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A Comparative Study of Wireless Protocols Bandwidth-Efficient Wpan OFDM Protocol with Applications to UWB Communications

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ABSTRACT: This paper investigates the Multi-band OFDM (MB-OFDM) based Ultra-Wideband for working group on short-range high data-rate Ultra-wide-Band (UWB) communications. An overview of the MB-OFDM PHY layer architecture with its various parameters is presented and the optimal choice of critical parameters is discussed. Next, we derive the theoretical un coded bit error rate (BER) of MB-OFDM over the fading channel. Performance results over realistic UWB channel models are analyzed and compared to a pulsed-OFDM based approach. Although pulsed- OFDM was presented in the literature as an enhancement to the MB-OFDM approach, simulation results showed that with same redundancy factor, both systems address almost similar BER performance.

Keywords: Multi-band-OFDM, Pulsed-MB-OFDM, Ultra-wide-Band (UWB) Communications system

I. INTRODUCTION

Recent advances in consumer electronics (camcorders, DVD players, wireless USB's etc.) have created a great need for wireless communications at very high data rates over short distances. Ultra-wide-Band (UWB) systems have shown their ability to satisfy such needs by providing data rates of several hundred Mbps [1]. In 2002, the Federal Communications Commission (FCC) allocated a large spectral mask from 3.1 GHz to 10.6 GHz for unlicensed use of commercial UWB communication devices [2]. Since then, UWB systems have gained high interest in both academic and industrial research community UWB was first used to directly modulate an impulse like waveform with very short duration occupying several GHz of bandwidth. Two examples of such systems are Time-Hopping Pulse Position Modulation (TH-PPM) introduced in [3] and Direct-Sequence UWB (DS-UWB) [4]. Employing these traditional UWB techniques over the whole allocated band has many disadvantages including need for high complexity Rake receivers to capture multipath energy, high speed analog to digital converters (ADC) and high power consumptions. These considerations motivated a shift in UWB system design from initial 'Single-band' radio that occupies the whole allocated spectrum in favor of 'Multi-band' design approach [5]. Multi-banding' consists in dividing the available UWB spectrum into several sub-bands, each one occupying approximately 500 MHz (minimum bandwidth for a UWB system according to FCC definition). By interleaving symbols across different sub-bands, UWB system can still maintain the same transmit power as if it was using the entire bandwidth. Narrower sub-band bandwidths also relaxes the requirement on sampling rates of ADCs consequently enhancing digital processing capability. Multiband-OFDM (MB-OFDM) [5]-[6] is one of the promising candidates for PHY layer of short-range high data-rate UWB communications. It combines Orthogonal frequency division Multiplexing (OFDM) with the above multi-band approach enabling UWB transmission to inherit all the strength of OFDM technique which has already been proven for wireless communications (ADSL, DVB, 802.11a, 802.16.a, etc.). For that reasons MB-OFDM was proposed for the PHY layer within IEEE 802.15.3a that covers UWB communication in a wireless personal area network (WPAN).The objective of this paper is to investigate the performance of the MB-OFDM based PHY layer over IEEE UWB channel models [7] and to make comparison with a competitive pulsed-MB-OFDM approach [8]. Optimal choice of some critical system parameters like Cyclic Prefix (CP) length and number of sub carriers (IFFT/FFT size) is also discussed.

The first section gives a brief introduction to UWB technology. Section 2 presents the architecture and parameters of the MB-OFDM transceiver with discussion over optimal choice of parameters. We also derive the theoretical bit error rate (BER) of MB-OFDM over Rayleigh fading channels.

Section 3 describes the UWB channel model proposed by IEEE channel modeling sub-committee that we used in our simulations. Section 4 gives BER performance results of MB-OFDM on various UWB channel environments. Pulsed-MB-OFDM [8] approach will be introduced in section 5 along with its performance comparison to MB-OFDM.

II. UWB DEFINITION

According to the FCC definition [1], a UWB device is any device where the fractional bandwidth is greater than 25% of its center frequency or occupies 1.5 GHz, whichever is less. The fractional bandwidth is defined The essence of this ruling is to limit the power spectral density (PSD) measured in a 1– MHz bandwidth at the output of an isotropic transmit antenna to that shown in Fig. 1. The above spectral mask allows UWB-enabled devices to overlay existing systems while ensuring sufficient attenuation to limit adjacent channel interference. Additional PSD limits have been placed below 2 GHz to protect critical applications such as global positioning system (GPS) as shown. The first consequence of this spectral mask imposed by the FCC is to render the use of baseband pulse shapes difficult without additional transmit filtering to limit the out-of-band emission spectra

.The increasing rate of wireless communication, demand the efficient and quality oriented process for transmitter and receiver. Analysis of transmitter or receiver diversity has been conducted over the last several decades to characterize the performance of different diversity-combining methods for different numbers of antennas and different fading distributions. For a point-to-point communication link without CCI, it is well-known that maximal-ratio combining (MRC) is the optimal combining technique in terms of maximizing the signal-to-noise power ratio (SNR) at the combined output. Several recent works have investigated the performance of MRC.

