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CAPACITY ANALYSIS OF MIMO (8X8) SYSTEM WITH OR WITHOUT CSI UNDER DIFFERENT WIRELESS FADING CHANNELS

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Abstract. The growing demand of Multimedia based services and growth of data requirement of wireless application lead to increasing interest to high speed communication. MIMO (Multiple input and multi output system) are today considered as one of most important research area of wireless communication. Because multimedia application requires higher data rate which can be possible by MIMO (8x8) system. In this paper the capacity of (8x8) has been measured in the term of Channel capacity. This paper calculate the channel capacity with CSI or without CSI at transmitter. Paper calculate the ergodic capacity, outage capacity and channel capacity in presence of correlation. There is also work regarding to analysis of BER for (8x8)MIMO system.

Keywords. MIMO, CSI, MISO , SIMO, ZF (zero forcing), MMSE (minimum mean square error),ML (maximum like hood detector).

1 Introduction

MIMO system use array of multiple antenna at both transmitter and receiver end. In the case of MIMO(8x8) [1]system capacity increases. And BER reduces. Because Capacity increases linearly with min (N_t, N_r) for a given fixed transmitted power and bandwidth. In other words, the capacity of the wireless channel can be increased by simply increasing the number of transmitter and receiver antennas. MIMO technology has attracted attention in wireless communications, because it offers significant increases in data throughput and link range without additional bandwidth or Increased transmit power. It achieves this goal by spreading the same total transmit power over the antennas to achieve an array gain that improves the spectral efficiency (more bits per second per hertz of bandwidth) . In spatial multiplexing, a high rate signal is break into multiple lower rate streams and each stream is transmitted from a different transmit antenna in the same frequency channel. In beamforming, the same signal is transmitted from each of the transmit antennas with different phase. Weighting such that the signal power is maximized at the receiver input. If we increase the number of antenna at both the transmitter and receiver it will increase the capacity of MIMO system. Channel capacity is defined as the maximum rate at which data can be transmitted at an arbitrarily small error probability. The capacity of MIMO channels has been well studied for the Rayleigh scenario. On the other hand, in practice, MIMO channels do not always follow the Rayleigh fading condition. Actually, there is [2] often a line-of-sight (LOS) path between the transmitter and the receiver, and in such fading conditions, the channel is represented by the Rician fading model. The Rayleigh fading model can be viewed as a special case of the Rician fading model by setting the mean to zero. CSI [3] plays important role during capacity calculation. It is difficult for transmitter to know the channel state information, it is assumed that receiver know the channel state information .Correlation plays important role during capacity calculation. Correlation decreases the channel capacity. When transmitter has no information about channel state information. Equal power ρ is distribute [4] among the transmit antennas. In the case of water pouring principle[5] the channel parameter are known to transmitter and more power is given to that channel which is in good condition or less or none which is in bad condition.

2 MIMO SYSTEM MODEL

We have consider a MIMO system with transmit array of N_t antenna and receive array of N_r antenna[6] as shown in figure 1 . The transmitted matrix is $N_t \times 1$ column matrix X where X_i is ith component which is transmitted from ith antenna. We suppose the channel is Gaussian channel and elements of channel are supposed to independent identically distributed (i.i.d) Gaussian variables. If channel is unknown at the transmitter side we assume [4] that equal power E_X/N_t. is given to each transmitter antenna. The covariance of transmitted matrix is given by

$$R_{xx} = \frac{E_X}{N_t} I_{N_t} \quad (1)$$

Where E_X is the power across transmitter irrespective number of antennas where I_{N_t} is a $N_t \times N_t$ identity matrix. The transmitted signal bandwidth is so small that channel is assumed to flat. The channel matrix H is a $N_t \times N_r$complex matrix. The component $h_{i,j}$ of the matrix is the fading coefficient from jth transmit antenna to ith receive. If we assume that channel matrix is known at only receiver side not at transmitter side. The

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channel matrix at receiver can be estimated by training sequence. If transmitter to know this channel we can communicate this information to transmitter via feedback channel.

