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Inter-Cell Interference Mitigation Techniques in a Heterogeneous LTE-Advanced Access Network

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Abstract*— As LTE (Long Term Evolution) networks proliferate and network traffic increases, LTE operators face the problem of interference. Because LTE spectrum is limited, most operators deploy single frequency networks to maximize capacity. However, while single frequency networks increase spectral efficiency, they also increase the potential for interference. Interference is highly unpredictable and depends on various factors such as channel conditions, traffic from other terminal and noise. Interference occurs between various equipment in a heterogeneous LTE-A access network and is a threat to the technology of wireless network. Hence, this research work seeks to analyze the various techniques for combating interference in LTE–Advanced access network per unit area using different combination of methods. Network-based interference mitigation solutions are not yet available to address the interference problems of today's LTE networks. However, Terminal-based interference solutions are available today as they offer operators a powerful weapon to combat interference. The introduction of Femtocell to users has also made interference mitigation scheme achievable. The Femtocell interference mitigation technique mitigates the interference between network components such as Macro-cell and Femtocell in a heterogeneous LTE-A access network. The work also emphasizes the importance of heterogeneous network in a wireless communication and the basic sources of interference and their mitigation techniques in this kind of network. The implementation of all the suggested mitigation techniques and power control formula as explained in this work has been proposed to target the performance of heterogeneous LTE-Advanced access network. This, as a result, will improve the signal quality of the received signal, and end users will experience higher throughput and better service continuity, and LTE operators will improve coverage and increase the capacity of their networks.

***Index Terms*—Interference Mitigation, Heterogeneous Network, LTE, Femtocell, Picocell, Simulation**

I. Introduction

LTE is a 4G wireless technology standardized by the 3GPP (3G Partnership Project) that is being deployed today by leading operators around the world to provide high-speed data and multimedia services. According to [1], a 4G technology is considered to complete the cycle of technological advancements in wireless communications. As LTE networks proliferate and network traffic increases, LTE operators face the problem of interference.

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LTE-Advanced Access network is targeted at achieving higher capacity, improved coverage, and higher system performance than that of LTE for bandwidth and peak throughput as well as meeting or exceeding IMT-Advanced requirements within the ITU-R time plan. The driving force is to further develop LTE towards LTE–Advanced. LTE Release10 was developed to provide higher bitrates in a cost efficient way and, at the same time, completely fulfil the requirements set by International Telecommunication Union (ITU) for IMT- Advanced, also referred to as 4G [1]. But interference still remains a great threat to this technology.

During the last two decades, wireless communication has evolved from an optical convenience to an indispensable necessity in daily life. There has been advancement in digital signal processing, digital computing, and radio transmission technologies, which have facilitated the introduction of a wide range of wireless communication services. In [1], second generation wireless mobile communication system such as GSM, IS-95, IS-136 and PDC provide people with reliable narrowband communication link mostly for voice and text traces with high mobility, and high-speed private-access and public-access local/personal area networks such as Wi-Fi and Bluetooth, which deliver broadband multimedia with limited mobility. This is often encumbered by occasional denial of service which was spotted in [1] as a challenging issue in wireless communications often caused by interference effects. As a result, increasing demand on high-capacity wireless multimedia service with sufficient mobility have created challenging tasks to the designers of next generation wireless mobile communication system [2].

Interference has been a major problem in wireless communication system and particularly in LTE, as systems compete for a finite amount of spectrum. Everything from background noise to the electronic noise caused by base stations themselves contributes to poor voice signals, slower data speeds and latency problems. Network operators have used filters in base stations or constructed more towers to address interference, but receivers have become broader and cover more spectrum than ever, making it difficult for filters to keep interference completely out.

Considering the geometric growth in wireless communications, service providers have been asked to come up with something that will meet all the needs of their subscribers. Since the advent of the second Generation (2G), subscribers have been promised an excellent internet experience, which has not been completely achieved. According to [3], LTE-Advanced, also known as LTE release 10/11, is designed to provide higher data transfer in a cost

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efficient way and also to focus on higher capacity, increased peak data rate, increased number of simultaneously active subscriber, improved performance and higher spectral efficiency. LTE-Advanced is intended to support further evolution of LTE and to establish E-UTRAN as an IMT-Advanced technology, worldwide functionality and roaming compatibility of services, inter-working with other radio access systems [4]. To achieve the goal of LTE-A, several component upgrading is being considered. At the physical layer, LTE is expected to provide substantial improvement in peak, average and cell-edge spectral efficiencies, under the assumption of 8 x 8 antenna configuration in the downlink and 4 x 4 in the uplink. Small cells such as Pico-cells and femto-cells bring the network closer to users and provide a big leap in performance [2, 4]. LTE-A enhances users' experience for all the users including those on the cell-edge with higher data rates, even when the small cells are not positioned in optimal locations. Furthermore, LTE-A supports the technology of heterogeneous network and this has exponentially increased the satisfaction of network users. To address the problem of interference in heterogeneous LTE-A access network, different approaches, as outlined in this work, are needed to be implemented so as to meet the demands of subscribers.

