ADAPTIVE MIMO TECHNOLOGY FOR 4G

A Thesis submitted in partial fulfillment of the requirements for Degree of Bachelor of technology in Electronics and Communication Engineering

By

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UNDER THE EXPERT GUIDANCE OF
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CERTIFICATE

This is to certify that the thesis entitled "Adaptive MIMO technology for 4G" submitted by Ranjan kumar Rath in partial fulfilment of the requirements for the award of Bachelor of technology degree in Electronics and Communication Engineering at National Institute of Technology, Rourkela(Deemed University) is an authentic work carried by him under my guidance during session 2011-2012.

To the best of my knowledge the matter embodied in this thesis has not been submitted to any institute/ university for the award of degree or diploma.

Date: 12/05/2012

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ABSTRACT

The communication industry is one of the fastest growing industries. The cellular systems started in the 80's with 1G have now reached to 4G. The growing demand of high data rates are increasing exponentially with time. The typical goals of a communication engineer are high speed communication for which the data rate should be high, better quality of signal for which we have to minimize the bit error rate as low as possible, less power consumption and VLSI implement ability. The 4G system ensures us data rate of 1Gbps which cannot be achieved by SISO systems and hence we go for MIMO system. The various benefits of MIMO are discussed in this report. The implementation of Alamouti scheme is also discussed and then the various methods of channel estimation are discussed and simulated.

The proposed MIMO system has distinguished advantages over the conventional SISO systems and this is being implemented in 4G cellular, MIMO radar and in various other emerging communication technologies.

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Chapter-1

Introduction

INTRODUCTION

In the 80's the first cellular system was implemented by NIPPON TELEPHONE AND TELEGRAPH, Tokyo, Japan. Analog modulation schemes were predominantly used. In the United States the Advanced Mobile Phone Systems (AMPS) became popular in the 80's. The bandwidth allocated was 40Mhz within the radio bandwidth of 800Mhz to 900Mhz. In 1988 additional 10Mhz of bandwidth was added for better performance. AMPS was using Frequency Modulation (FM) technique and only speech was transmitted. Later 1.5G was evolved providing an improvisation to 1G. Then consequently 2G came into market which used digital modulation schemes for transmission of speed and data. The remarkable thing in 2G was the ability to transmit data. Another notable thing was it was much efficient in spectrum and used multiple access techniques such as time division multiple access (TDMA), frequency division multiple access (FDMA) etc.

In Europe the Global system for mobile communication started and became very popular for almost 20 years. Then the 3G (third generation) cellular system came into existence and it allows high speed data transmission as well as internet access. It also supported voice activated calls. Then the 4G system has become a hot topic. It ensures us data rate more than 100Mbps i.e. almost no waste of time and multi mega bit internet access. But the real challenge involved in 4G is how to design such a network. The conventional SISO (single input and single output) systems can never reach the barrier of 100Mbps.

WHY MIMO?

The typical aspirations of a system designer are high data rate, low bit error rate, low power consumption, low cost and easy implement ability. The MIMO system ensures us very high data rates even more than 1Gbps while minimizing the bit error rate. By Shanon's theorem the rate of transmission is always less than or equal to the capacity. Practically it is less than the capacity. The capacity depends on the bandwidth of the channel and SNR of the channel. Both the bandwidth and signal to noise ratio are characteristics of the channel. The SNR can be improved either by reducing noise power or by increasing signal power. Reduction in noise power is not possible while increase in signal power requires more power for transmission which should be avoided for a good design. The improvement of bandwidth is not possible. However there are techniques like

OFDM (orthogonal frequency division multiplexing) which assure us efficient use of the channel i.e. spectral efficiency. But however the use of multiple antennas at the transmitter and at the receiver that is use of MIMO meets the ongoing requirements in 4G. The bit error rate in MIMO is very less as compared to conventional SISO systems.

Chapter-2

MIMO SYSTEMS & CAPACITY

MIMO SYSTEMS and CAPACITY

As the name suggests MIMO uses multiple antennas both at the transmitter and at the receiver as shown below.

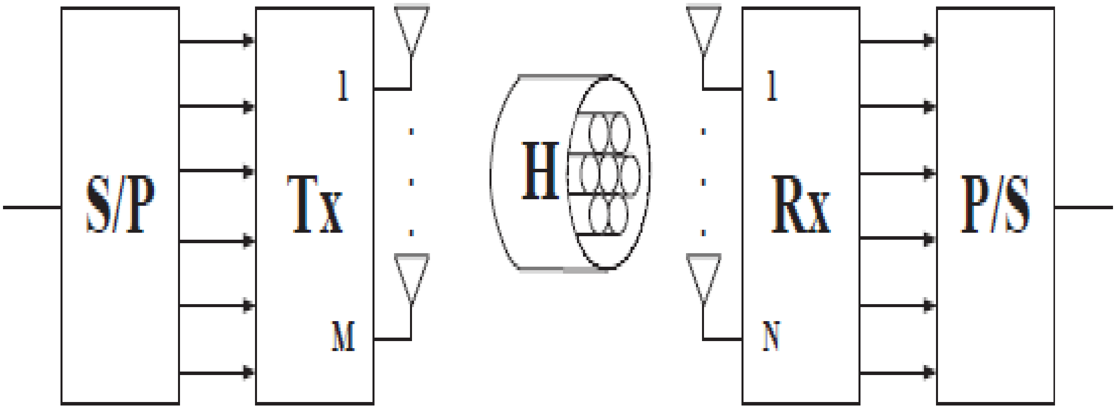

Figure 1. MIMO system modeling

Here the system uses 'M' number of transmit antennas at the transmitter and 'N' number of receiving antennas at the receiver. The data stream is first converted to parallel data streams and then processed through the antennas. Here 'H' stands for the channel matrix.

Channel capacity

Channel capacity is the measure of the maximum amount of information that can be transmitted over a certain channel and can be received with a certain probability of error or less than that. For a memory less channel, if we represent the input as X and the output as Y then the capacity may be defined as the maximum of mutual information between X and Y. Mathematically that is represented by

$$C = \max_{p(x)} I(X;Y) \tag{1}$$

Here p(x) is the probability distribution function (pdf) of the input variable X.

A channel is said to be memory less or having zero memory if the probability distribution function (pdf) of the output depends upon the input only at a time and is conditionally independent of previous inputs and outputs.

Mathematically, we can represent the input output relations of a single user narrowband MIMO channel as

$$\mathbf{y} = \mathbf{H}\mathbf{x} + \mathbf{n} \tag{2}$$

Where

'X' is the transmit vector of size (nT x 1)

'y' is the (nR x 1) receive vector

'n' is the additive white Gaussian noise at a particular instant of time having size (nR x 1).

'H' is the (nR x nT) channel matrix.

The channel matrix is represented as

$$\mathbf{H} = \begin{bmatrix} h_{11} & \cdots & h_{1n_T} \\ h_{21} & \cdots & h_{2n_T} \\ \vdots & \ddots & \vdots \\ h_{n_R 1} & \cdots & h_{n_R n_T} \end{bmatrix}$$

We assume that

- The channel is rich in scattering which will provide us an ideal situation to implement MIMO
- The channel matrix is random and the receiver has exact knowledge about the channel matrix entries.
- The channel is memory less that is the channel is used independently for each and every time.
- The coefficients of the channel matrix are complex valued and normally distributed random variables while we take |hij| are Rayleigh distributed.

