MIMO based Efficient JPEG Image Transmission and Reception by Multistage Receivers

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ABSTRACT
This paper deals with the efficient transmission of JPEG compressed images over Multiple Input Multiple Output (MIMO) systems using spatial multiplexing. By exploiting the spatial multiplexing using multiple antennas; data-rate, reliability, and throughput can be improved. The JPEG compressed image is divided into different quality layer and the antenna path with highest Signal to Interference Noise Ratio (SINR) is selected to transmit the different layers of image. Depending upon the SINR of various paths, the best antenna is selected to transmit the most important feature using a simple unequal power allocation scheme. The performance is evaluated by multistage receivers like VBLAST/ZF and LLSE. The proposed scheme provides significant image quality improvement and less distortion compared to known schemes.

Keywords
MIMO, JPEG compression, sub-optimum receivers

1. INTRODUCTION
Of all communication services available today, wireless services are having a dramatic impact on our personal and professional lives. In wireless communication, single input single output system (SISO) came into action in the year 1948. Single input single output systems refer to a simple control system with only one input and one output, employing single antenna at both the transmitter and receiver ends. In the last few years, wireless services have become more and more important. The growing demand of multimedia services and the growth of Internet related contents lead to increasing interest to high speed communications, network capacity and performance. The available radio spectrum is limited and the communication capacity needs cannot be met without a significant increase in spectral efficiency. Several options like higher bandwidth, optimized modulation or even code-multiplex systems offer practically limited potential to increase the spectral efficiency. Significant further advances in spectral efficiency are available through increasing the number of antennas either at the transmitter or at the receiver and at the both ends. The systems employed were single input multiple output systems(SIMO) and multiple input single output systems(MISO) which consists of single transmitter antenna and multiple receiver antennae multiple transmitter antennae and single receiving antennae respectively. MIMO (Multiple Input Multiple Output) Systems consists multiple antennas both at the transmitter and the receiver ends. In real-time wireless environment, the signal propagates from the transmitter to the receiver through multipaths providing a form of MIMO system. JPEG Standard [1] proposed in 1992 is widely used for still image compression and standard. W.B. Pennebaker and J.L Mitchell introduced the JPEG still image standard [2]. In literature, joint source channel coding has been discussed in [3-5]. Linear receivers have been discussed in [6-8] and Alamouti introduced the concept of MIMO system [9]. Sabir et. al has done extensive research on unequal power allocation scheme for JPEG transmission[10-11]. In this paper, we provide an efficient scheme for transmission of Joint Photograph Experts Group (JPEG) compressed images over MIMO system by employing spatial multiplexing. The image under test is compressed using JPEG compression algorithm and all the pixels are transmitted with an optimal unequal power allocation algorithm. V-BLAST/ ZF receiver is selected for symbol detection and the image is reconstructed by decompression algorithm at the receiver. The paper is organized as follows: Section II introduces the system model and antenna selection and power allocation are discussed in Section III and IV. Section V describes the symbol detection scheme for estimating the MIMO channel input and section VI provides the simulation details. In section VII, we discuss our results and future enhancements.

2. SYSTEM MODEL
A block diagram of the proposed scheme is provided in Figure 1.The features of the image are extracted using DCT based quality layer method and are transmitted through a fading channel.

2.1. Transmitter

The block diagram of the image encoder is given in figure 2.

2.1.1 RGB space to YCbCr Space

For visually acceptable results, it is necessary to provide three samples (*color channels*) for each pixel, which are interpreted as coordinates in some color space. The RGB color space is commonly used in computer displays. The RGB color model is an additive color model in which red, green, and blue light are added together in various ways to reproduce a broad array of colors. Conversion of image from RGB space to YC_bC_r should be done. To convert RGB space to YC_bC_r space, the following equations are used.

$$Y = 0.299\,R + 0.587\,G + 0.114\,B \quad (1a)$$

$$Cb = -0.1687\,R - 0.3313\,G + 0.5\,B + 128 \quad (1b)$$

$$C_r = 0.5\,R - 0.4187\,G - 0.0813\,B + 128 \quad (1c)$$

Y is the luma component and C_b and C_r are the blue and red chroma components.

