Coordinated Multi-Point MIMO Processing for 4G

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Abstract— The concept of cooperative Multiple-Input-Multiple-Output (MIMO), also referred to as network MIMO, or as Coordinated Multi-Point Transmission (CoMP), was standardized in 3GPP Release 11. The goal of CoMP is to improve the coverage of high data rates and cell-edge throughput, and also to increase system throughput. In this paper we analyze only the latter scenario, using system level simulations in accordance with 3GPP guidelines. It is shown that the use of joint coordinated multipoint transmission achieves additional throughput gains. However, the gains depend on the scheduling type. This paper also indicates that the criterion of fairness is an important parameter when the number of users is high.

1. INTRODUCTION

4G networks are gaining momentum, and mobile data traffic is growing exponentially with new multimedia applications on smart mobile devices. This new paradigm is putting more stringent demands on the quality of service. In addition to supporting efficiently the signaling and traffic from interactive video and gaming applications, 4G networks also need to handle the signaling and traffic from a multitude of machine-type communication devices.

Heterogeneous networks comprising macrocells and low-power nodes are gaining importance. Macrocells are essential for provision of wide-area coverage and support of high-mobility. The addition of small cells is the mechanism for providing exponential capacity growth to match demand. These and others features are also among the key requirements that have driven the development of LTE Release 11 [1–3]. Features such as CoMP transmission/reception, machine type communication and energy saving are among the new features introduced in Release 11.

This paper presents system level simulations for CoMP transmission considering various 3GPP scenarios. In Section 2, CoMP is introduced, while Section 3 provides a description of the system level simulations. Numerical results and conclusions are then presented in Sections 4 and 5.

2. COORDINATED MULTI-POINT TRANSMISSION

Using CoMP transmission, independent antenna elements of different BSs are grouped together, forming a cluster, and the User Equipments (UE) can experience a throughput increase or performance improvement. A pre-processing is typically employed at the BSs side such that the signals that reach the UE do not require any type of post-processing.

In case each BS uses the MIMO scheme, the resulting MIMO can be viewed as a "giant MIMO", consisting of a combination of independent antenna elements from different BSs (see Figure 1).

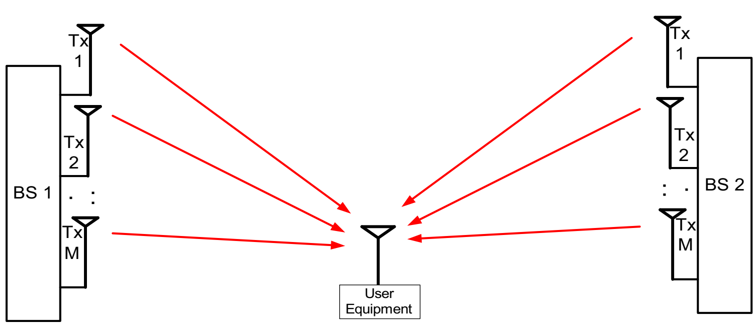

Figure 1: CoMP implemented as a downlink MIMO.

Coordinated multi-point transmission comprises the coordinated transmission of signals from adjacent BSs, and the corresponding reception from a UE. The signal received at the UE side consists of the sum of independent signals sent by different BSs.

CoMP transmission is an important technique that can mitigate inter-cell interference, improve the throughput, exploit diversity and, therefore, improve the spectrum efficiency. Note that CoMP transmission allows a spectrum efficiency improvement, even at the cell edge. CoMP transmission can be viewed as a special type of Multi-User MIMO (MU-MIMO).

Similar to MU-MIMO, a pre-processing such as beamforming, Zero Forcing (ZF), Minimum Mean Square Error (MMSE) or dirty-paper coding is employed, in order to assure that the UE receives a combined signal coming from multiple BSs. In this case, the UE commonly employs a low-complexity and regular detector. Alternatively, a single-user like MIMO detector can be employed at the receiver (UE) or a coordinated scheduling can also be used. In the latter case, CoMP transmission can be associated to carrier aggregation, activating or de-activating some carriers in order to optimize the performance.

