Modeling and Analyzing the BER Performance of MIMO System using Different Modulation Technique

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***Abstract*— MIMO technology is a radio communication technology which uses multiple antennas at both transmitter and receiver side to make use of reflected signals that provides gain in channel robustness and increases throughput. The demand of MIMO system is increasing day by day due to its capability of robustness against multipath fading. In this paper we mainly focus on modeling of MIMO systems and analysis of system using different modulation techniques such as BPSK, QPSK, 16 QAM, 64 QAM and BER is determined for all the systems. Performances of system have been observed for various parameters and channel conditions using customizable channel. And finally the comparison of BER for all the system is determined.**

Keywords*— Multiple input multiple outputs (MIMO), Quadrature Phase Shift Keying (QPSK), Quadrature Amplitude Modulation (QAM), Bit Error Rate (BER) and Signal to Noise Ratio (SNR).

I. INTRODUCTION

Wireless communication can be regarded as the most important and significant development in the modern society [5]. In the last few years multiple antennas technology have gained much more attention for communications systems because of the huge gain they can introduce in the communications reliability and channel capacity levels. Channel in the wireless communication is mainly affected by multipath fading. In wireless telecommunication, multipath is the propagation phenomenon which results in the arrival of transmitted signal at receiver with two or more path and with different time delays and frequency. To mitigate this problem MIMO diversity schemes were developed [8], [9], [10].

Wireless communication systems needs high data rates and reliability in order to meet the increasing demand for multimedia applications such as high quality audio and video. Existing technology cannot meet the above demand because these technologies are highly sensitive to multipath fading. In today's communication, MIMO is one of the most promising techniques which are beneficial in many areas such as high spectral efficiency, robustness and low computational complexity [4], [5].

MIMO is an important part of modern wireless communication standards such as 802.11 (Wifi), 4G, 3GPP Long Term Evolution and WIMAX [6]. The overall effects of the MIMO systems can be summarized in terms of reduction of bit error rate and increase in capacity and more efficient use of the transmitted power [7].

This paper is organized as follows: in section II we present discussion about MIMO systems and in section III we have described different modulation techniques in details which are used in this experiment. Section IV is dedicated to Experimental design setup and section V deals with simulation results and discussions. Finally we have concluded in section VI.

II. MIMO SYSTEM

MIMO system consists of N_T transmit antennas and N_R receive antennas and there is a channel/path between each of the transmit and receive antennas [2], [6].

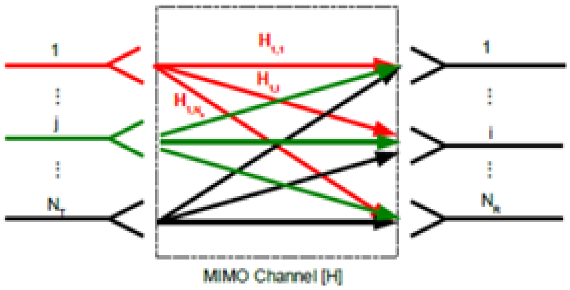

Fig 1: MIMO System along with transmit antennas and receive antennas

Let us consider 2x2 MIMO system

The received signal on the first receive antenna is

$$r_1 = h_{11}s_1 + h_{12}s_2 + n_1 \cdots\cdots\cdots(1)$$

The received signal on the second receive antenna is

$$r_2 = h_{21}s_1 + h_{22}s_2 + n_2 \cdots\cdots\cdots(2)$$

Where r_1 and r_2 are the received symbol on the first and second antenna respectively,

h_{11} is the channel from 1st transmit antenna to 1st receive antenna,

h_{12} is the channel from 2nd transmit antenna to 1st receive antenna,

h_{21} is the channel from 1st transmit antenna to 2nd receive antenna,

h_{22} is the channel from 2nd transmit antenna to 2nd receive antenna,

s_1 and s_2 are the transmitted symbols and n_1 and n_2 is the noise on the 1st and 2nd receive antennas respectively.

