PERFORMANCE COMPARISON BETWEEN MB-OFDM AND DS-UWB IN INTERFERED MULTIPATH CHANNELS

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ABSTRACT

Performances of multiband orthogonal frequency division multiplexing (MB-OFDM) and direct sequence based ultra wideband (DS-UWB) systems are studied in interfered multipath channel. The radio channel is based on the modified Saleh-Valenzuela model. The studies related to the comparison between MB-OFDM and DS-UWB within interference seems to be unsubstantial in the literature. Therefore, it is crucial to fill this gap. We focus more on coded MB-OFDM systems, whereas uncoded DS-UWB is applied as a point of comparison. Simulation assumptions are the same spectral allocation and data rate between these two systems. No interference mitigation techniques are applied. Simulation results showed that MB-OFDM system is more sensitive to interference than the corresponding DS-UWB. Uncoded DS-UWB, which is therefore also simpler approach, can give similar performance than coded MB-OFDM in several interfered cases.

INTRODUCTION

In recent years, the demand for high data rate wireless links has arisen, e.g., due to the heavier digital imaging and multimedia applications. Ultra wideband (UWB) is an emerging technology that offers promises to satisfy the requirements of low cost and high-speed digital home networks. UWB technology promises to offer data rate of 110 Mbps at a distance of 10 m and 480 Mbps at a distance of 2 m [1]. The future goals are even higher data rates.

The fundamental decision for exploitation of UWB was made by the Federal Communications Commission (FCC) when it released the band from 3.1 to 10.6 GHz in the USA [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 find universal standard having the best features in all manners. By the end of 2003, it was succeeded to merge proposals to two: multiband and singleband solutions [3]. However, 19th of January 2006, both parties declared to withdraw their proposals and take UWB to market without IEEE 802.15.3a standard [4,5]. This announcement led to the dissolution of the task group 15.3a.

Literature survey points out that the performance studies of MB-OFDM without interference are 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, e.g., [10,11]. In the literature, the interference studies of MB-OFDM in AWGN and multipath channels are, however, unsubstantial. In addition, the comparative studies between MB-OFDM and DS-UWB with interference, or co-existing systems, are missing. In this paper, this essential vacuum is partially filled up by adopting multipath channel, while AWGN is discussed in [12].

This paper is organized as follows; the second section presents the system models for MB-OFDM and DS-UWB. In addition, the interference and channel models are briefly discussed. The third section provides the used simulation parameters and justification for the parameters. Simulation results are presented and discussed in the fourth section. Finally, the paper is concluded in the fifth section.

SYSTEM MODELS

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

Multiband-OFDM

According to [13], multiband-OFDM approach for UWB is based on several subbands, each allocating 528 MHz fraction of the whole UWB band, and applying orthogonal frequency division multiplexing (OFDM). Frequency hopping (FH) between the subbands is also exploited so that the transmitted signal hops between the subbands in every 312.5 ns OFDM symbol period. OFDM is a modulation and multiple access technique, and it has been studied more than 20 years. In OFDM system, single high rate data flow is divided into the several low rate flows. Every flow is mapped to the orthogonal frequencies using the inverse fast Fourier transform (IFFT) [14]. The MB-OFDM spectrum allocation is illustrated in Figure 1 [13].

Each subband contains 128 subcarriers. Ten of these are used as guard tones and can be used for various purposes, twelve of subcarriers are dedicated to the pilot signals and 100 are for information. The remaining six tones are set to zero [13].

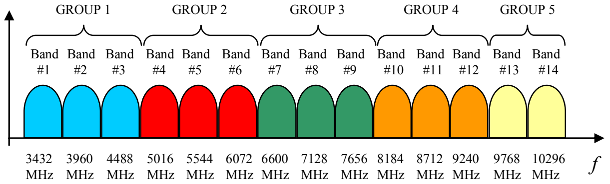

Figure 1. Band allocation for MB-OFDM.