2.1.2 Source Coder

A progressive Discrete Cosine Transform (DCT) based JPEG coder with spectral selection mode is used. DCT-II is performed over small 8x8 blocks according to the equation (2).

$$F(x,y)=\frac{1}{4}\sum_{u=0}^{7}\sum_{v=0}^{7}F(u,v)\cos\frac{[2u+1]x\pi}{16}\cos\frac{[2v+1]y\pi}{16} \quad (2)$$

The DCT coefficients are organized into 64 quality layers: 1 dc layer followed by 63 ac layers. The resolution and quality of the reconstructed image improve when more layers are decoded.

2.1.3 Headers and markers

Within each layer, headers and reset markers are introduced to prevent error propagation between different parts of the bit stream. Bit errors occurring during transmission can affect the headers, the markers, the dc layer and ac layers. If there is an error in the header, the entire image will be damaged and cannot be recovered. In case of error in reset markers, synchronization will be lost. So it is assumed that headers and reset markers are transmitted error free.

2.1.4 Huffman Coding

Huffman coding is a statistical technique that attempts to reduce the amount of bits by encoding most frequently occurring symbols with shorter codes and longer codes for less significant symbols.

2.1.5 Quantization

The DCT coefficients are quantized and divided into sub bands that are encoded in separate passes. Quantization is a lossy compression technique achieved by compressing a range of values to a single quantum value. When the number of discrete symbols in a given stream is reduced, the stream becomes more compressible. A quantization matrix is used in combination with a DCT coefficient matrix. Quantization matrices are specifically designed to keep certain frequencies in the source to avoid losing image quality.

2.1.6 Zig-Zag scanning

The quantized matrix is then zigzag scanned. The purpose of the zigzag scan is to group low frequency coefficients in top of vectors. It maps 8x8 to a 1x 64 vector. The zigzag scanning pattern for run-length coding of the quantized DCT coefficients was established in the original JPEG standard. The same pattern is used for luminance and for chrominance. The scanning direction is given in figure 3**.**

2.1.7 Spatial Multiplexing (SM)

SM is a transmission technique to transmit independent and separately encoded data signals from each of the transmit antennas. If the transmitter is equipped with N_t antennas and receiver has N_r antennas, the maximum spatial multiplexing order is

$$Ns = \min\ (Nt, Nr) \quad (3)$$

This means that N_s streams can be transmitted in parallel, leading to a 'Ns' increase of the spectral efficiency.

2.1.8 Channel (H)

The Rayleigh flat fading channel (H) is commonly used to describe multipath fading channels when there is no Line-Of-Sight (LOS) component, the number of independent copies (multipath) of the signal arriving at the receiver is large, and the coherence bandwidth of the channel is greater than the bandwidth of the signal itself. It can be shown by central limit theorem that such a channel, where each arriving signal is of approximately equal energy, can be modeled as a zero mean circularly symmetric complex Gaussian random variable. The envelope of this fading channel can then be modeled using a Rayleigh distribution. For the purpose of simulation, a single channel is generated as follows:

$$h = \mu + \sigma \times (\mathrm{N}(0,1) + \mathrm{i} \times \mathrm{N}(0,1)) \quad (4)$$

where, μ is the mean of the random variable (assumed to be zero), σ is the standard deviation of the random variable (assumed as one or 0.5) and N(0,1) denotes a Normal (Gaussian) distributed random variable with zero-mean and unit-variance. The channel is assumed to be slow-fading, with variations occurring at intervals equal to the symbol duration.

3. ANTENNA SELECTION

The number of transmitters and receivers considered here is 4. We initially transmit the same set of data through all the four antennas and determine the mean squared error (MSE) of the received data for various paths. Mathematically SINR can be found using the relation (2), assuming the channel is well known to the transmitter and receiver. The SINR of the k^{th} stream of the n^{th} path is given by

$$\mathcal{E}k = \frac{1}{[(Xn\ H^*\ H+Ik)^{-1}]} - 1 \quad (5)$$

H is the random channel, I_k is the k^{th} order identity matrix and X_n is the power matrix. The SINR of various paths are calculated and the transmit antenna with the highest SINR is selected as the best antenna.

4. POWER ALLOCATION SCHEMES

To maximize the total capacity, the transmission power needs to be distributed dynamically under the total power constraint. The image is divided into smaller blocks corresponding to the number of antenna used in the system and the total constant power is P_{tot}.