Equation (1) and (2) can be represented in matrix form

$$\begin{bmatrix} r_1 \\ r_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} s_1 \\ s_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} \qquad \ldots\ldots\ldots\ldots\ldots (3)$$

Then received vector can be expressed as

$$r = H_s + n \qquad \ldots\ldots\ldots\ldots\ldots (4)$$

The MIMO channel at any given time instant may be expressed as an N_T x N_R matrix

$$\text{H} = \begin{bmatrix} H_{1,1} & H_{1,2} & \cdots & H_{1,M_T} \\ H_{2,1} & H_{2,2} & \cdots & H_{2,M_T} \\ \vdots & \vdots & \ddots & \vdots \\ H_{M_R,1} & H_{M_R,2} & \cdots & H_{M_R,M_T} \end{bmatrix} \ldots\ldots\ldots (5)$$

III. Various Modulation Techniques

3.1. PSK (Phase Shift Keying): In PSK we change the phase of carrier signal to indicate information.

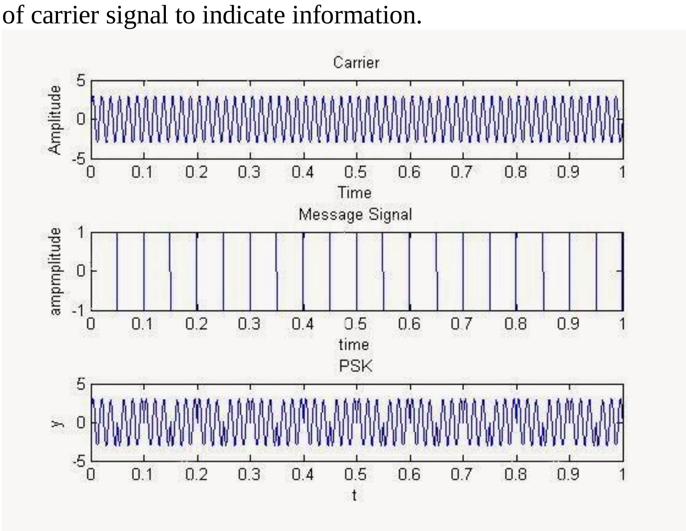

Fig 1: Graphical Representation of PSK.

Based on the number of symbols used, PSK is further divided into a few categories:

3.1.1. BPSK (Binary PSK): using M=2 symbols.

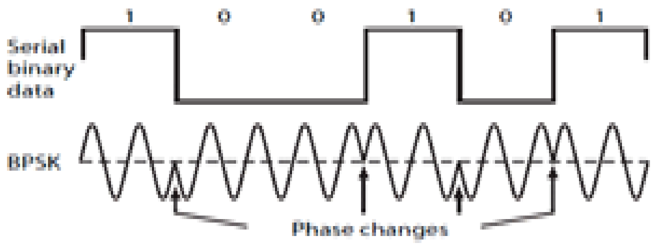

Fig 2: Graphical Representation of BPSK.

Here in binary phase shift keying, binary 0 is 0˚while a binary 1 is 180˚. The phase changes when the binary state switches so the signal is coherent.

3.1.2. QPSK (Quadrature PSK): using M=4 symbols.
QPSK (Quadrature Phase Shift Keying) is type of phase shift keying. Unlike BPSK which is a DSBCS modulation scheme with digital information for the message, QPSK is also a DSBCS modulation scheme but it sends two bits of digital information a time (without the use of another carrier frequency).
The amount of radio frequency spectrum required to transmit QPSK reliably is half that required for BPSK signals, which in turn makes room for more users on the channel.

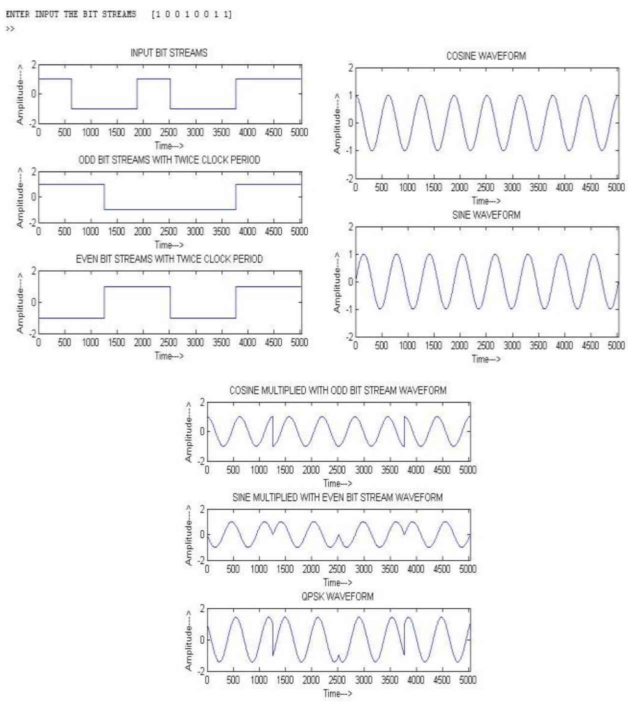

Fig 3: Graphical Representation of QPSK

8PSK (8-bit PSK) using M=8 symbols.

