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Performance Evaluation of MIMO-OFDM with Different Noise Cancellation Techniques in Wireless Communication System

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Abstract: In the concept of global village, wireless communication system is the smart choice for the digital generations to come. Multiple Input Multiple Output (MIMO) technique is the implementation of multiple transmitting and receiving antennas to enhance the performance of Wireless Communication System. It saves additional bandwidth and transmitting power when it is embedded with the Orthogonal Frequency Division Multiple Access (OFDM) technique. But noise is always an issue to be solved to ensure the best performance. If suitable noise cancellation techniques can be chosen, MIMO-OFDM can jointly play an important role in transmitting multimedia data.
In this paper, we evaluate the performance of different noise cancellation techniques for the MIMO- OFDM system to provide the best data throughput. Our simulation results show that, Least Mean Square technique provides the best solution to noise mitigation for QAM modulation when combined with Zero Forcing channel equalization technique. For the next generation of wireless communication system, MIMO-OFDM along with LMS and Zero Forcing techniques will strengthen the high speed network backbone by providing high quality multimedia streams.

Keywords: MIMO, OFDM, LMS Algorithm, Zero Forcing

Introduction: From the very beginning of the 20th century, there has been a remarkable change in the world of wireless communication [1]. But range, reliability and capacity are the major issue to be dealt with. So for the active researchers in the field of communication, there is always a high demand of "all in one package" that could solve all the problems [2]. Luckily, we were blessed with the invention of MIMO system by Greg Releigh in 1996 [3]. He suggested that different data could be sent using same frequencies by deploying multiple transmitting and receiving antennas. It was a reliable communication system and also covered high range. But in the real world, bandwidth is always costly. So the researchers were seeking for the accurate method to save the bandwidth. Later it was proved that, if we can combine MIMO with OFDM [4][5][6], it results in outstanding outcomes. OFDM splits the main data stream of channel into multiple adjacent sub-channels. After that modulation is performed on each of sub-channel with different sub carriers. In this way bandwidth can be saved and capacity is considerably increased.
But still today we need to fight with noise from different sources [7][8][9], those mingle itself with the baseband signal propagating through the wireless channel. Communication technology is changing very significantly with the invention of different modulation techniques and noise cancellation schemes. But we need to select the appropriate techniques and schemes to ensure the best performance under different conditions. In our research we have evaluated the performance of MIMO-OFDM techniques under different conditions and applying

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different techniques. Our simulation results will help to select the best parameters for error free communication in MIMO-OFDM.

MIMO OFDM: To beat with the crosstalk in cellular communication, OFDM technique [10][11] was introduced based on Frequency Division Multiplexing (FDM) technique. It is also used for WLAN and Wi-Fi. It can efficiently deal with the multipath components and creates a strong barrier against Inter Symbol Interference (ISI). It offers less complexity than single carrier system with equalizer. If we can calculate the Signal to Noise (SNR) for a particular subcarrier, the adding respective data rate will increase the overall capacity of the system.