II. OVERVIEW OF INTER-CELL INTERFERENCE IN A HETEROGENEOUS LTE AND LTE-ADVANCED NETWORK

A. Introduction

Long Term Evolution (LTE) is all about 4G, which tends to complement LTE (3G) networks with higher data rates, low latency and a flat, IP-based architecture. It also allows operators to use a new and a much wider spectrum when compared to the previous standards. Apart from the enhancements in the radio link, the next performance leap in wireless networks will come from an evolved network topology. The concept is to improve spectral efficiency per unit area. According to [5], with various combinations of femtocells, relays and picocells, heterogeneous networks can provide the optimal experience to the user. In any cellular mobile communication system, two major classes of interference must be considered, namely: intra-cell interference, and inter-cell interference. In the former, interference is caused between frequency channels, within the same cell, due to adjacency of both frequencies and power leakage from one channel to an adjacent channel. In the latter, interference is caused by a frequency channel in one cell on the same frequency channel used in an adjacent cell. When networks are adjacent to frequency, the signals emitted by wireless network tend to interfere with each other. This affects the quality of data transfer on network, impair user experience and even cause network failures in extreme circumstances [5]. The drawback to all this is that there will be severe interference between various components in the heterogeneous networks. Furthermore, as the femtocells are user deployed, the interference management schemes become even much important. Due to limited spectrum resources, network operators adopt the approach of single-frequency network, which is a deployment scheme whereby a single carrier frequency is reused in all cells of the network. LTE networks are deployed in a frequency reuse = 1 configuration. Single frequency networks are the most efficient in terms of overall spectral efficiency, but are limited by inter-cell interference [6].

Three major inter-cell interference mitigation techniques exist: cancellation, randomization, and avoidance. Interference cancellation is a situation where the interference signals are detected and subtracted from the desired received signal, or if multiple antenna system is employed, the receiver can select the best quality signal among the various received signals. There have been several publications on the topic of interference cancellation techniques. For instance, in [7], interference mitigation for 2G systems were discussed as well as some of the interference related issues in a heterogeneous network; whereas in [8], the 3GPP was spotted working on various aspects to improve LTE performance in the framework of LTE-A and heterogeneous networks. The 3GPP LTE standard suggests a different approach for inter-cell interference handling termed Inter-Cell Interference Coordination (ICIC). ICIC provides tools for dynamic inter-cell-interference coordination of the scheduling in neighboring cells such that cell-edge users in different cells are preferably scheduled in complementary parts of the spectrum when required. Inter-cell interference (ICI) presents a great challenge that limits the system performance, especially for users located at the cell edge. Inter-cell interference coordination (ICIC) has been investigated as a key technology to alleviate the impact of interference in LTE systems to improve system performance and increase bit rates at the cell edge.

While the theoretical aspects and the basic principles of algorithm as it relates to interference mitigation techniques are well understood, major challenges lie in the implementation of these techniques in an LTE-A terminal. For instance, the LTE waveform is based on OFDMA modulation, which is not the same as 2G/3G modulation [8]. It becomes pertinent to develop new techniques since channel estimation and receiver design for the multi-carrier OFDMA modulation of LTE is not the same with that used for single-carrier WCDMA modulation of 2G/3G. So, practical implementation of interference mitigation theory would require sound knowledge of OFDMA architecture [8]. Again, for LTE-A, the throughput is very much more significant when compared to that of LTE (2G/3G). But its power consumption budget is constrained to meet the requirements of battery-powered devices; hence implementation must be designed to accommodate minimal hardware resources in order to consume minimal power.