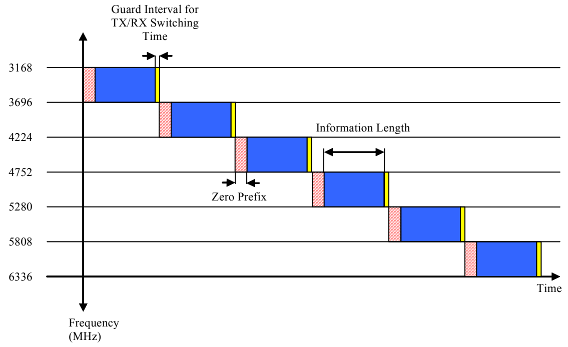

Figure 2. TFC over six OFDM symbols.

The system utilizes time-frequency coding (TFC) to interleave data over subbands. In Figure 2, TFC is performed over six OFDM symbols and six bands. The 9.47 ns guard intervals are providing sufficient time for transmitter and receiver to switch to the next carrier frequency [15].

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 converted to the complex numbers according to the QPSK constellation diagram. In the case of DCM, four-bit groups are formed, and each group is mapped into two different 16-point constellations [16]. The achieved advantage is that the two resulting 16-point symbols are separated by 50 tones. Therefore, the probability that there are deep fades on the separated tones is quite small [16]. The output symbols of DCM modulation can be expressed as [17]

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

In (1), y_n means the n^{th} output symbol, n having values 0…49 and $x_{a(n)}$ is the input bit defined by $a(n)$ as [17]

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

MB-OFDM proposal also utilizes convolution coding with a coding rate of 1/3, 11/32, 1/2, 5/8 and 3/4. The rate of 1/3 is generated by using 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 [13]. The system also uses three-stage interleaving, and both time and frequency domain spreading to mitigate fast fading [16].

One advantage of MB-OFDM is the interference mitigation ability that can be done by avoiding the certain part of the spectrum. Strong signal energy at the MB-OFDM band can be detected, and the overlapping tones are possible to mitigate [13]. This method can be used to decrease the interference MB-OFDM will cause to the other radio systems. Similarly at the receiver, the interfered part of the spectrum can be abandoned. Frequency hopping also improves the coexistence ability by averaging out the aggregating interference.

DS-UWB

In direct sequence UWB, the pulse repetition is applied by using a pseudo random noise code like is used in conventional direct sequence spread spectrum systems, but having a chip waveform self-generating an ultra wideband spectrum [18]. In extreme case, DS-UWB transmission is continuous, i.e., its duty cycle is 100%. Data can be attached using, e.g., binary pulse amplitude modulation (BPAM), which was shown to be a reasonable bipolar modulation scheme for DS-UWB [18,19]. The transmitted BPAM signal can then be given as [18]

$$s(t) = \sum_{k=-\infty}^{\infty} \sum_{j=1}^{N} w\left(t - kT_\mathrm{d} - jT_\mathrm{f}\right)\left(c_\mathrm{p}\right)_j d_k \,. \tag{3}$$

In (3), T_d and T_f are data and frame lengths, respectively, $(c_\mathrm{p})_j$ is a code phase out of N possible phases, and t is time. Pulse waveform and k^{th} data bit are depicted with w and d_k, respectively. Polarity of the transmitted pulse is defined by the chip polarity and data bit [18]. DS-UWB signal structure is depicted in Figure 3.

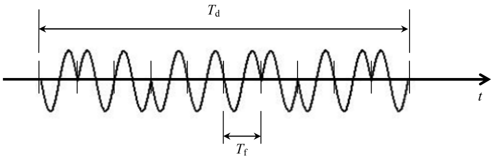

Figure 3. Time domain presentation of DS-UWB.

Interference

Due to the ever-increasing fashion to use civilian systems also in military applications, this study assumes that the interference against the desired UWB systems is based on the forth-coming 4G, which is sharing the same frequency band with MB-OFDM. In the sake of simplicity, the interference from co-existing systems is modeled as colored Gaussian noise (CGN) that is band-limited version of white Gaussian noise [20]. Modeled 4G is assumed to have either 4.5 GHz or 5 GHz center frequency, and has 100 MHz bandwidth. In addition, situation when both center frequencies are operating simultaneously are covered. The studied UWB systems are also obeying the civilian regulations (FCC), and therefore all the systems' spectra are overlapping and coexistence is mandatory.

