Propagation Assessment of MB-OFDM Ultrawide Band (UWB) MIMO Based Communication in Fading Channels

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Abstract

Ultra wideband (UWB) technology is one of the promising solutions for future short-range communication which has recently received a great attention by many researchers. However, interest in UWB devices prior to 2001 was primarily limited to radar systems, mainly for military applications due to bandwidth resources becoming increasingly scarce and also its interference with other commutation networks. This research work provides performance analysis of multiband orthogonal frequency division multiplexing (MB-OFDM) UWB MIMO system in the presence of binary phase-shift keying time-hopping (BPSK-TH) UWB or BPSK-DS UWB interfering transmissions under Nakagami-m and Lognormal fading channels employing various modulation schemes using MATLAB simulations. The research work indicates that it is totally impossible to predict the performance of UWB system in Lognormal channel.

Keywords – Multiband (MB), UWB, multiple interferers, orthogonal frequency-division multiplexing

(OFDM), 802.15.3a, MIMO.

1 Introduction

Ultra wideband (UWB) characterizes transmission systems with instantaneous spectral occupancy in excess of 500 MHz [1] and is a fast emerging technology with uniquely attractive features inviting major advances in wireless communications, networking, radar, imaging, and positioning systems**.** Interestingly scholars and researchers have predicted that it is the promising solutions for future short-range communication thus UWB transmission has recently received significant attention in both academia and industry for applications in wireless communications [2]. After two proposals have been made by IEEE 802.15.3a task group as future ultra wideband (UWB) standards: multiband orthogonal frequency division multiplexing (MB-OFDM) UWB and Direct Sequence UWB (DS-UWB) approach [3], the demand for higher data rates has become necessary and one possible solution is to exploit both spatial and multipath diversities via the use of multiple-input multiple-output (MIMO) and proper coding techniques. Lui and the group [4] investigated MIMO-OFDM multiband UWB system in Nakagami fading. Also, in [5], the authors analyzed error performance of MIMO-based singleband and multiband UWB system in lognormal fading channel but they did not consider OFDM technique in their work. Cao and et al [6] looked at uncoded adaptive modulated MIMO-OFDM benefit from both multiple transmit/receive antenna diversity order and exploiting the multipath diversity of the UWB channel. The authors in [7] also investigated BER variation in an UWB OFDM MIMO communications system based on measurements made in a picocell Wireless environment. Up to now, there is not much research to evaluate the performance of MIMO- OFDM multiband UWB system. Authors in [8] concentrated on performance MIMO-OFDM multiband UWB system and derived a lower bound of pairwise-error probability (PEP) of the system using lognormal fading channel. The research work is organized as follows; Section 2, will focus on UWB signals models with Section 3, describing the OFDM-MIMO transceiver system as well as MIMO frequency selective channel. In Section 4, we provide simulation results and Section 5 summarizes and concludes the research work.

2 UWB Spectrum 'Spreading' Models

The two main approaches to randomizing the pulse train are time hopping (TH) and direct sequence (DS) techniques [9]. Consider UWB channel with N users and N_I interferers,$N = N_i - 1$, theK^{th} user is assigned a unique random spreading C^K(of length2^K data length).Let$\{\gamma_i^K\}$ be the spreading sequence associated to user K.User K then will be transmitting a spreaded signal consisting of2^K frames of L chips of length T_c.Each chip has power$\sqrt{E_s}$ the power of each frame is then$\left(\sqrt{E_s} * L\right)$,$L$ being the processing gain or the spreading gain. With DS-BPSK UWB model the user K transmits.

$$S^{(k)}(t) = \sum_{i=-\infty}^{+\infty} \sum_{j=0}^{L-1} \sqrt{E_s}\gamma_i^k d_i(k) s(t - iT_f - jT_c) \tag{1}$$

A typical UWB TH-BPSK can be molded as follows:

$$S^{(K)}(t) = \sum_{i=-\infty}^{+\infty} \sqrt{E_s} d_{j/N_i} s(t - jT_f - c_j{}^{(k)T_c} \tag{2}$$

where t is the time index, $S(t)$ is the transmitted UWB pulse shape with pulse duration T_p and E_s as energy per pulse. jT_f Refers to jth frame of length T_r. The OFDM received signal is given by [2]:

$$r(t) = S_R(t) + I_{UWB} + n(t) \tag{3}$$

where $S_R(t)$ is the received signal for the OFDM symbol I_{UWB} is the interfering signal applying the same approach in [2, 3, 12] and $n(t)$ is the receiver noise.