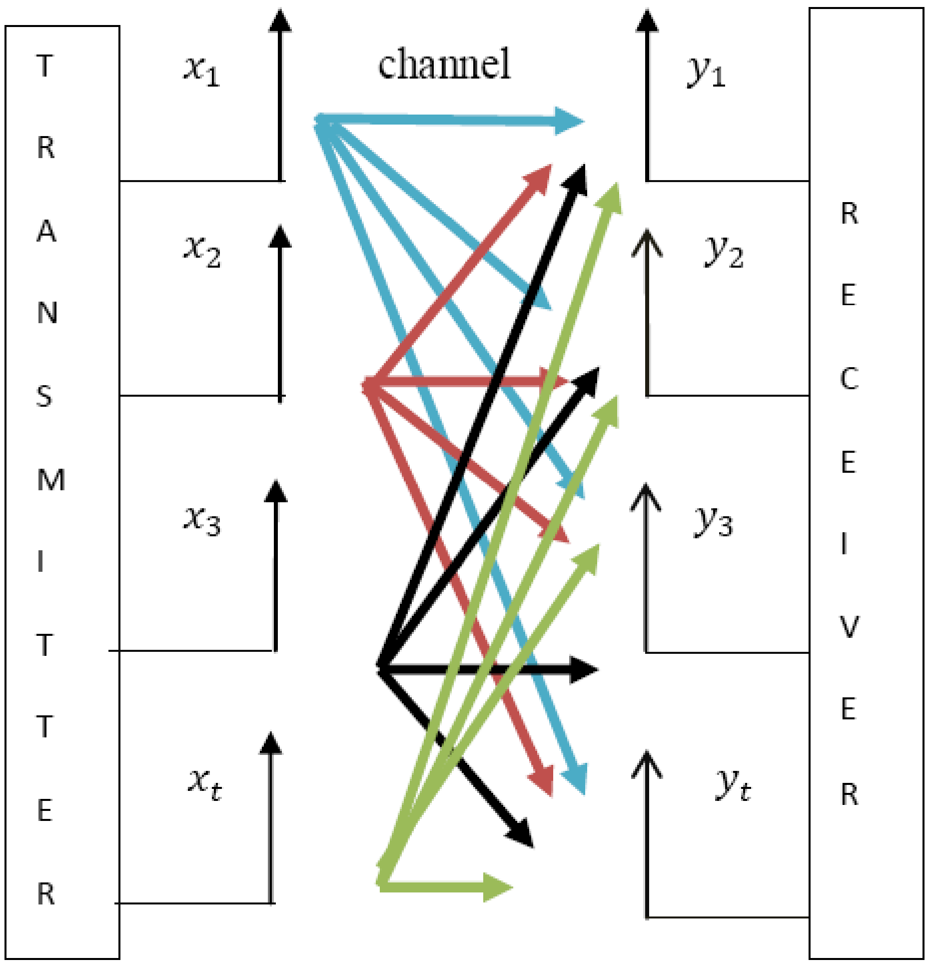

Fig. 1. MIMO System

Noise at the receiver is another column of size $N_r \times 1$, denoted by n. The components of **n** are zero mean circularly mean .We ignore the signal attenuation, antenna gain and other things, for a deterministic channel as

$$\sum_{j=1}^{N_t} |h_{i,j}|^2 = N_t \text{ , i = 1 , 2 ,3 } \ldots N_t \quad (2)$$

The covariance matrix of receiver noise given by

$$R_{nn} = E\{nn^H\} \quad (3)$$

If there is not any correlation between component of n then

$$R_{nn} = N_o I_{N_r} \quad (4)$$

Each of the N_r receive branches has identical noise power N_o. Since we have assume the total power received power per antenna is equal to total transmitted power. The SNR can be written as

$$\gamma = \frac{E_X}{N_t} \quad (5)$$

There for receiver vector can expressed as

$$R = Hx + n \quad (6)$$

3 DETERMINISTIC MIMO CHANNEL CAPACITY

For two random vector x and y the mutual information is defined as

$$I(x,y) = H(y) – H(y|x) \quad (7)$$

Where H(y|x) the conditional entropy.

$$H(x/y) = -E[log_2(p(x|y))] \quad (8)$$

For a linear complex model

$$Y = Hx + n \quad (9)$$

The mutual information is given as

$$I(y,x|H) = \log_2 \det\left(I + \frac{1}{\sigma_n^2} HPH^H\right) \quad (10)$$

The Shanon capacity is the maximum mutual information between received vector and transmitted vector

$$C(H) = B \det\left(I + \frac{1}{\sigma_n^2} HPH^H\right) \quad (11)$$

When full transmitter CSI and receiver CSI are available, the capacity of the MIMO system is maximum.

4. MIMO CHANNEL CAPACITY

When receiver know what is the channel state information and transmitter has no any idea about channel state information. Receiver can know the channel state information by training and tracking whereas the channel state information at the transmitter may be available or not . Furthermore, we assume an ergodic block fading channel model where the channel remains constant over a block of consecutive symbols, and changes in an independent fashion across blocks. The average SNR of each receive antennas is given by E_x/σ^2 Here E_x is available power and σ^2 is power spectral density of given noise. In fading channels there are essentially two notions of capacity: ergodic capacity and outage capacity [7][8],

Ergodic Capacity: This is the time-averaged capacity [8] of a stochastic channel. It is found by taking the mean of the capacity values obtained from a number of independent channel realizations.

5. Outage Capacity

In the case of Rayleigh channel:

Capacity [9] with the outage allows bits sent over a given transmission burst to be decoded at the end of burst with some probability that these bits will be decoded incorrectly. The transmitter fixes minimum received SNR m and encodes a data for C= Blog(1+m_{min}).Data is properly received if received SNR is greater than m_{min}. If received SNR value is less than m then there is probability that burst cannot be decoded properly approaches 1. Thus receiver declares as outage. The probability of outage is

$$P_{out} = p(\mathrm{m}<m_{min})$$

$$C_{out=}(1 - P_{out})\mathrm{Blog}(1 + m_{min}) \quad (12)$$

In the case of Rayleigh channel

$$\mathrm{P}(m_i) = \frac{1}{\bar{m}} e^{\frac{m_i}{\bar{m_i}}}$$

$$P_{OUT}(m_0) = 1 - e^{\frac{-m_0}{\bar{m_i}}} \quad (13)$$

Data will properly decode at 1-P_{out}

6. Channel Capacity when CSI is unknown to Transmitter

Practically [4] it is difficult for transmitter to know the channel state information. When transmitter has no any idea of CSI it is optimal to evenly distribute the available power ρ among the transmit antennas. Then capacity can be given as[2]

$$\mathrm{C}= log_2 E_H \left[\det\left(I_n + \frac{\rho}{N_t} V\right)\right] \quad (14)$$

Where EH{.} denote the expectation over H. $m = min(,N_t, N_r)$, $I_n$is the nx n identity matrix, ρ is the average signal-to-noise ratio (SNR) per receive antenna, and the m x m matrix V .

$$\mathrm{V}=\mathrm{H}H^H N_r \leq N_t \quad (15)$$

$$\mathrm{V}=H^H \mathrm{H} N_r > N_t \quad (16)$$

Using single value decomposition

$$\mathrm{C}= E_H \sum_{i=1}^{k} \log_2\left(1 + \frac{\rho}{N_t}\beta_i\right) \quad (17)$$

Where k, ($k \leq n$) is the rank of H, and β_i (i= 1, 2,…..,k) denotes the positive Eigen values of V.

