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Enhance the Capacity of MIMO Wireless Communication Channel using SVD and Optimal Power Allocation Algorithm

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***Abstract*—Multiple input multiple output (MIMO) is a multiple antenna technology used extensively in wireless communication systems. With the ever increasing demand in high data rates, MIMO system is the necessity of wireless communication. In MIMO wireless communication system, where the multiple antennas are placed on base station and mobile station, the major problem is the constant power of base station, which has to be allocated to data streams optimally. This problem is referred as a power allocation problem. In this research, singular value decomposition (SVD) is used to decouple the MIMO system in the presence of channel state information (CSI) at the base station and forms parallel channels between base station and mobile station. This practice parallel channel ensures the simultaneous transmission of parallel data streams between base station and mobile station. Along with this, water filling algorithm is used in this research to allocate power to each data stream optimally. Further the relationship between the channel capacity of MIMO wireless system and the number of antennas at the base station and the mobile station is derived mathematically. The performance comparison of channel capacity for MIMO systems, both in the presence and absence of CSI is done. Finally, the effect of channel correlation because of antennas at the base stations and the mobile stations in the MIMO systems is also measured.**

***Keywords*—MIMO, water filling algorithm, singular value decomposition, channel state information, channel capacity**

I. INTRODUCTION

THE The demand of high data rate is increasing day by day in a wireless communication system; the multiple antenna technology plays a vital role to enhance the data rate as well as the reliability of wireless communication systems. According to the white paper published by Cisco, the expected overall growth in mobile data rate is 48.3 Exabyte's per month by 2021 [1]. The single input single output (SISO) is incapable to meet this requirement of ever increasing data rates [2]. In SISO, the only single antenna is used at the base station and the mobile station so there is a single link between base station and mobile station, if this link gets faded, then it affects the complete communication and single link can not carry more data. Therefore, SISO system is less reliable and have low data rate communication system [3].

To meet the higher data rate requirement, mobile service provider companies are running toward 4G and 5G [4]. The 4G wireless network is capable of providing very high internet speed. The applications such as HD videos, online gaming, video conferencing etc. are supported by higher data rate services. So it is a big challenge for a wireless network to provide higher data rate services in limited spectrum [5-6].

Presently MIMO technology is playing a key role in wireless communication systems to achieve higher data rates with lesser transmitting power and bandwidth [7]. In MIMO system, multiple antennas are used at the transmitters and receivers, these multiple antennas provide diversity and spatial multiplexing to the wireless communication system [8]. In diversity, the same message symbol is transmitted through different antennas; thereby the reliability of wireless communication is improved. In spatial multiplexing, different symbols are transmitted through different antennas so that the data rate is improved. Diversity improves the reliability of wireless communication system by providing multiple paths between base station and mobile station and spatial multiplexing improves the capacity of wireless communication system by transmitting multiple data streams between base station and mobile station, simultaneously [9].

Consider a multiple antennas scenarios, firstly, when a base station has multiple antennas, and they communicate with single antenna at mobile station know as multiple input single output (MISO) system and the channel is called uplink channel (ULC) [10]. Secondly, when the mobile has multiple antennas to communicate with a single antenna base station knows as single input multiple output (SIMO) system and the channel is called downlink channel (DLC). Lastly, when base station and mobile station, both have multiple antennas so that system is called a MIMO system. MIMO system can also be classified as single user MIMO system and multiuser MIMO system. In single user MIMO system, base station communicates only with one mobile device. In multiuser MIMO system, base station communicates with multiple mobile devices. The single user MIMO system shown in Fig.1, has N_B antennas at the base station and N_M antennas at mobile station and a channel matrix C between base station and mobile station [11-12].

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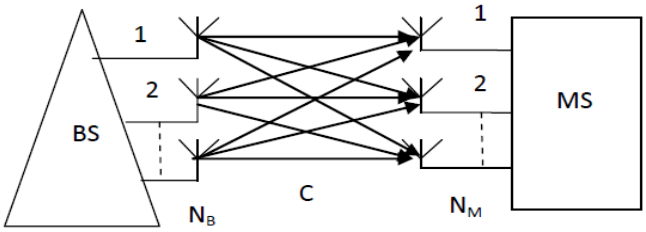

Fig.1. Single User MIMO System

The mathematical expression of receiving vector at the mobile station in a MIMO system according to Fig.1 is [13-15]

$$\bar{\mathbf{r}} = \mathbf{C}\,\bar{\mathbf{t}} + \bar{\mathbf{n}} \tag{1}$$

Where $\bar{\mathbf{r}}$ is received vector, $\mathbf{C}$ is channel matrix, $\bar{\mathbf{t}}$ is transmitting vector and $\bar{\mathbf{n}}$ is noise vector.

The multiple antenna technology faces two challenges: Firstly interference; a receiver antenna not only receives the data from the desired transmitting antenna, but also from the other antennas [16]. Secondly, constant power at base station; multiple antennas are placed at base station, but base station has constant power and this power has to be distributed to all transmitting data streams. To overcome these challenges, in this research SVD algorithm and water filling algorithm has been proposed [17].

II. Channel Capacity of MIMO System When CSI is Presented at Base Station

When CSI is available at the base station, MIMO wireless channel can easily decouple into parallel channels by using SVD. Now, the channel capacity MIMO wireless communication system can be defined as the sum of the capacity of each parallel channel [18].

A. SVD in MIMO System

SVD with MIMO system requires CSI at the base station and the mobile station. CSI is commonly measured at base station in the SVD-MIMO system by estimating pilot symbols and recovers CSI from pilot symbols and generates the optimized decoding matrices. SVD is a nonlinear function, in order to make state information accurate if there is a small error in CSI can do large variations in decoding matrix [19].