Therefore we can write-

$$\begin{aligned} h_{ij} &= \alpha + \jmath\beta \\ &= \sqrt{\alpha^2 + \beta^2} \cdot e^{-\jmath \arctan\frac{\beta}{\alpha}} \\ &= |h_{ij}| \cdot e^{\jmath\phi_{ij}}. \end{aligned}$$

The capacity as per Shanon's theorem applied for a memory less channel having power constraint Pt at the transmitter is given by

$$C = \max_{p(x):P \leq P_T} I(X;Y) \tag{3}$$

Where 'P' is the average power of code word and p(x) is the probability distribution function of the input.

The capacity of a SISO (single input single output) channel is given by

$$C = \mathcal{E}_H \left\{ \log_2 \left(1 + \rho \cdot |h_{11}|^2 \right) \right\} \tag{4}$$

Where p is the SNR (signal to noise ratio) and $\mathcal{E}_H$ denotes the expectation over all channel realizations.

MIMO capacity

For a MIMO memory less having power constraint Pt at the transmitter the ergodic capacity is given by

$$C = \max_{p(\mathbf{x}):tr(\Phi) \leq P_T} I(\mathbf{x};\mathbf{y}) \tag{5}$$

Where Φ is the covariance matrix of the transmitted vector.

Using the relationship between mutual information and entropy we find

$$I\ (x;y) = h(y) - h\ (n)$$

When y is Gaussian the mutual information is found to be maximized as the normal distribution maximizes the entropy of a given variance.

For a complex Gaussian vector y, h(y) <= $\log_2$ (det (π e K))

Equality holds if the covariance matrix of the output is K.

$$\begin{aligned}
\mathcal{E}\left\{\mathbf{y}\mathbf{y}^{\dagger}\right\} &= \mathcal{E}\left\{(\mathbf{H}\mathbf{x}+\mathbf{n})(\mathbf{H}\mathbf{x}+\mathbf{n})^{\dagger}\right\} \\
&= \mathcal{E}\left\{\mathbf{H}\mathbf{x}\mathbf{x}^{\dagger}\mathbf{H}^{\dagger}\right\} + \mathcal{E}\left\{\mathbf{n}\mathbf{n}^{\dagger}\right\} \\
&= \mathbf{H}\Phi\mathbf{H}^{\dagger} + \mathbf{K}^{n} \\
&= \mathbf{K}^{d} + \mathbf{K}^{n}.
\end{aligned} \tag{6}$$

For a random memory less MIMO channel the maximum mutual information is found to be

$$I(x;y) = \log_2 (\det (H\, \Phi\, H^t\, (Kn)^{-1} + I_{Nr}$$

We assume uniform power distribution that is $\Phi = (P_T / Nt)\, I_{Nr}$
And the noise is uncorrelated in each receiver so we can write $K^n = \sigma^2 I_{Nr}$
Putting these values we find that capacity for the MIMO channel is given by

$$C = \mathcal{E}_H \left\{ \log_2 \left[\det \left(\mathbf{I}_{n_R} + \frac{\rho}{nT} \mathbf{H}\mathbf{H}^{\dagger} \right) \right] \right\} \text{ bits/s/Hz} \tag{7}$$

Thus we have found an expression for capacity of memory less MIMO channel.

Chapter-3

Advantages of MIMO systems

Advantages of MIMO systems

MIMO provides two major advantages over SISO systems which makes it distinguished. They are

- Spatial multiplexing gain
- Spatial diversity gain

Spatial multiplexing gain

MIMO system provides a linear increase in data rate via spatial multiplexing. This means to send multiple independent data streams from the receiver within the bandwidth provided. If there is rich scattering then the receiver can easily separate the data streams. Each and every data stream realizes the same channel as they would in a SISO system and hence they effectively enhance the capacity of the channel by a multiplicative factor of number of data streams. Hence the spatial multiplexing gain improves the capacity of the system considerably.

Spatial diversity gain

In a wireless system due to multipath interference the signal level at the receiver never remains constant; it fluctuates or fades. If we transmit multiple copies of the same signal then the probability that the signal goes into deep fade is decreased. It may happen that a copy of the signal goes into deep fade while others may be accurate may not go into fading at all. The number of copies is named as diversity order. If we keep on increasing the independent copies of the same signal then our error keeps on decreasing. A MIMO system with MT transmit antennas at the transmitter and MR number of receiving antennas at the receiver offer a diversity order of MT MR.

Simulation of MIMO capacity

We have plotted the capacity of SISO, 2x2 MIMO, 3x3 MIMO, 4x4 MIMO vs. SNR for comparison. 2x3 and 3x4 MIMO capacities are also plotted vs. SNR.

