Evaluation of SINR for Practical Coordinated Multi-Point Networks

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In Partial Fulfillment of the Requirements

For the degree of

MASTER OF SCIENCE

In

Electrical Engineering

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Dedicated to my beloved mother and father, for planting the magic inside me and uplifting my spirit by supporting me all the way along...

// ACKNWLEDGMENTS

First and foremost thanks to Allah for giving me strength, patience and ability to accomplish this research.

My deep acknowledgement for my parents, sister, brother and uncle who spent their time prays and asks Allah to help me during my study. They have been and will be the sources of my joy throughout my life. Nothing would be meaningful without their substantive help during my different moods.

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ABSTRACT

Full Name : Ayham Nizar Jadallah

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Mobile operators are happy with the increasing number of users, but on the other hand, they are under pressure to satisfy the huge requirements of the data rates and enhance the network quality of service. A coordination technique between more than one cell sector called Coordinated Multipoint (CoMP) transmission and reception is one solution to enhance the service. CoMP is used to improve the cell edge throughput, improve the average data rate, mitigate the interference and increase the spectral efficiency. In CoMP, base stations cooperatively process User Equipment (UEs) connected to multi-points to eliminate the inter-cell interference. The cell edge UEs can be served in CoMP by more than one sector, so CoMP networks convert the interference signal into useful information by controlling the interfering signals among adjacent cells.

This thesis proposes some key research directions and deployment issues such as different types of clustering and optimization criteria, also investigates how CoMP communications can enhance the spectral efficiency and Signal-to-Interference and Noise Ratio (SINR) in inter-site and intra-site CoMP. In addition, we study CoMP static clustering technique and applying different optimization criteria to enhance clustering selection methodology in both ideal and practical cases.

Special emphasis is given to practical implementation by considering both inter-site and intra-site CoMP. Also we propose sectors weighting function according to the average number of sector connected users which can reduce the error of uniform UEs assumption and evaluate the performance of practical CoMP network. We consider Al-Khobar city topography and terrain data to simulate the received power and SINR behavior in specific cases. Practical network deployment is utilized to show SINR improvement in CoMP networks.

The conducted research shows that practical CoMP networks can enhance the system SINR to similar level as in ideal CoMP networks, despite of the non-uniform distribution for UEs and BSs. This work also proposed a cluster selection algorithm based on SINR threshold values for the ideal networks and a quality weight function in practical network that increase the utilization of practical network resources.

ملخص الرسالة

الاسم الكامل: أيهم نزار فؤاد جادالله

عنوان الرسالة: تقييم نسبة الاشارة إلى التداخل والضجيج للشبكات العملية المنسقة متعددة النقاط

التخصص: الهندسة الكهربائية

تاريخ الدرجة العلمية: ديسمبر 2013

مشغلي شبكات الهاتف النقال سعداء مع تزايد عدد المستخدمين، ولكن من ناحية أخرى، فهم تحت الضغط لتلبية متطلبات ضخمة من معدلات البيانات وتعزيز جودة الشبكة و الخدمة.

تقنية التنسيق بين أكثر من موقع خلية واحدة تسمى التنسيق متعدد نقاط الإرسال والاستقبال و هي أحد حلول تعزيز الخدمة. يتم استخدام التنسيق متعدد النقاط لتحسين الإنتاجية عند مستخدمي حافة الخلية، وتحسين معدل متوسط البيانات، والتخفيف من التداخل وزيادة كفاءة استخدام الطيف. في التنسيق متعدد النقاط، قاعدة المحطات تعالج بشكل تعاوني مستخدمي الاجهزة المتصلة بمتعدد النقاط لتجنب التداخل بين الخلايا. مستخدمي الاجهزة عند اطراف الخلية يمكن ان يخدموا في المنسق متعدد النقاط من خلال قاعدة محطة واحدة، لذلك فإن المنسق متعدد النقاط يحول الاشارة المتداخلة الى بيانات مفيدة من خلال التحكم في الاشارات المتداخلة بين الخلايا المتقاربة.

هذا العمل يناقش بعض الاتجاهات الأساسية في مجال البحث، مثل قضايا التثبيت و امكانية تحسين استخدام الطيف و تقييم نسبة الاشارة إلى التداخل والضجيج في التنسيق متعدد النقاط، اضافة لذلك تم دراسة تأثيرات طريقة التجمع الثابت للتنسيق متعدد النقاط على مستخدمين في أماكن مختلفة و تطبيق اساليب مختلفة لتحسين منهجية اختيار التجمع.

قد استخدمنا الطبوغرافيا و بيانات التضايس لمدينة الخبر في المملكة العربية السعودية لمحاكاة تصرف القدرة المستقبلة و نسبة الاشارة إلى التدخل ونسبة الضوضاء في ظروف معينة. التطبيق الفعلي للتنسيق متعدد النقاط يؤدي لاظهار التحسن في نسبة الاشارة إلى التداخل ونسبة الضوضاء.

يظهر هذا البحث ان المنسق متعدد النقاط في الشبكات العملية يمكنه تحسين نسبة الاشارة إلى التداخل ونسبة الضوضاء بمستوى يقارب الشبكات المثالية، على الرغم من التوزيع الغير منتظم لمستخدمي الاجهزة و قواعد المحطات. اقترح هذا العمل خوارزمية اختيار طريقة التجمع على أساس القيم الحدية لنسبة الاشارة إلى التداخل ونسبة الضوضاء في الشبكات المثالية و طريقة لوزن الجودة في الشبكات العملية و هذا يزيد اسغلال موارد الشبكات العملية.

INTRODUCTION AND MOTIVATION

1.1 Introduction

Our demands for mobile communications services and higher data rates are increasing day by day, which is a serious concern for network operators. As the number of mobile phone subscribers has passed 5 billion, Research and Development (R&D) centers of different telecom operators and vendors have been working on finding creative higher spectral efficiency network solutions, to meet the huge data traffic and required quality of service. Frequency reuse is one of the solutions used to satisfy high data demands and at the same time reduces the interference which limits the performance of cellular systems. Even with frequency reuse other problems persist like the inter-cell interference which limits the cell edge User Equipment (UE) data rates. Coordinated Multipoint (CoMP) [1] is an advanced wireless mechanism in mobile communication transmission and reception which proposes a better solution to overcome the inter-cell interference and enhance the cell edge data rates.

In CoMP technology, Base Stations (BSs) connect the UE to more than one base station (multipoint) in a coordinated way to cooperatively eliminate the inter-cell interference. CoMP transmission enhances the network average data rate and increases the spectral efficiency. CoMP was initially used for Code Division Multiple Access (CDMA) systems in the beginning of this century [2], and later was extended to Orthogonal Frequency Division Multiple Access (OFDMA) systems [3] which is the multiple access technique used recently in Long Term Evolution (LTE) technology.

Coordinated BSs exchange information about the received signals from the served UE. This information is needed to perform multi-cell joint signal processing. The UE can be served cooperatively from more than one BS which enhances the performance at the cost of additional overhead data bits and huge backhaul infrastructure.

After evaluation of the current research directions related to CoMP networks, this thesis addresses the practical aspects of CoMP networks. Signal to Interference and Noise Ratio (SINR) is used as the main performance criteria. Al-Khobar network is used as our case study. The SINR enhancement between traditional cellular systems and CoMP ones in both real and practical system models is compared. A proper weighting is also introduced to reduce the error due to the assumption of uniform UE distribution. The thesis also proposes modification to the clustering criteria where the cluster size depends on threshold values.

After the thesis organization and contribution, the early part of this chapter introduces a brief background about the conventional wireless network structure. This is followed by definitions of some major wireless concepts related to CoMP systems such as interference and spectral efficiency. Then, we summarize Multi Input Multi Output (MIMO), LTE and LTE-Advanced (LTE-A) technologies which are related to coordination. The third section illustrates CoMP schemes, clustering, features and deployments. The last part in this chapter is a comprehensive literature review.

1.2 Organization of the Thesis

This thesis is divided into five chapters. Chapter one starts with important concepts that motivate the topic such as interference types and effects and spectral efficiency. Then, the chapter discusses the conventional cellular systems, MIMO systems, and finally the 4th generation systems where CoMP is implemented in LTE-A. CoMP principles, schemes, clustering, deployment, cons and pros are discussed in 1.6 and 1.7. The last part of this chapter is a comprehensive literature review for CoMP and its main research directions. The thesis contribution is presented at the beginning of this chapter.

Chapter 2 presents the system models which are used in our simulations. This chapter is divided into two parts, the first part introduces and evaluates the ideal network model, while the second part addresses the real system model scenario in Al-Khobar city. SINR behavior investigations are performed using Matlab® and WinProp® network planning software. Chapter 3 illustrates the clustering types in the ideal system using different clustering schemes, proposes a modified clustering type and applies different optimization criteria.

In the fourth chapter, we focus on practical CoMP networks using different clustering techniques. Further discussion for the performance of the clustering in real networks is discussed by proposing weight function to correct for the non-uniform UE distribution. Chapter 5 is dedicated for the conclusion and suggestions for future work. The thesis is augmented with a list of abbreviations and a list of variables.

1.3 Thesis Contribution

Coordination multipoint concept has opened new windows that promise new effective ways of improving UEs spectral efficiency and enhancing their SINR. This field of research has attracted researchers from diverse areas of mobile communications.

Our thesis contribution can be summarized as follows:

- Comparison between CoMP and non-CoMP SINR performance in ideal and practical networks using fixed cluster size. The ideal network is made of three tiers of hexagonal cells. The practical network is based on 20 BSs that covers a large part of Al-Khobar city. The performance was compared with the non-CoMP scenario. Both overlapped and non-overlapped clustering were considered.
- In ideal non-overlapped outage measure optimization, we investigated the relation between UE SINR threshold γ and the average time of achieving γ in a specific granularity of our ideal system model.
- Demonstrating the SINR performance enhancement with increasing the cluster size. We studied the behavior for uniformly distributed UEs in the ideal system model using coordination cluster sizes between two and six.
- Proposing a new clustering technique to overcome the limitations in [4] by implementing a cluster selection algorithm. This technique considers both overlapped and non-overlapped clustering inside one network, and it assures the flexibility in cluster size selection, where the initial clusters are selected to achieve the SINR threshold.
- Evaluate the SINR performance in real network using different coordination scenarios: no coordination, inter-cell (cluster size 3), intra-cell (cluster size 3) and mix coordination between inter-cell and intra-cell (cluster size 4).
- Proposed cell weighting function based on the average number of users that are served by each sector. This weight function assigns different priority to each sector in the network, thus we recreate the coordination clusters according to this function.

1.4 Cellular System Architecture and Important Terms

The accelerated mobile communication revolution from the beginning of wireless generations till LTE-A uses the same basic structure, it consists of a transmitter, a receiver and the channel. The BSs and UEs can act as a transmitter or receiver according to the signal direction. The transmission from BS to UE is called downlink transmission, while the transmission from UE to BS is called uplink transmission.

The power level determines how far the signal can travel since the signal power decays with distance. Each serving BS sends data at a specific transmitted power to cover the cell. In cellular communication systems, each cell has distinct carrier frequency to avoid interference with other cells. Frequency reuse is utilized due to the limitations in the available spectrum channels.

In a conventional single antenna cellular architecture, the antenna is located in the cell center and serves the UEs which are distributed inside the cell. Each UE can be served from one BS only and it considers the signals which are received from other BSs as interference or undesired signals. Figure 1 (left) depicts a conventional network with three cells where each UE is served by one BS. Figure 1 (right) illustrates the concept of CoMP and how each UE can be served from more than a single BS. Next sections discuss two important terms in cellular systems related to the thesis work, namely: interference and spectral efficiency.

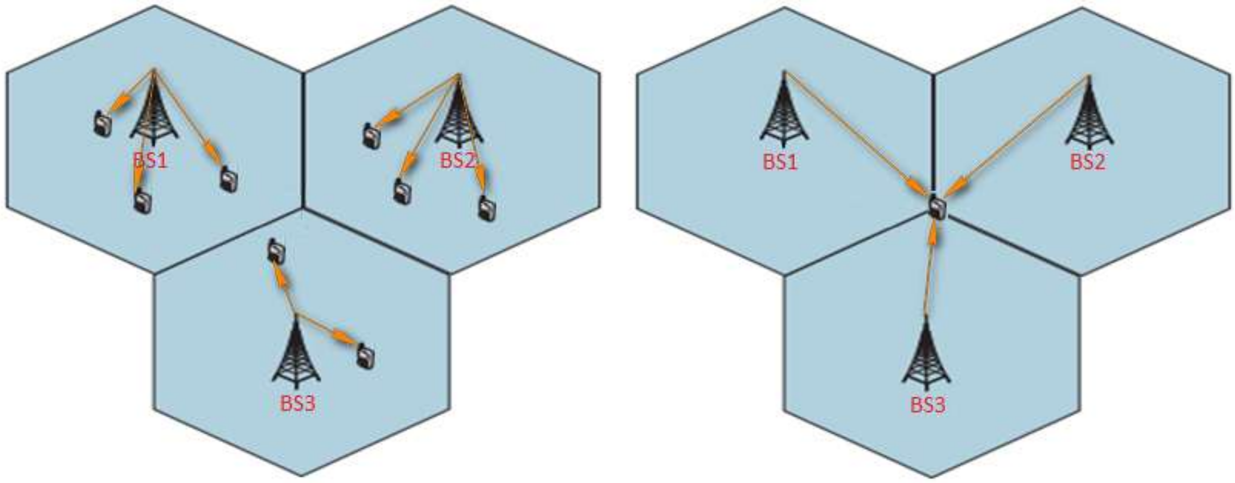


Figure 1 Conventional network (left side) and CoMP network (right side)

1.4.1 Interference Types and Mitigation

Growing demands on the frequency spectrum have increased the possibility of receiving undesired signals which are called radio frequency interference. Interference is the main performance limiting factor for most wireless networks, where the interfering signals can disrupt, delay and reduce the network reliability [5]. The interfering signals may share the same channel with the desired signal, therefore the network quality of service and capacity are substantially affected [6]. Two key factors affecting the interference impact are the network geometry and the path loss [7].

Frequency reuse technique is applied due to limited frequency spectrum, where relatively separated cells use the same frequency in the same mobile communication network. These cells are called co-channel cells, and the interference between signals from these cells is called *co-channel interference*. The experienced interference from adjacent frequency signals to the desired signals is called *adjacent channel interference*.

Two major types of interference are experienced at the polarization level, *cross-polarization* and *co-polarization* interference [6]. Cross-polarization indicates radiating waves in the opposite direction, while co-polarization interference occurs from two different signals which have the same wave polarization.

UEs may experience inter-cell and/or intra-cell interference caused by other users. Interference caused by users in other cells is called *inter-cell interference*, while the *intra-cell interference* is produced by other users served within the same cell. Those two types are considered as main limiting factors in enhancing cellular systems performance.

Each BS in Figure 2 communicates with one user at a single time slot inside the cell. This reduces the intra-cell interference, but can't eliminate the inter-cell interference resulting from adjacent cells.

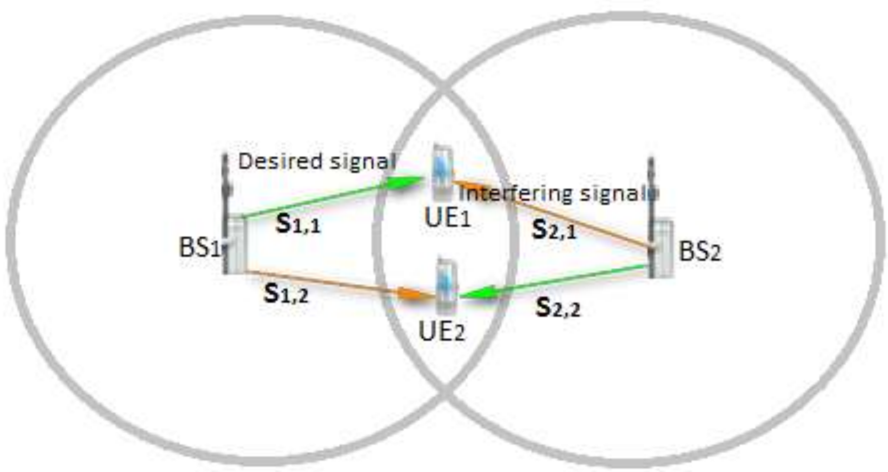


Figure 2 Downlink inter-cell interference

The BS is sum the total received power under a time t seconds, then the interference is calculated by subtracting the desired received signal power from the total received power which formulated in dBm through formula **(0-1)**:

$$Interference = 10 * log_{10}(Total\ received\ power - Desired\ signal\ power) + 30 \quad (0\text{-}1)$$

Figure 2 clarifies the relation between the downstream SINR and inter-cell interference where S refers to UE received signal. UE_1 in this figure is served by the desired signal ($S_{1,1}$) from BS_1 and it considers the coming signal from BS_2 as interfering signal ($S_{2,1}$). So the SINR experienced by UE_1 is:

$$SINR = \frac{P_{Rx1}}{P_{Rx2} + P_{N1}} \quad (0\text{-}2)$$

where P_{Rx1} refers to the UE received power from BS_1, P_{Rx2} is the UE received power from BS_2 and P_{N1} is the noise power at UE_1. **(0-2)** is valid for a UE that receives power from two BSs only. For traditional networks, the received power from more BSs can be added to the received interference signal in the denominator of equation **(0-2)**. Uplink SINR counts the effects of all UEs at each BS, where different UEs operates on same carrier frequency.

In non-coordinated cellular systems, intra-cell interference doesn't exist because there is only one user that communicates with the BS at a single time slot, while the UE in such networks suffers from inter-cell interference especially at cell edge. Signal attenuation increases as the UE distance from the BS does, that makes cell edge UE experience high path loss and inter-cell interference which limits the maximum possible data rate.

Planners and designers of mobile communication networks use different techniques to avoid or reduce the inter-cell interference. The experienced downlink SINR for j UE in conventional cellular networks is:

$$SINR_j = \frac{P_j |h_j|^2}{\sigma^2 + \sum_k P_k} \tag{0-3}$$

where P_j is the transmit power for each user, h_j is the fading channel gain, σ^2 is the noise variance and P_k refers to the interfering signal power from co-channel user k. Different methods are used to mitigate inter-cell interference, such as frequency reuse, sectorization and base stations coordination.

Reuse frequency technique in different cells inside the cellular network is one of the solutions to overcome limited spectrum challenge. Frequency reuse is applied between relatively separated cells where any power signal is attenuated with distance. Figure 3 shows how the same frequency is used in three separated locations.

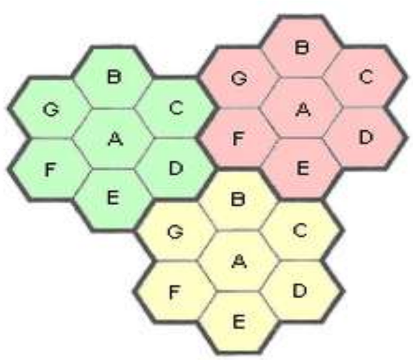


Figure 3 Cellular network frequency reuse

Another efficient technique to reduce the inter-cell interference is cell sectorization, where multiple directive antennas are used instead of omni-directional antennas in each cell, so each cell consists of sub-cells/sectors. Each one has different channel and each sector can cause interference to the cells that are within its transmission coverage angle.

1.4.2 Spectral Efficiency

Spectral efficiency is defined as the aggregate throughput of all users divided by channel bandwidth; it is the maximum bandwidth which can be utilized with the lowest counts of transmission errors and it is measured in bits per second (bps) per Hz. Decreasing system interference has great gains in improving its spectral efficiency. Spectral efficiency requirements for cell and cell edge UEs spectral efficiency are described in Table 1 and Table 2 different environment [9]:

Environment	Downlink (b/s/Hz/cell)	Uplink (b/s/Hz/cell)
Indoor	3	2.25
Microcellular	2.6	1.8
Base coverage urban	2.2	1.4
High speed	1.1	0.7

Table 1 Cell spectral efficency (from ITU-R M.2134)

Environment	Downlink (b/s/Hz/cell)	Uplink (b/s/Hz/cell)
Indoor	0.1	0.07
Microcellular	0.075	0.05
Base coverage urban	0.06	0.03
High speed	0.04	0.015

Table 2 Cell edge user spectral efficency (from ITU-R M.2134)

Cell spectral efficiency, η, is defined in formula **(0-4)**, where x_j is the number of correctly received bits per user *j* (downlink) or from user *j* (uplink) using *N* users and *M* cells network, *B* refers to the channel bandwidth size and *T* is the required receiving time for the data bits [9].

$$\eta = \frac{\sum_{j=1}^{N} x_j}{T.B.M} \tag{0-4}$$

1.5 The Road to Coordinated Multipoint

This section presents the road to CoMP. We introduce the concept of MIMO and general overview about the different generations of mobile communications where CoMP is intended to be implemented in LTE-A starting from the Third Generation Partnership Project (3GPP) release 10.

MIMO technology uses multiple antennas at both the transmitter and receiver ends to enhance the network performance. The implementation of MIMO systems leads to a major increment in data capacity by utilizing the different paths to carry additional traffic and reliability where MIMO systems can mitigate fading. Hence, MIMO get involved in most of cellular system technologies.