Consider a MIMO system with N_M (number of antennas at the mobile station) and N_B (number of antennas at the base station). The channel matrix $\mathbf{C}$ in the equation (1) is replaced by its SVD, the received vector at mobile station can be written as

$$\bar{\mathbf{r}} = \underbrace{\mathbf{X}\boldsymbol{\alpha}\mathbf{Y}^{\mathbf{H}}}_{\mathbf{C}}\ \bar{\mathbf{t}} + \bar{\mathbf{n}} \tag{2}$$

The channel matrix $\mathbf{C}$ in the equation (1) is replaced by its SVD, only if it satisfies the following properties

Property 1: $\mathbf{C} = \mathbf{X}\boldsymbol{\alpha}\mathbf{Y}^{\mathbf{H}}$ If $N_M \geq N_B$ (number of receiving antennas $\geq$ number of transmitting antennas)

Property 2: $\mathbf{X}_i^{\mathbf{H}} * \mathbf{X}_j = 0$ If $i \neq j$

Property 3: $\mathbf{X}_i^{\mathbf{H}} * \mathbf{X}_j = 1$ If $i = j$

Property 4: $\mathbf{X}^{\mathbf{H}} * \mathbf{X}$ and $\mathbf{Y}^{\mathbf{H}} * \mathbf{Y} = \mathbf{I}$ (Identity Matrix)

Property 5: The matrix $\boldsymbol{\alpha}$ is

$$\boldsymbol{\alpha} = \begin{bmatrix} \alpha_1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \alpha_{N_B} \end{bmatrix} \tag{3}$$

$\alpha_1, \alpha_2, \ldots\ldots\ldots, \alpha_{N_B}$ in equation (3) are called singular values.

These values must satisfy the following conditions
(i) The singular values must be non-negative,
$\alpha_1, \alpha_2, \ldots\ldots\ldots, \alpha_{N_B} \geq 0$.
(ii) The singular values are arranged in decreasing order of magnitude.

At the receiving end, the received vector $\bar{\mathbf{r}}$ is multiplied with $\mathbf{X}^{\mathbf{H}}$. Now the equation (2) can be written as

$$\underbrace{\mathbf{X}^{\mathbf{H}} * \bar{\mathbf{r}}}_{\tilde{\mathbf{r}}} = \mathbf{X}^{\mathbf{H}}(\underbrace{\mathbf{X}\boldsymbol{\alpha}\mathbf{Y}^{\mathbf{H}}}_{\mathbf{C}}\ \bar{\mathbf{t}} + \bar{\mathbf{n}}) \tag{4}$$

$$\tilde{\mathbf{r}} = \underbrace{\mathbf{X}^{\mathbf{H}}\mathbf{X}}_{\mathbf{I}}\ \boldsymbol{\alpha}\,\mathbf{Y}^{\mathbf{H}}\bar{\mathbf{t}} + \underbrace{\mathbf{X}^{\mathbf{H}}\bar{\mathbf{n}}}_{\tilde{\mathbf{n}}} \tag{5}$$

$$\tilde{\mathbf{r}} = \boldsymbol{\alpha}\,\mathbf{Y}^{\mathbf{H}}\bar{\mathbf{t}} + \tilde{\mathbf{n}} \tag{6}$$

The received vector $\bar{\mathbf{r}}$ is multiplied by $\mathbf{X}^{\mathbf{H}}$ at the receiving end. This process is called receive processing. Further, before transmission, the transmit vector $\bar{\mathbf{t}}$ is generated by $\bar{\mathbf{t}} = \mathbf{Y} * \tilde{\mathbf{t}}$ at the transmitting end, this process is called transmit precoding. Now, put the value $\bar{\mathbf{t}}$ in equation (6), the received vector $\tilde{\mathbf{r}}$ is expressed as

$$\tilde{\mathbf{r}} = \boldsymbol{\alpha}\ \underbrace{\mathbf{Y}^{\mathbf{H}}\mathbf{Y}}_{\mathbf{I}}\ \tilde{\mathbf{t}} + \tilde{\mathbf{n}} \tag{7}$$

Where: $\mathbf{Y}^{\mathbf{H}}\mathbf{Y}$ is an identity matrix, so the equation (7) can be written as

$$\tilde{\mathbf{r}} = \boldsymbol{\alpha}\ \tilde{\mathbf{t}} + \tilde{\mathbf{n}} \tag{8}$$

The equation (8) shows the MIMO system after the processing at the transmitting and receiving end. This equation can be written as

$$\begin{bmatrix} \tilde{r}_1 \\ \tilde{r}_2 \\ \vdots \\ \tilde{r}_{N_B} \end{bmatrix} = \begin{bmatrix} \alpha_1 & 0 & \cdots & 0 \\ 0 & \alpha_2 & \cdots & \vdots \\ \vdots & \vdots & \cdots & 0 \\ 0 & 0 & \cdots & \alpha_{N_B} \end{bmatrix} \begin{bmatrix} \tilde{t}_1 \\ \tilde{t}_2 \\ \vdots \\ \tilde{t}_{N_B} \end{bmatrix} + \begin{bmatrix} \tilde{n}_1 \\ \tilde{n}_2 \\ \vdots \\ \tilde{n}_{N_B} \end{bmatrix} \tag{9}$$

In equation (9), $\tilde{r}_1, \tilde{r}_2, \ldots\ldots, \tilde{r}_{N_B}$ are received symbols at the mobile station, $\tilde{t}_1, \tilde{t}_2 \ldots\ldots\ldots, \tilde{t}_{N_B}$ are the transmitted symbols from the transmitter, $\alpha_1, \alpha_2 \ldots\ldots \alpha_{N_B}$ are the gain on every channel and $\tilde{n}_1, \tilde{n}_2, \ldots\ldots, \tilde{n}_{N_B}$ are the Gaussian noise in every channel. The received symbol at every antenna can be expressed as [20]

$$\begin{aligned} \tilde{r}_1 &= \alpha_1\tilde{t}_1 + \tilde{n}_1 \\ \tilde{r}_2 &= \alpha_2\tilde{t}_2 + \tilde{n}_2 \\ \tilde{r}_3 &= \alpha_3\tilde{t}_3 + \tilde{n}_3 \\ &\vdots \\ \tilde{r}_{N_B} &= \alpha_{N_B}\tilde{t}_{N_B} + \tilde{n}_{N_B} \end{aligned} \tag{10}$$

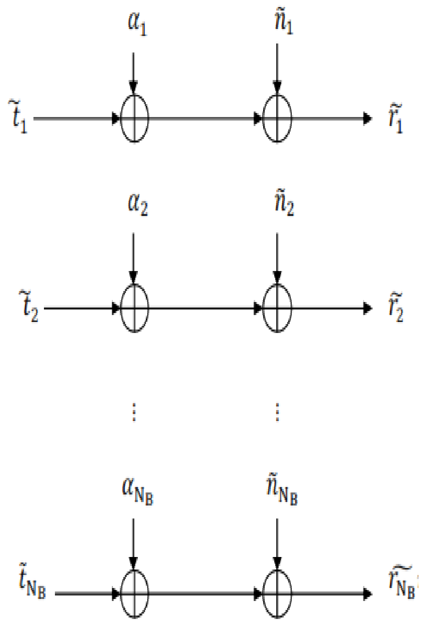

Fig.2. MIMO singular value decomposition parallel channel.

