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Performance Evaluation of Cyclic Prefix OFDM Using MIMO

[1]R. Meenakshi, [2]P. Indumathi and [3]R. Raja Kumar

[1]Research Scholar, Anna University, MIT Campus,
Asst. Prof. Valliammai Engineering College - 600023, India
[2]Anna University, MIT Campus, Chennai, 600044, Tamilnadu, India
[3]Department of Maths, Sathyabama University, Chennai, 600119, Tamilnadu, India

Abstract: OFDM stands for Orthogonal Frequency Division Multiplexing (OFDM) which is a multi carrier modulation technique that provides high bandwidth efficiency. There are number of benefits in using OFDM viz-a-viz higher data rate and bandwidth efficiency. Also, there are noticeable challenges, having drawbacks in high Bit Error Rate (BER) and large Peak to Average Power Ratio (PAPR). In the Broadband Wireless Communication (BWC) systems, along with reliable communications, higher spectral efficiency performance on fast fading wireless channels is becoming very vital using OFDM systems. In this paper, our study is to evaluate the performance of CP-OFDM (Cyclic Prefix OFDM) in terms of spectral efficiency, BER for MIMO (Multiple Inputs Multiple Outputs) - OFDM systems. This paper presents the study over the current system results based on frequency domain CP-OFDM MIMO systems along with its limitations. The basic OFDM with CP model is described for multiple transmitters and multiple receivers. In addition to this, we present a realistic and simple technique for computing the spectral efficiency for CP-OFDM MIMO Systems.

Key words: BER · Cyclic Prefix · CP-OFDM · MIMO · Spectral Efficiency

INTRODUCTION

In recent years, in broadband wireless systems the technique OFDM (Orthogonal Frequency Division Multiplexing) has attracted a lot of attention. In several wireless standards such as Digital Audio Broadcasting (DAB), Digital Video Broadcasting (DVB-T) adopted OFDM [1]. MIMO technology is one of the major topics of interest in wireless communications, since it offers significant increase in data throughput and coverage without additional bandwidth or transmitter power. It provides high spectral efficiency and link reliability. The combination of MIMO signal processing with OFDM is considered one of the most promising techniques for enhancing the data rate of next-generation wireless communication systems. Multi – Input Multi – Output Orthogonal Frequency Division Multiplexing (MIMO-OFDM) is a technology broadly used in various commercial communication systems including 3GPP Long Term Evolution (LTE) and IEEE wireless LAN standard [2]. The idea of OFDM is to distribute the high– rate stream to many low– rate data stream that are transmitted in a parallel way over many subchannels. OFDM converts a frequency selective channel into flat subchannels which are collected and connected in parallel. The subcarriers have the minimum frequency separation required to maintain orthogonality in time domain. The signal spectra of different subcarriers overlap in frequency domain and the bandwidth available is used efficiently. The subcarrier's frequencies are selected in such a way that they are orthogonal, in the sense that their respective frequency spectra do not influence each other even if they are overlapped which leads to the spectrally effective method.

In many applications high data – rate wireless access is the core demand. Generally, for higher data-rate transmission, more bandwidth is required. But, due to spectral limitations, it is often impractical or sometimes very expensive to increase bandwidth. In this case, an alternative solution is to use multiple transmit and receive antennas for spectrally efficient transmission. It is known that, in OFDM the entire channel is divided into many narrow parallel subchannels, resulting increasing the symbol duration and reducing or eliminating the ISI caused by the multipath. Hence, multiple transmit and receive antennas can be used with OFDM to further improve system performance.

Corresponding Author: R. Meenakshi, Research Scholar, Anna University, MIT Campus,
Asst. Prof. Valliammai Engineering College - 600023, India. E-mail: meenakshir.it@valliammai.co.in.

The key problem of OFDM systems is the block transmission method. There are main three methods of OFDM based schemes of block transmission such as Cyclic Prefix OFDM (CP-OFDM) [3], zero padding OFDM (ZP-OFDM) [4] and time domain synchronous OFDM (TDS-OFDM [5]. For both CP-OFDM and ZP-OFDM methods, frequency – domain pilots are required especially for synchronization and for channel estimation.