7. Transmitter know the CSI

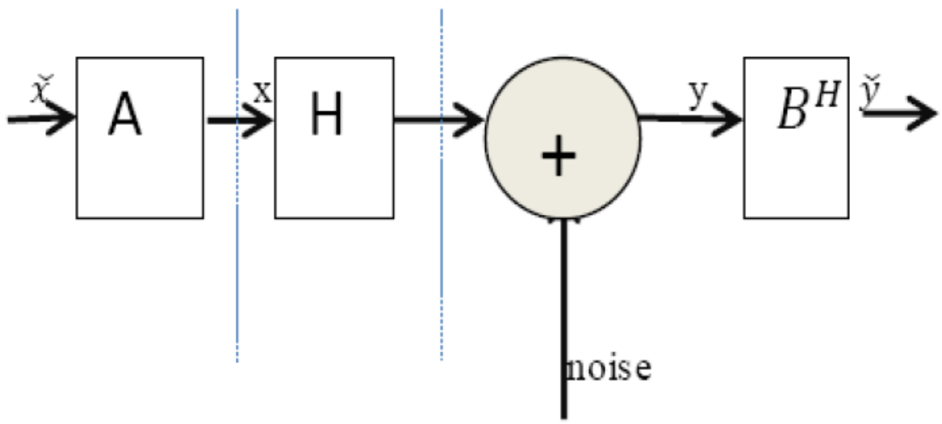

Fig. 2. Transmitter know the CSI

The channel H is decomposed using SVD (single value decomposition) as shown in figure 2, in which transmitted signal is preprocessed with A and received signal is post processed with $B^{H.}$

At transmitter $x = A\tilde{x}$.

At receiver $\tilde{y} = B^H y$ (18)

In this way MIMO channel id decomposed in to r_H parallel (figure 3) channels.

$$\tilde{y}_i = \sqrt{\frac{E_X}{N_t}}\sqrt{\beta_i}\,\tilde{x}_i \qquad i= 1,2\ldots\ldots r_H \tag{19}$$

The maximum capacity can obtain by maximizing the sum of individual capacity

$$C = max \sum_{i=1}^{r_H} log_2 \left(1 + \frac{\tilde{\gamma}}{N_t} E_i \beta_I\right)$$

$$\sum_{i=1}^{r_H} E_i = N_t \quad (20)$$

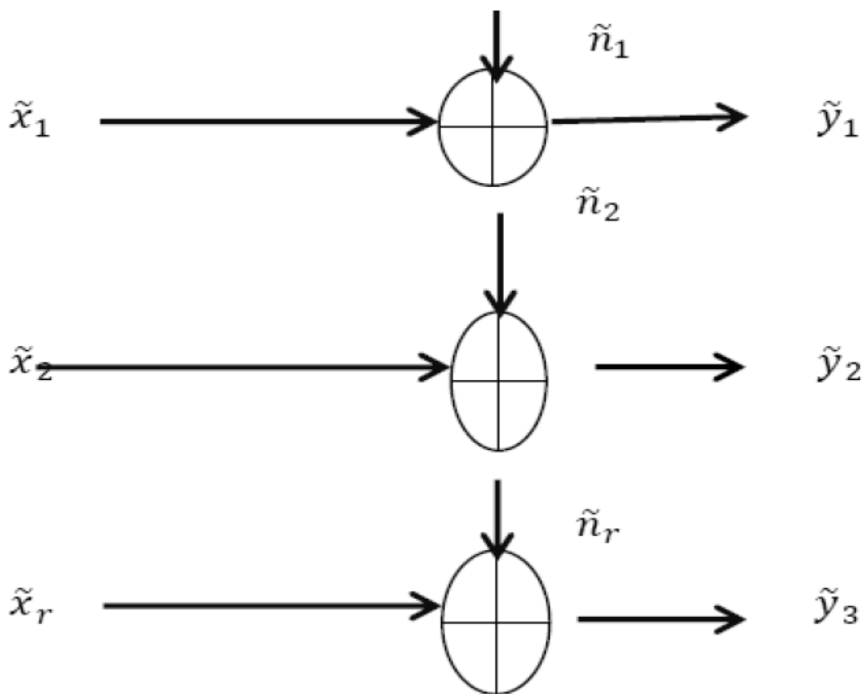

Fig. 3. The r virtual SISO channels obtained from model decomposition of MIMO channel

In the case of water pouring principle[10] the channel parameter are known to transmitter and more power is given to that channel which is in good condition or less or none which is in bad condition.

$$E_i = \left(\frac{\epsilon N_t}{E_x} - \frac{N_t}{\tilde{\gamma}\beta_i}\right) \quad (21)$$

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The optimal power given is estimated by iteration[5] . In each iteration , the constant ϵ is obtained . Then power which is given to every mode is calculated. If power allocated to node is negative, the mode is dropped and power given to another node is calculated.

8 EFFECT OF CORRELATION ON MIMO

MIMO channel capacity has been reduced due to correlation between transmit and receive antenna. We are taking a MIMO system in which channel gains between transmitter and receiver are correlated. The deterministic channel capacity can be written as

$$C = \max_{Tr(R_{xx})=N} \log_2 \det(R_{xx}) + \log_2 det\left(\frac{E_x}{NN_0} H_w H^H{}_W\right)$$

$$\text{When} \quad R_{xx} = I_N \tag{22}$$

Then capacity will become maximum.
We are taking correlated channel model[15]

$$H = R_r^{1/2} H_W R_t^{1/2} \tag{23}$$

Here R_t is the correlation between the column vectors H. R_r is the correlation between the row vector of H. The diagonal entries of R_t and R_r are forced to unity.

$$C = \log_2 \det\left(I_{N_r} + \frac{E_x}{N_t N_0} H H^H\right) \tag{24}$$

Put the value of H (equation 23) in (24)

$$C = \log_2 det\left(N_t + \frac{E_x}{N_t N_0} R_r^{1/2} H_W R_t H_w^H R_r^{1/2}\right)$$

$$\text{If} \ N_t = N_r = N \ \text{ and } R_t , R_r \ of\ full\ rank$$

$$C = \log_2 det\left(\frac{E_x}{N_t N_0} H_W H_W^H\right) + \log_2 det\,(R_r) + \log_2 det\,(R_r) \tag{25}$$

From equation (26) It shows that capacity decreases. The amount of correlation between transmitter and receiver is

$$\log_2 det\,(R_r) + \log_2 det\,(R_r) \tag{26}$$

$$\text{If } R_r = I_4$$

The correlation matrix R is defined[16]

$$r_{ij} = \begin{matrix} r^{i-j} & i \leq j \\ r^{*}{}_{j} & i > j \end{matrix}$$

