BER assessment of OFDM system augmented with MRC technique under the effect of CFO

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***Abstract* - Orthogonal frequency division multiplexing (OFDM) and Multiple input multiple output (MIMO) is capable to enhance data rates over the radio channel providing enough protection against the destructions caused in the path of the signal. But the bit error rate (BER) of the systems degrades due to the presence of Carrier frequency offset (CFO). The presence of CFO results in generation of Inter Carrier Interference (ICI) which in turn results in loss of orthogonality between the sub carriers. The significance of MIMO-OFDM is due to orthogonality among the carriers which is at stake due to presence of CFO. In this paper, the performance of the MIMO–OFDM system is analysed over the Rayleigh channel for 2 and 3-array antennas under the effect of CFO with Maximal Ratio Combining (MRC) diversity technique at receiver section. It is observed from simulations that the MIMO-MRC reduces the BER and improves the overall performance of the system which is very much useful to combat against the effects of CFO.**

Keywords— OFDM, MIMO, CFO, MRC, BER.

I. Introduction

In recent times, OFDM has emerged as a widely used multi-carrier modulation scheme as it utilizes a large number of overlapped sub-carriers which are orthogonal to each to other to transfer the information between two points. The overlapping of the orthogonal sub-carriers in the frequency domain results in enhanced spectral efficiency and reduced effect of multipath propagation. The orthogonality of the between the sub-carriers ensures a smooth reproduction of the original information at the receiver side without the requirement of complex detection algorithms [1]. Fourier transform is used to make the different sub-carriers orthogonal with respect to each other [2-4]. The techniques used like FFT and guard intervals makes it very efficient while computing the calculations and improving the interference among the channels and the symbols respectively. The extension of period in the symbol makes the synchronization of the codes present in the system a lot easier [5]. It has the capability to provide the large sum of the data rates over the radio providing enough protection against the destructions caused in the path of the data sent. But there is one effect that causes this error rate to get high and makes a lot of degradation in the performance of the system i.e. the Carrier frequency offset (CFO) which is considered to be an offset in the carriers based on frequencies; it is the main cause of the interference among the carriers leading to the Inter Carrier Interference (ICI) among them [6].

The ICI mainly occurs due to the shift of frequencies at both sides of T_x and R_x oscillators leading to the errors which can be cured by having the synchronization of the frequencies at the both the sides. Actually, the main factor of the OFDM is the orthogonality among the carriers that gets affected due to this factor. For its mitigation, different methods the algorithm have been proposed [7]. CFO has the capability to degrade the performance and reducing the efficiency of the bandwidth so it is better much required to be removed or reduced [26-27].

MIMO-OFDM is a system that is a combination of multiple antennas employed both at the transmitter and receiver end [8-10]. This implementation provides a great deal of diversity when used in conjunction with the techniques like singular value decomposition (SVD). The spatial multiplexing is a process that boosts the data transmission speed proportionally by a factor which is equal to the number of antennas applied at the transmitter. This technique utilizes the spectrum in an efficient manner as all data transmission at both sides is done in the same frequency band but with different spatial signatures. In this research, a study of the simple OFDM along with the effect of CFO on the system is studied. MIMO-OFDM augmented with Maximal Ratio Combining (MRC) is suggested for implementation to reduce BER and increase SNR.

II. Related Work

A design was developed [11] that conducts the hierarchical modulation of pilot signals and estimates the CFO efficiently. The CFO estimation at the receiver end is carried out on the principle that the BER will vary for variable CFO degrees i.e. the system exhibit different BER performance at different CFO values. A piece-wise linear approximation based on frequency-domain-equalizer is proposed in the literature [12]. The compensated CFO frequency which is added in the system depends mainly on the Doppler shift with optimal value ranging from 0.4 to 0.6.

P. Dharmawansa et al. developed a maximum likelihood CFO correction (ML-CFOC) method for reducing the adverse CFOs effects [14]. A novel method based on numerical calculations is proposed in the literature which demonstrates the reduction in bandwidth efficiency [8]. In the presence of frequency selective Nakagami-m fading channels, the average BER value is calculated by using closed-form expressions. The authors in [9] used the CF approach, provided the sum of the infinite series. For the first time, closed form analytical expressions were proposed for Binary PSK with CFO effect in different channels like AWGN, flat & frequency-selective Rayleigh fading channels. Researchers derived a closed form BER analysis with Inter Carrier Interference over diverse channels. Due to the ICI and frequency offset the orthogonality between the subcarriers got severely affected [16].

