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Grayscale Image Transmission over Rayleigh Fading Channel in a MIMO System Using Different Digital Modulation Techniques with STBC

Animish S. Andraskar[1], Pratik M. Bhombe[2], Shantanu S. Bhusari [3], Prof. Shital N. Raut[4]

[1](Department of Electronics & Telecommunication Engineering, Vishwakarma Institute of Technology, Pune-411037)
[2] (Department of Electronics Engineering, Vishwakarma Institute of Technology, Pune-411037)
[3](Department of Electronics Engineering, Vishwakarma Institute of Technology, Pune-411037)
[4](Department of Electronics Engineering, Vishwakarma Institute of Technology, Pune-411037)

ABSTRACT
The consistent demand for higher data rates and ability to send large volumes of data without compromising the quality of communication has led the development of a new generations of wireless systems. But range and data rate limitations are there in wireless devices. In an effort to overcome these limitations, Multi Input Multi Output (MIMO) systems can be used which also increase diversity and improve the bit error rate (BER) performance of wireless systems. They also increase the channel capacity, increase the transmitted data rate through spatial multiplexing, and/or reduce interference from other users. MIMO systems thus make a promising communication systems because of their high transmission rates without additional bandwidth or transmit power and robustness against multipath fading. This paper focuses on transmission of an image file using 2x2 MIMO system that achieves a full diversity gain using Alamouti's Space Time Block Coding technique for 2 transmitting antennas and 2 receiving antennas. Different modulation techniques viz. BPSK, QPSK, 16-QAM and 64-QAM are used and performances has been evaluated in terms of BER vs. SNR to find out the best modulation technique in a given environment. Space-Time Codes have been used which in addition to the time and spectral domain, also exploit the spatial domain. Simple maximum likelihood decoding algorithm is used at the receiver side to decode the received encoded signal.

Keywords- BER, PSK, QAM, Rayleigh fading, Maximum Liklihood Detection, MIMO, SNR, STBC.

I. INTRODUCTION

Maxwell predicted the existence of EM waves in 1867 and Marconi transmitted radio signals across Atlantic ocean in 1901. Since then there has been rapid advancements in the field of wireless communication. The *first generation mobile communication* systems were analog. The 2nd generation (2G) used digital multiple access technology. The 2G system (called GSM), along with its add-ons (viz. HSCSD and GPRS) provided data rates of 22.8 Kbps to 172.2 Kbps.[2] EDGE system based on GSM, with two add-ons namely *enhanced circuit switched data* (ECSD) and the *enhanced general packet radio service* (EGPRS) became very popular. The maximum data rate of the EDGE system is 473.6 Kbps. The *third generation* (3G) provided data transfer rates more than 2 Mbps.[8] *Universal Mobile Telephone System* (UMTS) is a leading technology for 3G systems. WCDMA is the air-interface technology for UMTS. The next generation is Internet Protocol (IP) based and called as *fourth generation* (4G). LTE - advanced which is one of the system standards for 4G is expected to achieve data download rates of about 3 gigabits per second and upload rates as high as 1.5 Gbps.[12] . With evolution in mobile communication standards, the demand for higher data rates has increased .

In a single carrier transmission (SISO) to achieve higher data rates, larger bandwidth is required. But the available spectrums are limited and hence stringent constraints are imposed on its use. Thus it is necessary to pack more number of bits per Hz of bandwidth.

A MIMO (*multiple-input multiple-output)* system has multiple antennas at both transmitter and receiver sides. Each antenna element uses the same time and frequency resources enabling capacity to be increased without increase in bandwidth or increased transmit power. MIMO systems provide a promising solution for future wireless communications systems. In MIMO systems the transmitter and the receiver antennas communicate in such a way that the quality (the bit error rate (BER) or the data rate) for each user is improved.

The wireless communication systems also suffer from multipath fading which gives rise to higher noise and thus the high bit error rate. MIMO systems resort to spatial diversity to combat fading. For this purpose Space Time Block Coding (STBC) is employed which exploits spatial domain along with time domain. STBC creates redundancy and thus reduces outage probability of the transmitted signal. It is thus possible to achieve high reliability, high spectral efficiency and high performance gain. The goal of STBC is to find code matrices that satisfy certain optimality criteria.

