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A Performance Analysis of Massive MIMO System using Antenna Selection Algorithms

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ABSTRACT- A large number of transmitting components makes Massive Multiple-Input Multiple-Output (MIMO) one of the most hopeful solution for the 5G technology. However, a large antenna system boosts the hardware intricacy and cost of the system because of RF transceivers used at the base station for every antenna element. Hence, antenna selection is one of the most effective schemes to select a good subset of antennas with the finest channel circumstances and contribute maximum to the channel capacity. This paper presents Branch and Bound (BAB) algorithm for efficient antenna selection in Massive MIMO technology. The effectiveness of the simulated BAB algorithm is evaluated based on channel capacity and compared with the traditional state of arts such as fast antenna selection algorithm, Exhaustive Search, Fast antenna selection, CBF, CBW, Random antenna selection, etc. Sunflower Optimization-based antenna selection has been shown to provide improved results in terms of channel capacity when compared to the traditional Branch and Bound algorithm. The results indicate that the Sunflower Optimization technique is a promising alternative for antenna selection in Massive MIMO systems, especially in cases where a large number of antennas are present at the transmitter and receiver ends. The proposed solution provides significant improvements over the traditional methods, making it an attractive option for optimizing MIMO performance in future wireless communication systems.

General Terms: Branch and Bound Algorithm, Exhaustive Search, Sunflower Optimization.
Keywords: Massive MIMO, Antenna Selection, Channel Capacity, Signal to Noise Ratio.

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1. INTRODUCTION

Over the past two years, the whole world is going through new transformations in the education system due to the pandemic, as online teaching took over and almost every child started using devices like mobile phones, laptops, smart devices, and computers which consume data. In other words, in the current scenario data becomes the daily need of people either for their work or for online study of children which is increasing the number of users and their demand for high data rate significantly [1-3]. To enhance the receiver efficiency, it is important to consider factors such as the sensitivity of the energy receiver, signal path loss, environmental and interference losses, and information routing methods. Additionally, synchronizing the phase and frequency of the RF signals received from different energy transmitters is crucial for improving receiver efficiency [4]. Also, Orthogonal Frequency Division Multiplexing (OFDM) is a most widely used technique for high-speed data transmission. When combined with antenna arrays at both the transmitter and receiver, OFDM can increase the diversity of signals captured and/or enhance system capacity on time-variant and frequency-selective channels, creating a Multiple-Input Multiple-Output (MIMO) setup [5]. Hence, the exploitation of the 5th generation of wireless communication technology becomes essential. 5th generation wireless technology is an upcoming technology commenced to achieve high spectral efficiency, high throughput, low latency, and low power consumption [6-7]. So, to achieve all these demands, it uses various techniques such as millimeter wave, massive MIMO, a device to device (D2D) communication, and beam-division multiple access. Massive MIMO output is one of the vital schemes used by the 5th generation framework to improve spectrally and power efficiency [8-10].

Massive MIMO (mMIMO), which scales up standard MIMO by orders of magnitude, is a large-scale MIMO device which is increasingly used in wireless communications [10]. It considers multi-user MIMO where a base station (BS) supports several single-antenna terminals at once using thousands or even hundreds of thousands of antennas. The dependability of the connection, the spectrum quality, and the effectiveness of the radiated energy are all improved in a device with several antenna components. At the base station, every antenna element is connected to a single RF chain made up of mixers, analog-to-digital converters (ADC), and amplifiers [11]. Physical limitations, complexity, and the price will also be brought on by the base station's expansion of antennas and related RF chains [12]. RF chains account for between 50 and 80 % of a BS's overall transceiver power consumption [13]. Thus, to make the system energy efficient and less complex, the number of RF transceiver chains has to be reduced. This can be obtained by optimal antenna selection that selects a good subset of antenna elements out of total antenna available at the BS which contributes to the maximum channel capacity at its best channel conditions by retaining the advantages of the full antenna system. It is one of the most proficient techniques used by massive MIMO. It also uses a switching system, in which RF switches are used to connect the selected antenna to one of the RF chains [14-16].