A new methodology for Kalman filer is proposed [17], [18], which utilize a robust method to enhance the memory and adaptive algorithm for fading environment thereby exhibiting an ability to track the variations of the state. An algorithm for estimation of frequency offset in OFDM systems, with analytical simulations are done in MATLAB [19]. A low dimensional method based on Kalman Filter was used for prediction in time and frequency selective channels [4]. A noble method based diversity technique is used for the estimation of the performance of the channel for the mobile based communication system's signals which are caused to be affected by the multipath fading over the Rayleigh is discussed [23].

The different types of diversity techniques are discussed that helps in increasing the performance of the radio channel by providing the receiver the several replicas of the same transmitted signal [20]. Several diversity techniques are discussed and the signals are coded using the space-time coding [21]. The technique under consideration utilized the LDPC filter along with OFDM in addition to the diversity methods. It is analysed that better performance prevails in the case of MRC [22]. The Alamouti STB code was used [10] for the improvement in the BER as the incorporation of the STB codes significantly reduces the effects of the multipath channels. In addition to the conventional Alamouti codes many other variants of the STB codes are being proposed in the literature to enhance the system performance in terms of capacity as well as BER performance.

III. Model Description

A. OFDM System Model

At the transmitter side the data is first encoded by using the convolutional encoding then the data is given to the interleaving block. After the block interleaving the data is forwarded to the digital modulation block which maps the incoming bits on to the constellation points depending upon the type and level of the modulation being chosen for the system [24]. The modulated data is then forwarded to the inverse fast Fourier transform (IFFT) block which map the modulated symbols onto the orthogonal sub carriers. Convolutional codes are more popular for their memory storage capabilities to keep the previous bits along with the current bits [25]. It has a property of encoding overall information stream in an individual code word without the need of segmenting. Both data and code words are of infinite length, so called as information and code sequence. Represented as (n, k, m) having code rate of R = k/n, where n is no. of output bits, k = input bits (constraint length) and input memory, m, that should be enormous enough to tackle probabilities of error, with condition $k < n$ as the performance of convolution codes depends on constraint length and code rate. A process called *Puncturing* is performed which means discarding the encoded bits and reducing the transmitted bits which are increasing the code rate automatically.

Interleaving contains permutation equations which correct the errors as it spreads the data over distributed carriers in the combination of 192 data carriers of OFDM symbol of total 256 carriers. It disperses code symbols in time before the transmission and broadcast the burst errors. Totally focuses on the position of the bits, thus reducing the errors and increasing the efficiency of FEC [7]. Block interleaver which mainly works for operating one block of the bit at a time and each bit is called as interleaving depth, which informs about the delay introduced on the side from where the signal is sent. Mainly, block interleaver is popular for its operation to write the data column wise and same can be read in row-wise format and vice versa.

According to the averaging of the constellation, random values are passed with the help of adaptive modulation schemes. Modulation is done based on the size of the data and different modulation schemes like BPSK, QPSK, 16 QAM and 64 QAM, etc. are used. Particular arrangements are done to adjust a signal, for instance, M-QAM and M-PSK and M is determined as bits according to which the constellation is mapped, and demodulation is performed to restore the transmitted digital data back. The function of IFFT is to obtain the signal in time domain, and after modulation, the produced symbols obtained can be taken as the sinusoidal amplitudes over a particular range. Before employing the IFFT algorithm, each of the discrete samples correlates to a single subcarrier. Rather keeping the fact that OFDM subcarriers are orthogonal, the IFFT is a prompt way to laterally modulate these subcarriers, through which the usage of numerous modulators and demodulators, operation, is avoided. It copies the end symbol and adds at the starting of every symbol of OFDM to mitigate the issue of inter-symbol interference which happens due to multipath propagation and delay.

