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Research Article

Analysis of performance of MIMO-OFDM system using spatial and temporal correlation

Madhavi Karan[†*] and Neeraj Shrivastava[‡]

[†]Department of ECE,R.G.P.V,Risala Bazar Morar Gwalior (M.P), India
[‡]ECE Department, R.J.I.T Bsf Tekanpur Gwalior, India

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Abstract

In modern scenario demand for high data transmission rates with the evolution of the very large scale integration (VLSI) technology is very high. The multiple input multiple output-orthogonal frequency division multiplexing (MIMO-OFDM) systems are used to fulfill these requirements because of their unique properties such as high spectral efficiency, high data rate and resistance towards multipath propagation. MIMO-OFDM systems are finding their applications in the modern wireless communication systems like IEEE 802.11n, 4G and LTE. They also offer reliable communication with the increased coverage area. Orthogonal Frequency Division Multiplexing is used to improve spectral efficiency and Multiple Input Multiple Output (MIMO) is used to improve spatial diversity in today wireless communications systems. This paper provides Bit Error Rate analysis For MIMO-OFDM Using Spatial and Temporal Correlations & analysis of performance of OFDM with MIMO-OFDM. MIMO OFDM is superior approach that exploits spatial and temporal correlation of Multiple Input Multiple Output (MIMO). Therefore this technology covers benefits of MIMO with advantages of OFDM. Finally, paper provides analysis of performance of MIMO-OFDM over conventional OFDM and found MIMO-OFDM is superior. Our Simulation result shows improvement in SNR according to BER after comparing both the techniques.

Keywords: *MIMO-OFDM, BER, SNR*

Introduction

In MIMO system, multiple numbers of transmitters at one end and multiple numbers of receivers at the other end are effectively combined to improve the channel capacity of wireless (Siavash .M Alamouti,1998) system. This technology highly improves the spectrum efficiency, reliability of system & coverage area . A simple MIMO system shown in figure1.

In background a wireless fading channel prediction algorithm for a pilot symbol aided OFDM technique (Y.Li *et al*,2003) analyzed by assuming a doubly selective (time and frequency varying) ray-based physical channel model and equispaced pilot subcarrier in time and frequency. This algorithm performs channel model parameter acquisition using a 2-step1-D ESPRIT (estimation of signal parameters via rotational invariance techniques) as a first stage and channel prediction via model extrapolation as a second stage.

In 2011, Zangjie *et al* ,presents a simulation model of MIMO-OFDM system based on STBC which built and transmission performances under different channels area analyzes(N.sesadri *et al*,1999)The simulation results show that the MIMO-OFDM system based on STBC outperforms other MIMO-OFDM system without STBC in BER performance.

In 2014, Melli ,X.wang ,K.zang analyise the least mean square (LMS) and Recursive least square (RLS) algorithms(H .Miao *et al*,2005) They applied these two algorithms to MIMO-OFDM system based on space time block coding (STBC). From the simulation results it is found that the RLS is better than LMS algorithm. They showed the practical aspect of analyzed scheme in MATLAB environment.

In 2014 author analyzed the the parametric sparse MIMO-OFDM channel estimation scheme based on FRI (finite rate innovation) theory(Ian.c wong *et al*,2008)by which super-resolution estimates of path delays with arbitrary values can be achieved.

MIMO

MIMO stand for multiple input and multiple output. MIMO is a technique which is used to increase the capacity of the radio link by using multiple transmitting and receiving antennas to exploit multipath propogation.

It can send more than one data symbols on same radio channels.

