

COMPARATIVE STUDIES OF MB-OFDM AND DS-UWB WITH CO-EXISTING SYSTEMS IN AWGN CHANNEL

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ABSTRACT

Multiband orthogonal frequency division multiplexing (MB-OFDM) and direct sequence ultra wideband (DS-UWB) systems' performances are studied in interfered AWGN channel. Co-existing systems, i.e., interference, are assumed to be based on the forth-coming 4G. The other source is 100 MHz interference locating at IEEE802.11a band. The published studies related to the comparison between MB-OFDM and DS-UWB in interfering environments seems to be unsubstantial in the literature. Therefore, it is crucial to fill this gap. We focus more on MB-OFDM systems, whereas the DS-UWB is applied as a reference. The studied victim systems share the same frequency band and have similar data rates. Simulation results indicate that MB-OFDM system can slightly tolerate interference to achieve reasonable bit error rate level. DS-UWB achieves similar bit error rate level with higher interference-to-signal power ratio than MB-OFDM is able to do. The center frequency of interference has only minor effect on systems' performances. Increasing the bandwidth of the interference will reduce the performance in the case of MB-OFDM, whereas DS-UWB seems to be quite resilient to it.

I. INTRODUCTION

Recently the demands for high data rate wireless links have been arisen. This is due to the heavier digital imaging and multimedia applications coming to market. Ultra wideband (UWB) is an emerging technology that has been seen to fulfil the requirements for low cost and high-speed digital home networks. UWB technology is providing data rate of 110 Mbps at a distance of 10 m and 480 Mbps at a distance of 2 m [1], but even higher data rates are coming.

The prevailing era of UWB is based on the Federal Communications Commission (FCC) ruling from 2002, when it released the band from 3.1 to 10.6 GHz in USA for UWB use [2]. At the same time, FCC gave a definition to UWB [2]. This decision led to the establishment of Institute of Electrical and Electronic Engineering (IEEE) 802.15 high rate alternative physical layer (PHY) Task Group 3a for wireless personal area networks (WPAN). The task group tried to define a universal standard that has the best features in all manners. By the end of 2003, it was succeeded to merge all the proposals in two: multiband and singleband solutions [3]. However, 19th of January 2006, both parties declared to withdraw their

proposals and take UWB to the market without IEEE 802.15.3a standard [4,5]. This announcement also led to the dissolution of task group 15.3a work.

Literature survey points out that performance study of MB-OFDM without interference is nowadays rather extensive. For example, the performance and sensitivity of MB-OFDM in multipath channels is studied in [6]. The various coding schemes are discussed in [7]. The performance evaluation of MB-OFDM and DS-UWB in AWGN and multipath channels is examined in [8]. In [9], the practical design of MB-OFDM and DS-UWB are discussed.

The impact of interference on DS-UWB system in AWGN channel is also well-studied topic [10,11,12]. In the literature, the interference studies of MB-OFDM in AWGN or multipath channels are, however, unsubstantial. In addition, the comparative studies between MB-OFDM and DS-UWB performances with interference or co-existing systems are inadequate. In this paper, this essential vacuum is partially filled up.

This paper is organized as follows; Section 2 presents the system models for MB-OFDM and DS-UWB. The interference model is also briefly discussed. Section 3 introduces the used simulation parameters and justification for the parameters. Simulation results are presented and discussed in Section 4. Finally, the conclusion is given in Section 5.

II. SYSTEM MODELS

In this section, the general system models for MB-OFDM and DS-UWB are presented.

A. Multiband OFDM

OFDM is a modulation and multiple access technique, and it has been studied over 20 years [13]. In OFDM system, single high rate dataflow is divided into the several low rate flows. Every flow is then mapped to the orthogonal frequencies using the inverse fast Fourier transform (IFFT).

For multiband-OFDM transmission, five frequency groups are specified in [14]. All of these groups are divided into subbands, each having a bandwidth greater than 528 MHz. In the each subband, orthogonal frequency division multiplexing (OFDM) is applied. Frequency hopping (FH) between different bands is supported so that the transmitted signal hops between subbands in every OFDM symbol duration, that is 312.5 ns

[14]. The MB-OFDM spectrum allocation is illustrated in Figure 1 [14]. Each subband contains 128 subcarriers. Ten of these are used as guard tones, twelve of the subcarriers are dedicated to the pilot signals, and 100 are for information. The remaining six tones are set to zero, according to [14].