These delays disturb the beginning of next symbol and make noise i.e. why the second symbol is placed away from the first symbol, and the cyclic prefix is detached at the receiver side to get the original signal [11]. The reverse operation is performed as done by the transmitter as well as channel estimation because it is needed to acknowledge channel coefficients not known to us. After the Cyclic Prefix is removed, then, the signal which is received is needed to be reformed into the frequency domain with the help of FFT and convolution operation is altered into multiplication. Then, de-interleaving, de-mapping, decoding with the help of Viterbi decoder is performed.

B. *MIMO System Model*

A technology containing radio antenna which transfers more data at the same time with the help of multiple antennas i.e. multiple transmitters and multiple receivers is a function of MIMO.

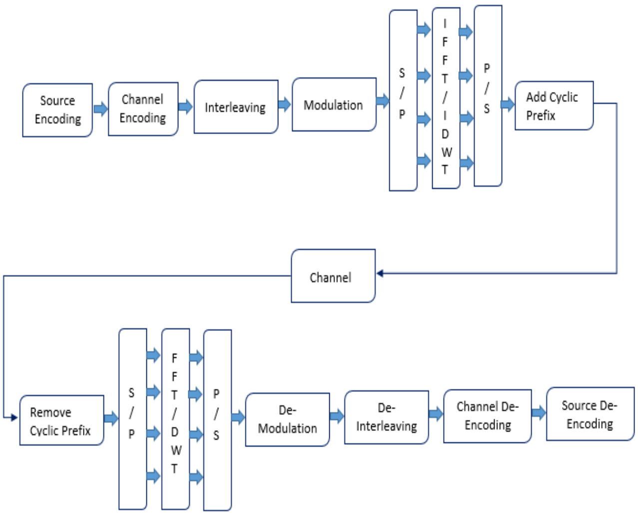


Fig. 1. Architecture of OFDM

By taking the asset of radio wave paradox, called 'multipath' and improved this by using spatial dimensions that directly increases the performance and scope of the system. Here from the fig. 2, we can see that multiple transmitters are sending unique data to receivers. Broadly assorted into three categories, firstly, beam-forming in which the signal is only sent at desired and needed direction. For proper gain and reliability, different antennas having different information are sent i.e. diversity is used. And for the throughput and increased data rate where different antennas have same information are sent called as spatial multiplexing.

Techniques to upgrade Signal to Noise Ratio (SNR) and mitigate multipath fading, in which dependent information is sent through different paths and at the receiver end we get multiple independent faded replicas of signal called as spatial diversity or transmit/receive diversity [3]. It alleviates fading and significantly improves link quality.

In this, maximum diversity gain d_{max} is achieved that is a sum of autonomous striking routes between transmitter and receiver side. Higher will be the diversity gain; lower will be the probability of error (P_e).

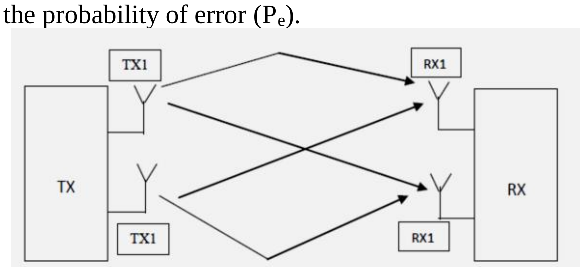


Fig. 2. Spatial Diversity in MIMO

Considering an (M_R, M_T) scheme, overall signal paths can be written as $M_R M_T$ [13].

C. *Maximal Ratio Combining (MRC)*

MRC, also known as ratio-squared combining and pre-detection combining**.** In MRC all the signals from every channel is added up. The gain attained in each of the channel is made up directly proportional to the *RMS* level of the signal and inversely to the mean square noise level in the same channel provide different different proportionality constants used for each channel as shown in fig. 3. Also, it has the capability to restore a signal to its original shape.

