IMPROVING PERFORMANCE-LIMITED INTERFERENCE SYSTEM WITH COORDINATED MULTIPOINT TRANSMISSION

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ABSTRACT

This paper describes an overview of the key component in coordinated multipoint in the context of LTE-Advanced which includes architectures, approaches, and main challenges. Most of the ideas presented are presently being studied and may vary throughout the standardization work. A system model is proposed to employ the cooperative communication in interference-limited scenario which may help to improve the cell-edge performance.

***KEYWORDS**: CoMP; Inter-cell interference; Joint processing; LTE-Advanced*

1.0 INTRODUCTION

Upcoming mobile and cellular networks will have to concurrently offer a huge range of users with very high data rates and improvement on the capacity of the latest radio access systems is needed. Conventionally, each user in the cellular systems is allocated to a base station relies on the parameter such as received signal strength. At the terminal side, all the signals coming from the other base stations in the form of nosiness severely bound the performance. The user corresponds with a single serving base station while inducing interference to the rest of base stations. Due to the performance limitation of cellular systems in term of interference, the mission to accomplish a very high data rate cannot be done by only increasing the transmission power. Each base station processes serving users separately, and the increased transmission power would make the rest of the users are seen as inter-cell interference to the current serving user.

One approach to diminish the performance-limiting interference is by reducing the inter-cell interference with the assist of joint transmission.

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Cooperative Multipoint (CoMP) transmission and reception is a structure that refers to a system where a number of geographically scattered antenna nodes work together with the mean of improving the execution of the users processed in the common collaboration area (Abe, Kishiyama, Kakura & Imamura, 2011). It covers all required system architectures to accomplish tight coordination for transmission and reception. Cooperation among base stations (denoted as eNBs in Long Term Evolution and Long Term Evolution-Advanced) is categorized by the need of an interconnection among the different access points via dedicated backhaul links. These backhaul links should be a very high speed and low-latency link. The criteria are crucial for the accomplishment of the cooperative communication, even though its design will be very challenging due to the huge amount of information that have to be interchanged between the nodes. Long Term Evolution-Advanced (LTE-A) will utilize the standard interface X2 for these roles.

There are several possible coordinating schemes available in the circumstance of LTE-Advanced. Coordinated beamforming/scheduling is a less complicated approach where only a single cell transmits user data to the user equipment (UE). Joint processing scheme, on the other hand, involves multiple nodes to transmit user data to the UE. There are two approaches are being considered in joint processing scheme: joint transmission, which needs multi-user linear precoding, and dynamic cell selection, where data are transmitted from only one cell that is dynamically selected. The transmission schemes can be implemented on any types of network configurations that will be presented in the following section. This paper aims to provide the basic CoMP concepts and approaches, deployment architectures and possible system model for future mobile networks.

2.0 COORDINATED MULTIPOINT TRANSMISSION AND RECEPTION

2.1 CoMP Network Architectures

CoMP is considered for LTE-A as a tool to improve the coverage of high data rates, the cell-edge throughput as well as to increase the system throughput. In a cellular deployment and specifically if frequencies are reused in each cell, other-cell interference traditionally degrades the system capacity. The aim in CoMP is to turn the other cell interference into a useful signal specifically at the cell border. There are different approaches possible for CoMP network deployment as illustrated in Figure 1: centralized control based on Remote Radio Equipment (RRE), or autonomous distributed control based on an independent eNB configuration (Sawahashi, Kishiyama, Morimoto, Nishikawa & Tanno, 2010).

