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BER Analysis and Performance of MIMO-OFDM System using BPSK Modulation Scheme for Next Generation Communication Systems

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Abstract

In this paper we present an analytical approach to evaluate the Bit error rate (BER) and performance of BPSK (or 2PSK) modulation and MIMO-OFDM system over multipath fading channel is compared and analyzed. In wireless communication systems, complex base-band signals must be converted in to real pass-band signals. Multi-carrier modulation (MC) is a technique for data-transmission by dividing a high-bit rate data stream is several parallel low bit-rate data streams and using these low bit-rate data streams to modulate several carriers. Multi-Carrier Transmission has a lot of useful properties such as delay-spread tolerance and spectrum efficiency that encourage their use in broadband wireless communications. OFDM is a multi-carrier modulation technique with densely spaced sub-carriers. This report is intended to provide a tutorial level introduction to OFDM Modulation, its advantages and demerits, and some applications of OFDM. I show the BER for an MIMO and OFDM system with BPSK modulation technique. The Simulation results show that the simulated bit error rate is a good agreement with the theoretical BER for BPSK modulation in OFDM system. All the results obtained are simulated by using the MATLAB.

Keyword: Binary Phase Shift Keying (BPSK), multiple-input multiple-output (MIMO), orthogonal frequency division multiplexing (OFDM), Bit error rate (BER), Additive White Gaussian Noise (AWGN)

Introduction

A basic and popular digital modulation scheme, Binary phase shift keying (BPSK) [9].phase shift keying (PSK) is a digital modulation scheme where the phase of carrier is changed or modulated according to the modulating waveform which is digital signal. In Binary phase shift keying (BPSK), the transmitted signal is sine wave of fixed amplitude. It has one fixed phase when the data is at one level and when the data is at the other level, the phase is different by 180 degree. BPSK is a coherent as the phase transitions occur at the zero crossing point. The proper de-modulation of BPSK needed the signal to be compared to a sine carrier of the same phase. Multi-carrier modulation is an approach to data transmission that involves segregating the data into several more or less equal components. The individual components are then routed across different carrier signals. At the termination point, the individual components are reassembled and delivered. Multi-carrier (MC) Modulation is an orthogonal frequency division multiplexing (OFDM).

OFDM is a modulation technique, based on the principle of frequency division multiplexing (FDM), but is utilized as a digital modulation scheme via DFT or IFFT, which uses a large number of parallel narrow-band sub-carriers instead of a single wideband carrier to transport information. OFDM works by splitting the radio signal into multiple smaller sub-signals that are then transmitted simultaneously at different frequency to the receiver. OFDM is attractive because it provides relative easy and simplified solutions to some difficult challenges that are encountered when using single-carrier modulation schemes on wireless channels. Single carrier is more sensitive to timing errors and less to frequency errors. OFDM simplified frequency domain equalization over single-carrier modulation with conventional time-domain equalization. OFDM is used to reduce Inter symbol interference (ISI), increase system performance and capacity, higher band width efficiency, maximum utilization of spectrum and high–data-rate wireless access [3]. OFDM has been adopted in several wireless standards such as digital audio broadcasting (DAB), digital video broadcasting (DVB-T), the IEEE 802.11a local area network (LAN) standard, the IEEE 802.11a&g wireless local area network (WLAN) standard, the IEEE 802.16 [9] wireless metropolitan area network (WMAN) standard operating in 2-11 GHz band of frequency, the IEEE 802.16a (WiMAX) standard, the IEEE 802.11n standard that is MIMO, system where multiple antennas are used. OFDM is also being purposed for dedicated short-range communications (DSRC) for road side to vehicle communications and potential candidate for fourth-generation (4G or LTE –Advanced, data rates 300Mbps) mobile wireless systems [13].

Multi-input Multi-output (MIMO) [5], wireless technology overlay for the IEEE 802.11 standard for WLANs the Wireless Next Generation (WNG) group. MIMO is the Iospan's product, combination with orthogonal frequency division multiplexing (MIMO-OFDM) [4], is an attractive air-interface solution for Next generation networks (NGNs). In this paper we will compare the bit error rate performance of BPSK modulation, OFDM modulation, MIMO system and OFDM-BPSK with multipath channel.

BPSK Modulation and De-modulation

BPSK (also called PRK, phase reversal keying, or 2PSK) is the simplest and coherent digital modulation scheme. In BPSK, individual data bits are used to control the phase of carrier. It uses two phases which are separated by 180 degrees or π radians apart as shown in fig.1. The theoretical equation for bit error rate (BER) with Binary Phase Shift Keying (BPSK) modulation scheme in Additive White Gaussian Noise (AWGN) channel will be derived.