Fig.2. shows that the SVD decoupled the MIMO system into the MIMO SVD parallel channel. Now, the transmit symbols $\tilde{t}_1$, $\tilde{t}_2$,………. ,$\tilde{t}_{N_B}$ transmits over N_B parallel channels simultaneously without any interference, this is called spatial multiplexing. According to Shannon theorem, the Shannon capacity of i[th] channel can be written as

$$C_{ai} = \log_2(1+P_i\,\alpha_i^2/\sigma_n^2) \quad (11)$$

In equation (11), the term $P_i\,\alpha_i^2/\sigma_n^2$ shows the signal to noise ratio (SNR) of i[th] channel. Where Pi is the power of i[th] stream (t_i) , α_i^2 and σ_n^2 are the power gain and noise power of i[th] channel.

Fig.2. also shows that the MIMO system is a collection of N_B parallel channels so that the capacity of MIMO system is the sum of the capacity of each parallel channel. The capacity of each channel can be expressed as (i = 1, 2, 3,…….., N_B) [21].

$$C_{a1} = \log_2(1 + P_1\,\alpha_1^2/\sigma_n^2)$$
$$C_{a2} = \log_2(1+P_2\,\alpha_2^2/\sigma_n^2) \quad (12)$$
$$\vdots$$
$$C_{aN_B} = \log_2(1 + P_{N_B}\,\alpha_{N_B}^2/\sigma_n^2)$$

The capacity of the MIMO system can be written as in [22]

$$C_{MIMO} = C_{a1} + C_{a2} + \ldots\ldots\ldots\ldots C_{aN_B} \quad (13)$$

$$C_{MIMO} = \sum_{i=1}^{N_B} \log_2(1 + Pi\,\alpha_i^2/\sigma_n^2) \quad (14)$$

III. Efficient Power Allocation in MIMO System

The main problem faced in MIMO system is that the base station has constant power P_T and multiple data streams are transmitted through multiple antennas. So this power has to be distributed to all data streams, and the distribution should be in such a way, that the capacity of MIMO system can be maximized. This problem is dissolved by water filling algorithm [23].

A. Water Filling Algorithm

The efficient power allocation problem can be represented as
(1) The capacity of MIMO system, $C_{MIMO} = \sum_{i=1}^{N_B} \log_2(1 + Pi\,\alpha_i^2/\sigma_n^2)$ must be maximized.
(2) Total power assigned to all data streams must be less than or equal to the total power of base station (P_T).

The Lagrange multiplier based technique is used for efficient power allocation problem. The Lagrange multiplier function can be represented as

$$f(\overline{P_T}, \lambda) = \sum_{i=1}^{N_B} \log_2(1 + Pi\,\alpha_i^2/\sigma_n^2) + \lambda\left(P_T - \sum_{i=1}^{N_B} P_i\right) \quad (15)$$

Where λ is the Lagrange multiplier and $\overline{P_T} = [P_1, P_2,\ldots,P_{N_B}]^T$.
To maximize the equation (15), differentiate it with respect to P_i and put it equal to zero.

$$\frac{\partial}{\partial Pi} f(\overline{P_T}, \lambda) = 0 \quad (16)$$

Put the value of function $f(\overline{P_T}, \lambda)$ in equation (16) and differential with respect to $P_{i.}$ We obtained

$$\frac{\alpha_i^2/\sigma_n^2}{1+\frac{Pi\alpha_i^2}{\sigma_n^2}} - \lambda = 0 \quad (17)$$

After solving the equation (17), the power of i[th] data stream can be written as

$$P_i = \left(\frac{1}{\lambda} - \frac{\sigma_n^2}{\alpha_i^2}\right)^+ \quad (18)$$

The plus sign in equation (18) shows that the power can not be negative. If $\left(\frac{1}{\lambda} - \frac{\sigma_n^2}{\alpha_i^2}\right)$ is consider as a β. So β^+ can be defined as

$$\beta^+ = \begin{cases} 0 & \text{if } \beta < 0 \\ \beta, & \text{if } \beta \geq 0 \end{cases} \quad (19)$$

The constraint in the efficient power allocation problem can be written as

$$\sum_{i=1}^{N_B} P_i = P_T \quad (20)$$

by putting the value P_i in equation (20), we obtain

$$\sum_{i=1}^{N_B} \left(\frac{1}{\lambda} - \frac{\sigma_n^2}{\alpha_i^2}\right)^+ = P_T \quad (21)$$

The above equation is known as efficient power allocation equation or water filling algorithm equation. This equation can be easily explained with the help of a vessel diagram [24-25].

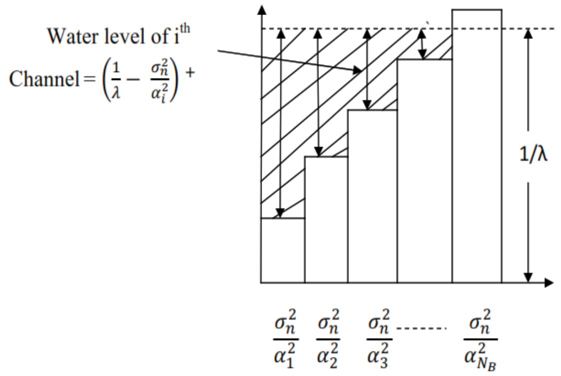

Fig.3.Vessel diagram of water filling algorithm in MIMO systems.

