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PERFORMANCE STUDIES OF 2X2 MIMO SYSTEM FOR DIFFERENT MODULATION AND OFDM MULTIPLEXING TECHNIQUES USING ML DETECTOR

R BHAGYA[1] & A G ANANTH[2]

[1]Assistant Professor, Department of Telecommunication Engineering, RV College of Engineering, Bangalore, India

[2]Professor, Department of Telecommunication Engineering, RV College of Engineering, Bangalore, India

ABSTRACT

A detail analysis of the performance of 2X2 MIMO (Multiple Input Multiple Output) antenna systems has been carried out for different modulation schemes and multiplexing techniques using ML detector at the receiver end. The transmission characteristics of the MIMO system have been determined for BPSK, QPSK, and 16-QAM modulation schemes presuming Additive White Gaussian Noise (AWGN) and for the flat fading Rayleigh channel. On the receiver side, Successive Interference Cancellation technique with Maximum Likelihood (ML-SIC) detectors has been employed for determining the BER Vs SNR performance of the communication channel. The simulation results show that for BER of $\sim 10^{-3}$, the SNR increases with higher modulation schemes from BPSK to 16-QAM. Further the results of the analysis indicate that for BPSK modulation at BER of $\sim 10^{-3}$, the SNR performance for OSTBC multiplexing is found to be 14.39 dB, for CDMA multiplexing the SNR ~13.37 dB and for OFDM multiplexing the SNR ~12.54 dB. Thus the BER performance of 2X2 MIMO-OFDM transmission channel with ML detector shows the lowest SNR ~12.54 dB for the OFDM multiplexing. Further the MIMO-OFDM multiplexing system shows an ~2 dB and 1 dB improvement with respect to OSTBC and CDMA multiplexing techniques. A comparison of the MIMO performance with different multiplexing techniques indicate that the 2x2 MIMO–OFDM transmission channel for BPSK modulation depicts better performance with ML detector system at the receiving end. The simulations results are presented and discussed in the paper.

KEYWORDS: Signal to Noise Ratio (SNR), Quadrature Amplitude Modulation (QAM), Phase Shift Keying (PSK), Orthogonal Frequency Division Multiplexing (OFDM), Orthogonal Space Time Block Codes (OSTBC), Multiple Input Multiple Output (MIMO), Code Division Multiple Access Techniques (CDMA), Bit Error Rate (BER)

INTRODUCTION

The major challenges of wireless communication systems is to provide high-data-rate wireless access at high quality of service (QoS), combined with limited spectrum resource and hostile propagation conditions. This demands/hassle increase spectral efficiency and improvement in link reliability. The wireless channel is much more changeable than the wire line channel because of factors such as multipath, shadow fading, Doppler spread and delay spread or time dispersion.

The demand for higher network capacity and for higher performance of wireless networks is not breakable. MIMO Systems are able to improve the spectral efficiency significantly and consequently MIMO will play a key role in many future wireless communication systems.

MIMO is a technique where multiple antennas are used at both the transmitter and the receiver to increase the link reliability, the spectral efficiency, or both. This concept has been around for many years but its use in wireless standards is more recent. This is probably due in part to the fact that OFDM (orthogonal frequency-division multiplexing), which facilitates the implementation of MIMO, is now commonly used in today's wireless standards. MIMO techniques are used today in technologies like Wi-Fi and LTE, and new techniques are under study for future standards like LTE Advanced [4, 5].

Orthogonal Frequency Division Multiplexing (OFDM) is one of the important physical layer technologies for high data rate wireless communications due to its robustness to frequency selective fading, high spectral efficiency, and low computational complexity. OFDM is a popular method for high data rate wireless transmission. This technique divides the frequency available into many closely spaced carriers which are individually modulated by low rate data streams. Multiple Input Multiple Output (MIMO) wireless systems use multiple antenna elements at transmit and receive to improve capacity over single antenna topologies in multipath channel characteristics play key role in determining communication performance. 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. The combination MIMO-OFDM is beneficial since OFDM enables support of more antennas and larger bandwidths since it simplifies equalization dramatically in MIMO systems [1, 14].