4.1. Equal power allocation with no spatial multiplexing

No spatial multiplexing is performed. The data streams are transmitted with equal power.

4.2. Equal power allocation with spatial multiplexing

The algorithm simplifies the optimization problem into by assigning equal power to all antennas that has N optimization parameters, i.e.

$$P_k = \frac{P_{tot}}{N_t} \qquad k=1:4 \qquad (6)$$

where 'N_t' corresponds to the total number of transmit antennas.

4.3. Unequal power allocation

It is known that for images and videos coded using most of the current standards, different parts of the bit stream have different importance. Therefore, distortion in the received images and videos can be reduced if more important parts of these sources are transmitted with higher reliability at the expense of lesser reliability for less important parts.

The suggested method (Figure 4) is to transmit different parts of the image or video using unequal power. In the UPA scheme for transmission of JPEG compressed images over MIMO systems, the image is divided in different quality streams, and these different streams are transmitted on separate antennas simultaneously with unequal power. Transmit power is allocated between different layers with the goal of minimizing the overall distortion in the received image. The total transmit power from all the transmit antennas during any symbol period is kept constant.

The algorithm simplifies the optimization problem by allocating optimum power to all antennas. Channel matrix H is perfectly known to the transmitter and receiver.

UPA algorithm:

Step 1: Initialize Po=H

Step 2: Multiply H with an identity matrix which is of same size as H.

P= eye (Nt,Nr) . H*

Step 3: Perform summation over the diagonal elements.

Psum= sum (P)

Step 4: Take the absolute value of 1/ Psum.

Pabs = abs (1/ Psum)

Step 5: Calculate the ratio of power as

Pratio = Pabs / Psum

Step 6: The power for individual antennas are

Pn= P_{TOT} ** Pratio*

The SINR of various paths are calculated according to eqn. (2) and the transmit antenna corresponding to the highest SINR is selected to transmit the most important feature of the image like edges. Then the transmit antenna with the next highest SINR is selected to transmit the other important feature and so on.

5. SYMBOL DETECTION

The block diagram for image reconstruction is given in figure 5. The received data 'y' is given by given

$$Y = a \times H + noise \qquad (7)$$

where 'a' is the transmitted vector and H is the random channel. The noise added is AWGN with zero mean and power spectral density N0/2. Symbol detection is the process of estimating the channel input 'a' from the received vector 'y'. The channel considered is an AWGN channel and is assumed to be constant for the entire duration of a frame. Linear receivers are the class of receivers for which the symbol estimate a ^ is given by a transformation of the received vector 'r' of the form

$$a^{\wedge} = Q\,(Wr) \qquad (8)$$

where W is a matrix that may depend on H and *Q* is a quantizer that maps its argument to the nearest signal point.

5.1. Zero-Forcing receiver

Zero-Forcing (ZF) receiver is a low-complexity linear detection algorithm that outputs

$$a^{\wedge} = Q\,(a^{\wedge}{}_{ZF}) \qquad (9)$$

where $a^{\wedge}{}_{ZF} = H^{+}$ r

and H^+ denotes the Moore-Penrose pseudo inverse of H, which is a generalized inverse that exists even when H is rank-deficient. The ZF receiver eliminates co-channel interference entirely since $H^+H = I$. On the other hand, ZF receivers are known to have the drawback of enhancing noise power.

5.2. Linear Least Square Estimation Receiver

The Linear Least Square Estimation Receiver (LLSE) receiver is a receiver that outputs the estimate

$$a^{\wedge} = Q\,(a^{\wedge}{}_{LLSE}) \qquad (10)$$

where $a^{\wedge}{}_{LLSE} = W\,r$

W is chosen to minimize $\mathcal{E}\{\,||W\,r - a||\}^2$

The LLSE matrix **W,** for Gaussian H is given by

$$W = \frac{\rho}{M} H^{+}(\frac{\rho}{M} HH^{+} + No\, I_N)^{-1} \quad (11)$$

The LLSE estimator does not eliminate the co-channel interference entirely since **WH** does not equal the identity matrix, unlike the case for the ZF estimator. On the other hand, the LLSE estimator has the desirable property of not enhancing noise as much as the ZF estimator.

