World Academy of Science, Engineering and Technology
International Journal of Electrical and Information Engineering
Vol:11, No:7, 2017

Comparison of Inter Cell Interference Coordination Approaches

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Abstract**—**This work aims to compare various techniques used in order to mitigate Inter-Cell Interference (ICI) in Long Term Evolution (LTE) and LTE-Advanced systems. For that, we will evaluate the performance of each one. In mobile communication networks, systems are limited by ICI particularly caused by deployment of small cells in conventional cell's implementation. Therefore, various mitigation techniques, named Inter-Cell Interference Coordination techniques (ICIC), enhanced Inter-Cell Interference Coordination (eICIC) techniques and Coordinated Multi-Point transmission and reception (CoMP) are proposed. This paper presents a comparative study of these strategies. It can be concluded that CoMP techniques can ameliorate SINR and capacity system compared to ICIC and eICIC. In fact, SINR value reaches 15 dB for a distance of 0.5 km between user equipment and servant base station if we use CoMP technology whereas it cannot exceed 12 dB and 9 dB for eICIC and ICIC approaches respectively as reflected in simulations.

Keywords**—**4th generation, interference, coordination, ICIC.

I. Introduction

THE critical problem to deal with in 4G mobile networks is the macro cell limitation for partially serving unseen users. Also, according to recent studies, in the next years, around 90% of the data services and 60% of the phone calls will take place on indoor areas (home, school, restaurant…) [1], [2]. Therefore, in order to take care these issues and strongly improve the quality of service (QoS) level for users located indoor and far from the macro base station, femto cell architecture has been adopted in the Third Generation Partnership Project (3GPP) specifications. Femto cell is deployed by LTE/LTE-Advanced standards, where it is considered as the main indoor technology which can provide a high data rate services to the end users [3]. Femto cell is a small cell, named; Home eNodeB (HeNB) or Home Base Station (HBS) in OFDMA based systems. This small cell is characterized by a low cost and a short range and it is installed by the end user. The former can communicate over a broadband connection such as ADSL or a modem cable [4]. Hence, Home eNodeB provides better indoor voice and data reception owing to the few number of users served by a femto cell (1 up 4 users), and the short distance between the femto cell base station and the user equipment. Based on various features, such as indoor coverage, data rate, capacity, this makes it an attractive solution for both operator and consumer. In fact, as the cost is widely reduced for operator, enhancement could likewise be detected over system capacity and gathered incomes [5]. Besides, for the consumer, femto cells widely enhance indoor coverage, data rate and QoS. Thanks to cell radius reduction, transceivers will be closer and path loss obviously shorter. Besides, best autonomy of the terminal will be noted. Unfortunately, seeing a macro cell using the same frequency resources as served user will introduce ICI that constitutes a drawback to be overcome.

In this paper, we recall an overview of ICI issue and we study various coordination techniques used in LTE/LTE-Advanced systems in order to mitigate this issue. So, after giving an ICI problem overview in Section II, Section III presents detailed survey on ICIC techniques. We compare these techniques in Section IV. Finally, Section V, concludes the paper.

II. ICI Problem Overview

The major cause of lower system capacity in mobile network is ICI. This constitutes a great issue coming from a common and simultaneous usage of the same resource affected to many users in neighboring cells. Suppose that we have two cells using the same frequency channel (F) and under the coverage region of each of two cells one User Equipment (UE). These two UEs utilize the same frequency resource (fi, fi ϵ F) as shown in Fig. 1. If both UEs are located in the cell centers such A2 and B2, then, no important power will be needed, there will be no interference observed. However, if they cells edge like A1 and B1, they will need higher powers and consequently an ICI problem appears [6].

In two tier cellular networks such as LTE-Advanced system where femto cells are integrated in the conventional macro cells, there are two types of ICI [7]:

Co-tier ICI: In this case, interference occurs among network elements that belong to the same layer. This type of interference can appear in both uplink and downlink directions. In fact, in the uplink, Femto User Equipment (FUE) can be a source of interference for the Femto Access Point (FAP) of neighboring cell and vice versa in downlink as shown in Fig. 2.

Cross tier inter-cellular interference is interference between network elements from different layers that is to say that this type of inter-cellular interference occurs among femto cell and macro cell as seen in Fig. 3. This kind of interference can affect both uplink and downlink transmission. In fact, FAP can cause interference for Macro cell User Equipment (MUE). Let's note that Macro cell Base Station (MBS) can be a source of interference for FUE and vice versa.