This paper is organized as: Section II providing information on system model for MIMO; Section III describing the algorithm and simulation model used for image transmission; Section IV stating the results obtained from simulation; and Section V giving the conclusions drawn.

II. MIMO SYSTEM MODEL

The MIMO system consists of three main elements, namely the transmitter, the receiver and the channel. [2]

Let us consider a MIMO system having N_T transmitting antennas and N_R receiving antennas as shown in fig. 1.

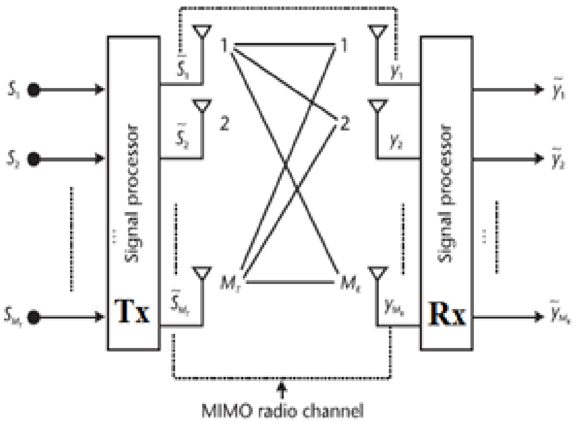

Fig. 1 MIMO system representation

The MIMO system can be characterized as:

$$\vec{y} = H.\vec{x} + \vec{n} \quad (1)$$

where y and x are received and transmitted vectors respectively and n is the noise vector. The received signal is a linear combination of each transmitted signal plus noise.

MIMO system is expressed in terms of its channel. For a system with N_T transmitting antennas and N_R receiving antennas, channel matrix is of size N_R x N_T. Each element in this matrix is called as the channel coefficient between one of the antennas from both transmitter and receiver side. Channel coefficient between antenna 1 to 1 is specified with h_{11}, from antenna 1 to 2 as h_{21}, etc. In this way we can obtain transmission matrix or channel matrix H .The channel matrix ***H*** is denoted as:

$$\boldsymbol{H} = \begin{pmatrix} h_{1,1} & h_{1,2} & \cdots & h_{1,N_t} \\ h_{2,1} & h_{2,2} & \cdots & h_{2,N_t} \\ \vdots & \vdots & \ddots & \vdots \\ h_{N_r,1} & h_{N_r,2} & \cdots & h_{N_r,N_t} \end{pmatrix} \quad (2)$$

Where each entry $h_{i,j}$ denotes the attenuation and phase shift (transfer function) between the j^{th} transmitter and the i^{th} receiver. [3]

Advantages of MIMO system:

- Increased system capacity
- Better coverage
- Higher data rates
- Robustness against multipath fading

III. SIMULATION MODEL

The simulation model consists of following blocks:

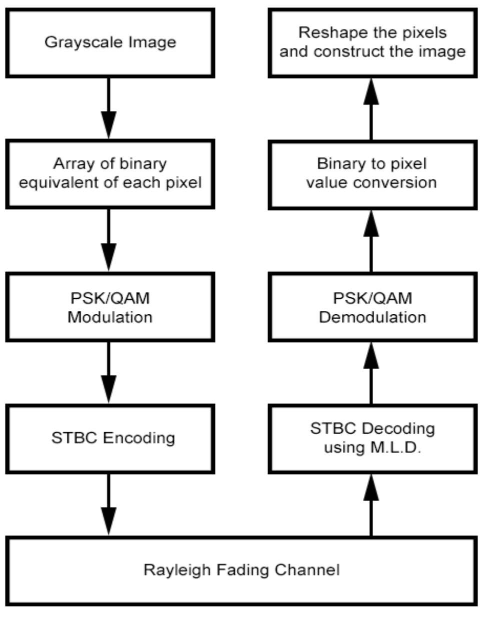

Fig. 2 Block diagram for grayscale image communication using STBC and MIMO.