16PSK (16-bit PSK) using M=16 symbols.

3.2. QAM (Quadrature Amplitude Modulation):- Quadrature amplitude modulation (QAM) is both an analog and a digital modulation scheme. It conveys two analog message signals, or two digital bit streams, by changing (modulating) the amplitudes of two carrier waves, using the amplitude-shift keying (ASK) digital modulation scheme or amplitude modulation (AM) analog modulation scheme. The two carrier waves, usually sinusoids, are out of phase with each other by 90° and are thus called quadrature carriers or quadrature components — hence the name of the scheme. The modulated waves are summed, and the final waveform is a combination of both phase-shift keying (PSK) and amplitude-shift keying (ASK). By moving to a higher-order constellation, it is possible to transmit more bits per symbol. For 16 QAM it transmits 4 bits/symbol whereas 64 QAM transmits 6 bits/symbol.

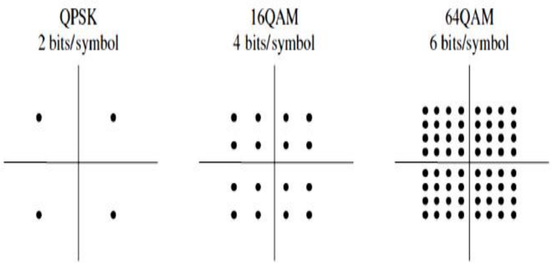

Fig 4: Constellation Diagram

4. BIT ERROR RATE

Bit error rate is defined as the rate at which errors occur in a transmission system during a studied time interval or it can be expressed as the number of receiving bits of a signal data over a communication channel that has been changed because of noise distortion, interference or bit synchronization redundancy. BER is a unit less quantity, often expressed as a percentage or 10 to the negative power.

The definition of BER can be translated into a simple formula:

$$\text{BER} = \frac{\text{Number of Error Bits}}{\text{Total Number of Transmitted Bits}}$$

5. SIGNAL TO NOISE RATIO (SNR)

The SNR is defined as the ratio of the received signal power over the noise power in the frequency range of the process. SNR is inversely related to BER that is for high SNR there should be decrease in BER. High BER results in increase in packet loss, delay and decreased throughput. SNR measures the clarity of the signal in a circuit or a wired/wireless transmission channel and measure in decibel (dB). The SNR is the ratio between the wanted signal and the unwanted background noise.

$$\text{SNR} = P_{Signal} / P_{Noise}$$

IV. EXPERIMENTAL DESIGN SETUP

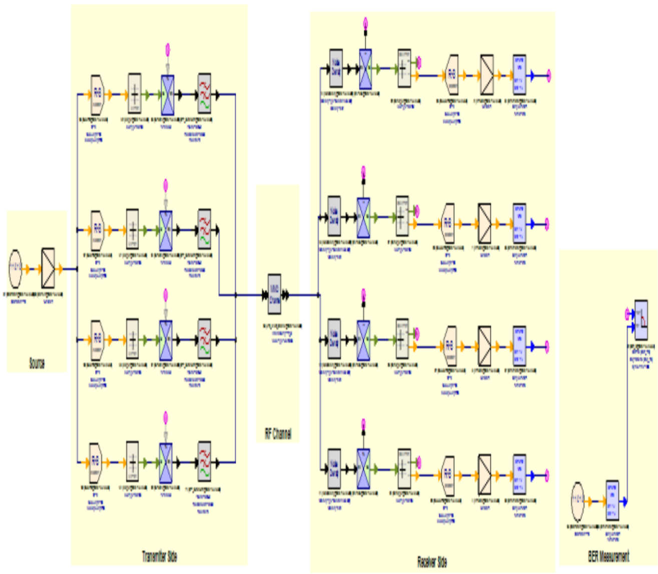

Fig 1: Experimental design model for MIMO with 4 Transmit and 4 Receive Antennas

The model represents the multiple input multiple output system. Here we have shown figure only for 4 transmitters and 4 receiver antennas. Systemvue platform has been chosen which represents the real time scenarios. The block diagram consists of transmitter, receiver and MIMO channel part.