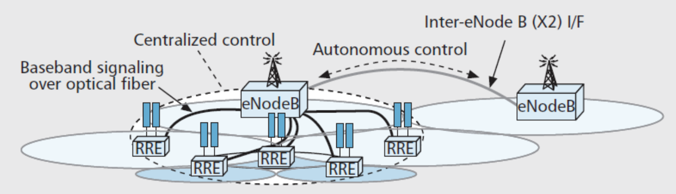


Figure 1. CoMP Network configuration (Sawahashi, Kishiyama, Morimoto, Nishikawa & Tanno, 2010)

In a centralized approach, multiples RREs are connected to the central eNB via an optical fiber carrying a baseband signal between cells and the central eNB. The central entity is required in order to collect the channel information from all the UEs in the area covered by the coordinating eNBs. This entity is also in charge of performing baseband signal processing and control, so the radio resources between the cells can be controlled accordingly. With this approach, the signaling delay and overhead between eNB are small and the control of high speed radio resources between cells is relatively easy. However, with high capacity optical fiber required, as the number of RRE increases, the processing load on the central eNB will also increase. This would be the limitation for this network configuration.

A distributed architecture is another method to carry out coordination that relieves the demands of a centralized approach. Based on the assumption that schedulers in all eNBs are identical and channel information regarding the whole coordinating set can be available to all cooperating nodes, inter-eNB communication links are no longer necessary to perform cooperation. Thus, this architecture has the great advantage of minimizing the infrastructure and signaling protocol cost associated with these links and the central processing unit, so conventional systems need not undergo major changes. Furthermore, the radio feedback to several nodes could be achieved without additional overhead.

2.2 CoMP Transmission Schemes

In this section, we present the possible CoMP categories that are figured in LTE-Advanced for both the uplink and the downlink. The transmission schemes can be independently implemented whether the architecture is a distributed or a centralized one. The schemes necessities in terms of measurements, signaling, and backhaul are distinct, where usually the best performance achieving schemes demand the most complex system.

In the downlink, two main CoMP transmission methods are discussed: cooperative scheduling/beamforming (CS/CB) and joint processing (JP). Their main difference lies in the fact that in the coordinated scheduling/beamforming scheme it is only one eNB that transmits data to the UE, although different eNBs may share control information. In the joint processing scheme, many eNBs transmit data simultaneously to the same UE. In the uplink, however, only a coordinated scheduling approach is discussed.

In general, the cost of the CoMP mode is found only beneficial to the cell-edge users where the perceived Signal-to-Interference-and-Noise Ratio (SINR) is low. This is because more system resources are allocated to a single user during its operation. However, simulation results suggest that CoMP can be used to increase both the average cell throughput and the cell-edge user throughput as compared with conventional non-cooperative system (Wang, Jiang, Liu & Yan, 2009).

2.2.1 Downlink

In coordinated scheduling/beamforming scheme, each UE is served by a single cell known as the serving cell as shown in Figure 2. Nevertheless, beamforming decisions and user scheduling are made with coordination among the selected cells to improve the sum throughput and minimize interference. The feedback design should be enhanced to give back up for this transmission scheme. The scheduler at each eNB forms its decisions independently but still need additional information about other user's channel conditions in order to perform a more optimal scheduling and beamforming. The generalization of this procedure to a more realistic scenario with a larger number of base stations and terminals is quite straightforward, although the accurate measurements in multiple UEs, the feedback, and the information exchange among eNBs still present some challenges. Nevertheless, simulations so far have demonstrated that CS/CB with improved feedback can deliver significant gain to cell-edge users (Motorola, 2009).

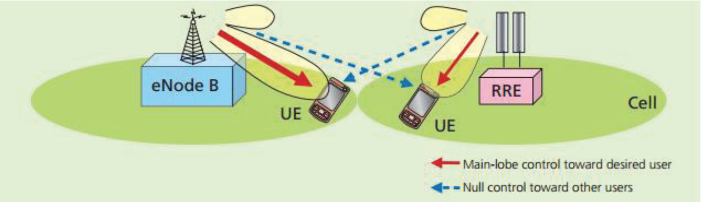
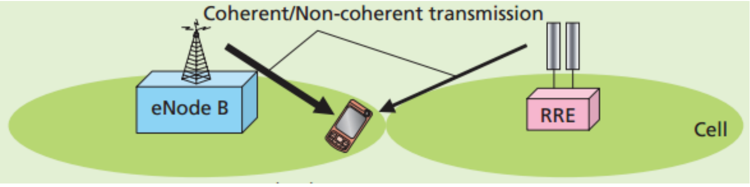


