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Efficient Antenna Selection Strategy for a Massive MIMO Downlink System

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Abstract—This paper focuses on an efficient antenna selection strategy for a distributed massive MIMO system. The objective of the proposed algorithm is to attain ergodic achievable rate as much as possible with antenna selection in a constrained capacity limited system. In this proposed work, the initial selection of antenna set is based on channel amplitude and correlation which then follows an iterative approach in order to select the best subset of transmit antenna elements from the overall antenna set. The proposed scheme significantly outperforms, in terms of ergodic rate with low complexity, the prevailing transmit antenna selection methods. Simulation results show that the performance of the proposed antenna selection method is close to select all transmission with a minimum throughput loss. Thus the proposed method is best suited for a large scale distributed Massive MIMO system without degradation in system performance and is of low computational complexity.

1. INTRODUCTION

The ubiquitous accessibility of broad band access has improved the quality of end users. Recent wireless communication systems have an ever-increasing number of instantaneous users and services. In order to meet the user requirements without increasing the system bandwidth distributed antenna systems (DAS) are preferred [1]. In DAS architecture, the remote antenna units (RAU) are geographically separated and connected by a fiber backhaul to a central unit where signal processing is performed. This forms a distributed network called as the cloud radio access network (CRAN) which reduces the access distance to the user and inter-cellular interference in outdoor applications [2]. Energy-efficient transmission is an important factor for the design of future wireless communication systems. The research work presented in [3] shows that enhanced throughput and better energy efficiency can be obtained in the case of precoding based massive MIMO systems. This illustrates the significance of massive MIMO antenna technology for data throughput and energy efficiency maximization in future 5G systems. The implementation cost of the high speed backhaul link is high whose limitation is in the distributed antenna systems. The importance of several antenna selection algorithms has been discussed for Multiuser MIMO (MU-MIMO) in [4–8]. Most of them employ an exhaustive search approach which increases the complexity of the system. Some of the algorithms which are proposed in [6, 8] do not consider the attainment of desired ergodic rate for users in a multi-cell environment. In papers [9] and [10], the authors consider a MIMO system with numerous antennas without considering the effect of computational complexity. Sum rate maximization of a distributed antenna system with limited backhaul for an uplink system has been discussed in [11]. In [12] by considering independent and identically distributed Rayleigh flat fading channels, the asymptotic higher capacity limits of massive MIMO with antenna selection for full array and sub array switching architectures are discussed.

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When MIMO antennas are considered for a terrestrial wireless channel, lack of rich scatters deteriorates the channel matrix resulting in high bit error rate performance. In a similar scenario considered in [13], the channel matrix is enhanced by properly selecting the appropriate antenna spacing. The improved channel obtained as a result of optimum antenna spacing is too large to be implemented for long range terrestrial wireless links. It is also shown that multilevel maximum ratio combining technique is capable of improving the detection efficiency. A method for distributed massive MIMO antenna selection is discussed in [14], where extremely correlated spatially clustered antennas are not given priority in the selection process. The technique of splitting the channel gain vector matrix into two equal size sub-matrices and then obtaining the enumerations of all channel gain vector pairs for each sub-matrix has been shown to reduce the complexity in the case of MIMO system considered in [15], but it is not suitable for a massive MIMO system where the number of antennas is large. In [16], joint adaptive antenna selection and power allocation for a modified Turbo-BLAST system is proposed. The adaptive transmit antenna selection method selects a suitable antenna subset for data transmission, and the power allocation for the selected antenna subset is based on the total transmit power constraint. It is also observed from the results that the proposed scheme has a considerable effect on the BER performance with less impact on improving the spectral efficiency and is inappropriate for a multi-user massive MIMO distributed antenna configuration. In [17], two simple antenna selection algorithms are proposed with the objective of attaining the utmost energy efficiency. The performance limits of massive MIMO systems under practical antenna selection algorithms using large scale system analysis that maximizes the energy efficiency are studied in [18]. In [19], the impacts of transmit antenna selection on the secrecy performance of massive MIMO systems are analyzed. It is found that in some wire tap settings under antenna selection, the increase in the number of active antennas improves the secrecy performance of the system up to some optimal number.