MIMO consists of *M* transmitting antennas and *N* receiving antennas, using the same allocated spectrum. In MIMO, each receiver gets the signal from more than one transmitter as shown in Figure 4. We refer to the channel from transmitter i to receiver j by h_{ij}. Based on that, we can implement a channel matrix **H**, and its dimensions are the number of transmitters and receivers in MIMO system as shown in equation (**0-5**).

$$\mathbf{H} = \begin{bmatrix} h_{11} & h_{12} & .. & h_{1M} \\ h_{21} & h_{21} & .. & h_{2M} \\ .. & .. & .. & .. \\ h_{N1} & h_{N2} & .. & h_{NM} \end{bmatrix} \tag{0-5}$$

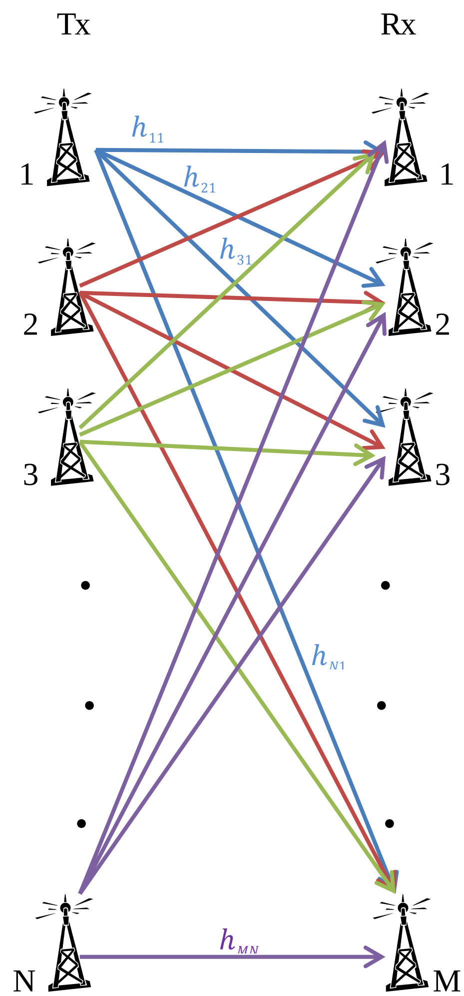


Figure 4 MIMO system model

In SISO systems, Shannon relation shows how the capacity, C, increases with bandwidth, B , and the Signal to Noise Ratio (SNR) [8]

$$C = B\ log_2\ (1 + SNR) \tag{0-6}$$

The capacity in MIMO systems increases linearly with the minimum number of transmit and receive antennas. This growth in MIMO capacity is called spatial multiplexing gain [10]

$$C = \min(M,N)\ log_2\ (SNR) \tag{0-7}$$

There are two main MIMO types, Single-User MIMO (SU-MIMO) and Multiple-User MU-MIMO. Multiple antennas are used for transmitting in both cases, a single user is served by SU-MIMO while the transmitter serves multiple users using the same allocated frequency by MU-MIMO. MU-MIMO is used in LTE-A to enhance the spectral efficiency [11].

3GPP LTE is a standard for wireless communication of high-speed data for mobile phones and data terminals. It is the latest standard in the mobile network technology tree that produced the Global System for Mobile/ Enhanced Data for GSM Evolution (GSM/EDGE) and Universal Mobile Telecommunications System/ High Speed Packet Access (UMTS/HSPA) network technologies. The LTE specifications provide downlink peak rates of 300 Mbit/s, uplink of 75 Mbit/s and round-trip times of less than 10 ms. LTE supports scalable carrier bandwidths, from 1.4 MHz to 20 MHz and supports both Frequency Division Duplexing (FDD) and Time Division Duplexing (TDD). Figure 5 shows the LTE superiority compared to HSPA.

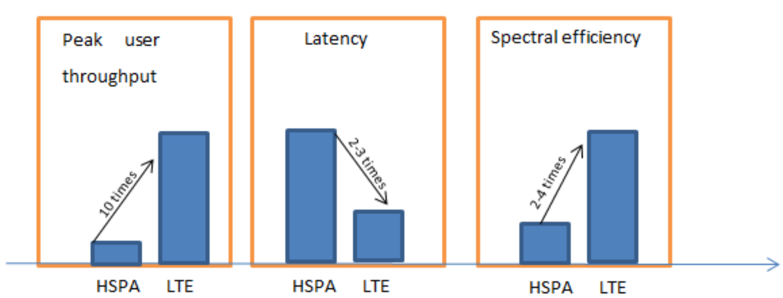


Figure 5 Main advantages of LTE compared to HSPA

The main advantages of LTE are the high throughput, low latency, higher spectral efficiency, plug and play, FDD and TDD in the same platform, an improved end-user experience and a simple architecture resulting in low operating costs. LTE can support seamless passing to cell towers with older network technology such as GSM, CDMA One, UMTS, and CDMA2000. The next step for LTE evolution is LTE-A where the antennas coordination is applied and currently being standardized in 3GPP Release 10 [12] , [13].

LTE-Advanced (LTE-A) is one of the most promising technologies to satisfy 4th generation objectives, especially enhancing system data rates and spectral efficiency. 3GPP aims to have peak data rates of 1 Gbps in downlink and 500 Mbps in uplink in a bandwidth of 100 MHz. The spectrum efficiency will then be 30 bit/s/Hz and 15 bit/s/Hz in downlink and uplink respectively. The key components that make this possible are, among others, carrier aggregation, higher order MIMO, Heterogeneous network deployment and CoMP [14].

1.6 Coordinated Multipoint Concept

Coordinated Multi-Point (CoMP) transmission and reception technique is one of the cooperative communication solutions used in the 3GPP LTE-Advanced. In general, a group of antennas/sectors are connected to a particular Transmission Point (TP)/BS that is configured as one site, where each antenna/sector serves one cell region. In conventional non-coordinated cellular systems, in a given time, each UE is connected to a single cell called the serving cell based on pre-configured criterion. Choosing the serving cell criterion is related to the downlink Received Signal power Level (RSL) and SINR parameters.

CoMP can be defined as coordination between cells/sectors, either the cells/sectors are connected to one BS in the same location or distributed between more than one BS [15]. The UE in CoMP case is communicating with the coordinated sectors, hence, UE can utilize the coordinated sectors available resources. The coordination usually occurs between geographically close sectors, so the inter-cell interference that is experienced from a specific sector will not necessarily be interference after coordination. The cell edge UEs which usually suffer from the interference are the most beneficiaries from coordination. The maximum possible throughput will increase in CoMP, since the UE can utilize the coordinated sectors resources during any communication process.

1.6.1 CoMP Schemes

Coordinated scheduling and Interference Rejection Combining (IRC) are uplink CoMP schemes [16]. The main downlink CoMP schemes are the Joint Processing (JP) and Coordinated Scheduling/ Beamforming (CS/CB). Figure 6 illustrates all schemes. In JP, the UE can receive data from two or more eNBs (Evolved Node B), while in CS/CB the data is received from only one eNB then the coordination could occur between group of BSs.

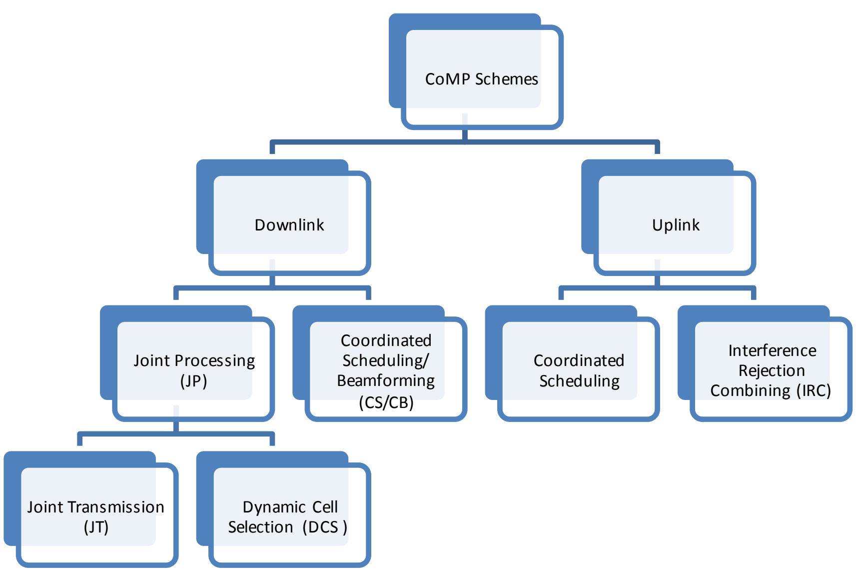


Figure 6 CoMP schemes

Joint processing is divided into two main classes, Dynamic Cell Selection (DCS) and Joint Transmission (JT). DCS is a joint processing mechanism, where the data to each user is transmitted from the coordinating cell with the optimum channel condition, while other sectors are muted, so inter-cell interference is canceled. In JT, the coordinated sectors transmit the same resource block, where specific type of pre-coding is applied to decrease overhead signals. Multiple sectors transmit simultaneously to a single UE in the coordinated cluster, therefore, UE information should be available among all BSs.

CS/CB usually can control and reduce the interference between various transmissions, where the optimum set of users is selected so the transmitter beams are assembled to mitigate the interference from adjacent users. The data to a single UE is simultaneously transmitted from multiple cells, where the user data is encoded and available at all the coordinated base stations in the transmission cells, this data and Channel State Information (CSI) are shared via backhaul links among the coordinated base stations. This will enhance the received signal quality and mitigate the interference for other UEs [17].

In CS/CB, the data is only available at serving cells, which can enhance the received signal quality and mitigate interference for other UEs. However, this scheme shares the CSI of users through the backhaul, which enables the base stations to coordinate their signaling strategies, like power allocations, beamforming and user scheduling. This allows effective control of inter-cell interference [17]. This work considers JT scheme.

1.6.2 CoMP Advantages

CoMP technology is one of the promising technologies in LTE-Advanced. We can summarize its main advantages as:

1. Base stations coordination is considered as an efficient solution to **increase the average data rates and signal level** in the UE which increase the total system capacity as well.
2. **Interference mitigation**, coordination between base stations converts undesired signals in conventional networks into useful signals that enhance the total throughput.
3. **Network utilization,** BSs that are exchanging the channel information using CoMP can send the data streams through the BS which has the lowest traffic load.
4. **Enhancing the spectral efficiency**, cell edge UEs spectral efficiency will be increased after applying CoMP due to receiving desired signals from more than one BS, as a result the number of dropped calls will decrease.

1.6.3 CoMP Drawbacks

Ever since CoMP has commenced in telecommunication, researchers and designers have encountered various challenges that affect the smooth functionality of such technology. Below are some of the difficulties:

1. **Synchronization**: the lack of frequency synchronization causes inter-carrier interference and unsynchronized base stations in time, that result in inter-carrier and inter-symbol interference [18]. The distance between the coordinated base stations is limited since different propagation delays of each user may conflict with guard interval. Specific equalization techniques can reduce this issue [19].
2. **Additional overhead:** exchanging the data CSI via the backhaul requires greater link capacity. More signaling overhead is required on air interface and through the backhaul [19].
3. **Complexity:** higher complexity processing algorithms are required; such as user scheduling, beamforming and power allocation algorithms [19].

1.7 CoMP Clustering Deployment Techniques

The term "cluster" refers to a subset of cells in the network that can coordinate in data transmission of multiple UEs in a time frequency block [20]. *BSs coordination cluster* is achieved when BSs coordinate to serve the same group of UEs, while a *UE coordination cluster* is formed when a group of UEs coordinate together. The coordination at UE level is not efficient enough because it is costly, so most of the clustering is held at BSs level [21]. Figure 7 clarifies the concept of clustering, where the solid hexagon in the middle of the figure is the cluster area and the dashed lines are the cell edge boarders. The three cell edge UEs are served by the clustered sectors.

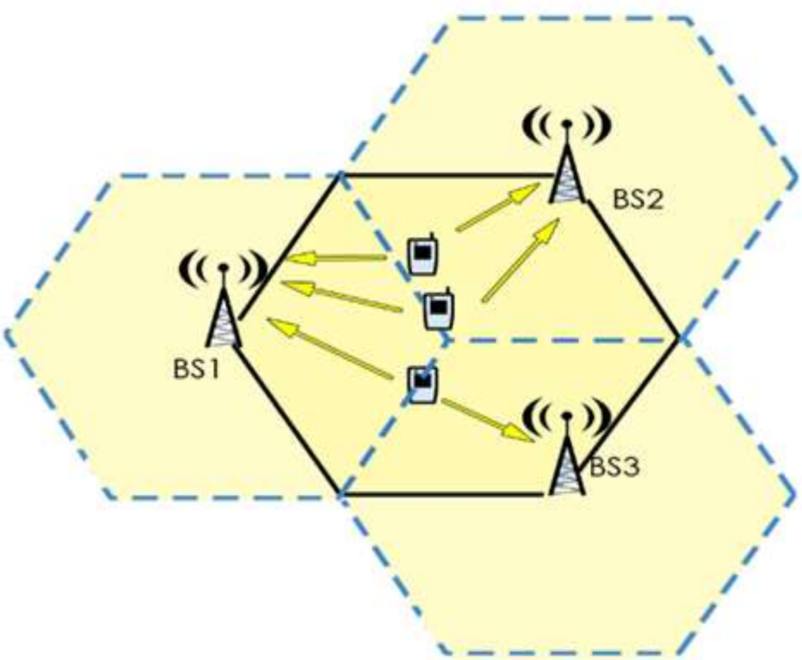


Figure 7 Cluster layout in cellular systems

1.7.1 CoMP Deployment

Two major types of clustering can be used in CoMP communication; *static* and *dynamic*. Static clustering is implemented one time, based on sites measurements and/or specific simulations of fixed network topology, used to break down the large cellular systems into reasonable-sized coordination clusters. In contrast, dynamic clustering allows the UE to select its serving coordination cluster according to the channel performance in different times; therefore the clusters are changed according to the signal quality and traffic demands. Dynamic clustering type has the ability to mitigate the interference from other sites. The major advantage of dynamic clustering is the flexibility in changing the coordinated cells inside each cluster according to the network status, which is mostly time variant. This definitely will help CoMP systems to choose optimum coordination clusters compared to static type, but this has the disadvantage of increased signals overhead and complexity. The dynamic clustering depends on measurements of the time-varying traffic demands and UE locations [4].

Clusters can be shaped in two forms, *overlapped* and *non-overlapped*. The cells in overlapped clusters can be part of different clusters at the same time while each cell in non-overlapped clusters is engaged in one cluster only. Overlapped clusters are complex and costly but they have great advantages in improving system performance. The UEs at the border between clusters will still experience low SINR in non-overlapped clusters, thus, overlapped ones have the advantage from this point of view.

CoMP networks are deployed in two different scenarios: *intra-site* CoMP and *inter-site* CoMP. The coordination in intra-site CoMP occurs between different sectors within one base station's cells and this guarantees involving all network sectors in the coordination process. Inter-site

CoMP requires coordination between multiple sectors in different base stations cells as shown in Figure 8. The great advantage of intra-site coordination is data exchange occurs only in the same BS, while inter-site coordination involves the backhaul between coordinated BSs which requires extra backhaul specifications. Inter-site coordination has the flexibility to coordinate the optimum selection of sectors since we are not limited to the same BS sectors, this make inter-site coordination is more efficient than intra-site type in improving cell edge UEs SINR.

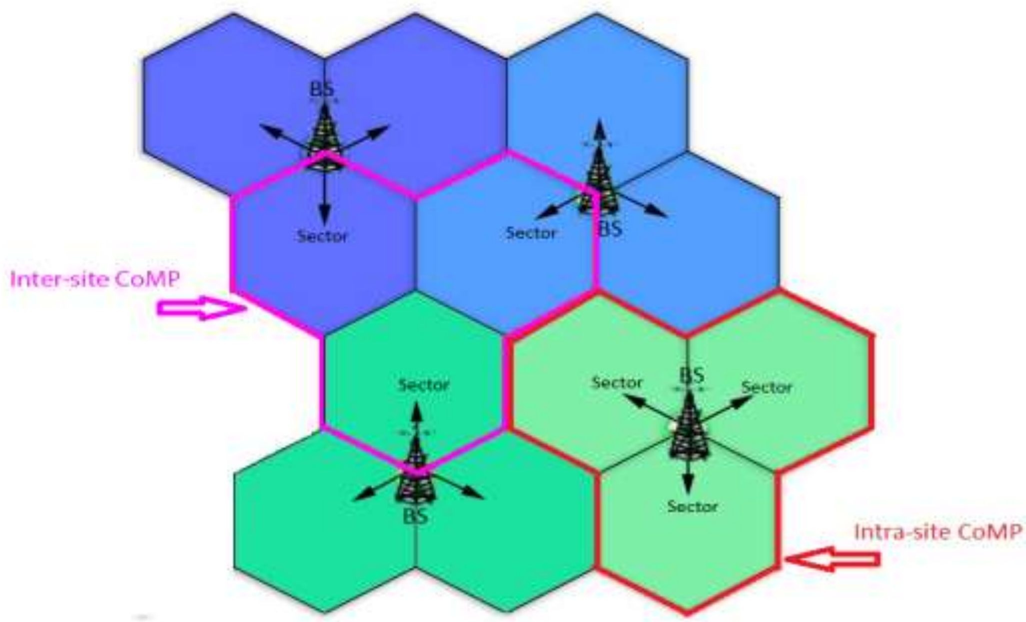


Figure 8 Inter-site and intra-site CoMP

In intra-site and inter-site CoMP, the clusters could be overlapped or not-overlapped. Each cell is involved in one different cluster in non-overlapped case while the cell could be involved in different clusters in the overlapped clusters which is more complex.

1.7.2 Centralized vs. Decentralized CoMP Architecture

CoMP technique can be held between different levels such as; coordination between BSs, coordination between relay nodes or mix coordination between both of them. Coordination between BSs has big advantages on spectral efficiency and inter-cell interference mitigation, increasing CoMP reliability by distributing the scheduling data between all BSs which have bad impact on the total overhead. There are two main approaches for exchanging data between BSs in CoMP systems, centralized and decentralized.

Centralized coordination is the approach that has been mostly considered so far for inter-site coordination. A control unit is needed to collect UEs data in the BSs coverage region as shown in Figure 9. This control unit is responsible also for signal processing actions such as pre-coding and user scheduling.

Pre-coding is a processing technique that has a precise estimation of the CSI at the transmitter side by adding some modifications on the transmitted signal [22]. One type of pre-coding is the linear pre-coding which is a linear transformation that achieves acceptable performance with low complexity in comparison with non-linear pre-coding. Linear pre-coding is effectively used in Single Input Single Output (SISO), Single Input Multi Output (SIMO) and MIMO channels [23].

For decentralized coordination the UE is communicated directly with all coordinated sectors without control unit which usually decides the method of joint scheduling. In case of the coordinated sectors are not wire-connected, then the major impact for the decentralized coordination is CoMP algorithm efficiency reduction.

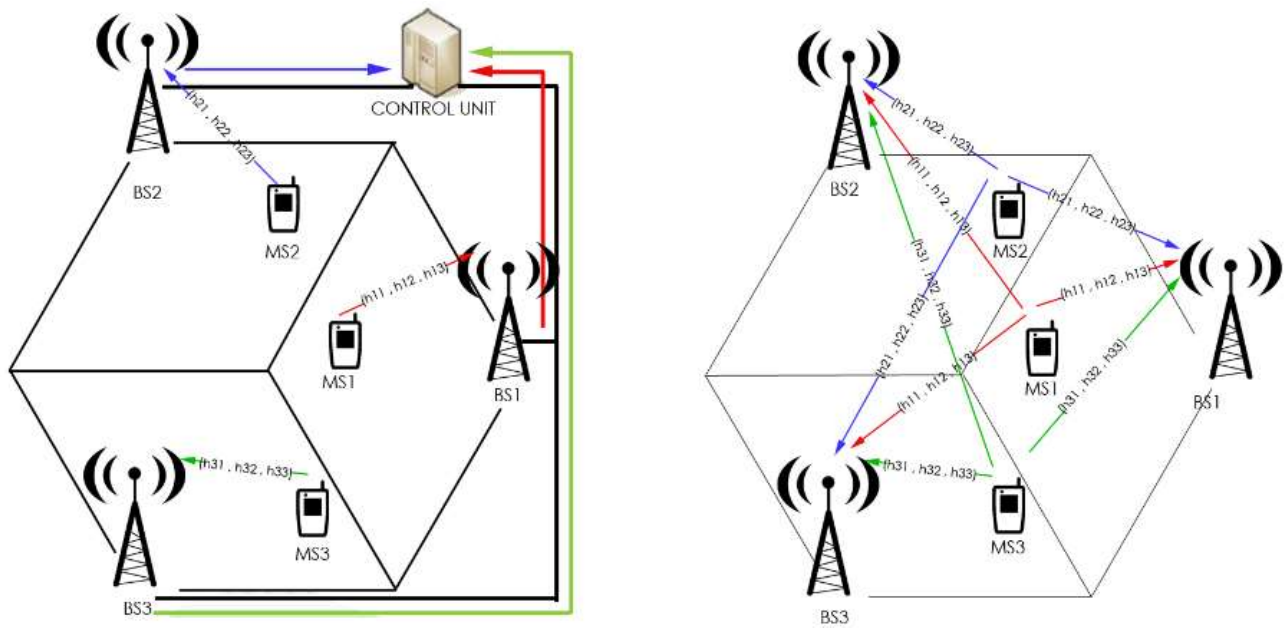


Figure 9 BSs coordination architecture, centralized (left) and decentralized (right)

1.8 Literature Review

Various CoMP techniques and mechanisms are proposed for mobile communications. Recent research in this area augments the theoretical work with field trials. The research trend focuses also on the comparisons between the different coordination techniques. In general, the research directions for CoMP can be categorized into four main areas:

1. **CoMP concept, advantages , challenges, and design schemes**: this area concentrates on the coordination multipoint principle, its schemes and the significant low level design details in mobile communication networks such as capacity, data rate, backhaul…etc.
2. **Field trial measurements**: this area basically utilizes the field measurement results under certain conditions and compares them with theoretical expectations.
3. **CoMP clustering techniques**: this area identifies the clustering techniques and classifies clustering according to different criteria.