3.1) INPUT DATA

An array of binary data is generated by converting intensity value of each pixel in the grayscale image to be transmitted into its equivalent binary values and is passed on to the next stage for symbol mapping.

3.2) DIGITAL MODULATION TECHNIQUES

In binary phase shift keying (*BPSK*), the phase of the carrier signal is varied according to the modulating signal. It uses two phases to represent the two binary digits '0' and '1'. BPSK is only able to modulate 1 bit/symbol and hence is unsuitable for high data-rate applications.

Quadrature phase shift keying (*QPSK*) uses phase shifts separated by multiples of $\pi/2$. More efficient use of bandwidth is achieved since each signaling element represents two bits rather than one. The input stream of binary digits is converted into two separate bit streams of half the data rate by taking alternate bits for the two streams. Each of them is then modulated as BPSK and two modulated signals are then added together and transmitted. [6][7].

In quadrature amplitude modulation (*QAM*), the data is transmitted by varying both amplitude and phase of the carrier signal. Generally two carrier waves are taken which are orthogonal (shifted by 90 degree) to each other. For QAM, each carrier is ASK modulated at different phases, further the data can be carried at different amplitudes.[5]

In *16-QAM*, four bits are grouped by taking two bits from each carrier to form a symbol. The number of possible symbols is 2^4=16 which are combination of real and imaginary values[11]. In *64-QAM*, each symbol is represented by 6 bits. In higher order QAM for the mean energy of the constellation to remain same, the constellation points must be closer together and are thus more susceptible to noise and other corruption. By moving to a higher-order constellation, it is possible to transmit more data but less reliability.

3.4) MIMO ENCODER

Alamouti's STBC for 2x2 MIMO system is used in the MIMO encoder. The encoder takes a block of two modulated symbols s_1 and s_2 in each encoding operation and gives it to the transmitting antennas according to the code matrix,

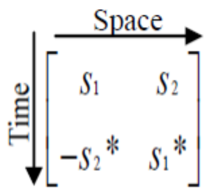

Fig. 3 Transmission matrix

This can be interpreted as follows:

During the first symbol period (t), the first antenna transmits s_1 and the second antenna transmits s_2. During the second symbol period (t+T), the first antenna transmits $-s_2{}^*$ and the second antenna transmits $s_1{}^*$ being the complex conjugate of s_1 [1] [4].

Thus we are transmitting both in space (across two antennas) and time (two transmission intervals). Hence is called space-time coding.

If s_1 and s_2 are the information sequence from the first antenna and the second antenna respectively.

Then

$s_1 = [\ s_1,\ \ -s_2{}^*]$ (3)

$s_2 = [\ s_2,\ \ s_1{}^*]$ (4)

Inner product of s_1 and s_2 is zero i.e., these sequences are orthogonal.[2]

3.5) CHANNEL

The signal which is being transmitted through a channel experiences a rapid fluctuation of the amplitude, phase or multipath delay of a radio signal, called as fading. Fading is caused by number of signals arriving at the reception point through different paths. We used Rayleigh fading which is a statistical model for the effect of propagation environment on radio signal to create such an environment . It is viewed as a reasonable model for tropospheric and ionospheric signal propagation as well as for the effect of urban environment on radio signal transmission. Rayleigh fading models assume that the magnitude of a signal that has passed through such a transmission medium (also called as communications channel) will vary randomly, or fade, according to a Rayleigh distribution — the radial component of the sum of two uncorrelated Gaussian random variables.[10]

Rayleigh fading channel model can be expressed as:

$$p(r) = \frac{r}{\sigma^2} \exp \frac{-r^2}{2\sigma^2} \quad \text{for } r \geq 0 \qquad (5)$$

In the above Rayleigh pdf, r is the envelope amplitude of the received signal, and $2\sigma^2$ is the pre-detection mean power of the multipath signal.

MIMO system is described in terms of the channel. For a 2x2 MIMO, the channel matrix will be of size 2x2 consisting of four entries [3].