IEEE 802.15.3a Channel model

The applied channels are based on the clustered UWB channel models defined by the IEEE 802.15.3a, and are derived from the Saleh-Valenzuela (SV) model [21]. The UWB channel impulse response $h_i(t)$ can be defined as [22]

$$h_i(t) = X_i \sum_{l=0}^{L-1} \sum_{v=0}^{K-1} \alpha_{v,l}^{i} \delta(t - T_l^i - \tau_{v,l}^i), \qquad (4)$$

where $\alpha_{v,l}^{i}$ is the multipath gain coefficient for the v^{th} multipath of the l^{th} cluster related to i^{th} channel realization, T_l^i is the delay of the l^{th} cluster, $\tau_{v,l}^i$ is the delay of the v^{th} multipath component relative to the l^{th} cluster arrival time T_l^i, K is the total number of the paths in l^{th} cluster, and L is the total number of clusters.

Based on the measurements, four different channel types are defined: SV1 and SV2 models for distance of 0 – 4 m in line-of-sight (LOS) and non-LOS, respectively. In addition, SV3 and SV4 for distance of 4 – 10 m in NLOS, SV4 having a long delay spread [22].

SIMULATION CONFIGURATIONS

In order to evaluate the performances of MB-OFDM and DS-UWB, software simulators were developed in Matlab©. In this section, the simulation assumptions for both systems are presented and justified.

The major goal in our work was to study the difference between the multiband and singleband UWB concepts that are occupying approximately the same frequency band. Therefore, 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 nominal center frequency and total bandwidth. Hence, the used FCC compatible Gaussian pulse waveforms for DS-UWB are referred as P5, P6 and P7, respectively. MB-OFDM utilizes TFC across six bands similarly as is presented in Figure 2 for three bands; the first symbol is transmitted in the first subband, the second symbol in second subband, and so on. The main point is that all frequency spectrum is used to maintain the given assumption, and thus the MB-OFDM and DS-UWB spectra are overlapping. The existing system specifications are proposing channel coding for MB-OFDM, but the DS-UWB is typically uncoded to maintain the simplicity of the system. The pulse width and processing gain for DS-UWB are fixed to 0.5 ns and 16 dB, respectively. Using these values, the information rate is approximately the lowest rate supported by the MB-OFDM, which is 53 Mbps [13], and which was also used in MB-OFDM simulations. All of these assumptions are included in the further studies to make the system models as equal to each other as possible. To keep systems simple, no detection and avoid (DAA) mechanism was used. If DAA is used, the system performance can be improved with the increasing complexity.

According to the proposal [13], the modulation schemes for MB-OFDM are QPSK and DCM, whereas DS-UWB applies BPAM. The results reported earlier showed that BPAM is a reasonable choice amongst the other studied binary data modulation schemes for singleband UWB system [18,19].

Due to system's poor performance in multipath channels, MB-OFDM utilizes coding, and DS-UWB applies a rake receiver to mitigate fading and interference [23]. Coding scheme for MB-OFDM is chosen to be convolutional coding having a rate of 1/3 and constraint length of 7. At the receiver, Viterbi decoding with soft decision is applied. In the case of DS-UWB, eight-finger selective rake (Srake) with maximum ratio combining (MRC) is applied at the reception [24]. In addition, DS-UWB system is uncoded due to its generic nature. As was mentioned in the second section, the interference is modeled as CGN. Interference utilizes center frequencies of 4.5 or 5.0 GHz, and applies the bandwidth of 100 MHz. All the simulation parameters are brought together in Table 1.

Table 1. Simulation parameters for the studied systems.

Parameter	MB-OFDM	DS-UWB
Bands	6	1
Modulation	QPSK, DCM	BPAM
Pulse waveforms	-	P5, P6 and P7
Individual 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
Coding	Conv. [3,1,7]	-
Pulse length [ns]	-	0.5
Processing gain [dB]	-	16
Receiver	Viterbi decoder	8-finger Srake+MRC
Information rate [Mbps]	53.3	50.2
Center frequency of interference [GHz]	4.5 and 5.0	4.5 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 SV1 and SV4 channels. Whereas, the simulations of BER as a function of interference center frequency (f_cj) or bandwidth (W_bj) use the 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 thoroughly 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 used with MB-OFDM.