*Corresponding author **Madhavi Karan; Neeraj Shrivastava** is working as Associate Professor

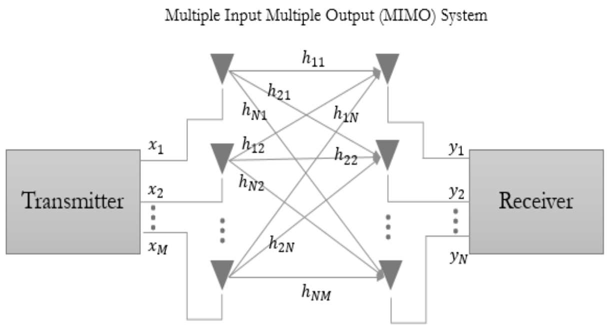


Figure 1

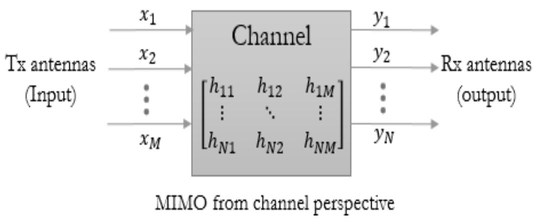


Figure 2

Here figure 1 represent the system model of mimo and figure 2 represent the matrix reprentation of mimo.

In MIMO systems, a transmitter sends multiple streams by multiple transmit antennas. The transmit streams go through a matrix channel which consists of all Nt, Nr paths between the Nt transmit antennas at the transmitter and Nr receive antennas at the receiver (Theodore S. Rappaport,2010; T Zhang Jie, *et al*,2011)then, the receiver gets the received signal vectors by the multiple receive antennas and decodes the received signal vectors into the original information. A narrowband flat fading MIMO system is modelled as

$$\mathbf{y} = \mathbf{H}\mathbf{x} + \mathbf{n}$$

Where y and x are the receive and transmit vectors, respectively, and H and n are the channel matrix and the noise vector, respectively. Referring to information theory, the ergodic channel capacity of MIMO systems where both the transmitter and the receiver have perfect instantaneous channel state information is

$$C_{\text{perfect-CSI}} = E\left[\max_{\mathbf{Q};\,\mathrm{tr}(\mathbf{Q})\leq 1} \log_2 \det\left(\mathbf{I} + \rho \mathbf{H}\mathbf{Q}\mathbf{H}^H\right)\right] = E\left[\log_2 \det\left(\mathbf{I} + \rho \mathbf{D}\mathbf{S}\mathbf{D}\right)\right]$$

Where ()H denotes Hermitian transpose and ρ is the ratio between transmit power and noise power (i.e., transmit SNR). The optimal signal covariance $Q=VSV^H$ is achieved through singular value decomposition of the channel matrix $UDV^H=H$ and an optimal diagonal power allocation matrix S=diag(S1,.....,Smin(Nt,Nr),0,0.....,0). The optimal power allocation is achieved through water filling, that is

$$s_i = \left(\mu - \frac{1}{\rho d_i^2}\right)^+, \quad \text{for } i = 1, \ldots, \min(N_t, N_r),$$

Where di =d1.....,dmin(Nt,Nr) are the diagonal elements of D, (.)+ is zero if its argument is negative, and μ is selected such that S1+.... +Smin (Nt, Nr) =Nt.

If the transmitter has only statistical channel state information, then the ergodic channel capacity will decrease as the signal covariance Q can only be optimized in terms of the average mutual information as

$$C_{\text{statistical-CSI}} = \max_{\mathbf{Q}} E\left[\log_2 \det\left(\mathbf{I} + \rho \mathbf{H}\mathbf{Q}\mathbf{H}^H\right)\right].$$

The spatial correlation of the channel has a strong impact on the ergodic channel capacity with statistical information. If the transmitter has no channel state information it can select the signal covariance Q to maximize channel channel under worst-case statistics, which means Q=1/Nt I and accordingly

$$C_{\text{no-CSI}} = E\left[\log_2 \det\left(\mathbf{I} + \frac{\rho}{N_t}\mathbf{H}\mathbf{H}^H\right)\right].$$

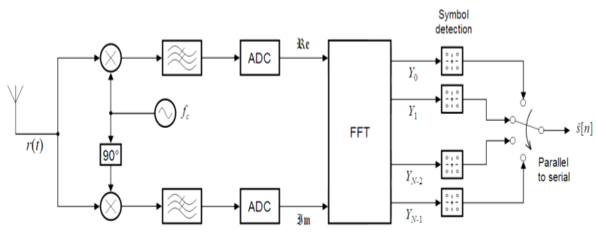
Depending on the statistical properties of the channel, the ergodic capacity is no greater than min (Nt, Nr) times larger than that of a SISO system.