3 MIMO-OFDM Multiband System

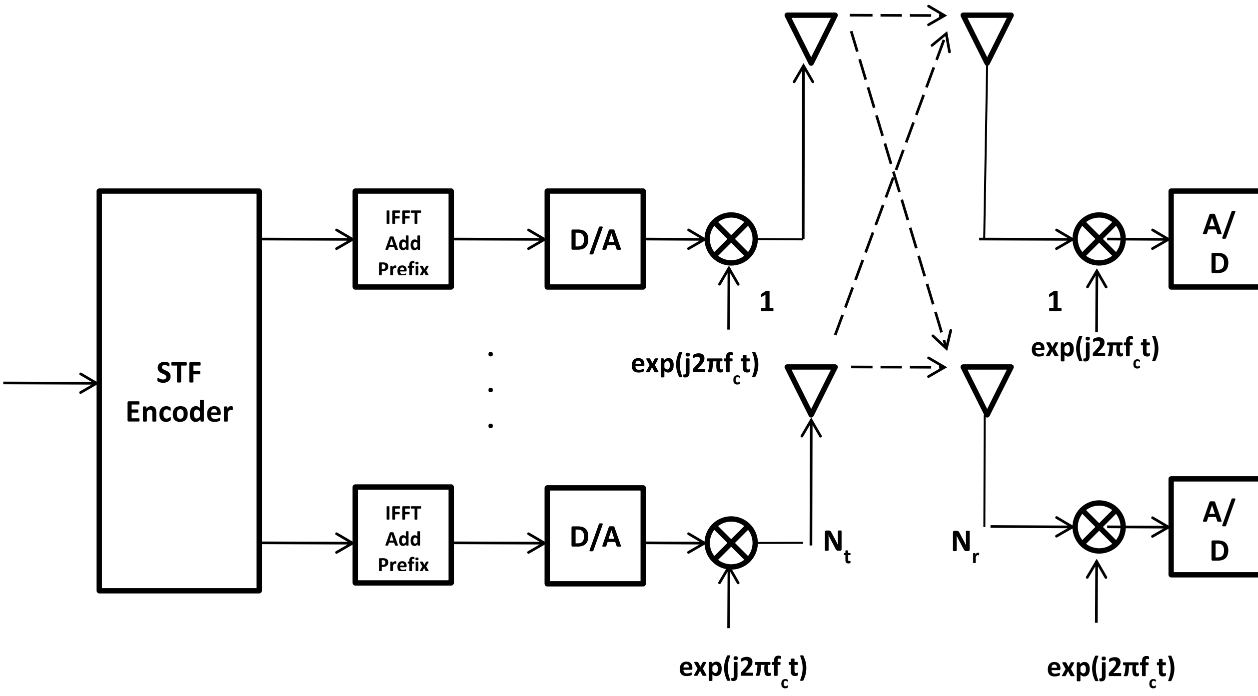


Figure 1 MIMO–OFDM multiband UWB system

3.1 Transmitter Description

Consider multiband UWB system with N_t transmit antenna and N_r receive antennas, as shown in Figure 1. At the transmitter, the coded information sequence from a channel encoder is divided into blocks of N_b bits. Each block is mapped onto $KN \times N_c$ Space–Time–Frequency (STF) codeword matrix [8]

