Performance Evaluation of Multiple Input Multiple Output Orthogonal Frequency Division Multiplexing (Mimo-Ofdm) for Alamouti Space Time Block Code using Various Digital Modulation Techniques

Ijlal Hyder Rafiqi, Javed Ashraf, Mehboob ul Amin, M.T Beg, G.Mohiudin Bhat

Abstract: ***With the evolution in the telecommunication generations, more and more research is going on in the field of wireless communications. The purpose of these researches has always been to provide good network coverage across the region with higher data rates, accuracy and better performance. Control on coverage and performance has always been in focus and is achieved using better and better antennas. Several techniques are used to get good performance out of the antennas system. One impressive way is the usage of multiple antennas techniques. The approach is to transmit and receive more unique data on a single radio channel. To increase the diversity gain with the use of multiple input multiple output (MIMO), OFDM is a good technology used at the physical layer. It provides robustness to frequency selective fading, high spectral efficiency and low computational complexity. So MIMO-OFDM generates a good basis for 3GPP (3rd Generation Partnership Project) and 4G telecommunication technologies as well as other wireless communications systems. With MIMO-OFDM as basis, different standards like WiMAX (Wireless Interoperability for Microwave Access) and LTE (Long Term Evolution) have been implemented now. The use of OFDM has some limitations when it is considered for uplink like high peak to average power ratio (PAPR).High PAPR leads to increase in Bit Error rate of the system, thereby decreasing the system performance. In this paper we investigate the percentage error and capacity comparison by using different digital modulation schemes like: BPSK, QPSK, 16PSK, 4QAM and 8QAM, in the presence of AWGN and Rayleigh Noise over Rayleigh Fading channel.***

Key Words: ***Multiple Input Multiple Output (MIMO), Orthogonal Frequency Division Multiplexing (OFDM) ,Space Time Block Coding (STBC), Signal Error Rate(SER),Signal-to-Interference-noise- ratio (SINR).***

I. INTRODUCTION

As the wireless communication is rapidly developing technology in present times with new product and service emerging almost on daily basis.

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These developments present enormous challenges for communication engineers as the demands for increased capacity growing explosively. The biggest challenge in wireless communication is the phenomena called multipath induced fading, namely random fluctuation in the channel gain that arises due to multi path scattering. Previously multipath scattering was seen as biggest impairment in wireless communication but today now by employing multiple antennas in the transmitter and receiver called MIMO, rich scattering environment can be exploited to create multiplicity of parallel links to increase the data rate without the expense of extra bandwidth. There is unprecedented growth in demand for providing high speed wireless communication link in order to support wide range of applications such as voice, video email web browsing to name few. The biggest challenge in this scenario is the scarcity of the available bandwidth which is the real price to pay. Now with MIMO system the following benefits without the expansion of the available bandwidth or increase of transmitted power can be achieved. By using multiple antennas at the transmitter and receiver, the signal to noise ratio is increased by coherently combining effect of wireless signals at the receiver which improves resistance to noise which results in larger coverage area of wireless system. MIMO systems offer tremendous linear increase in data rate by transmitting independent data streams with available bandwidth enhancing the capacity of wireless system. The spatial multiplexing increases the capacity of wireless channel. By exploiting the spatial dimension provided by multiple antennas, interference can be mitigated in that a way that it was not possible with single antenna. Hence the system is turned into less susceptible to interference. Multiple antennas can be used to counter act the fading due to multipath propagation. By increasing the number of multiple copies of signal at receiver, the probability that all the signals are in deep fade simultaneously is very low which causes diversity gain resulting in robustness of the wireless link[1][2][3][4]. In this paper MIMO- OFDM system with N subcarriers is used over MIMO frequency selective channel. The fading coefficients are spatially uncorrelated over frequency and they remain constant in time. Input data is in frequency domain, it is digitally modulated using any modulation scheme for instance QPSK

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or 16-QAM. The data is fed into Alamoti time space encoder which creates the code words according to Alamouti coding scheme. The data is converted in time domain by taking IFFT of code words generated by Alamouti encoder. Then the transmitter appends the cyclic prefix. After adding cyclic prefixes the Alamouti coded symbol are transmitted by the two antennas in the first instant. In second instant, other Alamouti coded symbol are transmitted. At the receiver cyclic prefix are removed from OFDM Alamouti code symbols, then they are converted in frequency domain by taking FFT. The output of FFT block is fed into Alamouti decoder which decouples the desired symbol form unwanted symbols according to Alamouti decoding. Finally the data is digitally demodulated to detect the correct symbol which was sent initially to get the output symbol.