OFDM

Orthogonal frequency-division multiplexing (OFDM) is a method of encoding digital data on multiple carrier frequencies. OFDM has developed into a popular scheme for wideband digital communication, used in applications such as digital television and audio broadcasting, DSL Internet access, wireless networks, power line networks, and 4G mobile communications (Y.Li *et al*,2003).

OFDM is a frequency-division multiplexing (FDM) scheme used as a digital multi-carrier modulation method. A large number of closely spaced orthogonal sub-carrier signals are used to carry data on several parallel data streams or channels (Ian.c wong *et al*,2008) Each sub-carrier is modulated with a conventional modulation scheme (such as quadrature amplitude modulation phase-shift keying) at a low symbol rate, maintaining total data rates similar to conventional single-carrier modulation schemes in the same bandwidth.

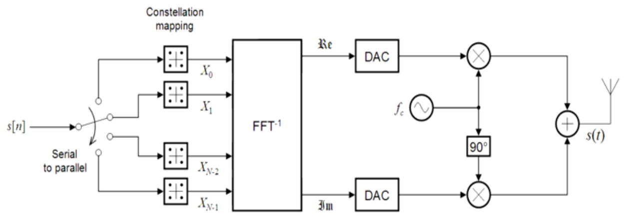
OFDM Transmitter



OFDM is basically a digital modulation technique which divides large bandwidth into number of subcarriers and each subcarrier has different frequency using IFFT.

At the transmitter side each subcarrier modulated independently by using modulation technique like- QPSK,BPSK and QAM.IFFT performs here for each symbol which gives which gives time domain samples.Now these samples qudrature mixed to passband. Real and imaginary components are first converted into analog domain using digital to analog convertor and then cosine and sine wave are modulated by using analog signals.then these signal are summened up to give desired signal s(t).

OFDM Receiver



Here receiver pick the signal r(t) which is then quadrature mixed to baseband using cosine and sine wave at carrier frequency. The baseband signal are then sampled and digitized and a forward FFT is used to convert back to the frequency domain. This returns N parallel streams, each of which is converted to a binary stream using an appropriate symbol detector. These streams are then re-combined into a serial stream, $\hat{s}[n]$.

The primary advantage of OFDM over single-carrier schemes is its ability to cope with severe channel conditions (for example, attenuation of high frequencies in a long copper wire, narrowband interference and frequency-selective fading due to multipath) without complex equalization filters. Channel equalization is simplified because OFDM may be viewed as using many slowly modulated narrowband signals rather than one rapidly modulated wideband signal. The low symbol rate makes the use of a guard interval between symbols affordable, making it possible to eliminate intersymbol interference (ISI) and utilize echoes and time-spreading (on analogue TV these are visible as ghosting and blurring, respectively) to achieve a diversity gain, i.e. a signal-to-noise ratio improvement. This mechanism also facilitates the design of single frequency networks (SFNs), where several adjacent transmitters send the same signal simultaneously at the same frequency (Zhang jie *et al*2011), as the signals from multiple distant transmitters may be combined constructively, rather than interfering as would typically occur in a traditional single-carrier system.

If N sub-carriers are used, and each sub-carrier is modulated using M alternative symbols, the OFDM symbol alphabet consists of M^N combined symbols.

The low-pass equivalent OFDM signal is expressed as:

$$\nu(t) = \sum_{k=0}^{N-1} X_k e^{j2\pi kt/T}, \quad 0 \le t < T,$$

Where $\{X_k\}$, are the data symbols, N is the number of sub-carriers, and T is the OFDM symbol time. The sub-carrier spacing of 1/T makes them orthogonal over each symbol period; this property is expressed as:

$$\frac{1}{T}\int_0^T \left(e^{j2\pi k_1 t/T}\right)^* \left(e^{j2\pi k_2 t/T}\right) dt$$
$$= \frac{1}{T}\int_0^T e^{j2\pi(k_2-k_1)t/T} dt = \delta_{k_1 k_2}$$

Where (.)* denotes the complex conjugate operator and δ is the Kronecker delta.