To maintain orthogonality among subcarriers, a Cyclic Prefix (CP) is added at the header of each symbol. The length of CP is greater than the expected length of Channel Impulse Response (CIR). The use of CP results in a lowering of spectral efficiency, many approaches have been proposed to cope with this problem [6-11]. Our interest is to analyze about CP-OFDM with simple technique. In this paper, we are presenting the study on practical evaluation and analysis of CP-OFDM systems in terms of spectral efficiency, BER and MSE performances. CP-OFDM outperformed ZP-OFDM in many previous research works; hence ZP-OFDM is out of the scope of this paper. MIMO-OFDM system was chosen in this study because it has been widely used today due to its high data rate, channel capacity and its adequate performance in frequency selective fading channels.

The remainder of the paper is organized as follows. Section II is presenting the details on OFDM basics, MIMO-OFDM and presenting the design of CP-OFDM model for simulation purpose. Section III is presenting the simulation parameters and results for CP-OFDM. Section IV is presenting the conclusion, limitations and future work.

Ofdm System Model: In this section, the basic concept of OFDM is discussed at first and then the MIMO-OFDM system model is outlined.

Basic Concept of the OFDM System

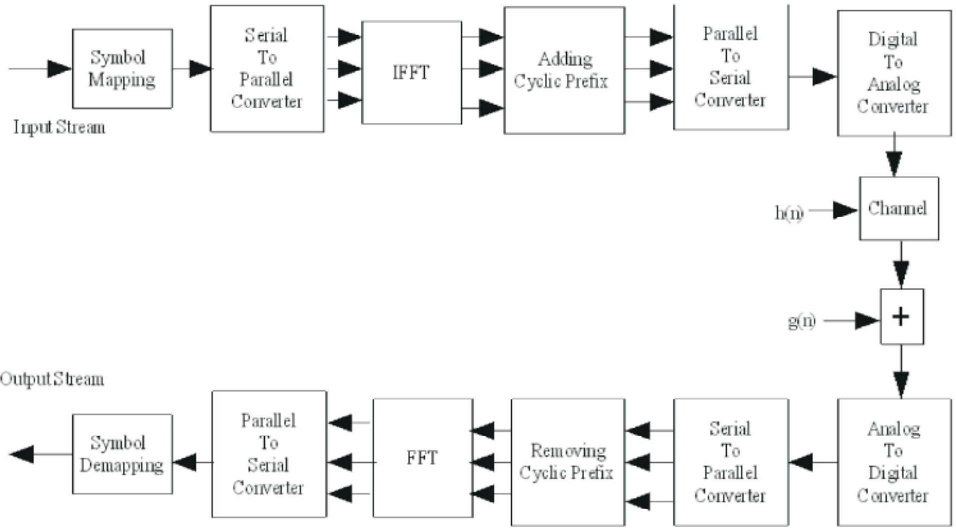

Fig. 1: Block diagram of OFDM system

In mobile communication the Orthogonal frequency division multiplexing (OFDM) is an attractive technique for high-speed data transmission [11-12]. According to the The basic principle of OFDM, it is to split a high – rate data stream into a number of lower rate streams. The lower rate streams are transmitted simultaneously over a number of subcarriers. The relative amount of dispersion in time caused by multipath delay spread is decreased since symbol duration increases for the lower rate parallel subcarriers. By introducing a guard time in every OFDM symbol, the Intersymbol Interference (ISI) is eliminated almost completely.

In the block representation of OFDM given in figure 1, the input data stream is modulated by a QAM modulator, which results in a complex symbol stream ‘N’. This series symbol stream is converted to set of ‘N’ parallel QAM symbols. These frequency components are converted into time samples by performing an Inverse Fast Fourier Transform (IFFT) algorithm. The output of IFFT is the multicarrier signal which consists of linearly modulated subchannels. The cyclic prefix is then added to the OFDM symbol, results a time samples. The time samples are ordered by the parallel - to - serial converter. This signal is passed through Digital to Analog (D/A) converter, results the passband OFDM signal. In the channel, the transmitted signal is filtered by the channel impulse response and it is corrupted by additive white Gaussian noise. Above signal is received by the receiver as received signal. At the receiver end, the Analog to Digital (A/D) converter samples the received signal and removes the cyclic prefix. These time samples are given to serial to parallel converter and passed through Fast Fourier Transform (FFT) which results scaled versions of the original symbols i.e. flat fading signal. The FFT output is given to parallel to serial converter and then to demodulator to recover the original data. Hence, the OFDM system effectively decomposes the wideband channel into set of narrowband orthogonal subchannels with a different QAM symbol sent over each subchannels.