B. What is a Heterogeneous Network?

A heterogeneous network (HetNet) is simply a network that comprises different Radio Access Technologies (RATs) such as Wi-Fi, GSM, UMTS/HSPA, LTE, and WiMax. In LTE-Advanced term, a HetNet is a network consisting of

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macro-cells, microcell, Pico-cells, remote radio heads, femtocells as well as relay stations. A HetNet has the potential of significantly boosting network performance, benefiting from transmitter-to-receiver distance reduction and enabling better special reuse of the spectrum [9]. Some of the advantages of HetNets as discussed in [9] include the following:

- Provides a cost effective roll-out plan with much reduced financial risk for operators
- Delivers a seamless user experience across outdoor and indoor environments
- Provides a platform where different RATs (Radio Access Technologies) are designed for different purposes, as well as different types of access nodes

C. *Classification of HetNet Access Nodes in LTE-A*

Table 1.1 below shows the specification of different elements in HetNets [9]

Types of Nodes	Transmit Power	Coverage	Backhaul
Macrocell	46 dBm	Few km	SI interface
Picocell	23-30 dBm	<300m	X2 interface
Femtocell	<23 dBm	<50m	Internet IP
Relay	30 dBm	300m	Wireless
RRH	46 dBm	Few km	Fibre

D. *Technical Challenges of HetNets*

In [7], [9], the following are identified as key technical challenges facing HetNets:

- Self-organization: Some cells of HetNets are user-deployed without operator supervision. This includes cells such as Picocells and Femtocells. Their operation is guided by their self-organizing features such that without Self-Organization, HetNet will not work well. According to [7], Self-Organized HetNets (SON) have the advantages of the following capability features, namely, self-configuration – a situation where newly deployed cells are automatically configured by downloaded software before entering into the operational state; self-healing – where cells automatically perform failure recovery whenever failure arises; and self-optimization – where cells constantly monitor the network status and optimize their settings to improve coverage and reduce interference. However, Self-Organized HetNet (SON) is a challenging task due to the various types of coexisting cells and the increasing number of the network parameters that need to be considered [9].
- Backhauling: Because the various types of coexisting cells are often in complex topology, there is the challenge of designing a network that will account for backhauling. For instance, Picocells have relatively higher backhauling costs because of its utility infrastructural requirements; while Femtocells require lower backhauling costs but may face the difficulties in maintaining Quality of Service (QoS) because backhauls depend on user's broadband connections [7] , [8]. Hence, operators need to plan HetNet backhaul carefully well so as to guarantee both cost effective and QoS solutions. Possible backhaul solutions may be guaranteed if some cells have dedicated interfaces to the core network, and if cells form a cluster to aggregate and forward the traffic to the core, while others may rely on relays as an alternative interface [9].
- Mobility management and handover: The importance of handover is seen when network users move in or out of a cell coverage. Handovers are also efficient for traffic load balancing, which involves shifting network users at the border of adjacent cells from the more congested cells to the less congested ones [8], [9]. Nevertheless, this comes with its own challenges. The challenge of mobility management and handover arises as a result of large number of small cells and the different types of backhaul links available for each type of cell. In essence, the probability of handover failure increases the probability of user outage [10]
- Interference: Among the various technical challenges facing HetNets, interference unarguably poses the major challenge. This is because the backhaul network that supports different kinds of cells may have different bandwidth and delay constraints, handover problems occasioned by the restricted access control associated with picocells and femtocells. Hence, we shall focus much of the discussions on the topic.

E. *Femtocells and Picocells*

In telecommunications, a Femtocell is a small, low-power cellular base station, typically designed for use in a home or small business. A broader term which is more widespread in the industry is small cell, with femtocell as a subset. It connects to the service provider's network via broadband (such as DSL or cable); current designs typically support two to four active mobile phones in enterprise settings. A femtocell allows service providers to extend service coverage indoors or at the cell-edge, especially where access would otherwise be limited or unavailable. Although much attention is focused on WCDMA, the concept is applicable to all standards, including GSM, CDMA2000, TD-SCDMA, WiMax and LTE solutions. On the other hand, a Picocell is a small cellular base station typically covering a small area, such as in-building (offices, shopping malls, train station, stock exchanges, etc.), or more recently in-aircraft. In cellular networks, picocells are typically used to extend coverage to indoor areas where outdoor signals do not reach well, or to add network capacity in areas with very dense phone usage, such as train stations or stadiums. Picocells provide coverage and capacity in areas difficult or expensive to reach using the more traditional macrocell approach. A Picocell is a small mobile base station that improves in-building cellular coverage. They have a range of up 30,000 square feet and can support up to 100 users. Picocells offer many of the benefits of "small cells" (similar to femtocells) in that they improve data throughput for mobile users and increase capacity in the mobile network. In particular, the integration of picocells with macrocells through a heterogeneous network can be useful in seamless hand-offs and increased mobile data capacity. Picocells are available for most cellular technologies including GSM, CDMA, UMTS and LTE.