The system utilizes time-frequency coding (TFC) to interleave data over subbands. As an example in Figure 2, TFC is performed over three OFDM symbols and subbands. 9.47 ns guard intervals are providing sufficient time for transmitter and receiver to switch to the next carrier frequency. [1]

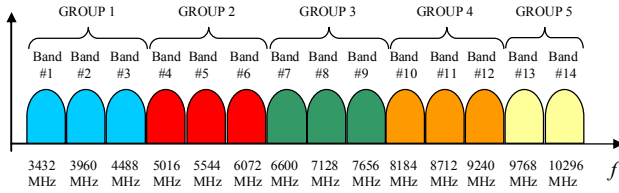


Figure 1. Band allocation for MB-OFDM.

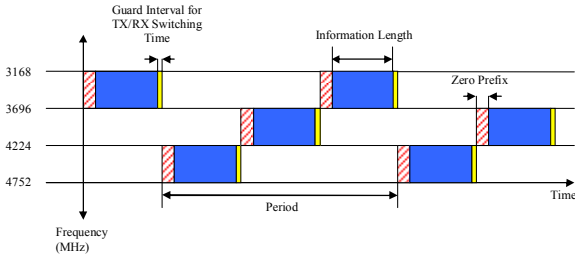


Figure 2. TFC over three OFDM symbols.

In MB-OFDM, quaternary phase shift keying (QPSK) and dual carrier modulation (DCM) are used for data modulation. In QPSK, serial input is divided into groups of two bits and then converted to the complex numbers according to QPSK constellation diagram. In the case of DCM, four bits groups are formed and each group is mapped into 2 different 16-point constellations [15]. The advantage is that the two resulting 16-point symbols are separated by 50 tones. Therefore, the probability that there are deep fades on corresponding tones is very small [15]. The output symbols of DCM modulation can be expressed as [16]

$$\begin{bmatrix} y_n \\ y_{n+50} \end{bmatrix} = \frac{1}{\sqrt{10}} \begin{bmatrix} 2 & 1 \\ 1 & -2 \end{bmatrix} \begin{bmatrix} x_{a(n)} + jx_{a(n)+50} \\ x_{a(n)+1} + jx_{a(n)+51} \end{bmatrix}. \quad (1)$$

In (1), y_n means the n -th output symbol, n having values $0 \dots 49$ and $x_a(n)$ is the input bit defined by $a(n)$

$$a(n) = \begin{cases} 2n & n = 0, 1, \dots, 24 \\ 2n + 50 & n = 25, 26, \dots, 49. \end{cases} \quad (2)$$

MB-OFDM proposal also utilizes the convolutional coding with a coding rate of 1/3, 11/32, 1/2, 5/8 or 3/4. The rate of 1/3 is generated by using the industry-standard generator polynomials, $g_0=133_8$, $g_1=165_8$, $g_2=171_8$. Other coding rates are derived from the rate of 1/3 by employing puncturing [14]. The system also uses three-stage interleaving, and time and frequency domain spreading to mitigate fast fading [15].

B. DS-UWB

In direct sequence UWB, the pulse repetition is applied by using a pseudo random noise code like in conventional direct sequence spread spectrum systems [17], but having a chip waveform generating inherently an ultra wideband spectrum. k th data bit can be attached using binary pulse amplitude modulation (BPAM), and the transmitted signal can then be given as [18]

$$s(t) = \sum_{k=-\infty}^{\infty} \sum_{j=1}^N w(t - kT_d - jT_f) (c_p)_j d_k, \quad (3)$$

where T_d and T_f are data and frame length, respectively, $(c_p)_j$ is a code phase out of N possible code phases, and t is time. Pulse waveform and data are depicted with w and d_k , respectively. Polarity of the transmitted pulse is defined by the chip polarity and data bit [18].

