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Improved Performance of Cooperative Massive MIMO for 5G Communication Networks

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ABSTRACT

Massive MIMO (multiple-input multiple-output) wireless technology uses a very large number of antennas with an order of magnitude more antennas than current LTE systems and is a leading candidate for inclusion in 5G systems. This will offer significant improvements in both the throughput and energy efficiency. As the number of antennas increases without limit, it is known that the effects of uncorrelated noise and small-scale fading can be removed completely. But, Due to the complexity and deployment consideration in practical scenarios at individual base stations, each base station site cannot be deployed with a large number of antennas. That means with a limited number of antennas, the inter-cell and intra-cell interference still exist if simple non-cooperative linear precoding is used individually in each base station site. Cooperative massive MIMO [CM-MIMO] where multiple base stations cooperate together and form a distributed antenna array to serve multiple users simultaneously is an attractive alternative. System level simulation performance of cooperative massive MIMO and non-cooperative massive MIMO system performance is compared under the uniform framework of the LTE TDD system. Here MF precoding is adopted for comparison owing to the benefit of low complexity of MF precoding and also in order to reduce the impact on the backhaul since no channel state information needs to be exchanged among base stations. The system level simulation takes into account various numbers of antenna configured in each base station site. This analysis provides insight on the potential system performance that can be achieved by using cooperative massive MIMO.

Keywords- Cooperative massive MIMO, MF precoding, 5G systems.

1. INTRODUCTION

Massive MIMO (multiple-input multiple-output) antenna technology can Provide significant performance improvement for cellular systems in terms of both throughput and energy efficiency. It is widely recognized that inter-user interference can be eliminated with a large number of antennas because of the asymptotical orthogonality among users when linear MF (Matched Filter) downlink precoding is used in the eNodeB.

Due to the complexity and deployment consideration in practical scenarios at individual eNodeBs, cooperative massive MIMO [CM-MIMO] where multiple base stations cooperate together and form a distributed antenna array to serve multiple users simultaneously is an attractive alternative. Furthermore, cooperative massive MIMO can also help increase the system performance especially for cell edge users because of the cooperative transmission among neighboring cells.
In this project, system level simulation performance for the downlink, based upon current LTE systems, provides an indication of the achievable potential system performance improvement by employing CM-MIMO in future (5G) cellular networks. It is demonstrated that CM-MIMO can improve the system performance of cell edge users significantly even if the cell average performance is very slightly degraded or maintained caused by the power imbalance of received signal from different cooperative neighboring cells. There are several terminologies that are used extensively throughout this project report.

1.1 MIMO ARCHITECTURE FOR WIRELESS COMMUNICATION

In this section, the use of multiple-input multiple-output (MIMO) architecture for wireless communication systems is considered. By employing MIMO architecture, architecture in which transmission and reception are carried out through multiple antennas, one can design a superior wireless communication system with respect to reliability, throughput, and power consumption.

In recent years, wireless communication devices have become more and more popular. However, at the same time, the design of faster, more reliable, and power-efficient wireless communication systems has become even more difficult. Wireless channels, as opposed to wired channels, exhibit highly irregular amplitude behaviour due to fading. The fading, essentially caused by the reception of multiple reflections of the transmitted signal, illustrated in Figure 2.2, is a key inherent problem of wireless channels, which, unfortunately, cannot be avoided.

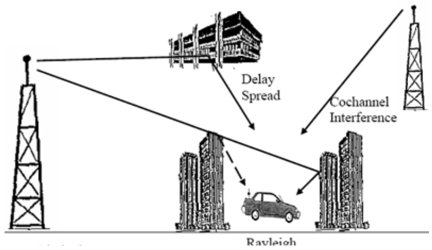


Fig.1.1 Wireless channel fading problem due to multiple reflection

Improved reliability is not the only outcome of using multiple antennas. About ten years ago, a remarkable theoretical result regarding the capacity of MIMO channels suggested that the transmission rate over wireless channels can be dramatically increased when using multiple antennas.