4. **CoMP interference:** this area evaluates interference effects in cellular networks and the improvements in SINR when CoMP is utilized.

The four research directions and some reviewed papers are demonstrated as a tree in Figure 10. The following subsections details the literature in these four main directions. These directions are not mutually exclusive and some literature covers more than one direction.

Figure 10 CoMP research directions

1.8.1 CoMP Concept, Advantages, Challenges and Design Schemes

Vendors and operators who are designing the standards for the next generation communication systems give enormous attention to CoMP techniques. CoMP technique utilizes multiple transmit and receive antennas from multiple site locations, which may or may not belong to the same BS. It aims to improve the received signal quality and decrease the possible interference [15], so it is considered as one of the promising approaches in cellular communications [23].

CoMP is considered as node cooperative communication, it can improve the network connectivity, enhance the power and spectral efficiency and reliability of communications. In addition to that cooperative communications have more deployment flexibility and hardware feasibility than the other existing techniques [23]. CoMP techniques applicable for downlink and uplink are used to enhance the cell edge coverage, increase average data rate, improve the spectral efficiency, and mitigate interference [19]. Qian Li et al. indicated that CoMP has great improvement in the capacity, diversity, network connectivity and power efficiency [23] and [15]. Analysis that shows how the coordination between multiple antennas can achieve great improvement in the spectral efficiency is addressed in [24] and [25].

Mamoru Sawahashi et al. defined in [16] the objective of CoMP systems in terms of capacity, cell edge data rate, and inter-cell interference coordination. Capacity analysis of CoMP at 2.35 GHz was investigated comprehensively in [26] using field trials to evaluate the network spectral efficiency. The authors in [27] evaluated the capacity gains from coordinated multipoint transmission and reception.

The authors in [16] proposed two types of inter-cell radio resource management configurations: centralized and autonomous, where CoMP provides a high gain in terms of capacity and cell edge throughput in the centralized type. Authors in [28] analyzed the effects of practical data traffic on CoMP under specific scenarios. Reference [29] addressed an antenna selection technique to reduce the feedback overhead.

The authors in [19] highlighted some technical challenges associated with CoMP technology, such as; synchronization, clustering, latency and capacity requirements. The need for large backhaul infrastructure in CoMP compared to non-coordinated networks is discussed in [1]. Fan Huang et al. examined drawbacks related to the amount of overhead signals [21].

Marsch and Fettweis analyzed the uplink CoMP under constrained backhaul infrastructure and imperfect CSI [30]. They discussed also the base station coordination in a joint downlink transmission under constrained backhaul in [31]. The authors in [23] investigated existing CoMP techniques and their LTE applications and evaluated the capacity performance of CoMP in LTE-Advanced systems which depend on the backhaul link quality.

Coordinated multipoint design schemes are mainly divided into two main schemes [32], [33], [34] and [29]: Joint processing (JP) and Coordinated Scheduling/ Beam-forming (CS/CB). In JP, data is simultaneously transmitted from more than one transmission point to the UE. While in CS, the Resource Block (RB) is transmitted only from the serving cell. Takao Okamaawari at el. proposed network control architecture for CoMP joint transmission to utilize the allowed capacity over Internet Protocol (IP) backhaul media and to reduce the delay [35]. Reference [36] addressed CS/CB beam-forming techniques for coordinated networks using the long term CSI of neighboring cells.

1.8.2 CoMP Field Trial Measurements

The works by Patrick Marsch, Gerhard Fettweis and Michael Grieger are considered the main researches in CoMP field trial direction. Those authors work comes as part of the EASY-C project which is funded by the German government, where one of the world's largest test beds and distributed CoMP was established in Dresden, Germany in June 2009 for LTE-Advanced researches. They discussed different field trial results for CoMP network in different papers [1], [19], [37], [38] , [39], and [40].

Downlink field results are presented in [41], [42] and [43], while the uplink is covered in [44], [1], [39] and [37]. Ralf Irmer et al. in [19] examined different field trials for uplink and downlink CoMP. They demonstrated a symmetric cell edge in the uplink for the setup in [1], where the UEs locations are changeable and several interference conditions have been considered. They recorded the received signals and simulated different coordination schemes. They found a relation between the average rates and the required backhaul for different uplink coordination schemes based on the measured data. In the downlink, they took advantage of the German EASY-C project measurements in Dresden. The trials showed important gains for coordinated downlink at cell edge. The authors in [41] implemented CoMP transmission in Frequency Division Duplexing (FDD) downlink, where the required backhaul is reduced using distributed approach in comparison with centralized one. Both centralized and distributed approaches were discussed in details [41].

Recent publications show how CoMP mitigates the interference, improving both the data rate and the spectral efficiency, which can be increased by 50% through coordination [37]. However, in large scale performance, there is no reliable prediction for this assumption, so the same authors installed an LTE-advanced test bed in Dresden which consists of 12 BSs at 5 different sites using single antenna BSs. In [40], they clarified how CoMP gains are different in multiple UE locations, and then they proposed two antenna BSs design in [39] for 16 BSs at 7 different cells, where they showed the influence of this change in the performance. The results indicate a trade-off between using more antennas per BSs and using coordinated joint detection. Both setups in [40] and [45] are not fully reliable, because the authors ignored the fact that UEs are not always in a fixed location and they didn't consider the history of the interference in that location.

In [37], two coordinating BSs detect two UEs; the authors measured the interference for the UEs in different locations. The authors in [37] didn't consider the required backhaul in their setup model. The authors used the system model in [1] and assumed one BS forwards compressed receives signals to the other, by observing Distributed Antenna System (DAS). Only hard-Successive Interference Cancelation (SIC) has been considered in that work after successful decoding, which can be accomplished locally at one BS, or remotely, if decoded data is shared over the backhaul.

As addressed before, any experimental field trials have some drawbacks, the investigators in [37] and [19] faced many challenges during their testing in uplink CoMP such as; suitable clustering form, the coordinated BSs synchronization, channel estimation, MIMO-OFDMA complexity and the required backhaul. Also they faced many challenges for downlink coordinated multipoint; cost of low phase noise transmitters, BSs synchronization feedback delay, clustering form and channel prediction.

Michael Grieger et al. proposed new algorithms in [38] for backhaul signal quantization, where the data used in these algorithms have been gathered by LTE-advanced equipment using the same setup which was used in [37]. They used different quantization methods; quantization in time/frequency domain and quantization of channel coefficients. The authors in [41] addressed an algorithm to assemble the CSI received over the feedback link in the coordinated multipoint. Low complexity and efficient pre-coding algorithm for linear CoMP transmission was presented in [43]. Holfeld et al. predicted the post pre-coding SINRs from channel measurements in the small scale and large scale for two different locations [42].

In [46], Patrick March and Gerhard Fettweis discussed the difference between coordination multipoint and relaying. They demonstrated how CoMP can decrease the interference levels. They tried to proof the possibility of achieving an acceptable practical system measurements compared to the theoretical expectations in [4] using static clustering mechanism.

Fenghua Zhang et al. investigated the capacity gain of the CoMP networks and evaluated the spectral efficiency performance using field measurements at 2.35 GHz [26]. Future field trials should focus on the impact of different UE distances, different BS antenna configurations and compression schemes for more backhaul efficient joint detection.

1.8.3 Clustering Coordinated Multipoint

Coordinated clustering is one key point to transmission gain. Shang Xiao defined the clustered super-cell as a group of Radio Access Points (RAPs) to serve a CoMP where each super-cell contains a smaller group of adjacent cells [20].

Two major types of clustering can be used in CoMP communication; static and dynamic clustering. Static clustering is implemented one time based on the sites measurements and/or specific simulations of fixed network topology used to break down the large cellular systems into reasonable sized coordination clusters [4]. Fan Huang et al. defined the static clustering in [21] as a pre-fixed design combinations of BSs, maintained for a long period with little signal overhead. A major disadvantage for a given UE with static cell clustering mechanism occurs when the cells that have the strongest link gain may not lie in its coordination cluster [20]. These cells would then cause strong interference. Moreover, corresponding to each clustering, some UEs can be located on the clustering boundaries. Dynamic clustering can solve these issues.

The dynamic or adaptive clustering depends on measurements of the time-varying traffic demand and UE locations [4]. Dynamic clustering allows each UE to be served by a suitable BSs based on the average channel quality, so these selected BSs dynamically mitigate the strongest interference from other BSs. References [21] and [47] suggested that static clustering can be based on location and/or priority of active users, where these aspects may differ with time [20]. They introduced an adaptive algorithm for dynamic clustering in the way that RAPs form clusters in order to serve the selected UEs. The sum-rate (total throughput) increases significantly together with fairness across UEs in comparison with static clustering schemes.

The concept of CoMP clustering in conjunction with recourse partitioning has been investigated in [48], [49] and [50]. Optimal frequency reuse for coordinated communications is discussed in [51]. Dynamic clustering depends on Received Signal Quality Indicator (RSQI) and radio proprieties measurements which are repeated each specific period [52], [53], [10], [21], [54] and

[4]. While the authors in [55] and [56] showed how various backhaul topologies and properties can affect the clustering feasibility.

March et al. in [4] discussed ideal and practical clustering layouts to show how static clustering can yield a performance close to the ideal clustering. Sun et al. proposed a dynamic cell clustering in FDD downlink CoMP based on configuration of joint processing. They found that the achievable throughput may not improve as the cluster size increases. Moreover, they divided the large clusters into sub-clusters due to the large sized pre-coding matrices and complexity, where each sub-cluster performs CoMP transmission. They design a specific pattern for each large cluster, based on maximum sum-rate capacity and throughput of each sub-cluster [54].

Dynamic clustering methods offer better coordination between sectors than the static one in terms of different achievable gains such as SINR and average data rates but they are more complex. A modified approach of the dynamic clustering to resize the cluster region was proposed in [21] and [41] by considering centralized and distributed clustering methods. In centralized approach, transmit antennas are assembled in one BS, while in distributed approach they are located in different sites. They evolve a semi-dynamic clustering approach in distributed clustering scheme, which resolve the coordination limitations in static clustering with relatively low increment on complexity. For the centralized scheme, they also provide an evolution path to get better performance. Stephen Grant at el. proposed two different CoMP clusters in [57]: center excited and edge excited, where all the sector antennas direction are inside the CoMP cell in edge excited method, while center excited appears to be close to the traditional layouts. The edge excited requires more site interconnections and exhibits larger gain than the center excited

Effective coordination requires exchanging data between the UE and the BSs. The user data should be distributed among coordination BSs to minimize this exchange. Hence, Zhao and Lei proposed two low complexity clustering methods in [53] to minimize exchanging user data. The first method is based on Signal to Leakage Ratio (SLR), where the BSs in this method achieve full coordination and reduce exchanging user data because they have the required data about UEs. The second method is channel strength based clustering, where the coordination is done with the strong links. This method does not account to the interference of each data stream to other UEs compared to the SLR based method, however, simulations showed that its performance does not degrade much compared to the SLR based algorithm.

1.8.4 CoMP Interference, SINR and other Impacts

All interference types (Inter-cell, Co-channel, Intra-cell, Inter-symbol …) are usually used as a Key Performance Indicator (KPI) for cellular communication. Reusing spectrum resources and using small cell size cause inter-cell interference, which is the main limiting factor in multi-cell networks [41]. Inter-cell interference can be defined as a collision of RBs where a RB is the smallest granularity time frequency unit used for scheduling [58], where reuse frequency in different cells will increase the probability of RBs colliding and thus inter-cell interference. Inter-cell Interference Coordination (ICIC) techniques are very important to avoid SINR degradation by minimizing RBs collision chances [59].

Inter-cell interference is still preventing old technologies from coming close to the theoretical rates in mobile communication systems where CDMA has strong interference rejection capability, OFDM systems suffer from inter-cell interference at the cell boundaries [32].

Cooperative signaling using MU-MIMO has the ability to reduce inter-cell interference and improve system spectral efficiency [19] and [60].

Interference cancellation mechanism depends on finding an optimal effective frequency reuse factor [32]. SINR is one of the main aspects that should be optimized in any wireless communication system. Micheal Grieger et al. evaluated the system performance in terms of the SINR of the equalized transmit signals in [38], while the SINR is computed for each subcarrier in [28]. In [23] the authors evaluated the SINR performance in LTE-Advanced system at UEs for two different intra-cell CoMP schemes. Zijia Huang et al. discussed an algorithm based on maximizing the Signal to Leakage and Noise Ratio (SLNR) and SNR criteria in [61] to let the UE have more throughputs and generate less interference to other users in the same coordinated cell. In [42], the authors predict post pre-coding SINRs from physical channel measurements in the small scale and applied the mapping between measured and estimated SINR to the large scale of two urban test bed areas. The authors in [24] showed how the SINR is especially essential in a network which suffers from strong fading.

March and Fettweis derived a formula for the SINR observed by a UE according to the proposed system model in [4]. Shang-hui Xiao defined a formula for the SINR experienced by each user when linear pre-coding exists, and he discussed the inter-cell co-channel interference comprehensively in [20]. Li Qiang et al. proposed specific system model and SINR formula in terms of the noise power, as they considered the UEs belong to different cells in the CoMP system [Qia10] [33]. Holand et al. in [43] defined the SINR of pre-coded user; they compared also the SINR between CoMP and OFDMA downlink transmission based on indoor measurements. The SINR observed by the UE at a specific distance has been derived in [32]. The authors in [62] tried to increase the normalized SINR at the destination using iterative algorithms that offer jointly optimal sources transmit powers and relaying processing matrices

Stephen Grant et al. suggested three possible ways to deal with the inter-cell interference [57]: Cancellation of inter-cell interference by advanced receiver processing, mitigation of interference using CoMP, and ignore the interference while accounting to its effects in the spectral efficiency. In [37], the authors implemented two base stations to detect two UEs. They set some predictions based on interference measurements in different scenarios.

Qimei Cui et al. proposed an effective inter-cell interference cancellation scheme for downlink CoMP in [34]. In [63], the authors investigated the Degree of Freedom (DoF) of the user interference channel with CoMP transmission and reception. A good background of interference avoidance through CoMP is given in [64] and [65]. The authors in [35] used joint transmission architecture to cancel the inter-cluster and inter-cell interference. Two suggested types of CoMP joint transmission are centralized and distributed. The authors demonstrated the distribution architecture that has better system throughput and no need to central node scheduler.

Ian Dexter Garcia et al. discussed different types of CoMP and their impacts on cell planning, namely: clustering impacts on UE spectral efficiency, clustering types and their impact on coordination region, and base station coordination impacts on coverage [66]. Dora Ben Cheikh et al. derived formula for the Probability Distribution Function (PDF) of the Signal to Interference Ratio (SIR) in path-loss and Rayleigh fading conditions [67]. Jeng and Chia derives different joint pre-coding techniques in CoMP systems to control the co-channel interference between the coordinated base stations and evaluated their Bit Error Rate (BER) [68].

SYSTEM MODEL AND PERFORMANCE ANALYSIS

System level simulation in telecommunication is a very valuable tool to analyse and design different mobile wireless networks and evaluate their performance. Detailed and clear signal and system models are required for correct interpretation of the final results. Two system models are presented in details, where the main target is to estimate the influence of coordination on mobile cellular systems. We also investigate some important aspects related to CoMP deployment, such as:

- UEs spectral efficiency
- UEs behaviour when applying CoMP interference mitigation
- Threshold values for SINR cellular network to achieve the target Key Performance Indicators (KPIs)
- The possible impact of different conditions and different network constraints
- Selection of network optimization criteria.

This chapter differentiates between two different system models, ideal and real ones. In the ideal system model, we addressed some important parameters such as path-loss; antenna pattern and SINR, while we focused on the practical aspects in the real system model such BSs information, terrain data and different configuration parameters for antennas and UEs. Both setups are followed by the SINR comparison for coordinated and non-coordinated scenarios.

Ideal models are simulated based on the hexagonal setup using Matlab while the real networks are simulated using ray tracing simulation tool called WinProp. WinProp is a propagation and network planning simulator that has been used in different publications, such as [69], [70] and [71].

Both setups consist of a set of BSs/sites, each one has three directive antennas/sectors and each directive antenna basically serves one cell through the entire network. Figure 11 demonstrates one BS that consists of three cells and each cell is served by one directive antenna. Figure 11 (left) displays an ideal hexagonal site that have three directive antennas and the right side shows one site with three antennas for real simulated network. This chapter will discuss both setups.

Ideal cells are hexagonal in shape, while simulated real cells have balloon-like shape. The cell coverage radius depends basically on different parameters such as antenna transmitted power and operating frequency. Reducing the cell size can increase the user capacity and decrease the power consumption in the UE.

In Figure 11 (right), the deviation of colours reflects the Received Signal Power Level (RSL) in different cell coverage distances from the site itself. The red and orange colours reflect high RSL regions, while green colour indicates lower received power and the blue refers to the lowest power scale where the UEs do not receive enough RSL to be served from this BS. Moreover, it's shown in Figure 11 that cell edge area has the weakest RSL compared to the antenna azimuth centre.

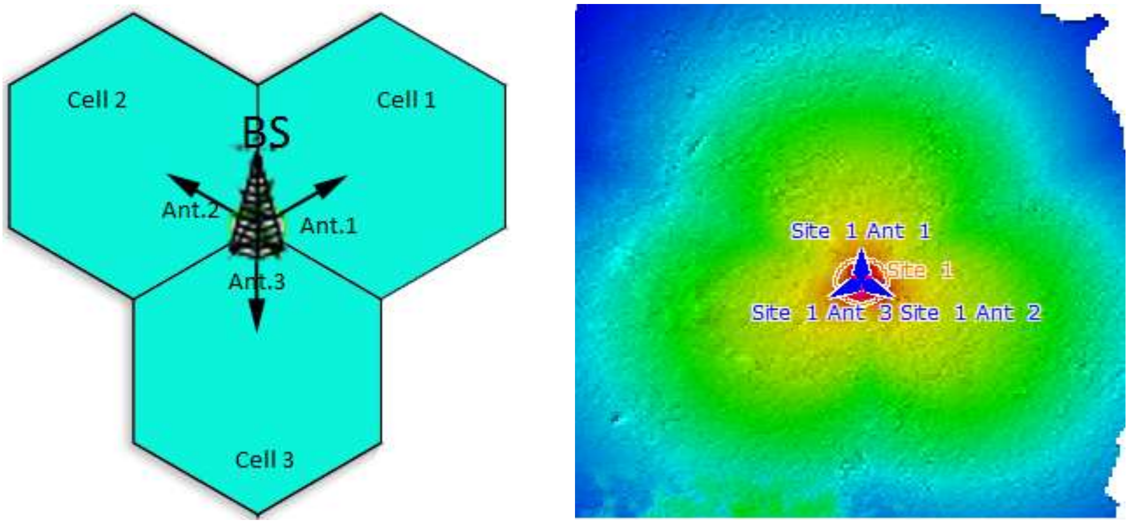


Figure 11 One site with three cells in ideal (left) and real (right) setups

1.9 Ideal Network and Signal Models

1.9.1 Ideal Network Layout

In the considered ideal network layout, each BS serves three hexagonal cells/sectors using three directive antennas. Each antenna covers one cell area, and the azimuth for each antenna is beaming 120° out of phase from the neighbouring antenna in the same base station. We considered three hexagonal tiers network which have 37 sites/BSs, and each one consists of three different sectors/cells making a total number of 111 sectors. The number of UEs is varied but the distribution is assumed to be uniform.

Figure 12 shows the ideal network setup where each unique colour refers to one BS that consists of three cells. Following 3GPP standards, we fixed the distance between each two BSs to 500 m as we are considering an urban area with macro BSs. This distance is called Inter Site Distance (ISD).