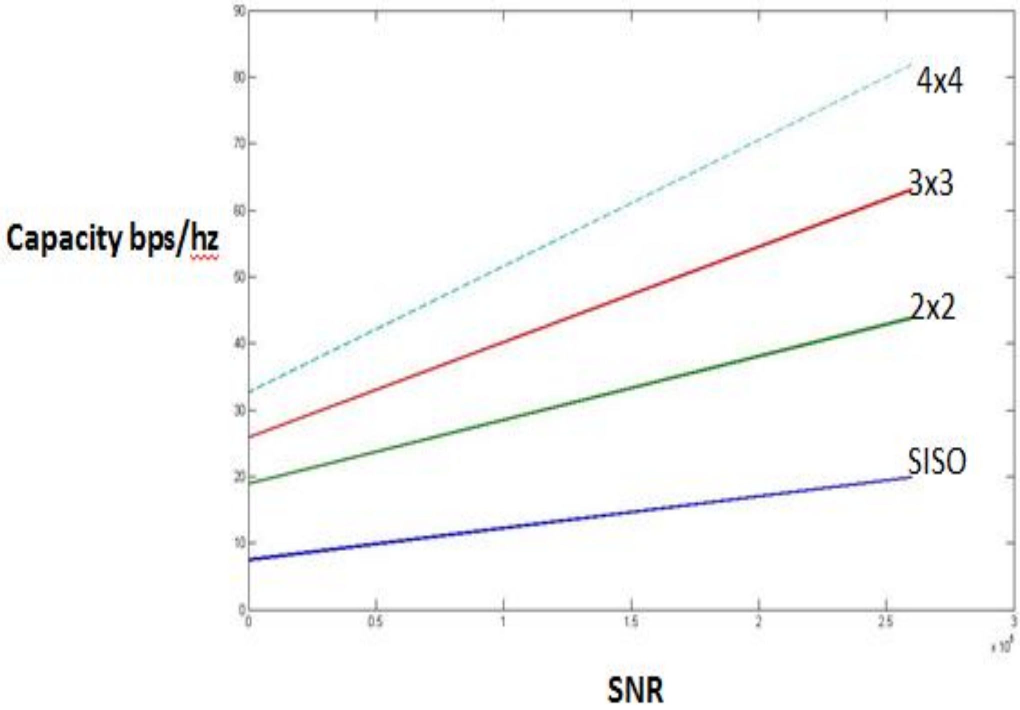

Figure-2. MIMO Capacity Vs. SNR

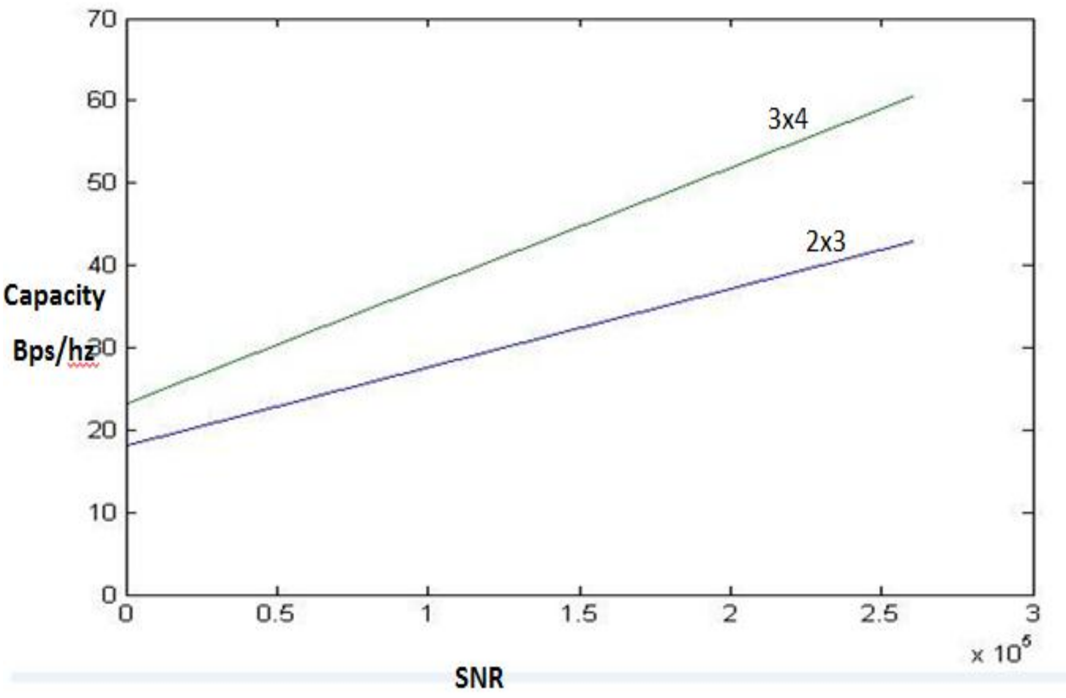

Figure-3. MxN MIMO Capacity Vs. SNR

Chapter-4

Alamouti scheme

The Alamouti Scheme

There are various algorithms such as V-Blast, D-Blast to implement MIMO. Here we will discuss about the Alamouti scheme. The Alamouti scheme is the simplest diversity techniques applied to MIMO systems having two number of the transmit antennas at the transmitter and any number of receive antennas at the receiver.

This uses the diversity gain. We send the multiple copies of the same signal via two different antennas. Here space time coding is used. In the first time slot x1 and x2 are transmitted from antenna1 and antenna2 respectively. In the next/ second time slot –x2* and x1* are transmitted from antenna1 and antenna2 respectively. Thus in effective two bits are transmitted per two time slots. Further more we assume that the channel remains constant for both the time slots.

Pictorially, It is represented as:

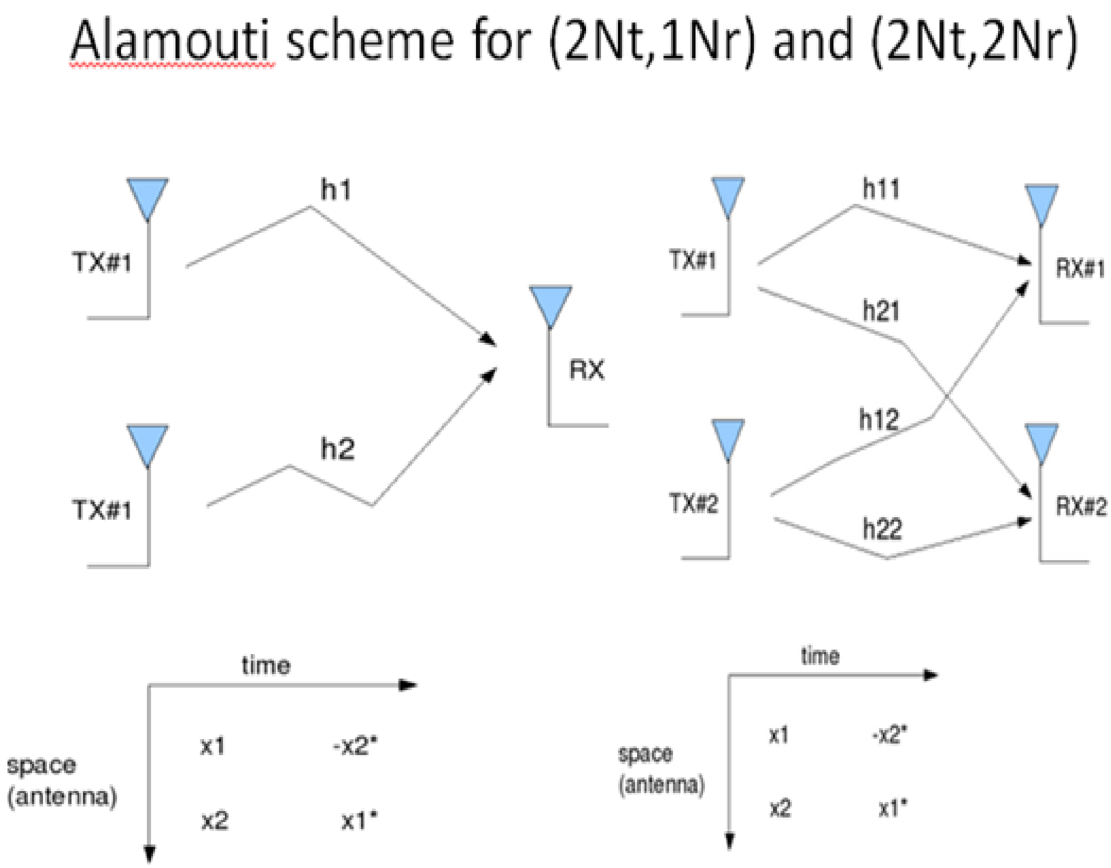

Figure-4. Pictorial view of Alamouti scheme

The received signal in the first time slot will be

$[y_1^1; y_2^1]^T = [h11\ h12; h21\ h22] * [x_1 ; x_2]^T + [n_1^1 ; n_2^1]^T$ (8)

The received signal in the second time slot is given by

$[y_1^2; y_2^2]^T = [h11\ h12; h21\ h22] * [-x_2* ; x_1]^T + [n_1^1 ; n_2^1]^T$ (9)

Where vector y represents the output at two different time slots for two different antennas at the receiver. And H is the 2x2 channel matrix.

Combining both the results we find that

$[y_1^1; y_2^1;y_1^2*; y_2^2 *]^T = [h11\ h12; h21\ h22; h12*\ -h11*; h22*\ -h21*] * [x_1 ; x_2]^T$

$+ [n_1^1 ; n_2^1 ; n_1^2 * ; n_2^2 *]^T$ (10)

Now in order to find the input at the receiver we have to find the inverse of the H matrix. Of course for which we must have knowledge about the channel matrix coefficients and they should not vary.