5.3. Zero-Forcing V-BLAST Receiver

The detection algorithm is a recursive procedure and suppresses the interference component. The algorithm is stated below

Intialize:

i=1

Gi=H+

k1= argmin $|| (G_{i)\,j} ||^{2}$

Recursion:

w k1= (Gi)ki

yki= wki T yi

a^ ki= Q(yki)

y i+1 = yi - a^ ki (H) ki

Gi+1= H+ ki

ki+1= argmin $|| (G_{i+1)\,j} ||^{2}$

i=i+1

Where H^{+} denotes the Moore-Penrose pseudo inverse of H, (W*i*)*j* is the j^{th} row of *Wi*, *Q*(.) is a quantizer to the nearest constellation point, $(H)_{ki}$ denotes he k^{th} column of H, $H\text{-}_{ki}$ denotes the matrix obtained by zeroing the columns *k*1*; k*2*;..; ki* of H, and $H_{\pm ki}$ denotes the pseudo-inverse of H_{ki}

In the above equations, k_i determines the order of the channels to be detected; yk_i performs *nulling* and computes the decision statistic; $\hat{a}_{k_i}$ slices computed decision statistic and yields the decision; r_{i+1} performs *cancellation* by decision feedback, and W_{i+1} computes the new pseudo-inverse for the next iteration. V-BLAST/ZF may be seen as a successive-cancellation scheme derived from the ZF scheme discussed in 5.1.

5.4. LLSE V-BLAST Receiver

The LLSE receiver suppresses both the interference and noise components. The algorithm is as follows

Intialize

i =1

r1=r

G1= (HiH^{H}*i+σ* ^{2} *I Nt)*$^{-1}$ *H*^{H}

ki= argmin $|| (G_{i)\,j} ||^{2}$

Recursion:

wki= (Gi)ki

yki= wT ki ri

a^ ki= Q(yki)

y i+1 = yi - a^ ki (H) ki

Gi+1= (HiHHi+σ 2 IMt)-1 HiH

ki+1= argmin $|| (G_{i+1)\,j} ||^{2}$

i= i+1

A slight improvement is achieved here when compared to the performance of V-BLAST/ZF algorithm.

6. IMAGE RECONSTRUCTION

The received image data will be noisy. Mostly in all transmission schemes error detection algorithms will be used to obtain the actual transmitted values by eliminating the errors. In this project it is assumed that the headers and markers are received without any errors. So error detection algorithms are not used. In image transmission, with the less corrupted image data actual image can be reconstructed easily. The errors in the image are discernable to human eyes.

6.1. Huffman Decoding

Like encoding a file, decoding a file is a two step process. First the header data is read in, and the Huffman code for each symbol is reconstructed. If the Huffman code is known for some encoded data, decoding may be accomplished by reading the encoded data one bit at a time. Once the bits read match a code for symbol, write out the symbol and start collecting bits again. Huffman encoding leads to the construction of an array of symbols sorted by the size of their code. Consequently, the array method for decoding files encoded with a Huffman code is used. The encoded file is read one bit at time, with each bit accumulating in a string of undecoded bits. Then all the codes of a length matching the string length are compared to the string. If a match is found, the string is decoded as the matching symbol and the bit string is cleared, else error will be displayed. The process repeats itself until all symbols have been decoded.

6.2. Reverse Zig-Zag scanning

In the transmitter side, the smaller image blocks are zigzag scanned. It is done to reduce the redundant data. So while reconstructing the image it is necessary to do reverse zigzag scanning. The data in a single row vector is transformed into blocks of size 8 X 8. The process is done as shown in figure 6. Then the received data is multiplied with the appropriate quantization matrices.

6.3. Inverse DCT

The Inverse Discrete Cosine Transform (IDCT) is performed with equation (12).

$$F(x,y) = \frac{1}{4} \sum_{u=0}^{7}\sum_{v=0}^{7} F(u,v)\, cos\, \frac{(2u+1)x\pi}{16} \cos\frac{(2v+1)y\pi}{16} \quad (12)$$

After taking IDCT, the smaller blocks of image are reconstructed into a single matrix. In case of color image, the matrix is 3-D and for gray scale image it is 2-D.