$$D = [D_0^T \; D_0^T \; \ldots D_{K-1}^T]^{\mathrm{T}} \tag{4}$$

where $d_k = [d_1^k d_2^k \ldots d_{N_t}^k]$ for $k = 1,2, \ldots, K-1$ and $d_i^k = [d_i^k(0) d_i^k(1) \ldots d_i^k(N-1]T, I = 1,2 \ldots N_t$ $d_i^k(n)$ (for $n = 0,1, \ldots N-1$ represents the complex symbol to be transmitted over n^{th} subcarrrier by i^{th} transmit antenna during k^{th} OFDM symbol period. The baseband OFDM signal to be transmitted by the i^{th} antenna at the k^{th} transmit antenna over K OFDM symbol periods can be expressed as [8]:

$$x_i^k(t) = \sqrt{E/N_o} \sum_{n=0}^{N-1} d_i^k(n) exp\{j2\pi n\Delta f(t - T_{cp})\} \tag{5}$$

where $\Delta f = 1/T_{FFT}$ and the factor $\sqrt{E/N_o}$ guarantees the average transmitted symbol is E independent on the number of transmit antenna. Thus, the transmitted multiband UWB at the i^{th} transmit antenna K OFDM symbol periods can expressed as [8]

$$S_i(t) = \sum_{n=0}^{K-1} R_e\{x_i^k(t - KT_{SYS})\exp(j2\pi f_c^k t)\} \tag{6}$$

where f_c^K specifies the subband. The carrier frequency can be changed from one OFDM block to another which enables frequency diversity. f_c^K is the same for each transmit antenna and the transmission from all N_t transmit antennas are simultaneous and synchronous. Since N_b bits are transmitted during KY_{SYS} seconds, the transmit rate (without channel coding) is $= N_b/KY_{SYS}$.

3.2 Frequency Selective MIMO Channel

The general structure of frequency- selective MIMO channel with N_t signals $\mu[k], 1 \le \mu \le N_1$.From the input of our system at each time instant k and thus obtain N_o output. Therefore, the v^{th} output at time instant k can be expressed as [9].

$$y_v[k] = \sum_{\mu=0}^{N_I} \sum_{k=0}^{L_T-1} h_{v,\mu}[K,\kappa].x_\mu[K-\kappa] + n[K] \tag{7}$$

where L_T denotes the largest number of taps among all the contributing channels. In (7), the channel matrix has the form [9].

$$H[K,\kappa] = \begin{bmatrix} h_{1,1}[K,\kappa] & \cdots & h_{1,N_I}[K,\kappa] \\ \vdots & \ddots & \vdots \\ h_{N_0,1}[K,\kappa] & \cdots & h_{N_o,1}[K,\kappa] \end{bmatrix} \tag{8}$$

3.3 BER Analysis of MB-OFDM UWB in Fading Channels

Having derived the necessary term for the variance of the UWB interference signal, we can express the bit error probability for the MB-OFDM system as [11]

$$P_{e/H=h} = Q\left(\sqrt{\frac{hP_T}{\sigma_\eta^2 + \sigma_{I_{UWB}}^2}}\right) \tag{9}$$

where $h(t,\tau)$ is the channel impulse at time t due to delta function τ [17] and $Q(a) = \int_a^\infty \frac{1}{\sqrt{2\pi}} e^{-x^2/2}\, dx$ is Gaussian Q- function or the complementary probability distribution function for Gaussian distribution [13]. $P_T$is the received power of the OFDM system and $\sigma_\eta^2 = N_o \Delta_T$ where N_o represent the noise spectral density. The average of L^{th} path equals $E\{|a_k|^2\}$ and assuming that $a_k = r$, then $E|R|^2 = \int_0^\infty r^2 f(r)dr$, K=$\frac{20log_{10}^e}{\sigma\sqrt{2\pi}}$, then

$$E|R|^2 = \int_0^\infty r^2 f(r)dr = K\int_0^\infty \frac{r^2}{r} exp\left[-\left(\frac{20log_{10}^r}{\sigma\sqrt{2}}\right)^2\right] \tag{11}$$