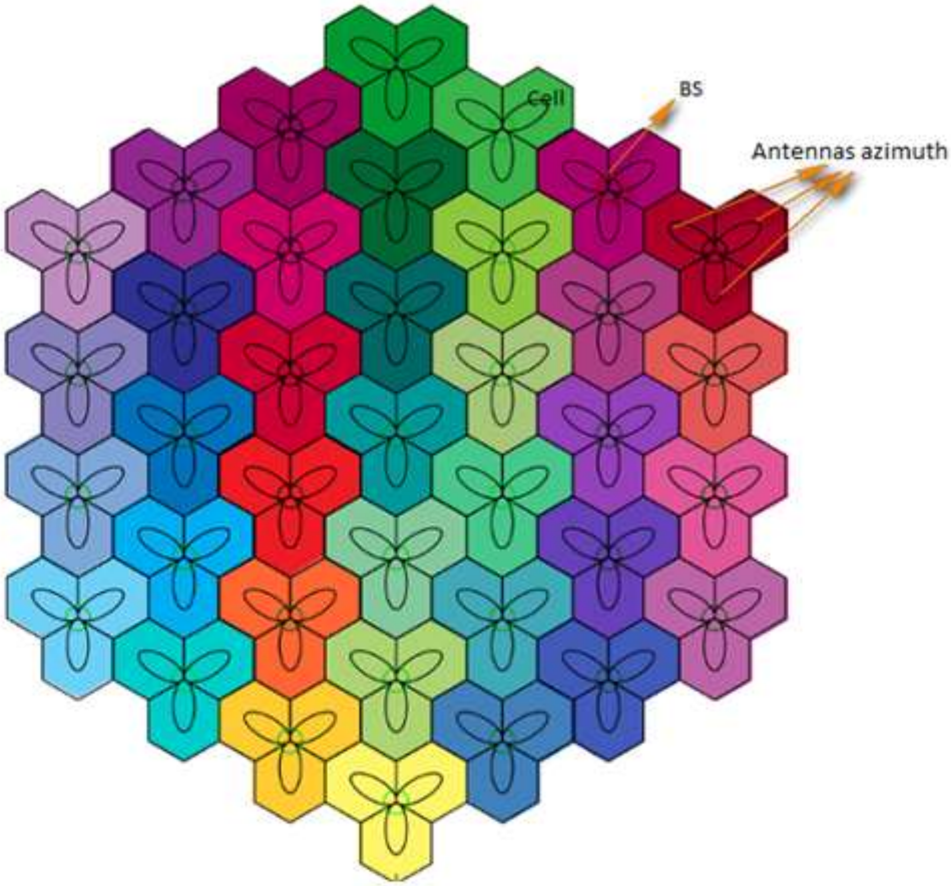


Figure 12 Ideal network layout

Serving cell selection criteria depends on UE downlink received power. Hence, the UE will be served from the sector which supports this UE with the highest RSL.

The sector transmitted power is different from UE RSL due to the impact of the channel. The remaining parts of this section discuss the major parameters in our simulation such as signal model, antenna pattern and the interference calculation.

1.9.2 Signal Path-loss Model

UE received signal power is inversely proportional to the distance between UE and its serving sector. The loss due to the distance is called Path-Loss (PL) which is defined as the linear ratio between the transmitted and received power. The Path-Gain (PG), on the other hand, is the inverse of the path-loss (PG=1/PL). The path loss in free space is given by Friis formula:

$$PL = \frac{\lambda G_T G_R}{(4\pi r)^2} \tag{0-1}$$

where λ is the wavelength, G_T and G_R are Tx and Rx antenna gains respectively and r is the distance between the Tx and the Rx [72].

Path-loss is affected by the antenna gain, atmospheric conditions and multipath effects that increase the roll-off of signals above the free-space roll-off. We consider -in this thesis- a flat-plane path-loss model [4]:

$$PL = 130.5 + 37.6.\log_{10}(d/km) \quad [dB] \tag{0-2}$$

where d refers to the distance between the UE and the BS. The path-loss exponent in equation **(0-2)** equals to 3.76 by assuming that we evaluated shadowed urban areas.

1.9.3 Base Station Antennas Pattern

The antenna pattern depends on the angle, θ, between the antenna azimuth and UE, the front-to-back ratio of the antenna and the maximum possible attenuation (Am), and the 3dB main lobe beam-width, θ_{3dB}. The antenna pattern equation can be defined as [73]:

$$A(\theta) = \min(12 \cdot \left|\frac{\theta}{\theta_{3dB}}\right|^2, Am) \tag{0-3}$$

The number of sectors per BS affects the design values of θ_{3dB} and Am. For example, θ_{3dB} equals to 70, 35, or 17.5 degrees and Am=20, 23, or 26 dB in 3, 6, or 12 sector scenarios, respectively [73].

In our case, each BS consists of 3 antennas with a gain equals to 14dB, each sector has a directional antennas with 120 degree beam-width. Any two antennas in the same BS are separated by 120 degrees. As the first antenna in each BS has 30 degrees angle with the x-axis, the second azimuth has 150 degrees and the third antenna azimuth has 270 degrees. The Antenna Loss (AL) due to antennas directivity and azimuth can be formulated as [4]:

$$AL = \min(12.\left|\frac{\theta}{70^o}\right|^2, 20) \quad [\text{dB}] \tag{0-4}$$

The above models for the path-loss and antenna loss are fundamental to simulating the received signal power and interference at any location in the network model

1.9.4 Signal to Interference and Noise Ratio (SINR)

Signal to Noise Ratio (SNR) is considered as a main concern to measure the reliability for mobile communication systems which require relatively high SNR levels. In the same track, the cellular communication systems generate various types of interference such as inter-cell and co-channel. Enhancing the SINR parameter is related to the used modulation scheme, where high modulation level such as 256 QAM allows high SINR values and increase UE possible throughput.

Increasing the frequency reuse factor can mitigate the inter-cell interference and increase UEs SINR values in GSM networks. A frequency reuse factor equals to 1 is the target for any communication system but limitation of RF spectrum and large extended networks require frequency reuse. On the other hand, the efficiency of mitigating the interference is less in LTE networks especially at cell edge locations [74]. In transmission and reception sides, the frequency reuse factor for the LTE and LTE-A varies according to the network planning demands.

UE SINR is degraded once this UE travels away from the serving sector due to two main reasons. The first reason is the inter-cell interference which increases as the UE get closer to the other sectors in the network. The second reason is RSL degradation.

CoMP technique improves the UEs SINR values and reduces the interference at cell edge, where appropriate network optimization that care about choosing the coordinated sectors in CoMP systems can enhance the network efficiently. Network sectors are divided into groups; each group has a number of sectors that are coordinated together, where those coordinated sectors inside each group are selected according to specific criteria which will be discussed later. Each group of coordinated sectors form a *cluster* and each UE in this network is served by the sector's cluster according to its location so the downlink UE SINR is improved.

We are considering J UEs and M cells in the ideal system model. The experienced SINR by a UE j from the *serving cluster* $M^{`}$ is formulated as:

$$SINR_j^{M^{`}} = \frac{P.\ \sum_{m\in M^{`}} \lambda_j^m}{P\ .\ \sum_{m\in\{M/M^{`}\}} \lambda_j^m + \sigma^2} \tag{0-5}$$

where λ_j^m is the path gain for the UE j which served from the cell m, P is the BS transmitted power and σ^2 is the UE noise variance. The summation in the denominator is over the non-coordinated BSs, $m \in \{M/M^{`}\}$.

By considering that each UE j is served by one cluster $M^{`}$, the UE j received power Pr_j^m from cell m can be calculated as:

$$Pr_j^m = P - PL_j^m - AL_j^m \text{ [dB]} \tag{0-6}$$

The cumulative distribution function (CDF) is a common probabilistic tool used to express the probability of a random variable being equal or less than a given value [75]. We used the CDF to measure the system model performance by applying the above formulas to simulate the SINR behavior in CoMP networks. We chose the coordinated cells according to UE received power, while next chapters will discuss clusters selection in details.

Simulating the network using different number of UEs leads to different results. We are using uniform row filling to distribute the UEs using same number of rows and columns. Considering 21 rows and 21 columns in Figure 12 scale leads to a 441 UEs which are uniformly distributed inside our network. Some of the UEs are close to cell center and some of them at cell edge which makes this distribution cover most UE location cases and this UEs number is reasonable with the network size.

The plots in Figure 13 show the UEs SINR CDF comparison between coordinated and non-coordinated networks, the solid line in this figure refers to SINR for CoMP systems and the dashed line refers to no-coordination case. Clearly SINR enhancement appears between coordination and no-coordination, the SINR is equal to 1 dB in conventional networks and 13 dB in CoMP networks when the SINR CDF equals to 0.8. This improvement reflects the fact that each UE utilizes the received power from three different antennas in CoMP, while the UE is served by only one antenna in no-CoMP case.

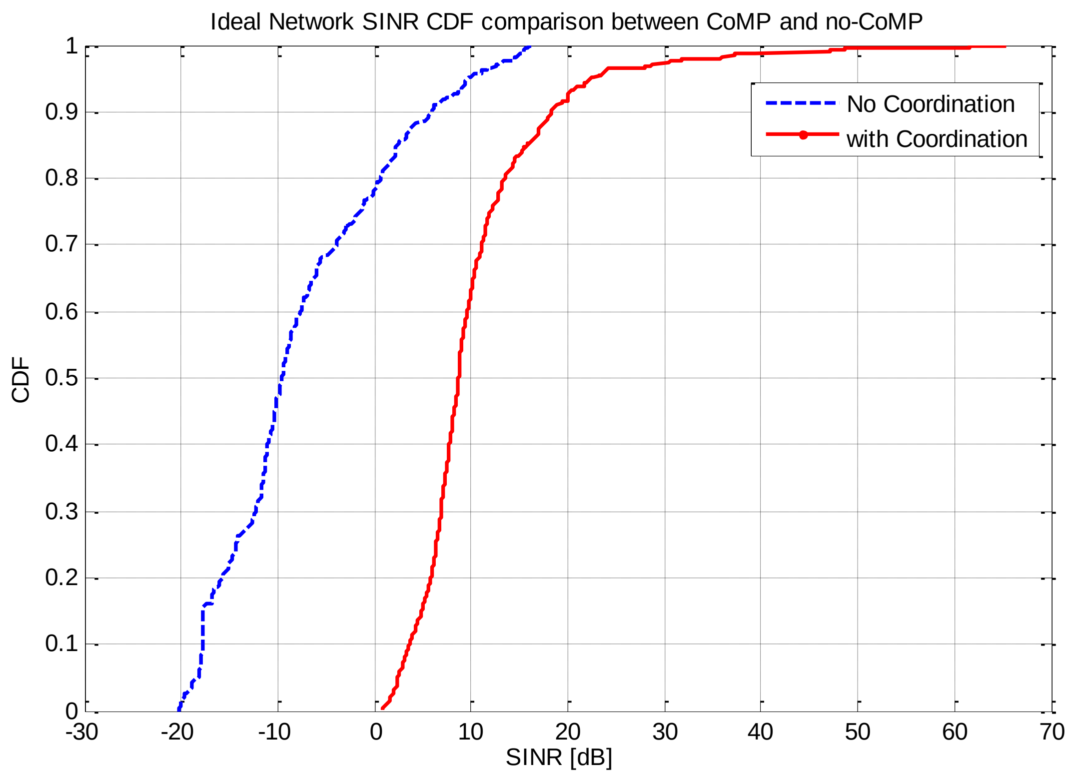


Figure 13 Ideal network SINR CDF comparison between CoMP and non-CoMP systems

1.10 Real Practical Network

For any cellular radio network implementation, the propagation prediction plays a crucial role in evaluating the network coverage, interference and the multipath. This evaluation is considered as the base for the high level network planning during mobile networks planning and installation [76].

We passed through three stages in our network planning process. The first stage is collecting accurate digital terrain data which includes the topography for the network area, terrain and buildings height statistics and land usage data, where a flat environment has different propagation behavior than hills, mountains and jungle environment.

The second stage is the configuration process on BSs and network levels, this stage cares about different parameters that play a major role in determining the network behavior such as antenna pattern selection, RF and power configuration, UEs fading and noise figure. The third stage is choosing the coordinated sectors in each cluster; this stage is discussed in next chapter.

Most of the previous practical CoMP research was evaluated across Europe or China networks. Our study is using new topography that was not used in CoMP research. Our system model uses large part from Al-Khobar city in Saudi Arabia. This elevation topography of this coastal city is flat and close to the sea level.

We consider 20 BSs and 60 directive sectors in the real CoMP system model. The distribution of these BSs depends on practical network implementation with non-uniform ISD. Locating a BS needs a comprehensive planning process that depends on different conditions such as; highway locations, density of residential or business areas, rural or urban environment, weather conditions, traffic utilization demands and antennas height.

The simulation software was fed with different BSs information, such as the coordinates, antenna height and transmitted power. The distribution of those BSs represents the real life traffic demands, knowing that they are used for 2G, 3G and LTE networks. These sites are located above the surrounding obstacles in order to cover a large area.

Network simulations are based on the wave propagation within the same network and the definition of the wireless air interface. We simulated FDD LTE air interface network with 20 MHz bandwidth using MIMO-OFDMA, this technology requires precise propagation model to estimate the network interference.

Choosing the serving cell in this model depends on the highest received power of all carriers in the network and the minimum required SINR and power. We fixed two threshold values for cell assignment, the minimum required SINR is -10 dB and the minimum required power is -85 dBm. Any sector should at least provide both SINR and downlink received power thresholds to a specific UE so it can be considered the UE serving sector, unless there is another sector which provides higher SINR and downlink received power levels.

Figure 14 shows the 20 BSs and the azimuth for each antenna, where the different colour strength levels indicate the elevation differences between the sites and the empty space in the right side denotes the Arabian Gulf. The 20 BSs are raised on different types of cell towers where some of them are on flat rooftops in urban and suburban areas. Those structures could be homes, companies or governmental buildings. Other types of cell towers are the monopole, the greenfield and the unfixed type that is called Cell on Wheels (COW). The greenfield can carry antennas in different heights.

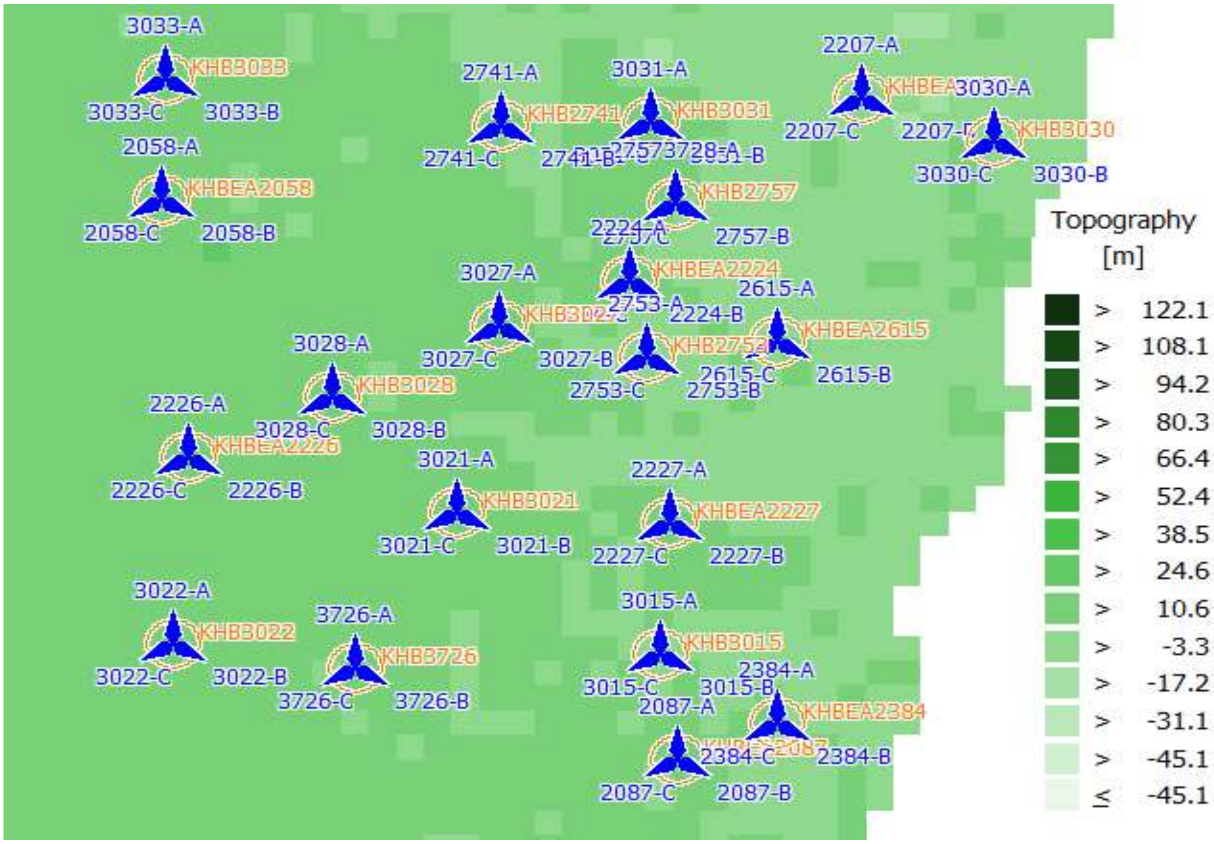


Figure 14 Real network setup

1.10.1 Simulation Power Definition for Downlink and Uplink

We define two types of power in downlink, the BS and UE power. In BS part, we define the output power of the power amplifier (P_C) and the Effective Isotropically Radiated Power ($EIRP$) in equations **(0-7)** and **(0-8)**, where P_A is the minimum BS antenna gain:

$$P_C = P_A - Cable\ Loss \tag{0-7}$$

$$EIRP = P_C + BS\ Antenna\ Gain \tag{0-8}$$

Figure 15 shows the downlink power representation where P_{R1} is the downlink UE received power including the UE antenna gain and we can see from the figure how the path loss is independent of the power mode $(P_C, EIRP)$ and cable loss as in equation **(0-9)**:

$$PL = EIRP - P_{R2} \tag{0-9}$$

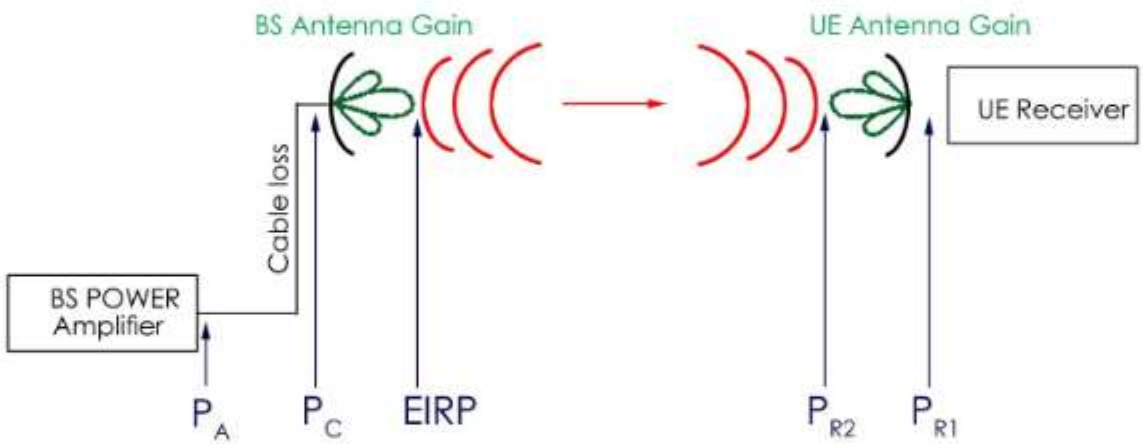


Figure 15 Downlink power representation

Figure 16 shows the power path in uplink where P_M refers to the output power of mobile amplifier without UE antenna gain which is the minimum UE transmitted power, P_B is the received power including the UE and BS antenna gains which is the maximum received BS power.

Figure 17 shows the simulated received power levels in the real CoMP system model, where we used 40 dBm for the antenna transmitted power. The UE received power is varied in the figure according what each UE considers the received signals, desired or interference.