When we compare the proposed antenna selection strategy with the existing works on antenna selection in massive MIMO systems, it is observed that in [6] antenna selection provides a low-hardware complexity solution for exploiting the spatial diversity benefits of MU- MIMO system, but it does not consider the attainment of desired ergodic rate for users in a multi-cell massive MIMO distributed antenna system. An antenna selection based on selection diversity which is achieved by scaling the larger SNR values is considered in [8]. This method does not consider the effect of inter-user interference in a multi-cell scenario. In [9], a cellular architecture with distributed antenna systems is introduced for broadband wireless communications (BWC). In particular, the DAS is discussed in combination with radio over fiber (RoF) technology for high speed train (HST) systems. In this work, a DAS system without considering the effect of backhaul link constraint is discussed. The downlink spectral efficiency analysis for a multi-cell multi-user large scale distributed antenna system with pilot contamination is studied for a composite correlated Rayleigh fading channel without considering the effects of antenna selection in [10]. A DAS with limited backhaul for an uplink system with the objective of only sum rate maximization without considering the effects of hardware complexity and fading in downlink is discussed in [12]. An improved channel matrix obtained by appropriate antenna spacing which is unsuitable for a large scale cellular system is discussed in [13]. In [14], highly correlated spatially clustered antennas are not given importance in the antenna selection process. The work proposed in [15] is not suitable for a massive MIMO system since the complexity linearly increases with the number of antennas. A joint adaptive transmit antenna selection and power allocation for the modified Turbo-BLAST system with less impact on spectral efficiency enhancement is considered in [16]. In [17] and [18], antenna selection algorithms are proposed with the purpose of attaining only utmost energy efficiency rather than considering sum rate maximization, interference, and complexity analysis. The effect of transmit antenna selection on the secrecy performance of massive MIMO systems is discussed in [19]. In [20], the complexity of antenna selection increases with the number of antennas which is very high for a massive MIMO system. In greedy based approach [21], a previously selected bad antenna becomes an unnecessary one when new antennas are selected but could not be removed from the overall antenna set. The proposed scheme focuses on an antenna selection algorithm which obtains the best possible subset of antennas from the overall antenna set to serve the users with the objective of attaining the desired ergodic achievable rate and is of low computational complexity. It overcomes the disadvantage of exhaustive search technique and is also a suitable choice without degrading the energy efficiency in a distributed massive MIMO system. The proposed antenna selection algorithm accomplishes significant reduction in complexity with enhanced sum rate. It performs closer to the select all scheme without much degradation in system performance. It also achieves a near optimal performance with minimum throughput loss. The ability of the algorithm to converge in finite number of steps makes it suitable for real time applications. Thus, the proposed work in particular is very suitable for a distributed Massive MIMO system with capacity constraint. In a massive MIMO system, the backhaul load is directly proportional to number of active antennas if the symbol rate is fixed. So the antenna selection strategy employed also helps in minimizing the backhaul load. The system model is given in Section 2. In Section 3, antenna selection algorithm is discussed. Section 4 presents the simulation results, and Section 5 concludes the paper.

NOTATIONS:

In this paper, all the boldface letters in lower case represent vectors and upper case for matrices. The transpose and Hermitian transpose operators are denoted by $(.)^T$, $(.)^H$. The Frobenius norm of $\mathbf{A}$ is denoted by $\|\mathbf{A}|$.

2. SYSTEM MODEL

Consider a cellular system with N hexagonal cells. Each cell consists of A remote antenna units which comprises L antennas. Inside each cell, there are U single antenna users who share the same bandwidth (Fig. 1). Here we consider transmission over frequency-flat fading channels. The performance of the above distributed antenna system is closely dependent on the positions of RAUs. The transmit antennas are connected to the base band processing unit by a fiber optic link. The signal on the fiber is in digitized form in a DAS so that it can transport the mobile signal at full strength to any remote antenna connected independent of distance from the main hub and base station (BS).