By adopting multiple-input multiple-output (MIMO) and orthogonal frequency-division multiplexing (OFDM) technologies, indoor wireless systems could reach data rates up to several hundreds of Mbits/s and achieve spectral efficiencies of several tens of bits/Hz/s, which are unattainable for conventional single-input single-output systems. The enhancements of data rate and spectral efficiency come from the fact that MIMO and OFDM schemes are indeed parallel transmission technologies in the space and frequency domains, respectively. MIMO-OFDM when generated OFDM signal is transmitted through a number of antennas in order to achieve diversity or to gain higher transmission rate then it is known as MIMO-OFDM. Orthogonal Frequency Division Multiplexing (OFDM) is a popular modulation scheme that is used in wireless LAN standards like 802.11a, g, HIPERLAN/2 and in the Digital Video Broadcasting standard (DVBT). It is also used in the ADSL standard, where it is referred to as Discrete Multitone modulation. OFDM modulation divides a broadband channel into many parallel sub channels. This makes it a very efficient scheme for transmission in multipath wireless channels. The use of an FFT/IFFT pair for modulation and demodulation make it computationally efficient as well.

The present study involves a number of procedures namely simulations of the 2X2 MIMO transmission system, OFDM multiplexing, Digital modulation and computation and comparison of BER for different SNR. The aim of the study is to identify appropriate multiplexing and modulation techniques for MIMO system that gives better Bit Error Rate (BER) performance for different digital modulation Schemes (BPSK, QPSK, 16-QAM) using MATLAB simulation.

MULTIPLE INPUT MULTIPLE OUTPUT (MIMO)

MIMO systems are a natural extension of developments in antenna array communication. While the advantages of multiple receive antennas, such as gain and spatial diversity, have been known and exploited for some time the use of transmit diversity has only been investigated recently. The advantages of MIMO communication, which exploits the physical channel between many transmit and receive antennas, are currently receiving significant attention.

MIMO systems provide a number of advantages over single antenna to single antenna communication. Sensitivity to fading is reduced by the spatial diversity provided by multiple spatial paths. Under certain environmental conditions, the power requirements associated with high spectral-efficiency communication can be significantly reduced. Here, spectral efficiency is defined as the total number of information bits per second per Hertz transmitted from one array to the other.

MIMO systems employ multiple antennas at both the transmitter and receiver. They transmit independent data (say x_1, x_2, …, x_N) on different transmit antennas simultaneously and in the same frequency band. At the receiver, a MIMO decoder users M×N antennas. Assuming N receive antennas, and representing the signal received by each antenna as r_j we have:

$r_1=h_{11}x_1+h_{12}x_2+\ldots\ldots +h_{1N}x_N$

$r_2=h_{21}x_1+h_{22}x_2+\ldots\ldots +h_{2N}x_N$

$r_N=h_{N1}x_1+h_{N2}x_2+\ldots\ldots +h_{NN}x_N$

As can be seen from the above set of equations, in making their way from the transmitter to the receiver, the independent signals {x_1, x_2, …, x_N} are all combined. By treating the channel as a matrix, we can in fact recover the independent on the modulation scheme in each sub-channel transmitted streams {x_i}. To recover the transmitted data stream {x_i} from the {r_j} we must estimate the individual channel weights h_{ij}, construct the channel matrix ***H***. Having estimated ***H***, multiplication of the vector ***r*** with the inverse of ***H*** produces the estimate of the transmitted vector **x**. This is equivalent to solving a set of N linear equations in N unknowns [2, 6].

ORTHOGONAL SPACE-TIME BLOCK CODES (OSTBC)

Orthogonal STBCs are an important subclass of linear STBCs that guarantee that the ML detection of different symbols {s_n} is decoupled and at the same time the transmission scheme achieves a diversity order equal to $n_t n_r$. The main disadvantage of OSTBCs is the facts that for more than two transmit antennas and complex-valued signals, OSTBCs only exist for code rates smaller than one symbol per time slot.

An OSTBC is a linear space-time block code S that has the following unitary property.

$$S^{H}S = \hat{U}_{n=1}^{N} H_n H I \tag{1}$$

The i^{th} row of S corresponds to the symbols transmitted from the i^{th} transmit antenna in N transmission periods, while the j^{th} column of S represents the symbols transmitted simultaneously through n_t transmit antennas at time j.