Transmitter Part

The data is generated through PN 9 source which is a random data source, consists of series of zeros and ones and its output is boolean. The generated data source is then passed through RS encoder which takes integer as input so boolean to integer converter is used in between PN 9 source and RS encoder. Here sample rate is 51.24e-6 Hz and bit rate is also same as sample rate i.e. 51.24e-6 Hz.

RS Encoder

This model reads k samples from input in and writes n samples to output out. RS codes are a class of block codes that operate on non-binary symbols. The symbols are formed from m bits of a binary data stream. A code block is then formed with n =2 m -1 symbols. In each block, k symbols are formed from the encoder input and (n - k) parity symbols are added. The code is thus a systematic code. The rate of the code is k/n, and the code is able to correct up to t = (n - k - 1)/2 or (n - k)/2 symbol errors in a block, depending on whether n - k is odd or even. Here code length is 255 and message length is 223 and code rate is 2/3.

Mapper- The incoming data stream is then passed through mapper which consists of different modulation techniques such as BPSK, QPSK, 16QAM and 64 QAM. If ModType is User_Defined and the size of MappingTable is N, then the symbol length is log 2 (N) bits. Here QPSK, 16 QAM and 64 QAM is used as modulator which transmits 2, 4, 6 bits/symbol.

MIMO Channel

By the use of MIMO Channel we can increase the number of antennas at both transmitter and receiver side. AntennasConfig defines the antenna configurations at eNodeB and UE respectively. The antenna configurations are in the format of MxN, where M is the number of Tx antennas, and N is the number of Rx antennas. The bus width at the input port should be equal to M, while the bus width at the output port should be equal to N. Here velocity is defined which specifies the mobile unit's velocity (v) relative to the base station, in units of kilometer/hour. Here we have used 1x1,1x2, 2x1, 2x2, 4x2, 4x4 antennas at both transmitter and receiver side.

Receiver Part

Noise Density
This model adds noise to the input signal. At every execution, it reads 1 sample from the input and writes 1 sample to the output. Here noise density is set to -173.975 W.
At the receiver side, inverse operation of transmitter side is performed like Demapper and Decoder are used.

Demapper
Demapper inputs a complex value, finds the nearest constellation node for the input, and outputs both the constellation node and the symbol value for the constellation node in a bit sequence specified by the BitOrder parameter. Here demodulation of QPSK, 16 QAM and 64 QAM is done.

RS Decoder
This model reads n samples from input in and writes k samples to output out. The RS decoding is performed via the Berlekamp iterative algorithm. Here also code length is 255 and message length is 223 and code rate is 2/3.

BER Measurement
After this output of decoder is given to BER block which takes the input as integer. The BER_IS model measures the probability of error based on the Improved Importance Sampling (IIS) method which can quickly estimate error probabilities for PAM, QAM, QPSK, DQPSK systems. In order to reduce simulation time, error events are made to occur more frequently by modifying the probability density function of the noise. The input1 signal is the reference data input and should have no distortion or intersymbol interference. The input2 signal is the one against which the BER measurement is made.

V. SIMULATION RESULTS AND DISCUSSION

This includes two parts: 1st part deals with BER measurement for different MIMO system with various modulation techniques and 2nd part includes BER measurement by varying channel conditions and finally comparison is done for all the systems.

Part I:

The simulation model has been implemented in systemvue software. Advantage of using systemvue simulation software is that it allows base-band designers to virtualize the RF and eliminate excess margin. This section includes the BER graph when number of antennas are increased at both transmitter and receiver side and with different modulation techniques.

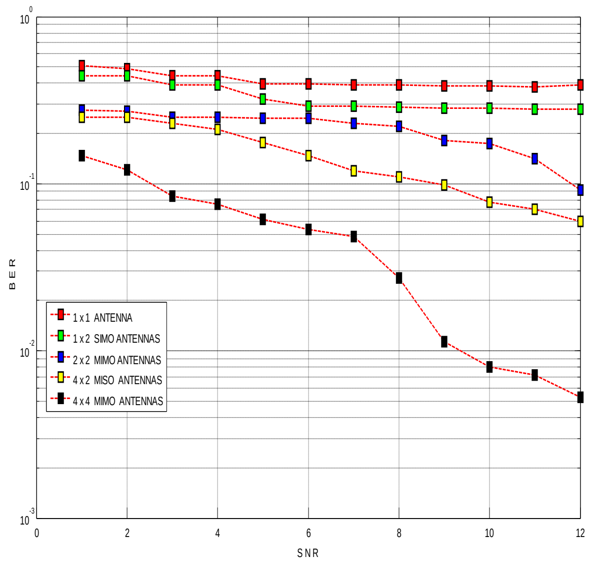

Fig 1: Comparison of BER for different antennas system (1x1, 1x2, 2x2, 4x2, 4x4)