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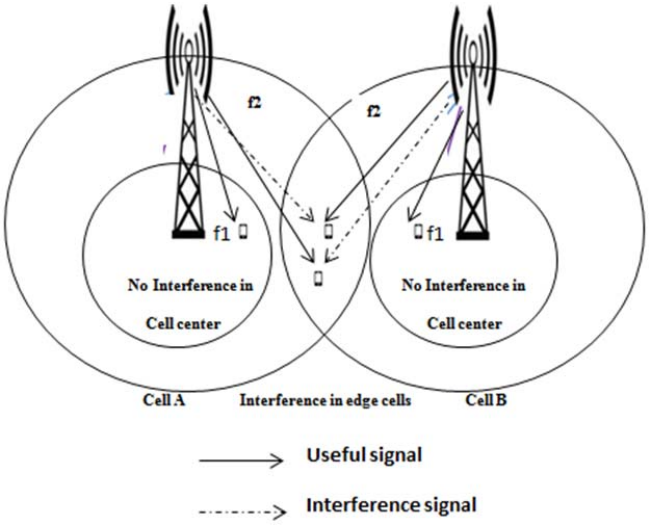


Fig. 1 ICI

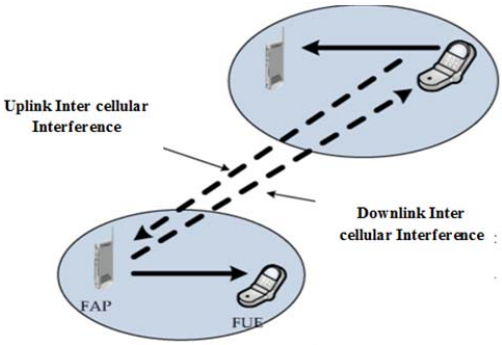


Fig. 2 Co tier inter-cellular interference

In order to eliminate ICI in 4G cellular systems, various schemes are developed [8]-[11]. These techniques will be compared hereafter.

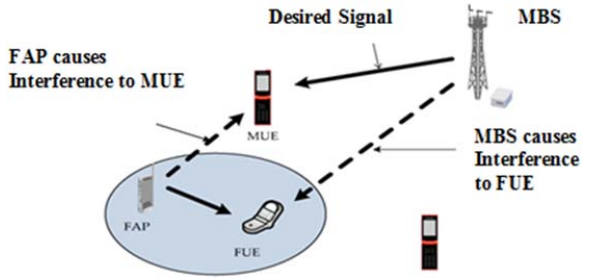


Fig. 3 Cross tier inter-cellular interference

III. ICI Reduction Approaches

In order to minimize ICI in LTE / LTE-Advanced systems, several techniques have been proposed [9]. Hereafter, we will mainly describe those named: ICIC, eICIC and CoMP.

A. ICIC Techniques

As developed by a number of studies, LTE is designed for frequency reuse 1 [12]. This looks for a spectrum efficiency maximizing. For that all close cells use the same frequency channels and therefore there is no cell-planning to deal with the interference issue, causing a high level interference and consequently a capacity limiting [12].

ICIC is conceptually defined in Release 8 for 3GPP as an interference coordination technology used in LTE system. It reduces ICI by allocating different resource blocks (RBs) to the UEs in the edge of cells [13]. The base stations that support this feature can generate interference information for each RB, and exchange information with neighboring base stations through messages via the X2 interface. Then, from these messages, neighboring base stations can know the level of interference for each RB and therefore allocate to their users RBs in a way that would allow avoiding interference.

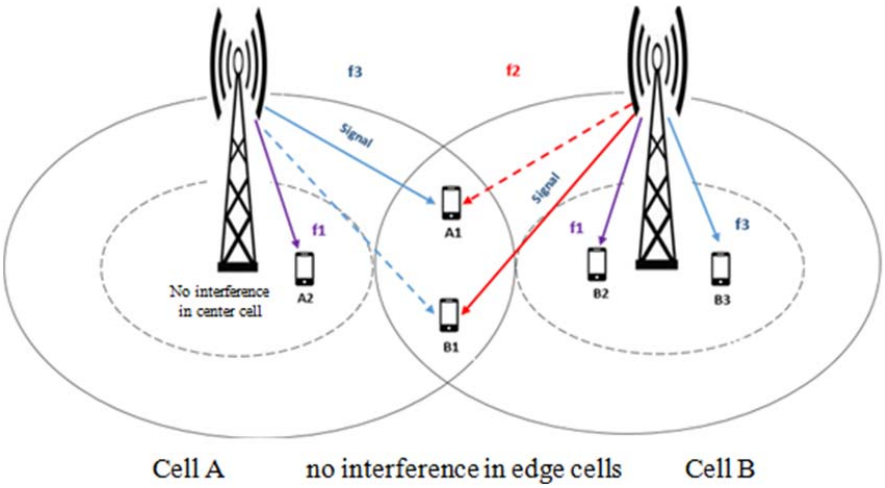


Fig. 4 ICIC concept

According to frequency usage rules, three techniques of ICIC have been defined to reduce interference [10]:

- Hard Frequency Reuse (HFR): The principle of this technique is that neighbor base stations use different sets of resource blocks throughout the cell at given time i.e. two neighbor base stations will not use same resource

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assignments for their UEs as shown in Fig. 5.

