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Review on Bit Error Rate Analysis of Frequency Selective Channel

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ABSTRACT

The 4G broadband wireless communication systems provide error free reliable high data rate transmission. Wireless data transmission suffers from multipath detrimental fading effects due to scatterers. The performance of a wireless system is evaluated in terms of Bit Error Rate (BER) and Quality of Service (QOS). Particularly BER depends on the estimated SNR and the Diversity order. Orthogonal Frequency Division Multiplexing (OFDM) is a multicarrier access technique in 4G used to convert wideband frequency selective fading channel into flat fading narrowband sub channels. In conjunction with Multiple Input Multiple Output (MIMO) access technique, it provides enhanced spectral efficiency and data rates upto 100Mbps. The Bit Error Rate (BER) evaluation of various digital modulation schemes is performed under frequency selective channel and the simulation results are compared with flat fading channel.

Keywords

BER, OFDM, MIMO, QOS.

INTRODUCTION

The future wireless mobile systems LTE and WiMAX shows a great importance to high rate data transmission like online gaming, High Definition TV (HDTV), Digital Audio Broadcasting (DAB), Digital Video Broadcasting (DVB). If the signal bandwidth is more, then Orthogonal frequency division multiplexing (OFDM) plays an important role in 4G as it eliminates the Inter symbol Interference (ISI) by the intoduction of cyclic prefix (CP). Synergetic effects can be achieved with OFDM and spatial modulation technique resulting in multi antenna at Tx and Rx Orthogonal Frequency Division Multiplexing (MIMO-OFDM) configuration.

Lot of work done in [1-7] to evaluate the BER expressions for different modulation schemes on AWGN channels and Vitthaladevuni and Alouini provide BER analysis for hierarchical M-QAM on flat fading channels. Our aim in this paper is on the analytical evaluation of the BER performance of MIMO OFDM using different modulation schemes under frequency selective fading channel.

The rest of the paper is organized as follows. Section 2 describes the system model of MIMO OFDM. Section 3 explains theoretical BER analysis of AWGN and Rayleigh fading channels. Section 4 describes the simulation results and concluded the paper in section 5.

SYSTEM MODEL

The transmission of radio frequency signals from base station to the mobile station suffered from multipath fading and shadowing effects results in Inter Symbol Interference (ISI) this leads to a high probability of errors. Hence the system's overall performance becomes very poor. OFDM based wireless systems is very attractive for high-speed data transmission and used to mitigate the frequency-selective fading encountered in wireless channel. Combining MIMO with OFDM provide ISI free spectrally efficient reliable system. The MIMO OFDM system model for BER analysis is given in fig 1.

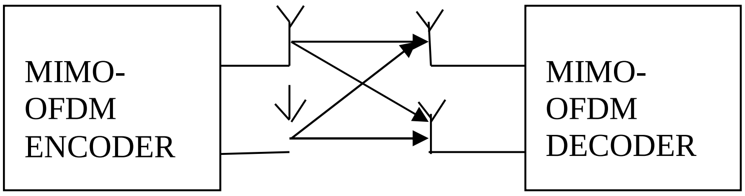

Fig. 1. MIMO-OFDM system model

The block diagram consists of transmitter, the channel and the receiver sections . The binary data generated from random source passed on to the error correcting codes and interleaver to convert burst errors due to frequency selectivity into random errors. OFDM block is then used to mitigate Inter Symbol Interference (ISI) by adding cyclic prefix (CP). The resulted OFDM symbol are transmitted through multiple antennas at transmitter. AWGN channel is Gaussian distributed which is additive in nature. Rayleigh Fading has no dominant LOS signal and Rician Fading has dominant line of sight. Reverse process of transmitter section is performed at the receiver.

BER ANALYSIS

BER of BPSK modulation over AWGN Channel

Consider the AWGN channel model where the encountered noise is additive in nature and given as,

$$y = x + n \tag{1}$$

Where

'x' is the transmitted symbol either 0 or 1.

'n' is white Gaussian noise which is Additive in nature with $\mathcal{N}(0,\sigma^2)$

'y' is the symbol received at the receiver.

So, the probability of bit error for n>1 can be,

$$P_e = \int_{\sqrt{\frac{p}{\sigma^2}}}^{\infty} \frac{1}{\sqrt{2\pi\sigma^2}} e^{-x^2/2\sigma^2} \tag{2}$$

By using Q-function, the P_e can be written as,

$$P_e = Q\left(\sqrt{\frac{P}{\sigma^2}}\right) = Q\left(\sqrt{SNR}\right) \tag{3}$$

Where as Q(.) is defined as,

$$Q(x) = \frac{1}{\sqrt{2\Pi}} \int_{x}^{\infty} e^{-x^2/2} dx \tag{4}$$

The approximation to Q function is

$$P_e = Q\left(\sqrt{SNR}\right) = \frac{1}{2} e^{-SNR/2} \tag{5}$$

BER of QPSK modulation over AWGN Channel

QPSK modulation has two branches in-phase and quadrature components of the signal and the BER of each branch is the same as BPSK. The number of bits (k) sent per symbol is $\log_2 M$.