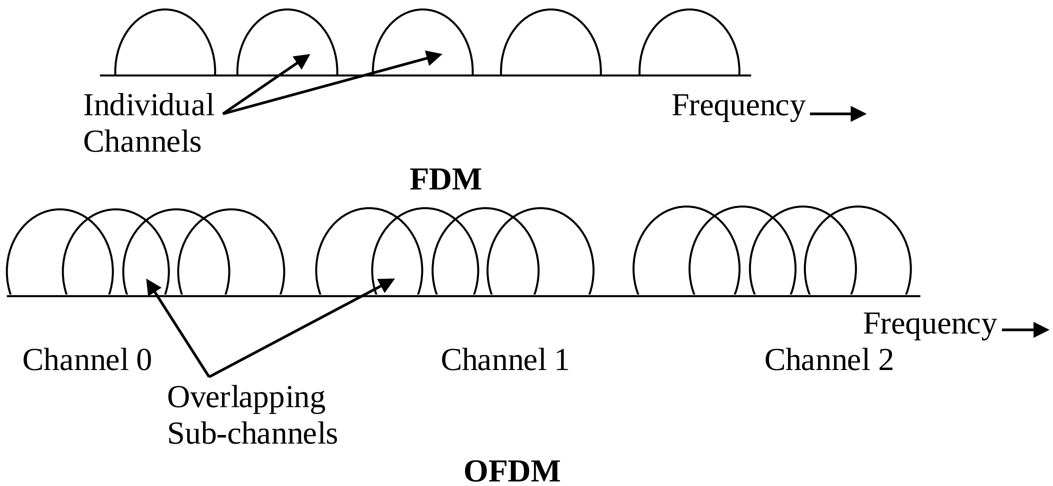


Fig. 1: OFDM technique in comparison with FDM

In this technique, the high rate baseband signal is divided into different low rate streams. Finally they are modulated with subcarriers of different frequency and transmitted by different sub-channels. The subcarriers are spaced by guard band to mitigate overlapping. But to enhance efficiency, overlapping between two channels are done without interfering each other by finding orthogonal frequencies. The power of the subcarriers calculated at the peak of the spectrum is zero.

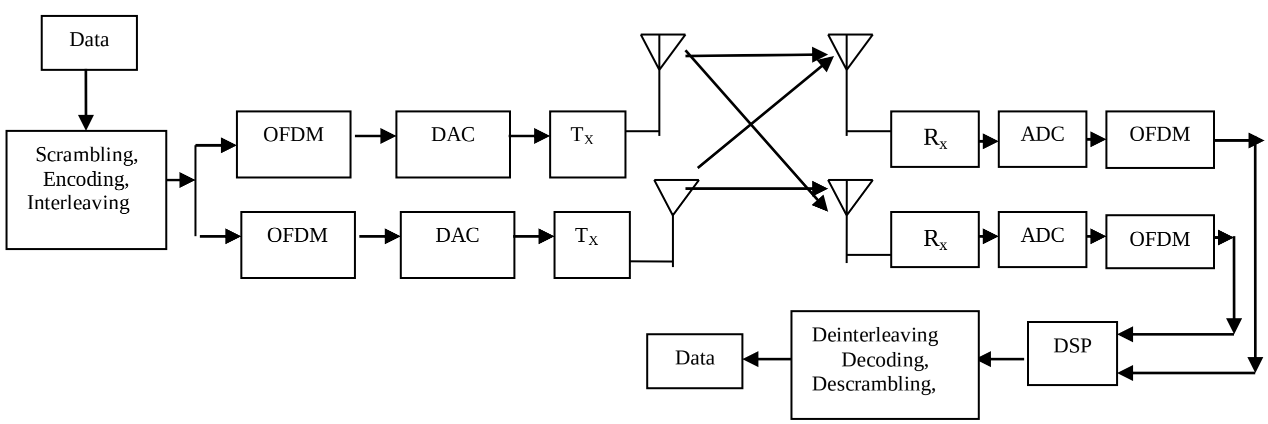


Fig. 2: Overview of MIMO technique

Multipath propagation is always considered to be great problem in wireless communication system. But MIMO [12] [13] technique uses this scattering property of the wave to be transmitted and received by an array of antennas which in return, multiplies the data rate. An expanded wireless connectivity may be ensured by enabling greater bandwidth a low cost. There is a linear relationship between the capacity and number of antennas. Each of the multipath routes can be used as separate channels and treated as "Virtual Wires." Different transmitting antennas (T_x) transmit this mixture of signals which are received by receiving antennas (R_x). The proportion of the received signal is depended on the channel. A simple equation-

$$R_{x1} = (h_{1,1} * T_{x1}) + (h_{2,1} * T_{x2}) \quad \text{eq.1}$$

Where, T_x are transmitter, R_x are receiver and h are different channels. We know that, Transmitting range and fidelity can be increased with the deduction of speed. If the issue is the range, then we need to mimic fidelity and speed. And fidelity could be ensured by sacrificing speed and range. MIMO OFDM can jointly offer us a solution to this problem. OFDM technique creates smaller sub signals and MIMO technique is used to transmit and receive them by deploying multiple antennas.

