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Coordinated Multipoint (CoMP) Reception and Transmission for LTE-Advanced/4G

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Abstract
Wireless data usage is increasing at a phenomenal rate and driving the need for continued innovations in wireless data technologies to provide more capacity and higher quality of service. In order to meet all the requirements of IMT-Advanced as defined by ITU for LTE-Advanced/4G, several key technology components have been investigated 3GPP. In addition to relaying and repeater solutions to enhance coverage and cell edge data rates, Coordinated Multi-Point transmission/reception (CoMP) is considered by 3GPP as a tool to improve coverage, cell-edge throughput and system efficiency. This paper provides a brief insight in to the technologies including its architecture, working and challenges in the deployment of CoMP.

Keywords
Wireless Mobile Communication, 4G, CoMP, LTE-Advanced, MIMO, 3GPP

I. Introduction
Coordinated multipoint or cooperative MIMO is one of the promising concepts to improve cell edge user data rate and spectral efficiency. Long Term Evolution (LTE) and mobile WiMAX use Multiple-Input Multiple-Output (MIMO)-Orthogonal Frequency-Division Multiplexing (OFDM) and achieve improved spectral efficiency within one cell. In this method coordination of base stations to avoid interference and constructive exploitation of interference through coherent base station cooperation is done. Conceptually, we extend single-cell MIMO techniques, such as multi-user (MU-MIMO), to multiple cells. The cooperation techniques aim to avoid or exploit interference in order to improve the cell edge and average data rates. CoMP can be applied both in the uplink and downlink.

One of the fundamental differences between CoMP Multi-User (MU) MIMO systems and single-cell MU MIMO systems lies in the per base station power constraint. By using CoMP, coherent transmission with coordinated base stations can significantly improve both the cell average throughput and the cell edge throughput [1].

Different approaches to CoMP can be analysed using system-level simulations with hexagonal cells and evaluation methodologies customary in the 3GPP, Next Generation Mobile Networks (NGMN), and International Telecommunication Union (ITU). Unless otherwise specified, the intersite distance in all computer simulations has been set to 500 m, a terminal speed of 3 km/h is assumed, and the system bandwidth is 10 MHz [2,7,8].