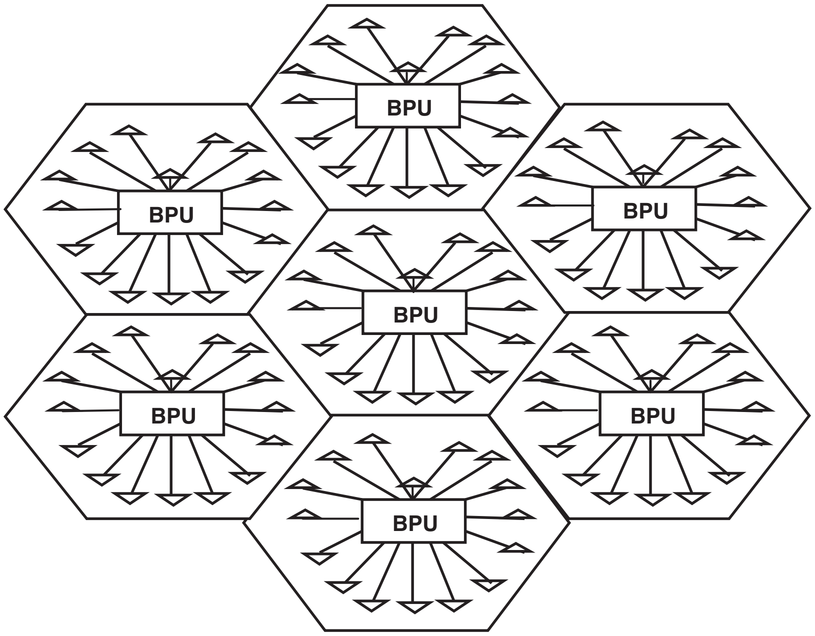

Figure 1. Hexagonal cellular system with central base band processing unit surrounded by sixteen remote antenna units connected through fiber optic link.

A large scale distributed antenna system can achieve considerable performance gain compared with a co-located massive MIMO system with the same number of antennas. Thus, DAS can mitigate large-scale fading which is a path loss using the many antennas distributed geographically [22]. Assuming channel reciprocity, the downlink of distributed massive MIMO system is considered to be operating in TDD mode.

In the system considered, the channel vector from the uth user in the nth cell to all of the RAUs of a particular base station is given by

$$\mathbf{h}_{i,n,u} = \frac{\mathbf{S}_{i,n,u}}{\sqrt{\mathbf{\Lambda}}_{i,n,u}} \tag{1}$$

$$\Lambda_{i,n,u} = \text{diag}[\lambda_{i,1,n,u}, \lambda_{i,2,n,u}, \lambda_{i,3,n,u}, \ldots, \lambda_{i,A,n,u}] \tag{2}$$

$$\lambda_{i,a,n,u} = \frac{c}{d^{\alpha}} \text{where } d \text{ is distance} \tag{3}$$

The path loss exponent value is considered to be in the range of 3–5, and c is the median of mean path gain [9, 10].

$$\mathbf{S}_{i,n,u} = \left[\mathbf{S}^T_{i,1,n,u}, \mathbf{S}^T_{i,2,n,u}, \ldots, \mathbf{S}^T_{i,A,n,u}\right]^T \tag{4}$$

In Eq. (4), $\mathbf{S}_{i,n,u}$ represents the small scale fast fading, whose elements contain independent identically distributed zero mean circularly symmetric complex Gaussian random variables with zero mean and unit variance. If d is the $U \times 1$ data symbol vector of U users with symbol rate r_d and bit width of the precoded data X is represented as bw_x, then the backhaul load of the fibre with R active antennas is given by

$$B_{load} = Rr_d bw_x N_c \tag{5}$$

where N_c is the OFDM subcarrier number for a MIMO-OFDM structure. According to Eq. (5) and the capacity constraint, the maximum number of active antennas can be determined.