if

$$u = \frac{20log_{10}^r}{\sigma\sqrt{2}} = \frac{20log_{10}^r log_{10,}^e}{\sigma\sqrt{2}} \tag{12}$$

$$r = 10^{u\sigma\sqrt{2}/20}, dr = \frac{r\sigma\sqrt{2}}{20log_{10}^e} du \tag{13}$$

thus,

$$E|R|^2 = \int_0^\infty r^2 f(r)dr = \frac{1}{\sqrt{\pi}}\int_0^\infty 10^{u\sigma\sqrt{2}/20} \exp[-u^2]\, d\,u \tag{14}$$

Using,

$$a^x = \left(e^{(log_e^a)^2}\right), \quad e^{\frac{2ur\sqrt{2}}{20} log_e^{10}} = e^{2uL}$$

therefore,

$$E|R|^2 = \int_{-\infty}^{+\infty} e^{-(u-L)^2} du = \frac{2e^{L^2}}{\sqrt{\pi}} \int_0^{+\infty} e^{-v^2}\, dv \tag{15}$$

$$= \frac{e^{L^2}}{\sqrt{\pi}} \int_0^{\infty} w^{-\frac{1}{2}} e^{-w} dw = \Omega_l$$

hence, for a given L^{th} the total average power can be expressed as[19]

$$h = \sum_{l=0}^{L-1} \Omega_l \tag{16}$$

Therefore, for lognormal distribution the probability of error (BER) is expressed as

$$P_e = E_H\left[Q\left(\frac{hP_T}{\sigma_\eta^2 + \sigma_{I_{UWB}}^2}\right)\right] = Q\left(\frac{P_T \sum_{l=0}^{L-1} \Omega_l}{\sigma_\eta^2 + \sigma_{I_{UWB}}^2}\right) \tag{17}$$

where $\sigma_{I_{UWB}}^2 = N_u \sigma_{U_l}^2(k)$ and σ_p is the variance of the Random Variable being considered Similarly, for Nakagami$-m$ distribution then probability is given as indicated in [11].

$$P_e = E_H\left[Q\left(\frac{hP_T}{\sigma_\eta^2 + \sigma_{I_{UWB}}^2}\right)\right] = \frac{2}{\Gamma(m)}\left(\frac{m}{\Omega}\right)^m \int_0^{\infty} h^{2m-1} e^{\frac{mh^2}{\Omega}} Q\left(\frac{hP_T}{\sigma_\eta^2 + \sigma_{I_{UWB}}^2}\right) dh \tag{18}$$

3.4 Receiver Processing

If coherent single-user matched filter is used where the receiver is assumed to know the fading coefficients of the user of interest and the transmitted signal from each antenna $K = 1$[10], then an antenna will receive

$$y_1 = A_{11} b s_{11}(t) + \sigma n_1(\mathrm{t})$$

$$\vdots \qquad (1$$

$$y_D = A_{D1} b s_{D1} \quad + \quad \sigma n_D(\mathrm{t})$$

The Optimum decision rule selects $b \in \{-1, 1\}$ that minimizes [16]

$$\int_0^1 \sum_{d=1}^{D} |y_d(t) - A_{d1} b s(t)|^2 dt \qquad (2$$

$$= \sum_{d=1}^{D} \int_0^T |y_d|^2 \, dt + \sum_{d=1}^{D} |A_{d1} S_{d1}|^2 - 2b \sum_{d=1}^{D} \Re\{y_d^* A_{d1} S_{d1}(t)\} \qquad (2$$