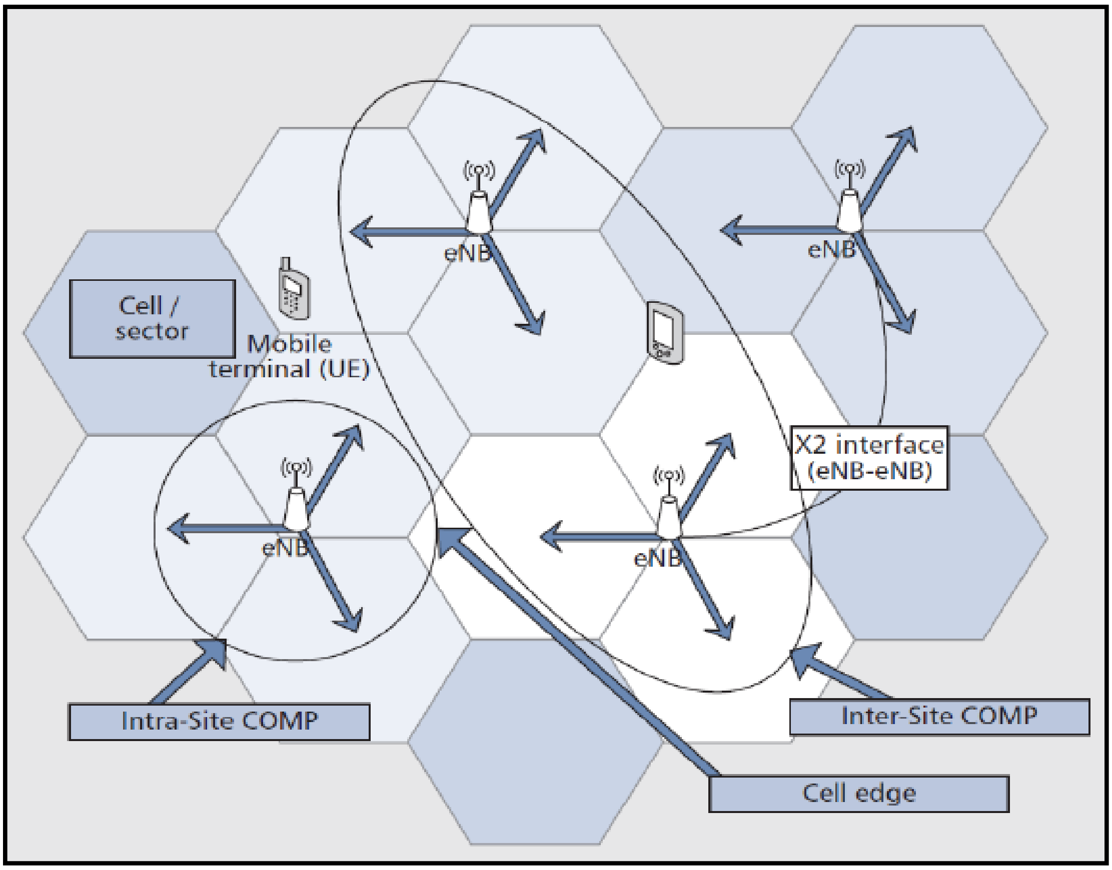

Fig.1: Base Station Cooperation: Inter-Site and Intra-Site CoMP

One key element of mobile radio networks is spatial reuse (i.e., the reuse of resource elements such as timeslots or frequency bands) in a geographical distance, where the signal strength is reduced due to path loss, shadowing, and so on. 3G and 4G technologies are using full frequency reuse, which in turn leads to interference between the cells. In network coordination has been presented as an approach to mitigate intercell interference and hence improve spectral efficiency. The spectrum resources are used in all sectors, leading to interference for terminals at the edge between the cells, where signals from multiple base stations are received with similar signal power in the downlink. Multiple sectors of one base station (eNB in 3GPP LTE terminology) can cooperate in intrasite CoMP, whereas intersite COMP involves multiple eNBs [1].
CoMP in the context of LTE-Advanced involves several possible coordinating schemes among the access points. Coordinated beamforming/scheduling is a simpler approach where user data are transmitted only from a single cell. Joint processing techniques; however, requires multiple nodes to transmit user data to the User Equipment (UE). Two approaches are being considered: joint transmission, which requires multi-user linear precoding, and dynamic cell selection, where data are transmitted from only one cell that is dynamically selected [3].

II. Inter-Cell Interference

The inter-cell interference (see fig. 1) is one of the major concerns that affects the data rates of the users at the cell-edge as well as the average spectral efficiency of the cell. The inter-cell interference can be dramatically reduced by increasing the frequency reuse factor that determines the minimum distance between cells operating on the same frequency band. Signal-to-Interference-plus-Noise-Ratio (SINR) improves significantly when high frequency reuse factor is used in 2G cellular networks. But the bandwidth available to reuse these frequencies is lower than the equivalent gain achieved by this SINR improvement.
Network coordination results in choosing the antennas from different Base Stations (BSs) in suitable ways such that the signal power is increased and the effect of inter-cell interference is reduced. There can also be a noteworthy increase in spectral efficiency attributed to the use of network coordination at high Signal-to-Noise Ratio (SNR). Base station coordination improves the user experience at the cell-edge, by exchanging the cell information among different base stations (see fig. 2) [4].