Simulation of Alamouti scheme

We have taken BPSK (binary phase shift keying) modulation for SISO and 2x1 MIMO system. In MIMO we applied the Alamouti model and compared with the BPSK for SISO system. We have plotted the BER (bit error rate) vs. Eb/N0. We can easily see that to achieve the same bit error rate the Alamouti scheme requires less SNR and hence very useful

.**A COMPARISION**

Scheme	Spectral Efficiency	P_e	Implementation Complexity
V-BLAST	HIGH	HIGH	LOW
D-BLAST	MODERATE	MODERATE	HIGH
ALAMOUTI	LOW	LOW	LOW

Table-1. Comparison of different MIMO techniques

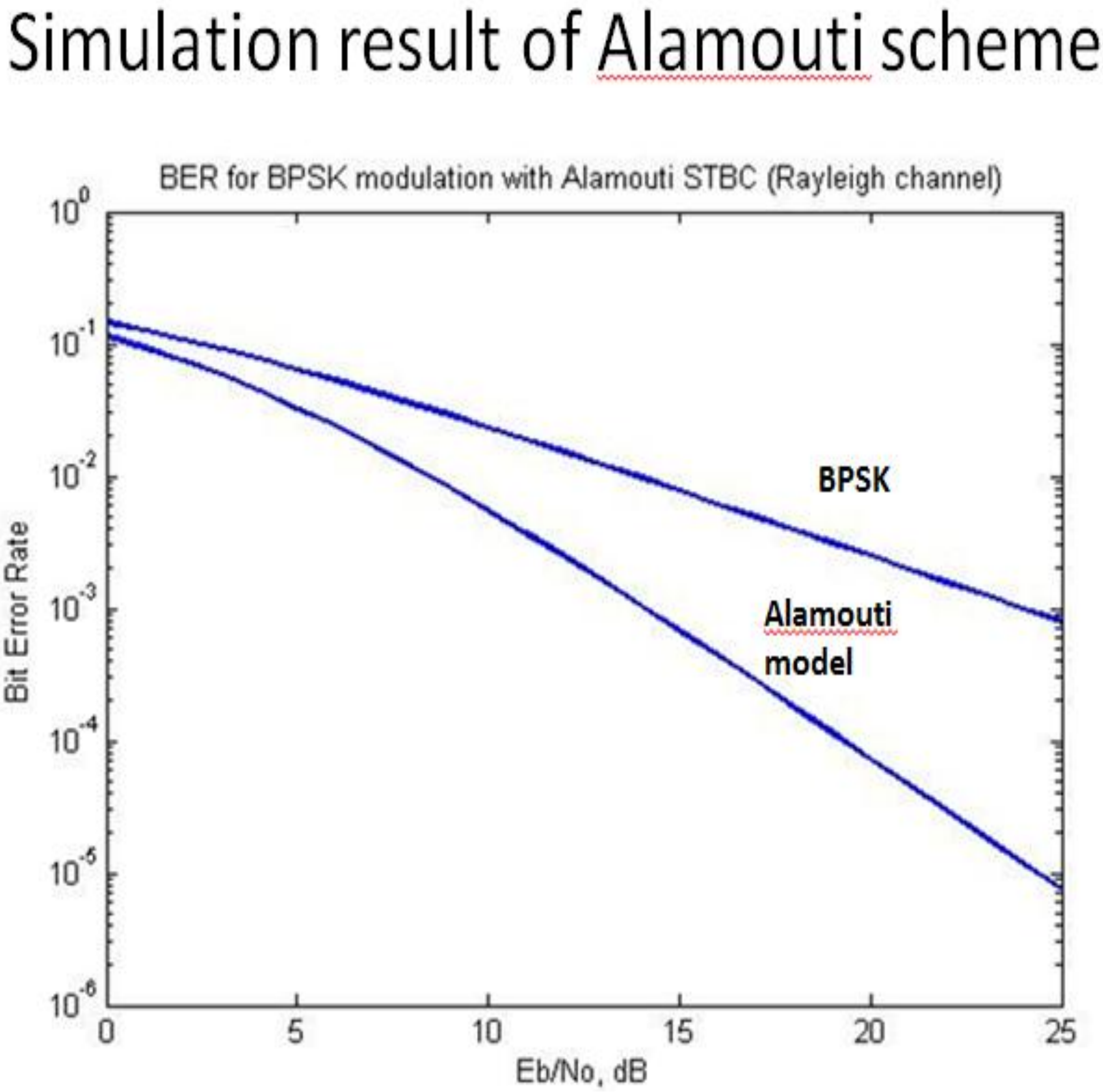

Figure-5. Simulation of Alamouti Model

For verifying the advantage of Alamouti model over SISO system we draw a horizontal line at a particular Bit error rate (say at bit error rate of 10^{-3}), the horizontal line will cut the Alamouti model curve and the BPSK SISO curve at two different points in the graph. The difference suggests that even at that amount of low SNR we still can have the same quality of the signal in Alamouti model as compared to BPSK.

Chapter-5

MIMO-OFDM

MIMO-OFDM

OFDM stands for orthogonal frequency division multiplexing. It is a method that uses the spectrum in the most efficient way. Typically the channel is irregular and frequency selective fading is prominent, OFDM divides the frequency selective channel into a number of sub-channels which are orthogonal to each other but having frequency-flat response so that frequency selective fading can be avoided.

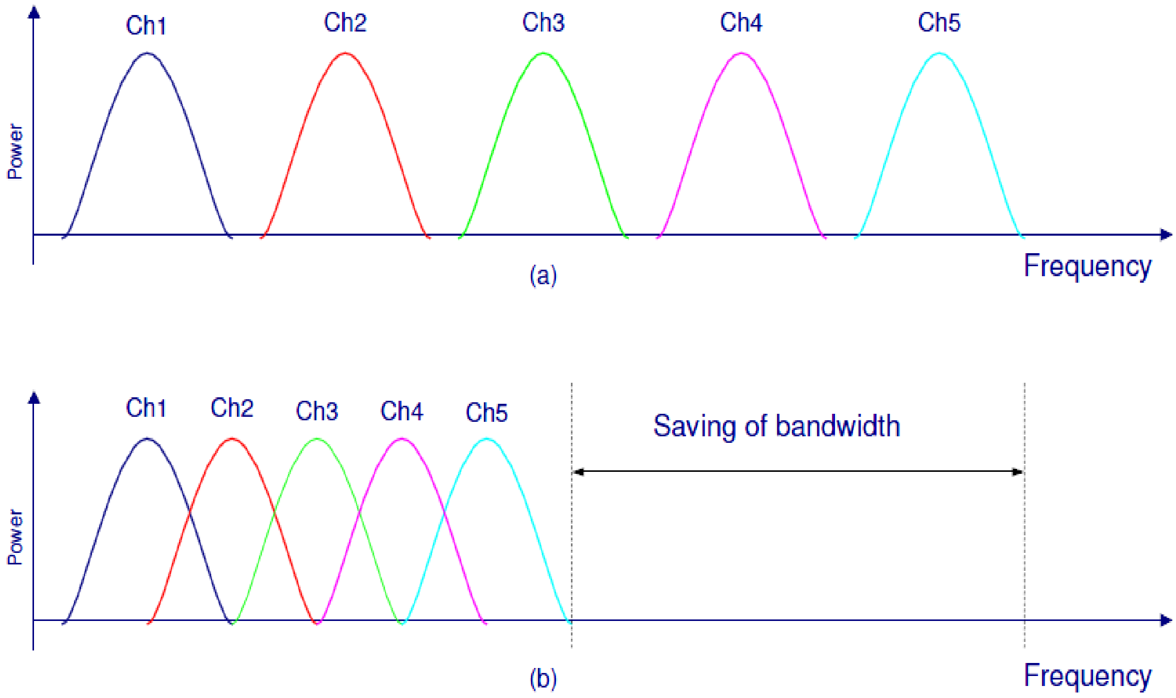

Figure-6. Bandwidth saving in OFDM

The OFDM implemented in MIMO is known as MIMO-OFDM. It ensures us great data rate as well as minimized bit error rate along with efficient use of the channel bandwidth. The implementing block diagram for MIMO-OFDM is shown below.