A BPSK signal can be defined by,

$s(t) = Am(t)cos2\pi f_c t,\ \ 0 \le t \le T$ (1)

Where A is the peak value of sinusoidal carrier, m (t) = +1 or -1, f_c is the carrier frequency, and T is the bit duration. The signal power P = $A^2/2$, so that A =$\sqrt{2P}$. Thus equation (1) can be written as

$s(t) = \pm\sqrt{2P}\cos 2\pi f_c t$ (2)

$= \pm\sqrt{PT}\sqrt{\frac{2}{T}}\cos 2\pi f_c t$

$=\pm\sqrt{E}\sqrt{\frac{2}{T}}\cos 2\pi f_c t$ (3)

Where E = PT is the energy contained in a bit duration.

If we take $\emptyset 1\ (t) = \sqrt{\frac{2}{T}}\cos 2\pi f_c t$ as the orthonormal basis function, the signal constellation diagram of the BPSK signals is shown in fig. 1.

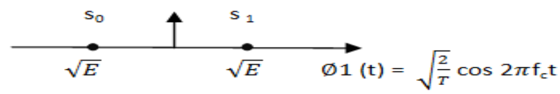

Figure 1 BPSK signal constellation diagram

In the fig. 2 (a) shows that BPSK modulated signal sequence generate by the binary sequence 0101100, fig. (b) Shows that de-modulated data sequence at the receiver side.

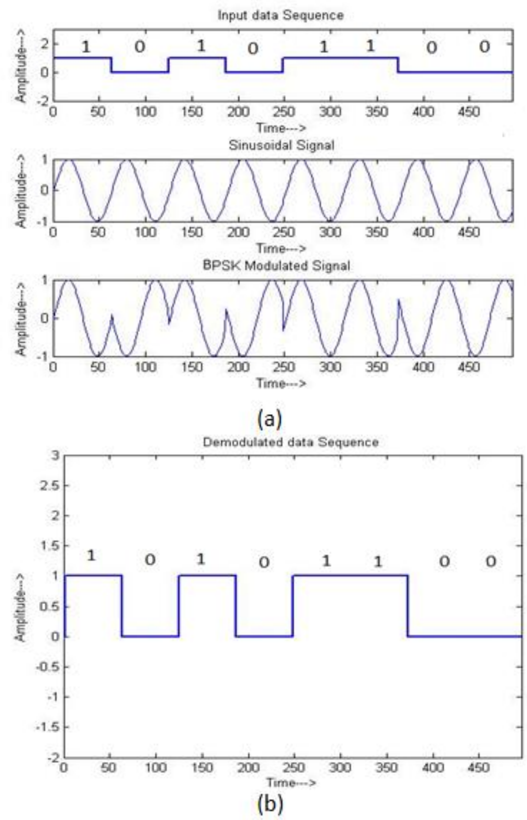

Figure 2 (a) Modulating signal, spectrum of input signal and spectrum of BPSK signals, (b) demodulated data sequence (a binary 0 is 0° while a binary 1 is 180°phase shift)

The modulator and coherent demodulator for BPSK signals are shown in fig. 3 with modulating signal $m(t)$ and carrier signal multiplied to formed output signal $s(t)$.

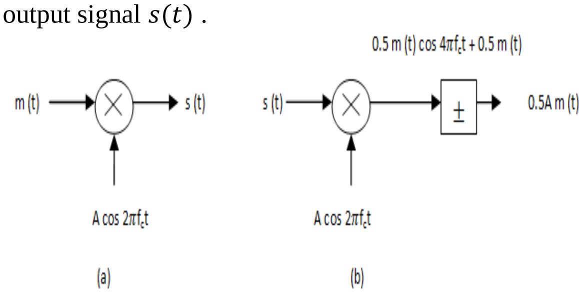

Figure 3 (a) BPSK modulator and (b) coherent demodulator

As the noise gets added to the received signal, the value of noise follows the Gaussian probability distribution function, the bit error probability is given by,

$$p_b = \frac{1}{2} \operatorname{erfc}\left(\sqrt{\frac{E_b}{N_0}}\right) \quad (4)$$

Basic Multiple- Input Multiple-Output (MIMO) System

Multiple antennas can be used at the transmitter and receiver, an arrangement called a multiple-input multiple-output (MIMO) system. MIMO is a wireless technology refers to the transmissions over wireless links formed by multiple antenna equipped at both the transmitter and receiver. MIMO systems may be implemented in a number is different ways to obtain either a diversity gain to combat signal fading or to obtain capacity gain and improve performance. It's potential for achieving higher data rate and providing more reliable reception performance compared with single-antenna system for wireless communications. As an example of MIMO applications, the IEEE802.11n standard is still being discussed, but one prototype can offer up to 250 Mbps. This is more than five times the speed of the existing IEEE802.11g hardware. For wideband channels, OFDM has to be used with MIMO techniques for ISI reduction and capacity improvement.