Femtocells differ from Picocells because they are intended to be much more autonomous. They are self-installed by the end-user in their home or office, primarily for their own

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benefit. Femtocell automatically determines which frequency and power levels to operate at, rather than being directed from a centrally determined master plan. This allows the network to adapt automatically as new femtocells are added or moved without the need for a complete frequency re-plan. The disadvantage is that femtocells would not normally broadcast a list of nearby neighboring cells. Mobile phones would thus maintain the connection on the femtocell as much as possible, but risk dropping the call or having an external macro or microcell. Picocells are normally installed and maintained directly by the network operator, who would pay for site rental, power and fixed network connections back their switching Centre.

The following are some of the key benefits of deploying femtocells:

- "5 bar" coverage when there is no existing signal or poor coverage
- Higher mobile data capacity, which is important if the end-user makes use mobile data on his mobile phone.
- Improved battery life for mobile devices due to reduced transmitter-receiver distances
- Can be used to give coverage in rural settings.
- Femtocells incorporate interference mitigation techniques –detecting macrocells, adjusting power and scrambling codes accordingly.

F. Comparing LTE and LTE-A

Table 1.2 below shows a comparison between LTE and LTE-Advanced

LTE	LTE-A
Long-term evolution of 3G using 3G spectrum	Evolution of LTE: Targets achievement of sufficiently higher system performance than that for LTE Bandwidth: 100 MHz Peak throughput: 1 Gbps
Smooth introduction of 4G	Backward compatible with LTE to enable continuous enhancement and deployment
	Meet or exceed IMT-Advanced requirements within the ITU-R time plan
	LTE-Advanced contains all features of LTE Rel. 8 & 9 and additional features for further evolution
Peak data rate = 300 Mbps	Peak data rate = 1 Gbps

G. Sources of Interference in HetNets

Interference issues that are encountered in HetNets are due to the following reasons cited in [7] – [10]:

- Power difference between nodes: since picocells and relays operate in an open access mode, users of a given operator can always have access to them. By so doing, DL interference will be minimized since end-users will always switch to the strongest cell with strong signal strength. But this strategy may not be the best, especially in HetNets, since users will tend to connect to macro-cells and not to those cells being at the shortest path loss distance [7], [9], [10]. Again, users that are connected to macrocells will severely interfere all low-power nodes located in their vicinity in the UL, due to server selection procedure in the DL.

Fig. 1 below illustrates how a user connected to a macrocell with the strongest received signal strength jams a nearby picocell UL.

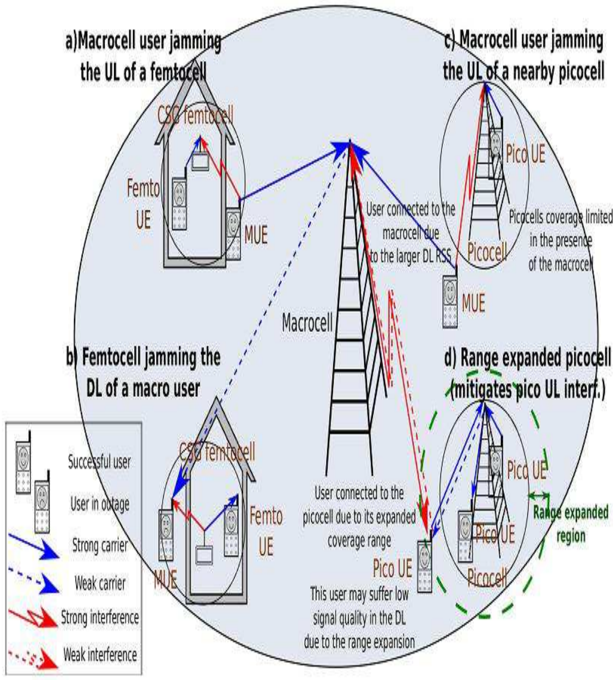

Fig. 1: Dominant DL and UL cross-tier interference scenarios in HetNets. [9]

- Range Expanded Users: In order to solve the problems occasioned by power difference between the nodes in HetNets, it becomes necessary to consider new cell selection methods which permit user association with cells that provide a weaker DL signal quality. This ultimately considers range expansion as the most suitable approach, in which an offset is added to the picocell's received signal strength in order to increase its DL coverage footprint [9]. See Fig 1 (d) above. As outlined in [7], [9], though range expansion can significantly reduce cross-tier interference, it is at the expense of reducing the DL signal quality of those users in the expanded region. Details of the sources of interference can be read from [7] – [9].