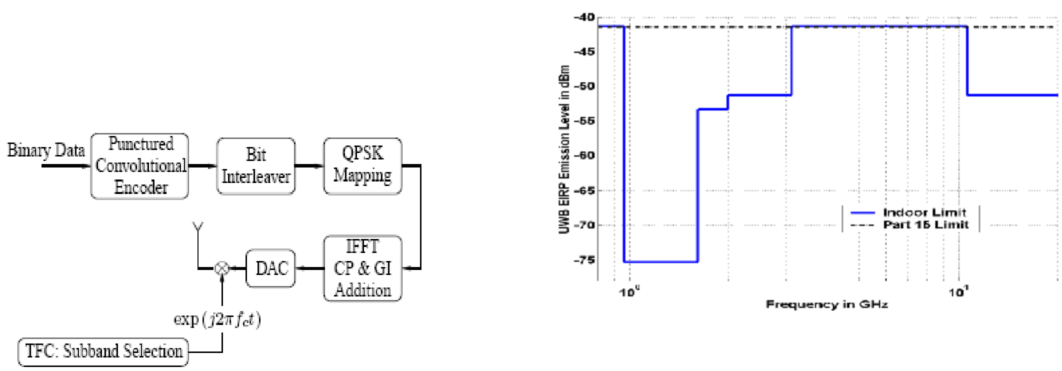

Fig. 1. UWB Communications.

In summary, UWB communications is allowed at a very low average transmit power4 compared to more conventional (narrowband) systems that effectively restricts UWB to short ranges. UWB is, thus, a candidate physical layer mechanism for IEEE 802.15Wireless Personal Area Network (WPAN) for short- range high-rate connectivity that complements other wireless technologies in terms of link ranges.

III. Overview of MB-OFDM based PHY Layer

A. System Architecture and Parameters

A multi-band OFDM system [5, 6, 9] divides the available bandwidth into smaller non-overlapping sub-bands such that the bandwidth of a single sub-band is still greater than 500MHz (FCC requirement for a UWB system). The system is denoted as an 'UWB-OFDM' system because OFDM operates over a very wide bandwidth, much larger than the bandwidth of conventional OFDM systems. OFDM symbols are transmitted using one of the sub-bands in a particular time-slot. The sub-band selection at each time-slot is determined by a Time-Frequency Code (TFC). The TFC is used not only to provide frequency diversity in the system but also to distinguish between multiple users. The proposed UWB system utilizes five sub- band groups formed with 3 frequency bands (called a band group) and TFC to interleave and spread coded data over 3 frequency bands. Four such band groups with 3 bands each and one band group with 2 bands are defined within the UWB spectrum mask (Fig. 2). There are also 4 3-band TFCs and 2 2-band TFCs, which, when combined with the appropriate band groups provide the capability to define eighteen separate logical channels or independent piconets.

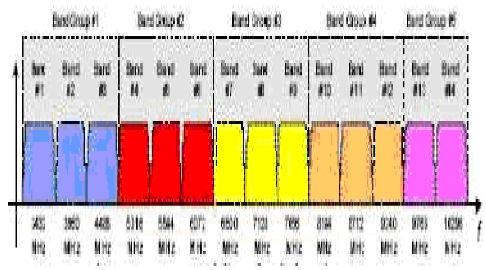

Fig. 2. 1.584GHz (3.168-4.752 GHz) 528MHz each.

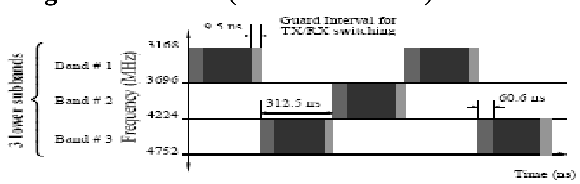

Fig. 3. Example of Time-Frequency Code in MB-OFDM system.