2. MASSIVE MIMO WIRELESS NETWORKS

INTRODUCTION:

According to CISCO, an American multinational technology company, by 2020, more people (5.4 B) will have mobile phones than have electricity (5.3 B), running water (3.5 B) and cars (2.8 B). In addition, 75% of the mobile data traffic will be bandwidth-hungry video. While conventional techniques struggling to provide these bit rates, massive multiple-input-multiple-output (MIMO) systems promise 10 s of Gbps data rates to support real-time wireless multimedia services without occupying much additional spectrum.

2.1 Networked MIMO and Massive MIMO

MIMO systems can be cooperative or non-cooperative. Cooperating systems are often called *Networked MIMO*, where a certain user is served by all BSs within its range of operation. The typical massive MIMO BSs do not cooperate in this sense. Both systems mitigate interferences of multi cellular wireless networks in separate ways and are not to be confused with each other. Networked MIMO emulates distributed antenna arrays by creating clusters of connected BSs.

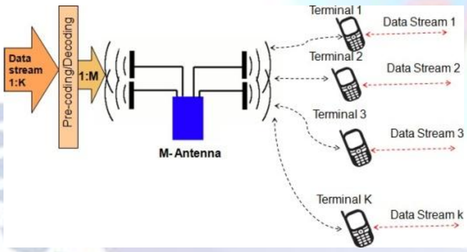
Table 1. Comparison between cooperating and non-cooperating multiple-input-multiple-output (MIMO) systems:

Cooperating Systems (Networked MIMO)	Non-Cooperating Systems (Conventional Massive MIMO)
Multiple fold increase in spectral efficiency.	Less.
Less energy consumption.	Less energy saving.
Cooperation between BSs with small antenna arrays.	Noncooperation: Each BS is robust against ICI [1]
More controls (yields in better performance).	Fewer controls (yields in better implementation).
Less downlink user rate.	Improvement in the downlink user rate.
Each user experiences less quality of service.	More user quality of service.
Increased system complexity, and the large Signaling overhead, which is reduced by distributed optimization?	Less Complexity.
Improved capacity, coverage, and cell edge throughput.	Improved capacity, coverage, and cell edge throughput.

2.2 Massive MIMO in Wireless Sensor Networks:

Wireless sensor networks (WSN) are special kinds of monitoring networks, aiming at detecting, measuring, monitoring certain physical phenomena, such as temperature, humidity, pressure, vibration, etc. Each device in the WSN is termed as a node that exchanges information with its neighbour. Typically nodes have limited connectivity and energy resources. All data will be poured into a BS node, or a sink, which in turn relays the information to an outside user, or a server to process it.

WSN nodes are small in size, cheap in cost, and do not



employ complicated processing units, except the sink node. WSN may be composed of hundreds or thousands of nodes to provide coverage on a large scale basis.

3. COOPERATIVE MIMO

3.1 INTRODUCTION

Cooperative communication is one of the fastest growing areas of research, and it is likely to be a key enabling technology for efficient spectrum use in future. 1 The key idea in user-cooperation is that of resource-sharing among multiple nodes in a network. The reason behind the exploration of user-cooperation is that willingness to share power and computation with neighboring nodes can lead to savings of overall network resources. Mesh networks provide an enormous application space for user-cooperation strategies to be implemented. Cooperation is possible whenever the number of communicating terminals exceeds two. Therefore, a three-terminal network is a fundamental unit in user- cooperation. Indeed, a vast portion of the literature, especially in the realm of information theory, has been devoted to a special three-terminal channel, labelled the *relay* channel. The focus of our discussion will be the relay channel, and its various extensions. In contrast, there is also a prominent portion of literature devoted to cooperation as viewed from a network-wide perspective, which we will only briefly allude to.