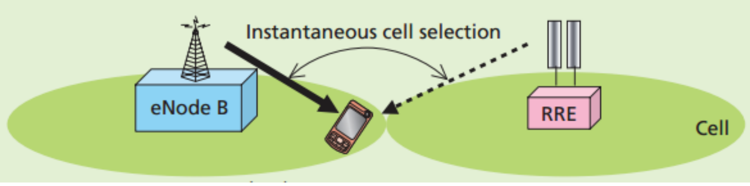
Figure 2. Coordinated scheduling/beamforming scheme
(Taoka et al., 2010)

In the category of joint processing, data intended for a particular UE are jointly transmitted from multiple eNBs to improve the received signal quality and cancel interference. The information theory paradigm to be exploited is the following: if antennas are uncorrelated, the number of independent communication channels is the same as the product of transmitting and receiving antennas. Different site location means inherent low correlation; hence, even though this approximation gives an upper bound for the system capacity, a high potential gain may be achievable.

Two different methods are being studied for the JP scheme: joint transmission and dynamic cell selection. In joint transmission, data are indeed transmitted from several sites at the same time using the same time and frequency radio resources. There are two approaches for joint transmission scheme: non-coherent transmission, which uses soft-combining reception of the OFDM signal; and coherent transmission, which does precoding between cells and uses in-phase combining at the receiver. For dynamic cell selection, cells can be selected at any time in consideration of interference. This advanced pair of techniques is particularly beneficial for cell-edge throughput and is anticipated to be the dominant application of CoMP. Figure 3 shows a simplified scheme of both techniques. In both cases user data need to be shared among base stations so a very fast link interconnecting them is required, although the complexity of the signal processing is higher in the joint transmission scheme.



(a) Joint transmission



(b) Dynamic cell selection

Figure 3. Joint processing techniques (Taoka et al., 2010)

2.2.2 Uplink

In the uplink the CoMP scheme, aimed at increasing the cell-edge user throughput, implies the reception of the signal transmitted by UEs at multiple and geographically separated points. Generally speaking, the terminal does not need to be aware of the nodes that are receiving its signal and what processing is carried out at these reception points. This is all an implementation issue, so CoMP reception is expected to have limited impact on the specifications, and no major change in the radio interference should be required. Nonetheless, scheduling decisions can be coordinated among cells, and some specification impact may be brought from this fact.

There are different schemes that can be used at multiple reception points to combine the received signals. Maximum Ratio Combining (MRC), Minimum Mean Square Error Combining (MMSEC), and Interference Rejection Combining (IRC) are examples of techniques that extract the transmitted information from the received signal. Despite the above-mentioned considerations, it has been noticed that there are some issues which may impact the system performance and should be further investigated.

2.3 Related Works

Generally, few field trials on coordinated multipoint transmission and reception have been reported. Ref. (Jungnickel et al., 2010) reported for the first tome on field trials in a real multicellular deployment using CoMP transmission in the dowlink. They have used distributed synchronization and virtual local area network. The experiment proved that downlink CoMP can be used with the distributed LTE architecture. In (Irmer et al., 2011), the principal feasibility of CoMP was tested in two field testbeds with multiple sites and different backhaul solution between the sites. Key challenges and potential benefits of using CoMP in specific scenarios also have been presented. From the technical points of view, intrasite cooperation is easier to be implemented. However, in order to benefit the potential of full interference reduction from base station cooperation, intersite cooperation is still will be needed. The hybrid combination of joint processing and joint scheduling between the sites will provide promising gains with limited backhaul.