Similar to MU-MIMO, accurate downlink Channel State Information (CSI) is typically required at BSs side, which consists of an implementation difficulty. In case of Time Division Duplexing (TDD), obtaining CSI is trivial, as the uplink and downlink channels are almost the same. Nevertheless, in case of Frequency Division Duplexing (FDD), obtaining CSI at the transmitter side is a complex task.

Depending on the way the coordination between different BSs is performed, and the way CSI is obtained (in FDD mode), two different architectures can be implemented:

- Centralized architecture: in this architecture there is a central Control Unit (CU) which decides about the transmission scheme and resources allocation to be used by different BSs. In this case, the CU is connected to different BSs of the cluster. Each UE estimates the downlink CSI of the signals received from each BS. Then, the CSI is sent back to the corresponding BS. At a third stage, CSI is sent from different BSs of the cluster to the CU through backhaul links. Based on CSI, the CU decides about the transmission scheme and resources allocation to be used by each BS, and sends this information to different BSs of the cluster. A major limitation of this architecture relies on the latency, whose factor may result in performance degradation due to fast CSI variations [4].
- Distributed architecture: in this architecture, each BS is associated to a different CU, and the decision about the transmission scheme and resources allocation is performed independently at the BS level. Then, this information is exchanged between the cluster's BSs. In this case, each UE estimates the downlink CSI to different BSs and sends this joint data back not only to the BS of reference, but to all BSs. This way the CU associated to each BS has information about different downlink CSI and makes the decision accordingly. An advantage of this architecture relies on the fact that latency is much reduced, and there is no need to use backhaul links for the purpose of exchanging CSI. Nevertheless, this architecture is more subject to errors caused by the uplink transmission [5].

The primary difference between standard MIMO and CoMP is that, for the latter, the transmitters are not physically co-located. In the case of downlink CoMP there is, however, the possibility of linking the transmitters at baseband to enable sharing of payload data for the purposes of coordinated precoding. For the standard network topology in which the BSs are physically distributed, the provision of a high capacity and low latency baseband link is challenging and would probably require augmentation of the inter-BSs interface bandwidth using fiber. However, a cost-effective solution for inter-BSs connectivity is offered by a network architecture in which the baseband and RF transceivers are located at a central site with distribution of the RF to the Remote Radio Heads (RRH) via fiber. Four downlink deployment scenarios were defined for the feasibility study in Release 11 [6]:

- CoMP scenario 1 corresponds to a homogeneous macro network (all cells have the same coverage area) with intra-site CoMP. This is the least complex form of CoMP and is limited to BSs sharing the same site.
- CoMP scenario 2 is also a homogeneous network but with high Tx-power RRHs. This is an extension of scenario 1 in which the six sites adjacent to the central site are connected via fiber optic links to enable baseband cooperation across a wider area than is possible with scenario 1.
- CoMP scenario 3 is a heterogeneous network in which low power RRHs with limited coverage are located within the macro cell coverage area.

- CoMP scenario 4 is a heterogeneous network in which low power RRHs with limited coverage are located within the macro cell coverage area. The transmission/reception points created by RRHs have the same cell identity as the macro cell scenarios 3 and are expected to be used in metropolitan areas, where network deployment is dense and RRHs of different transmission power levels coexist.

3. SYSTEM LEVEL SIMULATIONS

For the System Level Simulations (SLS), a nineteen cell network topology was used as the baseline network topology, as defined in [7]. In the simulations, only the downlink scenario has been considered. The system is modeled as a network of 7 clusters. Each cluster has 19 hexagonal cells with six cells in the first tier and twelve cells in the second tier surrounding the central cell of each cluster. Each cell has three sectors. To save simulation time the mobile users are only located on the seven cells at the center of the scenario, as illustrated in Figure 2. Mobiles are randomly assigned channel models, following a uniform distribution inside the system. The sector with best path to the user, taking into account slow fading characteristics (path loss, shadowing, and antenna gains) is chosen as the serving sector. Fading signal and fading interference are computed from each mobile station into each sector and from each sector to each mobile for each simulation interval. Moreover, users with a required traffic class shall be modeled according to the traffic models defined in this paper. Finally, packets are scheduled with a packet scheduler using the required scheduling technique. When a packet is lost, a retransmission process is carried out.