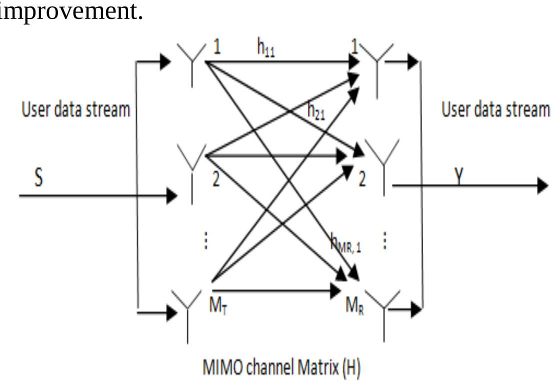

Figure 4 MIMO antennas system model

From the above fig. 4 output user data stream $y = Hs + \eta$ (input output relation of MIMO channel), where $s = [s_1\, s_2 \ldots s_M]^t$ is the transmitted data vector, $y = [y_1\, y_2 \ldots y_M]^t$ is the received data vector, and $\eta = [\eta_1\, \eta_2 \ldots \eta_M]^t$ is the Additive White Gaussian noise (AWGN) [11].

Consider a MIMO system with M_T transmit antennas and M_R receives antennas.

Let us denote the impulse response between the jth (j= 1, 2, … , M_T) transmit antenna and the ith (i= 1, 2, …, M_R) receiving antenna.

The MIMO channel can be represented using a $M_R \times M_T$ matrix format H is given by,

$$H = M_R \begin{bmatrix} h_{11} & h_{12} \ldots & h_{1,MT} \\ h_{21} & h_{22} \ldots & h_{2,MT} \\ \vdots & \vdots \;\ldots & \vdots \\ h_{MR,1} & h_{MR,2} \ldots & h_{MR,MT} \end{bmatrix}$$
$$M_T$$

Where h_{ij} is a complex Gaussian random variable that models fading gain between the ith transmit and jth receive antenna.

If a signal $S_j(t)$ is transmitted from the jth transmitted antenna, the signal receive at the ith receive antenna is given by $y_i(t) = \sum_{j=1}^{M_T} h_{i,j} S_j(t)$, i= 1, 2, … M_R. (5)

The received signal vector $y(t)$ is given by

$$y(t) = H(t)s(t) \quad (6)$$

For example 2×2 MIMO channel the received signal on the first receive antenna is,

$$y_1 = h_{1,1}s_1 + h_{1,2}s_2 + n_1 \quad (7)$$

The received signal on second receive antenna is

$$y_1 = h_{2,1}s_1 + h_{2,2}s_2 + n_2 \quad (8)$$

For Mean Square Error (MSE) [10], suppose S is an unknown random variable, and Y is a known random variable, an estimator $\hat{X}(y)$ is any function of the measurement Y and MSE mathematically given as:

$$MSE = E\{(\hat{X} - X^2)\} \quad (9)$$

Where the expectation is taken over both X and Y.

Multiplexing scheme has also introduced by transmitting multiple data streams to a single user in above figure, with multiple transmit and receive antennas. Among transmit diversity and receive diversity, the receiver diversity technique must be better to catch the more SNR signal from transmitter side. The receiver diversity technique for fading channel and BPSK modulation by taking M number of receiver antennas and noise n, the Gaussian probability density function on individual receiver antenna is given by,

$$p(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(x-\mu)^2/(2\sigma^2)} \quad (10)$$

Its standard normal distribution is given by taking $\mu = 0$ and $\sigma^2 = 1$ in general normal distribution is given by,

$$p(x)dx = \frac{1}{\sqrt{2\pi}} e^{-z^2/2} dz \quad (11)$$

Where x is the variable with mean μ and variance σ^2 and dz $= dx/\sigma$.

Signal Carrier vs. Multi-carriers Transmission

Digital band-pass modulation techniques can be broadly classified into two categories. The first is single-carrier modulation or SCM, where data is transmitted by using a single radio frequency (RF) carrier. The second one is multi-carrier modulation or MCM, where data is transmitted by simultaneously modulating multiple radio frequency (RF) carriers. In MCM, transmission bandwidth is split into many narrow sub-channels (or multiple sub- streams) which are transmitted in parallel. Each signal has its own frequency range (sub-carrier) which is then modulated by data. Each sub-carrier is separated by guard space to ensure that they do not overlap. The number of sub streams is chosen to make the symbol time on each sub stream much greater than the delay spread of the channel or, equivalently, to make the sub stream bandwidth less than the channel coherence bandwidth(B_c). This ensures that the sub streams will not experience significant ISI.