Under nearest neighbour approximation, the probability of bit error due to the nearest neighbour and the tight approximation of Q(.) function is given by,

$$P_e \approx Q\left(\sqrt{SNR}\right) \tag{6}$$

Performance evaluation of M-QAM modulation under AWGN Channel

The error probability of M-QAM constellation (M=8, 16, 32, 64, 128, 256) can be calculated by considering two M-PAM branches on in-phase and quadrature phase components. Under nearest neighbour approximation, the probability of bit error of 16 QAM occur due to 4 nearest neighbour with minimum distance d_{min} is,

$$P_e = \frac{3}{2k} Q\left(\sqrt{\frac{kSNR}{10}}\right) \tag{7}$$

Performance evaluation of BPSK modulation under Rayleigh fading Channel

The multipath wireless fading channel introduces multiplicative effect w.r.t. transmitted symbol 'x' and can be modeled

$$y = hx + n \tag{8}$$

Where 'h' be fading channel coefficient with magnitude, 'a' and the transmitted (x) and received symbols (y) are i.i.d. Gaussian random variables. The fading channel (h) depends on changes in channel attenuation (a_i) and changes in delays (τ_i).

Rayleigh channel is commonly used term when there is no line of sight signal. The Rayleigh channel is obtained from two orthogonal Gaussian variables with Rayleigh amplitude distributed and uniform phase distribution.

The fading SNR is,

$$SNR_F = \frac{a^2 P}{\sigma^2} = a^2\left(\frac{P}{\sigma^2}\right) = a^2 SNR$$
$$\therefore BER = Q\left(\sqrt{SNR_F}\right)$$
$$\Rightarrow BER = Q\left(\sqrt{a^2 SNR}\right) \tag{9}$$

The fading channel (h) is random in nature, so the bit error rate (BER) is also random in nature. To find the average BER with respect to Rayleigh fading distribution,

$$Avg.BER = \int_0^\infty Q\left(\sqrt{a^2 .SNR}\right).2ae^{-a^2}.da$$
$$= \frac{1}{2}\left(1 - \sqrt{\frac{SNR}{2 + SNR}}\right) \approx \frac{1}{2SNR} underhighSNR \tag{10}$$

BER of M-QAM modulation over Rayleigh fading Channel

The theoretical BER of M-QAM can be evaluated using probobility distribution function as follows.

From equation (9), consider

$$\gamma = a^2 SNR, then$$

$$P(\gamma) = \frac{1}{SNR} e^{-\frac{\gamma}{SNR}}, \gamma \geq 0$$

$$\therefore P_b = \int_0^\infty \frac{1}{2} Q\left(\sqrt{\gamma}\right) P(\gamma).d\gamma \tag{11}$$

$$P_{b\,4-QAM} = \frac{1}{2}\left(1 - \sqrt{\frac{\gamma}{k\left(1 + \frac{\gamma}{k}\right)}}\right) \tag{12}$$

$$P_{b16-QAM} = \frac{3}{8}\left(1 - \sqrt{\frac{2\gamma}{5k\left(1 + \frac{2\gamma}{5k}\right)}}\right) \tag{13}$$

$$P_{b64-QAM} = \frac{7}{24}\left(1 - \sqrt{\frac{\gamma}{7k\left(1 + \frac{\gamma}{7k}\right)}}\right) \tag{14}$$

Theoretical BER analysis of OFDM over Rayleigh Fading Channel

Orthogonal Frequency Division Multiplexing (OFDM) technique is used to overcome the time varying frequency selective channel and to suppress ISI by the addition of CP. The combination of OFDM and MIMO provides excess data rates of 100 Mbps. The IFFT at the transmitter and the FFT at the receiver are used to eliminate bunch of correlators for multicarrier modulation. The time varying fading channel becomes cyclically convoluted with its the periodic transmitted signal, to maintain the subcarriers remain orthogonal.