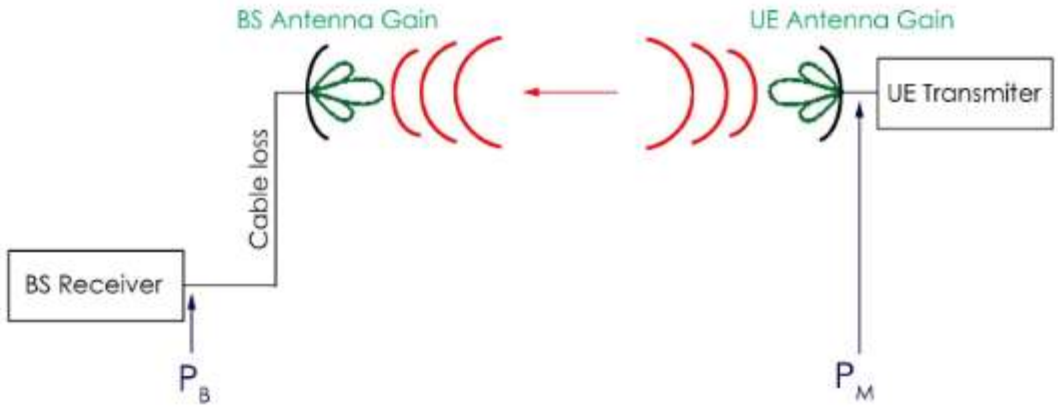


Figure 16 uplink power representation

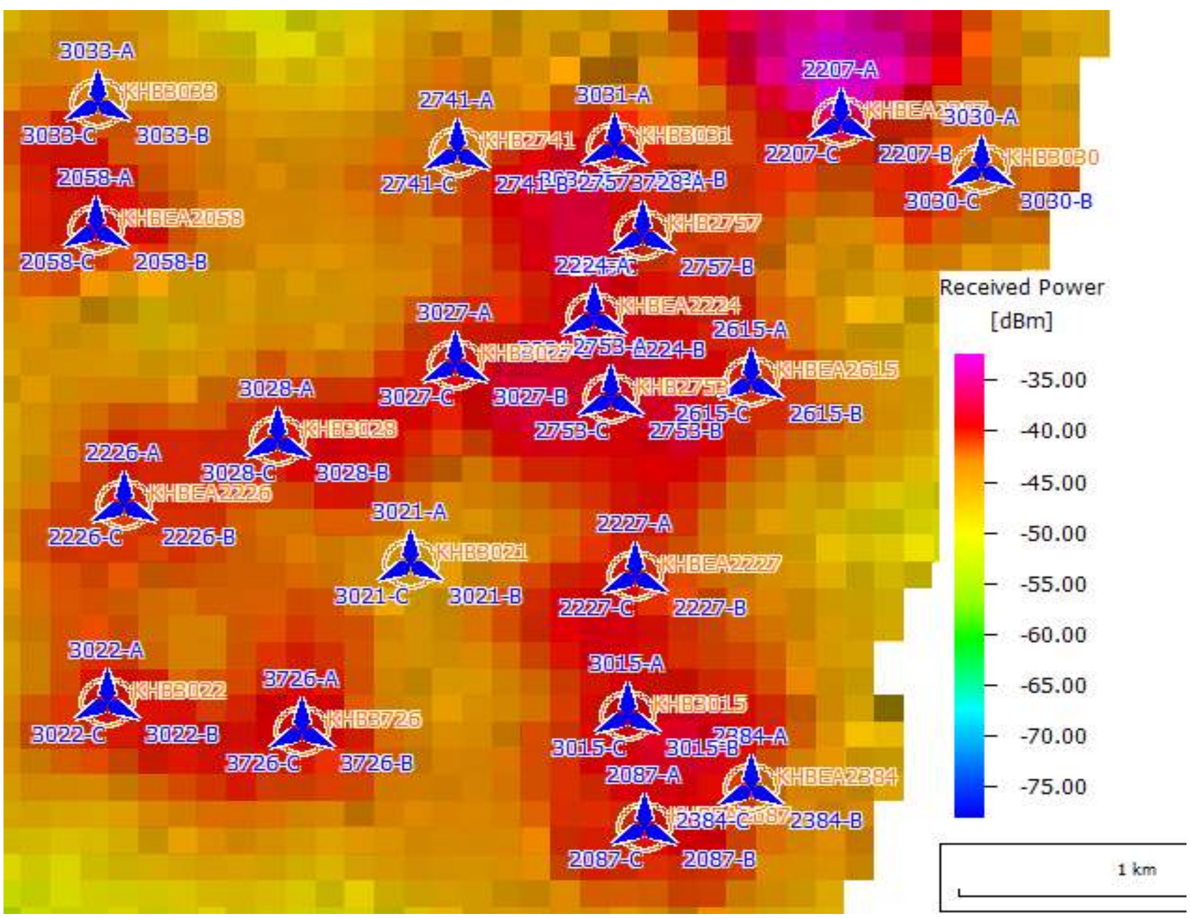


Figure 17 CoMP system model downlink received power

1.10.2 Real System SINR

As illustrated before, the SINR is a major performance indicator in cellular networks. A sufficient SINR should be maintained at the receiver side to guarantee the data is properly received, where SINR usually fluctuates according to the propagation environment. We are using LTE-A network to check SINR behavior in CoMP systems where its computation reflects the possible achievable data in the network.

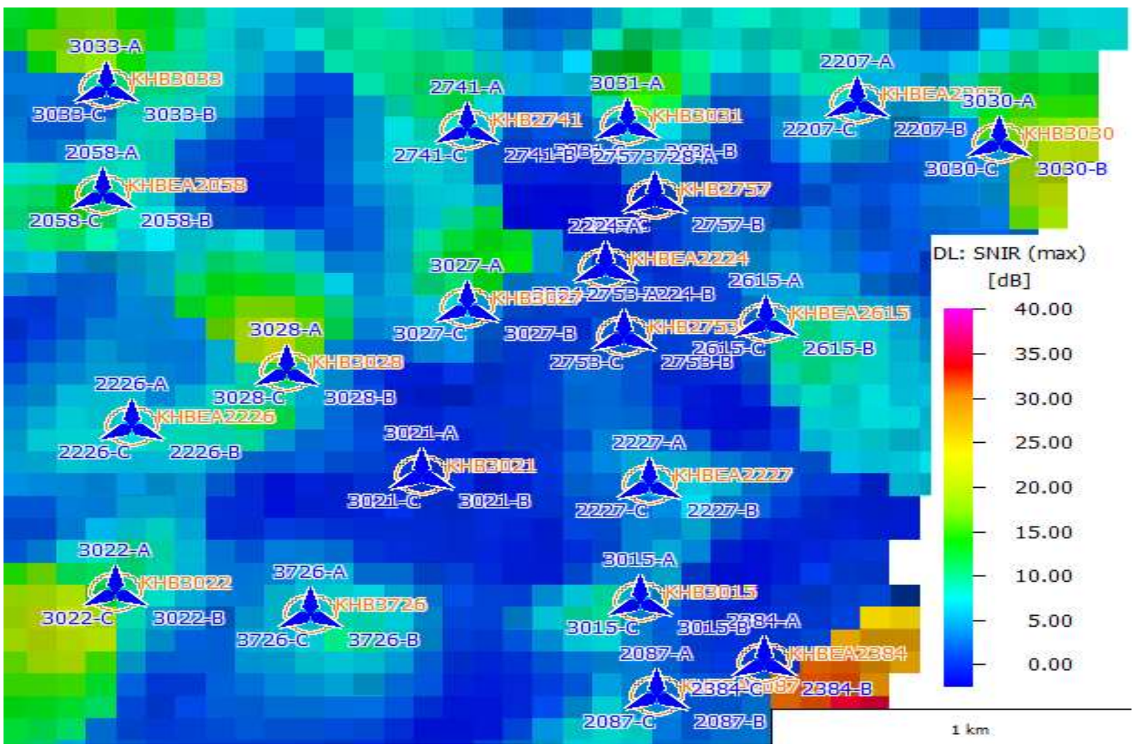
Applying coordination between different antennas has a great enhancement on SINR level. Figure 18 shows the network SINR distribution in conventional and inter-site CoMP networks. We reused the frequency in this CoMP network according to clustering needs where the cluster size in this simulated inter-site coordination is three cells per each cluster and we briefly evaluate the cluster size effect on network performance.

In spite of the flat surface and the short ISD, some areas have high SINR levels and others have less SINR as shown in Figure 18-b. farther discussion is shown in chapter 4 where reusing frequency plays a major role in system SINR behavior. Figure 19 illustrates the SINR CDF for both conventional and inter-site CoMP networks. At CDF value equals to 0.6. The SINR in conventional network will be 5dB and the inter-site CoMP will be 15dB.

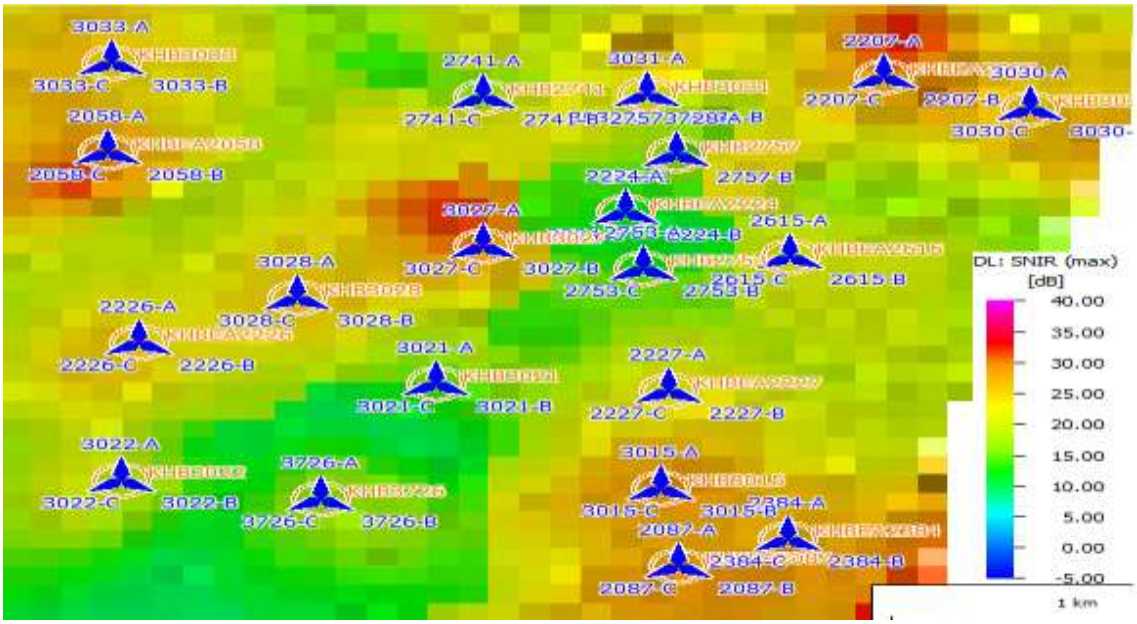
Figure 19 shows how the coordination improves the SINR about 10 dB in practical networks for 90% of the network distribution cases, while the enhancement for the ideal network is about 20 dB for most cases as shown in Figure 13. In general, a great SINR improvement is achieved in Al-Khobar practical network after CoMP. The network topology and the distances between BSs make the SINR improvement is changeable between network and network.

The SINR improvement after applying CoMP is decreased in high SINR levels in comparison with low SINR as we can notice in Figure 13 and Figure 19. This can ensure that the greatest beneficiaries of coordination are the cell edge UEs and the UEs that experience low SINR levels.

We are considering threshold values for minimum required SINR and power in practical network to achieve reasonable outcomes, hence, the lowest SINR value in ideal network which has no thresholds is less than the practical one.



(a) System Model SINR without Coordination



(b) System Model SINR with 3 Inter-site Antennas Coordination

Figure 18 System model SINR distribution

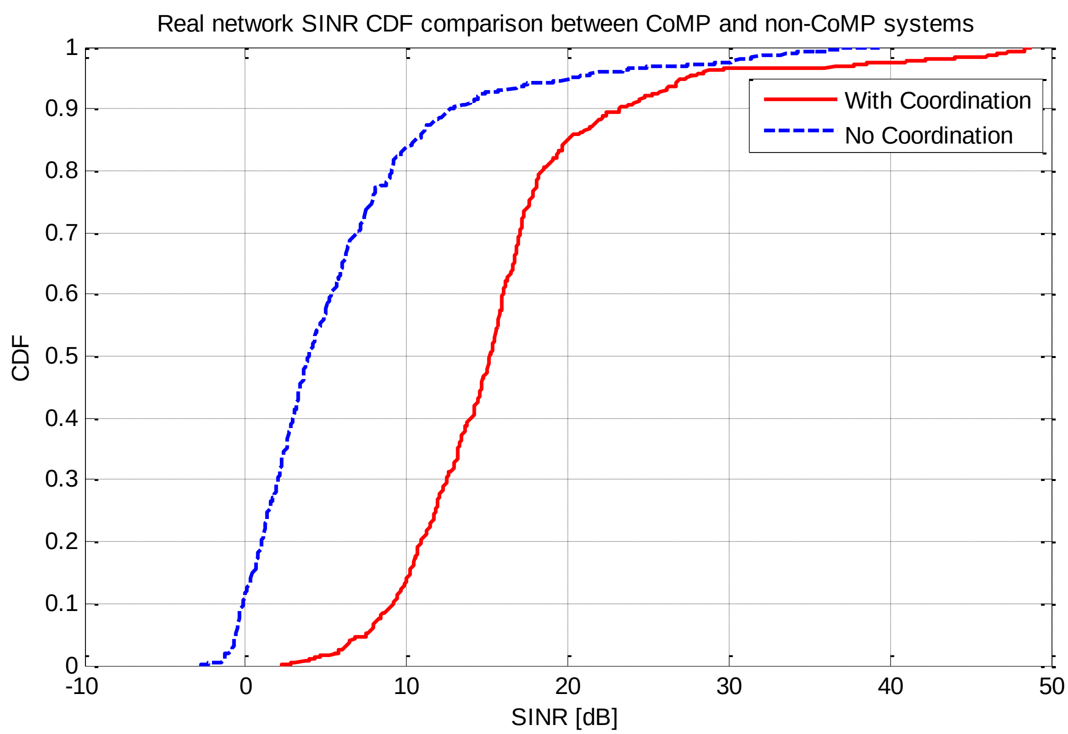


Figure 19 Real network SINR CDF comparison between CoMP and non-CoMP systems

Original Digital Elevation (ODE) generated by Shuttle Radar Topography Mission (SRTM) and a Ray tracing design software are used to simulate the real setup. We simulated 20 BSs using one of the LTE frequencies which is 2.6 GHz and 20 Mbps for bandwidth, and the ISD is non-uniform because we are using real BSs locations. We configured 40 dBm for each sector transmitted power which is a reasonable level of power that can be used in urban or suburban networks. Table 3 briefs the used simulation parameters.

Parameters	Value
Layout	20 sites with 3 cells (sectors)
ISD	500 m (in average)
Carrier Frequency	2.6 GHz
Bandwidth	20 Mbps
UE Noise Figure	6 dB
Antenna Gain	11.6 dBi
Resolution of prediction results	81 m
Sampling rate	384/250
Subcarrier spacing	15 KHz
Symbol duration	66.67 usec
Separation between Uplink and Downlink	120 MHz
Max Tx power	40 dBm

Table 3 Simulation parameters

As illustrated, CoMP has great enhancement in SINR levels. This chapter showed that we get noticeable SINR increment once applying coordination in ideal and real networks as shown in Figure 13 and Figure 19. In spite of the enhancement in practical CoMP is close to the ideal one but it still needs some optimizations to get closer, such as cluster selection methodology which will be discussed in chapter four.

Ideal and real CoMP system models have been investigated in this chapter. The ideal system model considered uniform parameters and aspects for the BSs and network by assuming typical configuration for all BSs and considering specific formulas for path-loss, antenna pattern and SINR. We get clear improvement in SINR level between CoMP and non-CoMP ideal networks.

In the real system model, we used a network planning methodology consists of three stages where the first two stages are discussed in this chapter while the third stage reserves a major part in next chapter. We briefly showed the power effect on the network behavior and simulated large part of Al-Khobar city using CoMP and non-CoMP assumptions, and we implement a simulation table to clarify the configuration parameter. In the last part of the real system model, we ensure the fact that coordination between different sectors can increase the SINR to close levels as in the ideal scenario.

As an example for the achieved SINR improvement, the SINR getter better by 13 dB in ideal network after coordination at CDF value equals to 0.8, while the enhancement in practical network is equal to 9 dB.

This chapter focused on CoMP system abilities to increase the SINR without giving more emphasis on clustering methodology between different clusters. Next chapter will illustrate different clustering techniques and optimization criteria in both ideal and real networks. Choosing appropriate clustering can enhance the network spectral efficiency and decrease the participants' resources in coordination process.

Clustering in Ideal CoMP Networks

The previous chapter presented the ideal and real system models and evaluated the SINR behavior in both scenarios. The number of coordinated sectors was fixed in Chapter 2 to three antennas in each cluster. This limits CoMP advantages and flexibility. Clustering must be optimized within the given system constrains.

One major concern in the coordination is how group of BSs and UEs can be selected. Choosing appropriate clustering can reduce the experienced interference between the BSs. Assigning the coordinated sectors inside each cluster, choosing clustering type and cluster size are the most important aspects in clustering selection. Clustering selection is easier in ideal CoMP networks compared with practical ones because of the uniformness of BSs and UEs distribution which give more flexibility in clustering design.

This chapter investigates cluster selection methodologies in ideal scenario. We reinvestigated the clustering techniques in [4]; non-overlapped and overlapped clustering, also we applied the optimization criteria in [4]; maximize mean SINR and outage measure probability to our ideal system model. In the last section, we propose a new clustering which mixes both non-overlapped and overlapped clustering in one type and improve the methodology of cluster size selection. This new type works according to a proposed cluster size selection algorithm which can enhance the spectral efficiency. Each group of coordinated antennas in CoMP forms a cluster which jointly serves a group of UEs. We should have reasonable number of antennas in each cluster since increasing the number of the coordinated antennas in one cluster increases the signal overhead, while decreasing the number of coordinated antennas reduces coordination gains. In general, the number of the cluster's coordinated cells is limited due to synchronization factors, signal overhead and the extended fiber connection between base stations [4]

Choosing the coordination cluster antennas depends on many factors such as distance between antennas, transmitted power level, UEs locations and number of coordinated antennas per cluster. The optimum selection of cluster cells is reflected on the cellular systems spectral efficiency improvement [77]. Static and dynamic clustering are the main types of clustering techniques. Cells cluster distribution in static clustering is selected one time according to pre-defined deployments that uses the site location and site radio frequency parameters as main characteristics in forming fixed clusters. Static clustering requires little signals overhead and less complexity to enhance the performance compared to dynamic clustering [21].

The wireless channel is a time varying which makes the CSI changes with time. The network ability to adapt with different system circumstances is important for network robustness. Large CoMP networks require CSI update in dynamic clustering so many optimization clustering techniques are established.

1.11 Ideal network clustering selection

The systematic distribution of BSs and UEs in ideal networks increases the ability to design sufficient clustering between different sectors and apply different network clustering optimization criteria which enhance the possibility of optimum clusters selection. We assumed static clustering in our work. The coming sections will differentiate between non-overlapped, overlapped cells clusters and a new type mix both of them in one CoMP system which is called hybrid clusters.

Selecting the proper cells in each cluster is the most important stage in cells coordination, where the UEs will not utilize CoMP advantages if we assign cells cluster in random manner or have been chosen in inefficient methodology. This will definitely lead to underestimate the coordination concept, increase the complexity and use resources without improving the spectral efficiency that will compel us to define a reliable quality function for clusters selection in terms of utilizing all network cells.

1.11.1 Non-Overlapped Clusters

The presented ideal network consists of 37 BSs, each one consists of 3 antennas and each antenna serves one cell. This forms a total number of cells, M, equals to 111 that serves a group of J UEs. Initially we choose J equals to 441 that are served by a number of non-overlapped clusters. We assumed that all UEs are stationary and uniformly distributed among cells. The UEs are uniformly distributed by uniform row filling where the 441 UEs are located in the intersection positions between 21 rows and 21 columns.

We consider that UE received power from each sector is the main factor that determine our metric quality function in clusters selection. Where each UE receives power, Pr, is defined in formula **(0-1)**:

$$Pr_j^m = P - AL_j^m - PL_j^m \tag{0-1}$$

where Pr_j^m is UE j received power that are experienced from cell m, AL_j^m is the antenna directivity attenuation from cell number m that affect UE j and PL_j^m is the path loss between cell m and UE j.

We will examine two optimization criteria in this section to enhance the methodology of selecting initial cluster cells. The initial clusters are selected according to a quality function passing through a number of steps. The first step is to assign one serving cluster to each UE j where each cluster consists of 3 different sectors. We calculate the received power to each UE from all the 111 sectors. Then we find out the sectors that provide the highest three received power values to a specific UE, and those three sectors will form one initial cluster. Hence, the number of clusters basically in this step is equal to the number of UEs j and we called those clusters as pre-selected or initial clusters.

Some of above initial clusters are common to different UEs. The second step is to rank the initial clusters according to their occurrence, where the most frequent clusters are the most desired ones. The number of occurrences is subject to some constraints such as the number of UEs, UEs location, BSs locations and UEs density distribution.

The third step is to cancel the repeated clusters and keep only one copy from each cluster so we have a row vector with unique C clusters. The distribution of M cells into C clusters is described in a binary matrix **A**:

$$\mathbf{A} \in \{0,1\}^{[M*C]} \tag{0-2}$$

where **A** matrix has C columns, each column has only three ones which refer to the cells numbers that form this cluster and all the remaining $M-3$ elements in each column are zeros, while the number of rows is equal to the number of network cells M. That means the element of the **A** matrix, $a_{m,c}$, equals to a value of "1" if the cell m is involved in the cluster c and it equals to zero if it doesn't belong to the cluster c.

Despite removing redundant clusters in the above methodology, the number of selected clusters is still large and many cells are still involved in different clusters at the same time.

In this section we evaluated two optimization criteria to choose reasonable number of clusters that involves all system cells without overlapping any cell between different clusters. The selected clusters after applying the optimization approach are initially derived from the initial clusters C. Solving the below mentioned optimization problems lead to the optimum clustering selection.