We then investigate relaying in the context of Gaussian channels, and summarize known results for well-known relaying protocols. In recent years, half-duplex relaying has been accepted as a practical form of relaying that has potential for implementation in near future. Therefore, we devote a section to the derivation of the fundamental limits of half-duplex relaying. Last, we consider a scenario where the source and the relay exchange roles, which is a departure from the conventional relay channel. This departure, however, captures the essence of user-cooperation where both nodes stand to gain from sharing their resources, which is why this model is a prominent candidate for future implementation.

4. SYSTEM SIMULATION SETUP

A. NON-COOPERATIVE AND COOPERATIVE SYSTEM

This paper considers a massive MIMO wireless cellular system with L cells denoted as 1,2, … , L respectively as shown in Figure 1. Each cell consists of one base station with M antennas and K users equipped with only one antenna for reduced complexity. In this paper, we assume users use orthogonal pilot resources to acquire the Channel State Information [CSI], so pilot contamination is not considered.

A. Non-cooperative Massive MIMO System:

The base station j transmits a M ∗ 1 precoded vector Sfj. The subscript f means forward link and the subscript *j* denotes the base station index. User K in base station l receives the signal from the transmitted vectors from all the base stations, which is written as,

$$X_{kl} = \sqrt{\rho_f} \sum_{j=1}^{L} G_{jkl} S_{fj} + W_{kl} \quad \text{...... (1)}$$

where ϱf is the signal-to-noise ratio of the forward link, WKL is the complex independent and identically distributed (i.i.d.) white Gaussian noise, and GJKL is the 1 ∗ M channel matrix between user K in base station L and M antennas in base station j (see Fig. 1).

$$G_{jkl} = H_{jkl} \beta_{jkl}^{1/2} \quad \text{......... (2)}$$

Assume linear MF precoding is used, and precise CSI is available in the base station, then the base station transmits

$$S_{fj} = \sum_{m=1}^{k} G_{jmj}^{*} a_{mj} \quad \text{............... (3)}$$

Where GJMJ is the 1 ∗ M channel matrix between user m and M antennas in base station j . The superscript ∗ denotes the

Fig.1. G_{jkl} is channel matrix between user k in base station l and M antennas in base station j.

Conjugate transpose. The symbol amj is the transmitted symbols for user m in base station j.

Substituting (3) into (1), then the received signal for user K in base station l is:

$$X_{kl} = \sqrt{\rho_f} \sum_{j=1}^{L} G_{jkl} \sum_{m=1}^{k} G_{jmj}^{*} a_{mj} + W_{kl} \quad \text{... (4)}$$

As the number of antennas M is increased to infinity, the channels will be orthogonal to each other, since according to random matrix theory [7]:

$$G_{jkl} G_{jmj}^{*} = \beta_{jkl}^{1/2} \beta^{*1/2}_{jmj} H_{jkl} H_{jmj}^{*} \to 0 \text{ when } l \neq j \text{ or } (l = j \text{ and } k \neq m) \quad (5)$$

$$G_{jkl} G_{jmj}^{*} = \beta_{\mathrm{jkl}} \|H_{jkl}\|^2 \to M\beta_{jkl} \text{ when } l = j \text{ and } k = m \quad (6)$$

where ‖·‖ is the Frobenius norm.

The received signal for user k in base station l becomes:

$$X_{kl} = \sqrt{\rho_f} M \beta_{lkl} a_{kl} + W_{kl} \quad \text{...... (7)}$$

The SINR (signal-to-interference-plus-noise ratio) of user k in base station l becomes:

$$SINR_{kl} = \rho_f M^2 \beta_{lkl}^2 \quad \text{............. (8)}$$

In (8), the small-scale fading effects disappear because (5)- (6) are assumed:

When the number of antennas M is asymptotically increased to infinity, the assumptions of (5)-(6) will hold asymptotically, and (7)-(8) are true asymptotically. When the number of antennas M is limited, the assumptions of (5)-(6) will not hold, (7)-(8) cannot be derived. The received signal of user K in base station L becomes.