According to equation (1), the columns of the transmission matrix S are orthogonal to each other. That means that in each block, the signal sequences from any two transmit antennas are orthogonal. The orthogonality enables us to achieve full transmit diversity and at the same time, it allows the receiver by means of simple MRC to decouple the signals transmitted from different antennas and consequently, it allows a simple ML decoding [3 ,8, 12].

Simulation for OSTBC

In a 2×2 MIMO channel, probable usage of the available 2 transmit antennas can be as follows: Consider that we have a transmission sequence, for example {x_1, x_2, x_3…..x_n}. In normal transmission, we will be sending x_1 in the first time slot, x_2 in the second time slot, x_3 in the third time slot and so on. However, as we now have 2 transmit antennas, we may group the symbols into groups of two. In the first timeslot, send x_1 and x_2 from the first and second antenna. In second time slot, send x_3 and x_4 from the first and second antenna; send x_5 and x_6 in the third time slot and so on. Notice that as we are grouping two symbols and sending them in one time slot, we need only n/2 time slots to complete the transmission data rate is doubled.

This forms the simple explanation of a probable MIMO transmission scheme with 2 transmit antennas and 2 receive antennas assuming channel is flat fading. The results of the analysis of BER performance with SNR for the MIMO–OSTBC transmission for different digital modulation are presented and discussed in the paper [17].

CODE DIVISION MULTIPLE ACCESS (CDMA)

CDMA is a channel access method used by various radio communication technologies. CDMA is an example of multiple accesses, which is where several transmitters can send information simultaneously over a single communication channel. This allows several users to share a band of frequencies. To permit this to be achieved without undue interference between the users, CDMA employs spread-spectrum technology and a special coding scheme (where each transmitter is assigned a code). CDMA is used as the access method in many mobile phone standards such as CDMAOne, CDMA2000 (the 3G evolution of CDMAOne), and WCDMA (the 3G standard used by GSM carriers), which are often referred to as simply CDMA [9, 10].

SIMULATION FOR CDMA

CDMA is a spread-spectrum multiple access technique. A spread spectrum technique spreads the bandwidth of the data uniformly for the same transmitted power. A spreading code is a pseudo-random code that has a narrow ambiguity function, unlike other narrow pulse codes. In CDMA a locally generated code runs at a much higher rate than the data to be transmitted. Data for transmission is combined via bitwise XOR (exclusive OR) with the faster code. The data signal with pulse duration of T_b (symbol period) is XOR'ed with the code signal with pulse duration of T_c (chip period). Therefore, the bandwidth of the data signal is $1/T_b$and the bandwidth of the spread spectrum signal is $1/T_c$. Since T_c is much smaller than T_b, the bandwidth of the spread spectrum signal is much larger than the bandwidth of the original signal. The ratio T_b/T_c is called the spreading factor or processing gain and determines to a certain extent the upper limit of the total number of users supported simultaneously by a base station.

Each user in a CDMA system uses a different code to modulate their signal. Choosing the codes used to modulate the signal is very important in the performance of CDMA systems. The best performance will occur when there is good separation between the signal of a desired user and the signals of other users. The separation of the signals is made by correlating the received signal with the locally generated code of the desired user. If the signal matches the desired user's code then the correlation function will be high and the system can extract that signal. If the desired user's code has nothing in common with the signal the correlation should be as close to zero as possible (thus eliminating the signal); this is referred to as cross-correlation. If the code is correlated with the signal at any time offset other than zero, the correlation should be as close to zero as possible. This is referred to as auto-correlation and is used to reject multi-path interference [11].

ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING (OFDM)

OFDM (Orthogonal Frequency Division Multiplexing) is a Multi-Carrier Modulation technique in which a single high rate data-stream is divided into multiple low rate data-streams and is modulated using sub-carriers which are orthogonal to each other and can be thought of as a large number of low bit rate carriers transmitting in parallel. All these carriers transmitted using synchronized time and frequency, forming a single block of spectrum, to ensure that the orthogonal nature of the structure is maintained.