Fig. 3 shows the vessel diagram of the water filling algorithm. This diagram shows that there are N_B number of bars and the height of i^{th} bar is $\frac{\sigma_n^2}{\alpha_i^2}$. This vessel is filled with water up to the level of $\frac{1}{\lambda}$, the water level at i^{th} bar is $\left(\frac{1}{\lambda}-\frac{\sigma_n^2}{\alpha_i^2}\right)^+$. In this diagram, we have considered that $\alpha_1 > \alpha_2 > \ldots \alpha_{N_B}$ and power assigned to the channel is proportional to the value of α_i (i= 1,2,3,……., N_B), if the value of α_i is large then the height of i^{th} bar is small and water level at i^{th} bar is large, high power is assigned to that channel and if the value of α_i is smaller then the height of i^{th} bar is large and water level at i^{th} bar is small, low power is assigned to that channel but if the height of the bar is greater than $\frac{1}{\lambda}$, it means that the water level at i^{th} bar is $\left(\frac{1}{\lambda}-\frac{\sigma_n^2}{\alpha_i^2}\right)^+ < 0$, the zero power is then assigned to that channel because the channel is very weak [26].

IV. Asymptotic Channel Capacity of MIMO System When CSI is Not Presented at The Base Station

When CSI is not available at the base station, total power P_T at the base station is distributed equally to all the transmit antennas. The Asymptotic Channel capacity of MIMO when channels are completely un-correlated can be defined as C_A [27-29].

$$\mathbf{C_A} = \log_2 \det\left(\mathbf{I} + \frac{\mathbf{1}}{\sigma_n^2}\, \mathbf{C}\, \mathbf{R_t}\, \mathbf{C^H}\right) \tag{22}$$

Where; **C** is the un-correlated channel matrix, R_t is transmits covariance and it shows the power allocated to transmit signal. When CSI is not presented at the transmitter end, the equal power is distributed to each antenna so that the transmits covariance can be defined as

$$R_t = \frac{P_T}{N_B} * I \tag{23}$$

by putting the value R_t in equation (22), asymptotic channel capacity can be written as

$$\mathbf{C_A} = \log_2 \det\left(I + \frac{P_T}{N_B\, \sigma_n^2}\, \mathbf{C}\, \mathbf{C^H}\right) \tag{24}$$

Assume that the number of antennas at the transmitting end are larger in number than the number of antennas at receiving end (N_B >>>>>> N_M). In this case $\mathbf{CC^H} = N_B\mathbf{I}$, put this value in equation (24). The channel capacity can be written as

$$C_A = \log_2 \det\left(I + \frac{P_T}{\sigma_n^2} I\right) \tag{25}$$

$$\det\left(I + \frac{P_T}{\sigma_n^2} I\right) = \left(1 + \frac{P_T}{\sigma_n^2}\right)^{N_M} \tag{26}$$

Substitute the value of equation (26) in equation (25) and we get

$$C_A = N_M \log_2 \left(1 + \frac{P_T}{\sigma_n^2}\right) \tag{27}$$

When N_B >>>>>> N_M, the equation (27) can be written as

$$C_A = \min(N_B, N_M)\, \log_2 \left(1 + \frac{P_T}{\sigma_n^2}\right) \tag{28}$$

This equation shows that the channel capacity of MIMO systems increased proportionally by a factor of min (N_B, N_M) without increasing the base station power and channel bandwidth.

V. Channel Capacity of MIMO System With Channel Correlations at The Base Station and Mobile Station

In the above section, the channel capacity of MIMO systems, when channels are completely independent and identically distributed at the base station and the mobile station. Now, this section shows the channel capacity of MIMO systems when channels are correlated at the base station and the mobile station, because generally channels are not independent [30].

Consider a MIMO system with correlated channels at the base station and the mobile station, the correlated channel matrix can be defined as

$$\mathbf{C} = \mathbf{C_B^{\frac{1}{2}}}\, \mathbf{C_W}\, \mathbf{C_M^{\frac{1}{2}}} \tag{29}$$

Where; **C** is the correlated matrix and $\mathbf{C_B}$ is the correlation matrix of the base station, shows the correlations between antennas at the base station, $\mathbf{C_M}$ is the correlation matrix of the mobile station, shows the correlations between antennas at the mobile stations and $\mathbf{C_W}$ is the channel gain matrix of identically distributed Rayleigh fading channel [31].
Substituting the value of equation (29) in equation (22), the channel capacity of MIMO system can be written as

$$\mathbf{C_A} = \log_2 \det\left(I + \frac{1}{\sigma_n^2}\, \mathbf{C_B^{\frac{1}{2}}}\, \mathbf{C_W}\, \mathbf{C_M^{\frac{1}{2}}}\, \mathbf{R_t}\, \mathbf{C_B^{\frac{H}{2}}}\, \mathbf{C_W^H}\, \mathbf{C_M^{\frac{H}{2}}}\right) \tag{30}$$

If we assumed equal number of antennas at the base station and mobile station ($N_B = N_M = N$), the rank of $\mathbf{C_B}$ and $\mathbf{C_M}$ are full and signal to noise is high, the approximate value of equation (30) can be written as

$$\mathbf{C_A} \approx \log_2 \det\left(\frac{R_t}{\sigma_n^2}\right) + \log_2 \det(\mathbf{C_B}) + \log_2 \det(\mathbf{C_M}) \tag{31}$$

The equation (31) shows that the channel capacity of MIMO system will be reduced by the amount of antenna correlation at the base station and the mobile station, the values of $\log_2 \det(\mathbf{C_B})$ and $\log_2 \det(\mathbf{C_M})$ are always negative for any correlation matrix of $\mathbf{C_B}$ and $\mathbf{C_M}$ [32].

VI. Workflow Chart of Proposed Work

The overall functioning of the proposed work can be understood with the help of the following work flowchart.