MIMO-OFDM Model

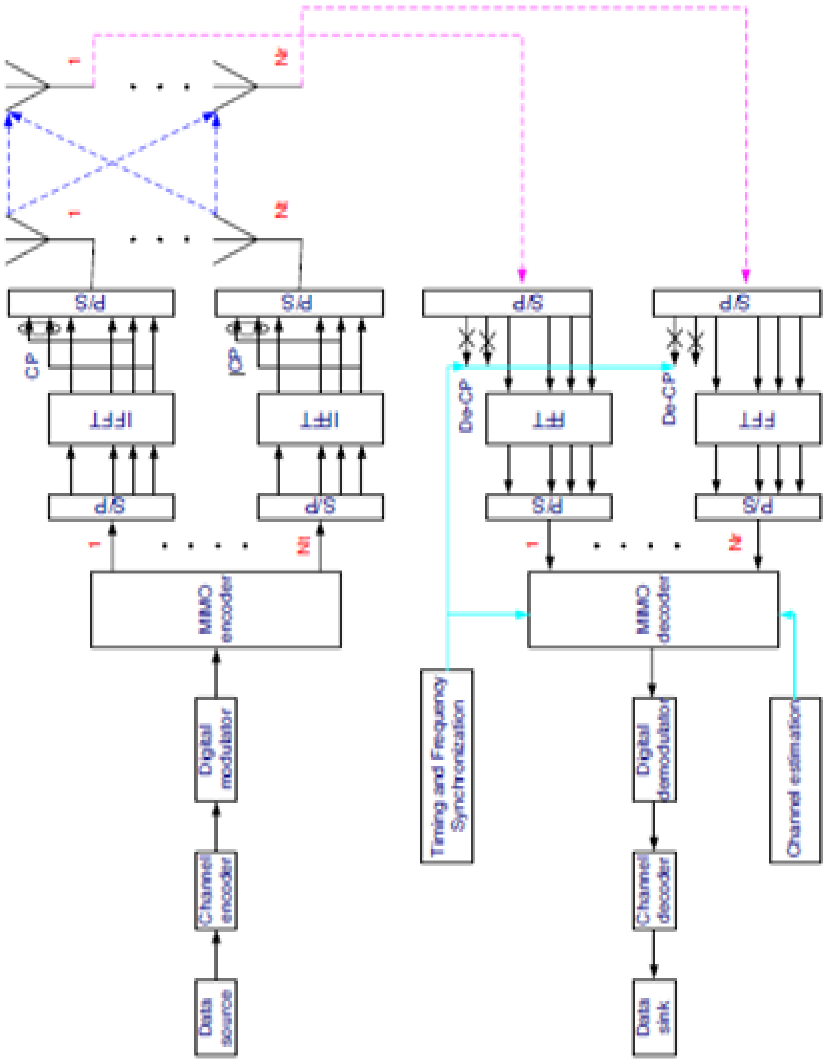

Figure-7. MIMO OFDM Model

The IFFT (inverse fast Fourier transform) is used at the transmitter and FFT (fast Fourier transform) is used at the receiver as usual in OFDM model. First the data is converted from serial stream to parallel stream before it goes to IFFT block and then it is transmitted via MIMO antennas. The inverse is used at the receiver.

Chapter-6

MIMO Channel estimation

MIMO Channel estimation

As we have seen that for calculating the capacity we need to know the channel, for calculating the signal that was transmitted we have to know the channel, therefor the knowledge of the channel is a major challenge in a communication system. In MIMO the channel is of mxn size. We can find or estimate the channel by many ways. The various methods used for it are the blind channel estimation, training based channel estimation etc.

In blind channel estimation method the channels estimation is carried out by evaluating the statistical information of the channel and certain properties of the input signal.

However in training based channel estimation method a known training bit is send first and the channel is found by some adaptive algorithm. Then with the knowledge of the channel we transmit the signal.

e.g. The GSM (global system for mobile communication) uses 26 training bits as shown. The channel is assumed to be time invariant during the period of message transfer. The channel is then estimated again for the next burst of data before sending it.

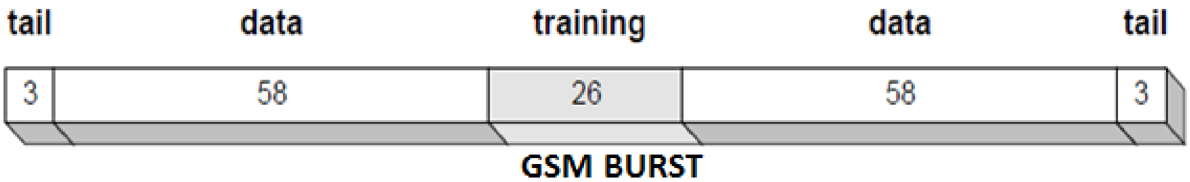

Figure-8. GSM Burst

We can see the GSM uses 3 tail bits for synchronization and error detect and correct purposes. The digitized message is of 58 bits while the training bits are 26 bits. During transmission after the channel is estimated, we assume that the channel remains the same for next 58 data bits and 3 tail bits. That is a total of 61Tb where Tb is the bit duration.

The block diagram of a typical training based channel estimator is as shown:

CHANNEL ESTIMATION MODEL

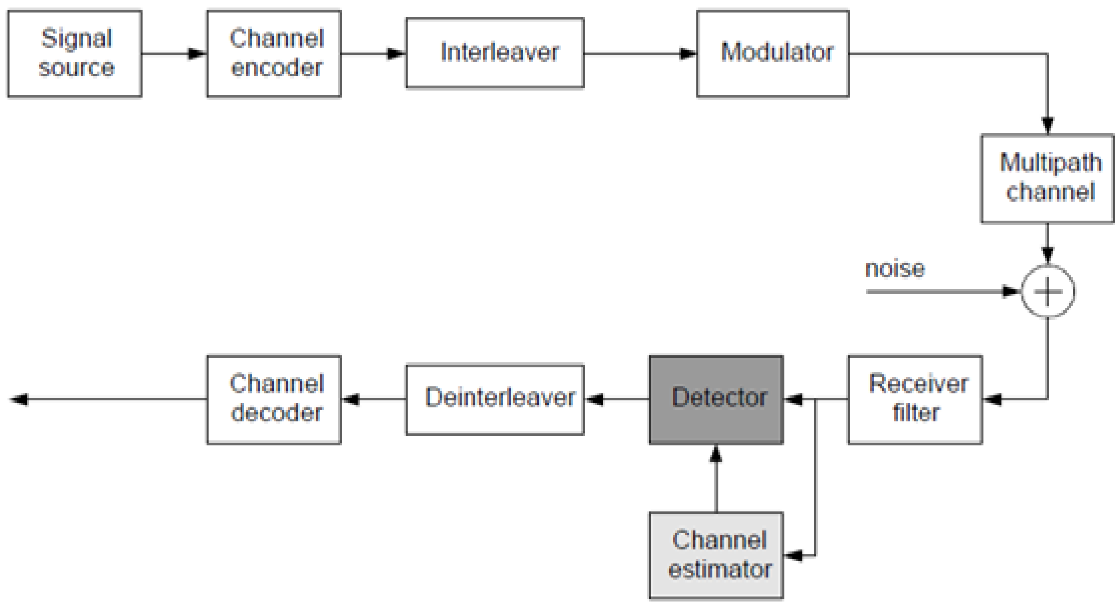

Figure-9. Channel estimation model

SIMULATION OF CHANNEL ESTIMATION

The channel estimation by LMS and RLS algorithm is discussed. LMS (least mean square) algorithm converges a bit slower than the RLS (recursive least m

