BER Analysis of MIMO OFDM System for AWGN & Rayleigh Fading Channel

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ABSTRACT
Orthogonal Frequency-Division Multiplexing (OFDM) is essentially identical to coded OFDM (COFDM) and discrete multi-tone modulation (DMT). It is a frequency-division multiplexing (FDM) scheme, which is used as a digital multi-carrier modulation method. The paper is aimed at analyzing the BER performance of the MIMO (Multi-Input Multi-Output) OFDM system for AWGN (Additive White Gaussian Noise) Channel, Rayleigh Fading Channel along with a simulation channel using different modulation technique. Also the result of the analysis suggest for the better technique in order to improve the BER characteristic of the MIMO-OFDM system.

General Terms
AWGN, OFDM, QAM, QPSK, Rayleigh Fading.

Keywords
Cyclic prefix, Guard period, MIMO OFDM, Zero padding.

1. INTRODUCTION
Orthogonal Frequency Division Multiplexing (OFDM) is one of the most promising technologies for high data rate wireless communications [1], due to its robustness, high spectral efficiency, frequency selective fading, and low computational complexity. OFDM can be used in conjunction with a Multiple-Input Multiple-Output (MIMO) transceiver to increase the diversity gain and/or the system capacity by exploiting spatial domain. Because the OFDM system effectively provides numerous parallel narrowband channels, MIMO-OFDM is considered a key technology in emerging high-data rate systems such as 4G, IEEE 802.16, and IEEE 802.11n [2].

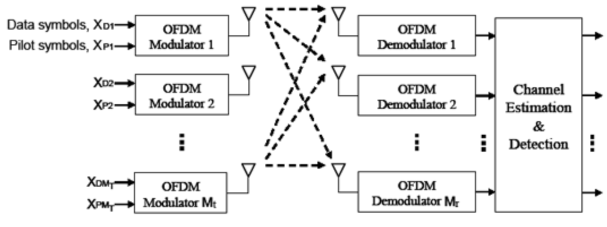

Fig.1. Combating ISI using a guard period

Figure 1 illustrates the basic model of MIMO OFDM system. MIMO [3], communication uses multiple antennas at both the transmitter and receiver to exploit the spatial domain for spatial multiplexing and/ or spatial diversity. In this paper MIMO OFDM is analyzed for AWGN & Rayleigh fading Channel and each sub-carrier being modulated with different conventional modulation scheme (such as quadrature amplitude modulation and quadrature phase shift keying) at a low symbol rate, maintaining total data rates similar to conventional single-carrier modulation schemes in the same bandwidth [4]. The primary advantage of OFDM over single-carrier schemes is its ability to cope with severe channel conditions. The low symbol rate makes the use of a guard period (also known as "Guard Interval") between symbols affordable, making it possible to eliminate inter-symbol interference (ISI) [5] and utilize echoes and time-spreading (that shows up as ghosting on analogue TV) to achieve a diversity gain, i.e. improved BER (Bit Error Rate) & SNR (Signal to Noise Ratio).There are several questions about the how much benefit can be avail by implementing this optimizing technique? Also how efficiently, the OFDM can be used with other technique to come-up with less complex & value-adding system?

The paper has been divided into two parts. In the first part we have explained, the different way of adding guard period to OFDM system, whereas second part shows BER analysis of OFDM-MIMO for different modulation technique, which has been summarized in the form of MATLAB simulation results.

2. CONTESTING ISI USING GUARD PERIOD
To optimize the performance of an OFDM link, time and frequency synchronization between the transmitter and receiver is of absolute importance. This can be achieved by using known pilot tones embedded in the OFDM [6], signal or attach fine frequency timing tracking algorithms within the OFDM signal's cyclic extension (guard Period/ Period). To prevent ISI, the individual blocks are separated by guard periods wherein the blocks are periodically extended. In addition, once the incoming signal is split into the respective transmission sub-carriers, a guard period is added between each symbol. Each symbol consists of useful symbol duration, T_s and a guard period, Δt, in which, part of the time, and a signal of T_s is cyclically repeated. This is shown in Fig. 2.

As long as the multi path propagation delays do not exceed the duration of the period, no inter-symbol interference occurs and no channel equalization is required. For a delay spread that is longer than the effective guard period, the BER (Bit Error Rate) rises rapidly due to the inter-symbol interference. The maximum BER that will occur is when the delay spread is very long (greater than the symbol time) as this will result in strong inter-symbol interference.

