ISSN : 2231-0711

STUDY OF TRANMISSION CHARACTERISTICS OF 2X2 MIMO SYSTEM FOR DIFFERENT DIGITAL MODULATION USING OFDM AND STBC MULTIPLEXING TECHNIQUES AND ZF EQUALIZER RECEIVER.

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***Abstract*:A detailed analysis of the performance of 2×2 Multiple Input Multiple Output (MIMO) antenna system has been carried out by determining the transmit diversity using Orthogonal Frequency Division Multiplexing (OFDM) techniques. The transmission characteristics are determined for BPSK, QPSK and 16-QAM modulation. Additive White Gaussian Noise (AWGN) has been used presuming flat fading Rayleigh channel. On the receiver side, linear equalization techniques such as Zero Forcing (ZF) were employed for computing the BER performance. The simulation results show that for BER of ~10^{-4}, the SNR achieved are found to be significantly high. The results indicate SNR ~32dB for BPSK modulation, the SNR ~37dB for QPSK modulation and the SNR ~40dB for 16-QAM modulation over OFDM transmission. The MIMO - OFDM multiplexing schemes show a overall improvement of ~ 8 dB for BER values of 10^{-4} between 16-QAM modulation and BPSK modulation. Further a detailed comparison of the performance of OFDM multiplexing with STBC multiplexing for MIMO transmission shows large improvement in BER performance for OFDM with digital modulation. The simulations results are presented and discussed in the paper.**

Keywords: Multiple Input Multiple Output (MIMO), Orthogonal Frequency Division Multiplexing (OFDM), Phase Shift Keying (PSK), Quadrature Amplitude modulation (QAM), Bit Error Rate (BER), Signal to Noise Ratio (SNR), Space Time Block Code (STBC).

INTRODUCTION

The future needs 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 increase spectral efficiency and improvement in link reliability. The wireless channel is much more unpredictable than the wire-line channel.

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. 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 [1, 4].

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 and 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 *x1*, *x2*, …, *xN*) 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 *rj* we have:

r1=h11x1+h12x2+……. +h1NxN
r2=h21x1+h22x2+……. +h2NxN
.
.
rN=hN1x1+hN2x2+……. +hNNxN

As can be seen from the above set of equations, in making their way from the transmitter to the receiver, the independent signals {x1, x2, …, xN} 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 {xi}. To recover the transmitted data stream *{xi}* from the *{rj}* we must estimate the individual channel weights *hij*, 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 [5, 6].

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.

For example consider a quadrature modulated data sequence of the N channels (d0, d1, d2, dN-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,

$$s(t) = \sum\sum (dIi(k)\cos(2\pi fi(t-kTs)) - dQi(k)\sin(2\pi fi(t-kTs))) f(t-kTs) + j\sum\sum(dIi(k)\sin(2\pi fi(t-kTs)) - dQi(k)\cos(2\pi fi(t-kTs)))\ f(t-kTs) \quad (1)$$

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,

$$f_i = f_0 + i/Ts \quad (2)$$

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

$$f(t) = \begin{cases} 1\ (0\ t\ Ts) \\ 0\ (otherwise) \end{cases} \quad (3)$$

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,

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

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

$$f(t) = \begin{cases} 1(Tg\ t\ Ts) \\ 0(t \le Tg, t > Ts) \end{cases} \quad (6)$$

At the receiver, the received signal is given by,

$$r(t) = h(\tau,t)s(t-\tau)d\tau + n(t) \quad (7)$$

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,

$$di'(k) = 1/Ts\, r(t)\exp(-j2\pi fi(t-kT_{total}))dt \quad (8)$$

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:

$$di''(k) = (hi'^*(k))/hi'(k)hi'^*(k)))(di'(k)) \quad (9)$$

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 [2,7].

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 with 2 transmit antennas and 2 receive antennas assuming channel is flat fading [1].