System Modeling: The simulation of different parts of a real communication system is very complicated and there is a lack of proper simulating algorithm. To this point, to complete our task, we made some assumptions to simplify the whole system. The different parts of the model is described as follows-

Simulation Parameters: The following listed generic values have been used to make our simulation realistic-

Table 1: List of parameters

Parameter	Value of Parameter
Number of bits	2 X 1024
Signal to Noise Ratio	-5 to 5 db
Modulation and Demodulation	QAM,BPSK, QPSK
Equalization Technique	ZF, MMSE
Forward Error Correction	CC
Simulation Channel	Additive White Gaussian Noise channel and Raleigh fading channel
T_x and R_x Structure	2 X 2

Description of the Simulated Model: For performing the simulations, codes are developed under a MATLAB 7.8 environment. The following is an overview of simulation procedures-

Input data block: In our simulation, Input data block serves as an input data source. We use standard random bit generator which generate random bits for input data block. The data block work as an original data source in the simulation. In our system, the input and output data form look alike.

Channel Coding and Decoding with Convolutional Codes (CC): Consecutive shift register stages combined with exclusive OR gates perform the core operation of convolutional coding technique. It is defined as CC (n, k, m)

Where, n= Number of output bits

k= Input bits

m= Constraint length of the encoder

We have used the 1/2 coding rate, input bits= 7 and generator polynomials are 01 = 171_{0CT} and 02 = 133_{OCT}.The structure is CC (2, 1, 7) encoder and shown in Fig. 2. Hard decision of Viterbi algorithm is used for decoding.

Interleaver and Deinterleaver: Interleaver is the mechanism to fight with the errors when the signal is propagating through the channel that can induce error to it. Especially for the case when the errors are mutually dependent on each other. This type of error is termed as “Burst Error.” The interleaver spreads out the burst error and ensures a random appearance at the receiver. Deinterleaver works as an inverter of inverleaver. In the deinterleaver, incoming data are rearranged so that output data returns back to the previous format of the interleaver. In the deinterleaver, the total number of bits remains the same i.e. if there is N number of input bits then the output also contains N number of bits.

Digital Modulation and Demodulation: Modulation is the process of mixing the baseband signal with the high frequency carrier wave so that, it can propagate through any channel with less distortions. The Amplitude, Phase or Frequency of the carrier signal is changed in accordance with the amplitude of the modulating signal. In digital modulation, the binary bits are changed into a mapped analog waveform. Demodulator works as an inverter of modulator. In the demodulator high frequency carrier eliminates and extracts the baseband frequency. For different modulation use different demodulator such as frequency demodulator, phase demodulator and amplitude demodulator. In frequency modulation the frequency of carrier signal change according to the instantaneous value of baseband signal. For amplitude modulation the amplitude of carrier signal change according to the instantaneous value of input baseband signal.

Spatial Multiplexing and Demultiplexing: For the case of MIMO channels, Spatial Multiplexing provides a many to one and Demultiplexing provides a one to many conversion scenario. The ultimate result is the linear increase in transmission rate. It does not need any extra bandwidth or additional power. Let us consider the situation where the number of T_x and R_x is two. Next the stream is split into two bit streams, resulting in the rate to be reduced by half. After that, they are modulated independently. Both the transmitting antennas are used for simultaneous transmission. We make a reuse of the of space dimension for encoded data signals. These individual bit streams are extracted and combined together by the receiving antennas so that the original bit streams may be recovered. With the increase of transmit-receive antenna pairs, the transmission rates increases proportionally. Spatial Demultiplexing is the opposite operation of spatial multiplexing.

P/S and S/P Converter: Parallel to serial (P/S) converter works as an inverter of serial to parallel (S/P) converter. In P/S, block the incoming parallel signal are converted into serial signal. In communication system, serial data bits pass one after another. On the other hand, parallel data bits pass at a single time. This converter is very useful for data communication. Serial to parallel(S/P) converter is a converter which is used to convert the incoming serial data to outgoing parallel data.