Another general description of a SLS is presented in [8].

The ITU-R IMT-Advanced MIMO channel model for SLS is a geometry-based stochastic model. It can also be called double directional channel model. It does not explicitly specify the locations of the scatters, but rather the directions of the rays, like the well-known Spatial Channel Model (SCM) [9]. Geometry-based modeling of the radio channel enables separation of propagation parameters and antennas.

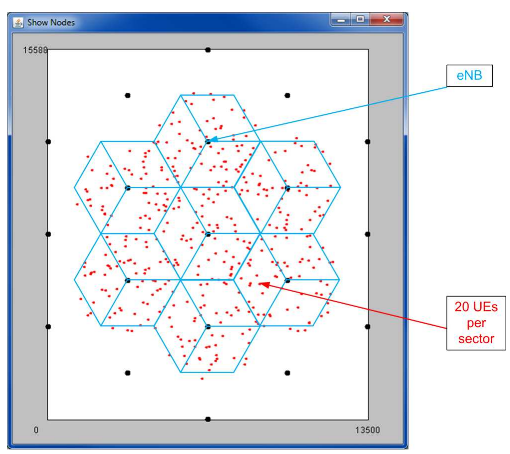

Figure 2: Users distribution inside the scenario.

Several different scenarios will be evaluated, considering different traffic services in Point-to-point (PtP) mode. The single-user SU-MIMO and CoMP scenarios [10] will be evaluated in the next section.

4. NUMERICAL RESULTS

In PtP scenario, every UE is served individually, and the link established by any given UE. If a user does not receive a packet properly, there is the option to retransmit the lost packet. Therefore, in this type of system the coverage is assured. In this scenario, service delay or outage can be experienced (e.g., due to large waiting times when scheduling), being outage one of the aspects that is analyzed here. Another important aspect to study is the overall system capacity, that is, the maximum number of users per cell that the system serves.

Since every UE is individually allocated with resources, and once these are finite, some sort of scheduling mechanism is necessary. Different scheduling mechanisms are tested, using different numbers of UEs in the system to better understand how every scheduling algorithm performs [11].

The scheduler Maximum Carrier-Interference (MCI), also referred to in the literature as 'Maximum SINR', or simply as 'Max C/I', is a channel aware scheduling algorithm where it is given more priority to users with good channel conditions (users located closer to the base-station). The scheduler chooses the user k with maximum Signal-to-Interference plus Noise Ratio (SINR) at instant t. The measurement of SINR is performed via constant periodic Channel Quality Indicator (CQI) feedback by every single user. It is commonly stated that the MCI is not fair because the scheduling decisions do not allocate resources to more delayed users. In this context, there are three 'fair' schedulers: the simple Round Robin (RR), the Proportional Fair (PF), and the Largest Delay First (LDF). In RR, users form a circular queue and the scheduler allocates equal timeslots for each and every user in the queue. PF is channel aware. In fact, we can look at PF as a less aggressive version of Max C/I scheduling algorithm. PF uses CQI feedback sent by users to determine the instantaneous possible data rate a user k can achieve at a given instant t, and also the average throughput a user k had until instant t. This way, users that have instantaneous throughputs higher than their average throughput are scheduled first. LDF takes into consideration first the users experiencing the largest overall delay in packets [13]. This delay is measured using time-stamps that indicate the time of packet creation and/or arrival at the transmission queue for each user. Because users at the cell edge typically experience worst SINR than users at the center of the cell, they can only use lower modulation schemes and coding rates, generally transmitting with lower throughputs than users at the center of the cell, and therefore having longer transmission queues. Consequently, the packets accumulate the highest delays. When LDF is used these users with lower SINR will be scheduled more often than users with high SINR and fairness can be achieved.