To avoid intersymbol interference in multipath fading channels, a guard interval of length Tg is inserted prior to the OFDM block (A. S. Khrwat *et al*,2012). During this interval, a cyclic prefix is transmitted such that the signal in the interval $-T_g \le t < 0$ equals the signal in the interval $(T-T_g) \le t < T$. The OFDM signal with cyclic prefix is thus:

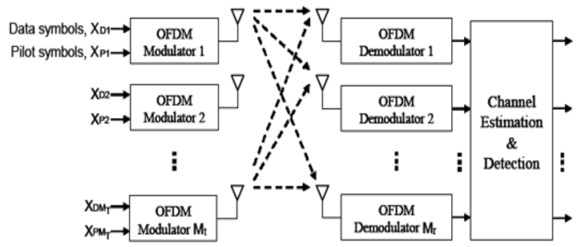
$$\nu(t) = \sum_{k=0}^{N-1} X_k e^{j2\pi kt/T}, \quad -T_{\mathrm{g}} \le t < T$$

The low-pass signal above can be either real or complex-valued. Real-valued low-pass equivalent signals are typically transmitted at baseband wire line applications such as DSL use this approach(M. Joham *et al*,2012)For wireless applications, the low-pass signal is typically complex-valued; in which case, the transmitted signal is up-converted to a carrier frequency f_c. In general, the transmitted signal can be represented as:

$$s(t) = \Re\left\{\nu(t)e^{j2\pi f_c t}\right\}$$
$$= \sum_{k=0}^{N-1} |X_k| \cos\left(2\pi[f_c + k/T]t + \arg[X_k]\right)$$

System model

A generic block diagram of a basic baseband-equivalent MIMO-OFDM system is given in figure. 4. A MIMO-OFDM system with N_{tx} transmit and N_{rx} receive antennas is assumed.

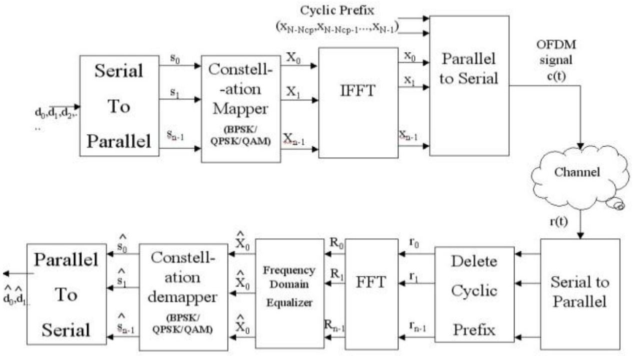


Combined Block Diagram of MIMO-OFDM System

The information bits can be coded and interleaved. The coded bits are then mapped into data symbols depending on the modulation type. Another stage of interleaving and coding can be performed for the modulated symbols (Meili,Xiang wang *et al*,2014) Although the symbols are in time domain, the data up to this point is considered to be in the frequency domain. The data is then demultiplexed for different transmitter antennas. The serial data symbols are then converted to parallel blocks, and an IFFT is applied to these parallel blocks to obtain the time domain OFDM symbols. For the transmit antenna, t_x, time domain samples of an OFDM symbol can be obtained from frequency domain symbols as

$$x_{tx}[n,m] = IFFT\{X_{tx}[n,k]\} = \sum_{k=0}^{K-1} X_{tx}[n,k]e^{j2\pi mk/K} \quad 0 \le k,m \le K-1$$

Where X_{tx} [n,k] is the data at the k_{th} subcarrier of the n_{th} OFDM symbol, *K* is the number of subcarriers, and m is the time domain sampling index.