Assuming that $h1(t)$ and $h2(t)$, which are the fading coefficients from antennas 1 and 2 respectively, at time *t*. are constant across two consecutive symbol transmission periods i.e. h1(t) = h1(t+T) then signals after passing through the channel can be expressed as, [2]

$r_1 = h_1 s_1 + h_2 s_2 + n_1$ (6)

$r_2 = -h_1 s_2{}^* + h_2 s_1{}^* + n_2$ (7)

r_1 and r_2 are the signals received at the receiver side.

3.6) MIMO DECODER

The decoder system consists of a channel estimator, a combiner and the maximum likelihood decoder.[1] We have assumed that the channel coefficients h_1 and h_2 can be recovered perfectly at the receiver and used as the CSI. The combiner combines the received signal as follows:

$$\tilde{s}_1 = h_1^* r_1 + h_2 r_2^* = (\alpha_1^2 + \alpha_2^2) s_1 + h_1^* n_1 + h_2 n_2^* \quad (8)$$

$$\tilde{s}_2 = h_2^* r_1^* - h_1 r_2^* = (\alpha_1^2 + \alpha_2^2) s_2 - h_1 n_2^* + h_2^* n_1 \quad (9)$$

and sends them to the maximum likelihood detector. [2]

Maximum Liklihood decoder is used to decode the received symbols. The job is to make 'best estimate' of transmitted signal $s_i(t)$ upon receiving r(t). Depending on the modulation and transmission strategy used, the receiver usually has the knowledge about the signal constellation that is in use . The fig. 4 shows a two-dimensional signal space showing a signal vector s_i and a received vector $\bar{r}$ and the noise vector ω.

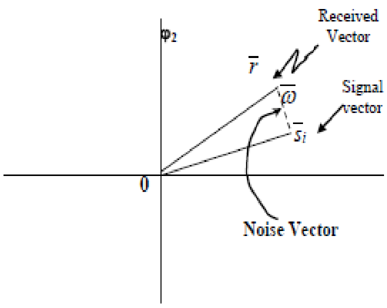

Fig. 4 Signal space showing signal vector s_i and r .

So, the decision rule simply is to choose the signal point s_i among all valid 's_i-s', if the received vector 'r' is closest to s_i in terms of Euclidean distance. The receiver then takes a decision that $r = s_i$. The MLD minimizes the following decision metrix over all possible values of s_1 and s_2.

$$|r_1 - h_1 s_1 - h_2 s_2|^2 + |r_2 + h_1 s_2^* - h_2 s_1^*|^2 \quad (10)$$

Equivalently, the decision rule for each combined signal $S_j\tilde{}$, $j = 1, 2$ becomes: [2]

Pick S_i iff

$$(\alpha_1^2 + \alpha_2^2 - 1)|s_i|^2 + d^2(\tilde{s}_j, s_i) \le (\alpha_1^2 + \alpha_2^2 - 1)|s_k|^2 + d^2(\tilde{s}_j, s_k) \quad (11)$$

$$\forall i \ne k$$

Thus the ML decoder decision statistic decodes in favor of s_1 and s_2 over all possible values of s_1 and s_2.

3.7) DIGITAL DEMODULATION

Demodulation is done with respective digital demodulation technique of the symbols s1 and s2 which are obtained from MLD. The original bits are obtained back in this way and the transmitted data file is recovered from this data

3.8) ALGORITHM FOR TRANSMISSION OF A GRAYSCALE IMAGE

1. Read the image file and find out the intensity levels for all the pixels.
2. Convert these intensity levels into their equivalent binary representations.
3. Modulate this binary data using PSK or QAM digital modulation technique.
4. This signal is then encoded using Alamouti's Space-Time Block Coding (STBC) scheme and transmission matrix is generated.
5. Multiply the STBC encoded data with the channel equation and send it to the receiver.
6. Decode the received data using maximum likelihood decoder and demodulate it.
7. Convert the demodulated binary representations into their equivalent intensity levels.
8. Rearrange the image pixels and save the new image file.