Devices operating in band group #1 (the three lowest frequency bands) are selected for the mandatory mode. There are many advantages associated with using the 'MB-OFDM' approach. This includes the ability to efficiently capture multipath energy, simplified transceiver architecture, enhanced frequency diversity, increased interference mitigation capability and spectral flexibility to avoid low quality sub-bands and to cope with local regulations. The TX and RX architecture of an MB-OFDM system is very similar to that of a conventional wireless OFDM system. The main difference provides TX with a different carrier frequency at each time-slot, corresponding to one of the center frequencies of different sub-bands. Figure 3 shows the presence of a time-frequency kernel in a typical OFDM TX architecture. In the case of figure 3, time-frequency kernel produces carriers with frequencies of 3.432MHz, 3.960MHz or 4.488MHz, corresponding to center frequency of sub-band 1, 2 and 3. The MB-OFDM based UWB PHY layer proposal [9] submitted to IEEE 802.15.3a working sub-committee for WPANs specifies parameters for different modules of PHY layer From the total available bandwidth of 7.5GHz (3.1-10.6 GHz), usage of 1.5GHz (3.1-4.75 GHz) is set mandatory for all MB-OFDM devices. Although sub-band bandwidth is required to be greater than 500 MHz (FCC requirement as stated earlier), hardware constraints impose using as narrow bandwidth as possible. Hence, a sub-band of 528 MHz was proposed in [6], because it can be generated using simpler synthesizer circuits. To reduce hardware complexity, the internal precision of the digital logic and DAC was limited by using QPSK for constellation mapping. Different channel coding rates (using 1/3 convolution coding and puncturing), time and frequency domain spreading of factor 2, are employed to generate data rates of 55, 80, 110, 160, 200, 320 and 480 Mbps. Frequency-domain spreading, consists in transmitting twice the same information in a single OFDM symbol. It introduces a spreading factor of 2 and results in intra-sub-band frequency diversity. On the other hand, time-domain spreading is obtained by repeating the same OFDM symbol over different sub-bands and hence, it results in inter-sub-band frequency diversity. A 128 point IFFT/FFT is used along with a short cyclic prefix (CP) length of 60.6 ns. Also, total OFDM symbol duration of 312.5 ns occupying 528 MHz (fig. 3) which is sent through the UWB channel. Under the assumption that the cyclic prefix is long enough, no Doppler shift and linear hardware, the OFDM transmission chain can be modeled by the independent sub carrier fading model. Then the received signal on sub carrier k can be modeled with complex base band representation as by a convolution encoder. Then the encoded bits are interleaved by a random interleaver. The QPSK modulator creates the complex symbols sequence which are modulated by an OFDM modulator implemented by an IFFT. After adding cyclic prefix and guard interval, the time domain signal is sent through the UWB channel with respect to the TFC described above. The IEEE UWB channel model is supposed constant during the transmission of one packet and no time variability is present within one packet. For each packet a different channel realization is used within 100 channel realization. Fortunately, the UWB channel is highly frequency selective which creates the opportunity to use error control coding and frequency diversity techniques in order to increase the quality of service.

IV. OPTIMAL CHOICE OF CRITICAL PARAMETERS

Two critical parameters in the MB-OFDM PHY layer, that greatly influence overall system complexity and performance, are the number of subcarriers (N_{sub}) or FFT size and the cyclic prefix duration (T_{cp}).

Here, we will try to find out their most suitable values for the MB-OFDM system. N sub must be set with respect to the factor B c /B sub, where Bc is the channel coherence bandwidth and B sub is the subcarrier bandwidth of the MB-OFDM system should be greater than 1 in order to allow flat-fading over each sub-channel. Table 1 provides the value of factor calculated for different FFT sizes in all four IEEE proposed channel environments when the OFDM symbol occupies a bandwidth of 528 MHz in the frequency range of 3.1-4.75 GHz.

Table 1. Coherence to sub carrier bandwidth ratio.

Channel	CM1	CM2	CM3	CM4
Bc	8.9 MHz	8.25 MHz	4.5 MHz	2.7 MHz
for 64 point FFT	1.078	1	0.545	0.327
for 128 point FFT	2.157	2	1.09	0.6545
for 256 point FFT	4.315	4	2.18	1.309

The above table clearly shows that is always greater than 1 when a 256 point FFT is used. However, the number of complex multiplications per nanosecond for a 64, 128 and 256 point FFT are respectively 0.614, 1.433 and 3.27. Since the MB-OFDM is targeted toward portable and handheld devices, an FFT size of 256 point is too complex for low-cost low-complexity solutions. This shows that the best compromise between performance and complexity is made with an FFT size of 128, which is proposed in [9] and will be used below in our simulations. The CP duration determines the amount of multipath energy captured. Multipath energy not captured during the CP window results in inter-carrier- interference (ICI). We will see in section 2.1 that the UWB channels are highly dispersive, a 4–10-m LOS channel environment has an rms delay spread of 14.28 ns, while the worst case channel environment (CM4) is expected to have an rms delay spread of 25 ns [7]. In [10], it was shown that the optimal value for CP duration in an OFDM system is equal to the delay spread of the channel. In order to minimize the impact of ICI and capture sufficient multipath energy in MB- OFDM systems, the CP duration was chosen to be 60.6 ns (1/4th of useful symbol period) for all channel environments.