In addition to conventional antenna selection algorithms, intelligent search algorithms were explored to enhance the channel capacity of the MIMO system. Algorithms such as simulated annealing, genetic, particle swarm optimization, and biogeography-based optimization were utilized to find suboptimal solutions for antenna selection, avoiding the issue of getting trapped in local optima [17-19]. The focus of the research is to implement the Sunflower Optimization Algorithm (SFO), a nature-inspired optimization technique based on population optimization for antenna selection in Massive MIMO system.

This paper presents a competent antenna selection scheme for massive MIMO. The chief contributions of the paper are summarized as follows:

- Implementation of efficient Branch and Bound (BAB) antenna selection scheme for massive MIMO to minimize the hardware complexity, computational complexity, and cost.
- Performance evaluation of proposed system based on channel capacity and execution time for antenna selection.

The remaining article is structured as follows: *Section 2* provides the associated work that creates focuses on findings from the recent work on antenna selection. *Section 3* gives exhaustive information regarding the massive MIMO model. *Section 4* gives detailed information on the branch and bound antenna selection algorithm. *Section 5* gives the details of proposed system. *Section 6* focuses on the simulation results of the offered scheme and discussions on the results. Lastly, *section 7* depicts the conclusion and opens the pathways for future improvement in the proposed antenna selection scheme.

2. LITERATURE SURVEY

Various antenna selection techniques have been presented for the conventional MIMO systems; however, it becomes complex for the massive MIMO with a larger number of base stations compared with the conventional MIMO. Some of the techniques were extended to massive MIMO but do not give the optimal solution. The selection criteria for the antenna subset are either based on error performance, channel capacity, power efficiency, computational complexity, or signal-to-noise ratio of the system. Research is required to implement optimal antenna selection for massive MIMO with high channel capacity and less computational complexity [15-16].

In the paper [20], the optimal antenna selection scheme or Exhaustive search is an algorithm that provides the optimal solution by exploring all the possible combinations. It means that every possible combination of the required antennas subset is evaluated and selected which contributes maximum to the channel capacity. But it is not feasible for massive MIMO because of huge number of antennas as it increases the computational complexity or time complexity of an algorithm exponentially. Post-processing SNR also has been used for antenna selection [21]. Computational complexity of Min-max-based selection is more, so needs to be reduced [22].

In the papers [23-24], a convex optimization-based antenna selection algorithm has shown superior performance in terms of sum rate maximization. In the link initialization algorithm, the selection of the antenna is decided by the base station itself. In [25], Link initialization-based antenna selection algorithm was proposed, where the mobile station itself decides from which antenna it wants to receive the data. But this becomes very crucial in the case of a handoff scenario.

In this paper [26], the Fast Antenna Selection Algorithm is an algorithm that gives a near-optimal solution for antenna selection. This algorithm first considers all the available antenna sets and then in every step it removes the antenna which has the lowest channel gain, or which has less contribution towards channel capacity. This process is repeated until L antennas remain. Another algorithm called a fast near-optimal antenna selection technique has less computational burden as compared to the fast antenna selection technique. This scheme begins with an empty set of antenna elements and then in every step one antenna is added which is contributing maximum towards channel capacity. This process repeats until L antennas get selected and added to the empty set.

In the paper [27], Fast and global searching algorithm was proposed by the author in that uses global searching for improvement in capacity performance which is based on the maximum volume square of a sub-matrix formed from the original H matrix. In [28], Correlation-based antenna selection; the correlation between the antennas can be used for the selection of an antenna. The first pair of antennas that are vastly concurrent are selected and then one of them which will not have any effect on the capacity is discarded. In other words, one which is having low channel gain is discarded. This process is repeated until L antennas remained. This neglects the antenna elements lower channel gain and larger value of correlation with already selected antenna elements and worst operating conditions. This method is known as a correlation-based worst-first (CWF) discarding technique. In the paper [29], the greedy search algorithm was proposed which is one of the antenna selection schemes which give suboptimal results. It is an algorithm that chooses an antenna that is best in the group. It means that it is using local maxima for selection in anticipation that it will lead to the globally optimal result for the antenna selection. So, for an objective function that needs to be optimized, a greedy search has to choose the optimized value of an objective function at every step of an algorithm, and once it makes the decision it never goes back to change it. No backtracking. This algorithm is easy as well as fast, but it has to work harder to choose the optimized value and also difficult to prove its correctness [30-31].