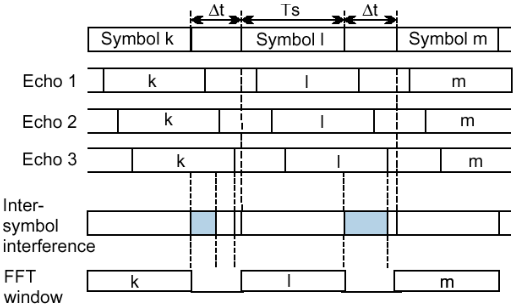

Fig.2. Combating ISI using a guard period [7]

In a practical system the length of the guard period can be chosen depending on the required multipath delay spread immunity required.

Figure 3 illustrates an ISI effect of the multipath channel over two successive OFDM symbols. Let T_{sub} denote the duration of the effective OFDM symbol without guard interval. Since $W = 1/T_s$ and thus, $\Delta f = W/N = 1/(NT_s)$ and $T_{sub} = NT_s = 1/\Delta f$. By extending the symbol duration by N times (i.e., $T_{sub}= NT_s$), the effect of the multipath fading channel is greatly reduced on the OFDM symbol. However, its effect still remains as a harmful factor that may break the orthogonality among the subcarriers in the OFDM scheme. As shown in Figure 3(b), the first received symbol (plotted in a solid line) is mixed up with the second received symbol (plotted in a dotted line), which incurs the ISI. It is obvious that all subcarriers are no longer orthogonal over the duration of each OFDM symbol. To warrant a performance of OFDM, there must be some means of dealing with the ISI effect over the multipath channel. As discussed in the sequel, a guard interval between two consecutive OFDM symbols will be essential.

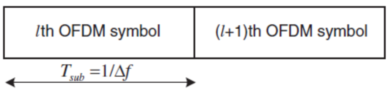

Fig. 3(a) OFDM symbol without guard period [8]

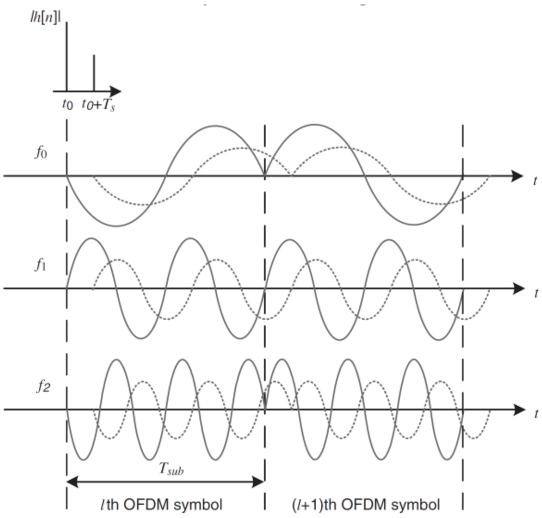

Fig. 3(b) Effect of a multipath channel on the received signal without guard period [9]

The Guard Period in OFDM System can be inserted in two different ways. One way is the zero padding (ZP) i.e. pads the guard period with zeros. The other way is the cyclic extension of the OFDM symbol (for some continuity) by insertion of CP (cyclic prefix) or CS (cyclic suffix). CP is to extend the OFDM symbol by copying the last samples of the OFDM symbol into its front.

2.1 Cyclic Prefix

Let T_G denote the length of CP in terms of samples. Then, the extended OFDM symbols now have the duration of $T_{sym}=T_{sub}+T_G$. Figure 4(a) shows two consecutive OFDM symbols, each of which has the CP of length TG, while illustrating the OFDM symbol of length $T_{sym}=T_{sub} +T_G$. While, Figure 4(b) shows the ISI effects of a multipath channel on some subcarriers of the OFDM symbol.

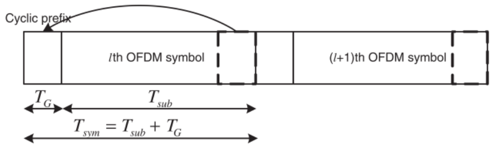

Fig.4 (a) OFDM symbol with CP [8]

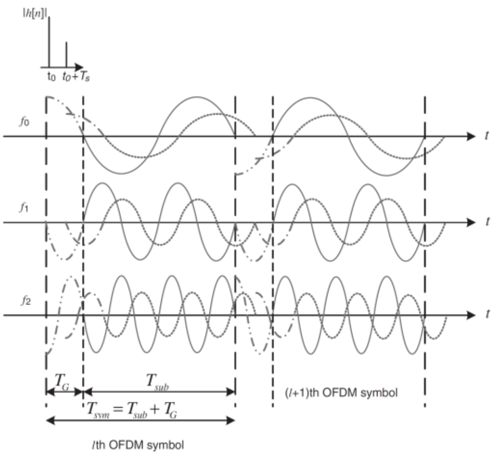

Fig. 4(b) ISI Effect of a multipath channel for each sub-carrier [9]

