

Cost Reduction and Channel Capacity Enhancement of MIMO System Using Antenna Selection Techniques

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Abstract—MIMO technology has become very popular in a wireless communication system because of the many advantages of multiple antennas at the transmitting end and receiving end. The main advantages of MIMO systems are higher data rate and higher reliability without the need of extra power and bandwidth. The MIMO system provides higher data rate by using spatial multiplexing technique and higher reliability by using diversity technique. The MIMO systems have not only advantages, but also have disadvantages. The main disadvantage of MIMO system is that the multiple antennas required extra high cost RF modules. The extra RF modules increase the cost of wireless communication systems. In this research, the antenna selection techniques are proposed to minimize the cost of MIMO systems. Furthermore, this research also presents techniques for antenna selection to enhance the capacity of channel in MIMO systems.

Keywords—Channel Capacity, MIMO, RF module, Antenna Selection Techniques

I. INTRODUCTION

IN conventional wireless communication systems, the main issues are low data rate and low reliability because of the one antenna at the transmitting end and receiving end [1]. This one antenna formed single path between transmitter and receiver. The complete communication is affected if this path is deep fade or disconnect. This single path provides low reliability and carries low data between transmitter and receiver. These issues are completely dissolved by multiple antennas technique [2]. The multiple antennas technique was invented for single user and it became a key technology in Long Term Evolution (LTE) to attain data rate 300 Mb/s when sending data from base station to mobile station and 75 Mb/s when sending data from mobile station to base station [3]. Then, it was mounted on multi-user and it's achieved approximately 1 Gb/s data rate [4]. Multiple antennas technique increased the data rate by spatial multiplexing and reliability by the diversity technique [5]. But, multiple antenna technique also increased the cost of wireless communication system. In the designing of wireless communication system, the high cost of the system is a very critical issue [6]. This

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research proposed the solution of this critical issue. The block diagram of multiple-inputs multiple-outputs (MIMO) system is depicted in Fig.1.

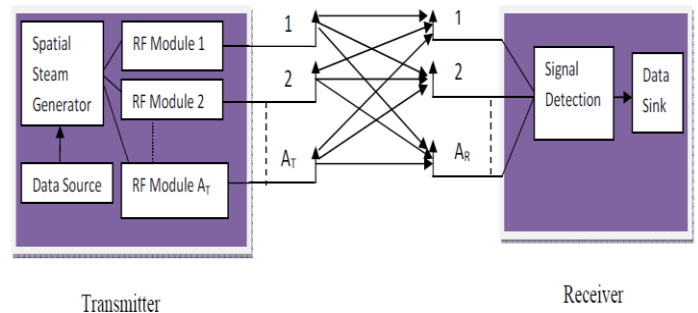


Fig.1 MIMO Wireless Communication System

In Fig.1, A_T number of antennas are placed on the transmitter. These A_T number of antennas are connected to the equal number of high cost RF modules. It shows that RF module requirement is proportional to the value of A_T . If value of A_T increased, the RF module requirement increased proportionally. The large number of RF modules increased the cost of MIMO system [7]. In this research, an antenna selection technique is used to reduce the cost of MIMO systems.

II. COST REDUCTION OF MIMO SYSTEM USING ANTENNA SELECTION TECHNIQUE

The below figure shows the point to point MIMO wireless communication system with antenna selection technique.

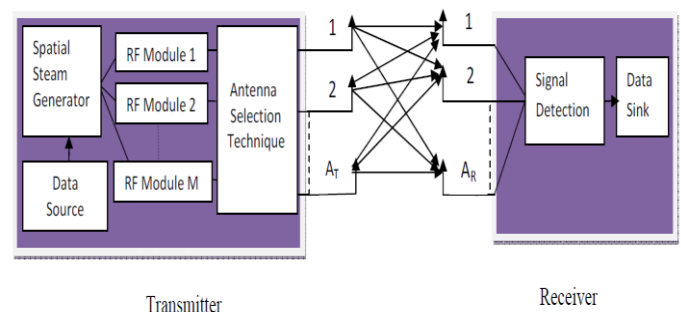


Fig.2. MIMO Wireless Communication System with Antenna Selection Technique

Fig.2 shows that only M number of RF modules are used at the transmitting end to support A_T number of antennas ($M < A_T$). Now, the antenna selection technique selects only the effective M number of antennas out of A_T antennas on the

basis of channel state information (CSI) [8, 9]. Antenna selection technique reduces the cost of MIMO systems by using less number of RF modules as compare to the number of antennas at the transmitting end [10].