By assuming the same data rate:

- Single-carrier
  $\frac{1}{T_{symb,SC}} > B_c$ => Distortion, interference (ISI)
- Multicarrier
  $\frac{1}{NT_{sumb,sc}} < B_c$=> No interference

From the above multicarrier relation, data rate can be increased by using large number of subcarriers and less equalization effort is required as ISI [1], reduced by a factor N.

Fig. 5 illustrates a multicarrier transmitter. The bit stream is divided into N sub-streams via serial-to-parallel converter. The nth sub-stream is linearly modulated relative to the subcarrier frequency f_n and occupies bandwidth B_N. The sub streams then occupy orthogonal sub-channels with bandwidth B_N, yielding a total bandwidth $NB_N = B$ and data rate $NR_N = R$.

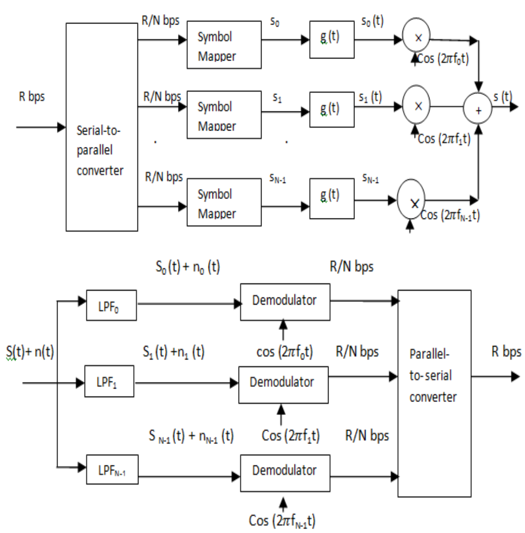

Figure 5 (a) Multi carrier transmitter and (b) multicarrier receiver

Thus, this form of multicarrier modulation does not change the signal bandwidth or data rate, but it almost completely eliminates ISI for $B_N << B_C$. The modulated signals associated with all the sub-channels are summed together to form the transmitted signal given by,

$s(t)= \sum_{i=0}^{N-1} s_i g(t) \cos(2\pi f_i t+\emptyset_i)$, (12)

The receiver part of multicarrier modulation is shown in figure (b). Each sub-stream is passed through a LPF, demodulated, and combined via a parallel-to-serial converter to form the original data stream. LPF will be required to maintain the orthogonality of the subcarriers at the reviver.

Orthogonal Frequency Division Multiplexing (OFDM) System Model and Equations

OFDM is a subset of frequency division multiplexing (just as it says in its name, *OFDM*) in which single carrier utilizes multiple sub-carriers on adjacent frequencies. In addition the sub-carriers in an OFDM system are overlapping to maximize spectral efficiency. Ordinarily, overlapping adjacent channels can interfere with one another. However, sub-carriers in an OFDM system are orthogonal to one another. Thus, they are able to overlap without interfering. As a result, OFDM systems are able to maximize spectral efficiency and high data rate without causing adjacent channel interference, an OFDM communication system must perform several steps.

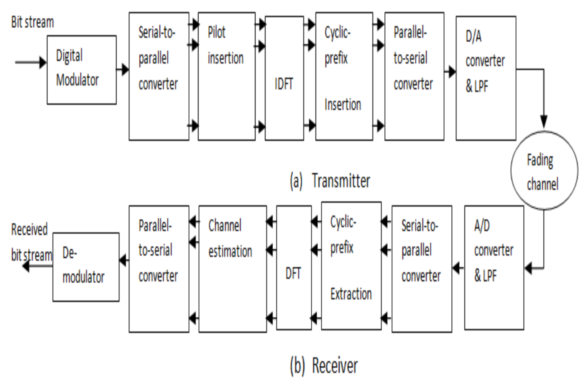

Figure 6 OFDM System

The fig. 6 shows that a simplified block diagram of an N-tone OFDM systems [15]. First, the incoming bits are mapped to data systems according to some modulation scheme such as BPSK, QPSK [12], or QAM. Then the serial data stream is converted in to a number of parallel blocks, and each of length-N. In OFDM system design, the series and parallel converter is considered to realize the concept of parallel data transmission. In a serial data system, the symbols are transmitted sequentially, with the frequency spectrum of each data symbol allowed to occupy the entire available bandwidth. In a parallel

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data system, total spectrum of an individual data stream occupies only a small part of available bandwidth. Dividing an entire channel bandwidth into many narrow sub-channels, the frequency response over each individual sub-channels is relatively flat, as shown in fig. 7.