1.11.1.1 Maximize mean SINR optimization criterion

The first optimization approach is to maximize the mean SINR experienced by J UEs in the initial clustering stage. Formula **(0-3**) describes the relation between the experienced SINR for UE j and its serving cluster c [4]:

$$SINR_j^c = \frac{P \,.\, \sum_{m \in M, a_{m,c}=1} \lambda_j^m}{P \,.\, \sum_{m \in M, a_{m,c}=0} \lambda_j^m + \sigma^2} \tag{0-3}$$

J UEs mean SINR, f_c , for the initial clusters can be identified in equation **(0-4**) :

$$f_c = \frac{1}{|J|} \sum_{j \in J} SINR_j^c \tag{0-4}$$

A is a binary matrix, so we have a binary optimization problem (Matlab toolbox) with linear constraints where binary integer programming is the problem of finding a binary vector **x** that maximizes a linear function $\mathbf{f}^T \mathbf{x}$, this algorithm browses for an ideal solution to the binary integer programming problem by solving a series of Linear Programming (LP) relaxation problems. To maximize the mean SINR, equations **(0-5)**, **(0-6)**, and **(0-7)** define the first optimization problem, where **x** is a binary vector [4]:

$$\max \quad \mathbf{f}^T \mathbf{x} \tag{0-5}$$

$$subject\ to\ \mathbf{Ax} \leq \mathbf{1}_{[M*1]} \tag{0-6}$$

$$and \quad \mathbf{x} \in \{0,1\}^{[C*1]} \tag{0-7}$$

If any element in the binary vector **x** is one then the associated cluster defined in matrix **A** is chosen by this optimization criteria. And if the value is zero then this cluster is not chosen. The linear inequality in the "subject to" sentence **(0-6**) can guarantee that each sector is defined inside at most one cluster.

The output of this optimization problem basically depends on the initial clusters and the number of simulated UEs J. In our case, simulating 441 UEs J in the non-overlapped clustering leads to 263 unique after excluding the repeated ones from the total 441 initial clusters. The number of J is reflected on the number of unique initial clusters where increasing J assures that all network cells are included in the initial clusters.

Applying the above stated optimization criterion led to 32 ones inside the vector **x** which means that the number of clusters after solving **(0-5)**, **(0-6)**, and **(0-7)** is 32 which include 96 cells out of 111 so there are 15 cells that are not included inside the optimized clusters and this is attributed to the fact that our optimization criteria select the optimum clusters choices among the initial clusters. Increasing the number of initial clusters will increase the probability of gaining more optimum optimized clusters. We run the simulation with less number of UEs $J = 121$, the initial clusters are 113 and the output of the optimization is 30. This supports our observation regarding the probability of including all cells inside the optimized clusters will be less if we reduce J.

Increasing the number of J or M increases the probability of selecting optimum clustering, where increasing J or M will increase the number of initial clusters. On the other hand, this adds more complexity and the simulation time will get longer, so selecting acceptable values of J, M and C reduces the complexity. Reduction of complexity can be achieved by decreasing the number of UEs, simulating smaller part from the network or decreasing the number of initial clusters as what we do in our second optimization criterion.

1.11.1.2 Outage measure optimization criterion

The second optimization criterion is the outage measure where a threshold SINR γ value is defined, and a binary matrix, $\mathbf{B}$, has the dimension [number of UEs J by number of clusters C] shows if the UE j can reach the threshold value or not. The elements $b_{j,c}$ of matrix $\mathbf{B}$ is equal to one if the UE j served by cluster c can achieve γ and it equals to zero if it can't.

The next step in the outage measure criterion is to maximize the number of UEs that can reach γ by redefining the optimization problem as [4]:

$$\max \quad \mathbf{1}^T \mathbf{z} \tag{0-8}$$

$$subject\ to\ \mathbf{Bx} \geq \mathbf{z} \tag{0-9}$$

$$and\ \mathbf{Ax} \leq \mathbf{1} \tag{0-10}$$

$$and \quad \mathbf{x} \in \{0,1\}^{[C*1]}, \mathbf{z} \in \{0,1\}^{[J*1]} \tag{0-11}$$

where $\mathbf{z}$ is a binary vector which indicates if the selected clusters allow to achieve γ at various locations or not. The number of ones inside $\mathbf{z}$ will increase as γ is decreased. We can involve both $\mathbf{x}$ and $\mathbf{z}$ inside one optimization problem to decrease problem solving complexity [4]:

$$\max[\mathbf{0}^T \quad \mathbf{1}^T] \begin{bmatrix} \mathbf{x} \\ \mathbf{z} \end{bmatrix} \tag{0-12}$$

$$subject\ to \begin{bmatrix} \mathbf{A} & \mathbf{0} \\ -\mathbf{B} & \mathbf{I}_{[J]} \end{bmatrix} \begin{bmatrix} \mathbf{x} \\ \mathbf{z} \end{bmatrix} \leq \begin{bmatrix} \mathbf{1}_{[M*1]} \\ \mathbf{0}_{[J*1]} \end{bmatrix} \tag{0-13}$$

$$and \quad \mathbf{x} \in \{0,1\}^{[C*1]}, \mathbf{z} \in \{0,1\}^{[J*1]} \tag{0-14}$$

1.11.1.3 Outage measure results and analysis in non-overlapped clustering

We evaluated the outage optimization criterion for non-overlapped clustering by solving the outage measure optimization problems for 100 UEs in the lower left quarter from our ideal system model where the ideal network is systematic and choosing smaller granularity gives clear view for the network performance and decrease the simulation complexity as well.

We choose 6 different values for γ (0, 5, 10, 15, 20 and 25). Figure 20 reflects the relation between γ and the number of times it has been achieved by the 100 UEs and this figure illustrate the fact that number of times that γ is achieved will decrease as the SINR threshold γ increases.

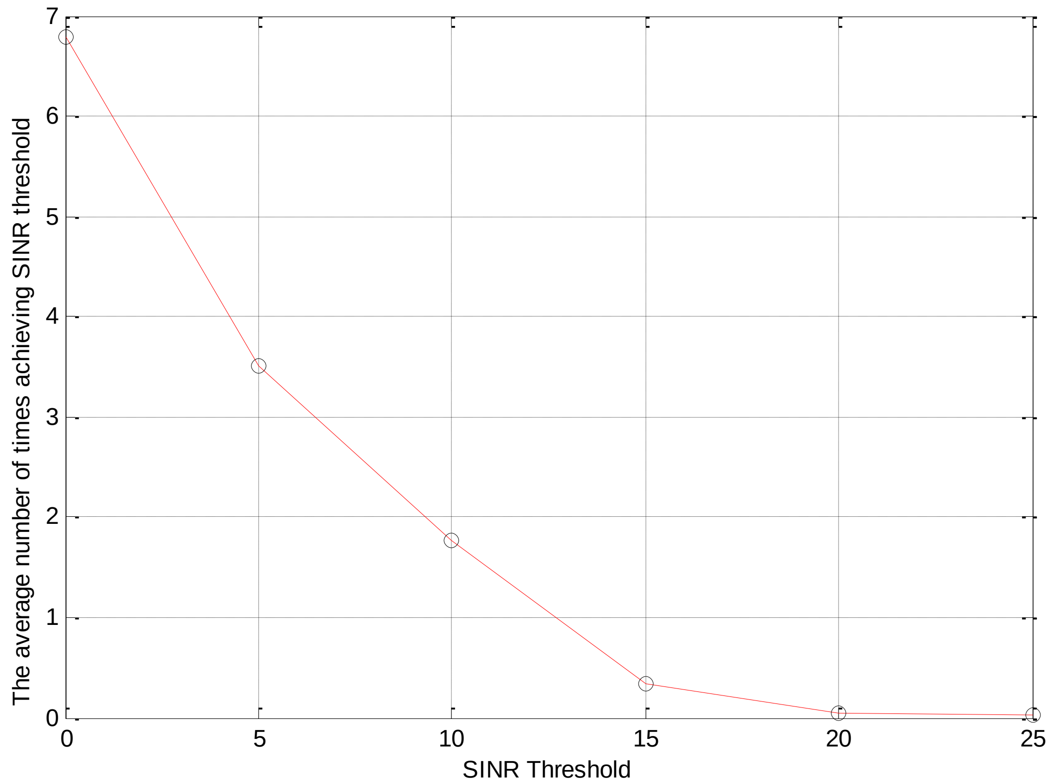


Figure 20 Relation between γ and average times of achieving γ in non-overlapped outage measure optimization

Figure 21 demonstrates the SINR CDF differences between clusters with different number of coordinated cells using 1600 UEs in the ideal system model. Cluster size is an important factor to determine the UE experienced SINR level. We concluded that the experienced SINR level increases when the number of coordinated sectors inside one cluster increases, where the experienced SINR by each UE is more if this UE is served from larger number of coordinated sectors inside the cluster, whilst increasing the cluster size increases the system signal overhead and complexity. Figure 21 shows how the largest SINR improvement is once we enlarge the cluster size from 2 to 3 cells inside each cluster. Improvement getting less by moving from 4 coordinated cells to 5 coordinated cells. The gain starts to saturate as the cluster size becomes 6 and large.

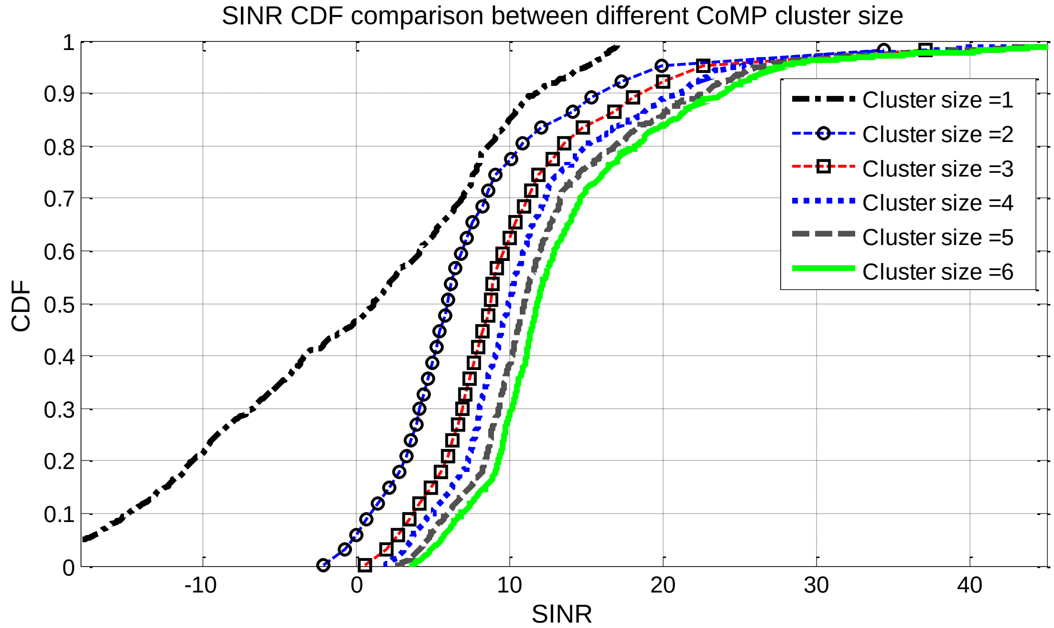


Figure 21 SINR CDF comparison between different CoMP cluster size

1.11.2 Overlapped Clusters

We discussed in the previous section the case of non-overlapped clustering where each cell only belongs to one cluster in which the cell reuse factor, *R*, is equal to one. We now discuss involving each cell in more than one cluster. This overlapping increase the SINR values at cell edge compared to non-overlapped clustering.

We simulated the ideal system model for the overlapped clustering with cell reuse factor, *R*, equals to three. This means each sector can be involved inside at most 3 different clusters. We utilized the upper section formulas to solve the below optimization problem to get the best selection of overlapped clusters. The SINR optimization problem in overlapped clustering is identified as [4]:

$$\max \quad [\mathbf{f}^T \mathbf{f}^T\ \mathbf{f}^T]\, \mathbf{x} \tag{0-15}$$

$$subject\ to \begin{bmatrix} \mathbf{A} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{A} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{A} \\ \mathbf{I}_{[C]} & \mathbf{I}_{[C]} & \mathbf{I}_{[C]} \end{bmatrix} \mathbf{x} \leq \mathbf{1}_{[R.M+C*1]} \tag{0-16}$$

$$and \quad \mathbf{x} \in \{0,1\}^{[R.C*1]} \tag{0-17}$$

Optimizing the problem of outage method in overlapped clustering is described in [4]:

$$\max [\mathbf{0}^T \quad \mathbf{1}^T] \begin{bmatrix} \mathbf{x} \\ \mathbf{z} \end{bmatrix} \tag{0-18}$$

$$subject\ to \begin{bmatrix} \mathbf{A} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{A} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{A} & \mathbf{0} \\ -\mathbf{B} & -\mathbf{B} & -\mathbf{B} & \mathbf{I}_{[J]} \end{bmatrix} \begin{bmatrix} \mathbf{x} \\ \mathbf{z} \end{bmatrix} \leq \begin{bmatrix} \mathbf{1}_{[R.M*1]} \\ \mathbf{0}_{[J*1]} \end{bmatrix} \tag{0-19}$$

$$and \quad \mathbf{x} \in \{0,1\}^{[R.C*1]}, \mathbf{z} \in \{0,1\}^{[J*1]} \tag{0-20}$$

Increasing UEs numbers linearly results in an exponential increase in the simulation complexity. We checked another criterion to decrease this complexity by simulating specific granularity from the entire network, this reduces simulation time.

We used a simulated granularity equals to one quarter of the entire network that uses 400 UEs distributed in the granularity. In this case, Matrix **A** creation provided 89 unique clusters out of the total 400 initial clusters. We checked the overlapped and non-overlapped mean SINR clustering where the number of selected clusters after solving mean SINR optimization problems was 8 for non-overlapped clustering while it was 23 for overlapped clustering. The simulated area is the lower left quarter of the ideal system model.

1.11.3 Hybrid Clusters

The above clustering techniques have great advantages to enhance the network performance, but those techniques have two main limitations. The first limitation is that each clustering type is designed with one structure; either overlapping or non-overlapping. This inflexible cluster overlapping reduces the efficiency of cell clustering. The second limitation is the fixed cluster size in both the discussed clustering techniques where we considered 3 cells per clusters in non-overlapped clustering and fixed number *R* cells for overlapping type.

This section proposes a new clustering technique to solve the limitations in the above mentioned clustering. This technique considers both overlapped and no-overlapped clustering in the same network structure and features the flexibility of choosing cluster size according to the needed demands by assigning SINR threshold value for each UE.

This technique works according to a specific algorithm as shown in Figure 22. The UE serving cell in no-coordination case is the cell sector that provides higher power to that UE, and from this power we calculate the experienced SINR according to the previously mentioned formula which should achieve the assigned threshold value to avoid coordination complexity. The coordination will take place if the experienced UE SINR in no coordination case does not reach the target SINR, hence the serving cluster size is increased gradually till the SINR threshold is achieved, and hence, the coordinated cells are selected according to the UEs received power.

The proposed new mechanism reduces coordination complexity in case of achieving SINR threshold without the need for coordination. In addition to that, it will guarantee that all UEs will feature the threshold SINR by applying different clustering sizes. Cell center UEs will be served by a smaller cluster size than cell edge UEs in this mechanism because they can achieve the SINR threshold using less number of cells. One another advantage for this mechanism is that it has flexibility in choosing cells cluster where some clusters include same cells site and other clusters could include cells from different sites where the only criterion for cluster selection is achieving SINR threshold.

We applied this mechanism by uniformly distributing 1600 UEs through the ideal system model to study the behavior of cluster size according to different SINR threshold values. We maintain the CoMP cluster size between one (no coordination) and six coordinating cells according to the SINR threshold which has been simulated in different values (0, 4, 8, 12 and 16 dB). Figure 23 illustrates the CDF for the distribution of each cluster size in comparison with different SINR threshold.

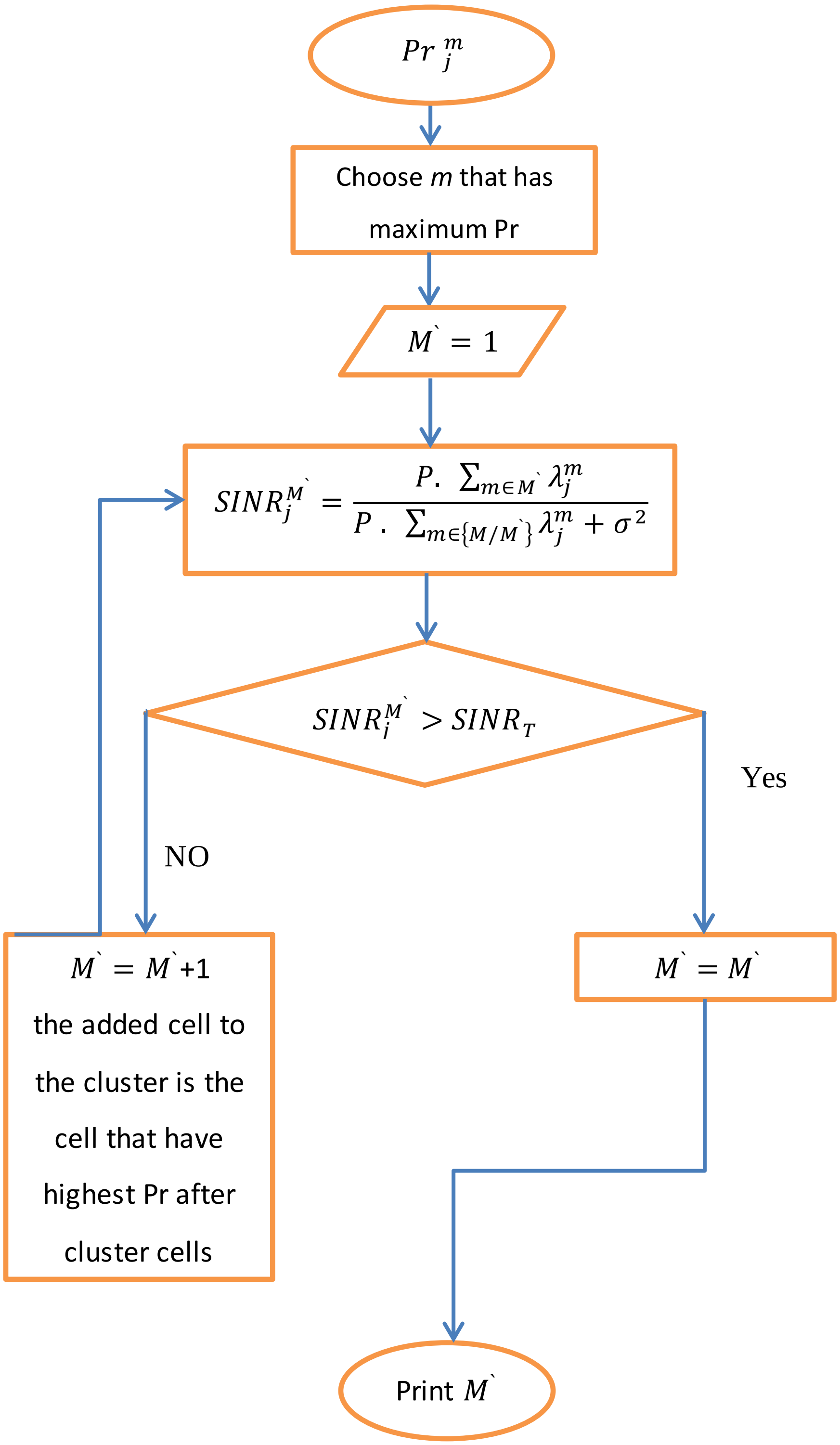


Figure 22 Cluster size selection algorithm

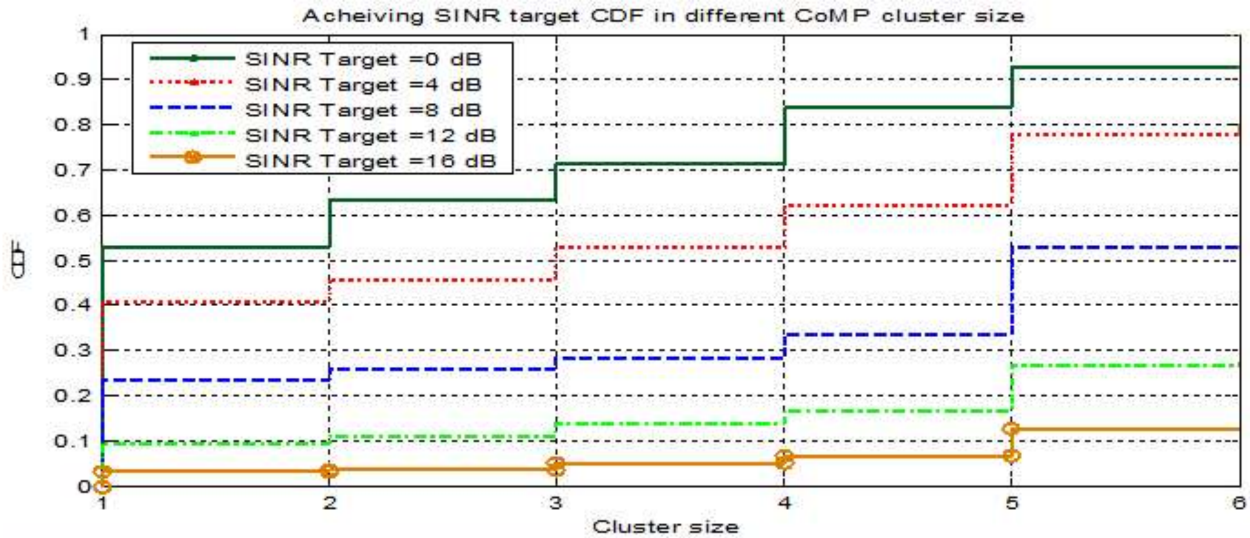


Figure 23 Cluster size CDF according to different SINR thresholds

The figure reflects the fact that cluster size is inversely related to SINR threshold, where more than 50% of the 1600 UEs in our system model don't need coordination to satisfy 0 dB SINR threshold and more than 85% UEs need cluster size equals to 6 or more to achieve SINR threshold equals to 16 dB.