Let us consider P_T is the total power at the transmitting end and this power is distributed to M antennas out of A_T antennas. P_i is the power assigned to each selected antenna ($i = 1, 2, \dots, M$). The columns of channel matrix are replaced by Q RF modules after antenna selection process, the channel matrix can be represented as $C_{AR \times Q}$.

The signal received in the MIMO system through techniques of antenna selection can be written as [11]

$$\mathbf{r} = \sqrt{\frac{E_t}{M}} \mathbf{C}_{\{A_1, A_2, A_3, \dots, A_M\}} \mathbf{t} + \mathbf{n} \quad (1)$$

where \mathbf{r} is the received signal, \mathbf{t} is the transmitted spatial stream mapped on M number of antennas, E_t is the energy of transmitting signal, \mathbf{C} is the channel matrix, M is number of selected antennas, A_1, A_2, \dots, A_M shows the M selected antennas and \mathbf{n} is channel noise.

The equation (1) shows that, the MIMO system's channel capacity depends on the value of M and the combination of antennas are selected for the communication. The following section will show that how the MIMO system's channel capacity can be enhanced using antenna selection technique.

III. CHANNEL CAPACITY ENHANCEMENT USING THE OPTIMUM TECHNIQUE OF ANTENNA SELECTION

In the technique of antenna selection, M antennas are selected out of A_T number of antennas. It means that the channel capacity of a MIMO system depends on the value of M and the combination of selected antennas. In this scenario, the MIMO system's channel capacity can be written as [12]

$$C_a = \max_{R_t} \log_2 \det \left(\begin{array}{c} I_{AM} + \frac{E_t}{MN_O} C_{\{A_1, A_2, A_3, \dots, A_M\}} \\ R_t C_{\{A_1, A_2, A_3, \dots, A_M\}}^H \end{array} \right) \text{bps} / \text{Hz} \quad (2)$$

In equation (2), \mathbf{R}_t is the transmit covariance and it is a $M \times M$ matrix. P_T is the total power at the transmitting end. If equal power is assigned to each selected antenna, the transmit covariance will become Identity matrix, $\mathbf{R}_t = \mathbf{I}_{MXM}$. Now, the channel capacity to M selected antennas can be written as [13]

$$C_{a\{A_1, A_2, A_3, \dots, A_M\}} = \log_2 \det \left(\begin{array}{c} I_{AM} + \frac{E_t}{MN_O} C_{\{A_1, A_2, A_3, \dots, A_M\}} \\ C_{\{A_1, A_2, A_3, \dots, A_M\}}^H \end{array} \right) \text{bps} / \text{Hz} \quad (3)$$

Equation (3) shows that, the M antenna selection must be optimized to maximize the channel capacity of MIMO system. The each antenna must be chosen with highest capacity, that is

$$\{A_1^{opt}, A_2^{opt}, \dots, A_n^{opt}\} = \{A_1, A_2, A_3, \dots, A_M\} \in D_M C_{a\{A_1, A_2, A_3, \dots, A_M\}} \quad (4)$$

where; D_M represents all possible different combinations of M selected antennas out of A_T . The equation (4) shows that, the combination of M selected antenna must be chosen, which gives maximum capacity.

As the number of antennas increase at the transmitter, the different combinations of M selected antennas will also increase. Because of that, the optimum selection of M antennas becomes very difficult or complex. Therefore, some methods are required to minimize this complexity. The following selection of this paper gives the solution of this problem.

IV. LESS – COMPLEX ANTENNA SELECTION TECHNIQUES

As mentioned in the above section, the optimum selection of M antennas becomes very complex, as the number of antennas increase at the transmitter. This section represents two less complex antenna selection techniques to the give solution of this problem.