IV. RESULTS

Fig. 5 shows the original image to be transmitted using a 2x2 MIMO system using Alamouti's STBC. PSK and QAM modulation techniques have been used to modulate the data before encoding.

The performance of the system is analyzed using BER (Bit Error Rate) which represents errors in a given number of transmitted bits over a communication channel caused due to the noise, interference or distortion.[6] Bit error rate is plotted as a function of SNR. BER vs. SNR performance is plotted for received image file with each of the modulation techniques.

Fig. 5 Original Image

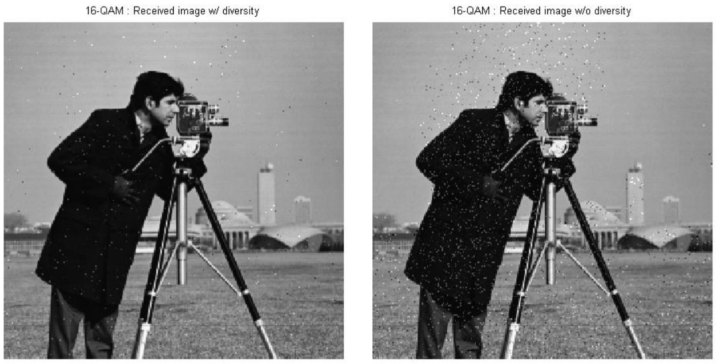

Fig. 6 Received image using BPSK at SNR=10 dB with and without diversity.

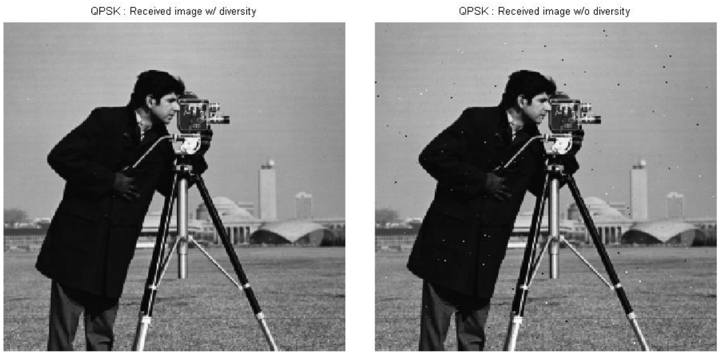

Fig. 7 Received image using QPSK at SNR=10 dB with and without diversity.

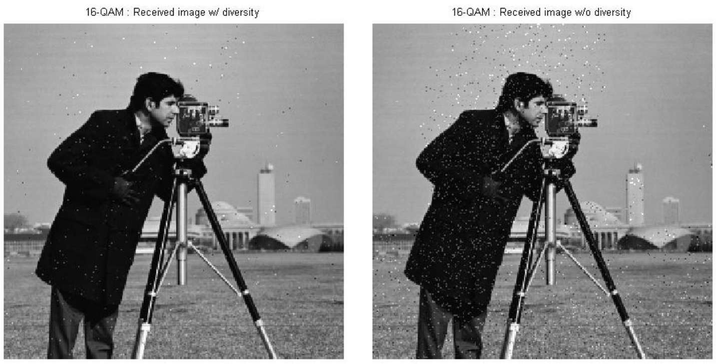

Fig. 8 Received image using 16-QAM at SNR= 10 dB with and without diversity.

Fig. 9 Received image using 64-QAM at SNR=10 dB with and without diversity.

Fig. 6 to Fig 9 represents the reconstructed images at the receiver when BPSK, QPSK, 16-QAM and 64- QAM digital modulation techniques were used respectively. Each fig. shows the received image with and without diversity scheme for a particular value of SNR.

The plot in Fig.10 shows BER vs. SNR performance of the image received with diversity and without diversity for each of the four modulation techniques used.

Out of the four modulation techniques (BPSK, QPSK, 16 QAM, 64 QAM), best results (reconstructed images) were obtained for BPSK in terms of lowest BER for given value of SNR.

