Interference Aware User Grouping Strategy for Downlink Massive MIMO Systems

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Abstract - *In a Multiuser massive MIMO system with time division duplex scheme serving multiple users inter-user interference will degrade the system performance and so the users with correlated channel condition can be served in different time slots. In this paper a user grouping algorithm which separates the users based on the interference power is proposed. The grouping process first finds the difference in interference power of the users based on which the users are separated in to groups. Here the number of groups formed is not fixed but it depends on the user interference. The isolated users in the corresponding groups are then served in different time slots. The proposed scheme tends to serve all the users thereby ensuring fairness among the users. Simulation results show the effectiveness of the proposed scheme even in a highly correlated channel condition.*

Key Words: **Massive MIMO, Channel state information, Time division duplex, signal to noise plus interference ratio, User grouping**

1. INTRODUCTION

Massive MIMO which is also known as very large MIMO or large scale antenna systems is one of the most promising technologies for the next generation cellular systems. It is envisioned that in massive MIMO, the BS is equipped with hundreds of antennas and serves tens of users at the same time. With excess spatial resources, massive MIMO can achieve all the merits of MIMO systems with a much greater scale. It is also assumed that the number of antennas M and the number of single-antenna users K go to infinity, while the ratio of K/M is fixed.

In massive MIMO, time division duplex (TDD) scheme can be used where the uplink transmission and the downlink transmission use the same frequency band while they are separated by different time slots. In TDD scheme, there is a possibility to obtain channel reciprocity where the downlink channel matrix equals to the transpose of the uplink channel matrix. Then the downlink CSI can be achieved by uplink training in which the complexity of uplink training scales as the number of users. [1-5]

Most of the existing MIMO schedulers estimate the orthogonality of user's spatial channel and serve the users with near-orthogonal channels simultaneously [6]. Serving multiple users with correlated channels would bring severe degradation in system capacity and so there is a need for user grouping in a multiuser MIMO system where users with correlated channels should be served by different time slots. In [7] angle between users (ABU) is used to measure the correlation between different users is proposed. The two users are served within the same time slot only when the ABU is greater than a certain threshold value otherwise TDMA will be used instead. A hierarchical user grouping algorithm is suggested in [8] where merging of individual users based on certain criteria for user grouping is done. Eventually, all users can form one single group or it can terminate when the desired number of groups is reached. In [9-11] the grouping process relies on finding the correlation coefficients that are larger than a certain threshold value and isolating the corresponding users in separate groups who are then served in different scheduled time.

The authors in [12-19] have studied the user grouping and scheduling problems based on a two-stage precoding framework for FDD massive MIMO systems where they have proposed weighted likelihood similarity measure, subspace projection based similarity measure, hierarchical clustering and K-medoids clustering for user grouping in order to achieve load balancing and user fairness for FDD massive MIMO systems.

The importance of the proposed scheme is to take advantage of TDMA when the users are highly spatially correlated while maintaining the good performance provided by MU-MIMO when the inter-user correlation is low. Instead of randomly selecting users from the large pool of users the grouping process select users with less interference and thereby exploiting multi user diversity. As a result users in the same time slot will have low spatial correlation and therefore higher capacity can be achieved. Unlike the other existing works the proposed user grouping algorithm aim on finding the interference between users which is used as an criterion for user grouping process and is effective for improving the system performance even under highly correlated channel conditions.

2. SYSTEM MODEL

A single cell multi-user massive MIMO system is considered which has a BS and K single antenna users. The BS is equipped with M antennas where M is assumed to be very large. Such MIMO systems are capable of achieving high data rates, wider coverage and increased reliability without using additional frequency spectrum. It also exploits multipath by spatial diversity as well as spatial multiplexing techniques. For each user the downlink channel is modeled as a Rayleigh flat fading channels. Rayleigh fading model is used for analysis mainly because of its generality and applicability to the practical situation. In a slow fading channel, where the coherence time is greater than the latency requirement the system capacity is indistinct as the maximum rate of reliable communications supported by the channel depends on the random channel gain which is unknown to the transmitter.

In a fast fading channel, where the latency requirement is greater than the coherence time and the code word length spans many coherence periods, we can average over many independent channel fades and thus it is possible to achieve a reliable rate of communication. Rayleigh fading model considers that the fading is caused by multipath reception. Rayleigh fading model assumes that the magnitude of a signal that has passed through transmission medium will vary randomly according to a Rayleigh distribution. Rayleigh fading is a reasonable model when there are many objects in the environment that scatter the radio signal before it arrives at the receiver. Rayleigh fading is most applicable when there is no dominant line-of-sight propagation between the transmitter and receiver. There are various properties of the fading channel except scattering, such as doppler spread, path loss, correlation can be taken into consideration while exploiting the characteristics of the channel. In this work we concentrate on user correlation in terms of interference power.