System Model of MIMO-OFDM System

The channel at time *t* is expressed as,

$$h(t,\tau) = \sum_{l=0}^{L-1} \alpha_l(t)\delta(\tau - \tau_l),$$

Where *L* is the number of taps, α_l is the l_{th} complex path gain, and τ_l is the corresponding path delay. The individual paths can be correlated, and the channel can be sparse. At time t, the CFR of the CIR is given by

$$H(t,f) = \int_{-\infty}^{+\infty} h(t,\tau)e^{-j2\pi f\tau}d\tau$$

CFR can be if proper path is found

$$H[n,k] \equiv H(nT_f, k\Delta f) = \sum_{l=0}^{L-1} h[n,l]F_K^{kl}$$

Where $h[n, l] = h(nT_f, kt_s)$, and $F_K = e^{-2\pi j/k}$, T_f is the symbol length including CP, Δf is the subcarrier spacing, and $t_s = 1/Df$ is the sample interval.

for the nth OFDM symbol, Eq. 5 can be rewritten as

H = Fh

H is the column vector containing the channel at each subcarrier, F is the unitary FFT matrix, and h is the column vector containing the CIR taps.

At the receive antenna, *rx*, can be formulated as

$$y_{rx}[n,m] = \sum_{tx=1}^{N_{tx}} \sum_{l=0}^{L-1} x_{tx}[n,m-l]h_{rxtx}^{m}[n,l] + i_{rx}[n,m] + w_{rx}[n,m],$$

Where, *rx =1, …,* N_{rx},

After taking FFT of the time domain samples, the received samples in frequency domain can be expressed as,

$$Y_{rx}[n,k] = \frac{1}{K}\sum_{m=0}^{K-1} y_{rx}[n,m]e^{-j\frac{2\pi km}{K}}$$

$$= \frac{1}{K}\sum_{m=0}^{K-1}\left[\sum_{tx=1}^{N_{tx}}\sum_{l=0}^{L-1} x_{tx}[n,m-l]h_{rxtx}^{m}[n,l] + i_{rx}[n,m] + w_{rx}[n,m]\right]e^{-j\frac{2\pi km}{K}}$$

$$= \sum_{tx=1}^{N_{tx}} \frac{1}{K}\sum_{m=0}^{K-1}\left[\sum_{l=0}^{L-1}\left[\sum_{k'=0}^{K-1} x_{tx}[n,k']e^{j2\pi(m-l)k'/K}\right] h_{rxtx}^{m}[n,l]\right]e^{-j\frac{2\pi km}{K}} + I_{rx}[n,k] + W_{rx}[n,k]$$

where $I_{rx}[n, k]$ and $W_{rx}[n, k]$ are the corresponding frequency domain components calculated from $i_{rx}[n, m]$ and $w_{rx}[n, m]$, respectively.

for rx_{th} receive antenna and n_{th} OFDM symbol, we get

$$\mathbf{Y}_{rx} = \sum_{tx=1}^{N_{tx}} \mathbf{F}\boldsymbol{\Xi}_{rxtx}\mathbf{F}^{H}\mathbf{X}_{tx} + \mathbf{I}_{rx} + \mathbf{W}_{rx},$$

$$= \sum_{tx=1}^{N_{tx}} \boldsymbol{\Psi}\mathbf{X}_{tx} + \mathbf{I}_{rx} + \mathbf{W}_{rx}.$$

Here, Y_{rx} is column vector storing the received signal at each subcarrier, *F* is the unitary FFT matrix with entries $e^{-j2\pi mk/K}\sqrt{K}$ with *m* and *k* being the row and column index and $\psi = \boldsymbol{F\Xi_{rxtx}F^H}$, which can be considered as the equivalent channel between each received and all the transmitted subcarriers(A. S. Khrwat *et al*,2012)