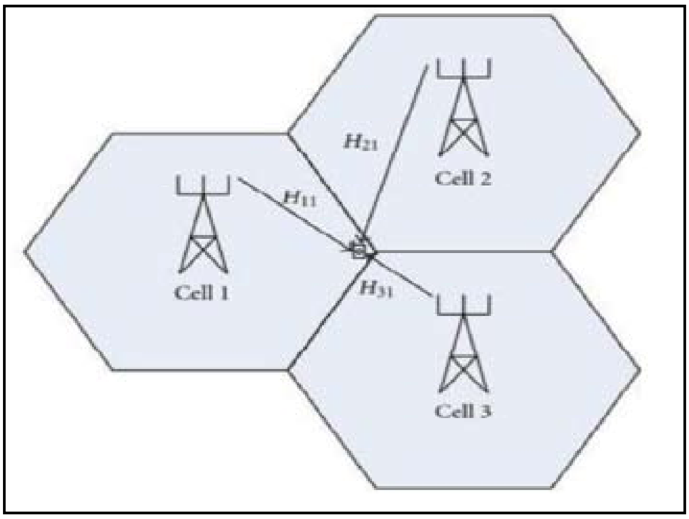

Fig. 2: Coordinated Multipoint Transmission in Downlink

III. The CoMP Architecture

Coordination among eNBs is a very promising technique to reduce inter-cell interference in the network in both the downlink and the uplink. CoMP is applied in the downlink by performing a coordinated transmission from the base station, whereas interference in the uplink can be reduced by means of a coordinated reception in eNBs. Most of the CoMP approaches share the requirement of needing some scheduling information regarding the users at the different base stations that must be shared among them. This means that very-low-latency links are required so that information can be exchanged between coordinated nodes in the order of milliseconds [3].

IV. Working

Coordination between BSs can be achieved on the Uplink (UL) and Downlink (DL). When there is coordination in the UL, this is referred as CoMP reception or Joint Detection. The received UL signal at multiple BSs may be combined using techniques such as Maximum Ratio Combining (MRC), etc. This is perceived to be implementation dependent with no impact on the radio interface. Coordination in the DL is referred to as Coordinated MultiPoint transmission or Joint Transmission. In MU-MIMO, the DL and the UL correspond to the BroadCast (BC) and Multiple Access Channel (MAC), respectively [5].

V. CoMP Transmission and Reception

A. Downlink

1. Transmission Scheme

In downlink CoMP transmission,two transmission schemes are mainly considered: Joint Processing (JP) and coordinated scheduling/beamforming (CS/CB). In CoMP transmission the related control channels, including the Physical Downlink Control Channel (PDCCH), are transmitted only from the serving (anchor) cell regardless of the transmission scheme.

2. Joint Processing

JP is further categorized into Joint Transmission (JT) and Dynamic Cell Selection (DCS), (see fig. 3(a) & 3(b)).
In JT the same Resource Block (RB) of the PDSCH is transmitted from multiple cells associated with a UE specific demodulation reference signal (US-RS) among coordinated cells (i.e., from non-serving cell (s) as well as the serving cell). For instance, JT is achieved by codebook-based precoding to reduce feedback signal overhead. In principle, the best precoding matrixes for intercell site coordination are selected in addition to the individual selection of the best precoding matrix at each cell site so that the received signal-tointerference-plus-noise power ratio (SINR) is maximized at a UE set among the predetermined precoding matrix candidates. Other implementation methods are also considered to achieve the principle operation. A UE set feeds back a Channel Quality Indicator (CQI) based on the combined received SINR to the serving cell, and then an RB is dynamically assigned to the UE by fast scheduling at the central BS. Since the transmission power resources of multiple cell sites can be used through coherent transmissions, the cell edge user throughput is improved significantly.
In DCS an RB of the PDSCH associated with a US-RS is transmitted from one cell among the coordinated cells, and the cell transmitting the PDSCH with the minimum path loss is dynamically selected through fast scheduling at the central BS. Then, for instance, the other cells

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among the coordinated cells are muted (i.e., they do not transmit the RB), so the cell edge UE does not receive other-cell interference. Therefore, the maximum received signal power is obtained, and the interference from neighboring cells is significantly mitigated.