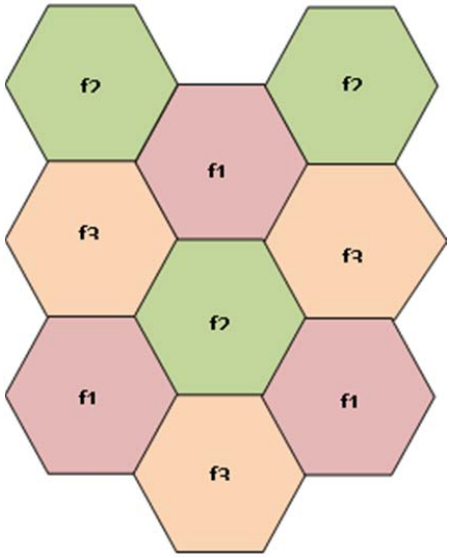


Fig. 5 Hard Frequency Reuse

- Soft Frequency Reuse (SFR): In this technique, a frequency reuse with factor 1 is used in central region of a cell. However, in cell edge zone, frequency reuse with factor greater than 1 is used. The principle of this technique is shown in Fig. 6.

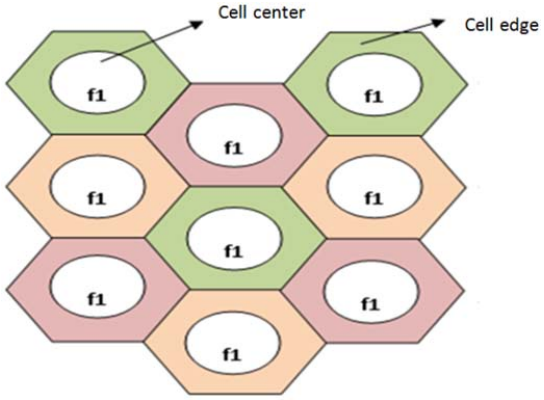


Fig. 6 Soft Frequency Reuse

- Fractional Frequency Reuse (FFR): The principle of this technique is that all frequency resources are used in each cell. The condition which must be checked in this technique is that a frequency or a frequency band used at the center of a given cell will be used in the edge region of its neighboring cell and vice versa. This is illustrated over the following example (Fig. 7).

Let's note that, in those situations, ICIC has only examined interference scenarios in homogeneous network. So, to deal with interference issue in heterogeneous network, eICIC technology was standardized in 3GPP Release 10 [10] as it will be indicated.

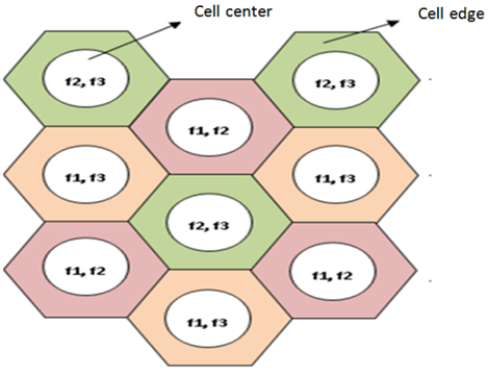


Fig. 7 Fractional Frequency Reuse

2) eICIC Techniques

LTE-Advanced, as an evolution of the LTE standard, aims to provide better QoS and extend coverage. For these reasons, LTE-Advanced integrates femto cells which can use the same frequencies with existing macro cells. That's why, an ICI problem appears between macro and femto cells. On the other hand, eICIC is an interference reduction technique defined for heterogeneous deployment [9]. To suppress ICI, ICIC allows cell-edge users' equipment's in neighbor cells to use different frequencies. On the other hand, eICIC allows them to use the same frequency but at different time intervals (sub frames) for the same purpose. So, eICIC uses frequency and time domains to mitigate interference on traffic and control channels in heterogeneous networks [14]. In fact, there are two different categories of eICIC solutions that are proposed to mitigate interference between macro and femto cells. These solutions are as following [15]:

- Time-domain techniques: These techniques are based on Almost Blank Sub frame (ABS) concept. The principle of time domain techniques is to use the same frequency channel in different network layers and to manage interference based on time domain. In fact, the transmitted data by the macro base station (source of interference) are stopped at certain times. These moments are called ABS and allocated to users of small cells (femto or pico cells) as illustrated in Fig. 8.
- Frequency-domain techniques: These techniques are based on carrier aggregation. Indeed, aggregation is one of the important features of the LTE-Advanced standard that enables a user equipment to use multiple subcarriers simultaneously. The concept of carrier aggregation in a heterogeneous LTE-Advanced network is to partition the available spectrum into, for example, 2 separate component carriers, and assign the primary component carrier (f1) to macro cell layer and the second component carrier (f2) to femto cell layer as shown in Fig. 9.