V. UWB PROPAGATION CHANNEL MODEL

In order to evaluate different PHY layer proposals, IEEE 802.15.3a channel modeling sub-committee proposed a channel model for realistic UWB environments [7]. During 2002 and 2003, the IEEE 802.15.3 Working Group for Wireless Personal Area Networks, and especially its channel modelling subcommittee decided to use the so called modified

A. MB-OFDM Performance Analysis in Different UWB Channel Scenarios

In this section the performance of the MB-OFDM based PHY layer is evaluated over different indoor UWB channel scenarios as defined in the previous sub-section.

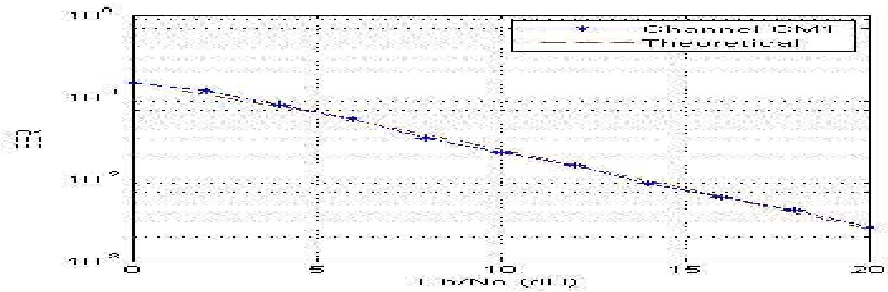

Fig. 4. Theoretical and simulated BER of uncoded MB-OFDM over Rayleigh (theoretical) fading and CM1 (simulation) channels.

We simulated mode 1 of the MB-OFDM based PHY layer proposal [9]. This mode employs three sub-bands of 528 MHz (3.1-4.684 GHz). All simulation results were obtained using a transmission of at least 500 packets with a payload of 1024 bytes each. The proposal is targeting data transmission at rates of 110 Mbps over 10 meters, 220 Mbps over 4 meters and 480 Mbps over 1 meter [12]. The BER must be less.

B. Multi band Pulsed-OFDM System

Multi band pulsed-OFDM uses orthogonal 'pulsed' sub carriers, instead of continuous sub carriers [8]. Pulsed OFDM signal is generated by up-sampling the digital OFDM symbol after IFFT block. Up-sampling Interesting performance results were observed for lowest (55 Mbps) and highest (480 Mbps) data-rate mode, in various channel scenarios. The inherent high frequency-selective nature of UWB channels can be exploited in a positive way by using different diversity-combining techniques. This was observed in the most robust mode (55 Mbps), where channel diversity was fully exploited by employing MRC technique. Thus the MB-OFDM performs better in the CM4 channel environment than in the CM1 channel thanks to its inherent frequency diversity as shown in figure 9. These results comply with those presented in [14]. In 480 Mbps mode, a different behavior was observed. The performance in CM1 was found to be better than in CM4. This is due to the absence of time and frequency-domain spreading and low coding rate that prevents the exploitation of channel diversity.

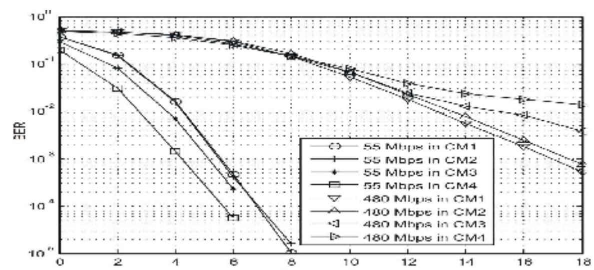

Fig. 5. Performance of 55 and 480 Mbps modes over different channel models.

VI. CONCLUSIONS

MB-OFDM system presents a very good technical solution to be used as UWB PHY layer for short-range high data-rate wireless applications.

Performance results were obtained by simulating an MB-OFDM system over various realistic UWB channel scenarios. We also derived the theoretical BER of uncoded MB-OFDM over Rayleigh fading channels and compared it with simulation results. It was found that severe indoor UWB propagation environments like CM4, being highly frequency-selective in nature, necessitate the usage of diversity combining techniques to achieve target BER of 10 □5 . Also performance comparison was ma with another approach (pulsed-MB-OFDM). We observed that for high SNR values, the latter approach gives slightly better BER results as compared to MB-OFDM system.

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