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

Value [dB]	MB-OFDM		DS-UWB		
	QPSK	DCM	P5	P6	P7
SV1: E_b/N_0	17	19	15	15	15
SV4: E_b/N_0	17	15	17	17	17
SV1: ISR	-17, *8*, *17*	-17, *8*, *17*	8	8	8
SV4: ISR	-17, *8*, *17*	-17, *8*, *17*	8	8	8

SIMULATION RESULTS

In Figure 4 and Figure 5, system's reference performances without interference are given as a function of E_b/N_0 in all SV channels. The performance deviation of P5, P6 and P7 is less than 1 dB in all the studied channels. Therefore, for the sake of visibility, only P5 is depicted in Figure 5. From the results, it can be seen that MB-OFDM needs higher E_b/N_0 than DS-UWB to achieve BER level of 10^{-4} in general. The noteworthy matter is that MB-OFDM is better in the long distance channels SV3 and SV4 than it is in SV1 and SV2. The performance difference in uncoded DS-UWB system in different SV channels using different pulses is quite insignificant, as can be seen from Figure 5 but it outperforms the corresponding coded MB-OFDM.

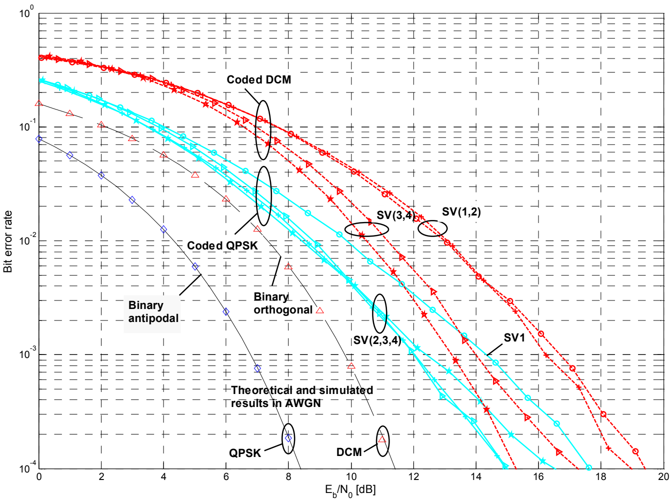

Figure 4. MB-OFDM: BER as a function of E_b/N_0.

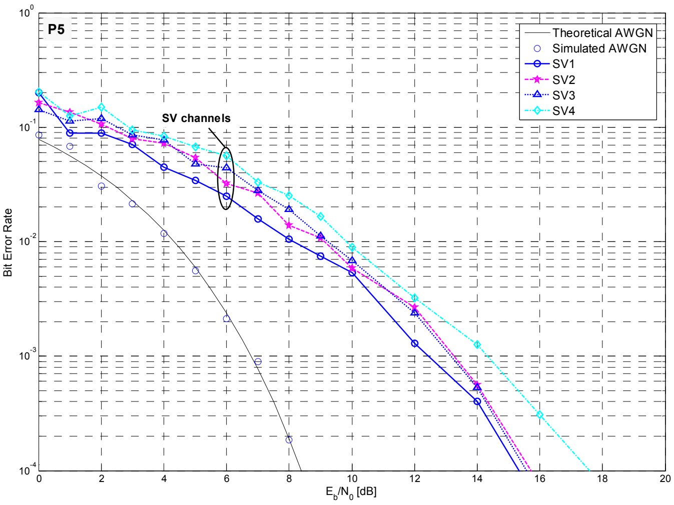

Figure 5. DS-UWB: BER as a function of E_b/N_0.