In the MIMO channel model considered the signal at the output of the receiving antennas in flat fading can be written as $y = \mathbf{H}s+\mathbf{n}$ where the signal to transmit s is coded into de-correlated branches that are transmitted over a channel Matrix H.s is the M_T dimensional vector and n is M_R dimensional vector with zero mean independent and identically distributed (i.i.d) complex Gaussian entries with independent real and imaginary parts having equal variance. **H** models the fading characteristic of the channel with respect to each transmitted and received signal. Thus the received signal y is a combination of transmitted signal and noise **n** and with various multipath components that must be combined coherently to detect the desired signal.

Let **H** be the K × M channel matrix and $\mathbf{h}_k$ *is* the 1×M channel vector from the BS antennas to the k^{th} user. In the absence of an LOS component, the channel matrix is modeled as CN~ (0, 1). We assume that the BS has perfect downlink CSI which can be achieved when TDD scheme is used and channel reciprocity holds. Let q be the K×1 symbol vector. q_k is the symbol for User k and independent of q_j (j = 1, 2, • • •, K, j ≠ k). The power of each data symbol is normalized to 1, i.e. $E\,|q_k|^2 = 1$. In this work, MRT precoding is considered which has low complexity and good asymptotic performance. With MRT precoding, the transmit signal vector from the BS to all users is defined as

$$s = \sqrt{\alpha \mathbf{H}^H q} \tag{1}$$

where α is a coefficient used for total average transmit power constraint. Defining P_t as the average total transmit power where

$$E\|s\|^2 = P_t \tag{2}$$

Since Rayleigh flat fading is assumed, the coefficient α can be calculated to be

$$\alpha = \frac{P_t}{E[tr(\mathbf{H}^H\mathbf{H})]} = \frac{P_t}{KM} \tag{3}$$

The received signal vector x is

$$x = \frac{\sqrt{P_t}}{KM}\mathbf{H}^H\mathbf{H}_q + n \tag{4}$$

where n is the noise vector whose entries are distributed as $CN\sim(0,\,1)$. In a multiuser system in order to achieve good signal to noise plus interference ratio (SINR) at the mobile stations the interference by signals from other users should be as low as possible. The SINR is determined as the ratio of the received strength for the desired signal to the strength of undesired signal obtained as the sum of noise and interference signal. The SNIR is used to access the upper bound on the rate of information transfer in wireless communication systems. Some of the factors that contribute to the SINR include the signal propagation and the positioning of network transmitters and receivers. As SINR increases the information rate increases while still preventing the errors due to noise. Then the SINR of User k is given by

$$SINR_k = \frac{\frac{P_t}{KM}\left|h_k h_k^H\right|^2}{1+\frac{P_t}{KM}\sum_{j=1,j\neq k}^{K}\left|h_k h_j^H\right|^2} \tag{5}$$

The interference resulting from the signals that are adjacent in frequency to the desired signal is called adjacent channel interference. One of the limiting factor for improvement in SINR is the interference power I which is due to interference from the users in a cellular system and is random since the location of the single interferer is uncertain. If the interferer is close, then I will be large. In a multiuser transmission system some users are distributed far away from each other, while some users may be close to each other. For users who are located very close severe inter-user interference exists between them. In this case, there is a need for interference control otherwise the performance of the multiuser transmission system will degrade significantly. Since precoding and user grouping are the key techniques to control the interference in downlink transmission schemes, proper design of precoding matrix and user grouping plays a very important role in such systems.

Let I_k denote the power of the interference experienced by User k, i.e.

$$I_k = \frac{1}{M} \sum_{j=1, j \neq k}^{K} \left| h_k h_j^H \right|^2 \tag{6}$$

Shannon capacity is the expected value of capacity taken over all realizations of the channel. Based on Shannon theorem, the achievable rate for User k is given by

$$R_{K=} \left(1 + SINR_k \right) \tag{7}$$

3. THE PROPOSED USERGROUPING ALGORITHM

Susceptibility and interference problems associated with mobile communications equipment are because of the problem of time congestion within the electromagnetic spectrum. It is the limiting factor in the performance of cellular systems. This interference can occur from another mobile in the same cell or because of a call in the adjacent cell. There can be interference between the base stations operating at same frequency band or any other non-cellular system's energy leaking inadvertently into the frequency band of the cellular system. If there is an interference in the voice channels, cross talk is heard will appear as noise between the users. The interference in the control channels leads to missed and error calls because of digital signaling. Interference is more severe in urban areas because of the greater RF noise and greater density of mobiles and base stations.