X_{tx} denotes the column vector for transmitted symbols from tx_{th} transmit antenna, I_{rx} is the column vector for interferers, W*rx* is the column vector for noise, and Ξ_{rxtx} is the matrix he channel taps at each m index. The entries of Ξ are given by

$$\Xi_{rxtx}=\begin{bmatrix} h^{0}_{rxtx}[n,0] & 0 & 0 \\ h^{1}_{rxtx}[n,1] & h^{1}_{rxtx}[n,0] & 0 \\ \vdots & \vdots & \vdots \\ h^{L-1}_{rxtx}[n,L-1] & h^{L-1}_{rxtx}[n,L-2] & 0 \\ \vdots & \vdots & \vdots \\ 0 & 0 & 0 \end{bmatrix} \left| \begin{matrix} \cdots & h^{0}_{rxtx}[n,2] & h^{0}_{rxtx}[n,1] \\ \cdots & h^{1}_{rxtx}[n,3] & h^{1}_{rxtx}[n,2] \\ \vdots & \vdots & \vdots \\ \cdots & 0 & 0 \\ \vdots & \vdots & \vdots \\ \cdots & h^{K-1}_{rxtx}[n,L-1] & h^{K-1}_{rxtx}[n,0] \end{matrix} \right|.$$

Pilot based channel estimation technique

In the pilot mode, only few subcarriers are used for the initial estimation process. Depending on the stage where the estimation is performed, estimation techniques will be considered under time and frequency domains techniques. In frequency domain estimation techniques, as a first step (C. Min *et al*,2007) CFR for the known pilot subcarriers is estimated. These LS estimates are then extrapolated to get the channel at the non-pilot subcarriers. The process of the extrapolation can be denoted as

^H=Q^H*LS*

Where Q is the interpolation matrix. The goal of the estimation technique is to obtain Q with lower computational complexity but at the same time is to achieve higher accuracy for a given system. In this subsection, the calculation of matrix Q for simple interpolation techniques will be discussed.
Let A is the diagonal matrix of pilots as *A=diag*{ *A*0 , *A*1, ... , *AN* ⍰1⍰, *N* is the number of pilots in one OFDM symbol, ĥ is the impulse response of the pilots of one OFDM symbol, and Z is the Channel noise.

At the receiving end signal received is written as

$$B = AF\hat{h} + Z$$

where B is the vector of output signal after OFDM demodulation as $B=\{B_0,B_1,\ldots B_{N-1}\}^T$

F is the Fourier transfer matrix as

$$F=\begin{bmatrix} W_N^{00} & \cdots & W_N^{0(N-1)} \\ \vdots & \ddots & \vdots \\ W_N^{(N-1)0} & \cdots & W_N^{(N-1)(N-1)} \end{bmatrix}$$

Where weight of the fourier matrix is

$$W_N^{i,k} = \frac{1}{\sqrt{N}} e^{-j2\pi(\frac{ik}{N})}$$

The deletition function is

$$\begin{aligned} K &= \left| B - AF\hat{h} \right|^2 \\ &= (B - AF\hat{h})^H (B - AF\hat{h}) \\ &= B^H B - B^H AF\hat{h} - A^H BF^H \hat{h}^H + A^H F^H \hat{h}^H AF\hat{h} \end{aligned}$$

For the minimization of K

$$\frac{\partial K}{\partial \hat{h}^H} = 0$$

$$= -F^H A^H B + F^H A^H AF\hat{h}$$

$= 0$

Simulation results

We simulate MIMO-OFDM systems with K=5 users. The user symbols are drawn from a unit-energy QPSK constellation with processing gain P=Q=32. We assume a rich scattering environment and generate the FIR channel coefficients as complex Gaussian random variables with zero mean and variance 1/M. The SNR is defined as

$$\mathrm{SNR} = 10\log_{10}\left(\frac{1}{\sigma_v^2}\right) \text{ in dB}$$

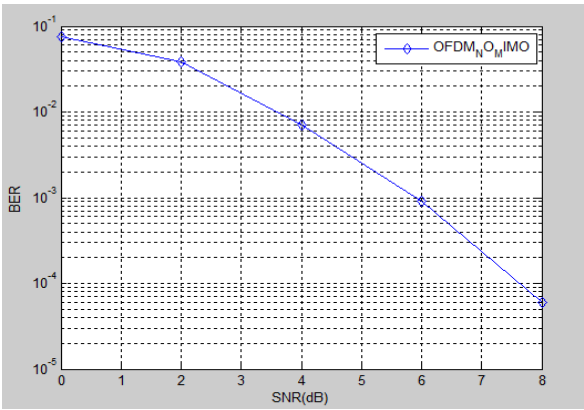


Figure 3 BER performance of the OFDM System in a Rayleigh fading environment for K=5 users