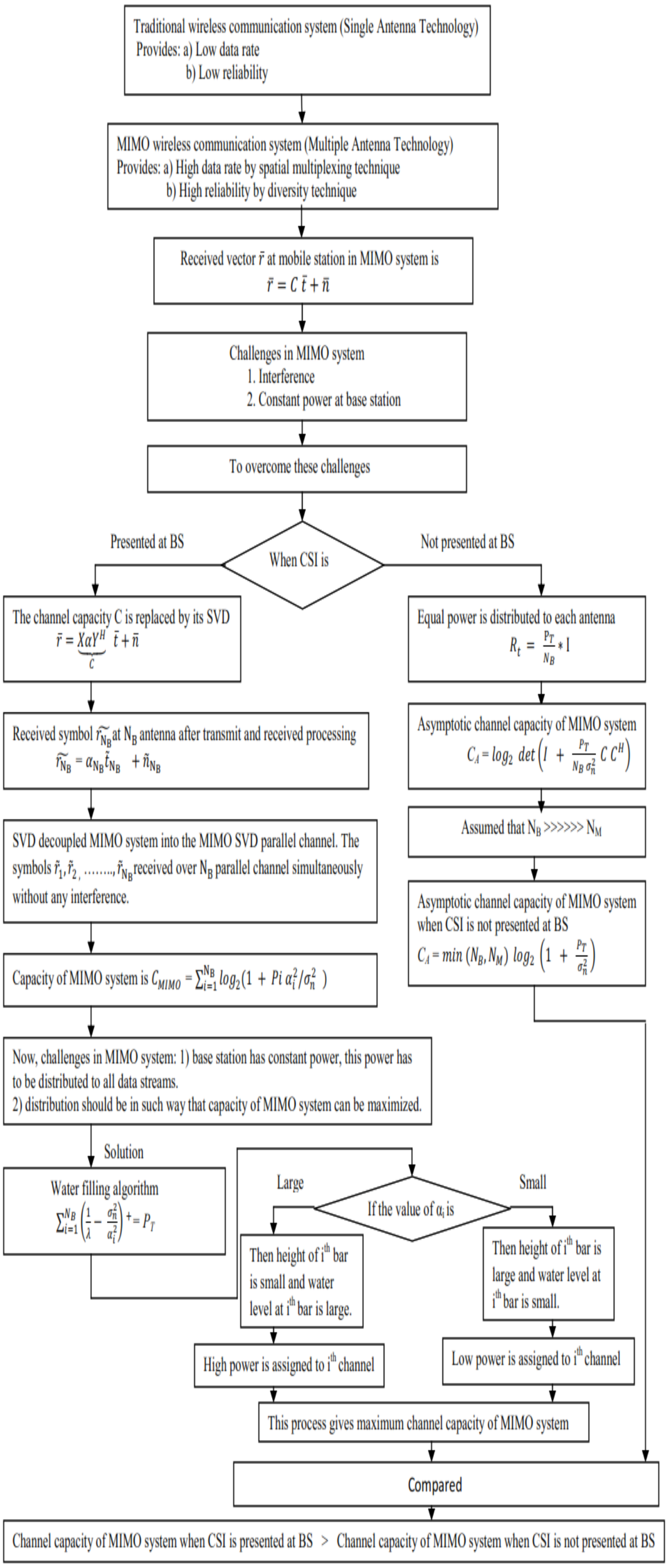

Fig.4. Workflow diagram of proposed work.

VII. Simulation Results

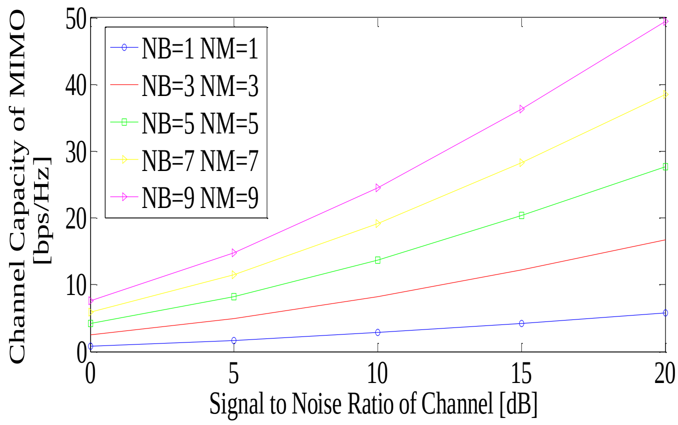

Fig.5. Channel capacity of MIMO systems for odd number of antennas at the base station and mobile station when CSI is not presented at the base station.

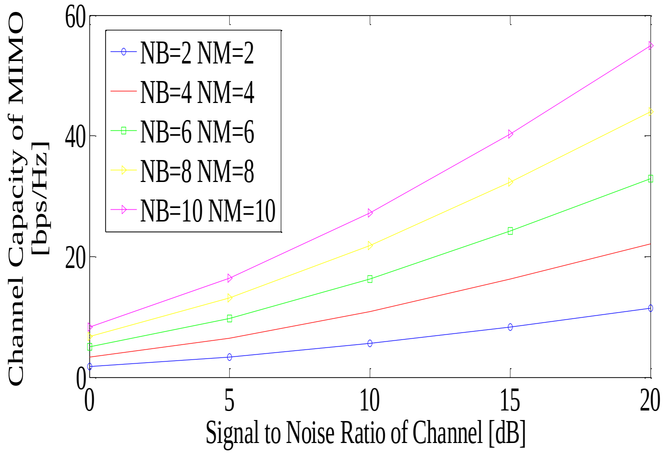

Fig.6. Channel capacity of MIMO systems for even number of antennas at the base station and mobile station when CSI is not presented at the base station.