The MIMO - OFDM System: The combination of MIMO signal processing with OFDM is considered one of the most promising techniques for enhancing the data rate of next-generation wireless communication systems. Figure 2 shows the structure of MIMO-OFDM.

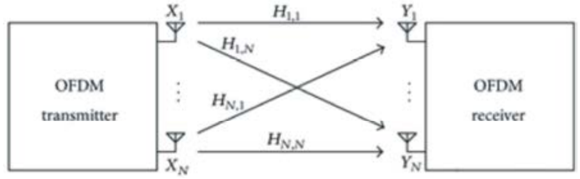

Fig. 2: Basic block diagram of MIMO-OFDM system

Consider the transmitter block consisting a data source, signal modulator, serial to parallel converter, IFFT and parallel to serial converter with cyclic prefix adder. The receiver consists of a serial to parallel converter, cyclic prefix remover, FFT, channel estimator with equalization, Demodulator and parallel to serial convertor and finally the estimated output.

Efficient implementation of MIMO-OFDM system is based on the Fast Fourier Transform (FFT) algorithm used to transmit data in parallel over a large number of orthogonal subcarriers. At the transmitter, the OFDM modulator appends at each symbol block head a cyclic prefix (CP), with length no shorter than the channel impulse response (CIR) interval, (i.e CP should be greater than the maximum delay spread of the channel) for removing inter-symbol interference (ISI). By considering that the channel is invariant within an OFDM symbol, subcarrier orthogonality is maintained, when an adequate number of subcarriers are used in conjunction with a CP of adequate length. For many high data rate systems, the addition of a CP causes more than a bandwidth expansion leads to a significant loss of a valuable resource. In OFDM the broadband signal is divided into multiple narrowband subcarriers, where each subcarrier is more robust to multipath. A Cyclic Prefix (CP) is inserted between two successive symbols as guard interval. The cyclic prefix has not only mitigates Inter Symbol Interference (ISI), but also converts the linear convolution between the transmitted OFDM symbol and channel impulse response to a circular one. At the receiver, the CP is discarded and ISI free part of the OFDM symbol is used for channel estimation and data detection. The insertion of CP at the transmitter results in a lowering of spectral efficiency and several approaches have been proposed to cope with this problem. OFDM combined with multiple transmit and receive antennas that are multi-input multi-output (MIMO) OFDM, have become a key communication technique over frequency-selective fading channels.

Proposed System Model: In the system model, consider a (N_t, N_r) MIMO-OFDM system with N_t transmit antenna and Nr receive antenna and k subcarriers. At the transmitter side, a serial input bit stream is mapped to a symbol stream by a modulator. Then, this serial bit stream is converted into parallel sub stream.

The pilot symbols for the channel estimation are inserted into these parallel sub streams, in the frequency domain. Next, OFDM modulation is performed by Inverse Fast Fourier Transform.

Let $X = \{X_0, X_1, X_2 \ldots X_{Nb-1}\}$ (1)

Which represents the $N_{b\text{-}}$ length data symbol block.

The data block X yields the time domain sequence x.

$$x = \{x_0, x_1, x_2 \ldots x_{Nb-1}\} \quad (2)$$

i.e

$$x_n = IFFT_{Nb}\ \{X_k\}\ (n) \quad (3)$$

To mitigate the effect of channel delay spread i.e Intersymbol interference (ISI), a guard interval is comprised of either a Cyclic Prefix (CP) or suffix is appended to the sequence X, such that the length of the CP is at least equal to the channel length. Consider the CP is used and then the transmitted sequence with guard interval is;

$$x_n^g = x(n)_{Nb} \quad (4)$$

where n = -G, …. -1, 0, 1, …..N_b- 1 , $(n)_N$ is the residue of n Modulo N_b and G is the guard interval length in samples. In this condition, the linear convolution of the transmitted sequence and the channel is converted to a circular convolution which results the complete elimination of the effect of ISI [1].