Consider a quadrature modulated data sequence of the N channels (d_0, d_1, d_2, d_{N-1}) and {±1, ±3} in 16-QAM. These modulated data are fed into an inverse fast Fourier transform (IFFT) circuit and an OFDM signal is generated. The transmitted data is given by,

$$\begin{aligned} s(t) = \Sigma\Sigma\,(dIi(k)\cos(2\pi fi(t-kTs)) \\ -dQi(k)\sin(2\pi fi(t-kTs))) \\ f(t-kTs)+j\Sigma\Sigma\,(dIi(k) \\ \sin(2\pi fi(t-kTs))-dQi(k) \\ \cos(2\pi fi(t-kTs)))\,f(t-kTs) \end{aligned} \quad (2)$$

where Ts is the symbol duration of the OFDM signal and

f_i (i =0, 1, 2 …) is the frequency of the i^{th} subcarrier given by,

$$f_i = f_0 + i/Ts \quad (3)$$

Here, $f(t)$ is the pulse waveform of each of the symbols and it is defined as,

$$f(t) = \begin{cases} 1\ (0\ t\ Ts) \\ 0\ (otherwise) \end{cases}$$

The OFDM signal includes many carrier signals with their own frequencies which is then fed into a guard time insertion circuit to reduce ISI. Since the duration of each symbol is long, it can be affordable to insert a guard interval between the OFDM symbols and thus the inter-symbols interference [ISI] can be eliminated.

The total symbol duration:

$$T_{total} = T_g + T_{n\_} \quad (4)$$

where, T_g = guard time interval

After the insertion of a guard interval, the OFDM signal is given by,

$$s'(t) = \Sigma\Sigma di(k)\exp(2\pi fi(t-kT_{total}))f'(t-kT_{total}) - \quad (5)$$

where $f'(t)$ is the modified pulse waveform of each symbol defined as

$$f(t)=\begin{cases}1(Tg\ t\ Ts)\\0(t\leq Tg,t>Ts)\end{cases}$$

At the receiver, the received signal is given by,

$$r(t)=h(\tau,t)s(t-\tau)d\tau+n(\tau) \tag{6}$$

where $h(\tau,t)$ is the impulse response of the radio channel at time t, $n(t)$ is the complex AWGN.

At the receiver, received signal $r(t)$ is filtered by a band pass filter. An orthogonal detector is then applied to the signal where the signal is down converted to IF band. Then, an FFT circuit is applied to the signal to obtain Fourier coefficients of the signal in observation periods $[iT_{total}, iT_{total}+Ts]$. The output, $di'(k)$ of the FFT circuit of the ith OFDM sub channel is given by,

$$di'(k)=1/Ts\,r(t)\exp(-j2\pi fi(t-kT_{total}))dt \tag{7}$$

The characteristics of delayed wave, $hi'(k)$ in a multipath fading environment can be estimated; therefore the received data also can be equalized as follows:

$$di''(k)=(hi'*(k))/hi'(k)hi'*(k)))(di'(k)) \tag{8}$$

Where * indicates the complex conjugate.

By comparing $di'(k)$ and $di''(k)$ the BER performance can be calculated. The BER depends on the level of the receiver's noise. Thus in OFDM transmission, the orthogonal is preserved and the BER performance depends on the modulation scheme in each sub-channel.

Here, receiver diversity is used by considering the ML equalizer which is intended to remove the effect of channel from the received signal, in particular the Inter Symbol Interference (ISI), when the channel is noiseless. However when the channel is noisy, the ML equalizer will amplify the noise greatly at frequencies f where the channel response is $J = |y - H\hat{x}|^2$ has a small magnitude in the attempt to invert the channel completely [14, 15].

SIMULATION FOR OFDM

In a 2×2 MIMO channel, probable usage of the available 2 transmit antennas can be as follows: At first a serial data stream is converted into parallel stream and is encoded and interleaved. A suitable digital modulation technique is used. For synchronization pilot bits are added. Then inverse discrete Fourier transform is applied and cyclic prefix is added to include guard bits. Finally the signal will be transmitted through multiple antennas. Received signal is processed and recovered using the reverse process of transmitter at the receiver. This forms the simple explanation of a probable MIMO transmission scheme with2 transmit antennas and 2 receive antennas assuming channel is flat fading [13].

MIMO RECEIVER DESIGN

Maximum Likelihood (ML) Receiver

Maximum Likelihood (ML) Receiver achieves the best system performance (maximum diversity and lowest bit error ratio (BER) can be obtained), but needs the most complex detection algorithm. The ML receiver calculates all possible noiseless receive signals by transforming all possible transmit signals by the known MIMO channel transfer matrix. Then it searches for that signal calculated in advance, which minimizes the Euclidean distance to the actually received signal. The undisturbed transmit signal that leads to this minimum distance is considered as the most likely transmit signal. Note that the above described detection process is optimum in sense of BER for white Gaussian noise.