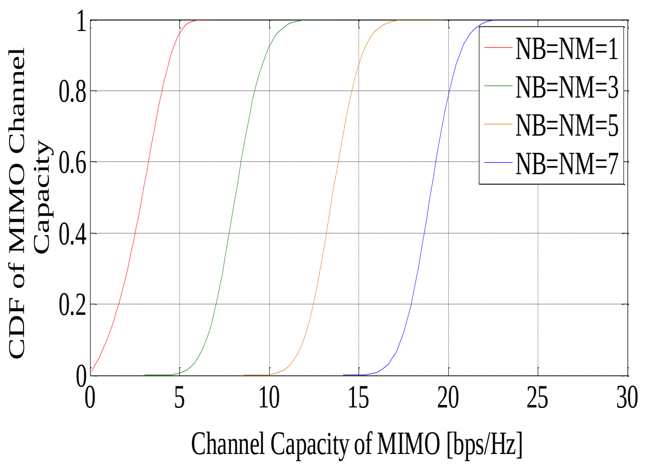

Fig.7. CDF of MIMO channel capacity for odd number antennas at the base station and mobile station when CSI is not presented at the base station (SNR=10 dB).

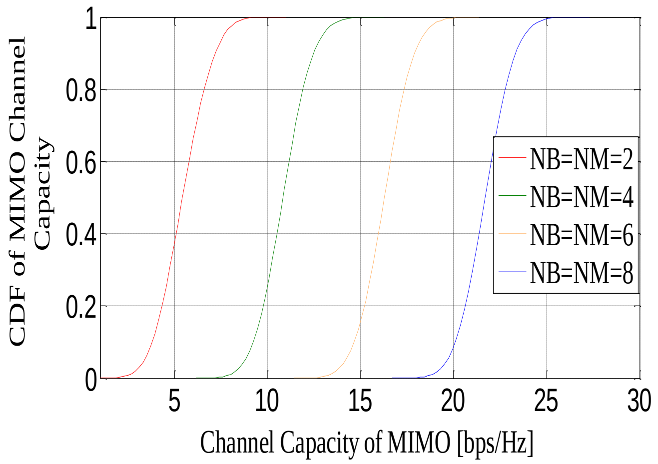

Fig.8. CDF of MIMO channel capacity for even number of antennas at the base station and mobile station when CSI is not presented at the base station (SNR=10dB).

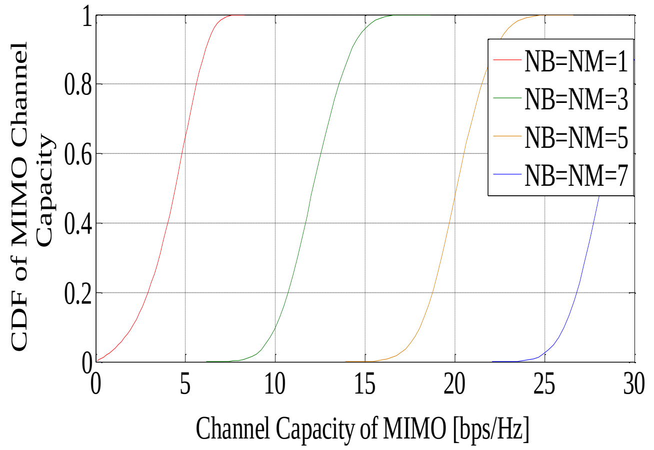

Fig.9. CDF of MIMO channel capacity for odd number of antennas at the base station and mobile station when CSI is not presented at the base station (SNR=15 dB).

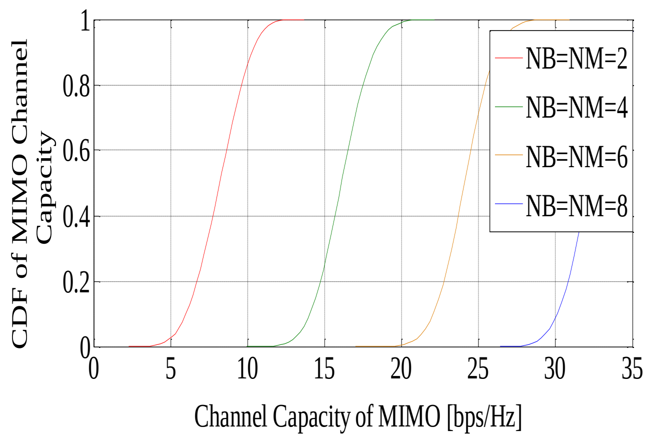

Fig.10. CDF of MIMO channel capacity for even number of antennas at the base station and mobile station when CSI is not presented at the base station (SNR=15 dB).

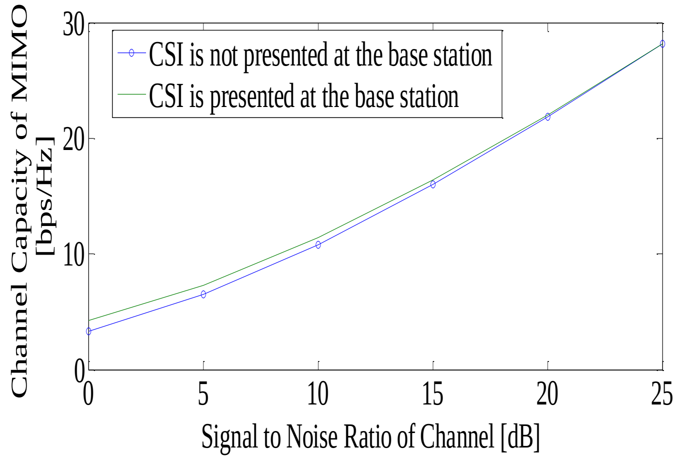

Fig.11. Channel capacity of the MIMO system when CSI is presented and not presented at the base station (N_B=N_M=4).