A. Antenna Selection In Ascending of Capacity

In previous technique, M antennas are selected simultaneously. In this technique, one antenna is selected at a time on basic of CSI. The antenna with highest capacity is selected first among A_T number of antennas as [14, 15]

$$\begin{aligned} A_1^{Subopt} &= \arg \max_{A_1} C_a \{A_1\} \\ A_1^{Subopt} &= \arg \max_{A_1} \log_2 \det \left(I_{AM} + \frac{E_t}{MN_O} C_{\{A_1\}} C_{\{A_1\}}^H \right) \end{aligned} \quad (5)$$

where; $C_a \{A_1\}$ is the channel capacity of first selected antenna, A_M is the number of antennas at the receiver and $C_{\{A_1\}}$ is the channel matrix of first antenna.

Now, the selection of next antenna must be in such a manner that the MIMO system's channel capacity is maximized, that is

$$A_2^{Subopt} = \arg \max_{A_2 \neq A_1^{Subopt}} C_a \{A_1^{Subopt}, A_2\} \quad (6)$$

Similarly, n numbers of antennas are selected $\{A_1^{Subopt}, A_2^{Subopt}, A_3^{Subopt}, \dots, A_n^{Subopt}\}$ so that the channel capacity is maximized, that is

$$\begin{aligned} A_3^{Subopt} &= \arg \max_{A_3 \neq A_2^{Subopt}} C_a \{A_1^{Subopt}, A_2^{Subopt}, A_3\} \\ &\vdots \\ A_n^{Subopt} &= \arg \max_{A_n \neq A_{n-1}^{Subopt}} C_a \{A_1^{Subopt}, A_2^{Subopt}, \dots, A_n\} \end{aligned} \quad (7)$$

If one more antenna says l^{th} is selected, the channel capacity of MIMO system can be represented as

$$C_l = \log_2 \det \left(I_{AM} + \frac{E_t}{MN_o} C_{\{A_1^{Subopt}, A_2^{Subopt}, \dots, A_n^{Subopt}\}} \right)$$

$$C_l = \log_2 \det \left(C_{\{A_1^{Subopt}, A_2^{Subopt}, \dots, A_n^{Subopt}\}}^H + C_l C_l^H \right)$$

$$+ \log_2 \left\{ 1 + \frac{E_t}{MN_o} C_l \left(I_{AM} + \frac{E_t}{MN_o} C_{\{A_1^{Subopt}, A_2^{Subopt}, \dots, A_n^{Subopt}\}} \right)^{-1} C_l^H \right\} \quad (8)$$

Now, total numbers of selected antennas are (n+1). The l^{th} antenna is selected in such a way that maximized the capacity of channel represents in equation (8).

$$A_{n+1}^{Subopt} = \arg \max_{l \in \{A_1^{Subopt}, A_2^{Subopt}, \dots, A_n^{Subopt}\}} C_l$$

$$A_{n+1}^{Subopt} = \arg \max_{l \in \{A_1^{Subopt}, A_2^{Subopt}, \dots, A_n^{Subopt}\}} C_l \left\{ C_{\{A_1^{Subopt}, A_2^{Subopt}, \dots, A_n^{Subopt}\}} + \frac{I_{AM} MN_o}{E_t} C_{\{A_1^{Subopt}, A_2^{Subopt}, \dots, A_n^{Subopt}\}}^H \right\}^{-1} C_l^H \quad (9)$$

The antennas selection process will be continued until M antennas (n+1 =M) are selected.

B. Antenna Selection In Descending of Capacity

The selection of antenna in descending order of capacity is a reverse process of selection of antenna in ascending order of capacity. In antenna selection in ascending order of capacity, the antenna contributes maximum to the channel capacity of MIMO system is selected first. Then, the selection of next antenna must be in such a manner that the MIMO system's channel capacity is maximized. This process will be continued until M (n+1 =M) antennas are selected. In antenna selection in descending order of capacity, first consider all the transmitting antennas $\mathbf{T}_{AS} = [1, 2, \dots, A_T]$. Then, first antenna is selected that contributes minimum to channel capacity of MIMO, that is [16, 17]

$$A_1^{\text{deleted}} = \arg \max_{A_1 \in \mathbf{T}_{AS}} \log_2 \det \left(I_{AR} + \frac{E_t}{MN_o} C_{\{T_{AS}-A_1\}} C_{\{T_{AS}-A_1\}}^H \right) \quad (10)$$

where; \mathbf{T}_{AS} is the set of antennas at transmitting end or set of transmitting antenna indices.