Interference coordination techniques developed in LTE release 8/9/10 can provide benefits in the management of ICI. But these benefits are limited in case of the condition of dynamic interference. Because of this limitation, another technology for this type of interference is introduced. It is a CoMP technology (Coordinated Mlti-Point transmission and

reception); it will be studied thereafter.

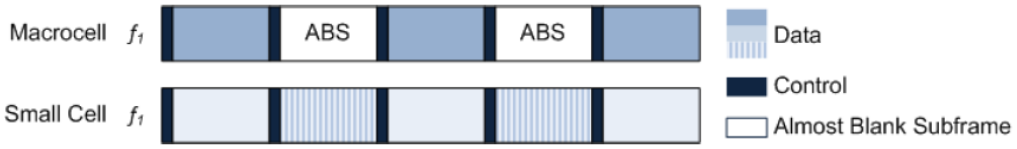


Fig. 8 Time-domain technique based on ABS concept [9]

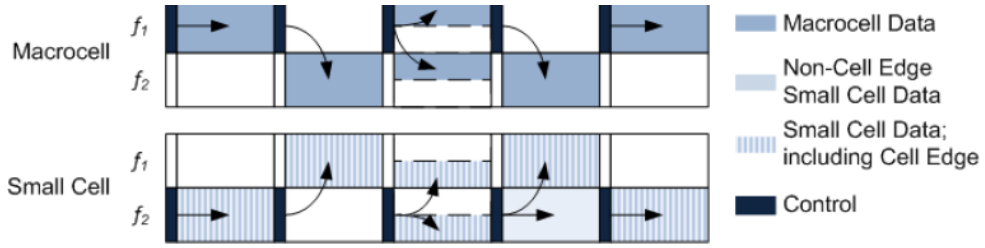


Fig. 9 Frequency-domain technique based on carrier aggregation

3) CoMP

In mobile networks, a user needs to dynamically adapt to new environments. In this context, the coordinated transmission by several base stations (CoMP) is introduced. Indeed, CoMP is an interference control technique introduced in 3GPP Release 11. The basic idea of CoMP is to transform the interference signal to a useful signal particularly in the edge region where performance may be degraded. As its name suggests, in CoMP a number of emission points (TX) ensures the coordinated transmission in the downlink and a number of points of reception (RX) provides coordinated reception in the uplink. Cells cooperation is interesting to better reflect the current network status, and dynamically make adapt. The main objective is to improve coverage and reduce the number of delinquent edges cells users. For this, the base stations communicate with each other to regulate the use of shared resources. This interaction between neighboring cells can be done directly by using the defined link X2 [9]. Besides, for CoMP techniques, we can retain a classification of CoMP methods into two categories: downlink CoMP techniques and uplink CoMP techniques. Downlink CoMP transmission is categorized as Coordinated Scheduling/Coordinated Beamforming (CS/CB), Dynamic Point Selection (DPS) and Joint Transmission (JT).

- In coordinated scheduling/beamforming scheme, the information at the UE is gotten from one of the base stations and coordination happens among an arrangement of base stations with a specific end goal to control and reduce interference at the terminal. The coordinated scheduling is accomplished by allocating different frequency resources to cell edge users. In coordinated scheduling, the cooperative cells share channel information to each user. Nevertheless, coordinated beamforming affects several beam patterns to cell edge users by using smart antenna technology.
- Joint Transmission: The JT-CoMP technique is the more powerful one [16]. The principle of this technique is summarized in the fact that a given user equipment data is simultaneously processed and transmitted from multiple cooperating base stations. In the heterogeneous scenario and in a dense network of small cells, the UEs received significant intensity of their signals from multiple base stations simultaneously. So, JT-CoMP tends to improve the spectral efficiency and the average throughput.
- Dynamic Point Selection (DPS): During the preparation phase, several cells share the same data. In data transmission phase, functions are different. Firstly, the UE channel quality is checked in each sub-frame, and the data are sent by a cell that has the minimum path loss. Other cells that are not selected are disabled. Since the data are sent from cells with higher channel quality, the UEs receiving quality can be improved more effectively [16].