FFT and IFFT : IFFT is an inverse process of FFT. Fast Fourier transforms (FFT) converts a time domain signal into a frequency domain signal where Inverse Fast Fourier transforms (IFFT) converts frequency domain signal into time domain signal. In the IFFT different frequency signals are combining into a single combined frequency signal. Where there are many frequencies in a single signal.

MIMO Channel: Figure-1 is the illustration of the generic idea of MIMO-OFDM system. It is called NxN system where the number of transmitter and receiver antenna is N respectively. By the obtained diversity and

capacity gain, it can fight with fading when it is implemented in several paths. Different fading channels are discussed below-

Rayleigh fading: Let us assume a situation where the signal is propagating from source to destination through different obstacles like mountains, skyscrapers or through dense wood.

This situation will generate the reflected and scattered N versions of the original signal. These signals look alike to the original signal and must be received by the receiving antenna. Since these different signals follow different routes with different length, there will be variation of the phase as well as receive signal power. Let, The i^{th} path posses the amplitude and phase a_i and φ_i respectively and the signal started with the frequency ω_c. If there is no Line-of Sight (LOS) or direct path component, the received signal Set will be expressed as:

s(t) = $\sum_{i=1}^{N} a_i \cos(w_c\ t + \varphi_i)$ eq.2

If the transmitter and receiver is in relative motion, there will be a change of the frequency of the received signal. In that case, we need to consider the Doppler Shift.

If w_{di} represents the shift for i^{th} component, the received signal will be as following:

s(t) = $\sum_{i=1}^{N} a_i \cos(w_c\ t + w_{di}t + \varphi_i)$ eq. 3

The range of φ_i is 0 to 2π. Let us consider that the value of N is large. Then while signal reception, the mean will be zero and standard deviation will be σ for the quadrature and in-phase components. The Probability Density Function (PDF) of this received signal envelope is expressed as:

f(r)=$\frac{r}{\varphi^2} \exp\{-\frac{r}{\varphi^2}\}$, r >= 0 eq. 4

Rician fading: In most of the cases, Rician fading and Rayleigh fading channel provide the same characteristics. But in Rician fading, direct path of (LOS) is another issue to be solved. The transmitted signal by the existence direct path (LOS) will be given as:

s(t) = $\sum_{i=1}^{N} a_i \cos(w_c\ t + w_{di}t + \varphi_i)\ldots + k_d \cos(w_c\ t + w_d t)$ eq. 5

In this case the envelope has a Rician density function as:

f(r)=$\frac{r}{\varphi^2} \exp\{-\frac{r^2+k_d^2}{\varphi^2}\} I_0 \{\frac{r k_d}{\varphi^2}\}$, r>=0 eq. 6

Where, I_0 is the 0^{th} order that is modified by Bessel function of the first kind.

Signal Detection: Signal detector are divided into two category- (a) linear (b) non linear. There is a number of detection techniques and algorithms. Among them Zero Forcing (ZF), Minimum Mean Square Estimator (MMSE) and maximum likelihood (*ML*) detection are very popular. The MIMO detection technique has been showed in Figure 3.

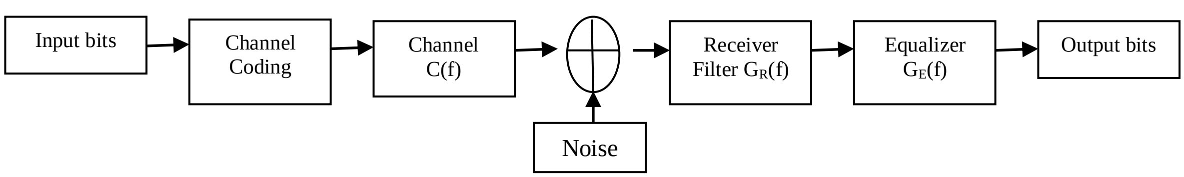


Fig. 3: Signal Detection Scheme

Zero Forcing (ZF) Detection

The basic Zero force equalizer of 2x2 MIMO channel can be modeled by taking received signal y_1 during first slot at receiver antenna as:

$y_1 = h_{1,1} x_1 + h_{1,2} x_2 + n_1 = [h_{1,1} \quad h_{1,2}] \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n$ eq. 7

The received signal y_2 at the second slot receiver antenna is:

$Y_2 = h_{2,1} x_1 + h_{2,2} x_2 + n_2 = [h_{2,1} \quad h_{2,2}] \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_2$ eq. 8

Where i=1, 2 in x_i is the transmitted symbol and i =1, 2 in $h_{i,j}$ is correlated matrix of fading channel, with j represented transmitted antenna and i represented receiver antenna, is the noise of first and second receiver antenna. The ZF equalizer is given by:

$W_{ZF} = (H^H)^{-1} H^H$ eq. 9

Where W_{ZF} is equalization matrix and H is a channel matrix. Assuming $M_R \geq M_T$ and H has full rank, the result of ZF equalization before quantization is written as:

$y_{ZF} = (H^H)^{-1} H^H y$ eq. 10

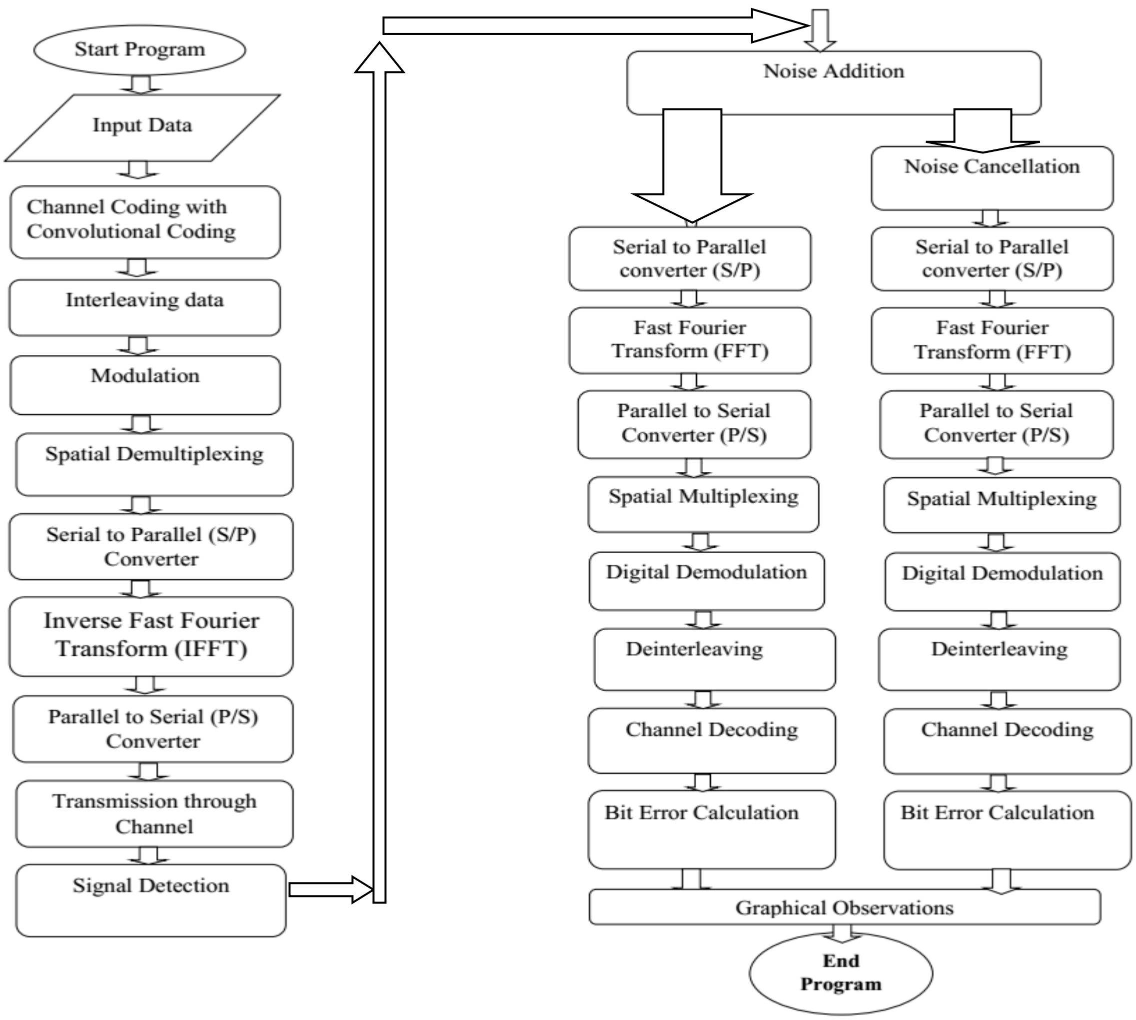
Minimum Mean Square Estimator (MMSE)