BER as a function of ISR in SV1 and SV4 channels for both systems are presented in Figures 6-9. Results indicate that the systems have very similar behavior in both channels. The choice of the channel does not seem to affect on performance when E_b/N_0 is fixed. With high ISR, more than 23 dB, MB-OFDM overtakes the DS-UWB and QPSK saturates to the BER level of 0.036, whereas P7 to the level of 0.15. Comparison between QPSK and DCM indicates that QPSK is generally the better one. The BER saturation levels and ISR values for BER level of 10^{-3} with different interfering schemes are summarized in Table 3 and Table 4, respectively.

Figure 10 and Figure 11 depict the effect of varying center frequency of interference to MB-OFDM and DS-UWB in SV1 channel, respectively. MB-OFDM seems to be quite resilient to it. However, when ISR is -17 dB, there is some oscillation in BER. In the case of DS-UWB, f_cj has most significant affect when it crosses the nominal center frequencies of pulses.

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

Channel	Scheme	E_b/N_0 [dB]	BER at ISR=30 dB		
		f_i	4.5	5.0	Both
SV1	QPSK	17	0.036	0.036	0.072
	DCM	19	0.074	0.074	0.148
	P5	15	0.219	0.155	0.257
	P6	15	0.195	0.148	0.257
	P7	15	0.151	0.145	0.209
SV4	QPSK	17	0.036	0.036	0.071
	DCM	15	0.074	0.066	0.148
	P5	17	0.186	0.155	0.229
	P6	17	0.148	0.148	0.219
	P7	17	0.115	0.141	0.204

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

Channel	Scheme	E_b/N_0 [dB]	ISR at BER=10^{-3} [dB]		
		f_j	4.5	5.0	Both
SV1	QPSK	17	-16.8	-16.5	-21.0
	DCM	19	-17.0	-16.0	-19.0
	P5	15	7.4	7.0	4.9
	P6	15	9.1	7.7	6.3
	P7	15	10.1	8.2	6.3
SV4	QPSK	17	-15.2	-14.5	-16.9
	DCM	15	-20.4	-16.1	-18.5
	P5	17	8.6	8.9	5.9
	P6	17	9.6	8.7	6.8
	P7	17	11.0	9.4	7.2

In Figure 12, the systems' performances are presented as a function of the bandwidth of interference in SV1 channel. When ISR = 8 dB or 17 dB, MB-OFDM suffers from expanding W_{bj}. The reason is that the wider bandwidth interfere more tones than the narrowband jammer does. If ISR = -17 dB, there exists again oscillation in MB-OFDM system. However, both systems are in the same BER level of approximately 10^{-3}. In the case of DS-UWB, W_{bj} does not have significant influence on system performance.

In [12,23], similar simulations are carried out in AWGN channel. Results indicate similar behavior in AWGN and multipath channels. The MB-OFDM is better when ISR is relative high, more than 15 dB. The impacts of f_{cj} and W_{bj} are identical to the multipath results.

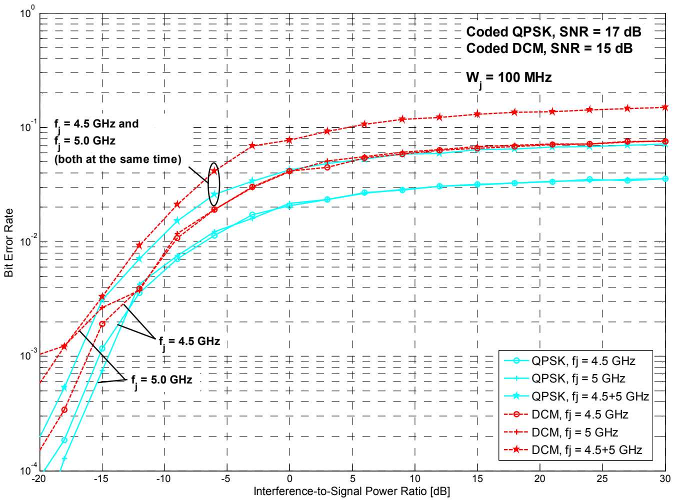

Figure 6. MB-OFDM: BER as a function of ISR in SV1.