In practical cellular networks due to the limitation of channel coherence interval non-orthogonal pilot sequences have to be utilized in different cells. So the channel estimate obtained in a given cell is contaminated by pilots transmitted by users in the other cells. This effect is called pilot contamination which reduces the system performance. In the above system, the channel is considered to be in the presence of pilot contamination. Channel estimation is done by including the users of the neighbouring cells in the estimation in order to improve the performance of users in the target cell. A minimum mean square channel estimator (MMSE) is considered for the system.

Large scale fading (LSF) is shadow variations caused by large terrain features such as small hills and tall buildings between the base station and mobile terminal. Large scale fading is due to the path loss of signal as a function of distance and shadowing by large objects such as buildings and hills. This occurs as the mobile moves through a distance of the order of the cell size and is typically frequency independent. Power variation statistics due to large scale fading can be well quantified as it is a type of slow fading. The equivalent large scale fading from a particular user in a cell to RAUs in other cells can be represented as

$$\beta_{n,a,i,u} = \lambda_{n,a,i,u}\left(\sum_{i}^{N} \lambda_{n,a,i,u} 1/SNR_{train}\right) \tag{6}$$

The downlink achievable rate is obtained for the above DAS with maximum ratio transmission (MRT) and the same set of orthogonal pilot sequences reused in every cell. For such a channel, the ergodic achievable rate in downlink transmission for a particular user u in the nth cell is given by [22]

$$D_{n,u}(dl) = \log\left[1 + \frac{r_n L^2 \left(\sum_{a=1}^{A} (\beta_{n,a,n,u})\right)^2}{L \sum_{ija} r_n \lambda_{i,a,n,u} \beta^2_{i,a,i,j} + L^2 \sum_{i \neq n} r_n \left(\sum_{a=1}^{A} \beta_{i,a,n,u} \beta_{i,a,i,u}\right) + \frac{1}{SNR(dl)}}\right] \tag{7}$$

The parameter $r_n = \frac{\text{U}}{\text{L}} \sum_{a,u} \beta_{i,a,i,u}$ normalizes the average transmit power per user in a particular cell.

3. ANTENNA SELECTION ALGORITHM FOR A DISTRIBUTED MASSIVE MIMO SYSTEM

In a massive MIMO system hundreds of antennas at a base station are simultaneously used for transmitting data to much smaller number of mobile stations (MS) with single antenna. However, large number of antennas at BS requires high hardware complexity in both digital and radio frequency (RF) analog domains. In order to reduce the hard ware complexity, transmit antenna selection (TAS) technique can be used [23].

In order to fully exploit the gain provided by massive MIMO, it is necessary that all the antennas should take part in transmission. To provide such a high-rate data transfer which permits all the antennas in the range of hundreds to work together an ultra high speed fiber backhaul is required, but commercially it is not possible to equip every base station with such an ultra high speed cable. In many existing systems, the backhaul links are capacity limited which is a drawback for realizing the potential performance gain of both downlink and uplink of massive MIMO over traditional MIMO system [24, 25]. In this situation, we can use antenna selection criterion to choose a subset of RAUs performing transmission and still achieve the possible gain of a massive MIMO array.

In a CRAN type of network, the base band processing unit generates the transmit signal at each antenna of an RAU and then transfers the signal to the RAU through a fiber cable. All the fiber cables associated with the RAUs are bunched in to a single fiber backhaul which then links the BPU. Considering a massive MIMO system with the data transmission scheme mentioned above and if the symbol rate and bit width of each recoded symbol is fixed, then the backhaul signaling load is proportional to the number of active antennas [26]. In the proposed work, the backhaul capacity C is taken as a limited one. The backhaul signaling load of the fibre B_{load} with R active antennas is given by Equation (5). In a DAS system, it is considered that $B_{load} \leq C$. According to Equation (1) and the constraint on C, the maximum number of active antennas R can be determined. Then based on the number of active antennas needed, the proposed algorithm selects a subset of antennas from the antenna set of all base station transmit antennas. The transmit power is taken as P. Then the problem lies on how to select a subset of antenna from the fixed antenna set of overall base station transmit antennas. Thus the objective of the proposed algorithm is to attain the ergodic achievable rate as much as possible with antenna selection in a constraint capacity limited system. In order to reduce the computational complexity, the proposed algorithm follows an iterative approach where the antennas are evaluated one by one in the selection process according to certain criteria.