II. PAPR PROBLEM

An important limitation of OFDM is that it suffers from a high Peak-to-Average Power Ratio (PAPR) resulting from the coherent sum of several carriers. This forces the power amplifier to have a large input back-off and operate inefficiently in its linear region to avoid intermodulation products. High PAPR also affects D/A converters negatively and may lower the range of transmission. PAPR is defined as:

$$PAPR = \frac{\max|s(t)|^2}{E\left[|s(t)|^2\right]} \tag{1}$$

Theoretically, the PAPR can be as high as N, but the occurrence of such peaks is rare. The summation of a large number of carriers assumes a Gaussian distribution. The numerator, max|s(t)|2, is also known as the PEP (Peak Envelope Power). It is also equal to:

$$PEP = \tilde{s}(t)\tilde{s}^*(t) \tag{2}$$

Several methods have been devised throughout the years to limit the PAPR of a multicarrier signal. These methods include clipping, filtering, and coding. Clipping methods are the most widely used but at the cost of degradation of performance [5]. Some filtering and coding methods modify an OFDM symbol to lower its PAPR [6][7]. The more sophisticated methods form error-correcting codes with inherently low PAPR. [5]

III. DIVERSITY

Diversity scheme is a technique which is used to improve the performance of the communication system by effectively transmitting the same information multiple times to improve the signal to noise ratio such that transmitted signal is detected correctly.

3.1Types of Diversity

There are several types of diversities which are explained below.

Time Diversity

It is the type of diversity in which same information bearing signal is transmitted in different intervals.

Frequency Diversity

It is the type of diversity in which information bearing signals are transmitted by means of several carriers sufficiently apart from each other to provide independent fading version of signal. OFDM modulation is the example of frequency diversity.

Space Diversity

It is type of diversity in which signal is sent over different propagation paths by using multiple antennas at the transmitter and at the receiver. The spacing is carefully chosen to ensure the independence of possible fading events occurring in the channel [8].

IV. ANTENNA AND BEAM SELECTION IN MIMO-OFDM SYSTEMS

The number of transmit and receive antenna chains is a key factor affecting the complexity (cost) of any MIMO-OFDM system. In general, each receive chain in MIMO OFDM system includes frequency conversion, IF filtering, and ADC conversion. The circuits performing these processes must be replicated for a number of times equals the number of receive antennas. Hence, whenever the number of antennas is increased, system complexity and cost are increased. However, spatial diversity and interference suppression techniques can be implemented with lower cost by using antenna and beam selection operations instead of using full receiver chains.

Antenna Selection

Antenna selection is a strategy by which the number of transmits and receives antennas is reduced in order to reduce system complexity. Many researches are made in this field, especially for flat-fading MIMO links. Many selection criteria can be used to select the transmit or the receive antennas, based on the presence or absence of the interference. The improvement on system performance is measured by the average SNR gain or the diversity gain. In MIMO systems where diversity gain is important, the switch used for antenna selection requires a special design and has a non-negligible insertion los. At the transmitter, insertion loss reduces the radiated power, whereas at the receiver, it degrades the SNR. This degradation can be reduced by using low-noise amplifiers between the antenna elements and the switch. The gain acquired by the antenna selection in MIMO OFDM system may not be as large as in the case of flat-fading channel, since the best selection of antennas changes with frequency.

Beam Selection

A more efficient approach to be used for OFDM-MIMO systems is the beam selection strategy. Beam selection is based on that the multipath angles are often clustered. Since the cluster angles are not expected to be very frequency dependent, the selection of beams will not change much with frequency. Hence, the SNRor the Sampled Impulse Response (SIR) will be improved if the beam width is properly matched to the cluster width. One popular application of this technique is beam forming. In beam forming, the signal of each user is spatially weighted and transmitted to be in the direction of the intended user. The beam forming circuits are not expensive as the switches used in antenna selection strategies; they can be implemented in strip line. Beam selection is a suitable technique to be used in MIMO-OFDM wireless cellular systems to mitigate CCI. It enhances the SNR and SIR of the system and improves its performance.