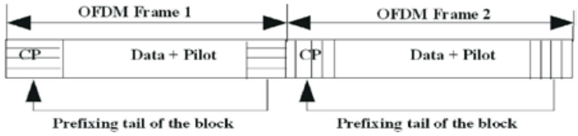

Fig. 3: Cyclic Prefix Structure

Figure 3 shows the structure of CP-OFDM in which the term *cyclic prefix* refers to the prefixing of a symbol with a repetition of the end. Although the receiver is typically configured to discard the cyclic prefix samples, the cyclic prefix serves two purposes. 1) It acts as a guard interval and eliminates the Intersymbol interference from the previous symbol. 2) As a repetition of the end of the symbol, it allows the linear convolution of a frequency-selective multipath channel to be modeled as circular convolution and may be transformed to the frequency domain using a Discrete Fourier Transform (DFT). This facilitate simple frequency domain processing, such as channel estimation and equalization.

The OFDM symbols transmitted over the multipath fading channel is corrupted by Additive White Gaussian Noise (AWGN).

For a MIMO channel, the output is given as;

$$Y = Hx(n) + g(n) \tag{5}$$

where g(n) is additive white Gaussian noise (AWGN).

Channel we consider is MIMO channel. Considering channel length 'L' the channel impulse response can be expressed as;

$$h = [h(0), h(1), h(2),...h(L-1)] \tag{6}$$

Channel matrix for MIMO channel is defined as;

$$H = \begin{bmatrix} h_{11} & h_{12} & \cdots h_{1N_r} \\ h_{21} & h_{22} & \cdots h_{2N_r} \\ \vdots & \vdots & \vdots \\ h_{N_t1} & h_{N_t2} & \cdots h_{N_tN_r} \end{bmatrix} \tag{7}$$

In this paper, consider the Rayleigh channel. The signal passed through Rayleigh channel can be represented as;

$$r_n(t) = r_n^g(t) \otimes h_n(t) + g(t) \tag{8}$$

where $r_n(t)$ is the transmitted signal through the channel, h_n (t) is the impulse response of the channel and g(t) is the AWGN.

At the receiver, upon analog to digital (ADC) conversion and removal of cyclic prefix, FFT operation ensures that the received signals are in the frequency domain. The channel is estimated and the channel impairment is observed. The channel impairment is compensated through equalization.

The estimated output is obtained through demodulation and suitable decoder.

With MIMO channel the received OFDM signal is represented as;

$$\begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_{N_t} \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} & \cdots h_{1N_r} \\ h_{21} & h_{22} & \cdots h_{2N_r} \\ \vdots & \vdots & \vdots \\ h_{N_t1} & h_{N_t2} & \cdots h_{N_tN_r} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_{N_r} \end{bmatrix} + \begin{bmatrix} g_1 \\ g_2 \\ \vdots \\ g_{N_t} \end{bmatrix} \tag{9}$$

In the received data, the CP is removed. Let $x_n^i(p)$, the (i, n) th element of X(p) be the base band signal, generally a complex symbol is transmitted from ith transmit antenna on the pth subcarrier during nth OFDM symbol interval. The output of the FFT on the jth receive antenna for the above specification is given as;

$$y_n^j(p) = \sum_{i=1}^{N_t} H_{ij}(p) x_p^i(p) + g_n^j(p) \tag{10}$$

where p= 0, 1, 2, ……k-1 and

$$H_{ij}(p) = \sum_{l=0}^{L} H_{ij}(l)\, e^{-j\left(\frac{2\pi}{k}\right)l_p} \tag{11}$$

where l = 0, 1, …..L-1

Equation (10) can be rewritten in matrix form as,

$$Y(p) = H(p)X(p) + G(p) \tag{12}$$

where p= 0, 1, 2, ……k-1

According to the channel state information obtained through channel estimation, the equalization process gives the estimated data and is represented as;

$$Y = \{Y_0, Y_1, \dots \dots Y_{Nb-1}\} \tag{13}$$

The bit error rate can be obtained from the transmitted data and the estimated data.