The problem Y is formulated as follows

$$Y : \max D(A, P)$$

such that $p = [p_1, p_2, p_3, \ldots, P_U]$ which is the power allocated for users $1, 2, 3, \ldots, U$, $1 \leq |U| \leq |A$, $\sum_{i=1}^{U} pi = P$, and A_1 belongs to A.

The first step involves the computation of channel matrix $\mathbf{H}$. Let us consider A as the set of all available antennas within the cell and U the users associated in the same cell. This algorithm with low complexity is characterized by computation of the sum of absolute values of channel coefficient between all the user terminals and the mth BS antenna initially. Then, the initial antenna set from the entire available antenna in the nth cell is derived based on the sum of absolute values of channel coefficient between UTs and a particular BS antenna sorted in descending order (Table 1). The number of activated antennas would depend on the fiber capacity [25]. Let M be the number of maximum active antennas that can be determined based on Eq. (5) and the maximum capacity constraint.

The initial antenna set is taken as A_0, and the scheduled user is U. The initialization process aims at selecting the antennas which has good channel gain towards the user. Let us consider the initial value of S as zero. The iterative updating of the antenna set is based on finding the new antenna set which is derived from the initial antenna set by adding the best antenna from $(\mathrm{A}^{S})^{q}$ and removing the antenna with least gain from A^{S}. W_j^s is the jth element of A^{S}, where $j = 1, 2, 3 \ldots M$ with M being the total number of selected antennas, and $(\mathrm{A}^{S})^{q}$ is the complementary set of A^{S}. Then, the ergodic achievable rate with the previous antenna set is compared with the new derived antenna set in order to obtain the final antenna set. This step is very essential to make sure about the convergence of the algorithm. The value of S is then incremented, and the iterative updating continues until the final antenna set is obtained which is taken as A_{final}.

The iterative process in the algorithm helps in updating the antennas with best channel gain towards the selected user at each step. The proposed scheme overcomes the disadvantages of select all transmission scheme in a downlink capacity limited distributed Massive MIMO system. The algorithm

Table 1. Proposed antenna selection algorithm.

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RATE MAXIMIZATION BASED ANTENNA SELECTION ALGORITHM
$v = [v_1, v_2, v_3, \dots v_M]$
for $m = 1 : M$
    $v_m = \sum_{u=1}^{U} |H(m,u)|^2$
end
Select M antennas with largest $v_m$ to form $A_0$
Let $S = 0$ and $A^{S-1} = \{\ \}$
While $A^S \neq A^{S-1}$ do
    $W_j^{s\#} = \arg\min \|H\{U,\ W_j^s\}\|$
    $W_j^s \epsilon\, A^S$
    $W_j^{\#} = \arg\max \|H\{U,\ W_j\}\|$
    $W_j \epsilon\, (A^S)^q$
    Formulate $A_{0new} = (A^S / W_j^{s\#} \cup \{Wj^{\#}\})$
    if D ($A_{0new}$, U, $r_n$) > D ($A_0$, U, $r_n$)
        $A^{S+1} = A_{0new}$
    else
        $A^{S+1} = A^S$
    end if
    S = S +1
end While
$A_{final} = A^S$
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converges in a finite number of steps. The actual number of iterations required is independent of the number of transmitting antennas and the users. Every time the updated antenna set occurs only if the achievable sum rate of the new antenna set is larger than the previous set.