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Thus, various antenna selection techniques along with sunflower optimization have been implemented for massive MIMO to improve the channel capacity, minimize bit error rate, improve spectral efficiency, and minimize the computational burden of the system.

3. SYSTEM MODEL

Figure 1 provides the system model of the massive MIMO antenna system. Where Lt and Lr denote transmitting and receiving antennas respectively. These antennas in the system model are considered as Lt number of user equipment and Lr number of base stations receiving antennas. At the receiver side, only Ls RF chains are selected to be connected with Ls optimal antennas among the complete set of Lr. At the transmitter, a single input bit stream is de-multiplexed into Lt sub streams and every stream is modulated separately. It is also assumed that total power is uniformly dispersed among all transmitting antennas.

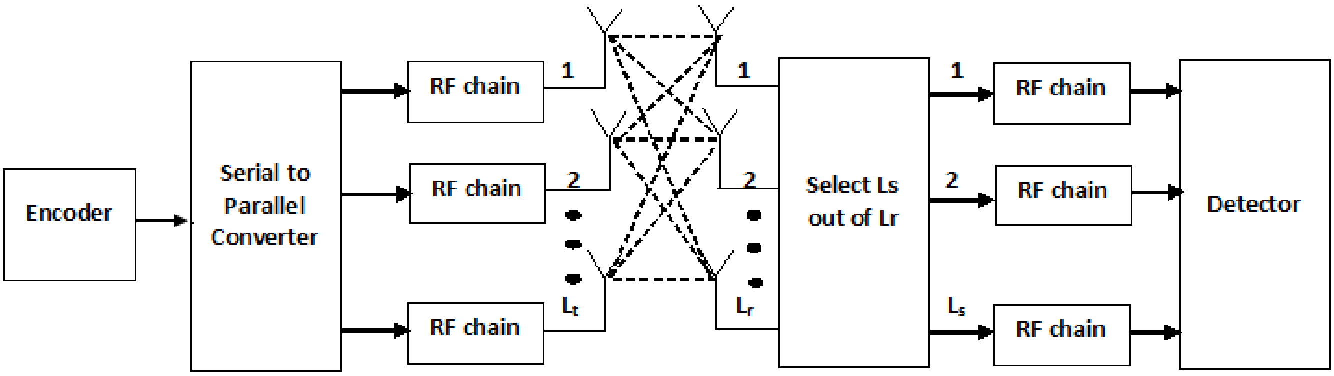

Figure 1. System Model for Massive MIMO

Consider x(t) =[x_1(t), x_2(t)…. xn(t)] represents the propagated symbol vector with dimension $L_t \times 1$ at time. Where x_i(t) denotes transmitted symbols from the i^{th} transmitter at time t. The received signal by L_r receiving antennas y(t) is given by equation 1 [16].

$$y(t) = \sqrt{\rho}\mathrm{Hx(t)} + n(t) \quad (1)$$

where, $[x]_{Nt\times 1}$ stands for transmitted vector, $[y]_{Nr\times 1}$ represents the received vector, $[H]_{Nr\ x\ Nt}$ depicts the channel matrix, h_{ij} describes the complex channel gain between j^{th} transmitting antenna and i^{th} receiving antenna. The elements of H are characterized by an independent complex Gaussian random variable with unit variance and zero mean. $[n]_{Lr\ x\ 1}$ is the receiver noise vector. The noise at the receiver antenna is considered a self-regulating and zero mean circularly symmetric complex gaussian random variable. ρ denotes the average signal-to-noise ratio at the receiver.