The OFDM system can be modeled as,

$$y = h \otimes x + n \tag{15}$$

The FFT of equation (15) will be,

$$Y(k) = H(k).X(k) + W(k) \tag{16}$$

Where,

N= Number of sub-carriers

L= Number of channel taps

K= K^{th} sub-carrier

H(k) = Rayleigh fading coefficient with average power 'L' and $\mathcal{N}(0,L)$

X(k)= k^{th} FFT point of Transmitted symbol with average power 'P'

Y(k)= k^{th} FFT point of Received symbol

W(k)= Gaussian noise with $\mathcal{N}(0,N\sigma^2)$

Then from equation (10), SNR at the output of FFT can be,

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$$SNR_r = \frac{|H(k)|^2 .P}{N.\sigma^2} = L\left(\frac{P}{N\sigma^2}\right)$$
$$\therefore BER = Q\left(\sqrt{SNR_r}\right)$$
$$\Rightarrow BER = \frac{1}{2}\left(1 - \sqrt{\frac{SNR_r}{2 + SNR_r}}\right)$$
$$\Rightarrow BER = \frac{1}{2}\left(1 - \sqrt{\frac{(L/N)SNR}{2 + (L/N)SNR}}\right) \quad (16)$$

4 Simulation Results

Consider the following simulation parameters for 4G system under frequency selective channel.

Table 1. Simulation Parameters

Parameter	**Vale**
Channel Bandwidth B	1.5MHz, 2.5MHz, 5MHz, 10MHz, 20MHz
Size of constellations M	BPSK, QPSK, M-QAM
Sub carrier spacing	15KHz
Number of channel taps L	7,10 taps
FFT size (Number of subcarriers) N	128, 256, 512, 1024, 2048
Cyclic prefix	16us
Channel types	AWGN, Rayleigh fading channel

From equation (5), the BER of AWGN decays exponentially w.r.t. SNR and it is observed in figure 1 below.

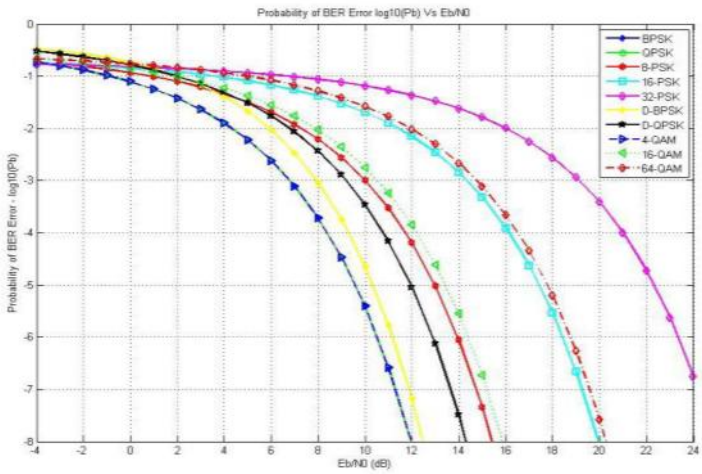

Fig.1. Performance of various digital modulation schemes under AWGN channel

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From equations (12-14), the theoretical BER analysis of 4-QAM, 16-QAM and 64-QAM under Rayleigh-fading channel is given below.

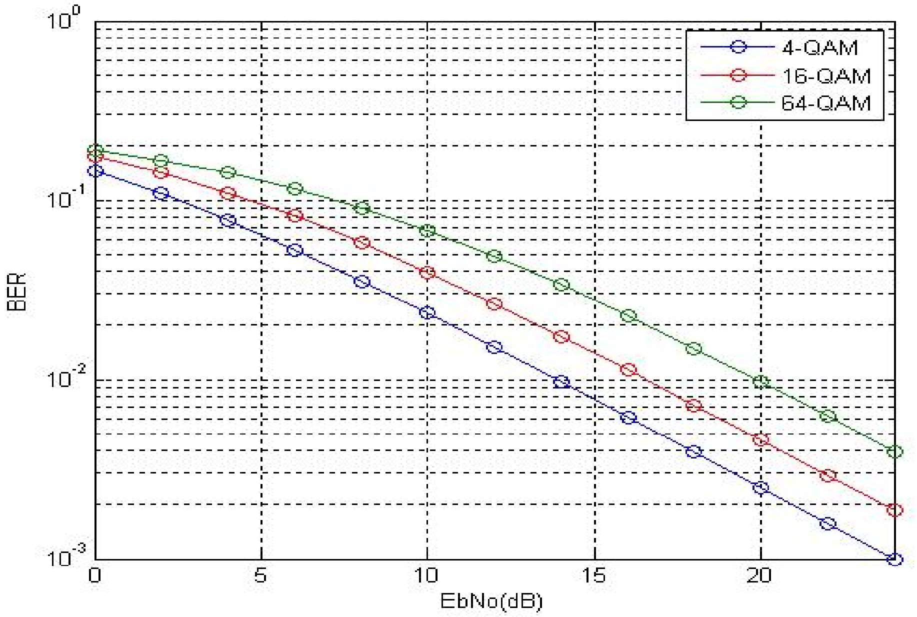

Fig.2. BER Performance of M-QAM Modulation schemes under Rayleigh channel

From figure 1 and 2, the BER of AWGN decays exponentially w.r.t. SNR where as under Rayleigh fading channel, BER is just inversely proportional to the SNR.