This selected antenna A_1 is deleted from the set of transmitting antenna (\mathbf{T}_{AS}). The new antenna set is $\mathbf{T}_{AS_1} = \mathbf{T}_{AS} - (A_1^{\text{deleted}})$. Now, the second antenna is selected among the antenna set \mathbf{T}_{AS_1} , that gives minimum contribution in the channel capacity, that is

$$A_2^{\text{deleted}} = \arg \max_{A_2 \in \mathbf{T}_{AS_1}} \log_2 \det \left(I_{AR} + \frac{E_t}{MN_o} C_{\{T_{AS_1}-A_2\}} C_{\{T_{AS_1}-A_2\}}^H \right) \quad (11)$$

The selected antenna A_2 is deleted from the set of transmitting antenna \mathbf{T}_{AS_1} . Now, new antenna set $\mathbf{T}_{AS_2} = \mathbf{T}_{AS_1} - (A_2^{\text{deleted}})$. This process will be continued until an M number of antennas are selected.

V. WORKFLOW CHART OF PROPOSED WORK

This flow chart shows the complete functioning of proposed work.

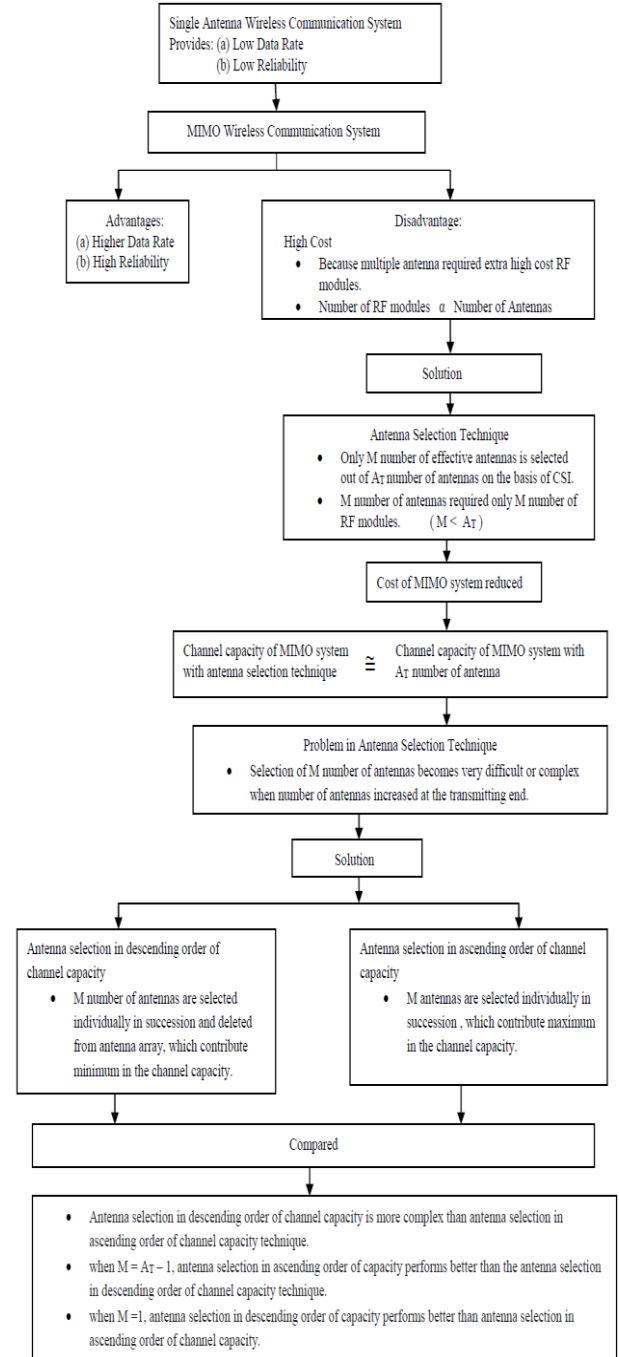


Fig.3. Workflow diagram of proposed work

VI. SIMULATION RESULTS

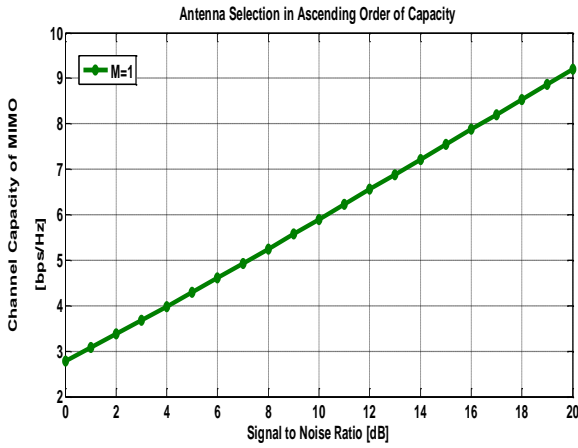


Fig.4 Channel Capacity of MIMO when first antenna (M=1) is selected.

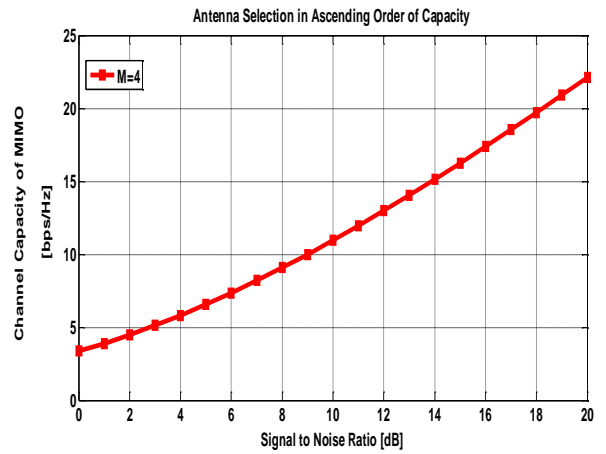


Fig.7 Channel Capacity of MIMO when fourth antenna (M=4) is selected.

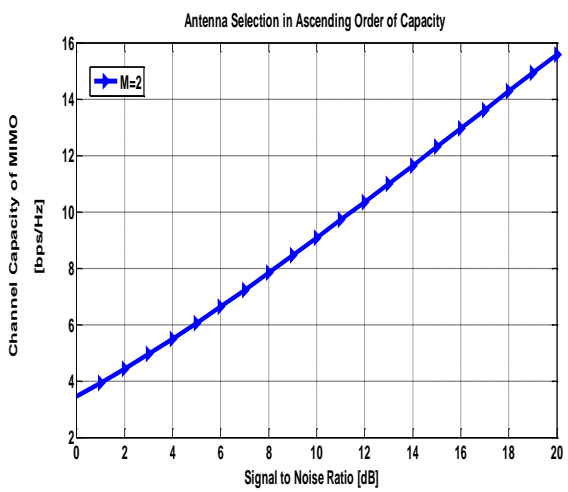


Fig.5 Channel Capacity of MIMO when second antenna (M=2) is selected.

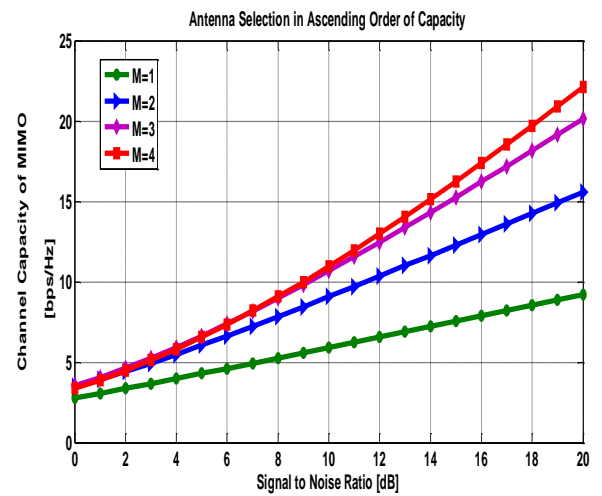


Fig.8 Channel Capacities of MIMO when antenna (M=1, 2, 3, 4) is selected in Ascending Order of Capacity.