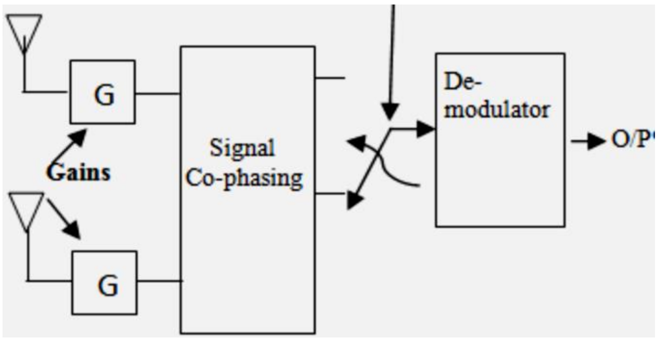
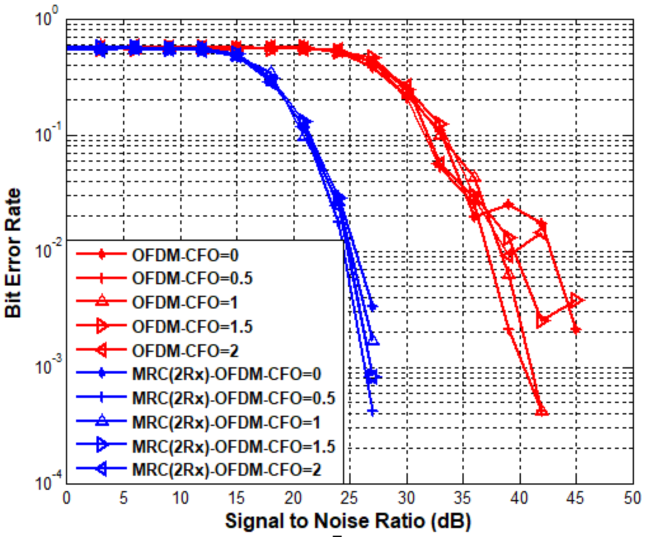


Fig. 3. Maximal Ratio Combining (MRC)

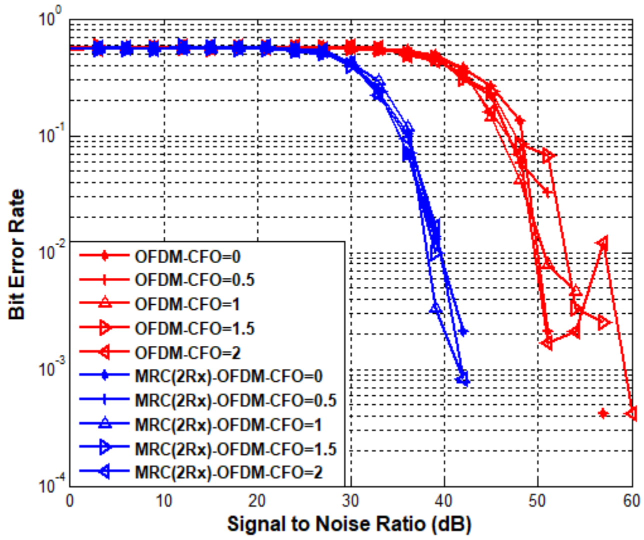
The combination of all the co-phased properly weighted signals achieves the high SNR at the reception side. The main purpose of using this technique is to achieve higher BER improvements in the system configuration only when the branches in the system are completely seem to be correlated. It has many advantages as well as disadvantages too, like it is little complicated and requires accurate estimation regarding the level of the instantaneous signals MRC is supposed to always perform way better than the either of all the selection diversity or equal gain combining.