As CoMP has a potential to be the efficient way of reducing inter-cell interference in cellular networks, further studies have been done in order to evaluate the feasibility of CoMP in managing interference. Ref. (Liu, Chong & Shroff, 2002) presented on opportunistic joint scheduling and power allocation schemes to facilitate inter-cell interference. The objective of their research is to minimize the average transmission power, which in turn will reduce interference to other cells, while keeping the needed data rate for each user within the cell. The study provided optimal solutions on the power savings as compared with a round-robin scheme. Further work on coordinated scheduling has been presented in (Yu, Kwon & Shin, 2011), where the researchers proposed on the decoupling of scheduling, beamforming and dynamic power spectrum adaptation. The proposed system gives a significant throughput and network utility improvement with coordination only at the resource allocation level. Another work on coordinated beamforming and jointly optimized transceiver algorithms called interference aware-coordinated beamforming has been presented in (Chae, Hwang, Heath & Tarokh, 2009) but only considering equal power allocation scheme. The proposed system considers a two-cell MIMO system.

Other works on interference limited environment were published in (Jaeckel et al., 2009) and (Jaeckel, Thiele & Jungnickel, 2010). Ref. (Jaeckel et al., 2009) reported on measurements at a frequency of 2.53 GHz with 20 MHz bandwidth in urban macro cell deployments. The measurements could help the design of multiuser and cooperative transmission and reception techniques to reduce the interference in cellular system. Ref. (Jaeckel, Thiele & Jungnickel, 2010) is the extended work of (Jaeckel et al., 2009) with further measurements on capacity of MIMO system has been evaluated. The field trial focused more on frequency reuse on limited network. Interference mitigation techniques for coordinated multipoint further reported in (Chatzinotas & Ottersten, 2011). In the study, two mitigation techniques, namely interference alignment and resource division multiple access were evaluated and compared. The authors suggested that resource division multiple access is preferred for dense cellular systems, while interference alignment is appropriate for average to sparse cellular systems on the expense of higher complexity. More literature studies on interference for cellular and mobile systems can be found in (Gesbert et al., 2010), (Xu, Zhang & Wang, 2011) and (Balasundram, Nandakumar, Ajanthkumar & Lingesh, 2011).

3.0 SYSTEM MODEL

The present study focuses only on downlink and is based on a dense small cell scenario, which typically corresponds to urban conditions with a high density of base stations to ensure coverage continuity and user requirements. The aim is to optimize the association of users to base stations (eNBs). Hence, joint processing will be used in the study to utilize the CoMP advantages. The system is based on LTE-A physical layer configuration. Each mobile is associated with at least one, the highest receiver power eNB, referred to as the primary base station. We consider multiple input multiple output (MIMO) transmissions, with Nt antennas at each eNB and Nr at each user equipment (UE). Joint processing is only allowed between base stations belonging to the same cluster, whereas base stations belonging to different clusters are not coordinated and thus produce inter-cluster interference signal. The combinations of signals from two or more base stations allows users to improve their signal-to-interference-plus-noise-ratio (SINR) level which the total interference power is decreased significantly by using the strongest interferer as useful signal. Figure 4 shows the proposed system model. Each cell is referred as "serving area" for the selected user and denoted as SA. Each cell is controlled by one serving base station (BS) and can be joint controlled by another two base stations from the neighbouring cells.

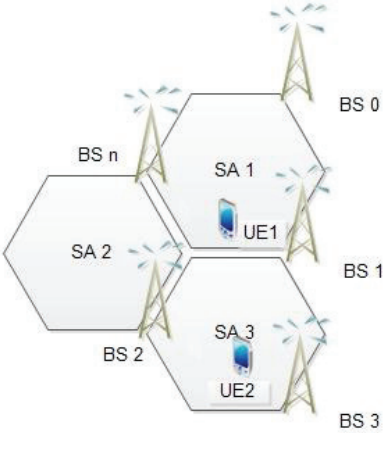


Figure 4. CoMP system model

In general case of the multiple antennas with single output link, the received signal for a given user can be expressed as:

$$y = \sum_{n \in K} h_n \sqrt{P_n} x_n + \sum_{k \notin K} h_k \sqrt{P_k} x_k + s \tag{1}$$

where considering **K** the set of base stations in the system that serve a given user, *s* is the additive white Gaussian noise with a σ_s standard deviation, *n* refers to transmitting antennas, *k* refers to cells not belong to **K** which indicates the interference signal to the given user in cell *n*, P_n and P_k are the average received power, h_n and h_k denote the channel matrix, x_n and x_k denote the transmission data. We assume a perfect channel state information (CSI) known at receiver side and coherent detection is used. The received SINR is given by:

$$SINR, \gamma(K) = \frac{\sum_{n \in K} |h_n|^2 P_n}{\sum_{k \notin K} |h_k|^2 P_k + \sigma_s^2} \qquad (2)$$

For the cooperative transmission with multiple inputs and multiple outputs link, the general case of the received signal for the particular user at eNodeB *n* can be expressed as:

$$y = H_n C_n \sqrt{\frac{p_n}{N_t}} x_n + \sum_{k \neq n} H_k C_k \sqrt{\frac{p_k}{N_t}} x_k + s \qquad (3)$$

where H_n and H_k are the channel matrices, C_n and C_k are the precoding matrices which contains the precoders c_i assigned for each of the users in the cell and p_n/N_t is the particular allocated power. For this case, block diagonalization (BD) algorithm is used as the joint precoding algorithm. Precoding uses knowledge of the users' channels and data streams to execute coding in an arranged manner among the users and because of that the interference at the transmitter can be removed. This is alike to the effect of the successive interference cancellation (SIC) which removes the interference at the receiver through ordered decoding. Therefore the coding and precoders are designed so that each user's received signal does not experience interference from users encoded after it.

4.0 RESULTS AND DISCUSSION

For the initial setting to test the performance of LTE transmission on an uncorrelated channel for several transmission modes, the simulation parameters used were shown in Table 1. The initial simulation was tested for a single user.

Table 1. Simulation Parameters (Mehlfuhrer, Colom Ikuno, Simko, Schwarz, Wrulich & Rupp, 2011)

Parameter	**Value**
Number of UEs	1
Bandwidth	1.4 MHz
HARQ Retransmissions	0
Channel type	TU uncorrelated
Filtering	Block Fading
Receiver type	Zero Forcing
Simulation length	1000 subframes
Transmit modes	SISO, TxD (Nt x Nr = 2 x 2), OLSM (2 x 2) and CLSM (4 x 2)

Result shown in Figure 5 provided the performance of single user in LTE system using different antenna configurations. Four types of antenna configurations are tested which are single-input single-output (SISO), transmit diversity, open-loop spatial multiplexing (OLSM) and closed-loop spatial multiplexing (CLSM). Higher number of antennas gave better throughput as compared to single antenna configuration. Further works on the performance of multiple antennas cooperation will be presented later.

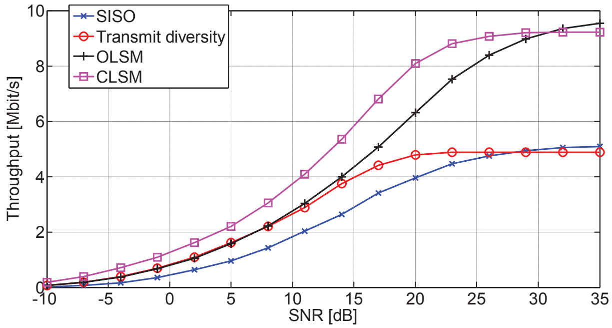


Figure 5. Performance of LTE for different transmission modes

5.0 CONCLUSION

In this paper, the basic concept of coordinated multipoint transmission and reception in the context of LTE-Advanced has been discussed. There are some limitations and advantages of each transmission schemes and deployment architectures which are still being studied. The proposed system model is still in progress and the results may vary alongside with the standardization works.

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