V. SPACE TIME CODING TECHNIQUES

In MIMO-OFDM systems, the space-time coding techniques are used to exploit the diversity from channels. Many traditional space-time codes were used to extract spatial diversity from flat-fading MIMO channel. Whereas, they are not effective at extracting the additional frequency (multipath) diversity of a frequency-selective fading channel. In general, the maximum achievable diversity order may reach the product of the number of transmit antennas, the number of receive antennas, and the number of resolvable propagation paths (the channel impulse response length). In order to achieve such high orders, the transmitted symbols must be properly spread over the carriers and the transmit antennas. An important strategy used to map the information symbols on the tones and antennas is the space-time-frequency code. It is used to extract both spatial and frequency diversity. The design of space-frequency and space-time-frequency codes is currently an active area of research.For MIMO-OFDM cellular systems that suffer from Co-Channel Interference (CCI), exploiting channel diversity can be done in such a way reducing this type of interference. One popular technique used for this purpose is the smart antennas (beam forming). This technique makes use of spatial diversity (SDMA) to compensate for channel impairments such as CCI between users from neighboring cells.

5.1 ALAMOUTI SPACE-TIME CODE

Alamouti for two transmit antennas developed a complex Orthogonal Space-Time Block Code (OSTBC) [9][10]. In the Alamouti encoder, two consecutive symbols x1 and x2 are encoded with the following space-time code word matrix:

$$\begin{bmatrix} x_1 & -x_2^* \\ x_2 & x_1^* \end{bmatrix} \quad (3)$$

Alamouti encoded signal is transmitted from the two transmit antennas over two symbol periods. During the first symbol period, two symbols x1 and x2 are simultaneously transmitted from the two transmit antennas. During the second symbol period, these symbols are transmitted again, where -x*2 is transmitted from the first transmit antenna and x*1 transmitted from the second transmit antenna.

Note that the code word X in equation (3) is a complex orthogonal matrix, i.e.

$$\mathrm{X}X^H=\begin{bmatrix} |X_1|^2+|X_2|^2 & 0 \\ 0 & |X_1|^2+|X_2|^2 \end{bmatrix}=(|X_1|^2+|X_2|^2)I_2$$

Where I2 denotes the 2 x 2 identity matrix. Since N = 2 and T = 2, the transmission rate of Alamouti code is unity. Consider two different Alamouti codes,

$$X_P=\begin{bmatrix} x_{1,P} & -x_{2,P}^* \\ x_{2,P} & x_{1,P}^* \end{bmatrix} X_q=\begin{bmatrix} x_{1,q} & -x_{2,q}^* \\ x_{2,q} & x_{1,q}^* \end{bmatrix} \quad (4)$$

Where$[X_{1,P},X_{2,P}]^T \neq [X_{1,q},X_{2,q}]^T$. Then the minimum rank is evaluated as

$$v=\min rank\{$$

$$\begin{bmatrix} x_{1,P}-x_{1,q} & -x_{2,P}^*+x_{2,q}^* \\ x_{2,P}-x_{2,q} & x_{1,P}^*-x_{1,q}^* \end{bmatrix}\begin{bmatrix} x_{1,P}-x_{1,q} & -x_{2,P}^*+x_{2,q}^* \\ x_{2,P}-x_{2,q} & x_{1,P}^*-x_{1,q}^* \end{bmatrix}^H\}$$

$$=\min rank\{\begin{bmatrix} e_1 & -e_2^* \\ e_2 & e_1^* \end{bmatrix}\begin{bmatrix} e_1 & e_2^* \\ -e_2 & e_1 \end{bmatrix}\}$$

$$=\min rank\{(|e_1|^2+|e_2|^2)I_2\}=2 \quad (5)$$

Where $\mathrm{e}_1=\mathrm{x}_{1,\mathrm{p}}-\mathrm{x}_{1,\mathrm{q}}$ and $\mathrm{e}_2=\mathrm{x}_{2,\mathrm{p}}-\mathrm{x}_{2,\mathrm{q}}$Note that e1 and e2 cannot be zeros simultaneously. From Equation (3.11), the Alamouti code has been shown to have a diversity gain of 2. Note that the diversity analysis is based on Maximum Likelihood (ML) signal detection at the receiver side. We now discuss ML signal detection for Alamouti space-time coding scheme. Here, we assume that two channel gains, h1(t) and h2(t), are time-invariant over two consecutive symbol periods, that is,