We have estimated the MIMO channel by LMS (least mean square) algorithm and by RLS(recursive least mean square) algorithm and plotted the mean square error for each of them taking 10dB and 20dB SNR(signal to noise ratio). Then the mean square error is plotted against the SNR for both of the algorithms.

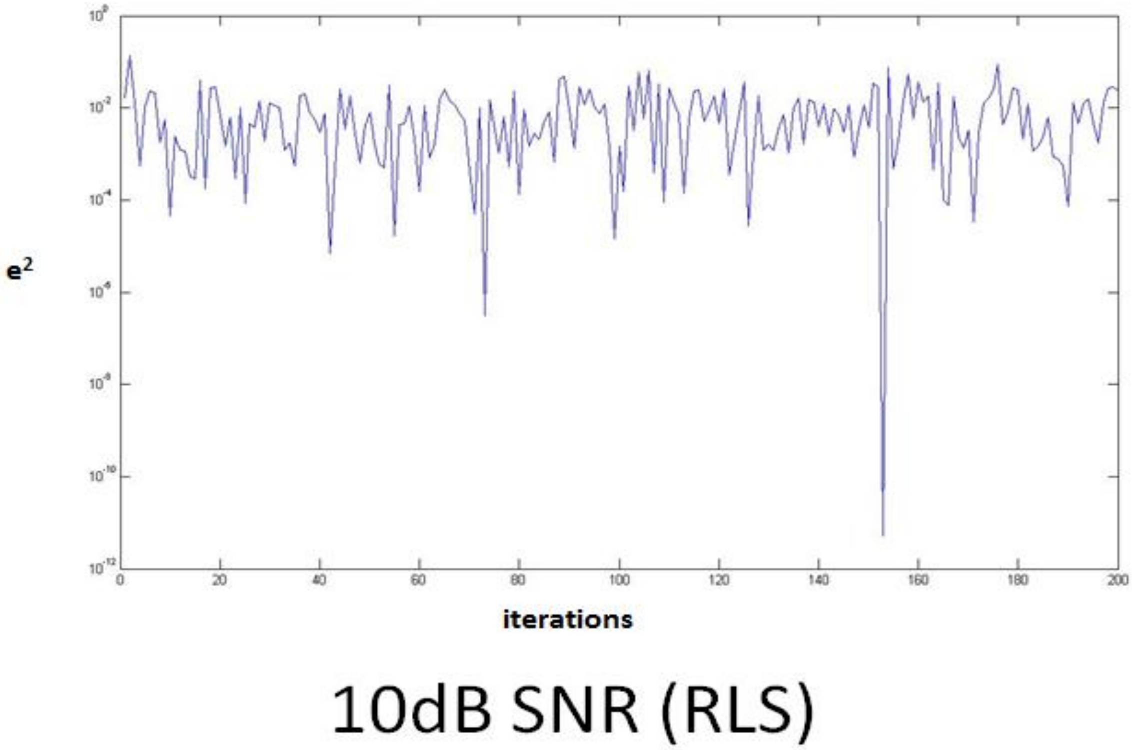

Figure-10. Channel estimation RLS 10 dB SNR

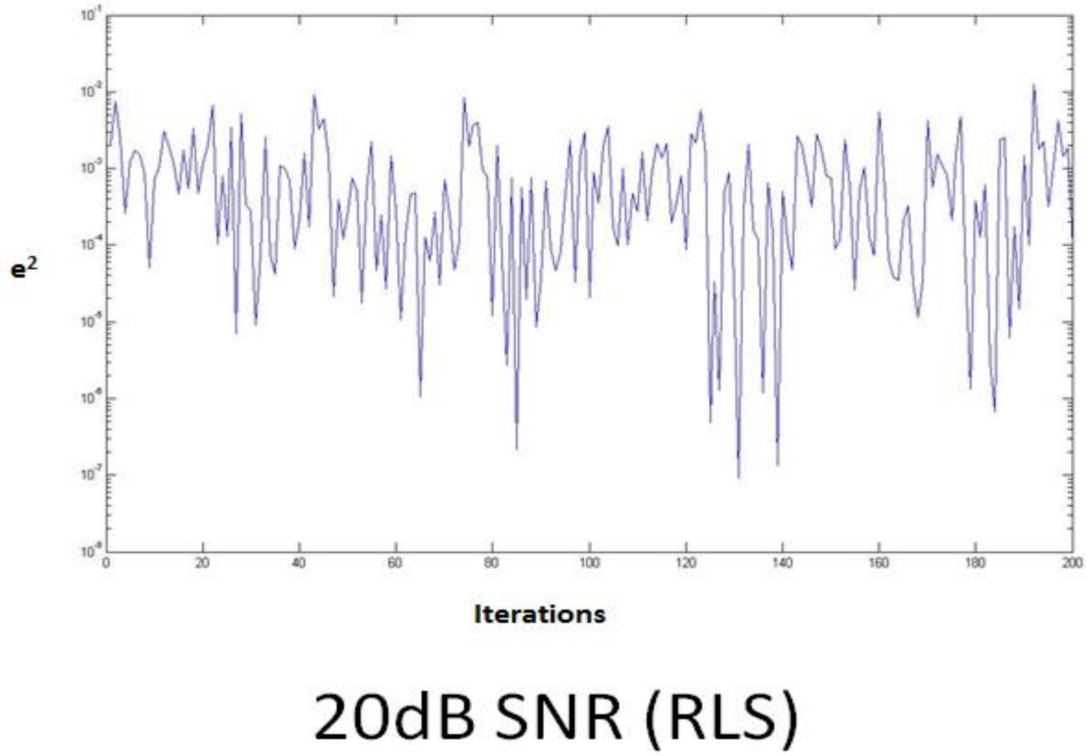

Figure-11. Channel estimation RLS 20dB SNR

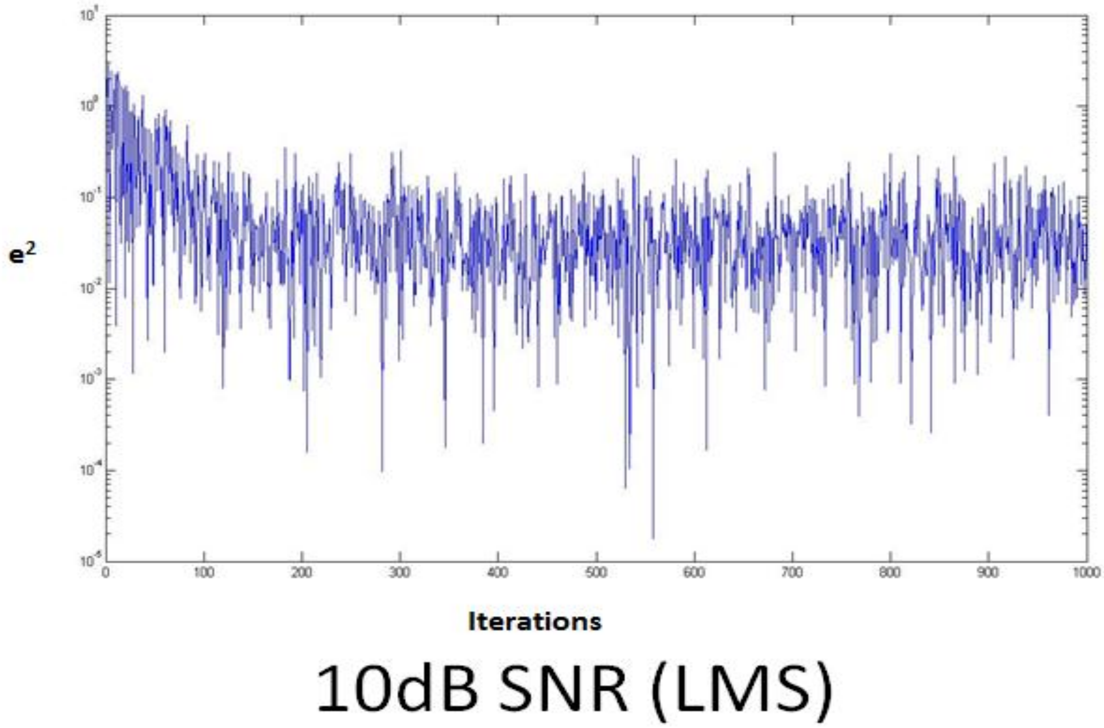

Figure-12. Channel estimation LMS 10dB SNR

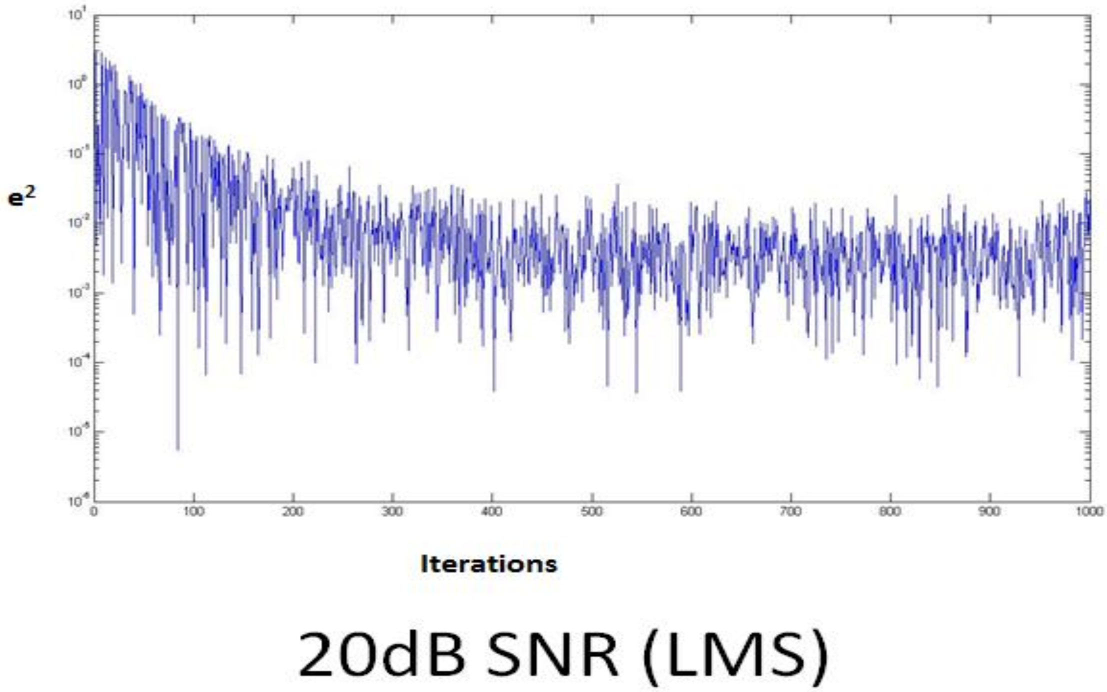

Figure-13. Channel estimation LMS 20dB SNR

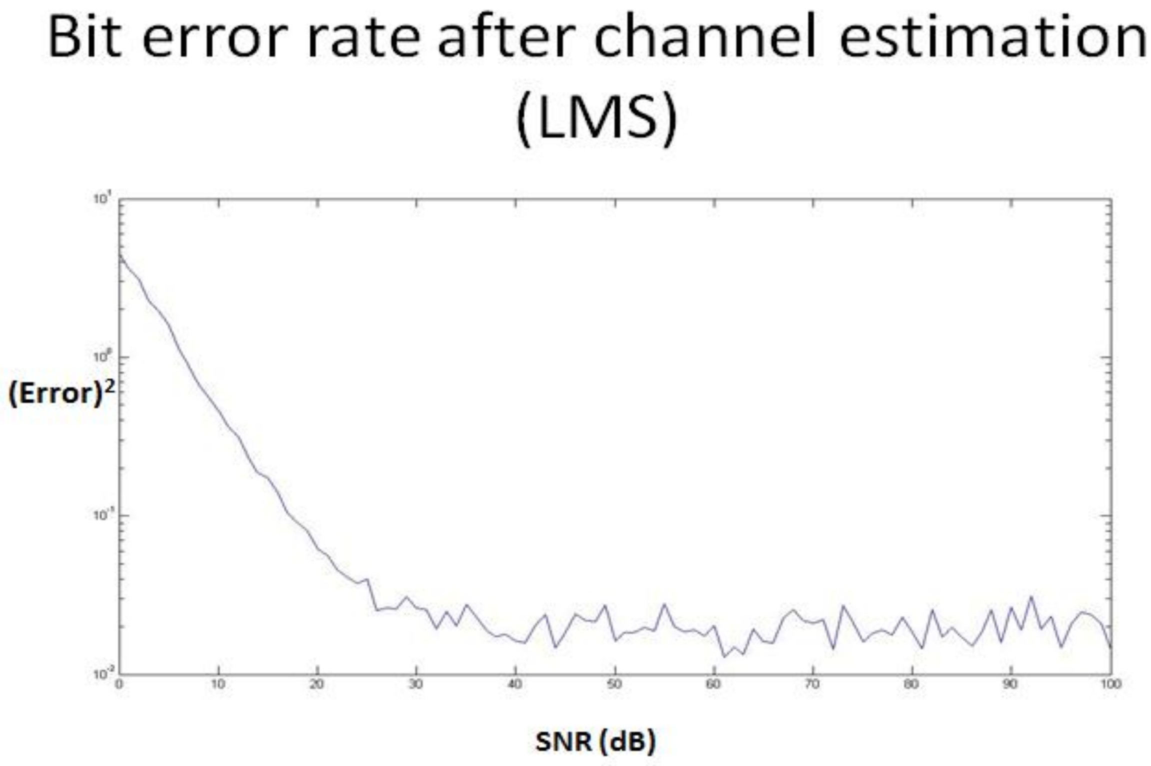

Figure-14. Squared error in bit LMS

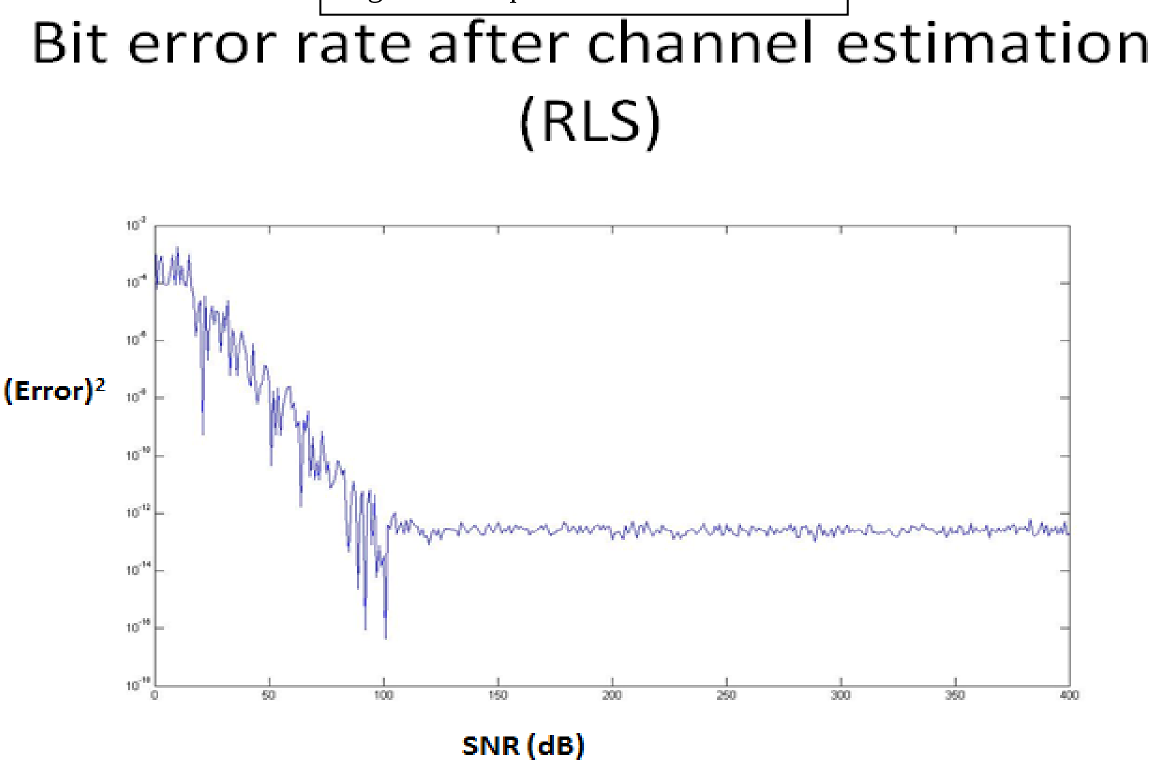

Figure-15. Squared error in bit RLS