The channel model for MMSE is same as ZF. The MMSE equalization is

$W_{MMSE} = arg_G^{min}\ E_{x,n}\,[\|x - \acute{x}\|^2]$ eq. 11

Where is WMMSE equalization matrix, H channel correlated matrix and n is channel noise $y_{MMSE} = H^H (HH^H + n_0 I_n)^{-1} y$ eq. 12

Programming Flow Chart:



Performance Evaluation: The p **Fig. 4:** Computer Flowchart following cases-

Case 1: Figure 5 shows the impact of LMS based implementation of MIMO-OFDM applying Zero Forcing (ZF) equalization, Interleaving and Convolutional coding in MIMO OFDM signal using QAM modulation scheme over AWGN and Rayleigh channel. From Figure 5 it is seen that when LMS based noise cancellation is not implemented, BER decreases when SNR increases but when LMS based noise cancellation scheme is implemented BER remains same with increasing SNR.

Case 2: Figure 6 shows the impact of LMS implementation of MIMO-OFDM applying Zero Forcing (ZF) equalization, Interleaving and Convolutional coding in MIMOOFDM signal using QPSK modulation scheme over AWGN and Rayleigh channel. From Figure 6 it is seen that when LMS based noise cancellation is not implemented BER decreases when SNR increases but when LMS based noise cancellation scheme is implemented, BER remains same with increasing SNR.

Case 3: Figure 7 shows the impact of LMS Based implementation of MIMO-OFDM applying Zero Forcing (ZF) equalization, Interleaving and Convolutional coding in MIMOOFDM signal using BPSK modulation scheme over AWGN and Rayleigh channel. From Figure 7 it is seen that when LMS based noise cancellation is not implemented BER decreases when SNR increases but when LMS based noise cancellation scheme is implemented, BER remains same with increasing SNR.

Case 4: Figure 8 shows the impact of LMS implementation of MIMO-OFDM applying Minimum Mean Square Estimator (MMSE) equalization, Interleaving and Convolutional coding in MIMO-OFDM signal using QAM modulation scheme over AWGN and Rayleigh channel. From Figure 8 it is seen that when LMS based noise cancellation is not implemented BER decreases when SNR increases but when LMS based noise cancellation scheme is implemented, BER remains same with increasing SNR.

Case 5: Figure 9 shows the impact of LMS based implementation of MIMO-OFDM applying Minimum Mean Square Estimator (MMSE) equalization, Interleaving and Convolutional coding in MIMO-OFDM signal using QPSK modulation scheme over AWGN and Rayleigh channel. From Figure 9 it is seen that when LMS based noise cancellation is not implemented BER decreases when SNR increases but when LMS based noise cancellation scheme is implemented, BER remains same with increasing SNR.