This means that the optimum rule decision also known as maximal-ratio combining for a single –user case is expressed as

$$\hat{b} = sgn\left(\Re\left\{A \sum_{d-1}^{D} A_{d1} y_{d1}^*\right\}\right) \qquad (2$$

where

$$y_{d1} = \int_0^T y_d(t) S_{d1}^*(t) dt \qquad (2$$

According to the optimum decision rule [10] the inner product of the $y(t)$ and $s(t)$ is the sufficient statistic[14]. Therefore the probability of error of a MB-OFDM UWB MIMO system could be expressed as [16]

$$P_K^{DC}(\sigma) = E\left[Q\left(\frac{\sum_{d=1}^{D} |A_{dk}|^2}{\sum_{d-1}^{D} |A_{dk}|^2 \left(\sigma^2 + \sigma^2_{I_{UWB}^{(k)}}\right)}\right)\right] \qquad (2$$

3.5 CHANNEL CAPACITY OF MIMO SYSTEMS

There are two major problems in broadband mobile communication i) frequency selective fading due to multi-path a technology for achieving high frequency utilization efficiency in terms of bits per Hertz (bit/s/Hz) or bits per/Hz/cell. As mention earlier, Space Division multiplexing (SDM) over MIMO channels using multiple transmitting and receiving antennas is one of the most promising technologies for improving bits per Hertz (bit/s/Hz). The MIMO channel capacity is given by [11].

$$C = log_2\left[det\left(I_{NR} + \frac{\beta}{N_T}H.H^H\right)\right] \tag{25}$$

As the parallel channel capacity, where I is n by n identity matrix, H is a channel matrix, N_T and N_R number of transmitting and receiving antennas, and $(\ )^H$ denotes the complex conjugate transpose. This equation indicates that the channel capacity can be increased in proportion to the number of antennas if $N_T = N_r$.

4 Result & Discussions

In this study, the size of FFT for the MB-OFDM analysis was taken as 128 without error control coding. The modulations were by the following: MPSK and MQAM. As for the TH and DS-UWB system, the frame duration T_F and the hop width T_c were chosen are chosen to be 1ns an 0.0625ns respectively, The number of hopsN_h equal 16. The analysis in AWGN indicated the average BER versus Eb/No of MB-OFDM UWB in noise. 8PSK performs extremely well followed by average performance by QPSK with BPSK and 16 QAM slightly below average, thus BER performance of MPSK is improves when the alphabet size $M = 2^K$inreases, however, the performance improves with the MIMO technology in AWGN. Similar performances were obtained in fading channels shown in Figure 2, 3 4 and 5. However, the performance in Nakagami-m fading channel outperforms the Lognormal channel, interestingly, the performance improves with MIMO technology in all cases. Looking at the results in multiple TH and DS UWB interferences shown in Figures 2 and 3, UWB system performs well in multiple TH interferences as compare to that of DS, moreover, the performance in Nakagami fading is better in comparison to Lognormal Fading channel.

In multiple interference, the performance of UWB communication systems with the same noise power in Nakagami-m fading channel outperforms that of Lognormal fading channel in section 4.3. Figure 4.2a shows the performance of MB-OFDM UWB system in multiple TH and DS interference and Nakagami-m fading channel, interestingly the performance improves significantly as the MIMO technology is introduce. Looking at figure 4.2c the performance of the MB-OFDM UWB (4*4) MIMO system, the BER performance is approximately twice that of the MB-OFDM UWB (2*2) MIMO system in figure 4.2b when the number of interferes is 5. It is important to add that the performance of MB-OFDM UWB MIMO system with the same transmitted power in 4.2b and 4.2c performs poorly as compare to that MB-OFDM UWB system shown in figure 4.2a MB-OFDM UWB when the number of interferes is 10, thus in MIMO technology is not suitable for UWB system especially when the number of interferes is high. In addition, the BER performance of UWB communication system is better in TH multiple interference than DS multiple interference.