6.3. YCbCr Space to RGB space

The color image is converted to RGB color space. The chrominance layers are up sampled before converting them into RGB colors. To convert from YC_bC_r space to RGB space, the following equations were used.

$$R = Y + 1.402\,(C_r - 128) \quad (13a)$$

$$G = Y - 0.34414\,(C_b - 128) - 0.71414\,(C_r - 128) \quad (13b)$$

$$B = Y + 1.772\,(C_b - 128) \quad (13c)$$

In case of gray scale image, this conversion is not required. The resulted image is the compressed form of the transmitted image.

7. SIMULATION DETAILS

A database of 25 grayscale and color images of random size is used for simulation. First we check whether the image is a grayscale or color image. The color image is converted from RGB space to YC_bC_r and DCT is performed over small 8x8 blocks of the image. We assume the number of transmitters and receivers to be variable, 'M_t' and 'M_r'. The channel model is considered to be an AWGN channel (H), which is perfectly known to the transmitter and the receiver. QAM modulation is employed and the channel is assumed to be constant for the entire duration of a frame. Initially the same set of data is transmitted through all transmit antennas and mean squared error (MSE) of the received data for various paths are determined. The SINR of various paths are calculated and the best transmit antenna is selected and allocated maximum power. The multi-user detection schemes like ZF and MMSE are used to estimate the transmitted vector and the estimation is on a symbol-by-symbol basis.

8. RESULTS AND DISCUSSIONS

The digital transmission of image over a noisy channel can be improved by selecting the best antenna. The transmit antenna corresponding to the highest SINR path is selected as the best antenna. The performance of this scheme is validated by computing its symbol error rate (SER) and bit error rate (BER). For an Eb/No of 10 dB, the SER is reduced by 25% if antenna selection is performed and 70% for unequal power allocation. From the results, we can infer that Unequal Power Allocation scheme performs better for the transmission of both color and grayscale images.

Performance comparison of multistage receivers is given in Fig 7 and VBLAST ZF algorithm is selected to be optimum. Original Lena image (Fig.8(a)) and reconstructed images **(**Fig. 8 (b)-(d)) are given**.** Symbol Error Rate (SER) and BER are plotted in Fig.9 and 10. The above results prove that transmission of important feature of the image through the best antenna with unequal power outperforms the known scheme. Table 1 gives the comparison of different power allocation schemes and % of pixel errors.

9. CONCLUSION

The key advantages of MIMO are exploited to obtain a reliable distortionless image transmission. Instead of transmitting all pixels in an image with equal power through the transmit antennas; the path with highest SINR is selected to transmit the most important feature of the image and the next best antenna to transmit the other important feature with a simple power allocation schemes. Results show that the proposed scheme provides significant image quality improvement and less distortion compared with equal power allocation with no antenna selection.

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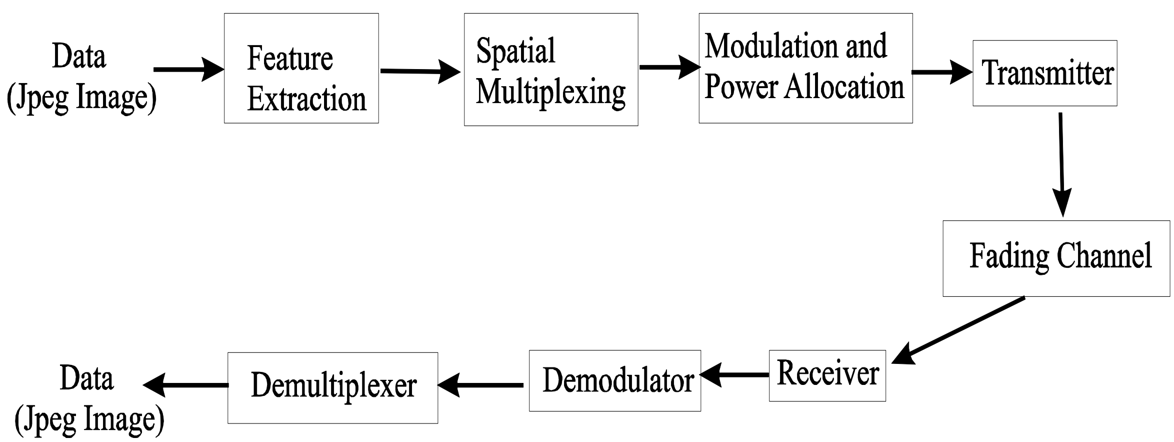