IV. RESULTS & DISCUSSIONS

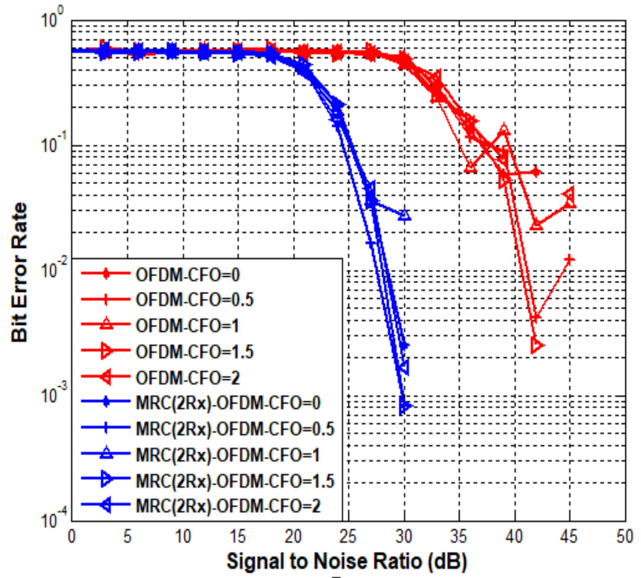
An analysis on the basis of MATLAB simulation is done for the MIMO-OFDM system. BER versus SNR calculations are carried out for the various values of CFO (ε values in the range of 0 to 2 in steps of 0.5). A comparative analysis is presented for OFDM system and MIMO-OFDM system employing MRC combining technique with 2 receiving antennas in the presence of CFO for diverse modulations levels i.e., BPSK, QPSK, 8-PSK, 16-PSK, 32-PSK in Figure 4 (a-f). The number of receiving antennas is also varied from 2 to 3 and similar comparative analysis has been presented in Figure 5 (a-f). It is very evident from the simulation results that the BER performance is depended upon the CFO, as the CFO values increase the BER performance of the system degrades and the SNR requirements to achieve a desired BER performance increases.