The results on the performance of UWB system in multiple TH and DS interference in Lognormal fading channel. From figure 4.3a the performance in Lognormal fading channel of MB-OFDM UWB system is such that at even 10 Eb/No BER virtually remains constant and poor performance even by MB-OFDM UWB (2*2) MIMO system. However, there is an improvement in performance as the number of antennas in the MIMO system increases as shown in figure 4.3a. Here also the BER performance of UWB communication system is better in TH multiple interference than DS multiple interference from the results shown and it is important to stress here that the performance of MB-OFDM UWB MIMO system with the same transmitted power in 4.3b and 4.3c performs poorly as compare to that MB-OFDM UWB system shown in figure 4.2a MB-OFDM UWB when the number of interferes is 10, also it can be concluded that MIMO technology is not suitable for UWB system especially when the number of interferes is high in Lognormal fading channel. However, in figure 4.3c the performance of the MB-OFDM UWB (4*4) MIMO system, is approximately twice that of the MB-OFDM UWB (2*2) MIMO system in figure 4.2b whenthe number of interferes is 5.For the same performance as in Nakagami-m fading channel the bit energy is increase from 1dB to 5dB in Lognormal channel.

Similar results in figure 4.1a was obtained by the author in [14] and the similar results in, figure 4.2a is also obtained by Mehbodniya et al in [4]. The poor performance in Lognormal fading channels buttress to point made by [6] that it is impossible to predict the performance of UWB system in Lognormal fading channels. Lastly, the performance of all the modulation schemes also support a point raised by Hu and the group that DS sequence out performs TH in larger values of SNR.

5 Conclusion & Future Work

In conclusion, the performance of UWB communication system is improved by using MIMO technology employing MPSK modulations with higher values of M also the performance analysis indicates that UWB communications in Nakagami-m fading outperform that of Lognormal fading channel. . It is however important to stress here that not only employing multiple input and multiple output (MIMO) could improve the performance but also using specific error control coding could also improve the performance tremendously.

Performance in Multiple Interference and in Nakagami-m Fading Channel

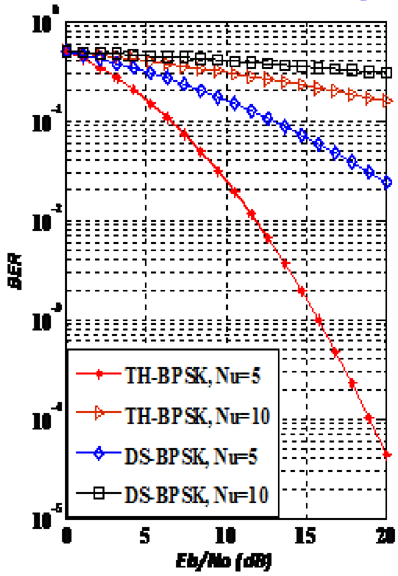


Fig. 2 a MB-OFDM UWB

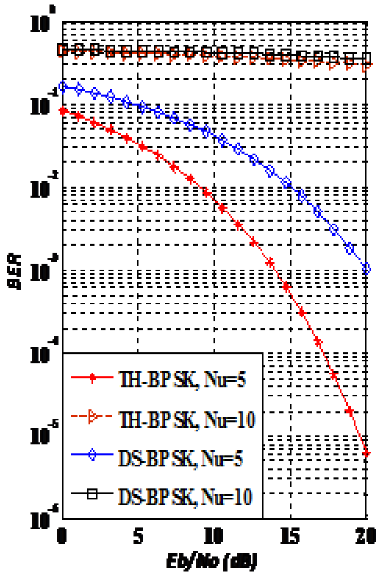


Fig.2b MB-OFDM UWB MIMO (2*2)

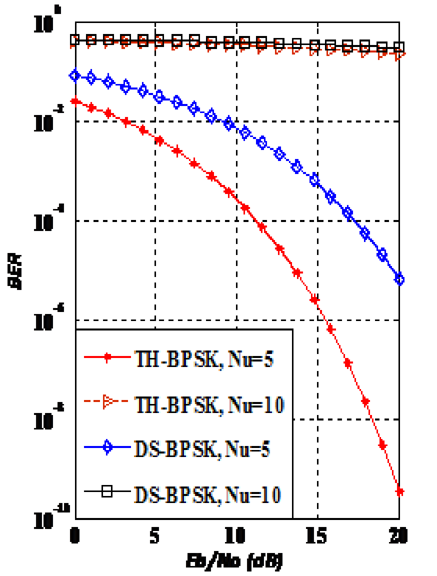


Fig.2 c MB-OFDM UWB MIMO (4*4)