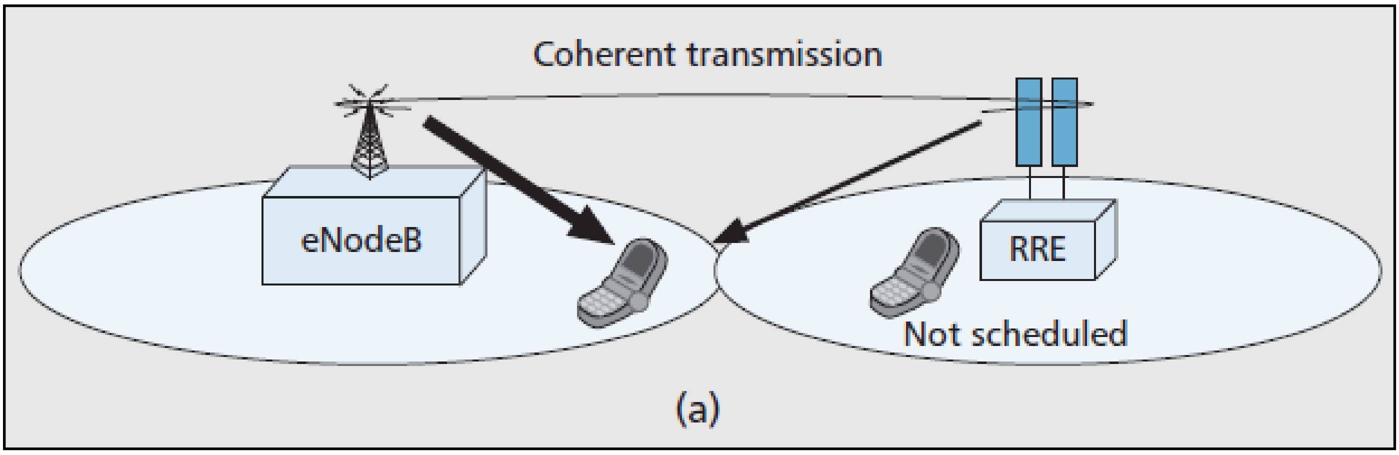

Fig. 3(a): The Operating Principle of JT in the Downlink

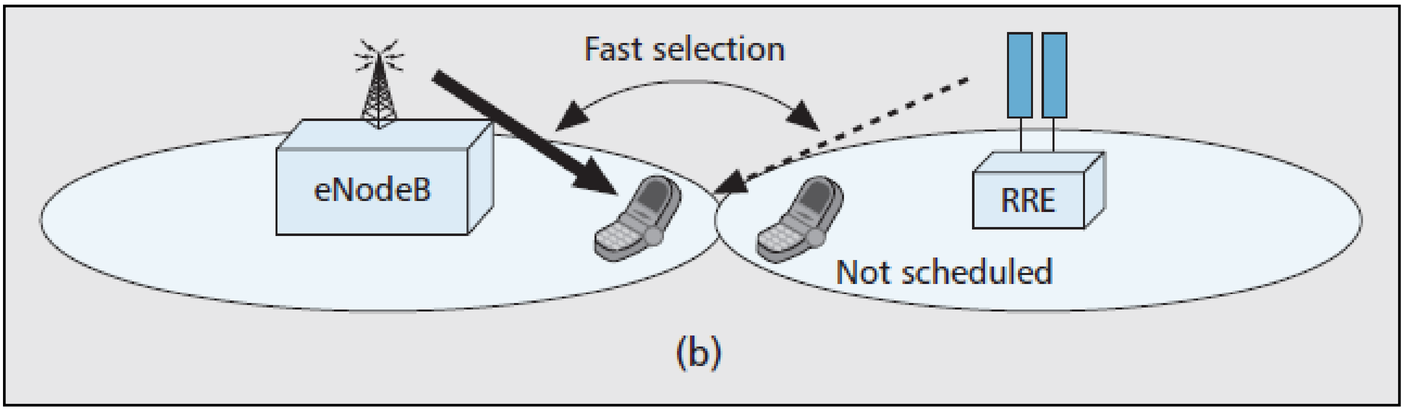

Fig. 3(b): The Operating Principle of DCS

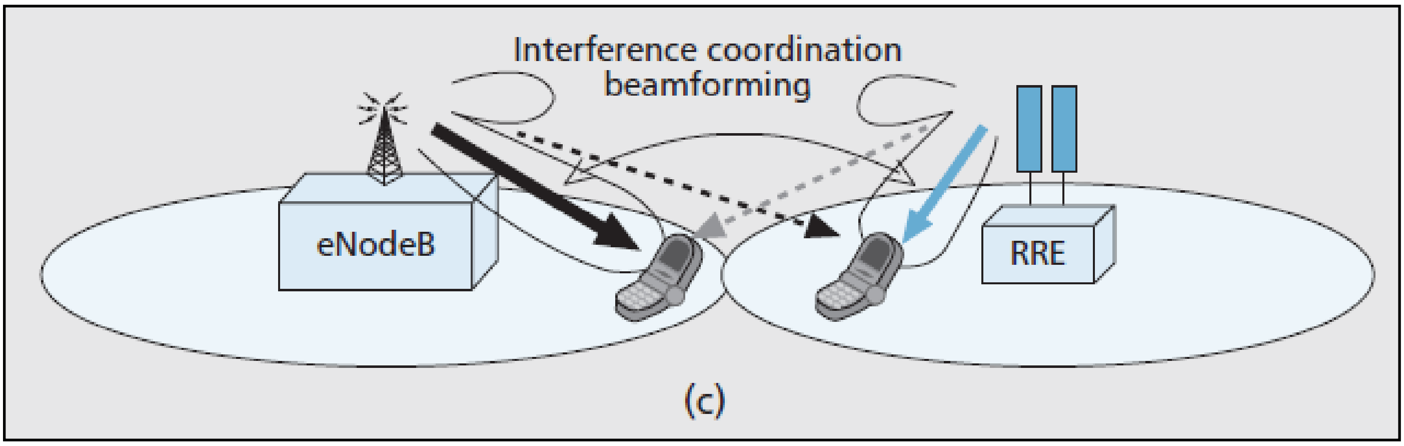

Fig. 3(c): The Operating Principle of Coordinated Beamforming

Unlike the aforementioned DCS, a resource block (RB) of the PDSCH is transmitted only from the serving cell together with the PDCCH. Hence, an RB is assigned to the UE with CS/CB by scheduling of the serving cell. However, scheduling/beamforming is coordinated among multiple coordinated cells (See fig. 3(c)). In this case transmit beamforming weights for each UE set are generated to reduce the unnecessary interference to other UE scheduled within the coordinated cells. Therefore, in particular, the cell edge user throughput can be improved due to the increase in received SINR.

1. Challenges in Downlink

The complexity of DL CoMP can be managed in real-world scenarios and that significant gain can be realized by forming small cooperation clusters in large-scale networks. However, solutions for the following are needed before it can be integrated in next-generation mobile networks:

- Reduced cost of base station synchronization and low-phase-

noise transmitters
- Efficient feedback compression
- Reduced feedback delay
- Efficient channel prediction at the precoder
- Flexible formation of cooperation clusters
- Handling of outer interference within the cluster
- Efficient multi-user selection
- Flexible networking behind CoMP
- Integration of CoMP into higher layers [2]

B. Uplink
In CoMP reception in the uplink, the Physical Uplink Shared Channel (PUSCH) is received at multiple cells. In this case, Maximal Ratio Combining (MRC) is used at multiple RREs. (see fig. 4(b)).