In the above figure (1) it is seen that there is a decrease in BER when number of antennas are increased at both transmitter and receiver side. Here the maximum number of antennas used at both transmitter and receiver side is four i.e. 4 at transmitter and 4 at receiver side simply we can say 4x4 antennas which has very less BER compared to others. At SNR 12 dB it has BER of 5.311e-3 which is very less.

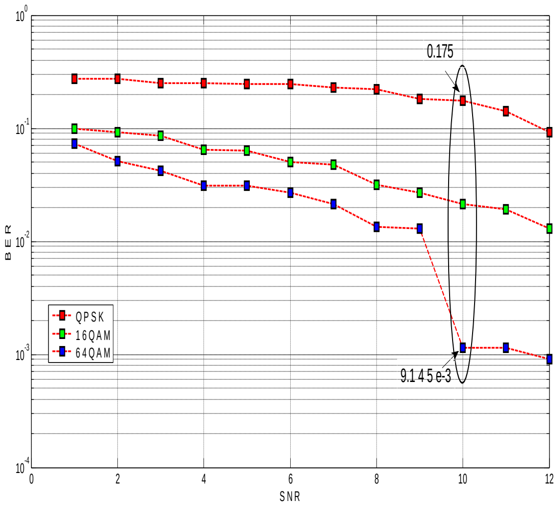

Fig 2: Comparison of BER when different modulation used in 2x2 Antennas

In this above figure it is compared that when different modulation techniques i.e. QPSK, 16 QAM and 64 QAM is used in 2x2 MIMO antennas then for higher modulation 64 QAM there is high decrease in BER and which is 9.145e-3 for 10 dB SNR whereas for QPSK it is 0.175.

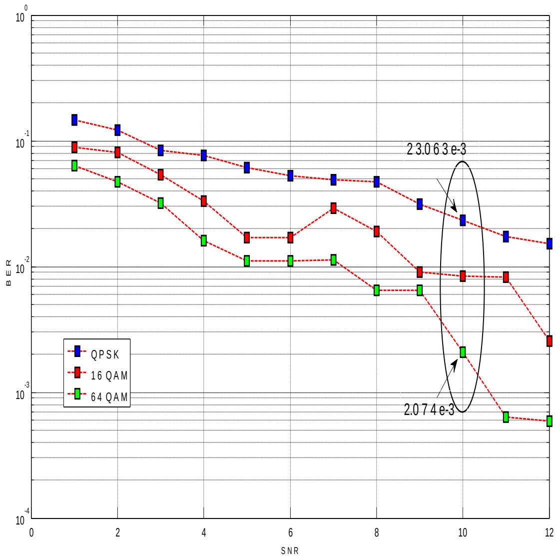

Fig 3: Comparison of BER when different modulation used in 4x4 Antennas

Above figure shows that for 4x4 MIMO antennas with 64 QAM there is a drastic decrease in BER i.e. 2.074e-3 as compared to QPSK and 16 QAM.

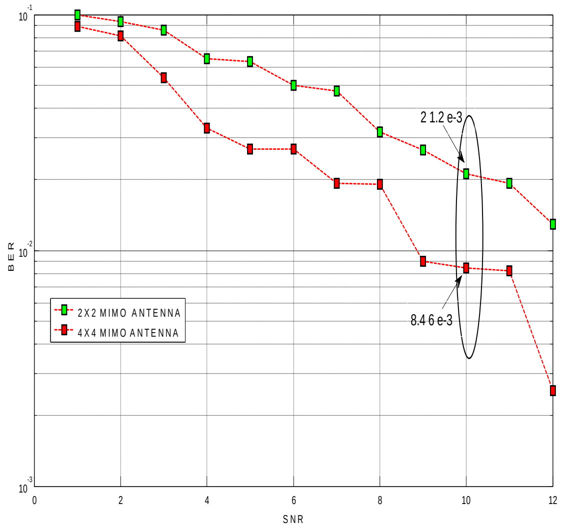

Fig 4: Comparison of BER at 16 QAM using 2x2 and 4x4 Antennas

Here the comparison of BER is done for 2x2 and 4x4 MIMO antennas when 16 QAM modulation is used for both and it shows the result that for higher antenna 4x4 BER is less i.e. 8.46e-3 at 10 dB.