Performance in Multiple Interference and in Lognormal Fading Channel

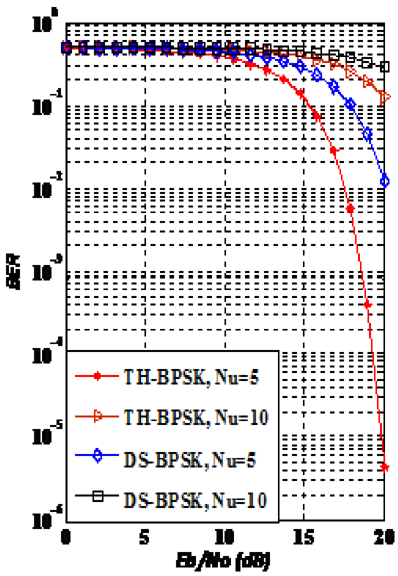


Fig. 3 a MB-OFDM UWB

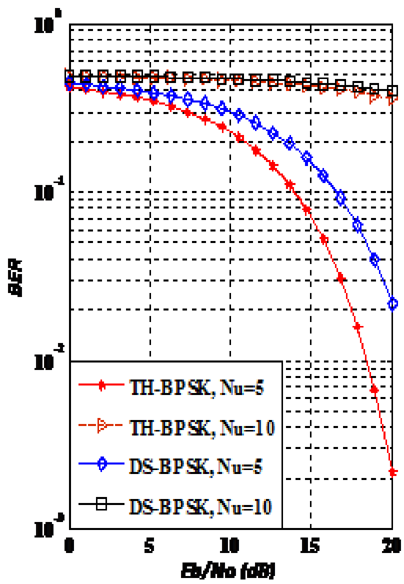


Fig.3b MB-OFDM UWB MIMO (2*2)

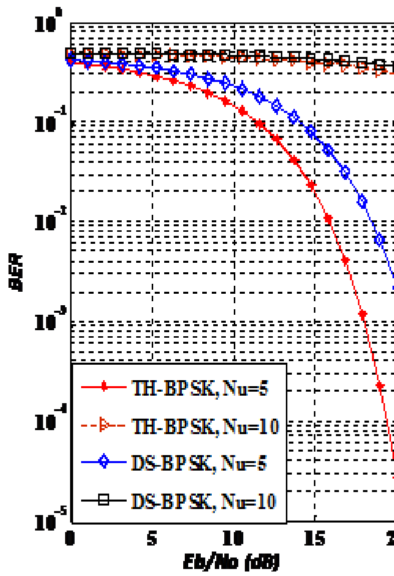


Fig.3 c MB-OFDM UWB MIMO

Performance of Modulation Schemes in DS UWB Multiple Interference and Nakagami-m Fadindg Channel

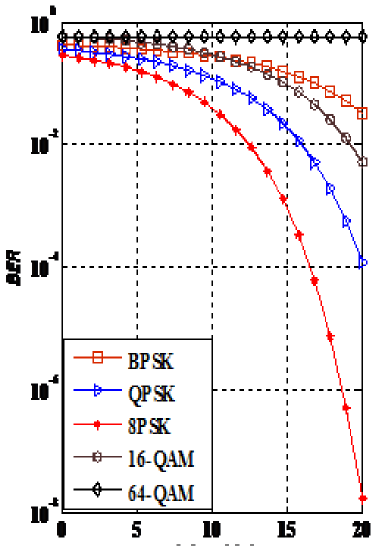


Fig.4 a MB-OFDM UWB

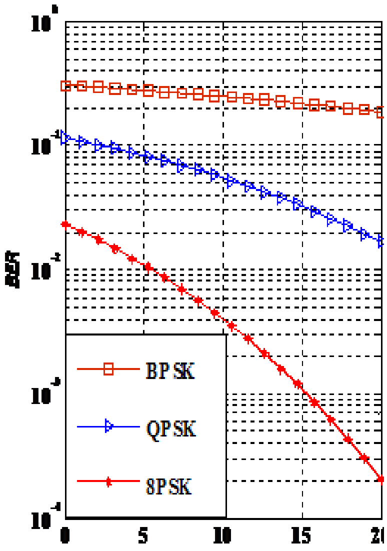


Fig.4 b MB-OFDM UWB MIMO (2*2)