The greedy algorithm at every step refurbish the transmit antenna subset by adding that antenna to the available subset that has the largest increment to the mutual information among the available antennas. So the complexity of the greedy algorithm is linear with respect to the number of antennas. Thus in the greedy based antenna selection the complexity grows with the number of antennas which is very high for a massive MIMO system.

In Norm based antenna selection (NBS), the row of channel matrix with maximum Frobenius norm is chosen in each step selection which is most appropriate for small SNR or only an RF link at the receiver but not advantageous in other scenarios. The overall complexity of the proposed algorithm is about O ($U_{\max}M^2$)+ O (M^2). Thus the proposed algorithm provides a balanced performance between computational complexity and sum rate without degrading the overall system performance.

4. PERFORMANCE EVALUATION

A hexagonal cellular system with $N = 7$ cells is considered with cell radius taken as 1 km. It is assumed that 16 RAUs are available in each cell, and the distance between two adjacent cells is normalized to $\sqrt{3}$. The RAUs are distributed in each cell with d_1 as centre such that $d_1 = 0$, d_2, d_3, $d_4 \dots d_{16} = (3-\sqrt{3})/2$. The angular separation of RAUs is considered as $\theta_1 = 0$, θ_2, θ_3, $\theta_4 \dots \theta_{16} = n\pi/6$ where $n = 1, 2, 3 \dots 15$. A distance based path loss model with path loss exponent $\alpha = 3$ is assumed, and the median of mean path gain c is considered as one. The downlink SNR is taken as 10 dB. The locations of the users are randomly generated from a uniform distribution within the coverage limit of the cell. The performance of the system is evaluated in terms of ergodic achievable rate.

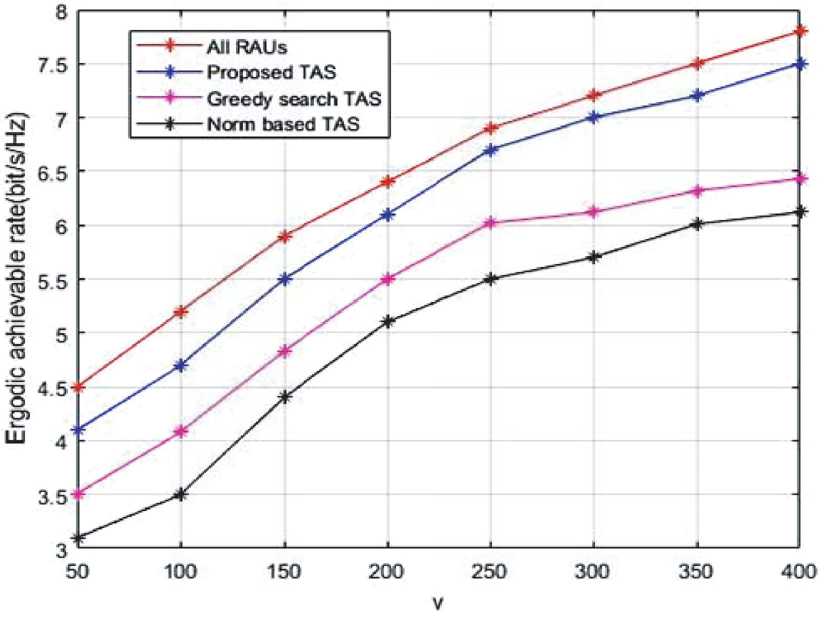

Figure 2. Ergodic achievable rate of a downlink distributed antenna system with ratio v.