B. Cooperative Massive MIMO System:

As with non-cooperative Massive MIMO system, in cooperative Massive MIMO system, the base station j transmits a M ∗ 1 preceded vector Sfj. What is different is that each cooperative base station pre codes the signals of all the K ∗ L users in the cooperative area at the same time:

$$S_{fj} = \sum_{m=1}^{K*L} G_{jmj}^{*} a_{mj} \quad \text{...... (9)}$$

Where the parameters in (10) mean the same as those in (3). Substituting (10) into (1), then the received signal for user K in base station L is:

$$X_{kl} = \sqrt{\rho_f'} \sum_{j=1}^{L} G_{jkl} \sum_{m=1}^{K*L} G_{jmj}^{*} a_{mj} + W_{kl} = \sqrt{\rho_f'} \sum_{j=1}^{L} \|G_{jkl}\|^2 a_{kl} + \sqrt{\rho_f'} \sum_{m=1, m\neq k}^{K*L} \sum_{j=1}^{L} G_{jkl} G_{jmj}^{*} a_{mj} + W_{kl} \quad \text{.... (11)}$$

Where ϱf is the signal-to-noise ratio for the forward link, and other parameters in (11) mean the same as those in (4).

As the number of antennas M is increased to infinity, (12)- (13) will hold. But the large-scale factor β in equation for user K from different cooperative base stations are different, an effect known as power imbalance.

5. SIMULATION RESULTS

The system level simulation is run using Matlab. The system simulation configuration is partly based upon LTE macro-cell system simulation baseline parameters as shown in Table I. Seven omni-directional sites are simulated with 10 single-antenna UEs in each site equipped with 15, 25, and 50 transmit antennas with ULA (Uniform Linear Array) configurations respectively. The path loss model of 3GPP 36.942 urban models is used [10]. The TDD duplex mode is assumed, where the downlink channel matrix can be obtained through TDD channel reciprocity from the uplink channel matrix. A system bandwidth of 20 MHz and all-user full bandwidth scheduling are used, which means all 10 users in each cell are scheduled at the same time to the full bandwidth. In the simulation, for simplification of illustration, we assume that all the system bandwidth is available for downlink data transmission in each sub frame.

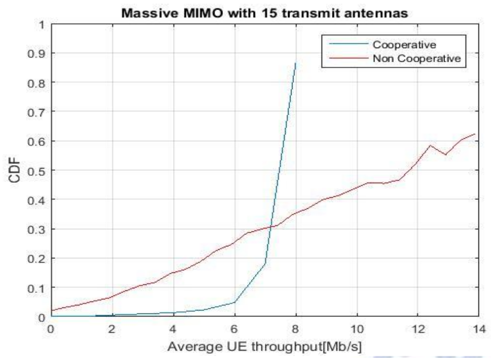


FIG 5.1: UE throughput CDF for non-cooperative and cooperative massive MIMO with 15 transmits antennas.

The net system throughput for a specific TDD uplink-downlink configuration [11] can be easily derived. In the simulation downlink MF precoding is utilized.

15 Transmit Antennas;

Figures shows the UE throughput CDF (Cumulative Distribution Function) for non-cooperative and cooperative massive MIMO with 15 transmit antennas deployed in each eNodeB. Table II also summarizes the 5% user throughput and cell average throughput for both non-cooperative and cooperative massive MIMO. It is observed that 5% user throughput is increased significantly from about 2.7 to 7.2 Mbps, whereas median user throughput is decreased from about 9 to 7.8 Mbps, and the cell average throughput is decreased from about 86.3 to 77.1 Mbps.

Figures of 25 antennas shows the UE throughput CDF for noncooperative and cooperative massive MIMO with 25 transmit antennas deployed in each eNodeB. It is observed from Fig. 3 and Table II that 5 % user throughput is increased significantly from about 4 to 10.5 Mbps, whereas median user throughput is decreased from about 13.5 to 11 Mbps, and the cell average throughput is decreased from about 123.0 to 112.2 Mbps.