Figure 1. System Model

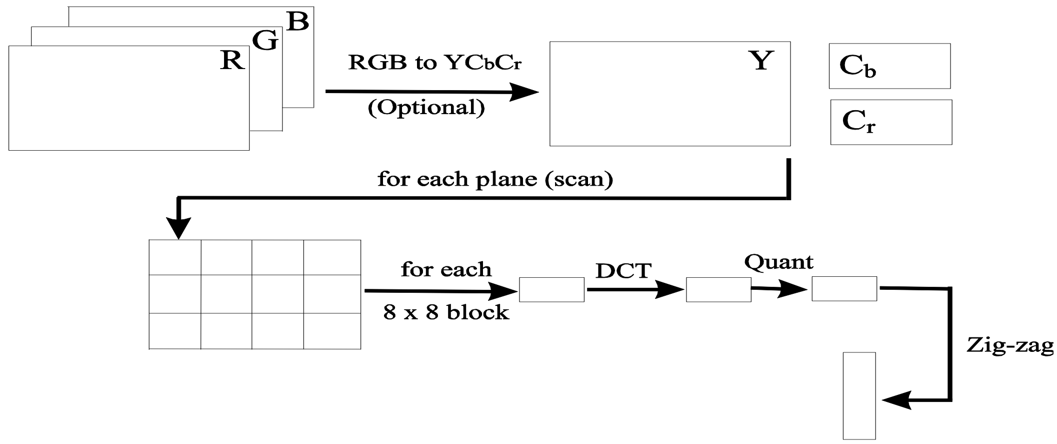

Figure 2: Block Diagram of image Encoder

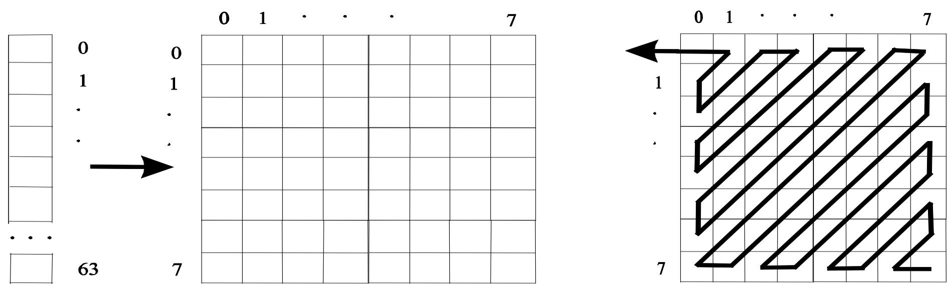

Figure 3. Zigzag scanning

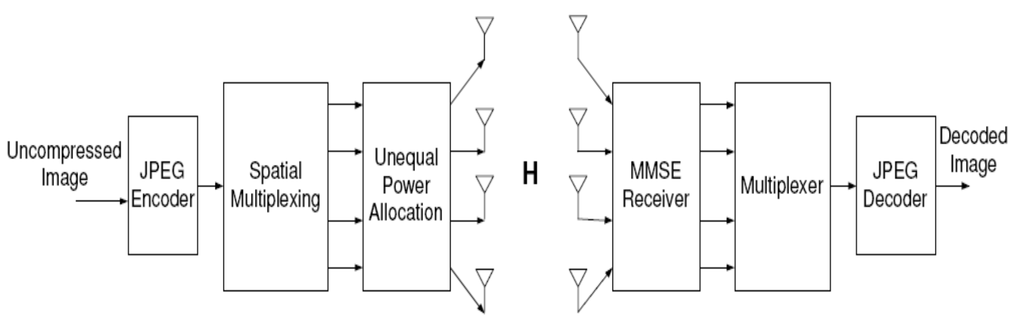

Figure 4. System model for UPA based MIMO system for JPEG image transmission

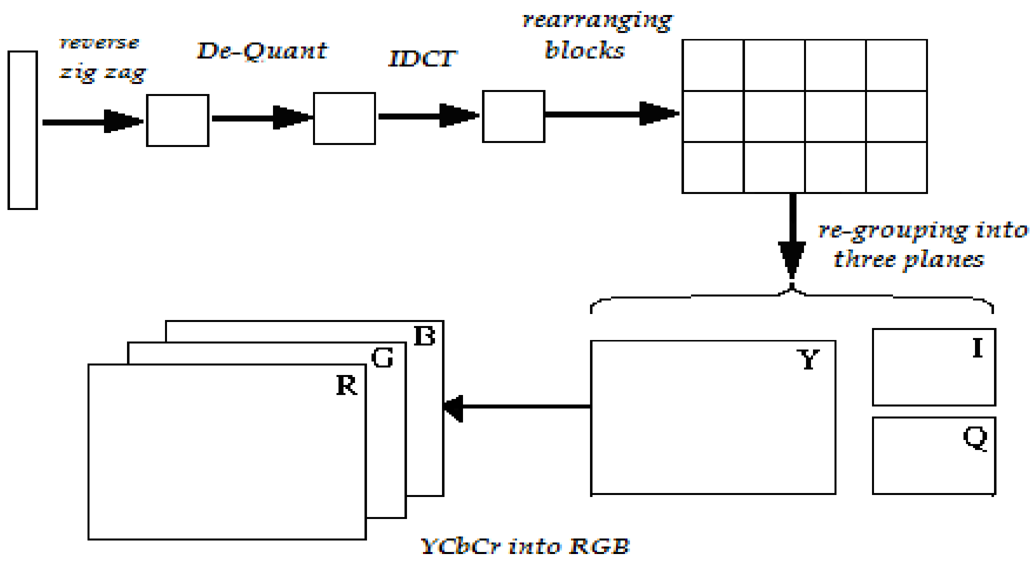

Figure 5. Block Diagram of Image Reconstruction