9 RICIAN CHANNEL

The MIMO channel capacity has been studied for the Rayleigh scenario. On the other hand, in reality , MIMO channels do not always satisfy the i.i.d Rayleigh fading condition. In reality, there is often a line-of-sight (LOS) path between the transmitter and the receiver, and in such fading conditions, the channel is reprensted by the Rician fading model. There is random channel matrix in a MIMO Rician fading channel is a complex Gaussian matrix with a non- zero mean matrix, in a Rayleigh-faded MIMO channel there the channel matrix is of zero mean. The Rayleigh fading model can be seen as a special case of the Rician fading model. In which mean is set to zero. Consider a single user MIMO system with $N_t$transmit antennas andN_r receiver antennas. For simplicity we consider only frequency flat fading; i.e., the fading is not frequency selective. The transmitted signal in each symbol period is represented by a N_t×1 column matrix s, where *i*th component *s*i, refers to the transmitted signal from antenna *i*. The channel matrix H is a $N_t \times N_r$ complex matrix. The component $h_{i,j}$ of the matrix is the fading coefficient from jth transmit antenna to ith receive.. The additive white Gaussian noise at the receiver is described by an N_r×N_t column matrix n. Thus, the system is described by the matrix equation [17],

$$y = \sqrt{\frac{E_S}{N_t}} Hs + n \tag{27}$$

In Rician fading the elements of H are non-zero mean complex Gaussians. Hence we can express H in matrix notation as[19]

$$\text{H} = aH^{sp} + bH^{sc} \tag{28}$$

Where the specular [21] and scattered components of H are denoted by superscripts, a >0, b >0 and $a^2 + b^2 = 1$.

$H^{sp}$is a matrix of unit entries denoted by H_1.

If there is no correlation at the transmitter or at the receiver side then the entries of H^{sc} are independent usually denoted by Hω.

- If there is correlated fading then the H^{sc} matrix can be modeled as
- $H^{sc} = R_r^{1/2} H_W R_t^{1/2}$ (29)

- Where Rt and Rr are the correlation matrix at the transmitter and at the receiver side respectively.

- The correlation matrix R is defined[9]

- $r_{ij} = \begin{matrix} r^{i-j} & i \leq j \\ r^{*}{}_{j} & i > j \end{matrix}$ (30)

H(correlated)[20]

$$=\sqrt{\frac{K}{K+1}}\text{H1}+\sqrt{\frac{1}{K+1}}R_r^{1/2} \quad (31)$$

- If value of k =0 then it acts as Rayleigh channel .
- If value of K(RICIAN FACTOR) increaces then capacity (MIMO) decreace .
- If value of K(RICIAN FACTOR) increaces then capacity (SIMO) increace.

10 BEAM FORMING

Beamforming [24] increase the system gain at the receive side by making signals emitted from different antennas add up constructively, and to reduce the multipath fading effect. A MIMO system with $N_t$transmitter antennas and $N_R$receiver antennas, including beamforming vectors and combining vectors. Assume that MIMO system is narrow bandwidth and block fading, discrete-time equivalent channel is modeled as $N_t \times N_R$ matrix ***H***, then the relation of space time block coding between input and output can be expressed as

$$\text{Y=Hx+n} \quad (32)$$

And the relation of beamforming between input and output can be expressed as

$$\mathrm{y = z^H Hmx + z^H n}$$

Here x is the transmitted symbol signal , ***m*** is the N_t×1 complex beamforming vector and ***z*** is theN_R×1receiver combining vector, which is the function of the channel information, i.e., ***m***,

$$\boldsymbol{z}=f(\boldsymbol{H}).\ (.)^H \tag{33}$$

The main motive is to how the design m and z to maximize the signal to noise ratio, which can reduce the bit error rate and increase the capacity. The MIMO beamforming technique is a scheme that maximizes the instantaneous output SNR by jointly choosing optimum transmitting weight vector ***m*** and receiving combining vector ***z***.

$$SNR[20] = \frac{\|z^H mH\|^2 E|SS^H|}{\|z^H\|^2 \sigma^2} = \frac{\|z^H mH\|^2}{\|z^H\|^2} n \tag{34}$$

where ||▪|| is the Frobenius norm of a matrix, which is the sum of the norms of all the matrix elements. η is the SNR at the receiver for a SISO channel. E|SS^H|= Es is the maximum total power transmitted on *T* antennas at one symbol time. Therefore, maximizing the SNR at the receiver is equivalent to maximizing $\frac{\|z^H wH\|^2}{\|z^H\|^2} n$.
For a beamforming system, the capacity of a given channel realization can be given as[21]

$$C_{bf} = \max_{m:m^H m=p}\left[log\left(1+\frac{\|z^H mH\|^2}{\|z^H\|^2 \sigma_n^2}\right)\right] \tag{35}$$

In the case of space time coding effective channel capacity given as

$$C_s = \frac{K}{L} log\left(1+\frac{n}{T}\|H\|^2\right) \tag{36}$$

11 DETECTION TECHNIQUES

The received signal on the first receive antenna is,

$$y_1 = h_{1,1}x_1 + h_{1,2}x_2 + n_1 = [h_{1,1} \quad h_{1,2}]\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_1$$

The received signal on the second receive antenna is,

$$y_2 = h_{2,1}x_1 + h_{2,2}x_2 + n_2 = [h_{2,1} \quad h_{2,2}]\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_2 \tag{37}$$

$h_{1,1}$ is the channel from 1st transmit to 1st receive antenna,

$h_{1,2}$ is the channel from 2nd transmit to 1st receive antenna,

$h_{2,1}$ is the channel from 1st transmit to 2nd receive antenna,

$h_{2,2}$ is the channel from 2nd transmit to 2nd receive antenna

In the same way we can calculate detection for 8x8 antena ,

11.1 Zero Forcing (ZF) Detector

The zero forcing approach tries to find a matrix W which satisfies WH=I. The Zero Forcing (ZF) linear detector for meeting this constraint is given by,

$$W = (H^H H)^{-1} H^H . \tag{38}$$

This matrix is also known as the pseudo inverse[11] [12]for a general m x n matrix.

11.2 Minimum Mean Square Error (MMSE) Detector

The Minimum Mean Square Error (MMSE) approach tries to find a coefficient W which minimizes the criteria.

$$E\{[Wy - x][Wy - x]^H\}$$

$$W = [H^H H + N_0 I]^{-1} H^H . \tag{39}$$

When the noise term is zero, the MMSE detector reduces to Zero Forcing detector.