In Fig. 2, the ergodic achievable rate for the system considered is given as a function of v which is the ratio of the total number of antennas in all RAUs within each cell to the number of users. The proposed algorithm is compared with the other transmit antenna selection methods

like norm based and greedy search selection approach. The results are also compared by considering all RAUs scheme where all the available antennas are considered for transmission without taking into account of capacity constraint. It is assumed that six users are uniformly distributed within each cell. It is found (Fig. 2) that for a smaller number of antennas the ergodic rate quickly increases, but with

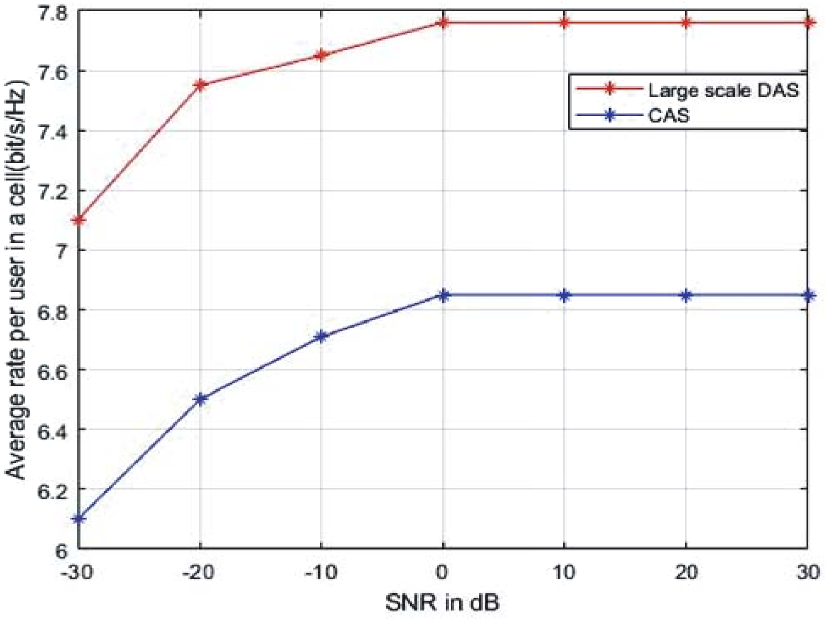

Figure 3. The average cell edge rate of the proposed algorithm at different SNR for co-located and distributed antenna system.

increasing number of antennas the rate of increase is slower due to the received SNR. It is shown that the proposed transmit antenna selection algorithm achieves relatively the same rate and is less complex with an insignificant throughput loss. Thus the proposed algorithm significantly outperforms the sum rate compared with norm and greedy based approaches.

Figure 3 shows the average rate per user in a cell with different SNR values for the proposed algorithm considering two different massive MIMO antenna configurations such as the co-located and distributed antenna system. Here we assume that the users are in uniform distribution with radius $\sqrt{3}/2\,R$ around the centre which is considered as the hexagonal cell edge.

It is observed (Fig. 3) that for small SNR the average cell edge rate increases as SNR increases; however in larger SNR regime, the rate almost gets saturated due to interference limitation independent of the values of v.

Due to the availability of RAUs in a distributed antenna system, the path losses of the radio frequency signals are avoided which gives a larger cell edge rate and significant overall performance than the co-located antenna system.

5. CONCLUSION

In this paper, a distributed Massive MIMO system with RAUs scattered in the cell and MRT used in downlink transmission is considered. For such a capacity limited system, the select all transmission scheme is inefficient. In order to overcome this antenna selection algorithm which provides a significant reduction in complexity with tradeoff between sum rate and complexity reduction is proposed. In this algorithm, the iterative process updates the best antenna at each step in order to achieve a higher ergodic achievable rate performance. It is infeasible to obtain optimal sum rate by exhaustive search method due to huge computational complexity involved.

Simulation results show that the proposed antenna selection algorithm performs better in terms of sum rate than the select all schemes without much degradation in system performance. Simulation results show that the proposed antenna selection algorithm performs closer to select all scheme without much degradation in system performance. It also achieves a near optimal performance with minimum throughput loss. The ability of the algorithm to converge in finite number of steps makes it suitable for real time applications. Thus, the proposed work in particular is suitable for a distributed Massive MIMO system with capacity constraint. The transmit antenna selection algorithm with existence of imperfect CSI can be considered for future work.

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