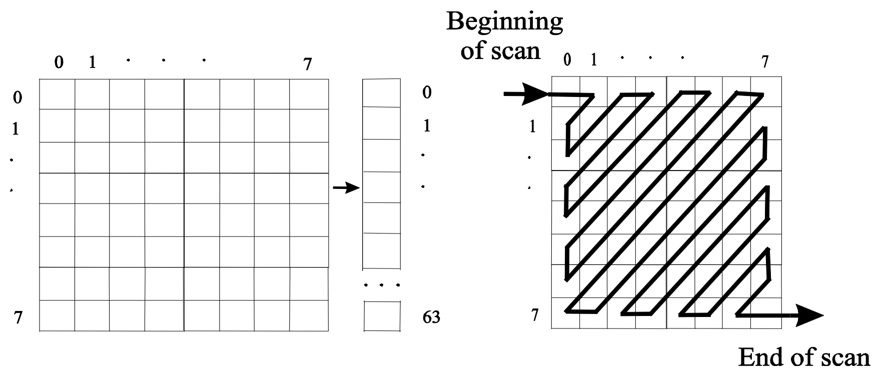

Figure 6. Reverse zigzag scanning

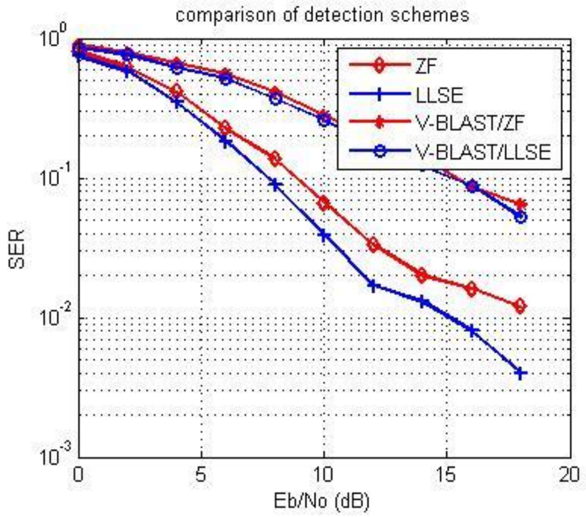

Figure.7 Performance Comparison of sub-optimum receivers

Table 1. Comparison of different power allocation schemes

FEATURE EXTRACTION METHOD	POWER ALLOCATION SCHEME	% OF ERRORS (PIXELS)
DCT based Quality Layers	EPA without Antenna selection	31%
	EPA with antenna selection	28%
	UPA - proposed scheme	25%