C. Interference

Co-existing systems in this study are assumed to be the forthcoming 4G and an intentional wideband interference locating at IEEE 802.11a wireless local area network (WLAN) band. In the sake of simplicity, the interference is modelled as coloured Gaussian noise (CGN) that is band-limited version of white Gaussian noise [19]. Intentional interference is operating at 5 GHz center frequency, and is occupying 100 MHz bandwidth. The 4G system is assumed to have 4.5 GHz center frequency, and having 100 MHz bandwidth as well.

III. SIMULATION CONFIGURATIONS

In order to evaluate performance of MB-OFDM and DS-UWB, software simulators were developed in Matlab[®]. In this section, the simulating parameters for both systems are presented and justified.

In our studies, MB-OFDM is using the six lowest subbands, thus having correspondence to the fifth, sixth and seventh derivatives of the Gaussian monocycle used in DS-UWB in the name of center frequency and total bandwidth. Hence, the used Gaussian pulse waveforms for DS-UWB are referred as P5, P6 and P7, respectively. These pulse waveforms are selected because they create spectra which are under the UWB radiation mask, which is defined by the FCC [2]. The use of six subbands is deviating from the original proposal from [14], where only three subbands are used. However, this is done to have maximal spectral overlapping with the competing DS-UWB system.

The pulse length and processing gain for DS-UWB are decided to be 0.5 ns and 16 dB, respectively. Processing gain of 16 dB is achieved with pulse repetition coding. Using these values, the information rate of DS-UWB is approximately the lowest rate supported by the MB-OFDM standard, being 53 Mbps [14]. This data rate was also used in MB-OFDM simulations.

Using these assumptions, both the UWB systems are spectrally occupying the same band and having approximately the same data rate. This makes it possible to compare the inherent performances of these two UWB systems under interference.

Modulation schemes for MB-OFDM are QPSK and DCM, according to the proposal [14], whereas DS-UWB applies BPAM. The earlier reported results show that BPAM is a reasonable choice amongst the other studied binary data modulation schemes [12,18]. MB-OFDM utilizes TFC across six bands similarly as is presented in Figure 2; the first symbol is transmitted in the first subband, the second symbol in the second subband, and so on. Detect and avoid mechanism in MB-OFDM system is not used in order to keep the system as simple as possible. On the other hand, in DS-UWB, there is no interference mitigation technique used either.

As was mentioned in Section 2, the interference is modelled as CGN. Interference utilizes center frequencies of 4.5 or 5.0 GHz or using both simultaneously, and applies the bandwidth of 100 MHz. All simulation parameters are brought together in Table 1.

Table 1. Simulation parameters for both studied systems

Parameter	MB-OFDM	DS-UWB
Bands	6	1
Modulation	QPSK and DCM	BPAM
Pulse waveforms	-	P5, P6 and P7
Center frequencies [GHz]	3.42, 3.92, 4.49, 5.02, 5.54, 6.07	4.53, 4.93, 5.38
Center frequency of 6 bands [GHz]	4.75	-
Total bandwidth [GHz]	3.19	4.43, 4.32, 5.38
Pulse length [ns]	-	0.5
Processing gain [dB]	-	16
Information rate [Mbps]	53.3	50.2
Center frequency of interference [GHz]	4.5 or/and 5.0	4.5 or/and 5.0
Bandwidth of interference [MHz]	100	100

In the interference simulations, bit energy-to-noise power density ratio (E_b/N_0) values are selected so that the bit error rate (BER) level of 10^{-4} is obtained in AWGN channel. Whereas, the simulations of BER as a function of interference center frequency (f_{ci}) or bandwidth (W_{bi}) use BER level of 10^{-3} to fix the interference-to-signal power ratio (ISR). In addition, the effect of interference on MB-OFDM system is examined more widely by using the additional ISR values. The used E_b/N_0 and ISR values are collected up to Table 2, where italicized values are additional values to study interference effects on MB-OFDM more widely.