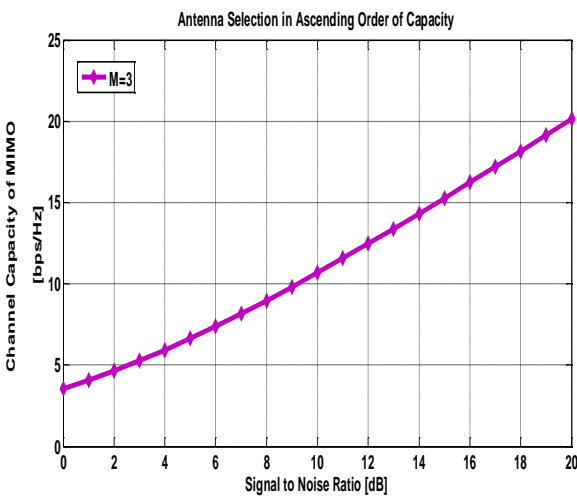


Fig.6 Channel Capacity of MIMO when third Antenna (M=3) is selected.

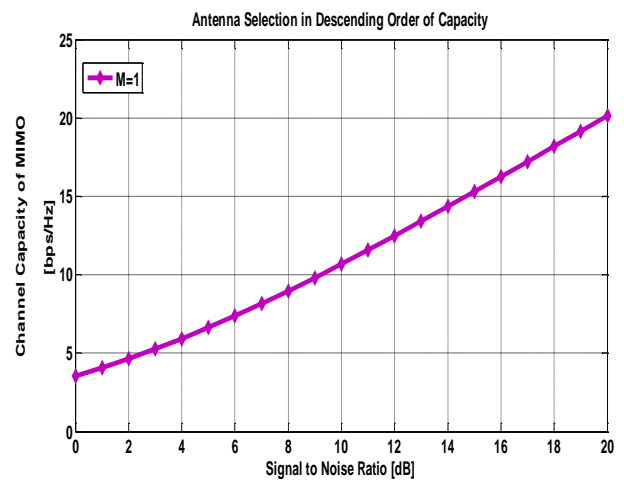


Fig.9 Channel Capacity of MIMO when first antenna (M=1) is selected and deleted from antenna array.

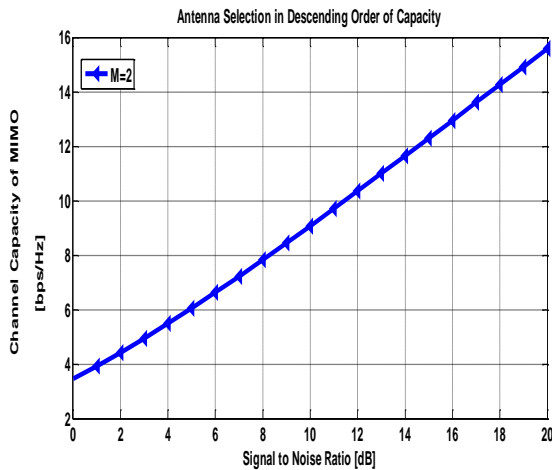


Fig.10 Channel Capacity of MIMO when second antenna (M=2) is selected and deleted from antenna array

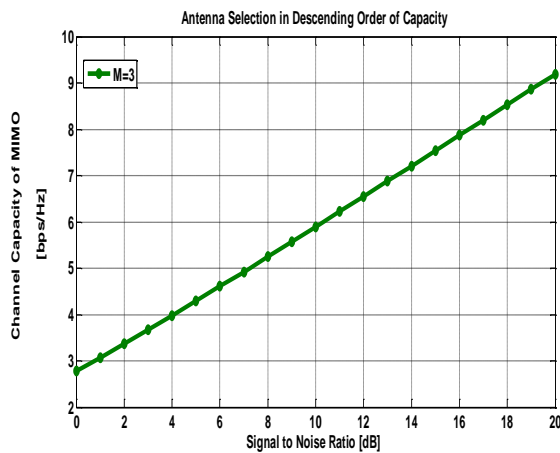


Fig.11 Channel Capacity of MIMO when third Antenna (M=3) is selected and deleted from antenna array