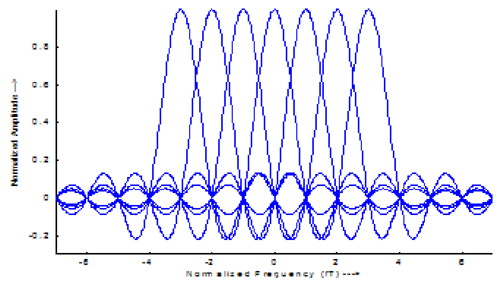


Figure 7 OFDM Orthogonal Signals

Then, each block of symbols (including pilot symbols, which are used for channel estimation or synchronization) will be forwarded to the DFFT and transformed into an OFDM signal. After that, the OFDM signal will be fed with a cyclic prefix (CP) [16], or Guard interval. By choosing the length of CP larger than the maximum path delay of the channel. ISI can be eliminated. Afterward, the OFDM signals will be converted in to serial signals. All digital signals are converted into analog format and finally sent out through filtering process. At the receiver, assuming a perfect timing and carrier frequency synchronization, the received signals will be first converted to parallel signals and then the CP will be removed. After going through DFT block, the data symbols are detected with the estimated channel information. After de-modulation original bit stream are recovered. OFDM can be regarded as a time-limited form of multicarrier modulation.

Let $\{sk\}_{K=0}^{N-1}$ be the complex symbols to be transmitted by OFDM modulation; the OFDM (modulated) signal can be expresses as [12],

$s(t) = \sum_{k=0}^{N-1} a_k{}^{j2\pi k\Delta ft} = \sum_{k=0}^{N-1} s_k\ \varphi_k(t)$, for $0 \le t \le T_s$ (13)

Passband OFDM signal is given by,

$s(t)$= Re $\{ \sum_{k=0}^{N-1} a_k{}^{j2\pi(fc+k\Delta f)t}\}$, $0 \le t \le T_s$ (14)

Where $f_k = f_o + k\Delta f$ and $\varphi_k(t) = \begin{cases} e^{j2\pi f_k t} & if\ 0\le t \le Ts, \\ 0 & otherwise, \end{cases}$

And for k= 0, 1, … , N-1, a_k = complex valued modulated symbols, N = number of sub-carriers, f_c= carrier frequency, T_s= sampling period and Δf = sub-carrier/channel spacing ($\Delta f = \frac{1}{T} = \frac{1}{NT_S}$) of OFDM respectively. In order for receiver to demodulate OFDM signal, the symbol duration must ne long enough such that $T_s\Delta f$=1, which is also called orthogonality condition.

Because of the orthogonality condition, we have

$\frac{1}{T_s}\int_0^{T_s} \varphi_k(t)\varphi_{(t)}^* \, dt$ (15)

$= \frac{1}{T_s}\int_0^{T_s} e^{i2\pi(f_k - f_l)t}\, dt$ (16)

$= \frac{1}{T_s}\int_0^{T_s} e^{i2\pi(k-l)\Delta ft}\, dt$ (17)

$=\delta[k-l]$, (18)

Where $\delta[k-l]$ is the delta function defined as

$\delta[n] = \begin{cases} 1, & if\ n=0, \\ 0, & otherwise, \end{cases}$ (19)

Equation (13) shows that $\{\varphi_k(t)\}_{k=0}^{N-1}$ is a set of orthogonal functions.

Using this property, the OFDM signal can be demodulated by

$\frac{1}{T_s}\int_0^{T_s} s(t)e^{-j2\pi f_k t}\, dt$ (20)

$= \frac{1}{T_s}\int_0^{T_s}(\sum_{l=0}^{N-1}\ s_l\varphi_l(t))\,\varphi_k^*(t)dt$

$=\sum_{l=0}^{N-1} s_l\delta[l-k]$ (21)

$= s_k$ (22)

A. DFT Implementation

From the eq. (19), an integral is used for demodulation of OFDM signals. Here we describe the relationship between OFDM and DFT, which can be implemented by low complexity fast Fourier transform (FFT); an OFDM (modulated) signal can be expresses as

$s(t) = \sum_{k=0}^{N-1} s_k{}^{j2\pi f_k t}$ (23)

If $s(t)$ is sampled at an interval of $Tsa = \frac{T_s}{N}$, then

$S_n = s(n\Delta s) = \sum_{k=0}^{N-1} s_k{}^{j2\pi f_k \frac{nT_s}{N}}$. (24)

Without loss of generality, setting f_0=0, then $f_k T_s = k$ and eq. (21) becomes

$S_n = \sum_{k=0}^{N-1} s_k{}^{j\frac{2\pi kn}{N}}$ = IDFT $\{s_k\}$, (25)

Therefore, the OFDM transmitter can be implemented using the IDFT and the receiver can be also implemented using DFT.