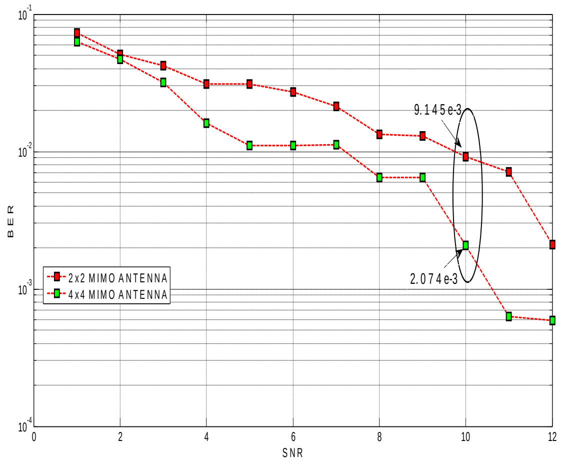

Fig 5: Comparison of BER at 64 QAM using 2x2 and 4x4 Antennas

Above figure shows the comparison of BER for 2x2 and 4x4 antennas when 64 QAM modulation is used for both of it. It shows that BER is less for 4x4 antennas i.e. it is 2.074e-3 at 10 dB SNR whereas for 2x2 antennas BER is 9.145e-3 at 10 dB SNR.

Part II: For different Channel Conditions

1. At different velocity in km/hr

For QPSK

Model Type	BER of 2x2 Antennas	BER of 4x4 Antennas
Pedestrian A (30 km/hr)	80.22e-2	6.45e-3
Vehicular A (60 km/hr)	90.89e-2	6.99e-3
Extended Pedestrian A (120 km/hr)	91.91e-2	8.03e-3

BER increases with increase in velocity for both 2x2 and 4x4 MIMO systems while using QPSK modulation technique for different model type.

For 16 QAM

Model Type	BER of 2x2 Antennas	BER of 4x4 Antennas
Pedestrian A (30 km/hr)	77.17e-3	83.363e-3
Vehicular A (60 km/hr)	74.97e-3	78.074e-3
Extended Pedestrian A (120 km/hr)	74.55e-3	69.011e-3

BER remains almost same with increase in velocity for 2x2 MIMO systems and there is a decrease in BER for 4x4 MIMO systems while using 16 QAM modulation techniques for different model type.

2. With /without Path loss

For QPSK

Model Type	Path Loss	BER of 2x2 Antennas	BER of 4x4 Antennas
Pedestrian A (30 km/hr)	Yes	0.113	0.053
	No	180.82e-2	148.53e-2
Vehicular A (60 km/hr)	Yes	0.119	0.061
	No	177.22e-2	143.03e-2
Extended Pedestrian A (120 km/hr)	Yes	0.147	0.066
	No	175.22e-3	138.03e-2

BER increases when path loss is added in the system, however it is comparatively less when there is no path loss for different model type while using QPSK modulation technique.

For 16 QAM

Model Type	Path Loss	BER of 2x2 Antennas	BER of 4x4 Antennas
Pedestrian A (30 km/hr)	Yes	0.0732	91.79e-3
	No	59.55e-3	27.15e-3
Vehicular A (60 km/hr)	Yes	0.0737	61.51e-3
	No	59.55e-3	27.15e-3
Extended Pedestrian A (120 km/hr)	Yes	0.0784	37.46e-3
	No	59.55e-3	27.15e-3

When 16 QAM is used as modulation and path loss is added then there is very less variation in BER for 2x2 whereas for 4x4 Antennas BER decreases and for without path loss the BER remains almost same for different model type.

VI. Conclusion

We have designed a model for 1x1, 1x2, 2x2, 4x2, 4x4 systems using different modulation techniques and under different channel conditions. BER is obtained and compared for all the systems. It has been observed that when numbers of antennas are increased at both transmitter and receiver side and also when higher modulation technique is used then there is a drastic decrease in BER. Higher modulations with high number of antennas are the best solution for future generation wireless technology. When multiple antennas are used then there is a possibility of achieving high data rate which is most important requirement of wireless communication.

For better enhancement of data rate and for decrease in bit error rate OFDM and FBMC can be used for future wireless technology.

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