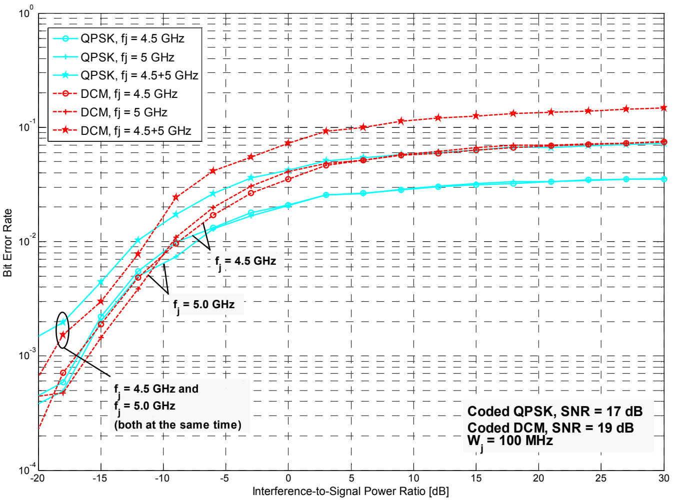

Figure 7. MB-OFDM: BER as a function of ISR in SV4.

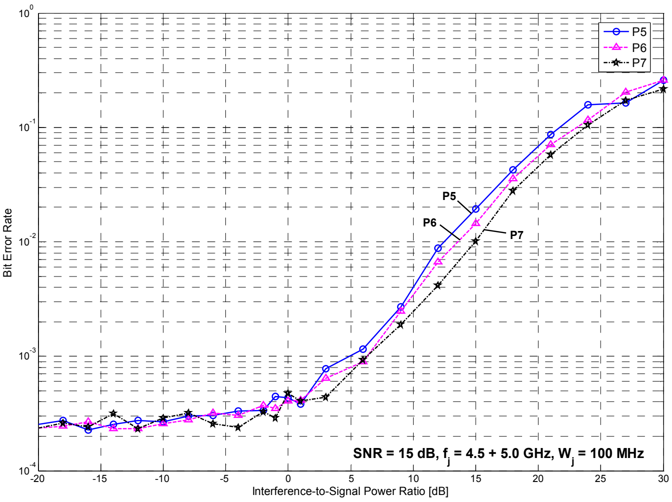

Figure 8. DS-UWB: BER as a function of ISR in SV1.

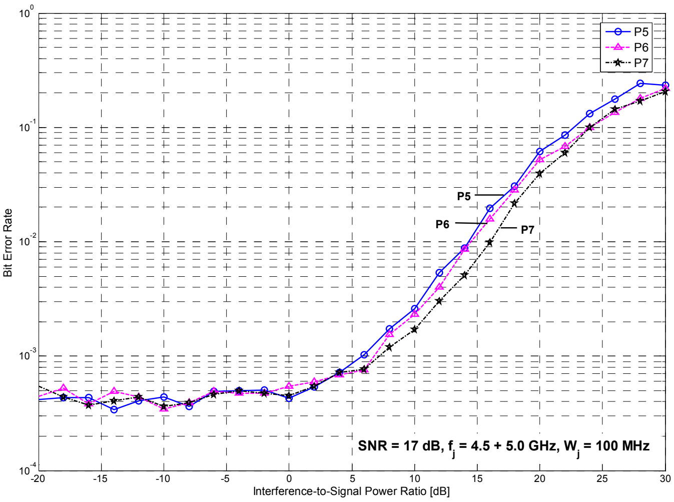

Figure 9. DS-UWB: BER as a function of ISR in SV4.

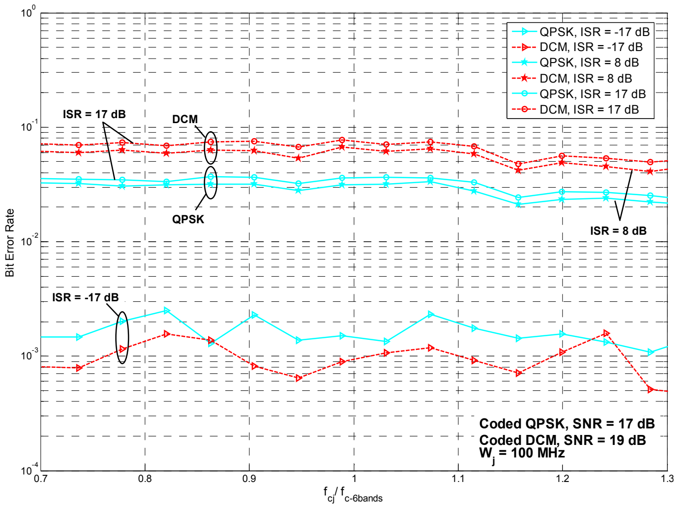

Figure 10. MB-OFDM: BER as a function of f_{cj} in SV1.