$$h_1(t)=h_1(t+T_s)=h_1=|h_1|e^{j\theta_i} \quad (6)$$

$$h_2(t)=h_2(t+T_s)=h_2=|h_2|e^{j\theta_2} \quad (7)$$

Where |hi| and Ɵi denote the amplitude gain and phase rotation over the two symbol periods, i = 1, 2. Let y1 and y2 denote the received signals at time t and t + Ts, respectively, then

$$y_1=h_1x_1+h_2x_2+z_1 \quad (8)$$

$$y_2=-h_1x_2^*+h_2x_2^*+z_2 \quad (9)$$

Where z1 and z2 are the additive noise at time t and t + Ts, respectively. Taking complex conjugation of the second received signal, we have the following matrix vector equation:

$$\begin{bmatrix} y_1 \\ y_2^* \end{bmatrix}=\begin{bmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{bmatrix}\begin{bmatrix} x_1 \\ x_2 \end{bmatrix}+\begin{bmatrix} z_1 \\ z_2^* \end{bmatrix} \quad (10)$$

In the course of time, from time t to t + T, the estimates for channels $\mathrm{h}_1$and h_2 are provided by the channel estimator. In the following discussion, however, we assume an ideal situation in which the channel gains, h1 and h2, are exactly known to the receiver. Then the transmit symbols are now two unknown variables in the matrix of Equation (). Multiplying both sides of Equation (3.17) by the Hermitian transpose of the channel matrix, that is,

$$\begin{bmatrix} h_1^* & h_2 \\ h_2^* & -h_1 \end{bmatrix}\begin{bmatrix} y_1 \\ y_2^* \end{bmatrix}=\begin{bmatrix} h_1^* & h_2 \\ h_2^* & -h_1 \end{bmatrix}\begin{bmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{bmatrix}\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} +\begin{bmatrix} h_1^* & h_2 \\ h_2^* & -h_1 \end{bmatrix}\begin{bmatrix} z_1 \\ z_1^* \end{bmatrix}$$

$$=(|h_1|^2+|h_2|^2)\begin{bmatrix} x_1 \\ x_2 \end{bmatrix}+\begin{bmatrix} h_1^*z_1+h_2z_1^* \\ h_2^*z_1-h_1z_1^* \end{bmatrix} \quad (11)$$

We obtain the following input output relation

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = (|h_1|^2 + |h_2|^2) \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} z_1 \\ z_2 \end{bmatrix} \quad (12)$$

Where

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} \triangleq \begin{bmatrix} h_1^* & h_2 \\ h_2^* & -h_1 \end{bmatrix} \begin{bmatrix} y_1 \\ y_2^* \end{bmatrix}$$

$$\begin{bmatrix} z_1 \\ z_2 \end{bmatrix} \triangleq \begin{bmatrix} h_1^* & h_2 \\ h_2^* & -h_1 \end{bmatrix} \begin{bmatrix} z_2 \\ z_1^* \end{bmatrix}$$

In Equation (3.18), we note that other antenna interference does not exist anymore, that is, the unwanted symbol x_2 dropped out of y_1, while the unwanted symbol x_1 dropped out of y_2. This is attributed to complex orthogonality of the Alamouti code in Equation (3). This particular feature allows for simplification of the ML receiver structure as follows:

$$x_{1,ML} = Q\left(\frac{y_i}{|h_1|^2+|h_2|^2}\right), \quad i=1, 2 \quad (13)$$

Where Q(.) denotes a slicing function that determines a transmit symbol for the given constellation set. The above equation implies that x_1 and x_2 can be decided separately, which reduces the decoding complexity of original ML-decoding algorithm from $|C|^2$ to $2|C|$ where C represents a constellation for the modulation symbols, x_1 and x_2. Furthermore, the scaling factor ($|h_1|^2 + |h_2|^2$) in Equation (3.19) warrants the second-order spatial diversity, which is one of the main features of the Alamouti code.