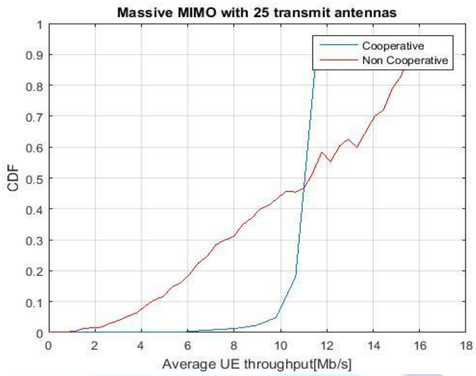


FIG 5.2: UE throughput CDF for non-cooperative and cooperative massive MIMO with 25 transmits antennas.

50 Transmit Antennas:

Figure 4 shows the UE throughput CDF (Cumulative Distribution Function) for non-cooperative and cooperative massive MIMO with 50 transmit antennas deployed in each eNodeB. It is observed from Fig 4 and Table II that 5 % user throughput is increased significantly from about 4 to 15.2 Mbps, whereas median user throughput is decreased from about 19 to 17.5 Mbps, and the cell average throughput is slightly increased from about 175.5 to 175.9 Mbps.

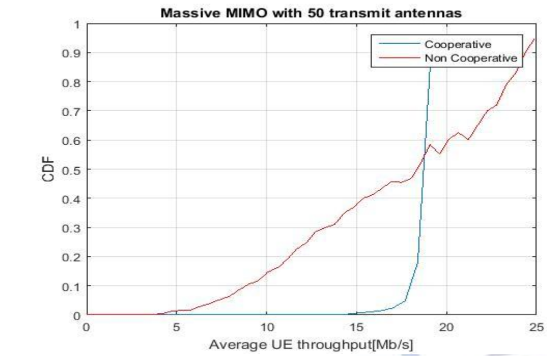


FIG 5.3: UE throughput CDF for non-cooperative and cooperative massive MIMO with 50 transmits antennas.

SNR VS BER:

As the fig shows the difference between two non cooperative and cooperative ,BER decreases when number of antennas increases as SNR (signal to noise ratio) maximizes up to some extent.

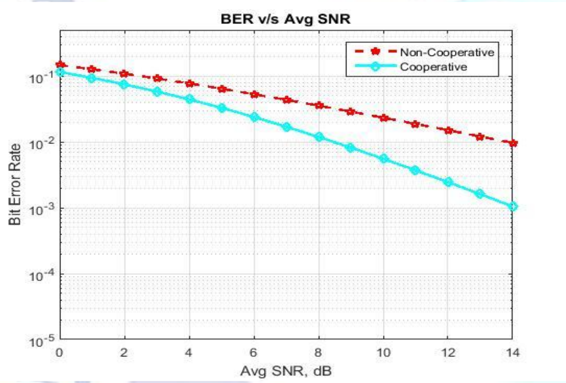


FIG 5.4. Difference between two non-cooperative and cooperative BER

The above three cases demonstrate that the cooperative massive MIMO can significantly improve cell edge users' system performance, whereas the cell average system performance is slightly degraded or maintained.

TABLE II SYSTEM SIMULATION PERFORMANCE

Cases		5 % User Throughput (Mbps)	Cell average Throughput (Mbps)
15 Antennas	Non-cooperative	2.7	86.3
	Cooperative	7.2	77.1
25 Antennas	Non-cooperative	4	123.0
	Cooperative	10.5	112.2
50 Antennas	Non-cooperative	4	175.6
	Cooperative	15.2	175.9

6. CONCLUSION & FUTURE SCOPE

In this, system level simulation performance of noncooperative and cooperative massive MIMO systems for downlink performance is presented based upon current LTE systems considering different numbers of antennas deployed in the base station. It is shown that through cooperation among base stations, system performance of cell edge users can be significantly improved, whereas cell average throughput is slightly degraded or maintained owing to the power imbalance for the cell centre users. The system simulations presented in this project provide a view of the potential system performance that can be achieved by cooperative massive MIMO technologies in practical 5G systems. Future research will be on system performance evaluation of cooperative massive MIMO only for cell edge users based upon 3D channel models.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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