We can observe in Figure 23 the number of UEs that need cluster size of one or two are so close in 16 dB, 12 dB and 8 dB, therefore, applying coordination with cluster size equals to two is not efficient enough as any coordination process is accompany with clustering complexity challenges. On the other hand, the signal overhead is increasing as long as there is coordination, which can be decreased by excluding inefficient coordination between two cells.

In mean SINR optimization, clusters can be shaped as inter-site or intra-site coordination while the cluster's sectors are usually part of different BSs in the outage SINR optimization which main advantage is increasing the spectral efficiency for the weak UEs.

In this chapter, we discussed the static clustering in ideal system model. We investigated three types of static clustering for the ideal system model which are non-overlapped, overlapped clustering and the new proposed one hybrid clusters.

We used two optimization criteria to enhance clustering selection methodology, maximizing mean SINR and outage measure criteria. We noticed that increasing the number of distributed UEs in the network will increase the number of selected clusters in non-overlapped type after applying optimization criteria and this can increase the probability of engaging all network cells in the selected clusters. The linear increase of UEs distribution will lead to exponential increase in simulation run time, so taking small granularity of the network can give clear view about the needed simulation results.

In the outage measure optimization criterion, we assigned different SINR threshold γ values and we concluded that the number of UEs achieving γ is decreased as γ is increased. On the other hand, both overlapped and non-overlapped clustering are inflexible enough, though we propose an algorithm that select the appropriate cluster size according to specific SINR threshold values. This algorithm can check if a specific UE can reach the SINR threshold from the main serving sector and thus no need for coordination in this case. This algorithm decreases CoMP complexity in some cases, but it requires more resources to manage the freedom in the selection of the cluster size and coordinated cells from UE to another. The amount of signal overhead will increase in this case because of the need to more CSI exchanging and high accuracy synchronization.

Clustering in Real Network

The main objective of this chapter is to evaluate the performance of CoMP techniques in realistic practical networks. In this chapter, we simulate two main types of coordination. The first type is held between sectors within the same BS which is called intra-site coordination, and the second type is between a set of sectors which belong to different BSs, this type is called inter-site coordination. Both of them are simulated for non-overlapped clustering. Last part of this chapter proposes a new criterion for clusters selection depends on cells weight function. The previously mentioned optimization criteria in ideal system model can be applied in the real network. All Matlab® and WinProp® simulations in this chapter consider Al-Khobar city topography and BSs distribution in the real system model.

1.12 The Network Simulation Tool for CoMP Evaluation

For mobile radio system implementation, wave propagation models are obligatory to determine the propagation characteristics. Path loss predictions are required for the coverage planning, the determination of multipath effects as well as for interference and cell calculations, which are the basis for the high-level network planning process. CoMP evaluation for the practical realistic networks is based on a software called WinProp®. The use of the software requires training. We just briefly give an idea about the tools which are used to generate the results.

WinProp® is a planning and design software that includes the prediction of the received power in order to determine the parameters of the base transceiver stations (or access points). The environments where these systems are intended to be installed are ranging from large rural areas (macro-cells) down to indoor environments (pico- and femto-cells). Hence, wave propagation prediction methods are required for the whole range of macro-, micro-, pico- and femto-cells including in-building scenarios and situations in special environments like tunnels or along highways.

WinProp software is a popular wireless propagation and planning software, more than 90 publications used WinProp modules to emphasize and analyze specific wireless cases in the cellular networks research, it consists of different modules. We used the network planning tool ProMan from WinProp package which offers sophisticated coverage and capacity planning for many predefined air interfaces: LTE, 3G (UMTS/HSPA and CDMA), 2G/2.5G (GSM, GPRS and EDGE), Tetra, WiMAX and wireless LAN as shown in Figure 24. MIMO and Distributed Antenna System (DAS) are supported as well as user-defined extensions for the air interfaces. Static, Monte Carlo, and dynamic system simulators are available to achieve the best performance for various applications [78].

CoMP is one of the LTE-A technologies; hence, we used the available LTE air interfaces in WinProp, in addition to specific configurations for the carrier spacing, interference parameters, serving cell and others. In this manner, we utilized WinProp abilities in choosing UE best server according to the threshold values for the UE received power and SINR, also we used the DAS technology in clustering selection process.

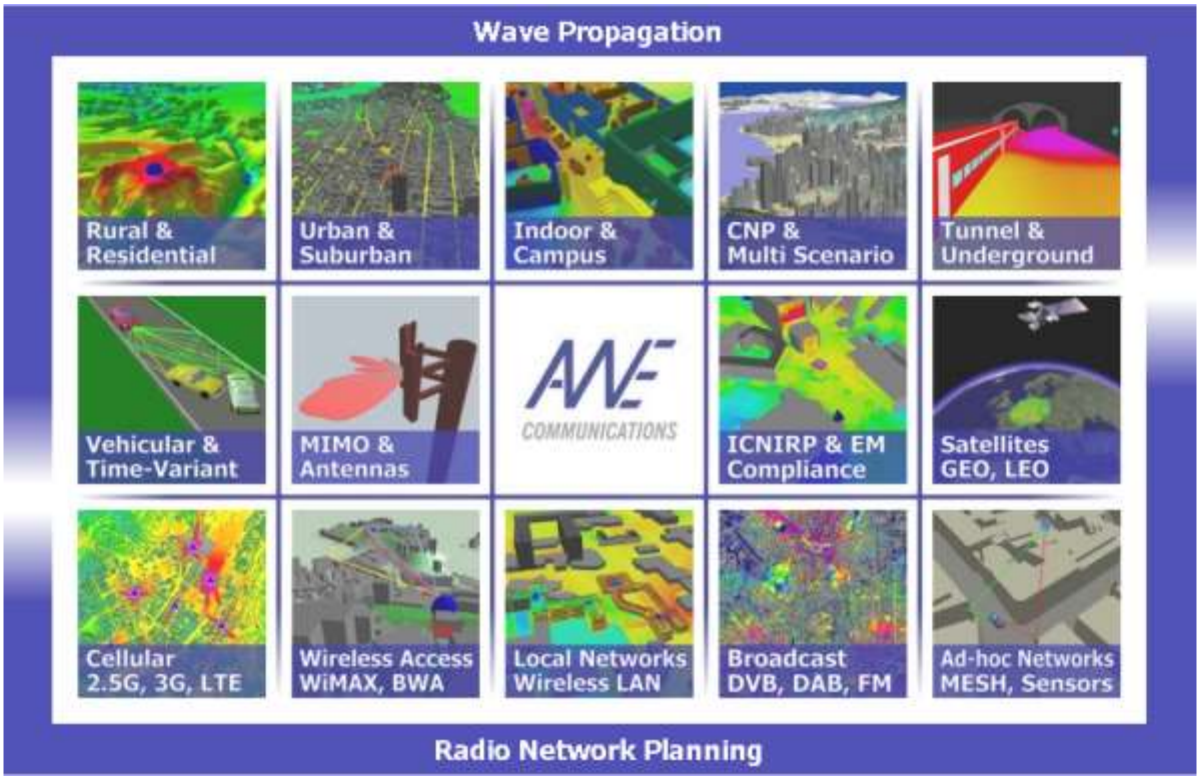


Figure 24 WinProp software overview of applications

1.13 Real Network System Model

Figure 25 and Figure 26 shows the real system model coordination and clustering in Google Earth® and WinProp® respectively, where 20 real location BSs are distributed in Al-Khobar according to specific terrain data and each 4 digit number in both figures refers to one real BS as categorized in Mobily network database. Each sector in real network is considered as best server for group of UEs where each unique colour in Figure 26 refers to the sector serving area. Serving area in real network is different unlike the ideal one. The unequal cells' areas are due to the different location of antennas, antennas height, environment, interference, BS elevation and transmitted power level.

Figure 25 Real model network satellite view from Google Earth

Figure 26 Conventional network serving cells

We can simulate up to seven carriers and two horizontal and vertical polarizations, thus we have 14 unique RF and polarization air interfaces. Using the same carrier causes different types of interference, and the system model has more than 14 clusters in both intra-site and inter-site coordination. The demands here are more than the available resources because we have only 14 unique RF and the number of clusters is more than 14, thus reuse of frequency spectrum and reduced cell size have to be implemented. This will lead to an increase in the interference level in the multi-cell networks which mainly especially the inter-cell interference type which has bad impacts on cell edge UE throughput.

We utilized frequency reuse concept and antenna polarization in simulating the system. We can reuse some of those 14 RF and polarization air interfaces in different clusters, where applying the reuse technique should occur between geographically separated clusters to prevent any overlapping between the spectrum resources as the interference and distance between clusters are inversely related.

1.14 Inter-site Clusters Coordination

The real system model consists of 20 sites with 60 cells. We simulated this system model using 23 clusters in inter-site coordination type. Choosing the 23 clusters in this stage is primary based on sectors locations where some of them are in the network borders and the others in the middle of the network. Figure 27 shows the 23 clusters network coverage, the clusters have different size due to non-uniform ISD and real network distribution.

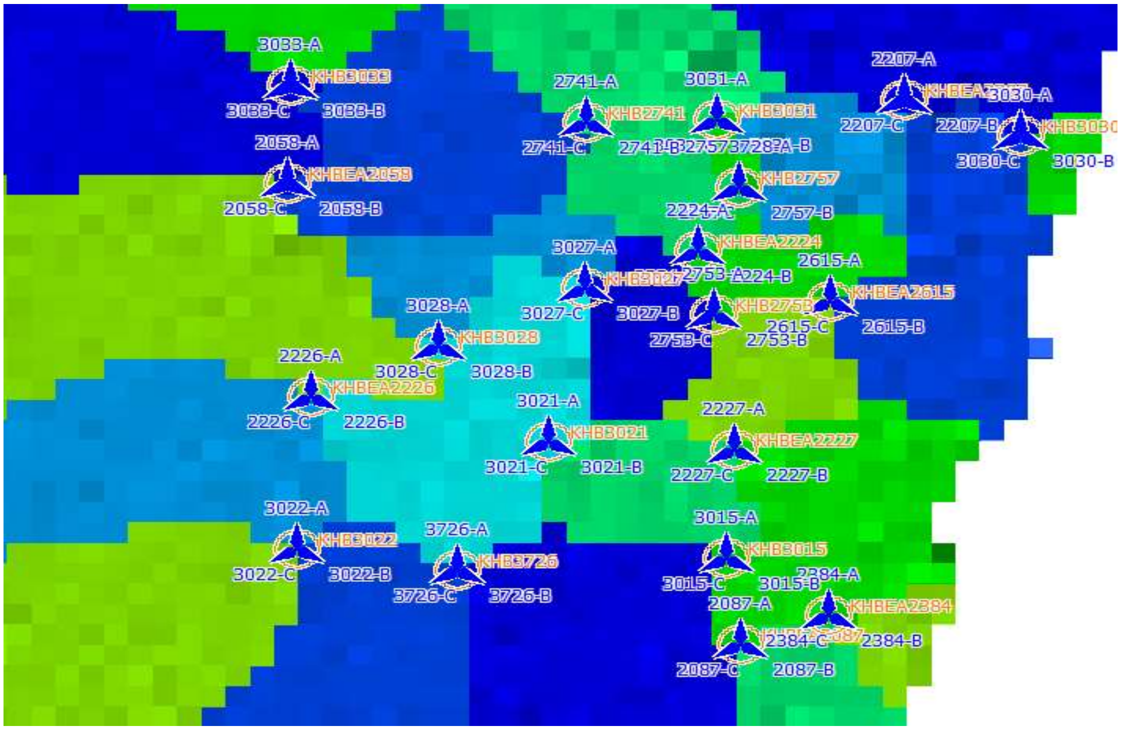


Figure 27 Real inter-site coordination network distribution

Since we have 23 clusters and we are limited in our simulation to 14 unique RF parameters, we have to apply reuse technique in different clusters. We reused 9 clusters RF parameters in different clusters, and only 5 clusters have unique RF parameters. Reuse technique allows us to expand our network and improve network capacity, but it still has minor impact on the interference. Figure 28 demonstrates how the downlink interference differs from one cluster to another. Less interference exists in the 5 clusters which have unique RF parameters while the interference is higher in the remaining 18 clusters because their RF spectrum has been reused twice.

Despite of the benefits of using frequency reuse technique, UEs still suffer some interference between the sectors in networks due to reused frequency especially in short ISD networks as shown in Figure 28. UEs in the middle of the network experience higher interference because they are affected by many undesired signals from neighboring sectors while the UEs in the network edge receives less undesired signals.

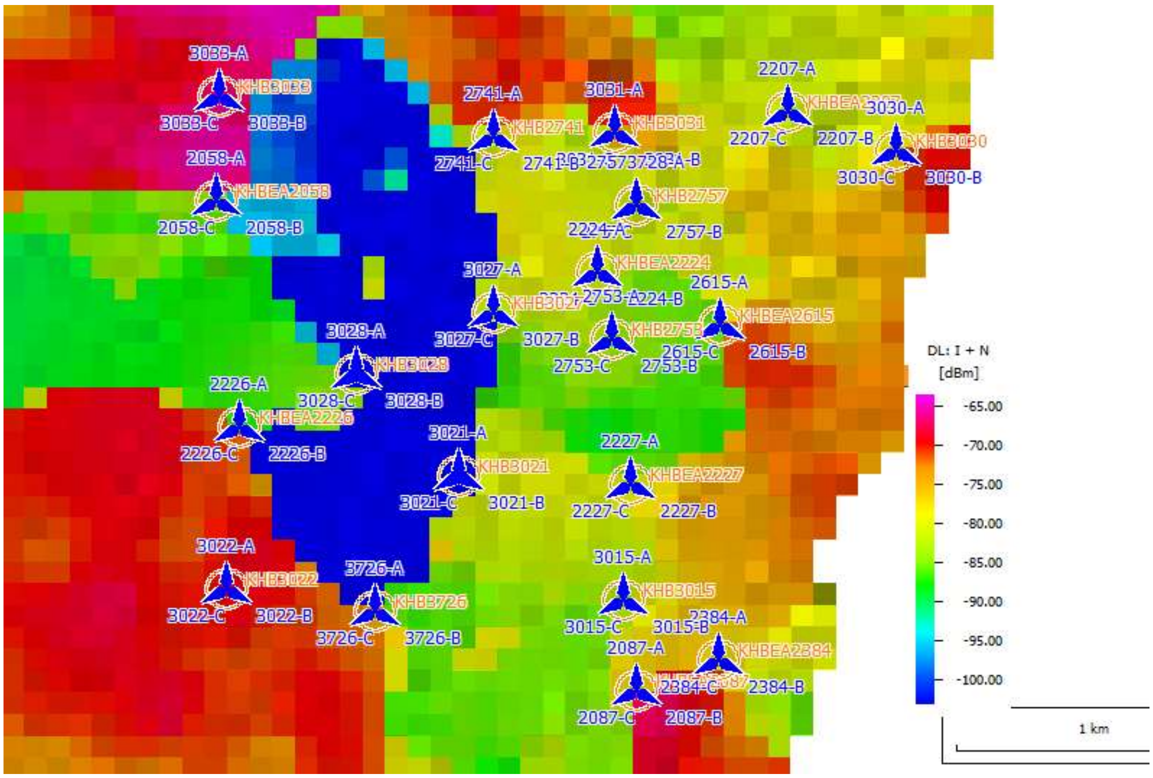


Figure 28 Inter-site coordination clusters interference

1.15 Intra-site Clusters Coordination

The coordination in intra-site clusters takes place on BS level where all BS cells belong to one cluster. The number of the clusters in intra-site coordination is equal to the number of sites which equal 20 sites in our real system model. Figure 29 shows the 20 intra-site clusters in the network where each colour refers to one cluster and each cluster has different size.

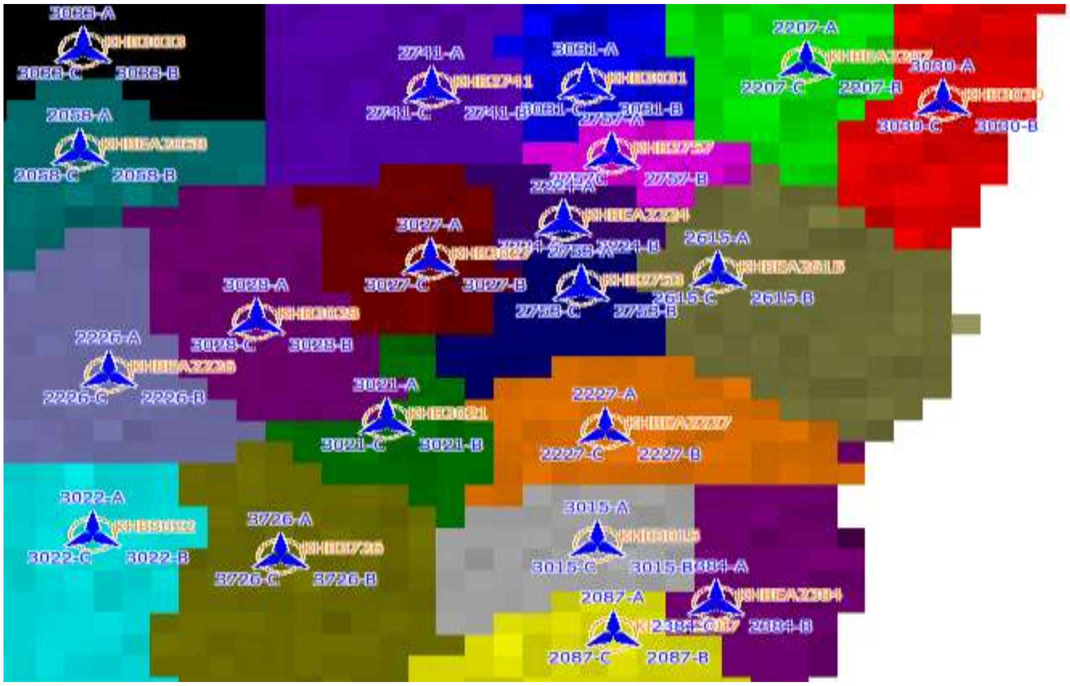


Figure 29 Real intra-site coordination clusters

Frequency reuse is applied in intra-site coordination case also, where there are 6 clusters with reused RF parameters. Figure 30 shows the clusters frequency distribution in intra-site coordination where same colour denotes the same frequency but it has been simulated with a different polarization except for the above mentioned 6 clusters since they have duplicate RF parameters with other clusters.

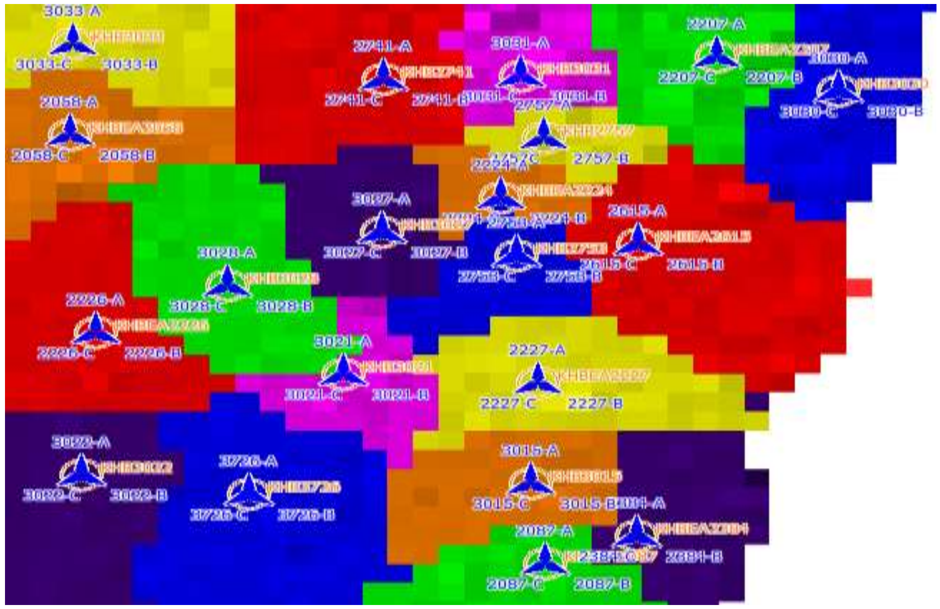


Figure 30 Intra-site coordination frequency reuse

Figure 31 shows the SINR level distribution in the system with intra-site coordination. There is no direct comparison between inter-site and intra-site coordination SINR levels since their sites have totally different RF plan and antennas cluster are different also.