VI. SIMULATION RESULTS

6.1 MIMO Model

In this model, we consider Alamouti's 2×2 MIMO systems to see simulation between Signal to Noise Ratio (SNR) and Symbol Error Rate (SER) for QPSK and 16PSK modulation. Then we compare the results with Shannon Capacity Limit for 2×2 MIMO systems. Figure 1 and Figure 2 show that capacity can be increased with higher SNR for error free transmission.

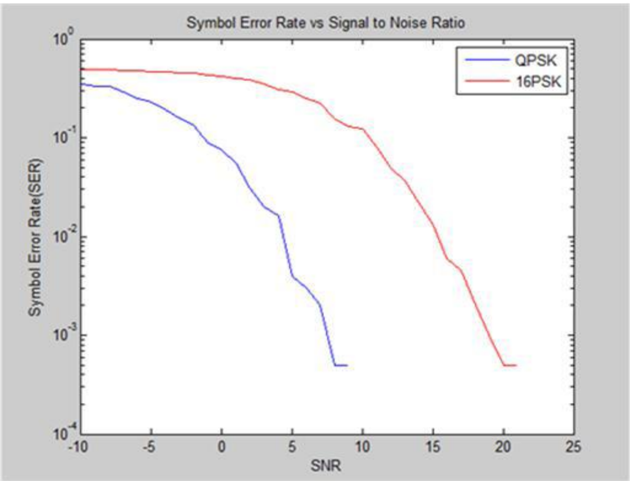

Figure 1. SER vs SNR with Alamouti 2x2 Scheme

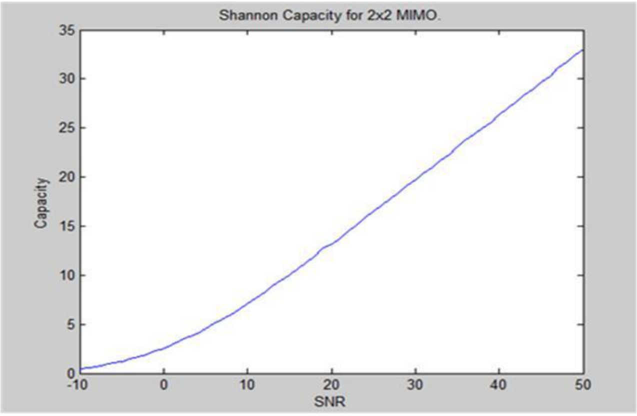

Figure 2. Shannon Capacity for 2x2 MIMO System

6.2 Comparison of SISO and MIMO Systems

In this section, we investigate symbol error and capacity performance of an OFDM system for SISO and MIMO Systems. Simulation results for following Specifications are plotted in figure 3and figure 4

Parameter	Requirement
Antenna System	SISO
Constellation	QPSK, 16PSK, 4QAM
FFT Size	64
Cyclic Prefix Size	15 % of FFT Size
Delay Spread	CP Size-1
Channel Model	Rayleigh Fading Multi taps (9 taps)
Noise Model	AWGN