The Maximum Likelihood receiver tries to find $\hat{x}$ which minimizes, $\mathrm{J} = |\mathrm{y} - \mathrm{H}\hat{\mathrm{x}}|^2$.

$$J = \left|\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} - \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} \hat{x}_1 \\ \hat{x}_2 \end{bmatrix}\right|^2$$

Since the modulation is BPSK, the possible values of x_1 is +1 or -1 similarly x_2 also take values +1 or -1. So, to find the Maximum Likelihood solution, we need to find the minimum from the all four combinations of x_1 and x_2 . The estimate of the transmit symbol is chosen based on the minimum value from the above four values i.e if the minimum is, $J_{+1,+1} \Rightarrow$ [1 1], if the minimum is $J_{+1,-1} \Rightarrow$ [1 0], if the minimum is $J_{-1,+1} \Rightarrow$ [0 1] and if the minimum is $J_{-1,-1} \Rightarrow$ [0 0].

The simulation mainly includes finding the minimum among the four possible transmit symbol combinations, based on the minimum chose the estimate of the transmit symbol and repeat for multiple values of E_b/N_0 and plot the simulation [16, 19].

RESULTS AND DISCUSSIONS

The simulation results for the performance of OFDM, CDMA and OSTBC for different modulation techniques with ML-SIC detector for Rayleigh channel are obtained using MATLAB. The BER values as a function of SNR are determined for the three OSTBC, CDMA and OFDM multiplexing Techniques. The BER performances derived as a function of SNR for 2X2 MIMO system for the three multiplexing techniques are shown in Figure 1 for BPSK and Figure 2 for QPSK and Figure 3 for 16-QAM modulation schemes.

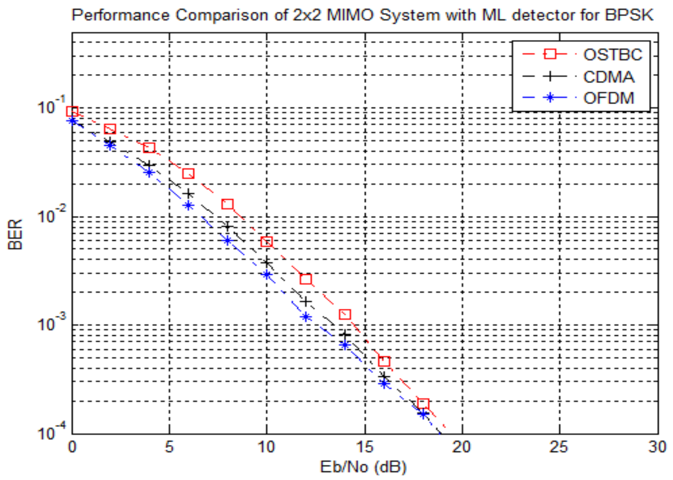

Figure 1: BER Plot of BPSK for 2×2 MIMO System for Different Multiplexing Techniques and ML Equalizer

From Figure 1, it can be observed that the BER values decreases as SNR increases for all the three types of multiplexing techniques. The figure indicates that at BER ~10^{-3}, the OSTBC shows that the SNR ~14.39 dB, CDMA SNR ~13.37 dB and OFDM SNR ~12.54 dB achievable for the BPSK modulation and ML detector. The result clearly demonstrates that the SNR values are the lowest ~12.54 dB for the OFDM multiplexing and maximum improvement of ~1.85 dB for OFDM compared to OSTBC multiplexing technique.