It can be seen from this figure that if the length of the guard interval (CP) is set longer than or equal to the maximum delay of a multipath channel, the ISI effect of an OFDM symbol (plotted in a dotted line) on the next symbol is confined within the guard interval so that it may not affect the FFT of the next OFDM symbol, taken for the duration of T_{sub}. This implies that the guard interval longer than the maximum delay of the multipath channel allows for maintaining the orthogonality among the subcarriers. As the continuity of each delayed subcarrier has been warranted by the CP, its orthogonality with all other subcarriers is maintained over T_{sub}, such that:

$$\frac{1}{T_{sub}}\int_{0}^{T_{sub}} e^{j2\pi f_k(t-t_0)}e^{j2\pi f_i(t-t_0)}dt = 0, k \neq i \qquad (1)$$

for the first OFDM signal that arrives with a delay of t_0, and

$$\frac{1}{T_{sub}}\int_{0}^{T_{sub}} e^{j2\pi f_k(t-t_0)}e^{j2\pi f_i(t-t_0-T_s)}dt = 0, k \neq i \qquad (2)$$

for the second OFDM signal that arrives with a delay of $t_0 +T_s$.

2.2 Cyclic Suffix (CS)

Cyclic suffix (CS) is also a cyclic extension of the OFDM system. It is different from CP only in that CS is the copy of the head part of an effective OFDM symbol, and it is inserted at the end of the symbol. CS is used to prevent the interference between upstream and downstream, and is also used as the guard interval for frequency hopping or RF convergence, and so on. Both CP and CS are used in Zipper-based VDSL systems in which the Zipper duplexing technique is a form of FDD (Frequency-Division Duplexing) that allocates different frequency bands (subcarriers) to downstream or upstream transmission in an OFDM symbol, allowing for bidirectional signal flow at the same time. Here, the purpose of CP and CS is to suppress the ISI effect of the multipath channel, while ensuring the orthogonality between the upstream and Therefore, the length of CP is set to cover the time dispersion of the channel, while the length of CS is set according to the difference between the upstream transmit time and downstream receive time. Figure 5 shows the structure of the OFDM symbol used in Zipper-based VDSL systems, where the length of the guard interval is the sum of CP length T_{CP} and CS length T_{CS}.

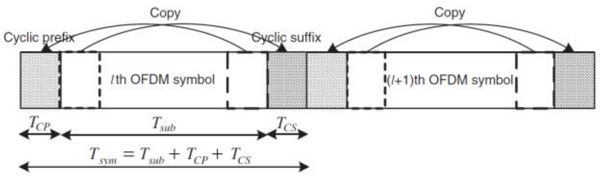

Fig.5. OFDM Symbol with CP & CS [10]

2.3 Zero Padding (ZP)

We may insert zero into the guard interval. This particular approach is adopted by multiband- OFDM (MB-OFDM) in an Ultra Wide-band (UWB) system. Figures 6 (a) and (b) show OFDM symbols with ZP and the ISI effect of a multipath channel on OFDM symbols for each subcarrier, respectively. Even with the length of ZP longer than the maximum delay of the multipath channel, a small STO causes the OFDM symbol of an effective duration to have a discontinuity within the FFT window and therefore, the guard interval part of the next OFDM symbol is copied and added into the head part of the current symbol to prevent ICI as described in Figure 7.

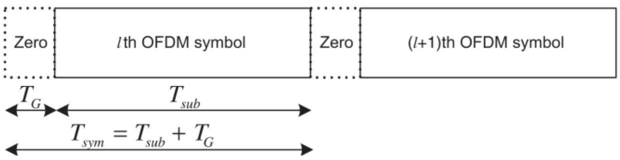

Fig. 6(a) OFDM Symbol with ZP [8]