Let, the receiver has the perfect knowledge about channel state information and the energy is equally distributed amongst transmitting antennas, then the channel capacity is given by *equation 2*.

$$C_L = log_2 det(I_{Lt} + \frac{\rho}{N} H^H H) \quad (2)$$

Where det(.) denotes the matrix determinant and (.)H denotes the Hermitian matrix. I_{Lt} is an identity matrix of dimension $L_t \times L_t$. As shown in the system model the receiver is connected with L_s RF chains. It is important to select the receiver antenna that desires the most efficient propagation paths that increases the channel capacity which is given by *equation 3*.

$$C_{Ls} = \log_2 \det(I_{\mathrm{Lt}} + \frac{\rho}{\mathrm{Lt}} H_s{}^H H_s) \quad (3)$$

Where H_s is $L_s\ x\ L_t$ sub-matrix of the original matrix H.

The antenna selection scheme initially commences with an empty set of potential antennas and includes one antenna element per iteration instead of calculating channel capacity for all probable grouping of selected antennas. In each iteration, one or more antenna element is selected that results in the highest channel capacity.

In n^{th} stage of the scheme, the channel matrix H_n having a dimension of $n\ x\ L_t$ represents the effect of n receiver antenna elements.

The j^{th} a row of the H is represented by h_j and its Hermitian transpose is denoted by h_j^H. The channel capacity for $(n+1)^{th}$ the step is calculated using *equations 4 and 5*.

$$C_L(H_{n+1}) = \log_2 \det(I_{\mathrm{Lt}} + \frac{\rho}{\mathrm{Lt}} H_{n+1}{}^H H_{n+1)} \quad (4)$$

$$H_{n+1}{}^H H_{n+1} = H_n{}^H H_n + h_j h_j^H \quad (5)$$

By applying the Sherman Morrison formula for determinants *equation 4* can be rewritten as [14]

$$C_L(H_{n+1}) = C_L(H_n) + \log_2[1 + \frac{\rho}{\mathrm{Lt}} h_j{}^H \left(I_{\mathrm{Lt}} + \frac{\rho}{\mathrm{Lt}} H_n{}^H H_n\right)^{-1} h_j)$$

(6)

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$$C_L(H_{n+1}) = C_L(H_n) + \log_2\left[1 + \frac{\rho}{\mathrm{Lt}}\alpha_{j,n}\right] \quad (7)$$

Where β_n and $\alpha_{j,n}$ are given by *equations 8* and *9* respectively.

$$\beta_n = \left(I_{\mathrm{Lt}} + \frac{\rho}{\mathrm{Lt}} H_n{}^H H_n\right)^{-1} \quad (8)$$

$$\alpha_{j,n} = h_j{}^H \beta_n h_j \quad (9)$$

Where $\alpha_{j,n}$ provides contribution made by j^{th} antenna to the channel capacity considered in the $(n+1)^{st}$ step of the algorithm. Finding J that maximizes $C_L(Hn+1)$ which is equivalent to obtaining J=argmax $\alpha_{j,n}$. The antenna Selection Algorithm has to be used to maximize the channel capacity given by C_{Ls} by selecting an appropriate number of antennas from the available ones.

4. BRANCH AND BOUND ALGORITHM FOR MASSIVE MIMO

BAB Algorithmic is one of the most widely used antenna selection algorithms which solve optimization problems. It is used to solve optimization problems where the time complexity is increasing exponentially and, in the case, where it is required to explore all the possible combinations. In other words, if an NP-Hard problem is given, a branch and bound algorithm provide an optimal solution using stepwise elimination of nodes through exploring the complete search space of possible solutions. It does not explore all the nodes in the tree and hence the time complexity of the BAB is less as compared to the other algorithms. It also finds a minimal path to reach the optimal solution. An important advantage of branch-and-bound algorithms is that we can control the quality of the solution to be expected.

Branch and Bound Algorithm

1. Input Channel Matrix H and number of antennas to be selected Lr.
2. Define the upper bound for channel capacity.
3. The channel vector hj is jth row of channel matrix H and j will be an element of [1, 2,.., Nr]
4. Compute Channel gain for each row of the channel matrix using $hj*hj^H$
5. Select the row with a maximum channel gain.
6. Compute the channel capacity using the maximum channel gain computed in step 4 to get the maxima.
7. Compare the defined bound with the calculated channel capacity.
8. If the value is greater than the defined bound, then replace the bound value and select jth row of the channel matrix.
9. Prune all the antennas having less channel gain than the selected one.
10. Go to step 3.
11. Repeat the process till the number of selected antennas will be Ls.