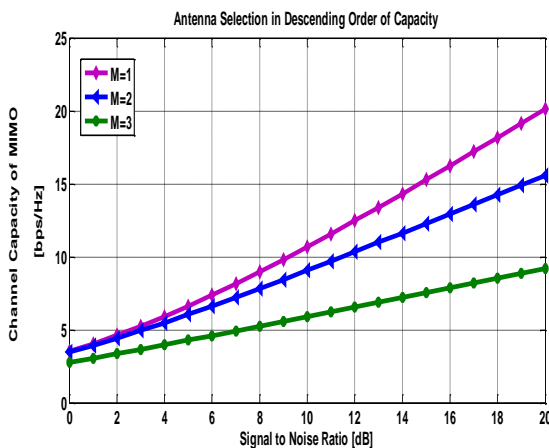


Fig.12 Channel Capacities of MIMO for antenna selection (M=1, 2, 3) in Descending Order of Capacity.

In Fig.(4), Fig.(5), Fig.(6) and Fig.(7), the MIMO system’s channel capacity is measured while first, second, third and fourth antennas are selected in ascending order of capacity. Fig.(8) shows the comparison of channel capacity while first, second, third and fourth antennas are selected in the ascending order of capacity. It is also shows that the MIMO system’s

channel capacity for $A_T - 1$ selected antenna approximately equal to channel capacity of MIMO when all antennas (A_T) are selected. In Fig.(9), Fig.(10) and Fig.(11), the MIMO system’s channel capacity is measured while first, second and third antennas are selected individually in succession and deleted from antenna array, which contribute minimum in channel capacity. Fig.(12) shows the comparison of capacity when antenna first, second and third are selected and deleted from antenna array. Fig.(12) also shows that the MIMO system’s channel capacity while first antenna ($M = 1$) selected and deleted from antenna array is approximately equal to the capacity of channel when all antennas (A_T) selected.

VII. CONCLUSION

This research shows that the MIMO system’s cost increases with the number of antennas at the transmitter (A_T). As each antenna is connected to RF module, the requirement of RF modules also increases with the number of antennas at the transmitting end. This extra RF module requirement increases the cost of MIMO system. In this research, the antenna selection techniques are used to reduce the cost of MIMO system. These techniques select specific number of antennas (M) instead of all antennas (A_T) at the transmitting end ($M < A_T$). So, only M numbers of RF modules are required instead of A_T . Therefore, the cost of a MIMO system reduced. Furthermore, this research also derives the mathematical relationship between the MIMO system’s channel capacity and number of selected antennas (M). This mathematical expression shows that the MIMO system’s channel capacity is proportional to the number of selected antennas. The selection of antenna becomes very complex when large numbers of antennas are placed at the transmitting end. Then, this research also presents the less complex antenna selection techniques, antenna selection in ascending and descending order of capacity to enhance the channel capacity of the MIMO system when large numbers of antennas are placed at transmitter. This research also shows the simulation results of antenna selection in ascending and descending order of channel capacity techniques. Finally, this research compares the results of both techniques and shows that antenna selection in descending order of capacity is more complex as compare to antenna selection in ascending order of channel capacity. From the channel capacity perspective, when $M = A_T - 1$, antenna selection in ascending order of capacity performs better than the selection of antenna in descending order of capacity technique and when $M = 1$, selection of antenna in descending order of capacity performs better than antenna selection in ascending order of capacity technique.

VIII. APPENDIX

ABBREVIATION TABLE

Symbols	Definitions
A_T	Number of transmitting antennas
A_R	Number of receiving antennas
CSI	Carrier State Information
P_T	Total power at the transmitting end
r	Signal received at the receiver
C	Channel matrix
n	Channel noise
M	Number of selected antenna
A_M	M^{th} selected antenna
t	Transmitted signal
E_t	Energy of transmitted signal
R_t	Transmit covariance
D_M	All possible combination of M selected antenna
C^H	Hermition of channel matrix

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