B. Cyclic Extension (or Guard Interval)

Two different sources of interference can be identified in the OFDM system. Inter symbol interference (ISI) is the crosstalk between signals within the same sub-channel of consecutive DFT frames, which are separated in time and Inter-carrier interference (ICI) is the crosstalk between adjacent sub channels or frequency bands of the same DFT frame. ISI can be eliminate by the help of Cyclic prefix (CP). This ensures that delayed replicas of the OFDM symbol always have an integer number of cycles within the DFT interval, as long as the delay is smaller than the guard interval.

In the fig. 7 (a) illustrate, how OFDM symbols are impact on channel, produces interference and which are induced by the channel are canceled by inserting a cyclic extension with Tg > T_{max} using cyclic extension as in figure (b) and total symbol duration T= T_s + T_g where T_g is the guard interval and T_S symbol duration. To eliminate ICI, the OFDM symbol is cyclically extended in the guard interval.

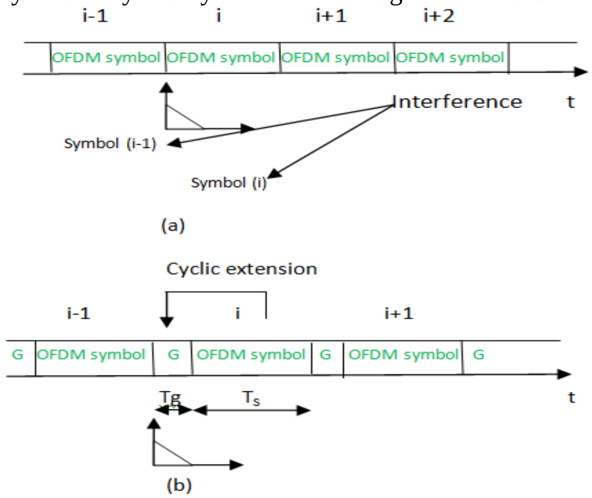
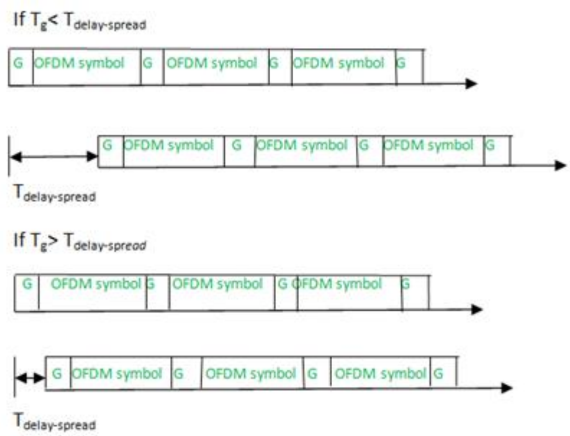


Figure 8 (a) Impact of wireless channel and (b) cyclic extension

From the figure 8, OFDM signal, $s(t)$, can be extended in to $\bar{s}(t)$ by



$$\bar{s}(t) = \begin{cases} s(t), & if\ 0 \le t \le T_s \\ s(t - T_s), & if\ T_s < T_s + T_g\ (= T) \end{cases} \quad (26)$$

With the cyclic extension, the actual OFDM symbol duration is increased from T_s to $T = T_s + T_g$.

Guard interval (or cyclic extension) is also used in OFDM systems to combat against multipath fading, $T_g > T_{delay\text{-}spread}$. In that case, however, the problem of intercarrier interference (ICI) would arise.

MIMO Systems and OFDM Modulation

MIMO is a narrow band technology but for wideband we have to use OFDM modulation technique with MIMO system [3]. Multiuser MIMO-OFDM systems benefit from the combination frequency and space domain freedom as well as multiuser diversity. Traditionally, multiple antennas (at one side of the wireless link i.e. either MISO or SIMO) have been used to perform interference cancellation and to realize diversity and array gain. The use of multiple antennas at both sides of the link (MIMO, fig. 9) offers an additional fundamental gain, which result, overall performance of the system and increased spectral efficiency.