Interference between the users leads to high spatial correlation and consequently the presence of larger interference power will reduce the SNR with degradation in system performance. If the number of data streams for users is larger than the number of base station antennas then the base station has to determine which user it wants to serve at a given time. The criterion for serving might be the maximization of the overall throughput without regard to fairness or it might want to ensure that each user is served with a certain minimum data rate. Thus different ways of selecting users by means of grouping them in certain timeslots lead to overall capacity and quality of service. Optimizing such criteria in principle requires an exhaustive search over all scheduling assignments which become infeasible if the number of users is large. It is more popular to perform a greedy search where the first user to be selected is the one that gives highest overall capacity. The next user that is selected from the remaining ones is the user that increases the capacity by the most significant amount and so on. But in a practical system it is important to serve as many users as possible thereby ensuring fairness amongst them. Thus a greedy search technique for user selection and grouping becomes complex when the number of users is large and it neglects those users with poor channel condition.

User grouping approaches have been used in massive MIMO to improve the overall system performance, where users are generally divided into groups and those users with poor channel conditions are not selected for capacity optimization. This approach leads the users to suffer from unexpected disruptions, delays and withdrawal from the network. In this paper, the user grouping approach discussed exploits the favorable propagation condition in massive MIMO. Correlation among the users is checked by considering the inference level of the users so as to achieve larger system capacity and ensure proportional fairness amongst them. The system can choose between grouping and non-grouping based on the interference power of the users in order to ensure lossless performance. This is achieved by choosing an optimal threshold value for difference in the interference power of the users in the grouping process.

For a Massive MIMO system with TDMA the proposed user grouping possess the criterion based on the user interference. After completion of the user grouping process, the users in different groups are separated in time to avoid inter-group interference. In order to improve the system performance under highly correlated channel conditions the multiuser MIMO schemes require users to be grouped for downstream transmissions.

Let the initial user set is defined as U= $\{u_1, u_2, u_3 \ldots u_K\}$, where K is the total number of users. A minimum threshold value Δ for difference in Interference power I_{ij} is fixed for the users. The Algorithm first finds the correlation between the users in U in terms of I_{ij} where i,j refers to i^{th} and j^{th} user respectively. Users in the initial set are compared one by one to find the difference in interference power which is given by

$$I_{diff} = \left| I_{i-} I_j \right| \tag{8}$$

where I_i and I_j refers to the interference power of users i and j respectively.

A threshold value of difference in interference power (Δ) between the users is fixed. Users with difference in Interference power < Δ are separated in to two groups and then they are removed from the initial user set (U). This process continues until all the users are placed in a group. Hence the number of groups is not fixed but it depends on the level of interference between the users in U. The algorithm then selects the remaining users in U one by one and then adds them to any one of the existing groups based on which group yields the highest difference in interference power. For same values of I_{diff} observed for more than one group, the users can be appended to any of the groups.

An optimal threshold value of Δ is an important measure in this user grouping process. If a very small value is used, then the users with high interference will not be separated in to groups leading to a poor system performance. If a larger value is used, users who have less interference will also be isolated causing a reduction in performance.

The total sum rate of the system is given by

$$R_{total} = \sum_{k=1}^{K} R_k \quad (9)$$

3.1 Interference aware user grouping algorithm for Massive MIMO downlink

Initialization

Let user set U = {u_1, u_2, u_3 ……. u_K}, where K is the total number of users. x=0 where x denote the x^{th} group number. G_X = { } and X= {G_1, G_2, G_3 ……. G_x } is the set that contains all user groups.

for i = 1 to K **do**

for j = i+1 to K **do**

$I_{diff} = |I_{i} - I_j|$

if $I_{diff} < \Delta$ **then**

if $u_i \in U$ **then**

x= x+1; $G_x = G_x \cup \{u_i\}$

$U = U \setminus \{u_i\}$; $X = X \cup G_x$

end if

end if

if $u_j \in U$ **then**

x= x+1; $G_x = G_x \cup \{u_j\}$

$U = U \setminus \{u_j\}$; $X = X \cup G_x$

end if

end for

end for

for i = 1 to $|U|$ **do**

for j= 1 to $|Z|$ **do**

Find a group $G_x \in X$ such that it yields argmax [I (u_i,G_x (j))]

$G_x = G_x \cup \{u_i\}$

end for

end for

After user grouping, the users in an activated group occupy the time and bandwidth resources during an allocated time slot and BS serves each group of users by time sharing.