V. CONCLUSION

The paper demonstrates the transmission of grayscale image using STBC and MIMO. A 2x2 MIMO System has been simulated and compared for BPSK, QPSK, 16-QAM and 64-QAM digital modulation techniques employed along with STBC over Rayleigh fading environment. The effect of noise on the received images in each case is observed in terms of visual quality of the received image as well as Bit Error rate (BER) vs. SNR plot.

It is observed that the effect of noise is significantly reduced when diversity scheme is employed as compared to images received without using diversity in each case. This result is verified for SNR= 10 dB for each of the four mentioned modulation techniques.

From obtained results, it is clear that at a particular value of SNR, Bit Error Rate (BER) is lowest for BPSK and highest for 64-QAM. Similar results are obtained in both cases i.e. for image received with diversity and without. Thus for every value of SNR, BER are in following decreasing order with respect to modulation techniques:

64- QAM > 16-QAM > QPSK > BPSK

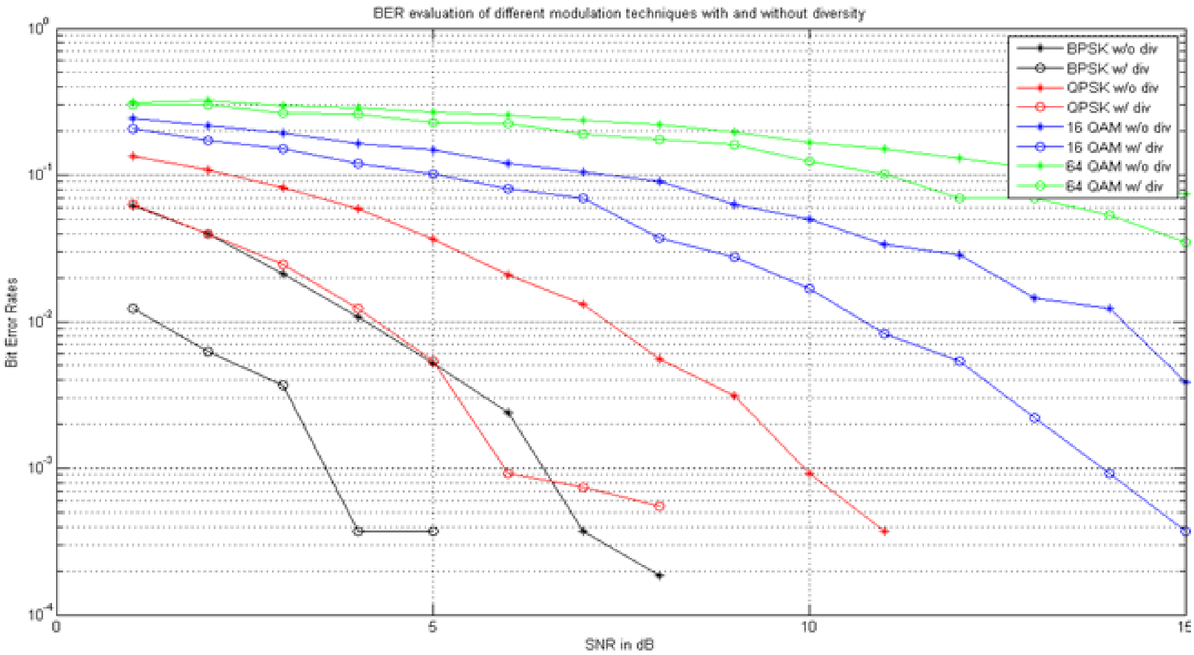

Fig. 9 BER vs. SNR plot for all four modulation techniques with and without diversity

Also it can be concluded that to achieve a certain BER, signal power requirement is minimum for BPSK and maximum for 64-QAM. Thus for systems in which power constraints is a major issue, BPSK modulation produces least noise at low signal strength, giving better quality of signal transmission. But the higher order modulation techniques like QAM packs more number of bits per symbol and thus increases the data rate but reduces the reliability of the received file. Thus a suitable modulation technique has to be selected in order to achieve a tradeoff between speed, quality of reception and power requirements.

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