The combination of MIMO-OFDM System model [2], has the potential of meeting the challenges like high data rate and high performance requirement since MIMO can boost the capacity and the diversity and OFDM can eliminate Interference due to multipath fading.

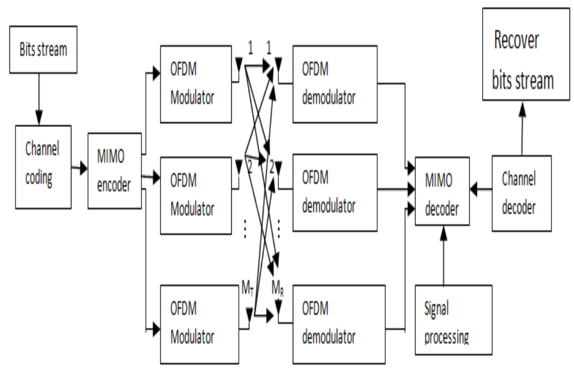


Figure 9 MIMO-OFDEM Systems

A multicarrier system can be efficiently implemented in discrete time using an inverse DFT (IDFT) to act as a modulator and a DFT to act as a demodulator. The transmitted data are the "frequency" domain coefficients and the samples at the output of the IDFT stage are "time" domain samples of the transmitted waveform.

After passing through the MIMO channels, the received signals will be first sent to the reverse OFDM block (cyclic prefix extraction and DFT) and then sent to the decoder. Finally original signal will be recovered.

Performance Parameters of MIMO-OFDM System

The performance of a MIMO-OFDM system with BPSK modulation depends upon a number of factors. There are certain parameters which decide the performance, BER and efficiency of the MIMO-OFDM technique for Wireless Next Generation Communication systems. Most important parameters are briefly explained as follows:

A. Number of Antennas

In a MIMO system, data is transmitted through a number of antennas. If number of antennas are used less then we require lesser power for transmission but there will be more bandwidth transmitted per antenna in this case. Hence inter symbol interference (ISI) will be more due to the symbol duration will be less. In the opposite case, with more number of antennas, the power required will be more but there will be less interference between the symbols and the complexity of the receiver is reduced.

B. Channel capacity

It is the maximum amount of information that can reliably be transmitted over any communication channel at any given instant. It is denoted by 'C' and can be given as:

$$C = B\log_2(1+\frac{S}{N}) \quad (28)$$

C. Bit Error Rate (BER)

In digital transmission, the number of bit error is the number of received bits of a data stream over a communication channel that has been altered due to noise, interference, distortion or bit synchronizations error. Bit Error Rate is the major parameter for end-to-end performance measurement. It is the relation between the number of output bits with errors and the total number of bits transmitted.

Noise is the main enemy of BER performance. For better performance of any communication system, BER should be minimum (ideally zero). The maximum BER occurs when there is strong inter symbol interference (ISI) in the system.

D. Signal to Noise Ratio (SNR)

The SNR is the ratio of the received signal power over the noise power in the frequency range of the process [7]. SNR is inversely related to BER [11], that is High SNR cause low BER. High BER causes an increase in packet data loss and decrease throughput. SNR measure in dB range is given by,

$$SNR = \frac{P_{signal}}{P_{noise}} \quad (29)$$

SNR formula in terms of diversity:

$$BER \propto \frac{1}{SNR^d} \quad (30)$$

Result Analysis

An understanding of how to interpret the standards is required to fully understand the increased throughput in the proposed newer drafts of each 802.11 standard.

A. BER of OFDM Simulation Result with BPSK Modulation

In the fig. 11, shows that the BER analysis of OFDM system by using BPSK modulation technique with increase bit rate, and fig. 10 shows that the mapping of data stream, where Blue lines are after data transmission or modulation mapping and Red lines are after data reception or de-modulation. The simulation result is given in the Table 1.

Table 1: Simulation Result of OFDM with BPSK Modulation

Sl.No	Name of Parameter	Description
1.	Channels	6
2.	Carriers	6
3.	Bits/channel	54
4.	Transmitted bits (n)	324
5.	DFFT & DFT Frame	6
6.	Start SNR	0 dB
7.	End SNR	40 dB