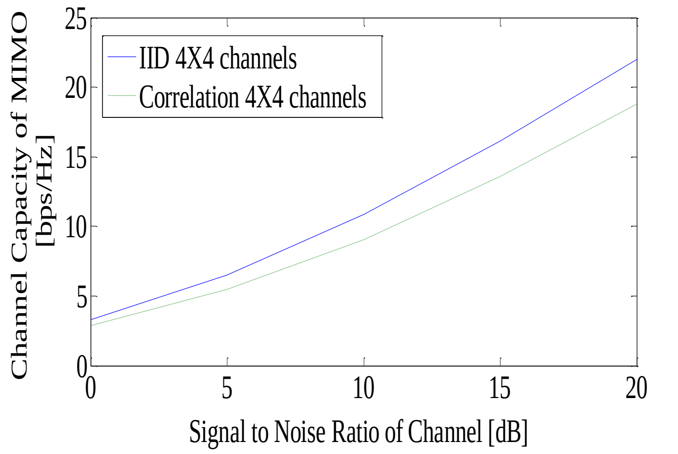

Fig.12. Channel capacity of MIMO system with and without correlation

In Fig.5, the channel capacity of MIMO system is measured for even number of antennas at the base station and mobile station when CSI is not presented at the base station. In Fig.6, the channel capacity of MIMO system is measured for odd number of antennas at the base station when CSI is not presented at the base station. Fig.5 and Fig.6 show that the channel capacity of a MIMO system increased proportionally with the number of antennas at the base station and the mobile station. In Fig.7 and Fig.8, the CDF of MIMO channel capacity is measured for odd and even number of antennas at the base station and mobile station with SNR equal to 10 dB. In Fig.9 and Fig.10, the CDF of MIMO channel capacity is measured for odd and even number of antennas at the base station and mobile station with SNR equal to 15 dB. The Fig.7, Fig.8, Fig.9 and Fig.10 show that the channel capacity of MIMO system is not only proportional to the number of antennas at the base station and mobile station but also to SNR. In Fig 11, the channel capacity of MIMO system is compared in the presence and absence of CSI for four numbers of antennas at the base station and the mobile station, the graph in this figure shows that the channel of the MIMO system when CSI is presented at the base station is greater than the channel capacity of the MIMO system when CSI is not presented at the base station. In Fig.12, the channel capacity of MIMO system with and without channel correlation is compared and the graph in this figure shows that the channel of MIMO is reduced as the channel correlation is increased at the base station and the mobile station.

VIII. Conclusion

In this research, the various MIMO parameters are compared through extensive simulation. The algorithm used for simulations are water filling and SVD. Firstly, this research derives a mathematical relationship between channel capacity and the number of antennas at the base station and mobile station when CSI is not presented at the base station. This relationship shows that the channel capacity of a MIMO system increased proportionally by a factor of min (N_B, N_M). Then, the channel capacity is measured in the absence of CSI for odd numbers of antennas at the base station and the mobile station. To make the simulation more fruitful, the channel capacity is measured for even number of antennas. Moving further, the CDF of the channel capacity of MIMO for both odd and even numbers of antennas in the absence of CSI is calculated at SNR equal to 10 dB and 15 dB. Then, the performance of MIMO on the basis of channel capacity in the presence and absence of CSI is compared. The performance analysis clearly shows that though the channel capacity of MIMO system is better in the presence of CSI, but increased SNR overshadows the presence of CSI i.e. presence of CSI does not affect the channel capacity at higher SNR. Lastly, the channel capacity of MIMO with and without channel correlation is compared. The comparison result shows that the channel capacity of MIMO is reduced by the amount of channel correlation at the base station and the mobile station.

IX. Appendix

Abbreviation Table

Symbols	**Definitions**
C	Channel matrix
$\bar{t}$	Transmitted vector
$\bar{n}$	Noise vector
$\bar{r}$	Received vector
N_M	Number of antennas at the mobile station
N_B	Number of antennas at the base station
$\bar{t}_{N_B}$	Transmitted symbol from the base station over N_B channel
$\bar{r}_{N_B}$	Received symbol at the mobile station from N_B channel
α_{N_B}	Gain of N_B channel
$\bar{n}_{N_B}$	Gaussian noise in N_B channel
X	Orthonormal column matrix
X^H	Hermition of X
Y	Unitary matrix
Y^H	Hermition of Y
α	Diagonal matrix of non-negative singular values
Pi	Power of ith stream
α_i^2	Power gain of ith channel
σ_n^2	Noise power of ith channel
C_{ai}	Shannon capacity of ith channel
f ($\bar{P}_T$, λ)	Lagrange multiplier function
P_T	Total power at the base station
$\frac{\sigma_n^2}{\alpha_i^2}$	Height of ith bar
$\frac{1}{\lambda}$	Water level threshold in the vessel
$\left(\frac{1}{\lambda}-\frac{\sigma_n^2}{\alpha_i^2}\right)^+$	Water level of ith bar
C_A	Asymptotic channel capacity of MIMO
R_t	Transmit covariance
C_B	Correlation matrix of the base station
C_M	Correlation matrix of the mobile station
C_W	Channel gain matrix of identically distributed Rayleigh fading channel

References

[1] Cisco VNI Mobile, Global Mobile Data Traffic Forecast Update, 2016 – 2021, *Growth Lakeland*. p. 42, 2017.

[2] M. Hanif, H.-C. Yang, G. Boudreau, E. Sich, and H. Seyedmehdi, "Low-complexity hybrid precoding for multi-user massive MIMO systems: a hybrid EGT/ZF approach, *IET Commun.*, vol. 11, no. 5, pp. 765–771, 2016.

[3] N. Haghighizadeh and A. MOHAMMADI, "Characterization of Wireless Mesh Backhaul Networks with MIMO Systems, *International Journal of Information & Communication Technology*, vol.1, no.3, pp. 15-21, 2009.

[4] J.-S. Roh, H.-R. Park, and S.-J. Cho, "Channel capacity of MIMO wideband CDMA system under the imperfect channel estimation and near/far effect, in *Personal Wireless Communications*, 2003, pp. 407–416.

[5] J. Mo and R. W. Heath, "Capacity analysis of one-bit quantized MIMO systems with transmitter channel state information, *IEEE Trans. signal Process.*, vol. 63, no. 20, pp. 5498–5512, 2015.

[6] S. Wang, W. Guo, and T. O'Farrell, Energy Efficiency Evaluation of SISO and MIMO between LTE-Femtocells and 802.11 n Networks, in *Vehicular Technology Conference (VTC Spring), 2012 IEEE 75th*, 2012, pp. 1–5.

[7] K. Tiwari, D. S. Saini, and S. V Bhooshan, On the capacity of MIMO Weibull-gamma fading channels in low SNR regime, *J. Electr. Comput. Eng.*, vol. 2016, 2016.

