantageous for future addition of Smart antenna capability to the system.
Spectrum resource flexibility	The proposed PHY can be scaled to any channel spacing. Modem bit rate can be easily modified to support 10 to 40 Mbps.
Channel Rate Flexibility	This data rate scalability can be obtained by changing FEC code rate and modulation scheme. The changes will have to meet the specified QoS in the FRD.
System service flexibility	The proposed PHY in conjunction with MAC layer will support various services defined within FRD that may require variable data rates and with different QoS requirements.
Protocol interfacing complexity	The proposed PHY will efficiently carry variable length packets and will comply with the delay and speed requirements by upper protocol layers.

Reference system gain	<p>In order to achieve a 10^{-6} BER excluding FEC, 13.5 dB S/N ratio is required for QPSK and 21 dB S/N ratio for the 16 QAM. The transmit power depend on the SS and BS frequency band and data rate (for Upstream varies between 14 dBm to 25 dBm and for the Downstream between 29.5 dBm to 37 dBm).</p> <p>The system gain for 16QAM, 3.5GHz band, and 3.5 MHz BW Gain=103.5 and</p> <p>The system gain for 16QAM, 10.5GHz band, and 3.5 MHz BW Gain=96.5.</p>
Robustness to interference	The proposed PHY uses powerful coding scheme with interleaving and good interference rejection capabilities.
Robustness to channel impairments	The multi-path robustness of OFDM an important capability of the system and it reduces (almost removes) the impact of small and large scale fading.
Robustness to radio	The proposed PHY has the capability to support multiple data rates, modulations, and power control circuitry. When the radio channel attenuation becomes severe, then through the MAC control loop, the PHY system can re-adjust the transmission level to the appropriate level to keep the good quality of service intact.
Support of advanced antenna techniques	The proposal supports the need for advanced antenna techniques such as smart antenna into the standard. This feature, in conjunction with OFDM can be powerful feature for the system.
Compatibility with existing standards and regulations	This proposal is compliant with ETSI, FCC, and other existing standards and regulations as provided in Table 2.

Statement on Intellectual Property Rights:

Harris Corporation Inc., has read this document and the IEEE patent policy and agree to abide by its terms.

References:

- [1] IEEE802.16.3-00/02r4, "Functional Requirements for the 802.16.3 Interoperability Standard", dated 2000-09-22.
- [2] A. Bolle, O, Eriksson and A. Nascimbene, "Competitive broadband access via microwave technology", Ericsson Review, No. 4, 1998.
- [3] R. Van Nee and R. Prasada, "OFDM for Wireless Multimedia Communications", Artech House Publisher, year 2000.