The major challenge is to obtain the channel state information accurately and promptly for coherent detection of information symbols. Channel state information can be obtained through training based, blind and semi blind channel estimation [16-17]. Channel estimation can be improved by the use of more number of pilot symbols but it leads to data rate reduction or bandwidth expansion. To estimate the channel coefficients and correct received signal, the pilot approach is analyzed in this paper.

Channel Estimation: Channel Estimation is critical in designing MIMO-OFDM system for coherent detection and decoding to obtain estimated output. The channel coefficient belongs to the pilot subcarriers are estimated using the Least Square (LS) method.

The LS channel estimator is generally represented by;

$$\hat{H}_{LS} = X_d^{-1} Y \tag{14}$$

where,

$X_d = diag\{X(0), X(1)...X(k-1)]$
$Y = [Y(0), Y(1),...Y(k-1)]$

The LS channel estimation for MIMO-OFDM system between N_t transmitter and N_r receiver antenna is given as,

$$\hat{H}_{LS}^{(\bar{N}_t,\bar{N}_r)} = \left(X^{(N_t)}\right)^{-1} Y^{N_r} \tag{15}$$

RESULTS AND DISCUSSION

We consider a MIMO – OFDM with different numbers of transmitting antennas N_t, receiving antenna N_r, k subcarriers and N_b - data symbol block was used for our simulation.

Steps followed for simulation for the proposed evolution technique are given below,

- Generation of random bits and framing of that bits
- Mapping the data using digital modulation
- Insertion of pilot signals to the modulated symbols
- Convert to IFFT of the symbols
- Addition of Cyclic Prefix to the IFFT signal to avoid Inter Symbol Interference (ISI)
- Subject the data to Rayleigh channel
- Addition of AWGN to the OFDM signal at the channel
- At the receiver, removal of CP then perform FFT
- Performing channel estimation by many iteration
- Performing equalization, demodulation
- Decoding the signal for estimated output
- Calculate the Bit Error from transmitted and estimated data.
- Performing the above for different number of CPs and Pilots and calculating the spectral efficiency.

The following performance metrics are computed for the comparative study of this work:

BER: This performance metrics is used to measure the difference among original transmitted signal and received signal at receiver end.

$$\text{BER}(t) = \text{abs}(x(t) - y(t)) \tag{16}$$

where, x (t) is original signal generated at transmitter end and y (t) is received signal at receiver end at time t.

MSE: Mean square error computation is done by using the formula given below,

$$\text{MSE}(t) = \text{variance}((x(t) - y(t)) \tag{17}$$

where, x (t) is original signal generated at transmitter end and y (t) is received signal at receiver end at time t.

Spectral Efficiency: As in any digital transmission system, the spectral efficiency of the transmission technique is expressed in bits/second/Hertz. This is expressing that how efficient does the system use the allocated bandwidth. The spectral efficiency is the measure of t overall efficiency of that system [18].

$$\eta_{eff} = \frac{max.data\ rate\,[bps]}{allocated\ Bandwidth\,[Hz]} \tag{18}$$

Based on the above we have measured the performance for CP-OFDM systems for BER, MSE and Spectral Efficiency using 16-QAM and 16-PSK modulation techniques.

The simulation parameters used in this approach for the analysis of the system performance are given in Table 1.

In this section, we present simulation results under the following categories. Each OFDM symbol has assigned to above tabulated values.