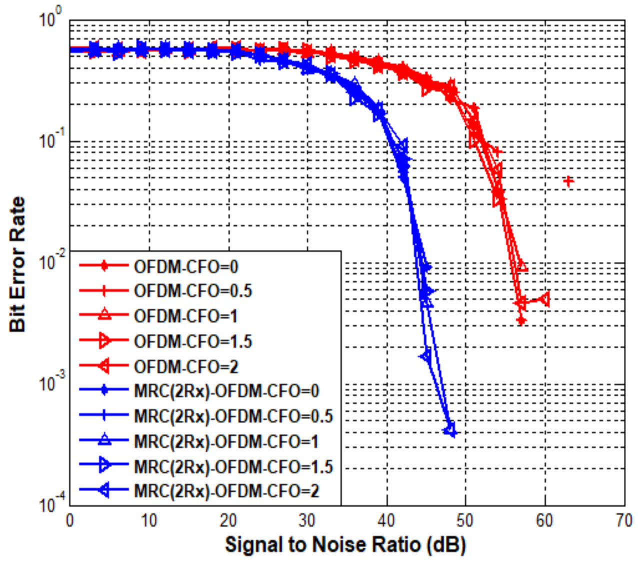
(a) BPSK



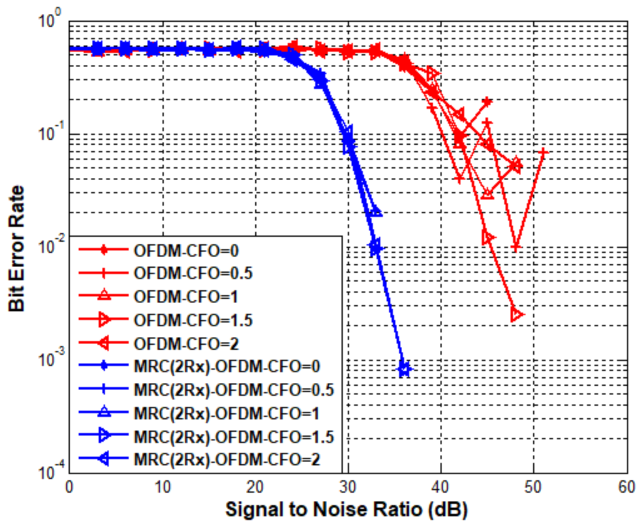
(d) 16-PSK



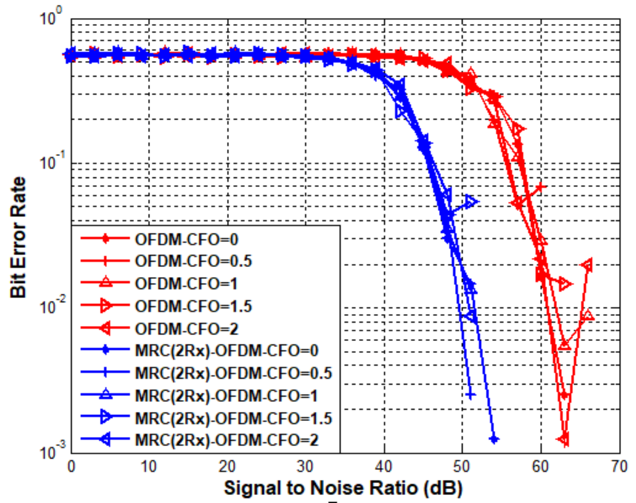
(b) QPSK



(e) 32-PSK

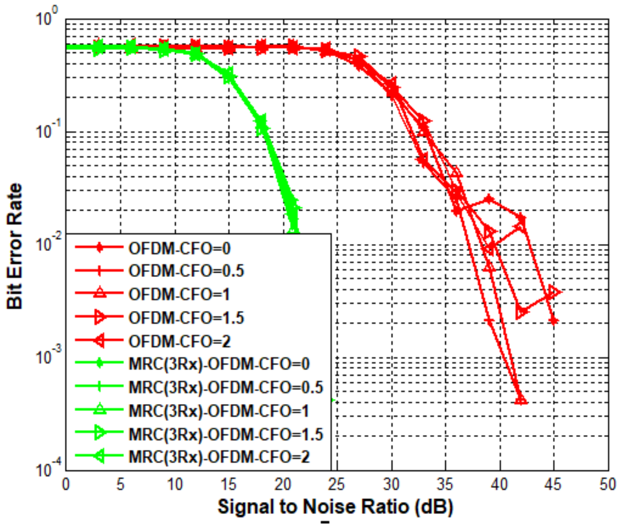


(c) 8-PSK

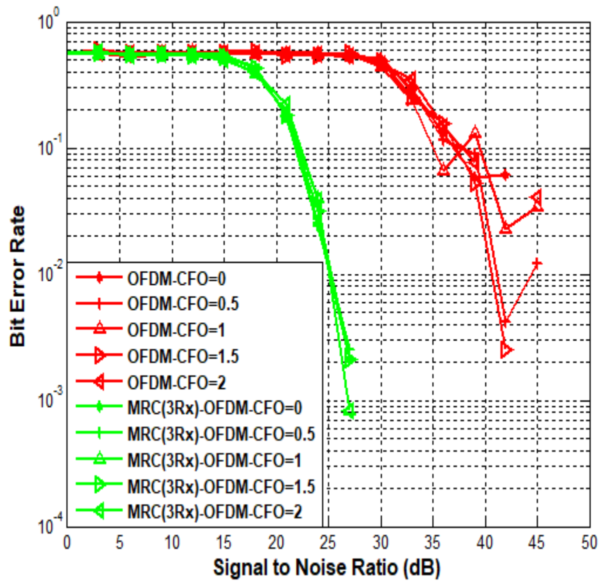


(f) 64-PSK

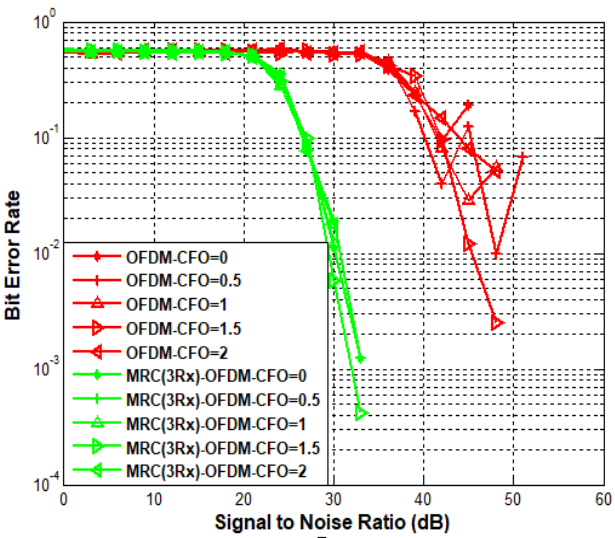
Fig. 4 (a-f). SNR vs. BER comparison for conventional OFDM and OFDM augmented with MRC technique with 2 receiving antennas for different values of CFO