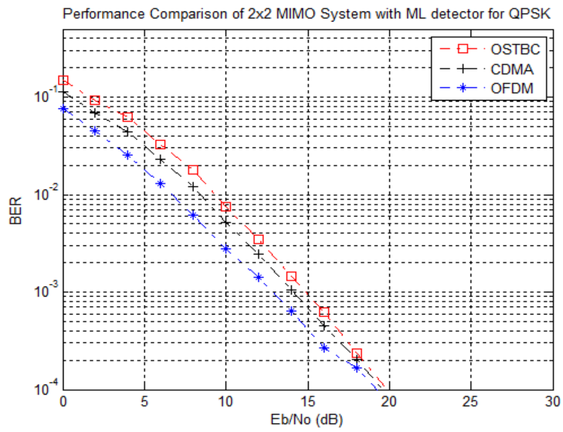

Figure 2: BER Plot of QPSK for 2×2 MIMO System for Different Multiplexing Techniques and ML Equalizer

From Figure 2, it can be seen that the BER values decreases as SNR increases for all the three types of multiplexing techniques. The figure indicates that at BER ~10^{-3}, for the OSTBC SNR ~14.9 dB, with CDMA the SNR ~14.07dB and OFDM the SNR ~12.9 dB achievable for the QPSK modulation. The result clearly demonstrates that the SNR values are the lowest ~12.9 dB for the OFDM multiplexing and maximum improvement of ~2 dB for OFDM compared to OSTBC multiplexing technique.

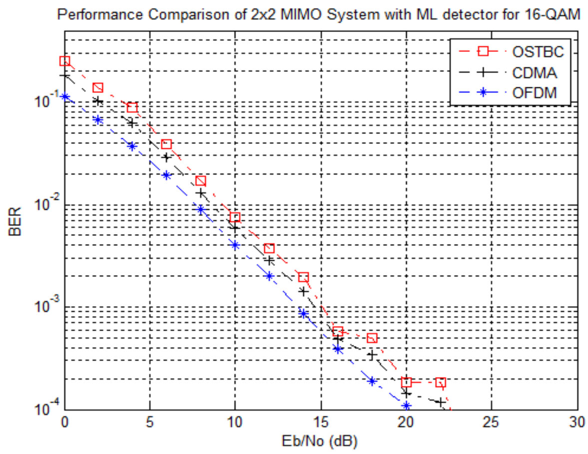

Figure 3: BER Plot of 16-QAM for 2×2 MIMO System for Different Multiplexing Techniques and ML Equalizer

From Figure 3, it can be seen that the BER values decreases as SNR increases for all the three types of multiplexing techniques. The figure indicates that at BER ~10^{-3}, for the OSTBC, the SNR ~15.05 dB, CDMA SNR ~14.63 dB and OFDM SNR ~13.65 dB achievable for the 16-QAM modulation. The result clearly demonstrates that the SNR values are the lowest ~3.65 dB for the OFDM multiplexing and maximum improvement of ~1.40 dB for OFDM compared to OSTBC multiplexing technique.

The simulation results at BER ~10^{-3}, the SNR performance of 2X2 MIMO systems obtained for three multiplexing techniques OSTBC, CDMA and OFDM for different modulation schemes BPSK, QPSK and 16-QAM are summarized in Table 1.

Table 1: Comparison of MIMO-OSTBC, MIMO-CDMA and MIMO-OFDM SNR Values for Different Modulation Techniques for BER ~ 10^{-3}

Multiplexing / Modulation	BPSK	QPSK	16-QAM
OSTBC	14.39	14.9	15.05
CDMA	13.37	14.07	14.63
OFDM	12.54	12.9	13.65

It is evident from the Table 1 that at BER ~10^{-3}, all the three multiplexing techniques depicts that as expected, the SNR values increases by ~1.5 dB as we go from BPSK to 16-QAM higher modulation scheme. However it is demonstrated that the SNR values for the OFDM multiplexing technique shows lowest values for all the three modulation schemes and shows better performance SNR >2 dB compared to OSTBC and SNR>1dB compared to CDMA multiplexing techniques.

CONCLUSIONS

It can be concluded from the results presented that,

- For a 2x2 MIMO system, with OFDM modulation at BER 10^{-3}, the SNR values increases by ~1.5 dB with increasing modulation from BPSK to 16-QAM.
- For the same MIMO-OFDM multiplexing system at BER 10^{-3} with ML detection shows lowest values of SNR ~12.54 dB compared to OSTBC and CDMA multiplexing technique.
- The SNR performance of OFDM at BER values ~10^{-3} indicates maximum improvement >2 dB for the OFDM multiplexing compared to OSTBC and SNR >1 dB compared to CDMA multiplexing techniques.
- It can be concluded from the simulation studies that the MIMO-OFDM transmission system offers better SNR performances with BER for BPSK modulation with ML-SIC detection system.

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