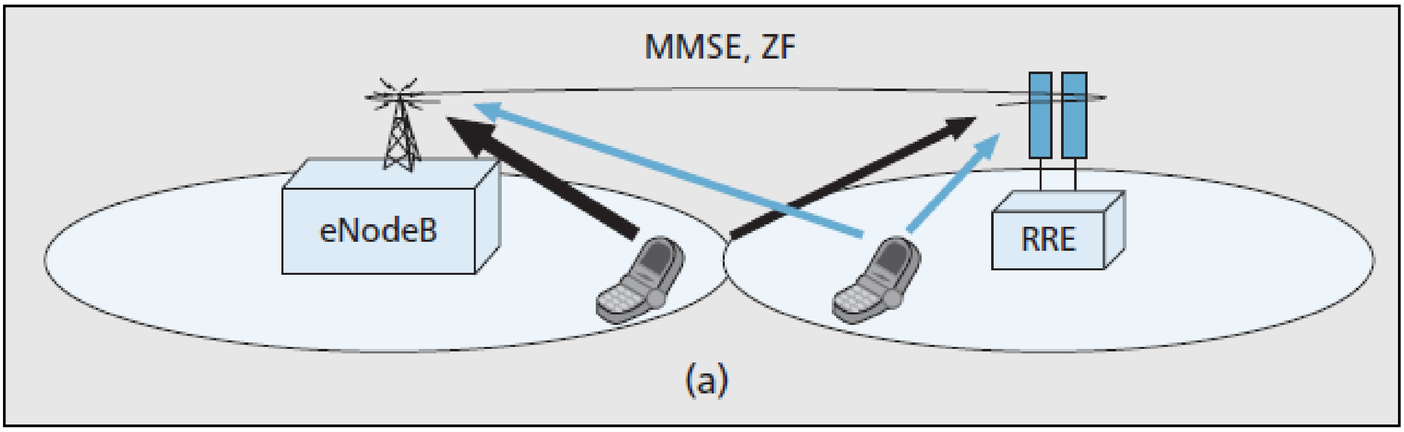

Fig.4(a): The CoMP Reception with Interference Rejection Combining (IRC)

In interference rejection combining, multiple UE sets transmit the PUSCH simultaneously using the same RB; however, received weights are generated so that the received SINR or signal power after combining at the central eNode B is maximized in CoMP reception with IRC (see fig. 4(a)). The Minimum Mean Squared Error (MMSE) or Zero Forcing (ZF) algorithm is typically used to combine the received PUSCHs at multiple cell sites.

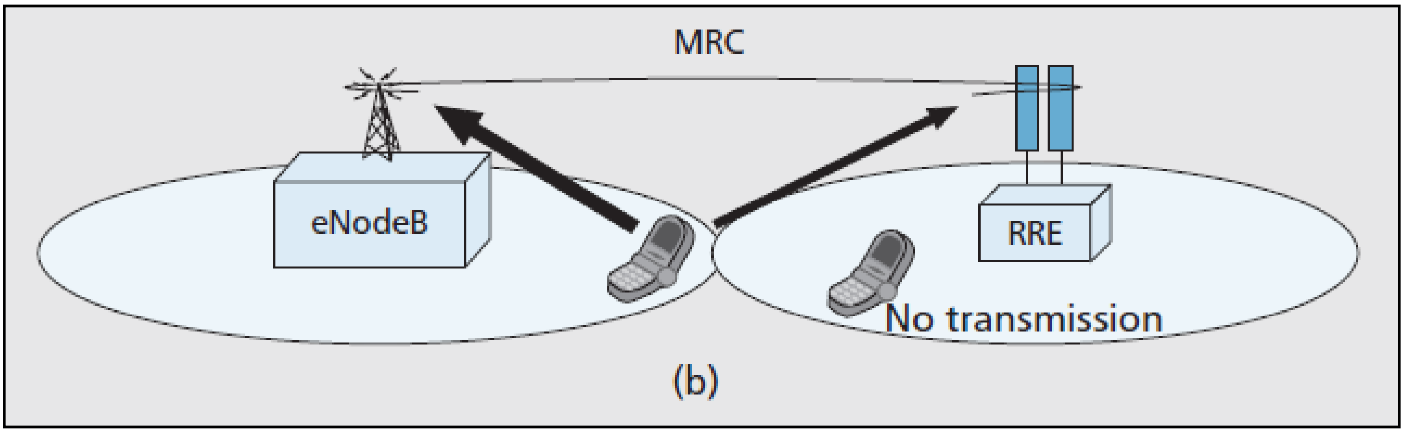

Fig. 4(b): The Multipoint Reception with Coordinated Scheduling

In coordinated scheduling only one UE set transmits the PUSCH using an RB based on the coordinated scheduling among cells in CoMP reception with coordinated scheduling.