11.3 Maximum Likelihood (ML) Detector

The Maximum Likelihood [13][14] receiver tries to find $\hat{\boldsymbol{x}}$ which minimizes,

$$\boldsymbol{j} = |\boldsymbol{y} - \boldsymbol{H}\hat{\boldsymbol{x}}|^2, \text{ or}$$

$$j = \left\| \begin{bmatrix} y_1 \\ y_2 \end{bmatrix} - \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{bmatrix} \begin{bmatrix} \hat{x}_1 \\ \hat{x}_2 \end{bmatrix} \right\|^2$$

Since the modulation is BPSK, the possible values of $x_1$is +1 or -1 similarly x_2 also take values +1 or -1. So, to find the Maximum Likelihood solution, we need to find the minimum from the all four combinations of $x_1$and x_2.

$$j_{+1,+1} = \left\| \begin{bmatrix} y_1 \\ y_2 \end{bmatrix} - \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{bmatrix} \begin{bmatrix} +1 \\ +1 \end{bmatrix} \right\|^2,$$

$$j_{+1,-1} = \left\| \begin{bmatrix} y_1 \\ y_2 \end{bmatrix} - \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{bmatrix} \begin{bmatrix} +1 \\ -1 \end{bmatrix} \right\|^2,$$

$$j_{-1,+1} = \left\| \begin{bmatrix} y_1 \\ y_2 \end{bmatrix} - \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{bmatrix} \begin{bmatrix} -1 \\ +1 \end{bmatrix} \right\|^2,$$

$$j_{-1,-1} = \left\| \begin{bmatrix} y_1 \\ y_2 \end{bmatrix} - \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{bmatrix} \begin{bmatrix} -1 \\ -1 \end{bmatrix} \right\|^2$$

The estimate of the transmit symbol is chosen based on the minimum value from the above four values i.e.

if the minimum is $j_{+1,+1} \Rightarrow [1 \quad 1]$,
if the minimum is $j_{+1,-1} \Rightarrow [1 \quad 0]$,
if the minimum is $j_{-1,+1} \Rightarrow [0 \quad 1]$, and
if the minimum is $j_{-1,-1} \Rightarrow [0 \quad 0]$.

- If there are four transmitter and four receiver total combination will be2^4.
- If there are four transmitter and four receiver total combination will be 2^8

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12 Results

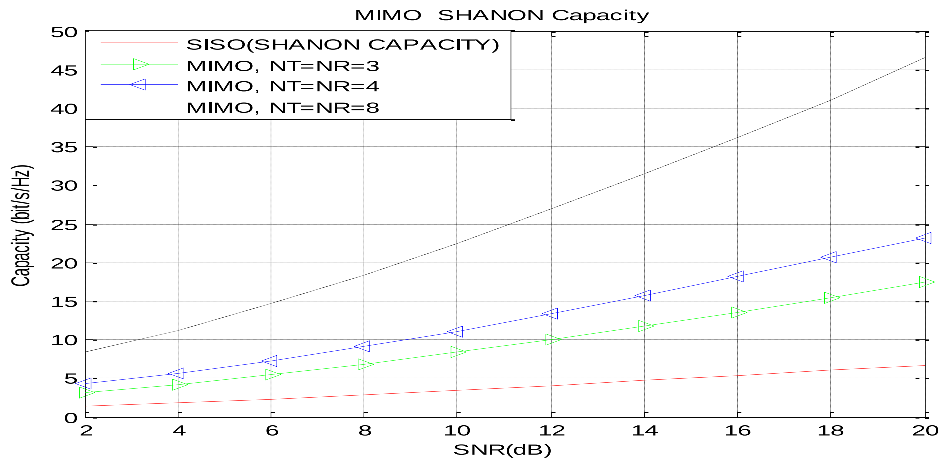

Fig. 4. Shanon capacity vs SNR

Capacity increases linearly with for min($N_{t,}N_R$) for a given fixed transmitter power and bandwidth in MIMO system.

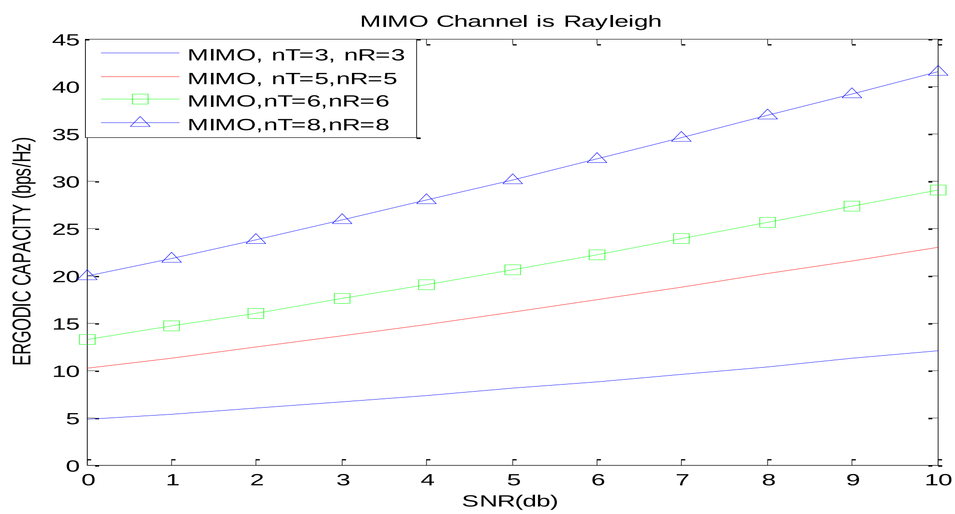

Fig. 6. Ergodic channel capacity when CSI is available at transmitter

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In this case we can use water pouring principle. In the case of water pouring principle the channel parameter are known to transmitter and more power is given to that channel which is in good condition or less or none which is in bad condition.