Space-Time Block Codes

Space-Time Codes additionally improve the performance and make Spatial Diversity useable. The signal copy is not only transmitted from another antenna but also at another time. This delayed transmission is called Delayed Diversity. Space-Time Codes combine spatial and temporal signal copies . The signals s_1 and s_2 are multiplexed in two data chains. After that a signal replication is added to create the Alamouti Space-Time Block Code.

The receiver sees a combination of what was transmitted from both transmit antennas. MIMO system attempt to overcome this by using various coding schemes that define what signals should be transmitted and at what times, to make it possible to recover the original signals from the jumbled version that is received. These coding schemes are known as “Space-Time” codes because they define a code across space (antennas) and time (symbols).

Simulation for STBC

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 $\{x_1, x_2, x_3 \ldots x_n\}$. 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 time slot, 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 [3]. The results of the analysis of BER performance with SNR for the MIMO – STBC transmission for different digital modulation are presented and discussed in the paper [9].

RESULTS AND DISCUSSIONS

The simulation results for the performance of OFDM and STBC for different modulation techniques for AWGN channel are obtained using MATLAB. The BER values as function of SNR are determined for the two multiplexing scheme.

The simulation results for the performance of OFDM over different digital modulation techniques BPSK, QPSK and 16-QAM for AWGN channel are obtained using MATLAB. The BER values as function of SNR are determined for each modulation scheme for the purpose of comparing their relative performances. The Figure 1, 2, 3 shows the bit-error-rate performances for OFDM as a function of SNR for the three different digital modulation schemes respectively.

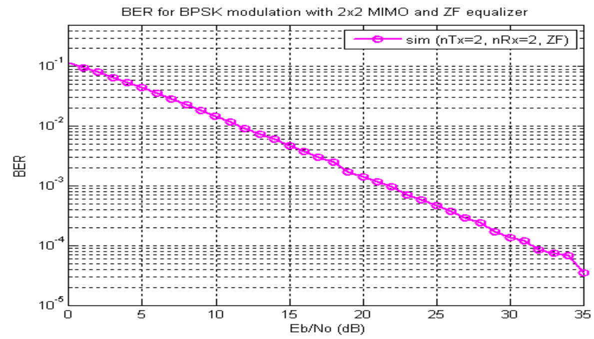

Figure 1: BER plot for BPSK with 2×2 OFDM and ZF equalizer

Figure 1 shows the performance of OFDM transmission using BPSK modulation. It can be seen from the figure that the BER decreases as SNR increases. The figure indicates that for BER ~$10^{-4,}$ the SNR ~32 dB is achievable for the BPSK modulation.

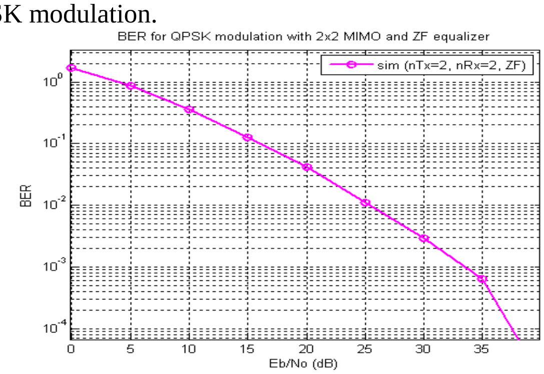

Figure 2: BER plot for QPSK with 2×2 OFDM and ZF equalizer

Similarly Figure 2 shows the performance of OFDM transmission using QPSK modulation. The figure shows that the BER decreases with SNR. For the QPSK modulation at BER values ~10^{-4}, the achievable SNR ~ 37 dB.