4. SIMULATION RESULTS

A circular cell is assumed with a radius of 1 km and no user is closer to the BS than 100 meters. The users are assumed to be in a random and uniformly distribution around the BS which is located in the center of the cell. A Uniform Linear Array (ULA) antenna is used at the BS with spacing between adjacent antennas as d = 0.5λ. The interference power level of the users is assumed to be in the range of -160dBm to -110dBm.

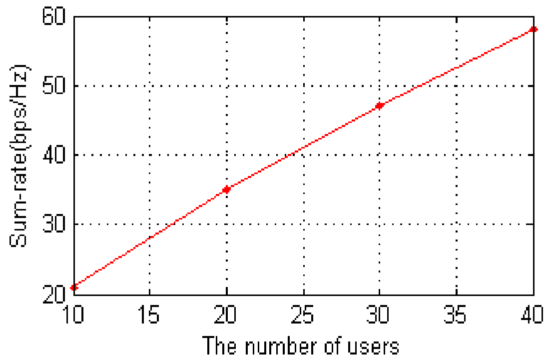

Fig -1: Sum rate performance for different number of users

Fig -1 shows the sum rate for different number of users where the number of antennas is taken as 100 and the total transmit power is 15 dB. As the number of user increases the sum rate has a nearly linear increase due to which when more users involved it introduces inter-user interference and then they are separated by the grouping process which enhances the system performance.

From the results of Figure 2, it is observed that when the number of base station antennas is small the interference between the users is high and choosing a larger threshold value of Δ in this case will not place them in separate groups leading to reduction in system performance. When the number of base station antennas is large it leads to low spatial correlation where choosing a large threshold value will be useful

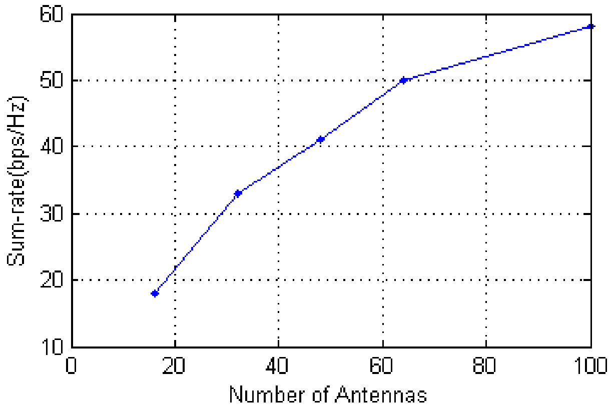

Fig - 2: Sum rate performance for different number of antennas

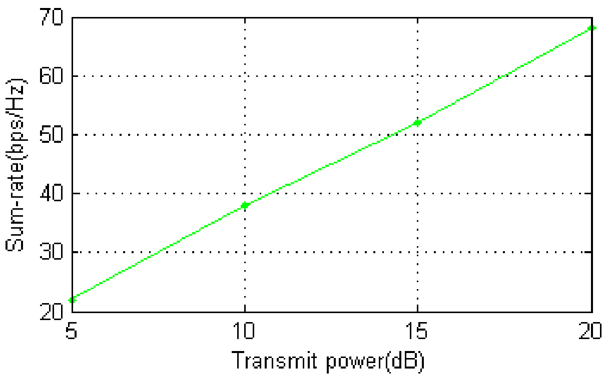

Fig - 3: Effect of Sum rate performance on Transmit Power

The transmit power depends not only on the wireless channel of a group of users, but also on the data rate of the transmitted signal. As user grouping cannot be updated every time the data rate is changed the transmit power should be evaluated as a function of the wireless channel. The performance of the proposed algorithm is obtained with respect to increase in transmit power with other parameters as fixed ie (M =100, K=40). It is observed that increasing the transmit power will result in an increase in the achievable rate for those users with less interference and is effective when the BS antenna elements are small.

5. CONCLUSIONS

In this paper the effect of inter-user interference on the performance of Massive MIMO system is considered through a user grouping algorithm. The proposed algorithm considers the difference in interference power between the users as a criterion for the grouping process.

The users in individual groups are then separated in time to improve the spatial multiplexing gain. It is observed that the sum rate increases linearly with SNR when users are grouped according to the proposed criterion The effect of variation in spatial correlation as a result of system parameters like number of users, number of antennas and transmit power is also discussed. The increase in the system performance is because of separating the users based on the level of interference in to different groups. Thus the proposed algorithm is effective in improving the system performance even under highly correlated channel conditions by reducing the multiuser interference.

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