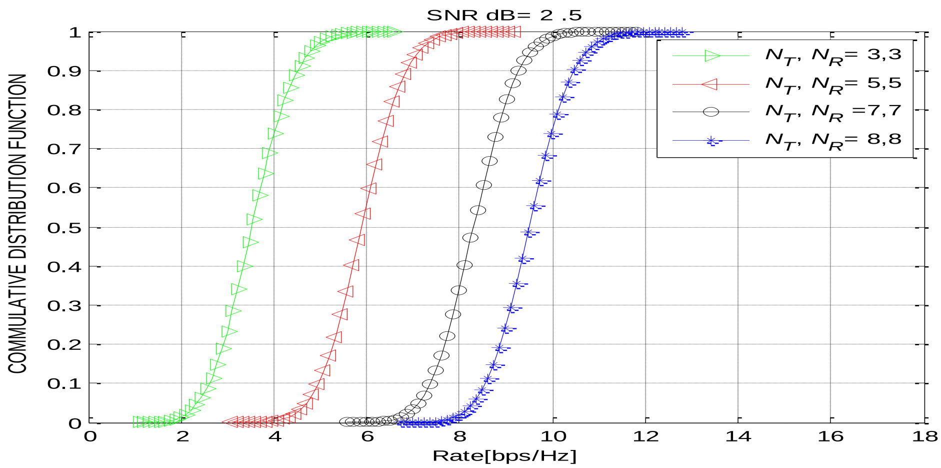

Fig. 7. Distribution of MIMO channel capacity

Commulative distribution function of mimo increases if we increase the number of transmitter and receiver.

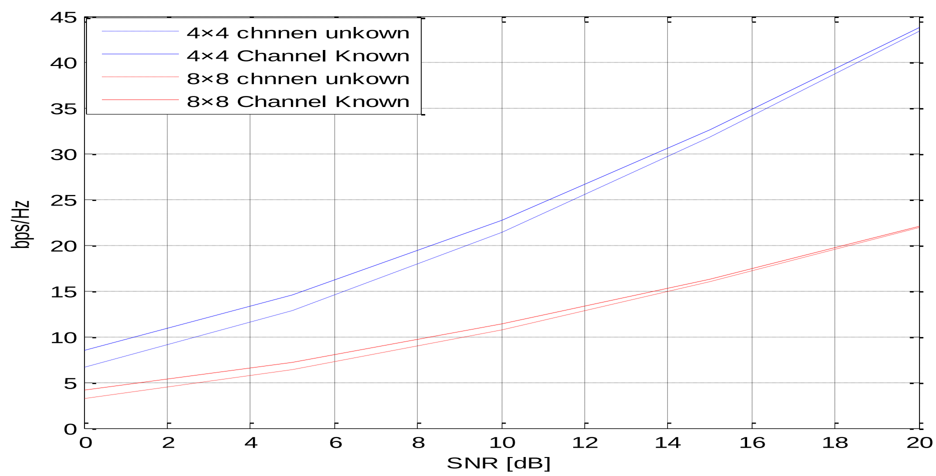

Fig. 8. channel unknown and channel known

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In the case of channel known water filling algorithim method is used.

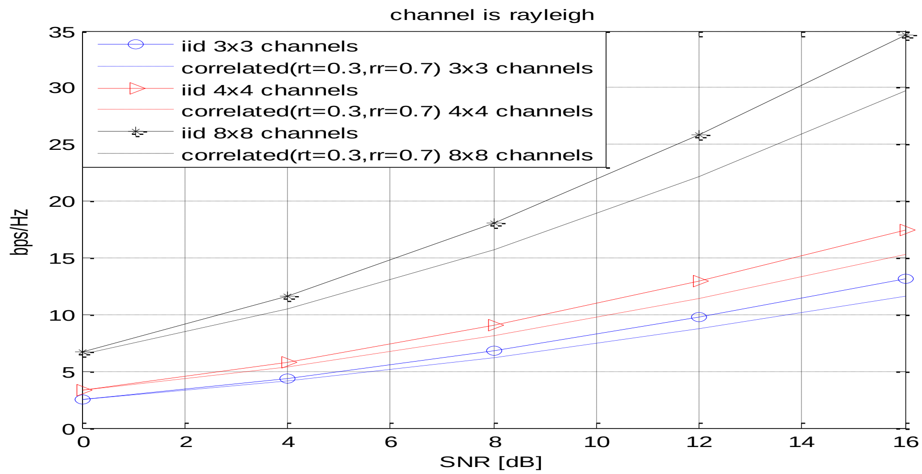

Fig. 9. Effect of correlation

Due to correlation channel capacity decreases. If we increase the number of transmitter and receiver the channel capacity increases.