The following results cover two traffic models. The File Transfer Protocol (FTP) traffic model emulates the traffic generated by FTP applications. This type of traffic is characterized by having sequences of packet transfers separated by reading times where the receiver checks the data received and decides to request more data to be sent. In FTP traffic, delay is not an important concern (it is not delay sensitive) but overall large waiting times can deteriorate the user experience. The FTP traffic model obeys the characteristics of the model described by 3GPP in [12], and the average load offered to each UE is around 925 kbps. On the other hand, the Constant Bit Rate (CBR) traffic model, as the name indicates, generates always the same amount of data, with exactly the same time intervals between consecutive data. This is the traffic model that comes closer to type of traffic generated in real sector transmissions. CBR traffic model generates a packet of 37,800 bits every 1 ms (millisecond). This represents a traffic generator offering a load of 37,800 kbps per UE and a maximum spectral efficiency per user of 3.7 bps/Hz in a 10 MHz band with MIMO 4×4 [1]. The influence of the type of used scheduling technique and the cell loading are here evaluated.

Figure 3 and Figure 4 show the Cumulative Distribution Function of throughput (CDF(x)) as a function of the throughput, for SU-MIMO 4×4, with eleven CQIs QPSK modulated (Quadrature Phase Shift Keying), and five CQIs 16QAM modulated (Quadrature Amplitude Modulation). The CDF(x) is the probability of the random variable % of UEs with throughput value less than or equal to x. The SU-MIMO considered in this paper refers to the multi-layer transmission initially

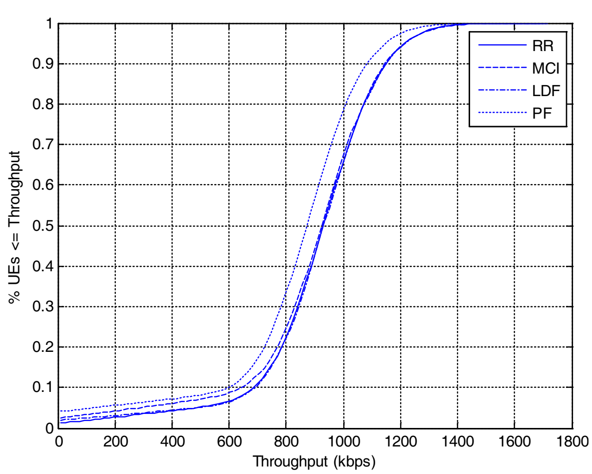

Figure 3: CDF Throughput for 5 users FTP traffic.

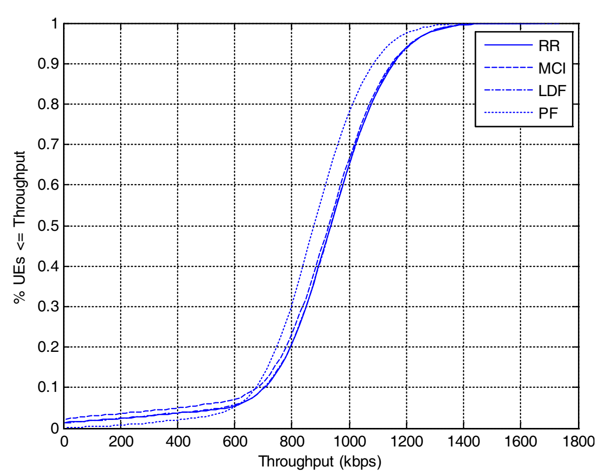

Figure 4: CDF Throughput for 20 users FTP traffic.

proposed by Foschini. The receiver considers a MMSE detector to perform the nulling algorithm, alongside with a Successive Interference Cancellation (SIC) algorithm, to perform the detection of different transmit antennas by their received power descending order.