For uplink, CoMP techniques include Joint Reception (JR) and Coordinated Scheduling (CS).

- Joint Reception: The fundamental idea driving this configuration is to use radio wires at various locales. By organizing between the distinctive eNBs it is conceivable to frame a virtual radio wire cluster. Signals got by the eNBs are then consolidated and handled to create the final signal. This method considers flags that are low in quality, or conceal by interference in a few regions to get with few issues.
- CS: This technique works by organizing the scheduling choices among the eNBs to minimize interference.

In next section, we aim to compare the different schemes of ICIC.

IV. Comparative Study

The ICIC reduces ICI by affecting different frequency resources to cells edge users. However, when eICIC is applied cell edge users in neighboring cells can use the same frequency resource but at different time intervals. On the other hand, CoMP technology consists to coordinate different base stations in order to enhance performances of edge users. In fact, the

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main idea behind this coordination scheme is the utilization of ICI in a constructive manner. This section presents the simulation results to compare ICIC, eICIC and CoMP ICI coordination approaches in terms of Signal to Interference plus Noise Ratio (SINR) and capacity given by:

$$SINR = \frac{S}{N + I} \quad (1)$$

$$Capacity = W \log_2(1 + SINR) \quad (2)$$

where W is the available bandwidth. Table I gives the simulation parameters.

TABLE I
SIMULATION PARAMETERS

Parameter	Value
Base station transmit power	46 dBm
Carrier frequency	2 GHz
Bandwidth	20 MHz
Subcarrier spacing	15 KHz

Obtained results show the variation of the SINR and capacity according to the distance between the user equipment and the servant base station. In fact, Fig. 10 investigates the variation of the SINR according to distance between the user and the servant base station if we use ICIC techniques. On the other hand, Fig. 11 shows the capacity' variation as a function of a distance between the user and his servant base station according to several ICIC approaches.

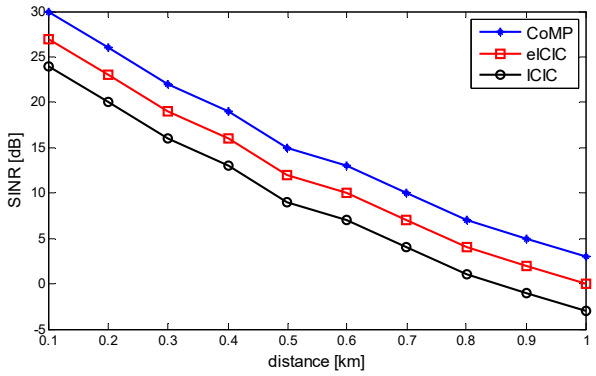


Fig. 10 SINR variation according to the distance for different coordination approaches

From Fig. 10, it can be deduced that SINR value will be increased from 9 dB to 12 dB, if the user is distant from the servant base station by a distance of 0.5 Km, when we use ICIC and eICIC. However, if we use the CoMP approaches SINR can achieved 15 dB for the same distance.

From Fig. 11, it could be concluded that the CoMP technology can increase the system capacity up to 80 Mbps for the distance of 0.5 km whereas it cannot exceed 74 Mbps and 66.5 Mbps for eICIC and ICIC respectively.

V. Conclusion

ICI suppression techniques are used to mitigate the impact of ICI on system performance. These schemes are classified into static and semi-static approaches such ICIC and enhanced-ICIC (eICIC). Dynamic approaches such as CoMP can improve SINR and system capacity as compared to the other techniques. For that, in next work, we aim to develop a strategy for ICI mitigation between macro and femto cells.

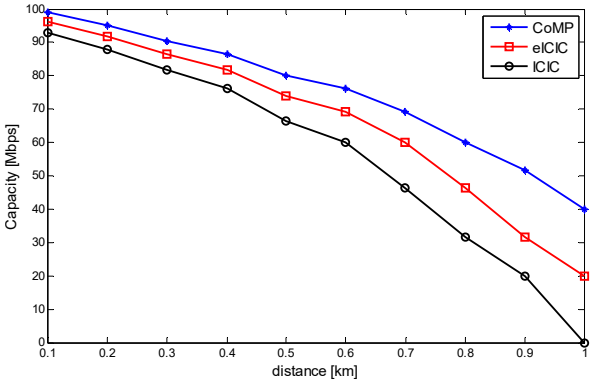


Fig. 11 Capacity variation according to the distance for different coordination approaches

Acknowledgment

This work was supported by the Ministry of the Higher Education and Scientific Research in Tunisia.

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