5. PROPOSED SYSTEM

In this proposed work, the focus is on the implementation of an optimal antenna selection algorithm using the Sunflower Optimization Algorithm (SFO) to achieve high channel capacity and reduce computational complexity for Massive MIMO systems. The use of SFO also helps to reduce the number of RF chains needed at the base station, ultimately reducing the overall cost, circuit complexity, and power consumption of the system. The SFO is a population-based, global optimization approach that has been proven to be effective in solving multi-modal problems, and it provides robustness through the use of root velocity and pollination terms. This technique is being applied to the inverse problem of structural damage detection in composite laminated plates. The results of the proposed SFO algorithm are compared to Branch and Bound to demonstrate its effectiveness in improving the efficiency.

6. RESULT AND DISCUSSION

The suggested system is simulated on the MATLAB2018b on a personal computer having 8GB RAM and a Windows operating environment. The simulation results of various antenna selection algorithms such as Exhaustive search [17], Fast Antenna Selection [22], Random Antenna Selection, Norm based Antenna Selection, Correlation-based best first, Correlation-based worst First [25], Branch and Bound algorithm [27][28] are presented and compared concerning the channel capacity.

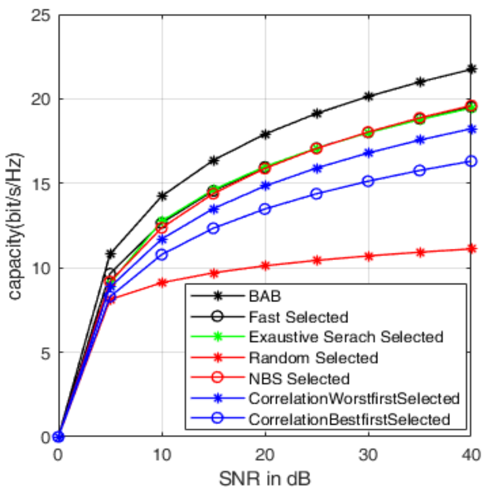

Figure 2. Performance for SNR vs channel capacity (L_t=16)

Figure 2 shows the SNR vs channel capacity performance comparison of BAB long with traditional antenna selection algorithms for different values of SNR. Increasing the SNR values results in increased channel capacity of the system. The BAB provides channel capacity of 22.30 bits/s/Hz that shows significant improvement over Fast Selected (20 bits/s/Hz), NBS Selected (19 bits/s/Hz), random selected (8 bits/s/Hz), Correlation-based Worst First Selection (11 bits/s/Hz), and Correlation best first selected (10 bits/s/Hz) for 40 dB SNR. The performance of antenna selection is poor in the low SNR regions.

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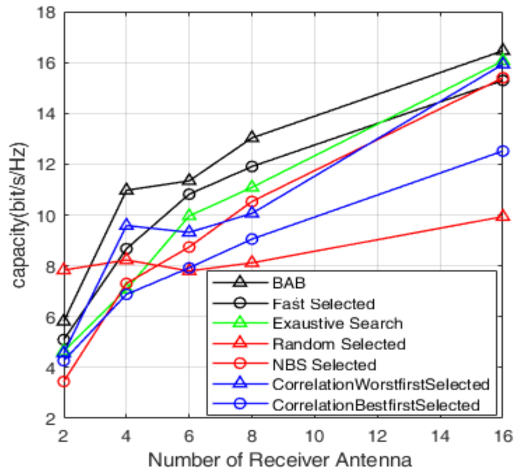

Figure 3. Performance for receiver antenna to be selected vs channel capacity (Lt=16, SNR=20dB)

Figure 3 depicts the effect of the selection of receiver antenna on channel capacity for massive MIMO. The higher number of receiver antennas generally gives better throughput. But for lower transmitter antennas, the BAB provides noteworthy improvement over the traditional state of arts.