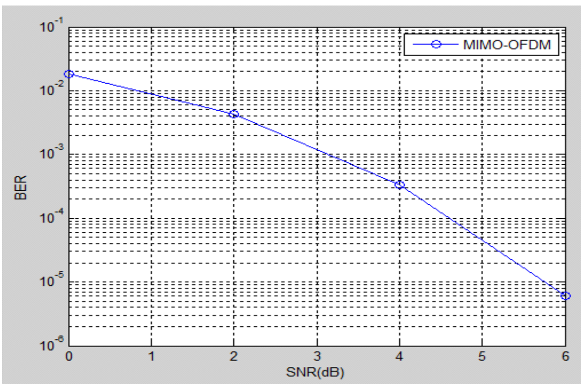


Figure 4 BER performance of the MIMO-OFDM System in a Rayleigh fading environment for K=5 users

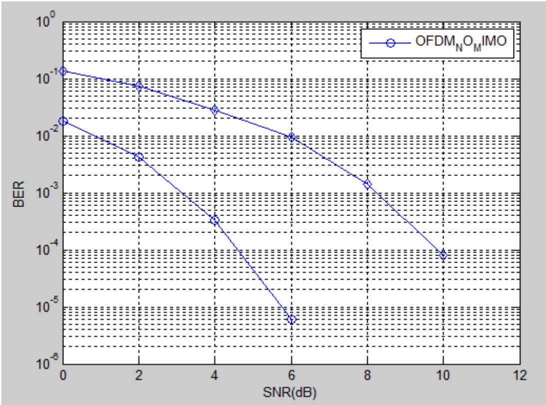


Figure 5 The comparative BER performance of the OFDM system with MIMO-OFDM System in a Rayleigh fading environment for *K*=5 users. It is clear that performance of the MIMO-OFDM system is better than conventional OFDM system.

In Figure3, we present the BER performance of the OFDM System in a Rayleigh fading environment for *K*=5 users. In Figure4, we present the BER performance of the MIMO-OFDM System in a Rayleigh fading environment for *K*=5 users. In Figure 5, we present the comparative BER performance of the OFDM system with MIMO-OFDM System in a Rayleigh fading environment for *K*=5 users. It is clear that performance of the MIMO-OFDM system is better than conventional OFDM system because in last figure we found 5db (app.) improvement in SNR at 0.0001 BER when both the techniques are compared, similarly at 0.001 we get 4.8(app.) improvement in SNR.

Conclusions

1) In this paper, we analyze the MIMO-OFDM Scheme. It is verified that significant performance gain can be achieved for the MIMO-OFDM System over conventional single transmit antenna OFDM systems .
2) Orthogonal Frequency Division Multiplexing is used to improve spectral efficiency and Multiple Input Multiple Output (MIMO) is used to improve spatial diversity in wireless communications systems.
3) By using spatial and temporal correlation and by analyzing graph between SNR and BER Here we analysis the performance of MIMO-OFDM over conventional OFDM and found MIMO-OFDM is superior.

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Ms. Madhavi karan is working towards a Master of Technology in E.C.E in Communication system at Rustamji institute of technology ,bsf tekanpur Gwalior.she has completed B.Tech in Electronics and Communication Engineering from Maharana pratap college of technology, Gwalior in 2012.

Mr.Neeraj shrivastav is presently working as an Associate Professor of Electronics Comm. Engineering in Rustamji Institute of technology,BSF Tekanpur Gwalior in India. He obtained p.hd degree from ABV IIITM Gwalior.