Table 1: Simulation parameters

Parameters	Value
OFDM Subcarriers N_b	128
Modulation Technique	16-QAM &16- QPSK
Number of Blocks	16
Length of CP	0, 1/2, 1/4 & 1/8
Channel	Rayleigh Fading
Noise	AWGN
SNR Range	0:5:50
Number of iterations	100
FFT Size	128 * 16 * 2
Channel Length	6
Status of Transmitting and Receiving Antenna	MIMO
Channel Estimation	LSE
Pilot Spacing	1, 2, 3, 4 &5

Table 2: Performance of 16PSK and 16QAM

Modulation Type	MSE (Average)	BER (Average)	Spectral Efficiency (%)
16 PSK - CP-OFDM	0.00207	0.1884	65.23 %
16QAM - CP-OFDM	0.00208	0.07941	64.62%

Table 3: Performance of 16 QAM under different antenna configuration

Antenna Configuration	MSE (Average)	BER (Average)	Spectral Efficiency in %
1x1	0.0020694	0.077359	86.1232
2x2	0.0020867	0.081054	64.6065
4x4	0.002079	0.083511	77.5304
1x2	0.0020591	0.028309	86.1268
2x4	0.0020813	0.037718	91.2209

Table 4: Performance of 16 QAM under different Guard Interval length

No. of cyclic prefix	MSE (Average)	BER (Average)	Spectral Efficiency in %
0	0.0037107	0.10897	96.90
1/2	0.0020783	0.081222	64.61
1/4	0.0020751	0.079458	77.54
1/8	0.0020817	0.079109	86.15
1/16	0.0020675	0.079564	91.22

Table 5: Performance of 16 QAM under different Pilot spacing

Pilot Spacing	MSE (Average)	BER (Average)	Spectral Efficiency in %
1	0.0020767	0.083724	86.14
2	0.0030993	0.09105	83.43
3	0.0041553	0.091286	80.69
4	0.0051353	0.094369	77.93
5	0.019325	0.25294	75.14

The Impact of Modulation Type: We compare the BER performance of different modulation technique with 2 transmit antennas and 2 receive antennas (2x2 MIMO). The pilot space considering is 1. Figure 4 shows that QAM has better performance than QPSK in terms of BER. The performance is tabulated in the Table 2.

Table 2 shows the performance comparison between 16PSK and 16QAM systems. Since the performance of 16 – QAM is better in BER, then our further analysis is based on 16-QAM.

The Impact of Number of Antenna: Figure 5 shows the BER performances of different number of transmit and receive antenna (MIMO). The modulation type adopted here is 16QAM.

From Table 3, the performance of BER and spectral efficiency can be analyzed

The Impact of Length of Guard Interval: In this simulation, the performance of the system through BER is analyzed. Figure 6 show the impact of the length of cyclic