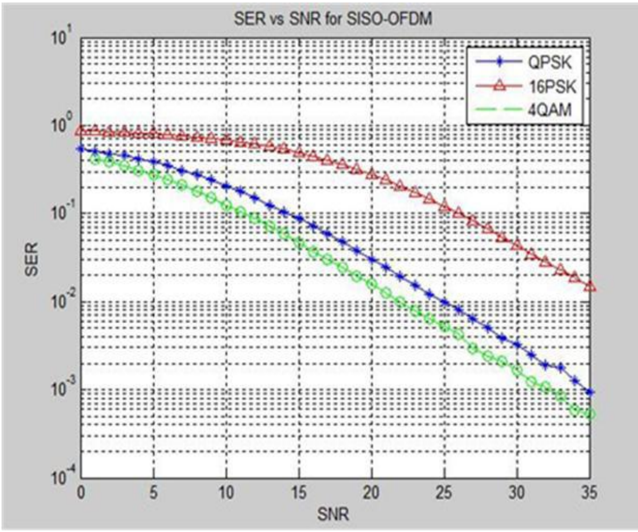

Figure 3. SER vs SNR for SISO-OFDM

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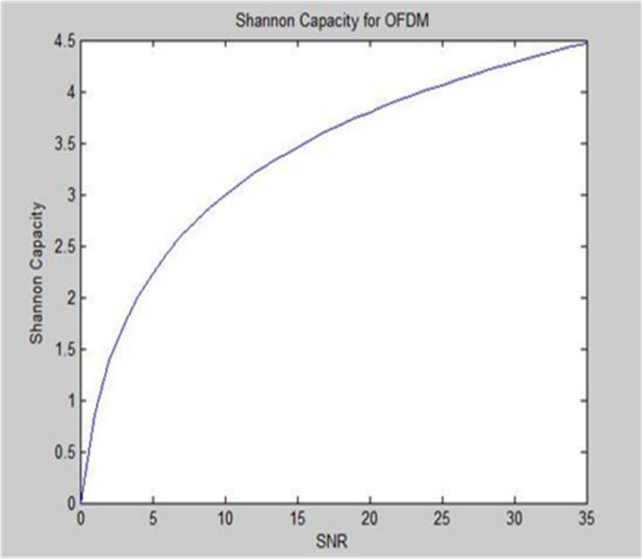

Figure 4. Shannon Capacity for OFDM

One can see different capacity comparisons between different modulation schemes. Simulation results for following specifcations are plotted in figure 5

Figure 5. SER vs SNR for MIMO-OFDM (Single Tap Channel)

Parameter	Requirement
Antenna System	MIMO Alamouti
Constellation	QPSK, 16PSK, 4QAM
FFT Size	64
Cyclic Prefix Size	15 % of FFT Size
Delay Spread	CP Size-1
Channel Model	Rayleigh Fading Single tap
Noise Model	Rayleigh Noise

Simulation results for following Specifications are plotted in figure 6

Parameter	Requirement
Antenna System	MIMO Alamouti
Constellation	QPSK, 16PSK, 4QAM
FFT Size	64
Cyclic Prefix	Size 15 % of FFT Size
Delay Spread	CP Size-1
Channel Model	Rayleigh Fading Multi taps
Noise Model	Rayleigh Noise

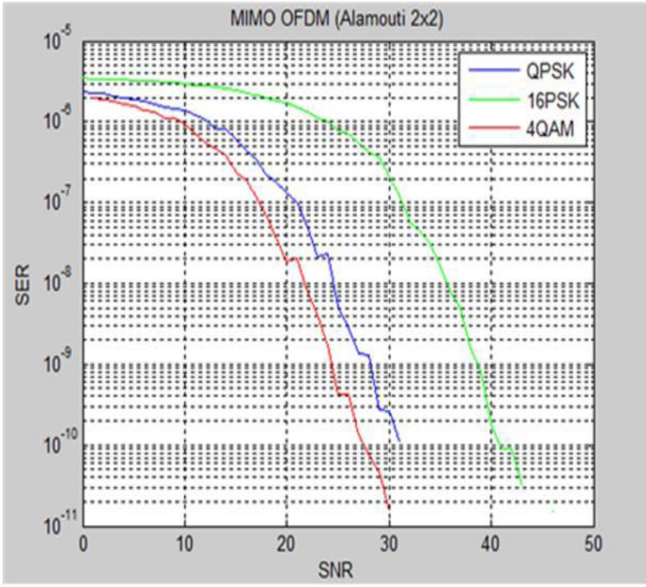

Figure 6. MIMO-OFDM (Alamouti2x2with Multiple Taps)

VII. CONCLUSION

The work presented in this paper is concerned with Performance Evaluation of Multiple Input Multiple Output Orthogonal Frequency Division Multiplexing (MIMO-OFDM) system for Wireless Communication Applications. A software based method for realization of transmitting and receiving system has been worked out. The MIMO-OFDM is an important air interface link in contemporary wireless communication system. It is considered as a potential candidate for digital audio and video broadcasting applications. It also finds its application in 4th generation cellular communication system. Fourth generation mobile communication systems are being designed to support very high speed wireless servers up to 1GbPS. For such high speed data transmission, the channel becomes severally frequency selective due to dispersion. A promising wireless multiple technique that can overcome the frequency selective fading as well as take advantage of this to improve the transmission quality is MIMO- OFDM. Using Multiple antennas at the transmitter and receiver we have seen that capacity of channel gets considerably increased.

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