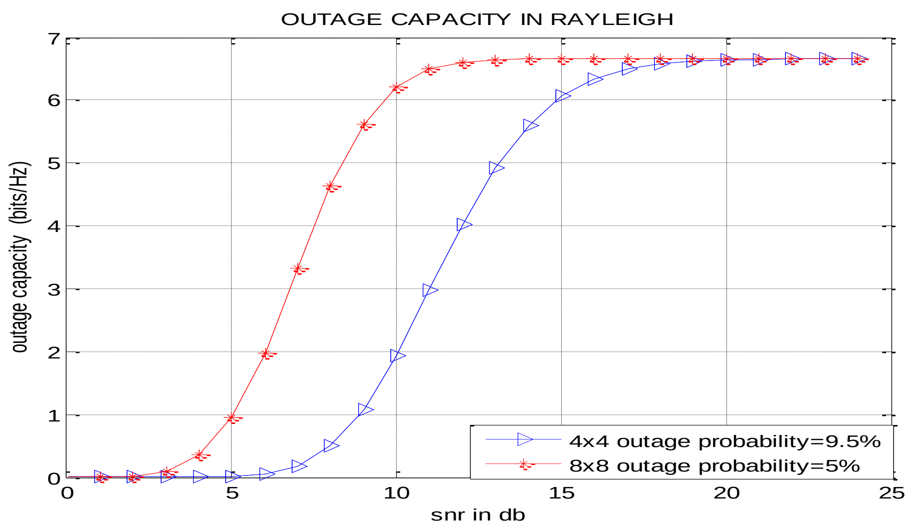

Fig. 10. Outage capacity vs SNR

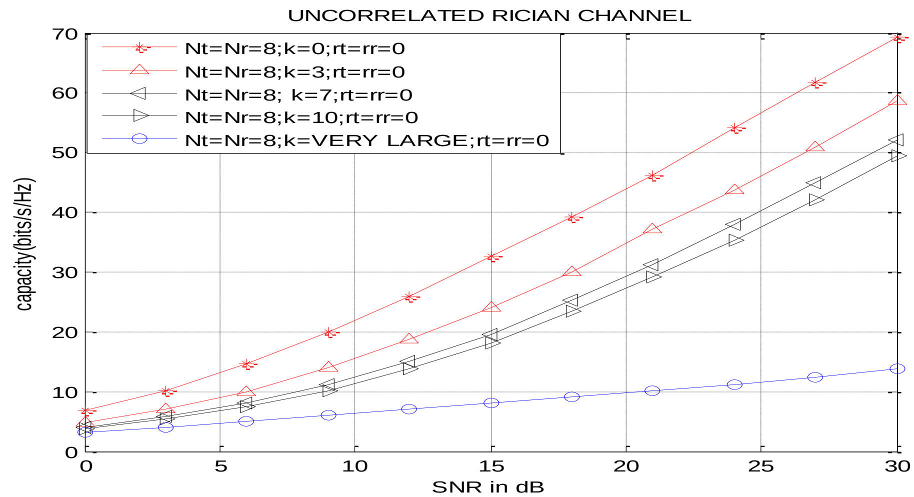

Fig. 11. Capacity analysis of uncorrelated Rician channel when CSI is not available at the transmitte side.

When k=0 channel is Rayleigh. As value of k increases capacity start to decrease. At very large value of k it acts as gaussian channel.

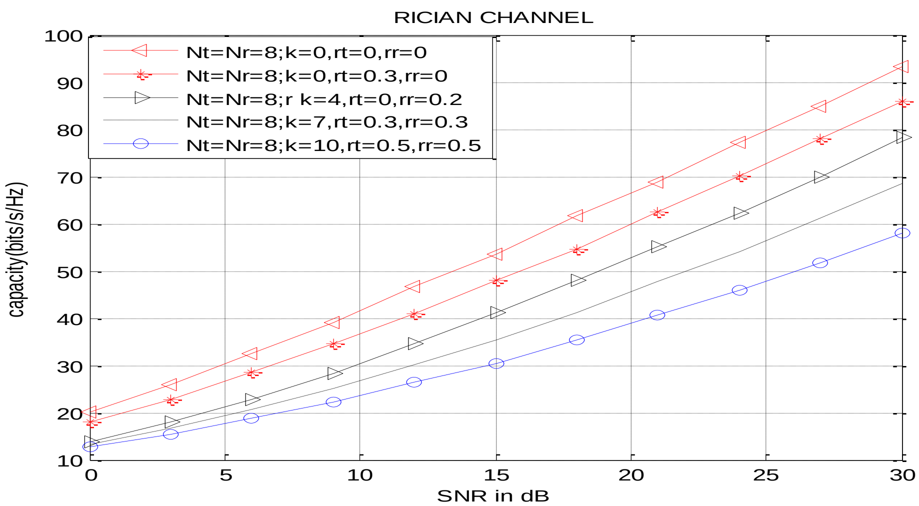

Fig. 12. Rician channel capacity when transmitter knows the CSI under different correlation channel parameters

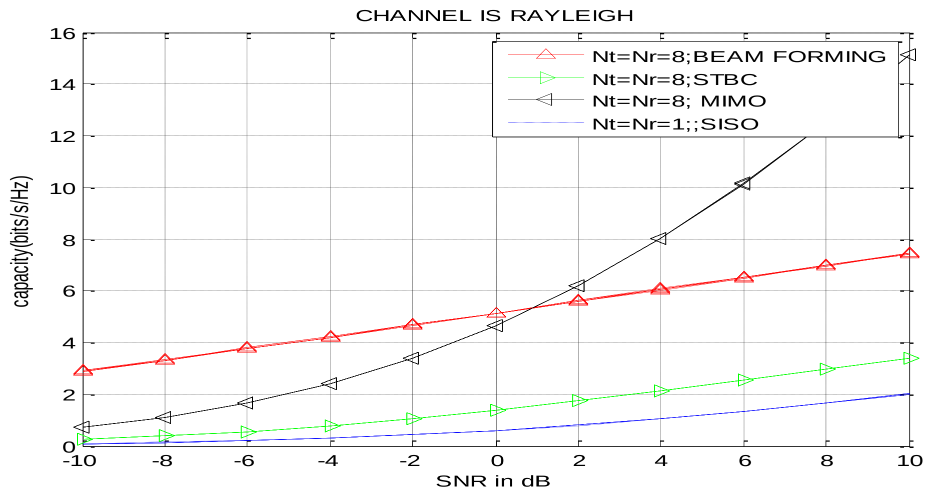

Fig. 13. Capacityvs SNR (Beamforming)

In beamforming, the same signal is transmitted from each of the transmit antennas with different phase. Weighting such that the signal power is maximized at the receiver input. Beamforming increase the system gain at the receive side by making signals emitted from different antennas add up constructively, and to reduce the multipath fading effect.

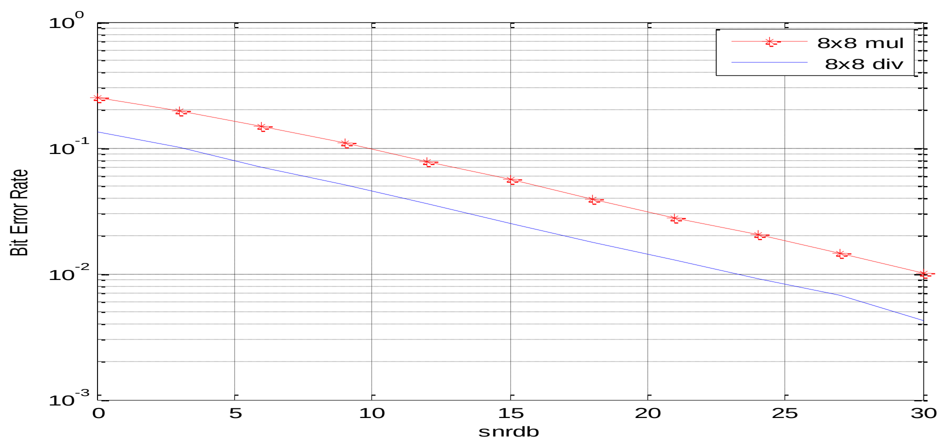

Fig.14. BER performance for 8×8 MIMO with ZF detection for BPSK in Rayleigh channel for multiplexing diversity techniques .