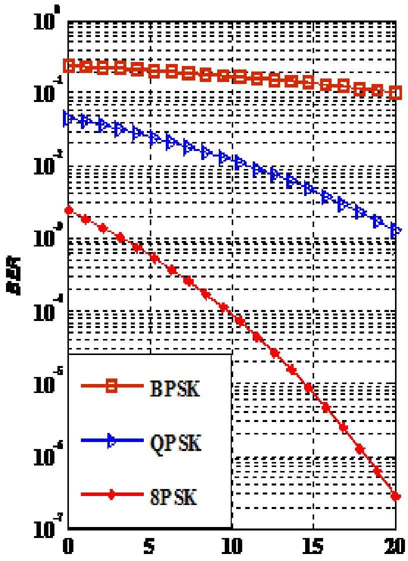
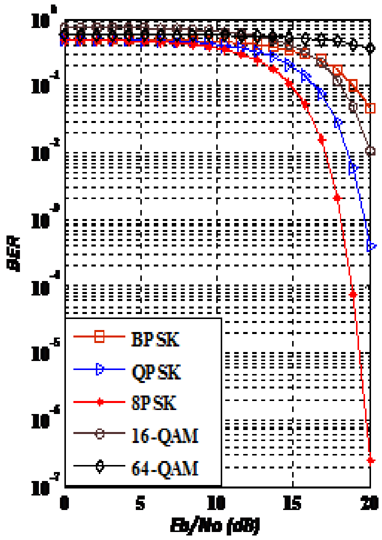
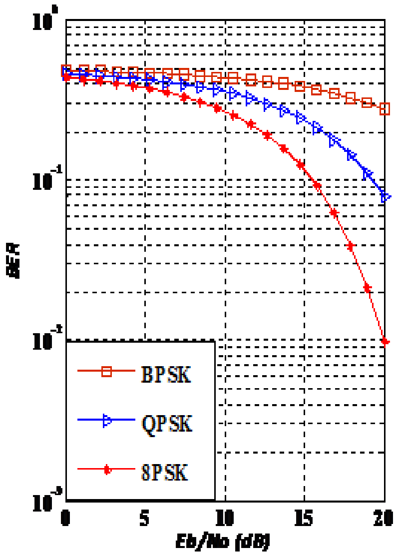


Fig.4 c MB-OFDM UWB MIMO (4*4)

Performance of Modulation Schemes in DS UWB Multiple Interference and in Lognormal Fading Channel





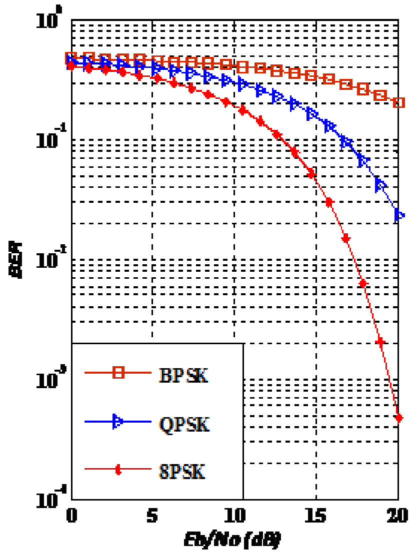


Fig. 5a MB-OFDM UWB

Fig.5 b MB-OFDM UWB MIMO (2*2)

Fig.5 c MB-OFDM UWB MIMO (4*4)

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