The FTP traffic and the four different schedulers are considered, where the number of users per sector is 5 and 20, respectively. As can be observed, there is no difference between the schedulers performance with 5 and 20 users because the average load per user is only 925 kbps and SU-MIMO 4×4 offers much higher capacity. For such a traffic load, the CDF(x) is almost independent of the scheduling mechanism.

Figure 5 and Figure 6 depict the CDF(x) of throughput for SU-MIMO 4×4, with the CBR traffic, where the number of users per sector is 5 and 20, respectively. It is obvious the difference between the performance of the schedulers specially with 20 users, because the average load per user is 7,560 kbps and 1,890 kbps for 5 and 20 users, respectively. LDF presents the best performance for 50% of users with 6,500 kbps and 1,750 kbps for 5 and 20 users, respectively. MCI assures throughput values above 8,000 kbps for more than 30% of 5 users and above 6,750 kbps for more than 10% of 20 users. However, for 50% of users, MCI performance is very low. The throughput performance of RR and PF schedulers is between the two extreme cases of LDF and MCI schedulers. For such traffic source with high load, it does matter what the scheduling technique is chosen by the operator in order to assure adequate quality of service.

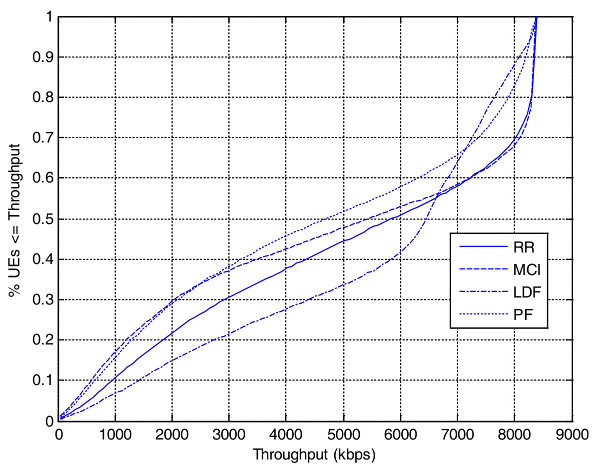

Figure 5: CDF Throughput for 5 users CBR traffic.

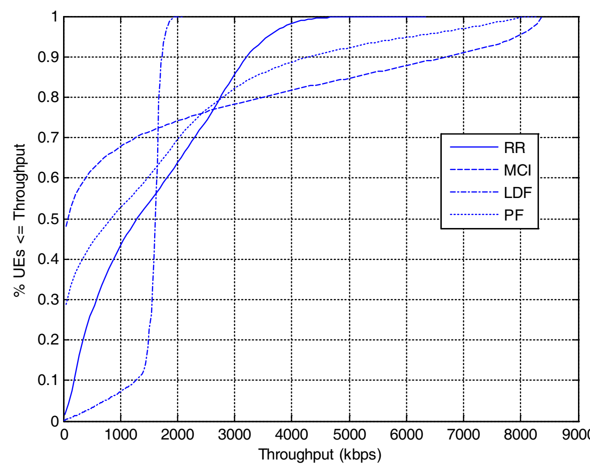

Figure 6: CDF Throughput for 20 users CBR traffic.

Data to a UE is simultaneously transmitted (joint transmission) from multiple points to coherently improve the received signal quality or data throughput. A combination of SU-MIMO with CoMP is employed. We take the simplification of assuming that the quality of CSI is very good (perfect estimation).

Figure 7 depicts the CDF(x) of throughput results for CoMP with SU-MIMO 4×4 (with $M = 4$ transmitting antennas per site), with the same adaptive modulation and coding schemes as before. The same four different schedulers are analyzed, where the number of users per sector is 20. LDF and RR present the best performance for 50% of users with 2,200 kbps for 20 users, followed by PF with 2,000 kbps. MCI assures throughput values above 7,800 kbps for more than 10% of 20 users but for 50% of users the throughput is bellow 1,000 kbps. There is a throughput gain due to CoMP but its computation is not straightforward because it depends on the scheduler. For LDF, the gain for 50% of users is 2,150/1,750 = 1.23, around 23%. For the cell edge users corresponding to the worse 5% of users, the gain is 1,500/750 = 2, around 100%. For RR, there is also throughput gain for 50% and 5% of the users due to CoMP and the way it operates.