FUTURE WORK

The MIMO is being implemented in advanced radar systems. It ensures us better performance. In military this has become a very popular and important field of research.

Radar is a device that gives information about the motion of objects (such as air crafts) in the air. The MIMO radar improves the parameter identifiability. It is the maximum number of targets that can be uniquely identified by th radar. The phased array send scaled version of same narrow width signals. Unlike the conventional phased array, MIMO radar sends independent signals of narrow width from different antennas. Hence the number of objects that can be detected is increased by th number of times transmit antennas are used. This is vast field of research and many researchers are working in this field.

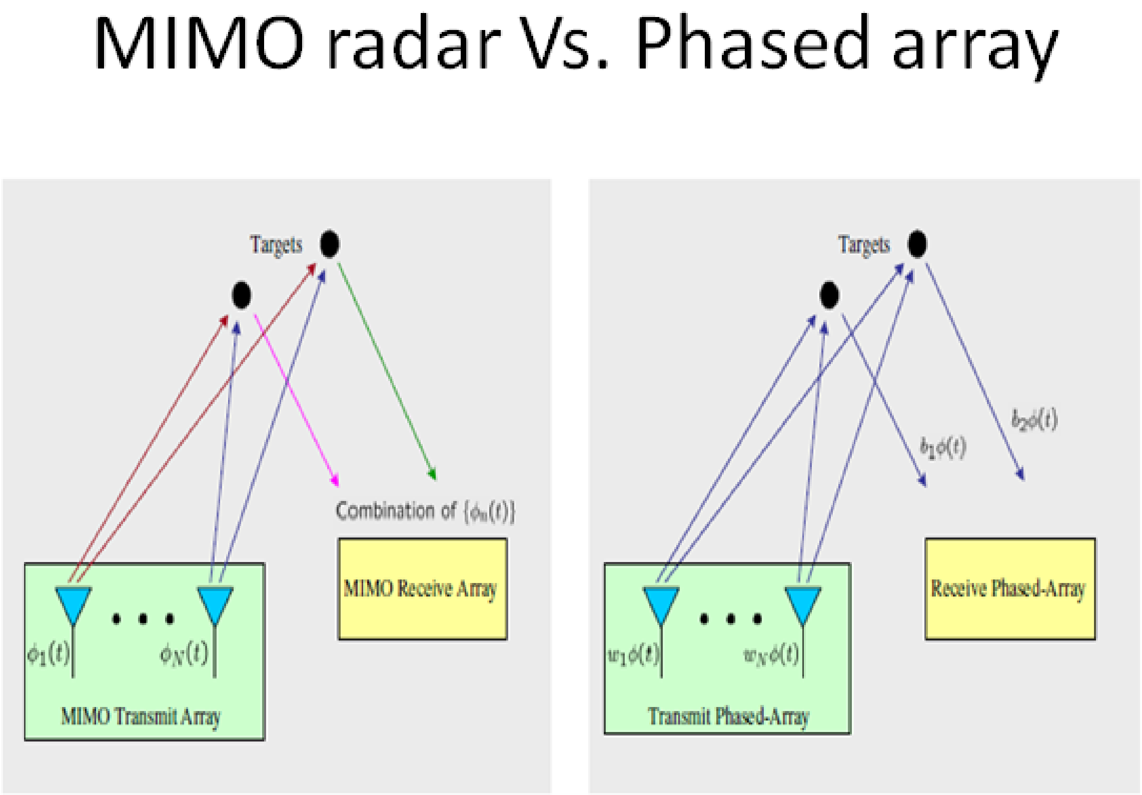

Figure-16. MIMO Radar Vs. Phased array

Conclusion

A brief study of MIMO is done. It is quite clear that MIMO meets the requirements of 4G. Hence it can be used. It provides enormous data rate while limiting the probability of error as verified both theoretically and by simulation. The MIMO can be accomplished with OFDM resulting in MIMO-OFDM which uses the spectrum efficiently. The Alamouti scheme provides us very less bit error rate as compared to SISO modulation schemes. The channel estimation problem is solved by using LMS and RLS algorithms. We see that the MIMO radar system is a breakthrough in military research and advancement. The MIMO technology will play an important role in coming generation wireless standards.

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