Table 2. E_b/N_0 and ISR values used in simulations

Value	MB-OFDM		DS-UWB		
	QPSK	DCM	P5	P6	P7
E_b/N_0 [dB]	8	11	8	8	8
ISR [dB]	-20, 4, 20	-20, 4, 20	4	4	4

IV. SIMULATION RESULTS

In Figure 3, the systems' reference performances without interference are given as a function of E_b/N_0 . As it can be seen, QPSK and DS-UWB follow nicely the theoretical curve for binary antipodal signal, whereas DCM can be considered as a binary orthogonal modulation. From these reference results, the E_b/N_0 values at the BER level of 10^{-4} for interference simulations are taken, and collected to Table 2.

In Figure 4 and Figure 5, BER results are given as a function of ISR for MB-OFDM and DS-UWB, respectively. Systems' performances are examined by using the interferences having center frequencies of either 4.5 GHz or 5.0 GHz, and using both interferences simultaneously. For the sake of visibility, interference from 5.0 GHz is left out from Figure 4. In Figure 5, only the worst interference case is presented. In the case of MB-OFDM, interference in 5.0 GHz has similar degrading effect to the system performance as 4.5 GHz. The performance increase for DS-UWB at the BER level of 10^{-3} , comparing to the worst case, is approximately 2 dB or 4 dB when using interference from 4.5 GHz or 5.0 GHz, respectively.

In the case of MB-OFDM, ISR can be only as low as -20 dB to assure BER level of 10^{-3} , whereas DS-UWB allows ISR to be 5 dB. On the other hand, MB-OFDM has better BER with very high ISR values, i.e., saturation level. DS-UWB is overtaken by MB-OFDM when ISR is more than 15 dB. Results indicate that for MB-OFDM QPSK is better modulation scheme than DCM when ISR is more than -12 dB. In addition, QPSK has approximately 18 times better BER at $\text{ISR} = 30$ dB than DS-UWB has. In DS-UWB, the order of superiority of pulse waveforms comes up when ISR is from 5 dB to 23 dB. In all cases, P7 seems to be the best one, since its nominal center frequency does not overlap with the interference.

In Table 3 and Table 4, BER saturation levels and ISR values for BER level of 10^{-3} are summarized using different interference schemes, respectively. The processing gain that the system has improves the tolerance against the interference.

The impact of the center frequency of interference on MB-OFDM and DS-UWB are illustrated in Figure 6 and Figure 7, respectively. The x-axes are normalized by using the center frequency of all six bands for MB-OFDM, or applying the nominal center frequencies of different pulse waveforms for DS-UWB. The results indicate that a change in f_{ci} has insignificant influence on MB-OFDM when the normalized center frequency of interference is more than 0.8. When the interference has fixed bandwidth, the same amount of tones is always interfered. By crossing the nominal center frequency of the pulse, the interference reduces DS-UWB performance. It is also noteworthy that increasing ISR from 4 dB to 20 dB does not degrade the BER significantly in MB-OFDM.

When using the BER criterion of 10^{-3} for ISR, the selection of interference bandwidth does not affect the performances of the systems, as is presented in Figure 8. When ISR is its lowest value in the case of MB-OFDM, that is -20 dB, DCM has very similar performance to QPSK. In DS-UWB, P6 is ex-

cluded from figure, but simulation points out that P6 places itself between P5 and P7.

When ISR is increased, the effect of interference bandwidth comes more clearly. The wider is the bandwidth, the bigger is the BER reduction in the case of MB-OFDM. In figures, x-axes are normalized by using the bandwidth of 6 subbands in MB-OFDM, or utilizing the -10 dB total bandwidth in DS-UWB.