H. Inter-Cell Interference Management Techniques

(i). Network-based Interference Management: The LTE standard is an evolving standard with systematic releases which began with Release 8, then Release 9 and currently with Release 10. LTE-Advanced networks based on Release 10 were expected to be deployed by the end of 2013 [6]. Releases based on 10 and 11 are expected to incorporate network-based interference management techniques, which are capable of limiting interference but cannot suppress it. Examples of such techniques include enhanced Inter-Cell Interference Coordination (eICIC) and coordinated multipoint transmission and reception (CoMP) [6].

(ii). Terminal-based Interference Management: This interference management scheme is gaining much interest as a result of unavailability and limitations associated with the

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network-based interference solutions. Terminal-based interference management solutions must be able to operate on current LTE networks (Release 8 and 9), and be ready to operate on future LTE-Advanced networks (Release 10 and 11). According to [6] , [11], terminals with embedded interference mitigation technology can benefit both users and operators by providing:

- ✓ Overall higher throughput
- ✓ More stable performance across various locations in the cell
- ✓ Better continuity of service when migrating across a network
- ✓ Higher total capacity
- ✓ Improved coverage
- ✓ Wider bandwidth (Carrier aggregation)
- ✓ Improvement in peak data rate and spectrum flexibility
- ✓ Advanced MIMO techniques
- ✓ Enhanced Inter-cell Interference Coordination (eICIC)
- ✓ Relaying (Improves coverage and cost effective deployment)
- ✓ Coordinated multipoint (CoMP) transmission and reception

I. Types of Interference & their Mitigation Techniques

- **Co-Site Interference**: This is a type of interference that occurs as a result of proximity to other equipment. Operators continue to invest in 2G, 3G and LTE networks as they evolve and the cost is quite enormous. Costs can be considerably minimized if resources of the existing 2G and 3G can be utilized by sharing sites with the LTE network. However, the challenge most operators face with this idea is how to combat co-site interference. Solutions have emerged such as the co-site adjacent channel interference solution, which is a solution that enables, for instance, a 3G network to use a frequency band for a 2G network with a smaller bandwidth than the standard one, while ensuring that the capacity and quality of the 2G network are not compromised [3]. The method for controlling co-site interference between GSM and UMTS can also be used in the co-site construction for GSM, UMTS and LTE networks to control interference among them [3].
- **Co-Channel Interference:** This involves a situation whereby two different radio transmitters make use of the same frequency bands. It is a form of crosstalk from two different radio transmitters in which a signal transmitted in one channel of transmission creates an undesired effect in another channel. For instance, a situation whereby a frequency band of GSM900 operating in urban areas is reframed to UMTS900 in rural areas, the same spectrum is used by UMTS900 in rural areas and GSM900 in urban areas, can cause a great deal of interference. The problem of co-channel interference can be solved by creating or setting up a geographical isolation zone between the two networks. Details of this can be spotted in [3]. Isolation zone guarantees performance while interference is controlled.

J. Interference Mitigation Techniques

Interference mitigation in a terminal receiver can be achieved using the following possible approaches:

- ❖ Non-linear approach: In this case, the interfering signal is first estimated and then subtracted from the received signal in an iterative fashion [6]. It demands an explicit modelling of the interfering signal. The approach provides excellent performance but is very sensitive to errors, since signal interference is based on estimate.
- ❖ Linear approach: This approach utilizes multiple antennas at the receive-end to perform spatial suppression of the interfering signal. The receiver forms a receive antenna beam with a spatial null in the direction of the interferer [6]. The approach is best suited with a large number of receive antennas as it has the capacity to handle a number of interferers. Receivers of such are termed as Interference Rejection Combiner (IRC) receivers.
- ❖ Sequans Active Interference Rejection (AIR): This is a compact LTE receiver designed by Sequans Communications with the capability of mitigating interference. The design was based on the specific requirements of interference mitigation in LTE, and is suited to the various transmission modes of LTE. Sequans AIR adopts the linear approach to interference mitigation, and has been co-developed with technology partner –ArrayComm, which is a pioneer in antenna processing and interference management techniques. Sequans has leveraged its own expertise in OFDMA and MIMO receivers to create innovative and interference mitigation algorithm and optimized implementation that is capable of mitigating interference not only from data channels but also from control channels [6]. Though control channels are designed to be more robust than data channels, it can still suffer from strong interference such that the terminal faces problem of demodulation and consequently loses connection from the network.