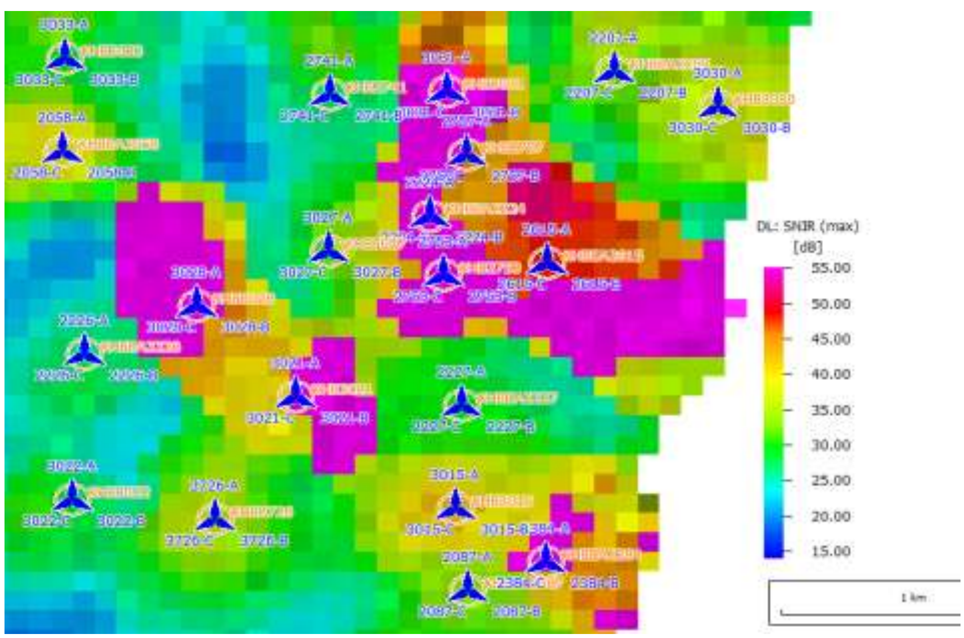


Figure 31 Intra-site coordination SINR

As illustrated in the ideal case, increasing cluster size has positive reflection on SINR level. Figure 32 shows the CDF SINR for no-CoMP, intra-cell CoMP, inter-cell CoMP (cluster size is 3) and mix coordination between intra-cell and inter-cell (cluster size is 4). This figure clearly shows the SINR behavior in the real network system model in different coordination cases by distributing 1600 UEs among this real network case.

We tried to select the clusters in Figure 32 efficiently, where we set a comprehensive plan in distributing the frequency between sectors to reduce the interference to the lowest possible level. Figure 32 shows SINR improvement between no-coordination and inter-cell CoMP can reach to 20 dB which is similar to ideal network.

This figure illustrates the fact that we can get better SINR enhancement in inter-cell CoMP in comparison with intra-cell CoMP, but this will be at the cost of the needed backhaul to exchange data between BSs. At CDF equals to 0.4, inter-cell CoMP SINR exceed intra-cell CoMP by 6 dB. Using both of them and increasing the cluster size lead to huge improvement in the SINR values in mix coordination case, but the signal overhead to exchange CSI increases. The plots in Figure 32 are based on real data so their behaviors don't follow any systematic way; they only depend on simulation results based on the non-uniform UEs distribution.

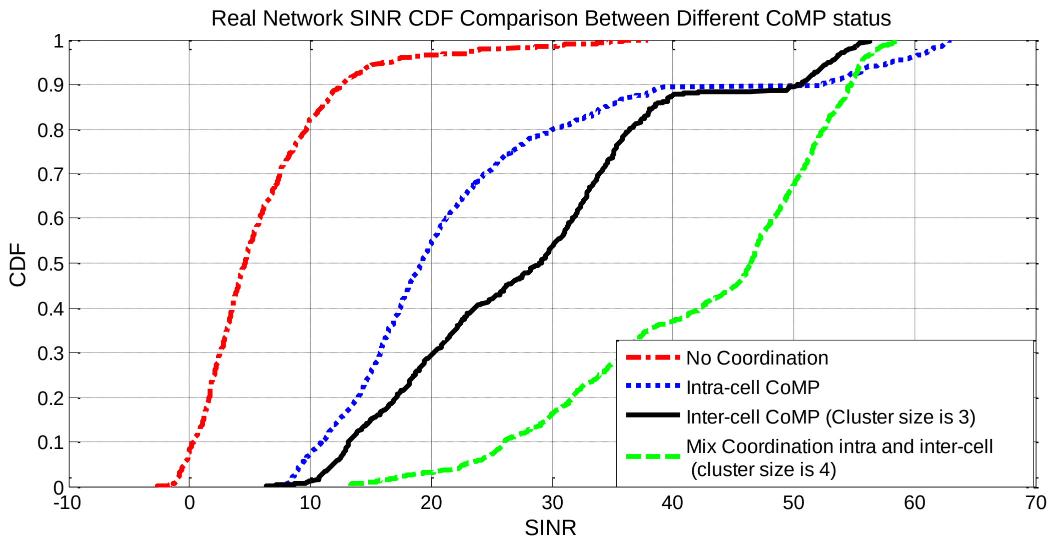


Figure 32 Real network SINR CDF comparison between different CoMP approaches

1.16 Weighted Real Network Performance

We applied three different optimization criteria in the ideal model where the system is more flexible to accept changes because sites and UEs in that model are somehow systematic. Applying a standard optimization criterion for real network is more complex due to different conditions such as; elevation, sites location, users distribution and antennas height.

SINR CDF comparison between coordination and no-coordination cases is important as well as between intra-site, inter-site and different cluster size coordination. But such comparisons give all serving cells equal importance while in our system model each cell/sector has different level weight where some sectors are serving more UEs than others in the real life because of the non-uniform user distribution. So a specific quality or weight function should be applied in a real network to enhance the overall performance where giving same level of significance for all networks sectors reduces the network efficiency.

We implemented a weight function to evaluate each sector according to the number of served UEs by each one using 3655 UEs that are distributed in Al-Khobar system model. Then, we restudied the 60 cells by creating this function according to their weight. Table 4 shows each sector weight according to its served UEs. The sector weight is more than one if its importance is above average compared with the existing 60 sectors and vice versa.

Equation **(0-1)** shows how the total sectors weight is equal to the number of sectors in the real network where SW_s refers to each sector weight and the maximum possible SW_s is equal to the total number of sectors in real network which is 60 in our case. Assigning each SW_s is based on field measurement for each sector according to the average number of served UEs by each sector, where some sectors serve more UEs which deserve higher SW_s than others and this can help us to choose the optimum clustering.

$$Total\ sectors\ weight = \sum_{s \in S} SW_s \qquad , 0 \leq SW_s \leq No. of\ sectors \qquad (0\text{-}1)$$

Sector	**2207A**	**2207B**	**2207C**	**3030A**	**3030B**	**3030C**	**3031A**	**3031B**	**3031C**	**2757A**
Weight	0.722	0.575	0.607	0.689	0.542	1.182	0.821	0.575	0.870	0.378
Sector	**2757B**	**2757C**	**2087A**	**2087B**	**2087C**	**2224A**	**2224B**	**2224C**	**2227A**	**2227B**
Weight	0.410	0.985	1.149	1.001	1.560	0.969	1.198	1.822	1.018	1.789
Sector	**2227C**	**2384A**	**2384B**	**2384C**	**2615A**	**2615B**	**2615C**	**3015A**	**3015B**	**3015C**
Weight	1.576	1.461	1.182	1.313	0.821	1.215	1.198	1.822	1.330	2.298
Sector	**2226A**	**2226B**	**2226C**	**3022A**	**3022B**	**3022C**	**2058A**	**2058B**	**2058C**	**3033A**
Weight	1.001	0.345	1.592	0.739	0.755	0.969	0.263	1.001	0.722	0.870

Sector	3033B	3033C	3021A	3021B	3021C	3027A	3027B	3027C	2753A	2753B
Weight	0.640	0.772	1.067	0.936	0.854	0.854	0.722	0.870	1.264	0.772
Sector	2753C	3028A	3028B	3028C	3726A	3726B	3726C	2741A	2741B	2741C
Weight	0.903	1.346	1.871	0.804	0.821	1.494	0.460	0.525	0.919	0.772

Table 4 Sectors weight according to number of users

We redraw the SINR CDF for inter-site CoMP by multiply each sector by each weight considering Table 4. Figure 33 compares the SINR CDF for the inter-site CoMP after and before applying the sectors weight clustering criterion. This figure doesn't reflect the SINR enhancement after using sectors weight because equation **(0-1)** results are the same in both cases, where we just have changed the weight for each sector, some of them less than one and some of them more but the total weight still 60. This CDF graph reflects the behavior for limited number of UEs which is 1600 and the distribution of them not ideal because we are dealing with practical network.

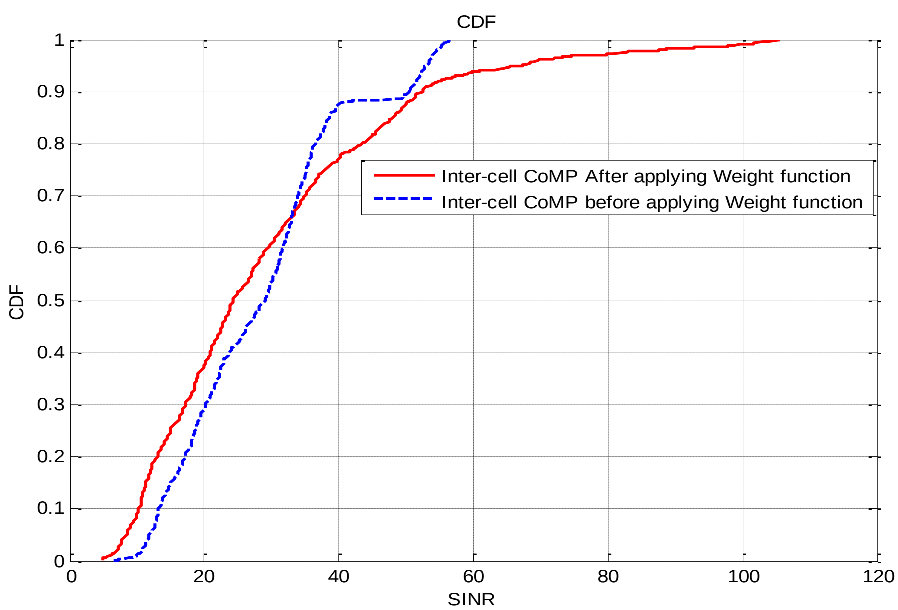


Figure 33 Real network SINR CDF after and before involving weight function

We should utilize the previously mentioned sectors weight function to create a specific methodology in cluster selection based on each sector importance level, where each sector has different weight than others, therefore choosing appropriate clustering is positively reflected on average UE data rates.

We propose a new clustering criterion for clusters selection in real system model by considering Table 5, so we determined different cluster sizes according to that table, where we involved the sectors that have higher weigh function value in large cluster size and vice versa as per Table 5. Any sector that has a weight value less than α will not be involved in a cluster size more than three and the clusters that have size of five at least include one cell that its weight value is more than 3* α. Anyhow, involving this new clustering table will add more complexity in different terms.

	Weight Value (W)	Clustering size
1	Less than α	Maximum three cells
2	α <W<1	Flexible between 3,4 or 5
3	2* α <W< 3* α	Flexible between 3,4 or 5
4	More than 3* α	Not less than five cells

Table 5 Weight value vs. cluster size

In our case we considered α =0.5, then we re-clustered the real network according to Table 5 new criterion. We compared the SINR CDF before and after applying this table in the Figure 34 which shows that the SINR is enhanced after applying Table 5 in the low SINR then the SINR get worst for 30% of SINR values in compared with mix clustering without applying Table 5. Applying Table 5 to the real network has no direct effect on the SINR enhancement as shown in

Figure 34 because this criterion cares about utilizing the network resources in efficient manner by studying the average number of connected UEs to each sector and re-clustering the real network according to these weighting factors. The real gain will return to the total system throughput and performance and the SINR will differ according to the new clustering positively or negatively. We can divide Figure 34 into 3 parts, the first part for the SINR between 12 till 33 dB where the SINR CDF before applying cluster weighting table is more than after applying this table, while the opposite case appears in the second part between SINR 33 till 47 dB and applying this table for high SINR in part three will not make noticeable difference.

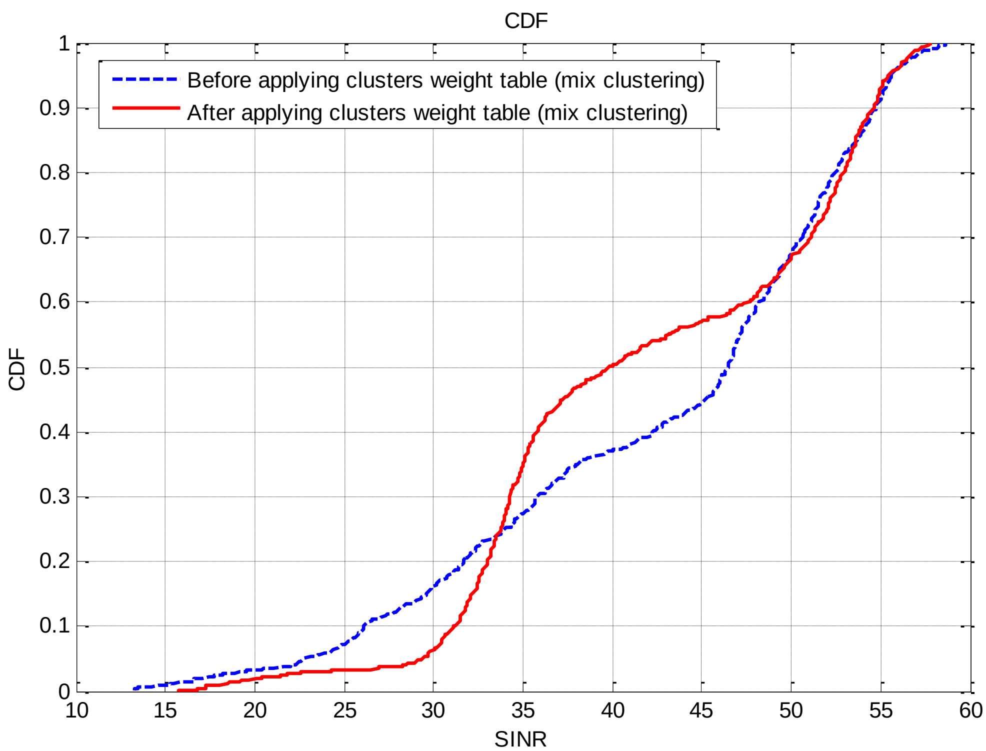


Figure 34 SINR CDF after and before applying weight table (mix clustering)

In real system model, we simulated inter-site and intra-site clusters and we checked their performance using different clustering shapes and sizes. This chapter presented the relation between reuse frequency and UE SINR behavior.

The last part of this chapter was dedicated to real network clustering method depending on sectors weight function, where we collect the average number of UEs that are connected to each sector daily in Al-Khobar city. We created new clustering according to the sector weight table and the cluster size depending on the weight of the participate sectors. This clustering criterion improved the real network available resources.

CONCLUSION AND FUTURE WORK

The thesis mainly focused on studying CoMP effects in improving the UEs SINR and comparing the performance of ideal and real practical CoMP networks with conventional ones. In addition to that, this thesis discussed CoMP clustering techniques. This chapter concludes the work of this thesis and gives an idea about the potential research that could be pursued.

1.17 Summary of Conclusions

In this work, we've investigated different clustering and optimization criteria to enhance the UEs experienced SINR. These investigations consider the ideal network scenario and a part from Al-Khobar city for the real practical scenario. The main parts of the thesis are concluded in the following:

It was shown in Chapter 1 that due to the fact that interference is one of the major limiting factors in networks performance, efficient technology like CoMP is needed to enhance networks spectral efficiency and data rates.

Chapter 2 draws a bridge between theory and practice through comprehensive discussion of ideal and real aspects related to CoMP. Moreover, the signal and system models have been discussed, also a SINR comparison between conventional and CoMP in both ideal and real networks showed the SINR improvement after the coordination.

In Chapter 3, we focused our investigation in static clustering ideal network. We maximized the mean SINR and the outage measure in overlapped and non-overlapped clusters. Maximizing mean SINR criterion has great advantaged in increasing the spectral efficiency for the weak UEs. On the other hand, outage measure criterion maximized the number of positions that can achieve the threshold SINR. Part of our analysis showed that the cooperation cluster size had a proportional relation with UEs achieved SINR.

We proposed a new optimization criterion that avoids the limitations in last two criteria where a hybrid clustering technique is implemented using both overlapped and non-overlapped clusters. Also, we utilized a cluster size selection algorithm to select UE cluster size according to achieving SINR thresholds.

Chapter 4 discussed the real CoMP system model in details by implementing inter-site and intra-site coordination clusters. We showed the effect of cluster size on achieved SINR for practical networks. Also we discussed how the locations and some practical aspects can help or limit real network performance because we applied real frequency reuse with limited spectrum resources for the LTE-A carriers where we explained how the interference increases in some parts of the network due to frequency reuse despite of applying sector coordination.

Last part of Chapter 4 discussed real network performance by creating sector weight function where we assign each sector a different weight according to its level of importance in the real network. Then, we applied a new clustering methodology considering each sector weight. This new proposed method helped us to utilize the real network available resources based on importance level.

1.18 Future Work

The work in this thesis considered coordination effect in SINR improvement for ideal and real networks. There are still several open problems whose solution could add a great benefit in the field of interest. We may summarize them in the following point:

- Clustering is one of the most important factors in CoMP. There is a room for identifying/combining different parameters to select the clusters such as UE received power, sectors locations, UEs average data rate, channel overhead and different aspects.
- Dynamic clustering based on CSI study can enhance the cooperation gains and a study for its gains vs. its complexity in practical networks would be of great value.
- We investigated the real CoMP network for Al-Khobar city which is small and coastal city. We believe a comprehensive investigation for applying coordination in non-coastal cities and comparing the gain with coastal ones deserves further work.
- The main aim for improving UEs SINR is to enhance their average data rate, thus, data rates improvement using CoMP could be investigated by considering the sectors air interface capacity and fiber backhaul abilities.
- Evaluating CoMP challenges, such as synchronization, channel overhead and CSI in practical real networks.
- Evaluating CoMP practical network efficiency using Coordinated Scheduling/ Beamforming scheme
- Investigating the linear preceding methodology in CoMP and how can we decrease its complexity.

APPENDIX

Table 6 Abbreviations

Abbreviation	Stand for
3GPP	Third Generation Partnership Project
BER	Bit Error Rate
BS	Base Stations
CB	Coordinated Beamforming
CDF	Cumulative Distribution Function
CDMA	Code Division Multiple Access
CoMP	Coordinated Multipoint
COW	Cell on Wheel
CS	Coordinated Scheduling
CSI	Channel State Information
DAS	Distributed Antenna System
DCS	Dynamic Cell Selection
DoF	Degree of Freedom
EDGE	Enhanced Data for GSM Evolution
FDD	Frequency Division Duplexing
GSM	Global System for Mobile
HSPA	High Speed Packet Access

ICIC	Inter-cell Interference Coordination
ISD	Internal Site Distance
JT	Joint Transmission
KPI	Key Performance Indicator
LTE	Long Term Evolution
LTE-A	LTE Advanced
MIMO	Multi Input Multi Output
MU-MIMO	Multi-User Multi Input Multi Output
ODE	Original Digital Elevation
OFDMA	Orthogonal Frequency Division Multiple Access
PDF	Probability Distribution Function
PL	Path-Loss
R&D	Research and Development
RAP	Radio Access Point
RB	Resource Block
RSL	Signal power Level
RSQI	Received Signal Quality Indicator
SDMA	Space Division Multiple Access

SIC	Successive Interference Cancelation
SIMO	Single Input Multi Output
SINR	Signal Interference and Noise Ratio
SIR	Signal to Interference Ratio
SISO	Single Input Single Output
SLNR	Signal to Leakage and Noise Ratio
SLR	Signal to Leakage Ratio
SNR	Signal to Noise Ratio
SRTM	Shuttle Radar Topography Mission
SU-MIMO	Single-User Multi Input Multi Output
TDD	Time Division Duplexing
TP	Transmission Point
UE	User Equipment
UMTS	Universal Mobile Telecommunications System

Table 7 List of variables

Variable	Indication
ρ^2	Noise variance
$\boldsymbol{\eta}$	Spectral efficiency
$\boldsymbol{\lambda}$	Wavelength
$\boldsymbol{\lambda_j^m}$	path gain from UE *j* to serving cell m
$\boldsymbol{\theta}$	angle between antenna azimuth and UE
$\boldsymbol{\theta_{3dB}}$	3dB beam-width
A	binary matrix A describe the distribution of M cells into C clusters
$\boldsymbol{A(\theta)}$	antenna pattern
$\boldsymbol{AL}$	attenuation in dB due to antennas directivity and azimuth
$\boldsymbol{AL_j^m}$	dependent attenuation from cell number m that affect UE j
Am	maximum possible attenuation
B	binary matrix shows if the UE j can reach the threshold value or not
$\boldsymbol{C}$	Capacity
$\boldsymbol{f_c}$	mean SINR
G	Antenna gain for Transmitter and Receiver
h_k	Fading channel gain
$\boldsymbol{P_{ds}(t)}$	Desired signal
$\boldsymbol{P^{noise}(t)}$	Noise interference

$P^{ICI}(t)$	Inter-cell Interference
P^{IUI}(t)	Intra-cell interference
P_k	Transmitted power for user k
PL	Path loss
P_E	Effective Isotropically Radiated Power
P_A	minimum BS antenna gain
P_C	power amplifier
Pr_j^m	UE j is received power from cell m
$R_k(t)$	Instantaneous rate of user k
$SINR_j^{M`}$	experienced SINR by a UE *j* from the serving cluster $M`$
T	Required receiving time
w	Channel bandwidth size
x	binary vector indicates if a specific cluster is selected or not
z	binary vector indicates if the selected clusters can achieve γ at various UEs or not

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