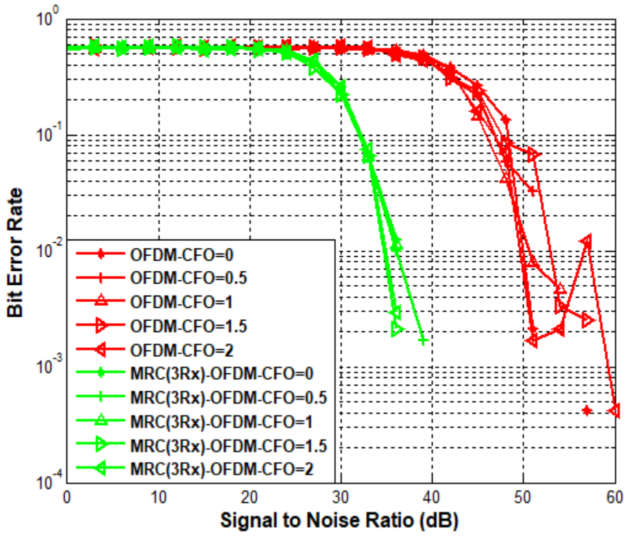
(a) BPSK



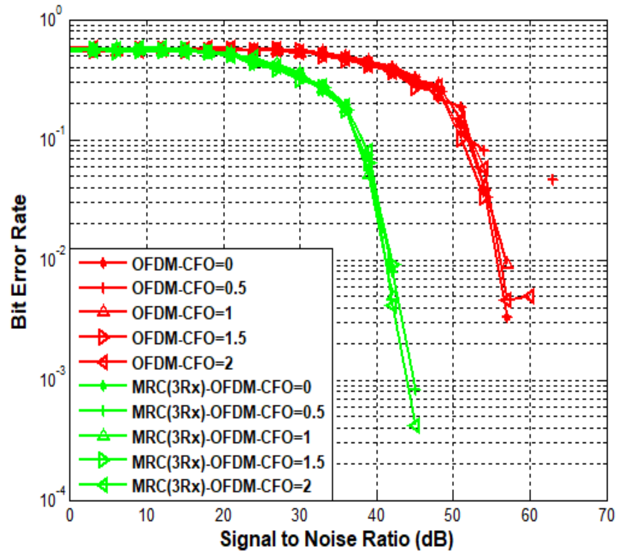
(b) QPSK



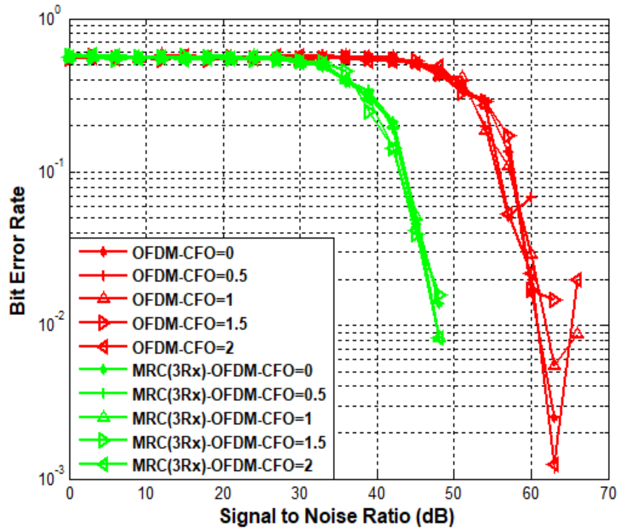
(c) 8-PSK



(d) 16-PSK



(e) 32-PSK



(f) 64-PSK

Fig. 5 (a-f). SNR vs. BER comparison for conventional OFDM and OFDM augmented with MRC technique with 3 receiving antennas for different values of CFO.

V. Conclusions

In this paper, we have proved that the MIMO-OFDM is considered as an efficient yet approachable method for faster data processing applications. The effects of the CFO are required to be mitigated to achieve a desired performance from the system without providing any additional SNR. Incorporation of the MIMO combining techniques along with the OFDM systems ensures a significant improvement in the BER performance of the system. On employing the MRC combining techniques the proposed MIMO-OFDM systems required 10-13 dB of less SNR in comparison to the conventional OFDM system to achieve a same BER performance. Integration of the MRC combining techniques also improves the BER performance of the MIMO-OFDM system under the effect of the CFO. Increase in the number of antennas at the receiver side further improves the system performance as demonstrated in the simulation results also.

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