In multiplexing, a high rate signal is broken into multiple lower rate streams and each stream is transmitted from a different transmit antenna in the same frequency channel. In diversity method same signal is transmitted from different antenna.

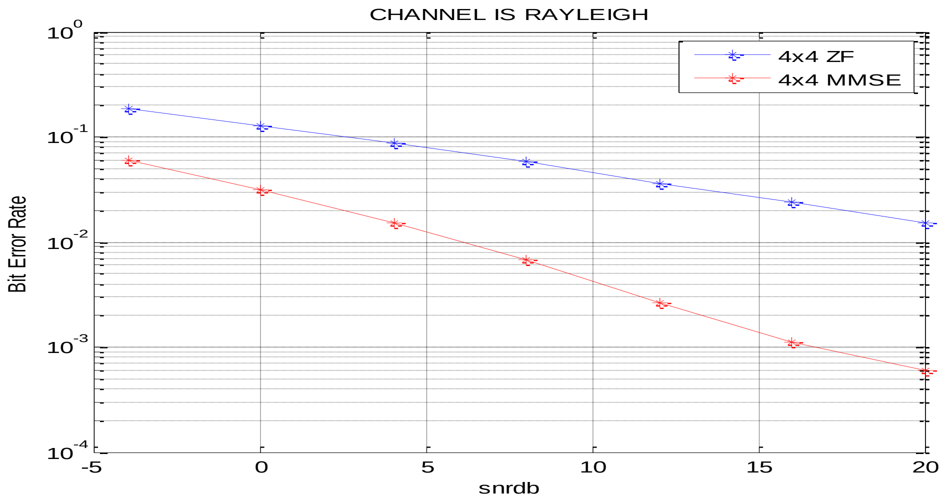

Fig. 15. Comparison of (4x4) ZF and Minimum Mean Square Error (MMSE Performance under Rayleigh channel.

when the noise term is zero, the MMSE detector reduces to Zero Forcing detector.

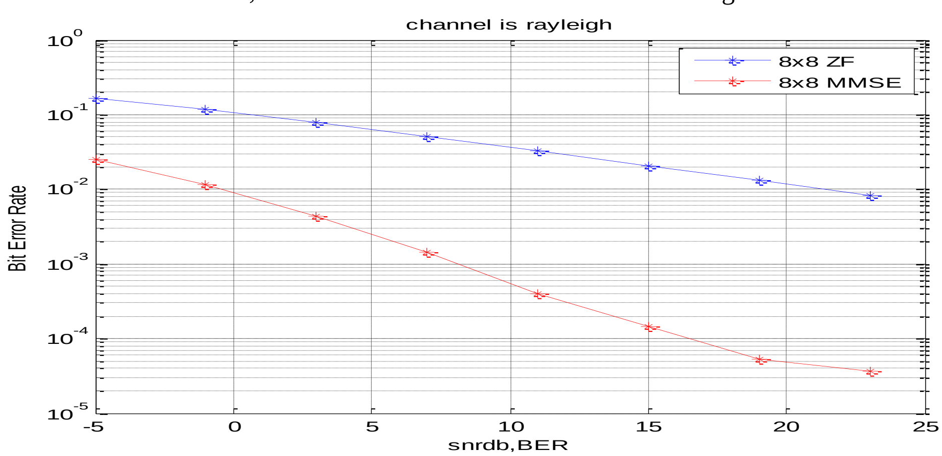

Fig. 16. comparison of (8x8) ZF and Minimum Mean Square Error (MMSE) Detector Performance under Rayleigh channel.

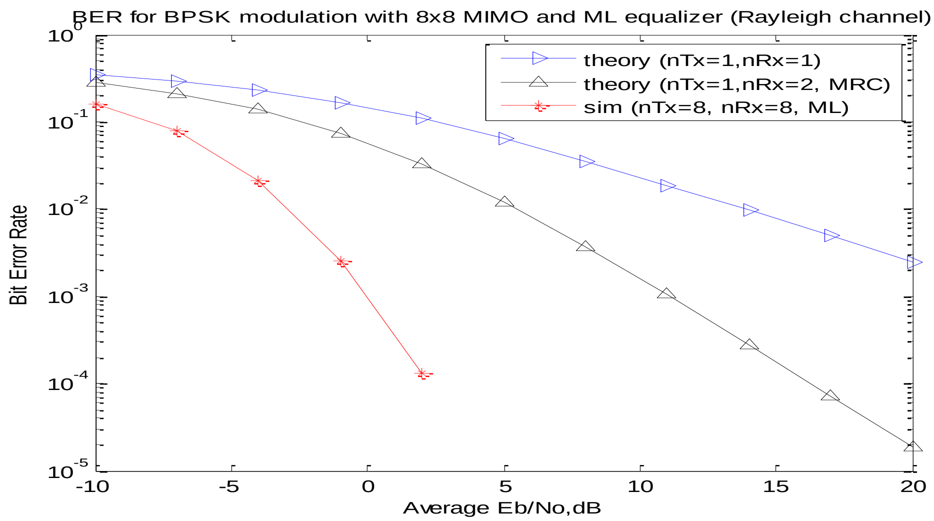

Fig. 17. BER plot for 8×8 MIMO with Maximum Likelihood (ML) Detector Performance detection in Rayleigh channel .

if we increase the number of transmitting and receiving antenna BER start to reduce.

13 Conclusion

It is observed that by increasing the number of transmitter and receiver antenna, the channel capacity can be increased but it increase the complexity of system. To increase the capacity we can further use CSI. The results shows that MIMO system with CSI available at the transmitter can greatly improve spectral efficiency over MIMO system without CSI at transmitter. We have shown that MIMO channel capacity depends on channel knowledge, SNR, and correlation between antenna elements.Paper has simulated the capacity of MIMO system over Rayleigh and Rician channel. Capacity decreases due to correlation .

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