Figure 8 depicts the throughput distribution versus the geometry factor of CoMP with SU-MIMO, $M = 4$ per site, and for $Nu = 20$ users per sector. Note that this corresponds to CDF(x) results in the environment of previous Figure 7. The geometry factor was the term used in UMTS to indicate the ratio of the wanted signal relating to the interference plus noise. This corresponds to SINR. Users located closer to the base-station have higher geometry than users located at the cell borders with lower geometry. LDF presents an almost constant throughput independently of the location of the mobiles. The opposite is MCI with a high linear increase of throughput for

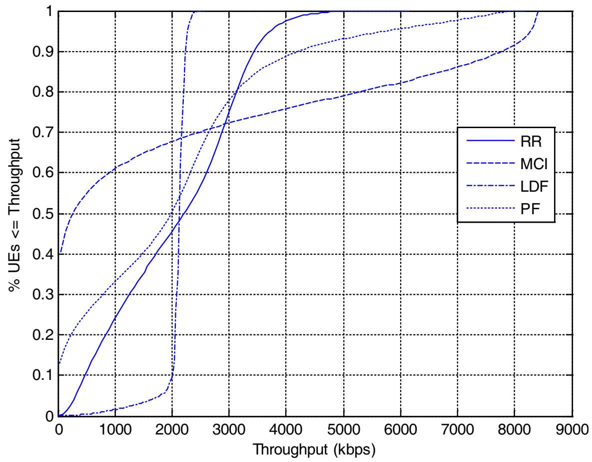

Figure 7: CDF Throughput for 20 users, CBR, CoMP.

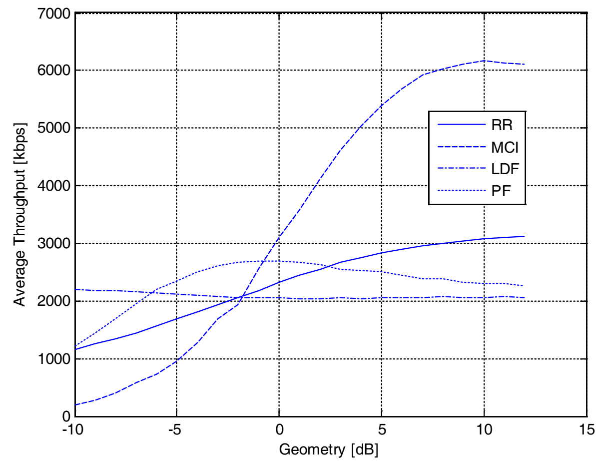

Figure 8: Throughput vs geometry, CoMP, $Nu = 20$.

users moving towards the base station site. RR provides a small linear increase of throughput for increasing geometry values. PF behavior is explained as a mix of MCI and LDF. Consequently, it presents a nonlinear throughput increase with increasing throughput value.

5. CONCLUSIONS

This paper analyzed the influence of the scheduler type and of the cell loading. It was viewed that there is no difference between the schedulers performance when the average load per user is small compared to the higher capacity of MIMO 4×4 transmission scheme. For such a traffic load it does not matter what the chosen scheduler is. In order to increase the spectral efficiency on average and/or at the cell borders, or when the number of users is increasing, CoMP with fair scheduling should be employed.

The use of joint CoMP transmission achieves additional throughput gains. Nevertheless, these gains depend on the scheduling type. The performance results indicate that the criterion of fairness giving priority to users at the cell border is important when the number of users is increasing and CoMP is employed.

ACKNOWLEDGMENT

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