Table 3. BER values at ISR of 30 dB for both system concept

System	Scheme	E_b/N_0 [dB]	BER at ISR=30 dB		
			f_j	4.5	5.0
MB-OFDM	QPSK	8	0.019	0.019	0.039
	DCM	11	0.039	0.038	0.076
DS-UWB	P5	8	0.372	0.363	0.417
	P6	8	0.363	0.339	0.372
	P7	8	0.339	0.363	0.437

Table 4. ISR values at BER level of 10^{-3} for both system concepts

System	Scheme	E_b/N_0 [dB]	ISR at BER= 10^{-3} [dB]		
			f_j	4.5	5.0
MB-OFDM	QPSK	8	-19.4	-19.4	-21.3
	DCM	11	-18.8	-18.8	-20.6
DS-UWB	P5	8	4.7	3.3	0.8
	P6	8	5.8	3.9	2.3
	P7	8	7.2	5.1	3.6

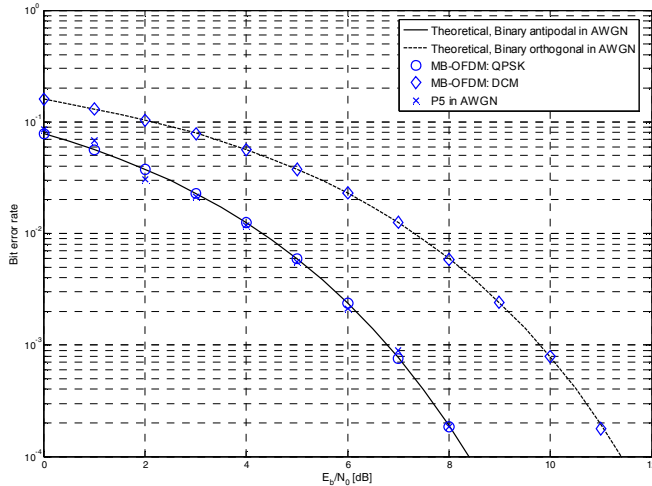


Figure 3. BER as a function of E_b/N_0 for both systems.

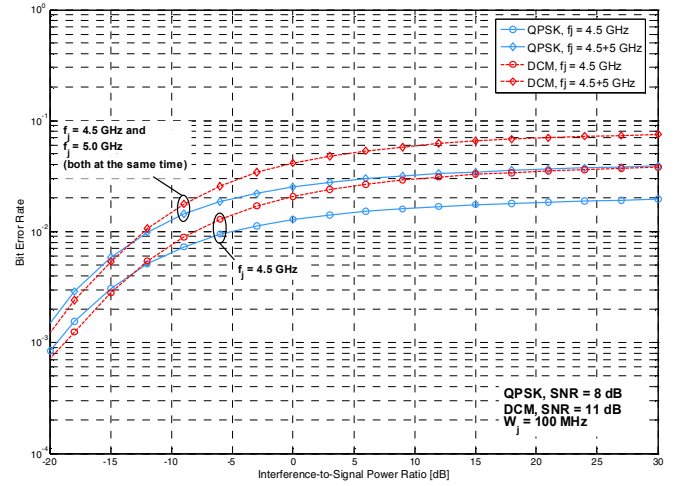


Figure 4. MB-OFDM: BER as a function of ISR.

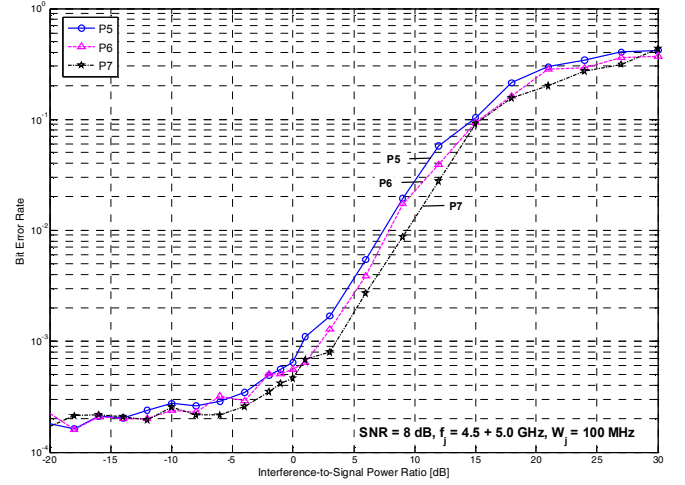


Figure 5. DS-UWB: BER as a function of ISR.