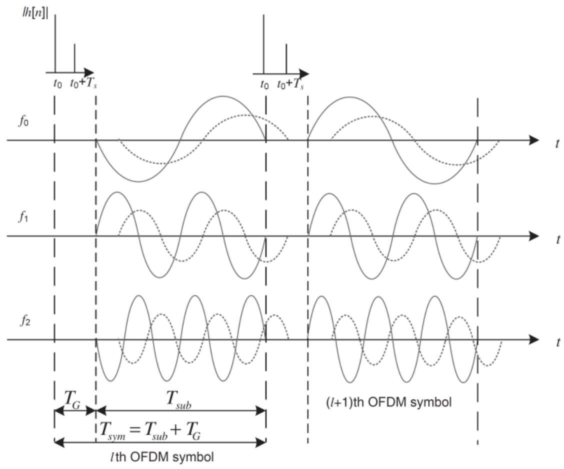

***Fig.* 6(b) ISI Effect of a multipath channel on OFDM symbols with ZP [9]**

Since the ZP is filled with zeros, the actual length of an OFDM symbol containing ZP is shorter than that of an OFDM symbol containing CP or CS and accordingly, the length of a rectangular window for transmission is also shorter, so that the corresponding sine-type spectrum may be wider. This implies that compared with an OFDM symbol containing CP or CS, an OFDM symbol containing ZP has PSD (Power Spectral Density) with the smaller in-band ripple and the larger out-of-band power, allowing more power to be used for transmission with the peak transmission power fixed.

Note that the data rate of the OFDM symbol is reduced by $T_{sub}/T_{sym}=T_{sub}/(T_{sub}+T_G)$ times due to the guard interval.

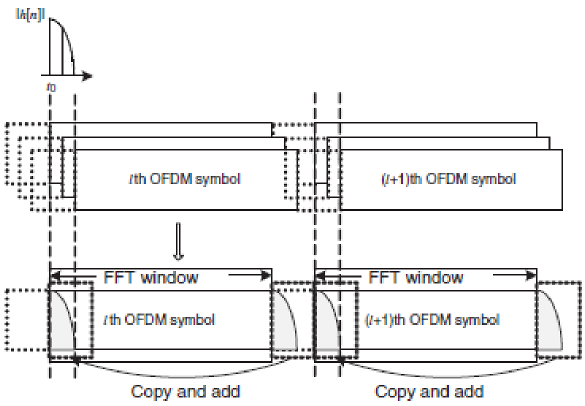

Fig.7. Copying and adding the guard interval of the next symbol into the head part of the current symbol to prevent ICI. [11]- [13]

3. BER ANALYSIS OF OFDM SYSTEM

The analytical BER expressions for M-ary QAM signaling in AWGN and Rayleigh channels are respectively given by equation (3) & equation (4) [14][15] as:

$$P_e = \frac{2(M-1)}{M\log_2 M} Q\left(\sqrt{\frac{6E_b}{N_0}\cdot\frac{\log_2 M}{M^2-1}}\right) \qquad (3)$$

$$P_e = \frac{(M-1)}{M\log_2 M}\left(1-\sqrt{\frac{3\gamma\log_2 M/\left(M^2-1\right)}{3\gamma\log_2 M/\left(M^2-1\right)+1}}\right) \quad (4)$$

Where, γ and M denote E_b/N_0 and the modulation order, respectively, while Q(x) [16] is the standard Q-function defined as:

$$Q(x)=\frac{1}{\sqrt{2\pi}}\int_x^{\infty} e^{-t^2/2}dt. \quad (5)$$

Note that if N_{used} subcarriers out of total N (FFT size) subcarriers (except $N_{vc}=N/N_{used}$ virtual subcarriers) are used for carrying data, the time-domain SNR, SNR_t [17], differs from the frequency-domain SNR, SNR_f , as follows:

$$SNR_t = SNR_f + 10\log\frac{N_{used}}{N}[dB] \quad (6)$$

4. RESULTS

The BER Performance of MIMO OFDM system has been analyzed for two scenarios, one is with Guard period inclusion and the other one without Guard period inclusion. Also the affect of the different modulation techniques over the performance of MIMO-OFDM system is illustrated thru the simulation results. After comparing the simulation result obtained by plotting Bit Error Rate (BER) against the Signal to Noise Ratio (SNR), there are two facts which are quite obvious and lead to conclusion. First, the presence of Guard Period in the MIMO OFDM System improves BER performance to the significant extent. Secondly, the different modulation techniques also affect the BER performance of the system.

The simulation set-up is divided into three sub-parts. In the first part, one of the three Guard period insertion techniques is chosen for the experiment purpose. As per results, since cyclic prefix gives better result at the selected guard period value, it has been selected for the present experimental set-up.

In the second part, alternatively different Modulation techniques has been taken to analyze, which techniques is most suited to MIMO OFDM system. The different techniques used for analyses in present set-up are QPSK, 16-QAM & 64-QAM.