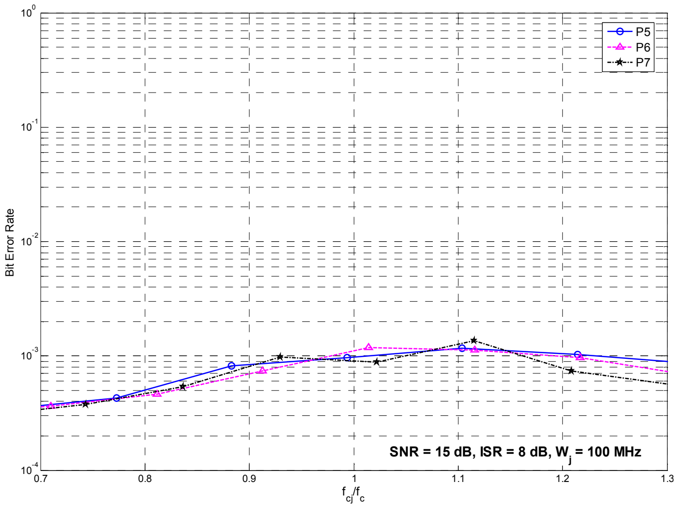

Figure 11. DS-UWB: BER as a function of f_{cj} in SV1.

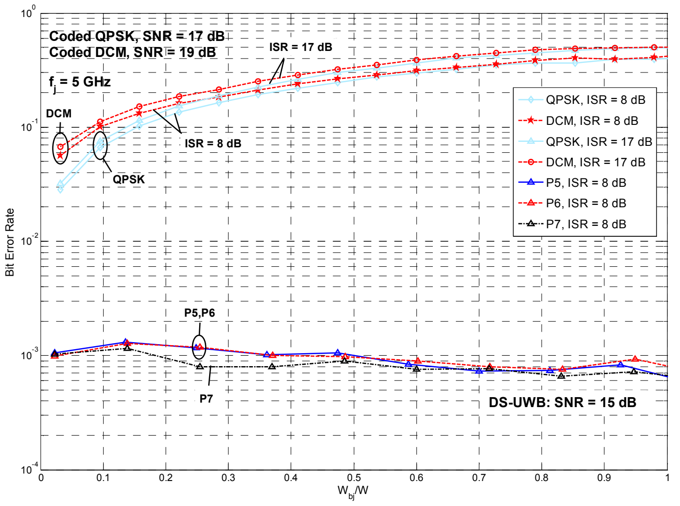

Figure 12. MB-OFDM and DS-UWB: BER as a function of W_{bj} in SV1.

CONCLUSION

In this paper, two UWB PHY layer solutions for high data rate WPAN were studied in interfered multipath channels. The studied UWB systems allocate the same frequency band and have approximately the same data rate. The interfering signal has a bandwidth of 100 MHz, and no interference mitigation techniques in UWB systems were used. Interference simulations indicate that MB-OFDM is better choice when ISR value is more than 23 dB, thus we are operating in a hostile environment. MB-OFDM seems to tolerate ISR values less than -15 dB to achieve reasonable BER level of 10^{-3}, whereas DS-UWB overtakes this level with ISR values of 5 - 10 dB. When the fixed E_b/N_0 values are used, the channel itself does not impact on the systems' performance. The results indicate that the center frequency of interference has insignificant influence on the MB-OFDM and has only minor impact on DS-UWB. In addition, with relative high interference power, the increasing bandwidth of interference reduces the MB-OFDM performance more than DS-UWB.

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