In both schemes, the cell-edge user throughput is improved due to the increase in the received signal power. Note that CoMP reception in the uplink is an implementation matter and does not require a significant change in the physical layer radio interface [6].

1. Challenges in Uplink
From the experience of implementing and testing UL CoMP, the following key challenges have become apparent.

(i). Clustering
Suitable clusters of cooperating base stations have to be found, which can be done in a static way or dynamically.

(ii). Synchronization
Cooperating base stations have to be synchronized in frequency such that inter-carrier interference is avoided, and in time in order to avoid both inter-symbol and inter-carrier interference. The maximum distance of cooperating base stations is limited since different propagation delays of different terminals may conflict with the guard interval. This aspect may be compensated through a more complex equalization.

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(iii). Channel Estimation

A large number of eNBs in the CoMP cluster in the UL will require a larger number of orthogonal UL pilot sequences. At some cluster sizes, the CoMP gains are outweighed by capacity losses due to additional pilot effort.

(iv). Complexity

The above mentioned field trials have been performed using orthogonal frequency- division multiple access (OFDMA) in the UL, as this enables a sub-carrier and symbol-wise MIMO equalization and detection in the frequency domain. If Single-Carrier (SC)-FDMA was used as in LTE Release 8, equalization would be more complex.

(v). Backhaul

It can be a severe issue if centralized decoding is applied. Hence, adaptive decentralized/ centralized cooperation appears to be an interesting option. Furthermore, source coding schemes appear interesting for backhaul compression [2].

VI. Obstacles

Some of the obstacles in realizing CoMP are discussed below. The solutions for the following are needed before it can be integrated in next-generation mobile networks:

1. Noncausal CSI

DPC achieves capacity in MU-MIMO but due to the complexity involved, this is not practically feasible.

2. Delay

The time delay in sharing information between BSs results in CSI mismatch, as the channel when measured for precoding is now different. Hence, with coherent joint processing, one needs to consider the trade-off between the latency involved in backhauling and the gains achievable with CoMP.

3. Synchronization

The signals shared between BSs need to be time and phase synchronized. This tight synchronization puts tremendous requirements for high speed backhauling. The coordination algorithms implemented at the FPGA (Field Programmable Gate Array) level gives better synchronization.

4. CSI Availability

Time Division Duplex (TDD) can exploit the reciprocal nature of UL and DL such that the CSI estimated at the BS on the UL can in turn be used in the DL. Hence, no CSI feedback from the MS is necessary. This reciprocal nature holds good as long as the transmit frequency and the receive frequency are within the coherence bandwidth (Bc / 1=TD, where Bc is the bandwidth over which the fading remains correlated and TD is the delay spread) of the channel.

In case of Frequency Division Duplex (FDD), the UL and DL transmissions are on different frequencies. Hence, CSI feedback from MS is indeed necessary and various techniques exist in the literature.

5. Impact of Feedback Errors

The potential errors due to quantization or data compression algorithms used by the MS to feedback the CSI will affect the beamformer [5].

VII. Conclusion

The use of ICT services, such as mobile phones and the Internet, continues to grow worldwide and trends show explosive bandwidth growth of the Internet at large and for mobile broadband networks in particular, which is driving the need for continued innovations in wireless data technologies to provide more capacity and higher quality of service. In order to meet all the requirements of IMT-Advanced as defined by ITU for LTE-Advanced/4G, several key technology components have been investigated 3GPP. In addition to relaying and repeater solutions to enhance coverage and cell edge data rates, Coordinated Multi-Point transmission/reception (CoMP) is considered by 3GPP as a tool to improve coverage, cell-edge throughput and system efficiency. This paper provides a brief insight in to the technologies including its architecture, working and challenges in the deployment of CoMP.

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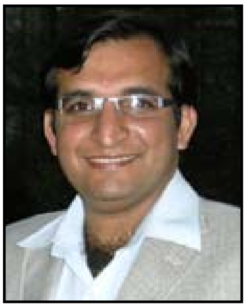

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