In the third part the value of Guard period is taken after successive testing. The two values which has been taken in present experimental set-up are GP=16 & GP=0 for two different cases, one with guard period & without guard period case respectively.

From Figure 8(a), 8(b) & 8(c), it is clear that the BER performance with CP of length of 16 samples shows some inconsistence with improvement as we move for 64-QAM to QPSK modulation technique with that of the analytic result in the Rayleigh fading channel. This implies that the OFDM system is just subject to a flat fading channel as long as GP is large enough. It is also clear that the BER performance in an AWGN channel is almost consistent with the simulation channel. This is true regardless of how long GP is, because there is no multipath delay in the AWGN channel. As illustrated in Figure 8(d) & compared to Figure 8(a), 8(b) & 8(c), however, the effect of ISI on the BER performance becomes significant in the multipath Rayleigh fading channel as the length of GP decreases, which eventually leads to an error floor.

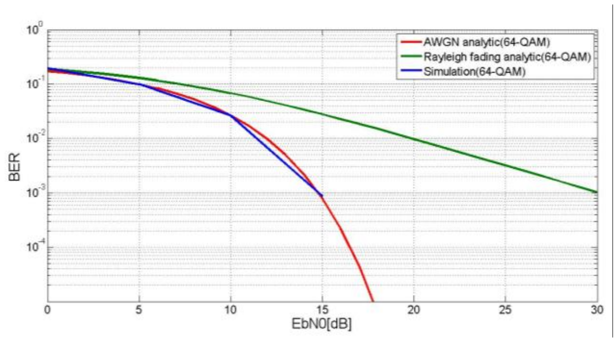

Fig. 8(a) GP length: Ng = N/4 = 16 with 64-QAM

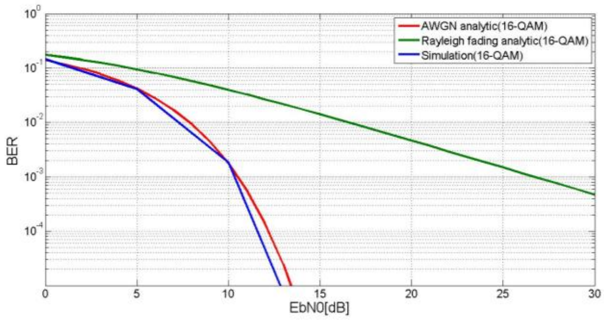

Fig. 8(b) GP length: Ng = N/4 = 16 with 16-QAM

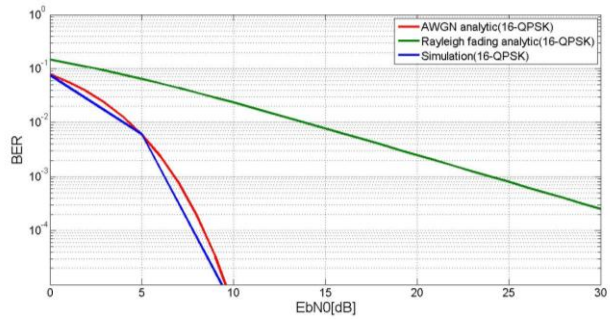

Fig. 8(c) GP length: Ng = N/4 = 16 with QPSK

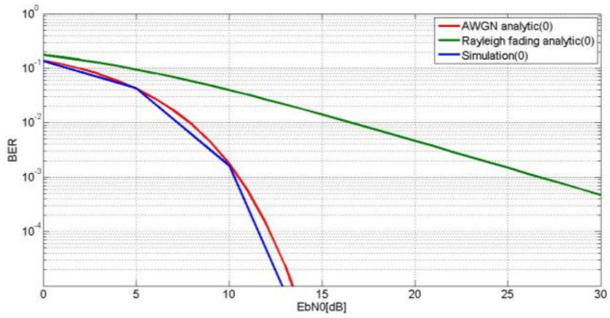

Fig. 8(d) GP length: Ng = 0 (i.e. no GP) with QPSK

Fig.8. BER Performance for OFDM system with 64-QAM, 16-QAM & QPSK.

5. CONCLUSION

Results analysis shows that the presence of Guard Period plays a very vital role in improving the BER performance of the MIMO-OFDM system. The performance of the system enhanced to significant extent on suitable value of Guard Period along with suitable modulation technique. Also the results depict the fact that the QPSK is best suited modulation technique for MIMO OFDM system in the presence of Guard period while QAM report no improvement in the BER performance of the system. However, there is further possibility of improving the BER performance by developing new technique to compensate ISI effect, as the Guard period insertion affects system efficiency due to increased overhead.

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