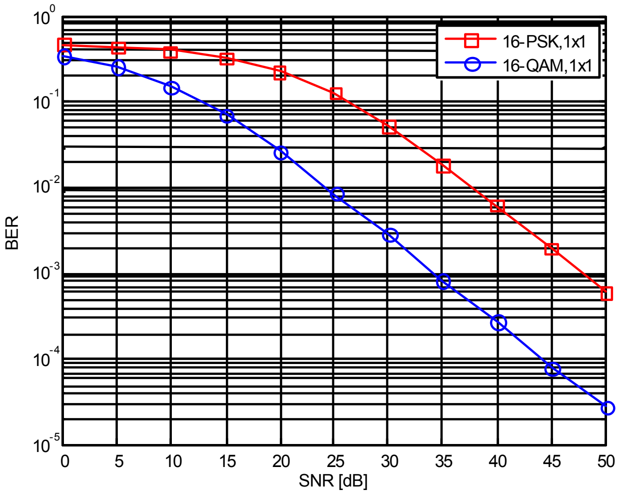

Fig. 4: BER Performance for CP-OFDM-MIMO Using 16 PSK and 16-QAM

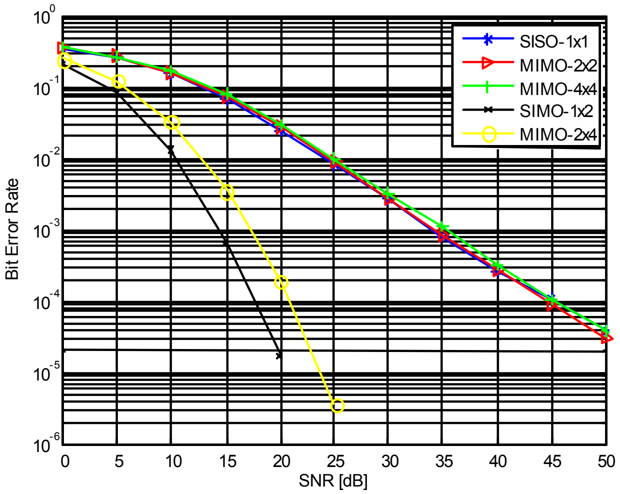

Fig. 5: BER Performance for CP-OFDM-MIMO Using different antenna configuration

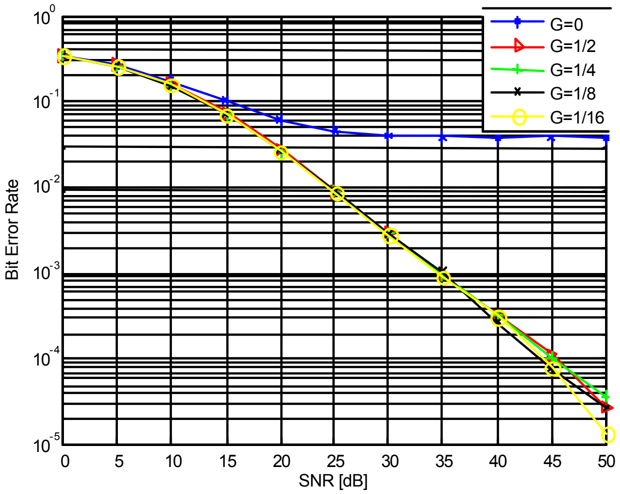

Fig. 6: BER Performance for CP-OFDM-MIMO using different length of Guard interval

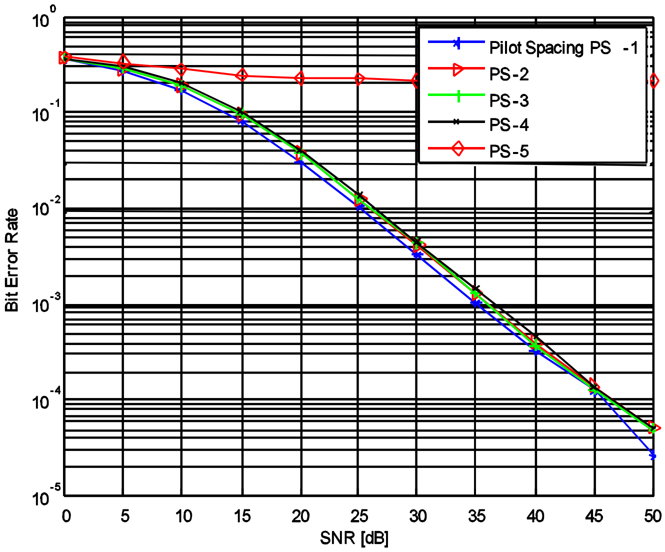

Fig. 7: BER Performance for CP-OFDM-MIMO Using different pilot spacing

prefix used to avoid ISI. The modulation adopted is 16 QAM. The pilot space considering is 1. The MIMO assumed for simulation is 2x2.

Table 4 shows the performance and the Guard Interval gives better BER performance. The GI shows the better spectral efficiency and the BER is 0.079564.

The Impact of Length of Pilots: Figure 7 shows the behavior of the system with different number of pilots which is used in channel estimation. To obtain the minimum MSE of the LS channel estimate, the pilot sequences must be equipowered, equispaced and phase shift orthogonal [19]. So, we considered the Pilot spacing in this estimates. From the result, PS=6 is undesired.

From Table 4 the number of pilot inserted for channel estimation affects the spectral efficiency of the CP-OFDM-MIMO. MMO consider for simulation is 4x4.

CONCLUSIONS AND FUTURE WORK

In this paper, we aimed to evaluate the performance of CP-OFDM MIMO systems under predefined simulation parameters and configuration settings in terms of MSE, BER and Spectral efficiency. In addition, the scope of this paper is targeted to present the system model for OFDM and CP-OFDM by considering the future research work. We have tabulated the limitations of CP-OFDM system using frequency domain data communication. The frequency domain CP-OFDM is having poor BER and less spectral efficiency performance as shown in our practical results analysis.

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