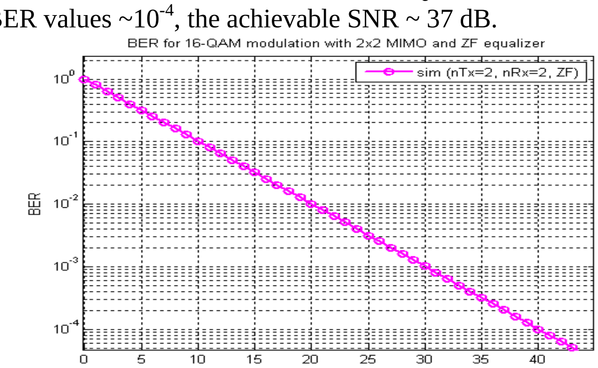

Figure 3: BER plot for 16-QAM with 2×2 OFDM and ZF equalizer

Further Figure 3 shows the SNR variation for the OFDM transmission using 16-QAM modulation. Even in this case the BER decreases with SNR. The figure indicates that for

BER values ~10^{-4} , the achievable SNR values ~40 dB for higher digital modulation.

It is evident from the Figures 1, 2 and 3 that for OFDM transmission, significant improvement in SNR performance can be achieved for 16-QAM modulation compared to BPSK modulation. Also it is seen that for BER ~10^{-4} and QPSK modulation, there is considerable improvement in SNR ~5dB compared to BPSK modulation Similarly for BER ~10^{-4} and 16 QAM modulation, there is considerable improvement of ~3 dB from QPSK modulation. These observations clearly indicate that there is significant increase in the SNR ~8 dB from BPSK to 16-QAM modulation schemes

The simulation results for the performance of STBC for different digital modulation techniques BPSK, QPSK and 16-QAM for AWGN channel are obtained using MATLAB. The BER values as function of SNR between OFDM and STBC multiplexing techniques for different modulation schemes are compared for evaluating their relative performances. The Table 1 shows the BER performance results tabulated for MIMO-OFDM and MIMO-STBC Multiplexing systems as function of SNR for three different digital modulation schemes.

MULTIPLEXING	BPSK	QPSK	16-QAM
STBC	11 dB	15 dB	27 dB
OFDM	32 dB	37 dB	40 dB

Table-1- Comparison of MIMO-OFDM and MIMO-STBC SNR Values for different modulation techniques for BER ~ 10^{-4}

It is evident from the Table 1 that for BER values of ~10^{-4} and BPSK modulation the OFDM shows SNR values ~32 dB compared to that for STBC where the SNR is ~ 11 dB. A large improvement in the performance of OFDM compared to that of STBC can be noted from the table. Similarly for the same BER values and QPSK modulation the OFDM shows SNR values ~ 37 dB compared to STBC where the SNR values ~15 dB. It is also found that for the same BER values for 16-QAM modulation the OFDM shows the SNR values ~ 40 dB compared to that of the STBC which shows SNR ~ 27 dB. In all the three cases the SNR values for OFDM multiplexing is very high and indicate a large improvement of > 13 dB for the three cases of digital modulation schemes.

The results of the present analysis show that the transmission characteristics of a MIMO (2X2) system employing OFDM transmission and ZF receiver, exhibits large improvement in SNR values between the OFDM and STBC multiplexing. It also indicates further increases in SNR improvement as we go from lower to higher digital modulation schemes.

CONCLUSIONS

It can be concluded from the results presented above that,

1. For a MIMO system, the OFDM multiplexing techniques and ZF receiver promotes achieving better SNR performances for digital transmission.
2. For MIMO-OFDM transmission for BER values of $10^{-4,}$ the SNR performance increases with different modulation schemes from BPSK to QPSK (~5 dB) and QPSK to QAM (~3 dB) and BPSK to QAM (~8 dB).
3. The SNR performance for BER values ~10^{-4} the OFDM multiplexing indicates large improvements > 13dB in the SNR values compared to that of STBC multiplexing techniques.
4. The comparison of performance between OFDM and STBC techniques indicates SNR improvement for BPSK modulation ~21dB, QPSK modulation ~22dB and 16-QAM modulation ~13 dB at BER ~10^{-4}.
5. It can be concluded from the simulation studies that the MIMO-OFDM transmission systems offers better SNR performances for higher digital modulation.

ACKNOWLEDGEMENT

We wish to acknowledge the support given by Principal, RV College of Engineering, Bangalore for carrying out the present research work and HOD department of telecommunication for constant encouragement. We also wish to thank Vasundhara.V and Shuba for software support.

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