Figure 8. Reconstructed image Quality layer method (a) Original Lena, (b) without spatial Multiplexing, (c) with spatial Multiplexing, (d) with UPA

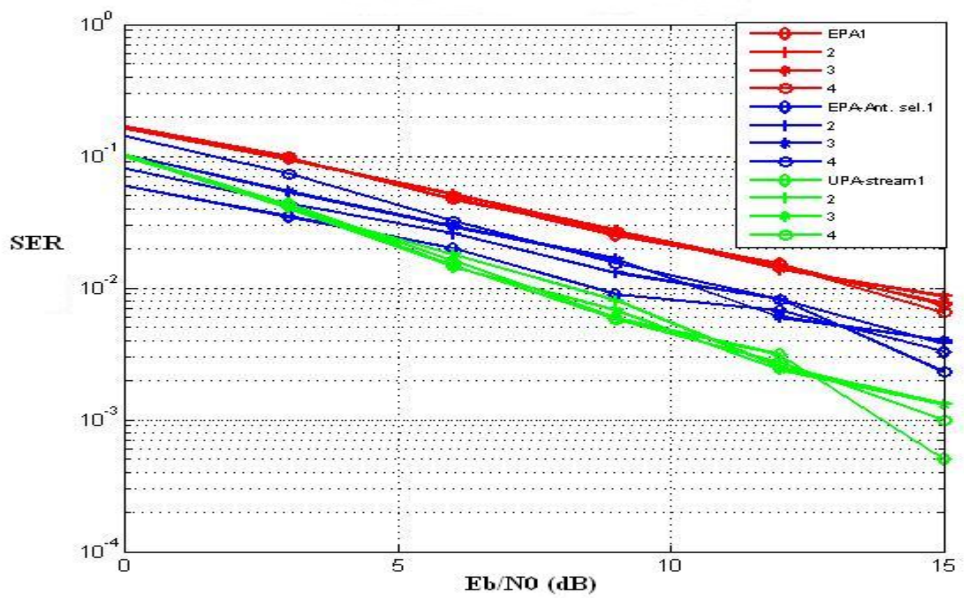

Figure.9 Symbol Error Rate Vs Eb /N0

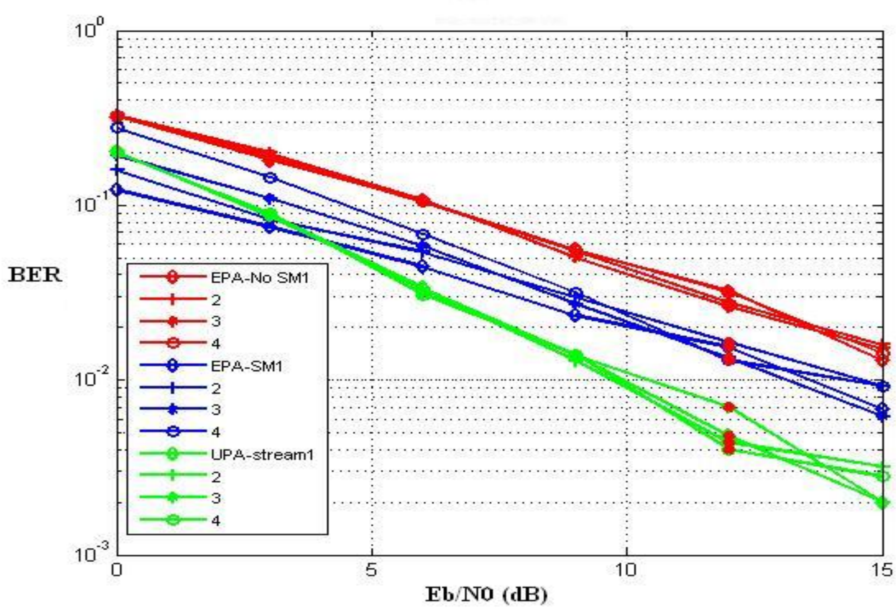

Figure.10 Bit Error Rate Vs Eb /N0