Case 6: Figure 10 shows the impact of LMS based implementation of MIMO-OFDM applying Minimum Mean Square Estimator (MMSE) equalization, Interleaving and Convolutional coding in MIMO-OFDM signal using BPSK modulation scheme over AWGN and Rayleigh channel. From Figure 10 it is seen that when LMS based noise cancellation is not implemented, BER decreases when SNR increases butwhen LMS based noise cancellation scheme is implemented, BER remains same with Increasing SNR. The overall performance is depicted in figure 11.

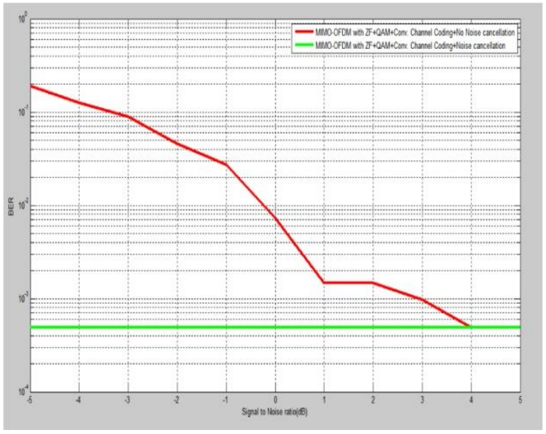


Fig. 5: SNR vs BER for QAM modulation with and without LMS and Zero Forcing

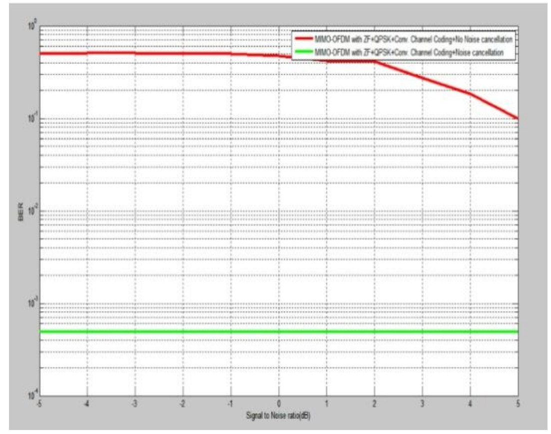


Fig. 6.: SNR vs BER for QPSK modulation with and without LMS and Zero Forcing

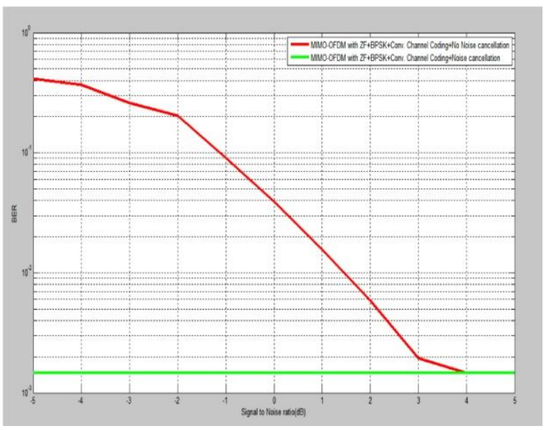


Fig. 7: SNR vs BER for BPSK modulation with and without LMS and Zero Forcing

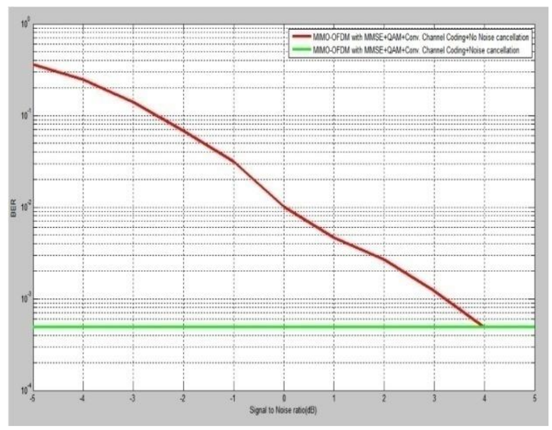


Fig. 8: SNR vs BER for QAM modulation with and without LMS and MMSE