[8] H. Dai, A. F. Molisch, and H. V. Poor, Downlink capacity of interference-limited MIMO systems with joint detection, *IEEE Trans. Wirel. Commun.*, vol. 3, no. 2, pp. 442–453, 2004.

[9] D. Thi, T. Tu, N. Van Hoc, P. D. Son, and V. Van Yem, Design and Implementation of Dual-Band MIMO Antenna with Low Mutual Coupling Using Electromagnetic Band Gap Structures for Portable Equipments, *International Journal of Engineering and Technology Innovation*, vol. 2, pp. 48–60, 2017.

[10] W. Ni, X. Dong, and W.-S. Lu, Near-optimal hybrid processing for massive MIMO systems via matrix decomposition, *IEEE Trans. Signal Process.*, 2017.

[11] C. Chen, W. Cai, X. Cheng, L. Yang, and Y. Jin, Low Complexity Beamforming and User Selection Schemes for 5G MIMO-NOMA Systems, *IEEE J. Sel. Areas Commun.*, 2017.

[12] R. Krishnan *et al.*, Linear massive MIMO precoders in the presence of phase noise—A large-scale analysis, *IEEE Trans. Veh. Technol.*, vol. 65, no. 5, pp. 3057–3071, 2016.

[13] A. Zanella and M. Chiani, Reduced complexity power allocation strategies for MIMO systems with singular value decomposition, *IEEE Trans. Veh. Technol.*, vol. 61, no. 9, pp. 4031–4041, 2012.

[14] Y. Yu and W. Zhang, A Relaying Scheme Based on Diagonalization for Multi-Relay Symmetric MIMO Communication Networks, *IEEE Commun. Lett.*, 2017.

[15] H. Sung, S.-R. Lee, and I. Lee, Generalized channel inversion methods for multiuser MIMO systems, *IEEE Trans. Commun.*, vol. 57, no. 11, 2009.

[16] Y. Fadlallah, K. Amis, A. Aïssa-El-Bey, and R. Pyndiah, Interference alignment for a multi-user SISO interference channel, *EURASIP J. Wirel. Commun. Netw.*, vol. 2014, no. 1, p. 79, 2014.

[17] T. Kaji, S. Yoshizawa, and Y. Miyanaga, Development of an ASIP-based singular value decomposition processor in SVD-MIMO systems, in *Intelligent Signal Processing and Communications Systems (ISPACS), 2011 International Symposium on*, 2011, pp. 1–5.

[18] P. Aquilina and T. Ratnarajah, Performance analysis of IA techniques in the MIMO IBC with imperfect CSI, *IEEE Trans. Commun.*, vol. 63, no. 4, pp. 1259–1270, 2015.

[19] J. Choi, J. Park, and B. L. Evans, Spectral Efficiency Bounds for Interference-Limited SVD-MIMO Cellular Communication Systems, *IEEE Wirel. Commun. Lett.*, vol. 6, no. 1, pp. 46–49, 2017.

[20] J. E. Giti, M. Z. I. Sarkar, S. A. H. Chowdhury, M. M. Ali, and T. Ratnarajah, Secure wireless multicasting through co-existing MIMO radio systems, in *Strategic Technology (IFOST), 2014 9th International Forum on*, 2014, pp. 195–198.

[21] K.-H. Chen and J.-F. Kiang, Effect of mutual coupling on the channel capacity of MIMO systems, *IEEE Trans. Veh. Technol.*, vol. 65, no. 1, pp. 398–403, 2016.

[22] A. F. Molisch, M. Steinbauer, M. Toeltsch, E. Bonek, and R. S. Thoma, Capacity of MIMO systems based on measured wireless channels, *IEEE J. Sel. areas Commun.*, vol. 20, no. 3, pp. 561–569, 2002.

[23] A. Emami-Forooshani and D. G. Michelson, A Water-Filling Algorithm for Distributed MIMO Systems in Underground Tunnels, *IEEE Antennas Wirel. Propag. Lett.*, vol. 14, pp. 595–597, 2015.

[24] M. Hong and A. Garcia, Averaged iterative water-filling algorithm: Robustness and convergence, *IEEE Trans. Signal Process.*, vol. 59, no. 5, pp. 2448–2454, 2011.

[25] H. Zhang and X.-G. Xia, Iterative decoding and demodulation for single-antenna vector OFDM systems, *IEEE Trans. Veh. Technol.*, vol. 55, no. 4, pp. 1447–1454, 2006.

[26] M. Kobayashi and G. Caire, An iterative water-filling algorithm for maximum weighted sum-rate of Gaussian MIMO-BC, *IEEE J. Sel. Areas Commun.*, vol. 24, no. 8, pp. 1640–1646, 2006.

[27] W. Cai, P. Wang, Y. Li, Y. Zhang, and P. Pan, Asymptotic Capacity Analysis for Sparse Multipath Multiple-Input Multiple-Output Channels, *IEEE Commun. Lett.*, vol. 19, no. 12, pp. 2262–2265, 2015.

[28] S. Wei, D. Goeckel, and R. Janaswamy, On the asymptotic capacity of MIMO systems with antenna arrays of fixed length, *IEEE Trans. Wirel. Commun.*, vol. 4, no. 4, pp. 1608–1621, 2005.

[29] O. Ertug, Asymptotic ergodic capacity of multidimensional vector-sensor array MIMO channels, in *Communication Systems, Networks and Digital Signal Processing, 2008. CNSDSP 2008. 6th International Symposium on*, 2008, pp. 731–735.

[30] X. Chen, Spatial correlation and ergodic capacity of MIMO channel in reverberation chamber, *Int. J. Antennas Propag.*, vol. 2012, 2012.

[31] X. Mestre, J. R. Fonollosa, and A. Pagès-Zamora, Capacity of MIMO channels: asymptotic evaluation under correlated fading, *IEEE J. Sel. Areas Commun.*, vol. 21, no. 5, pp. 829–838, 2003.

[32] M. K. M. Kang and M.-S. Alouini, Impact of correlation on the capacity of MIMO channels, *IEEE Int. Conf. Commun. 2003. ICC '03.*, vol. 4, pp. 2623–2627, 2003.