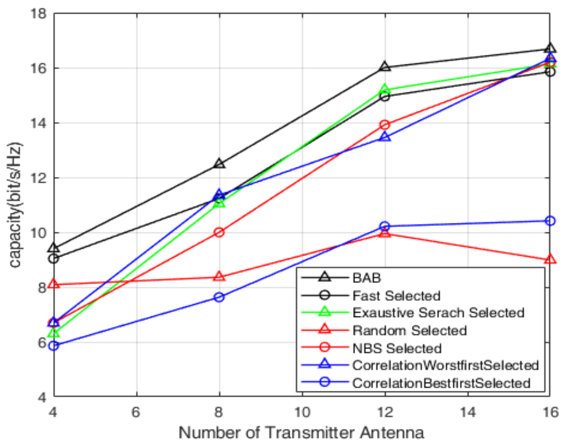

Figure 4. Performance for transmitter antenna to be selected vs channel capacity (Lr=16, SNR=20dB)

Figure 4 illustrates the performance of the BAB for different transmitter antennas. Higher values of the transmitter antenna increase the signal strength of the propagated signal, thus resulting in higher channel capacity. However, increasing the number of base stations (Lt) augments the computational complexity and hardware complexity of the system.

Table 1: Execution time for the antenna selection

Name of Algorithm	Execution time in Seconds
Optimal Antenna Selection	199.592 s
Random Antenna Selection	1.667 s
Correlation-based Worst First Antenna Selection	94.874 s
NBS Antenna Selection	12.368 s
Correlation-Based Best First Antenna Selection	9.612 s
Fast Antenna Selection	5.715 s
Branch and Bound Antenna Selection	13.412s

Table 1 shows the required execution time of all antenna selection algorithms. The execution time required by the Random Antenna Selection algorithm is less as compared to all other techniques, but it does not give optimum results in terms of Channel Capacity. After Random Antenna Selection, the Fast Antenna Selection algorithm has less execution time. So, these two techniques along with an Exhaustive Search have been taken as a reference. It has been observed that even if a branch and bound antenna selection algorithm required more execution time, the channel capacity performance is nearer to the exhaustive antenna search or optimum antenna selection algorithm.

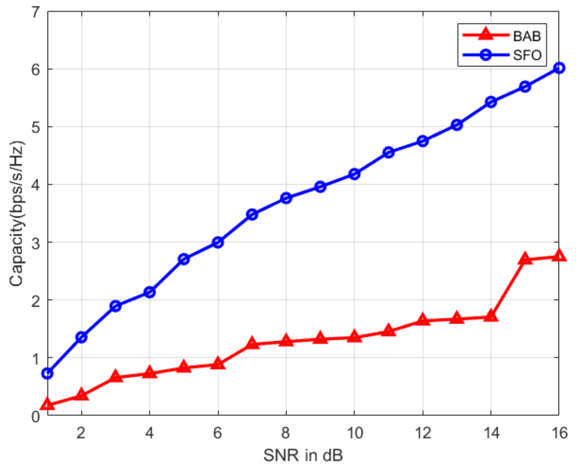

Figure 5. Performance for SNR Vs Channel Capacity for SFO and BAB (Lr= 64)

The *figure 5* shows the performance of Sunflower Optimization and BAB for 64 receiving antennas. The comparison demonstrates that the proposed sunflower optimization algorithm outperforms the branch and bound algorithm in terms of channel capacity. These results suggest that sunflower optimization is a promising alternative to traditional optimization techniques for antenna selection in MIMO systems.

6. CONCLUSION

In this study, various antenna selection techniques were implemented and compared using MATLAB programming software. The results were analyzed and compared to determine the best approach. While Exhaustive Search is the best option for maximum capacity, it takes longer to process. Fast Antenna Selection, on the other hand, is quicker but not as efficient in terms of capacity. The Branch and Bound Algorithm (BAB) was found to be the optimal solution, offering similar capacity as Exhaustive Search while also providing better trade-offs between capacity and processing time, particularly in noisy environments and with varying base stations and receiver antennas. However, the BAB can be slow when dealing with a large number of antennas and difficult to parallelize. Optimization Technique called sunflower Optimization has been implemented to improve the channel capacity for large number of antennas. It has been shown that the sunflower optimization (SFO) technique provides improved channel capacity compared to the branch and bound (BAB) algorithm for antenna selection in massive MIMO systems.

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