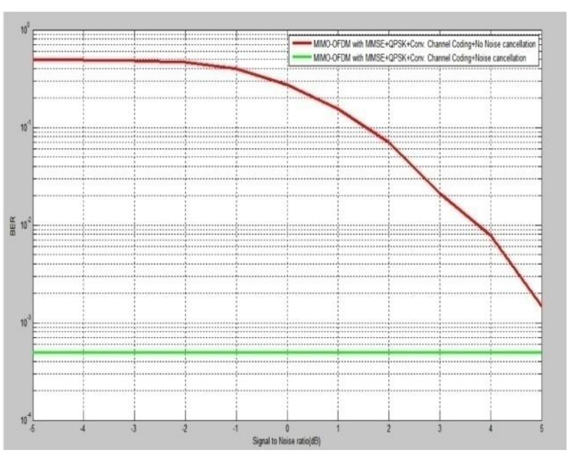


Fig. 9: SNR vs BER for QPSK modulation with and without LMS and MMSE

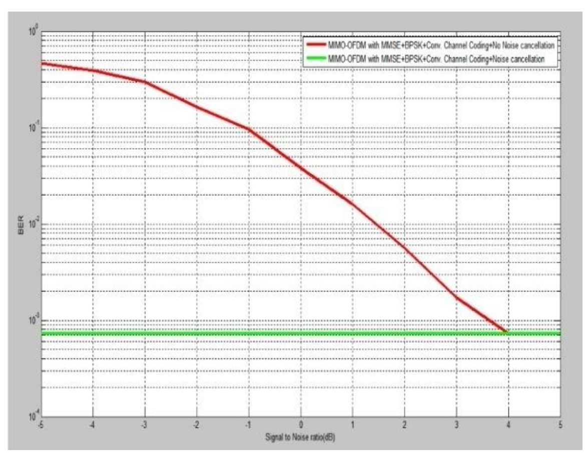


Fig. 10: SNR vs BER for BPSK modulation with and without LMS and MMSE

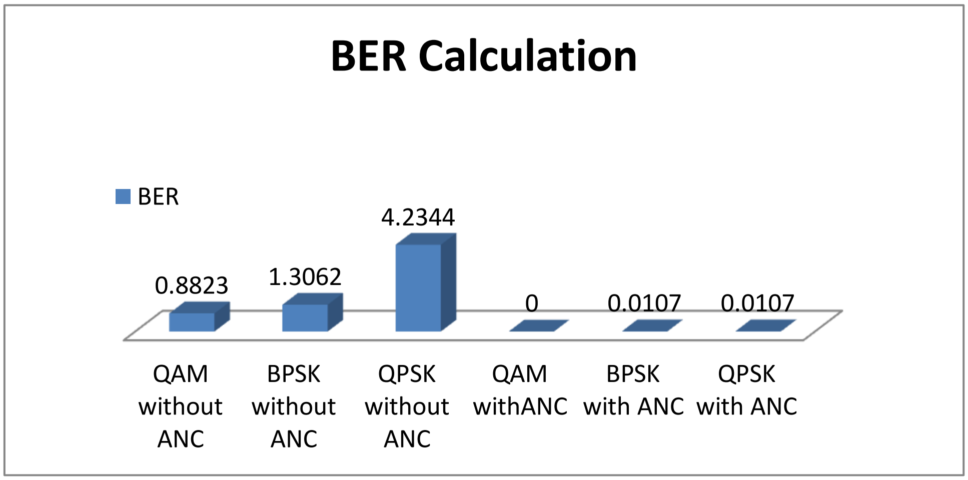


Fig. 11: Performance Evaluation in different criterion

Conclusion: In the world of modern communication, beating noises is always a touch challenge. But choice of proper parameters may be a solution to this. To derive the optimum results, the value of the chosen parameters varies with different techniques. Our simulated results show that for the case of MIMO-OFDM, if we can combine LMS noise cancellation and ZF Equalization technique along with QAM modulation and Convolutional channel coding, then the probability of generating noise free signal is almost 100 percent. Thus we can ensure a noise free data transmission for the days to come.

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