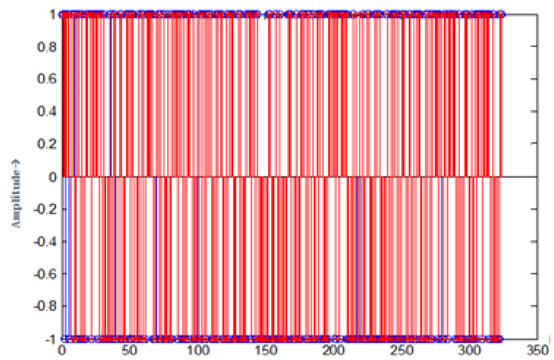


Figure. 10 Data stream after modulation mapping and de-modulation of OFDM system

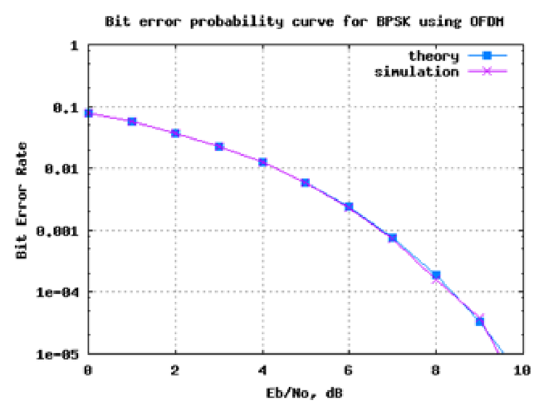


Figure. 11 BER vs. Probability of OFDM system with BPSK Scheme

B. BER of BPSK modulation in AWGN Channel and MIMO-OFDM Simulation Modeling

The possible combination of minimum transmitting antennas (M_T) and number of receiving antennas (M_R) is given in table 2.

Table 2: Transmitting and receiving antenna Combination

Combination	No. of Tx antenna	No. of Rx antenna
1.	1	1
2.	2	2
3.	2	3
4.	3	2
5.	4	4

In fig.12 BER performance of a MIMO system is discussed by taking different transmitting and receiving antennas with BPSK modulation technique

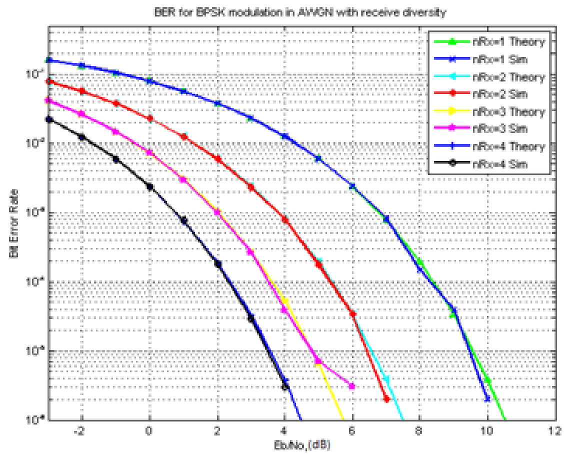


Figure. 12 BER of MIMO system

C. Capacity of MIMO system

For MIMO the capacity is given by the following equation:

$$C_{MIMO} = MB\log_2(1+\frac{S}{N}) \qquad (31)$$

Where B= Bandwidth in Hz, $\frac{S}{N}$= Signal to Noise Ratio and M (or N) is the minimum number of transmitting antennas (N_T) or number of receiving antennas (N_R).

The fig. 13, illustrate capacity of MIMO system versus the average SNR [6], for $N_T = N_R$=2 and $N_T = N_R$=4, we observe that at high SNR, the capacity of the (N_T, N_R) = (4, 4) MIMO system is approximately four times the capacity of the (1, 1) system. Thus, at high SNR, the capacity increases linearly with the number of antenna pairs when the channel is spatially white.

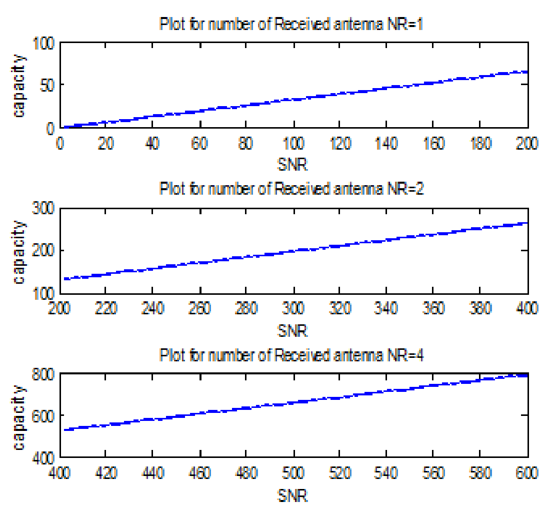


Figure 13: Capacity of MIMO system

Conclusion

In this paper, the basic concepts of a MIMO-OFDM system with relevant design and performance parameters are studied. The generalized block diagram of a basic MIMO-OFDM system which includes a number of transmitting and receiving antennas at the both ends has been explained in brief. Further, the BER and performance analysis of MIMO-OFDM systems with BPSK modulation has been covered in this paper.

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