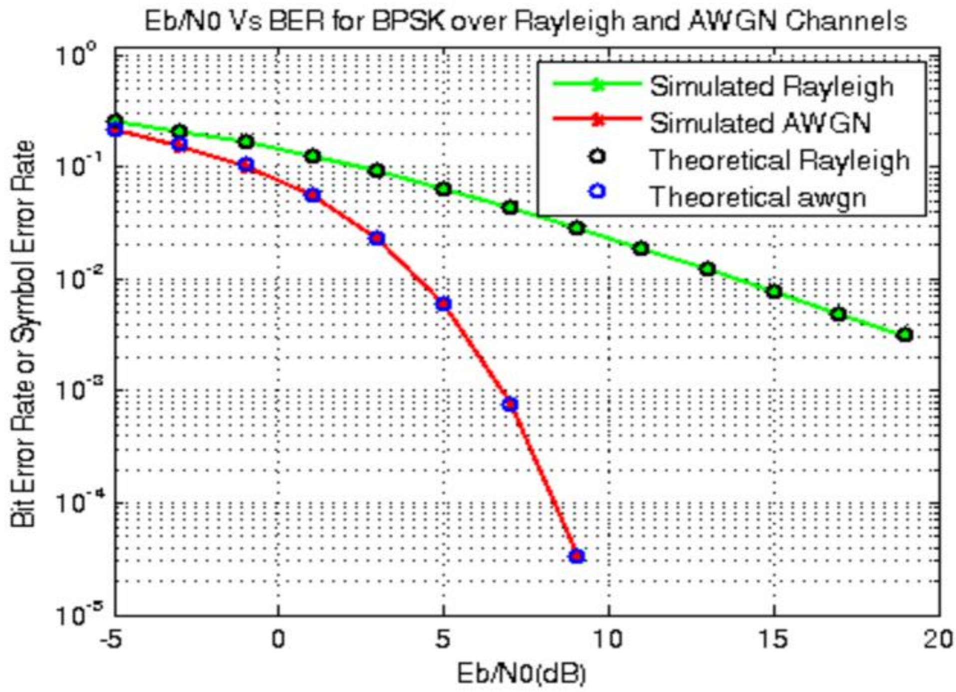

Fig.3. Performane analysis of BPSK over Raleigh and AWGN Channel

From figure 3, it is clear that there is approximately 17dB difference between the fading verses non fading channel at BER 10^{-3}.

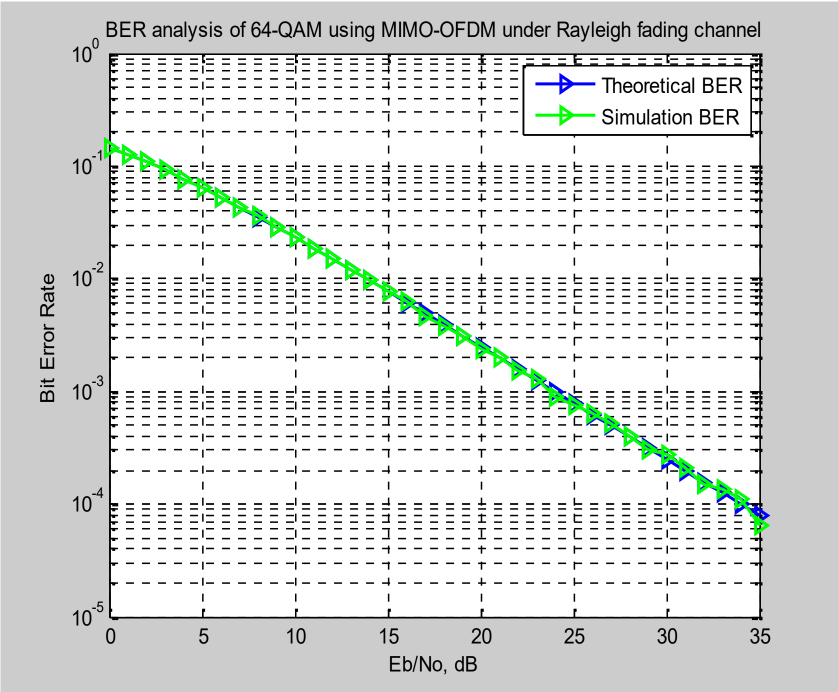

Fig..4. BER of MIMO OFDM under frequency selective channel using BPSK constellation

From figure 4, it is shown that the theoretical performance evaluation of digital modulation scheme under Rayleigh fading channel matches with the simulation parameters.

CONCLUSIONS

The performance of wireless communication system is critical due to its multipath frequency selective fading and can be combated by using OFDM and MIMO access techniques. Simulation results shows that it nullify the Inter Symbol Interference.

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