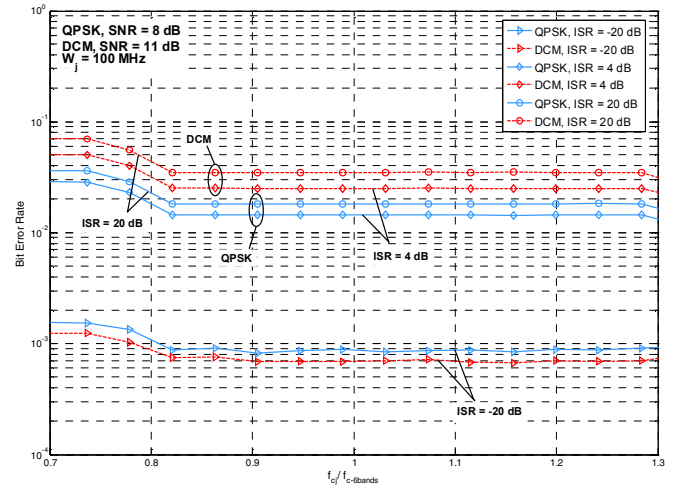
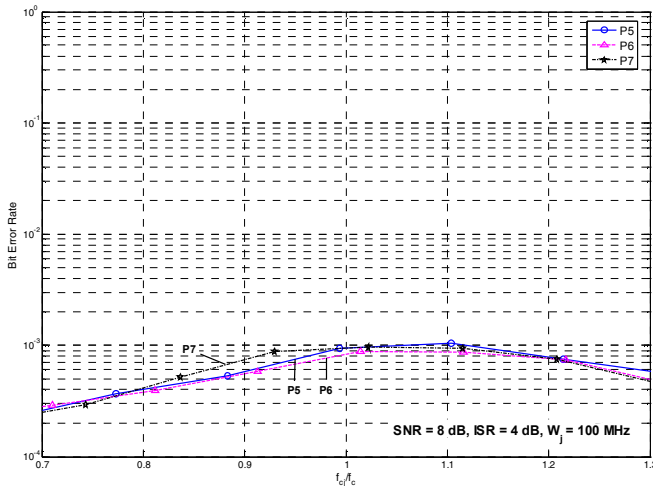
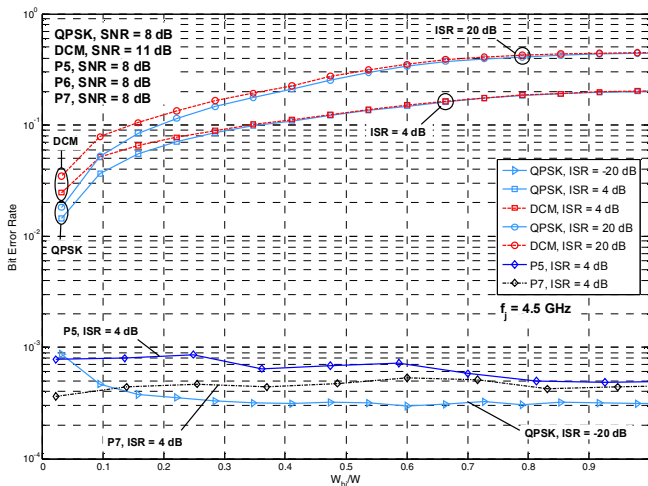


Figure 6. MB-OFDM: BER as a function of $f_c/f_{c-Bands}$.


Figure 7. DS-UWB: BER as a function of f_{cj} .

Figure 8. BER as a function of W_{bj} for both systems.

V. CONCLUSION AND FUTURE WORK

In this paper, two UWB PHY layer solutions for high data rate WPAN were studied in AWGN channel with co-existing systems. Interference simulations indicate that MB-OFDM is better choice when ISR value is more than 15 dB. MB-OFDM seems to tolerate ISR less than -20 dB to achieve reasonable BER level of 10^{-3} , whereas DS-UWB overtakes this level with ISR value of 5 dB. The results indicate that the center frequency of interference has insignificant influence on the MB-OFDM, and has only minor effect on DS-UWB. In addition, with relative high interference power, the increasing bandwidth of interference reduces the MB-OFDM performance more than in DS-UWB.

Next, the similar studies will be carried out and reported using the modified Saleh-Valenzuela channel models [20].

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