III. THE ENHANCED INTER-CELL INTERFERENCE COORDINATION (EICIC)

The Inter-Cell Interference Coordination ICIC methods specified in Release 8 and Release 9 do not specifically consider HetNet settings and may not be effective for dominant HetNet interference scenarios. To address this challenge, therefore, enhanced Inter-Cell Interference Coordination (eICIC) techniques were developed for Release 10 and 11. The solution techniques have been grouped according to the following categories:

- ✓ **Time Domain Techniques (Sub-frame Alignment):** When there is Multiple User Equipment (MUE) in the vicinity of a femtocell, they can be scheduled within the subframes overlapping with the Almost Blank Subframes (ABSFs) of the femtocells, which significantly mitigates cross-tier interference [9]. Where there is no interference coordination for range-expanded picocell users, it results in a large DL interference from the macrocell. Such interference problem can be mitigated through using ABSFs at the macrocell.
- ✓ **Frequency Domain Technique:** In frequency-domain eICIC solutions, control channels and physical signals of different cells are scheduled in reduced bandwidths in order to have totally orthogonal transmission of these signals at different cells [9].
- ✓ **Power Control Techniques:** According to [7], this very technique is heavily discussed in 3GPP for handling dominant interference scenarios, by applying different power control techniques at femtocells. The single most effective

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method for reducing the potential for harmful interference is to reduce the RF power being generated. Incidentally, reducing the radiated power at a femtocell may also reduce the total throughput of femtocells users, but significantly improves the performance of victim MUEs. Then, four different DL power control approaches at femtocells can be listed as follows (all values are in dBm):

a. Strongest macro eNB received power at a home eNB: the femtocell transmission power can be written as $P_{tx} = \max(\min(\alpha P_M + \beta, P_{max}), P_{min})$

b. Path loss between a home eNB and MUE: the home eNB transmission power can be set as $P_{tx} = \text{med}(P_M + P_{ofst}, P_{max}, P_{min})$, where the power offset is defined by $P_{ofst} = \text{med}(P_{ipl}, P_{ofst-max}, P_{ofst-min})$, with P_{ipl} denoting a power offset value that captures the indoor path and the penetration loss between home eNB and the nearest MUE, and $P_{ofst-max}$ and $P_{ofst-min}$ denote the minimum and maximum values of P_{ofst} respectively.

c. Objective SINR of Home User Equipment (HUE): In this approach, the received SINRs of home eNB users (HUEs) are restricted to a target value and transmit power at a femtocell and is reduced accordingly to achieve this target SINR using the following expression: $P_{tx} = \max(P_{min}, \min(PL + P_{rec, HUE}, P_{max}))$, where $P_{rec, HUE} = 10\log_{10}(10^{1/10} + 10^{No/10}) + SINR_{tar,}$ with I being the interference detected by the served UE, N_o is the background noise power, $SINR_{tar}$ is the target SINR for the HUE, and PL is the path loss estimate between the home eNB and the HUE.

d. Objective SINR of MUE: the goal of this approach is to guarantee a minimum SINR at MUEs, and the home eNB transmit power is given by $P_{tx} = \max(\min(\alpha P_{SINR} + \beta, P_{max}), P_{min})$, where P_{SINR} is the SINR of the MUE considering only the nearest femtocell interference.

IV. SIMULATION SET UP

This section introduces the eICIC performance analysis, in which the DL of an LTE-A HetNet is simulated to test the different eICIC schemes presented in the previous section. In this case, a residential area of size 300m x 300m containing 400 houses of which 63 were selected to host a CSG femtocells. Assuming 3 network operators with equal customer share corresponding approximately 50% femto penetration, eight mobile users that utilize a voice over IP (VoIP) service are to move along predefined paths according to a pedestrian model of mean speed 1.1 m/s. Meanwhile, the picocell and the femtocells are fully loaded and therefore utilize all subscribers. The cell power is uniformly distributed between subscribers and a pedestrian user carrying a VoIP service is considered to fall in outage if it cannot receive control data.

Let *Pmax* and *Pmin* denote the maximum and minimum home eNB transmit powers, respectively, *PM* denotes the received power from the strongest co-channel macro eNB at a home eNB, α and β denote two scalar power control variables.

Fig. 2 below is a simulation set up of the entire scenario

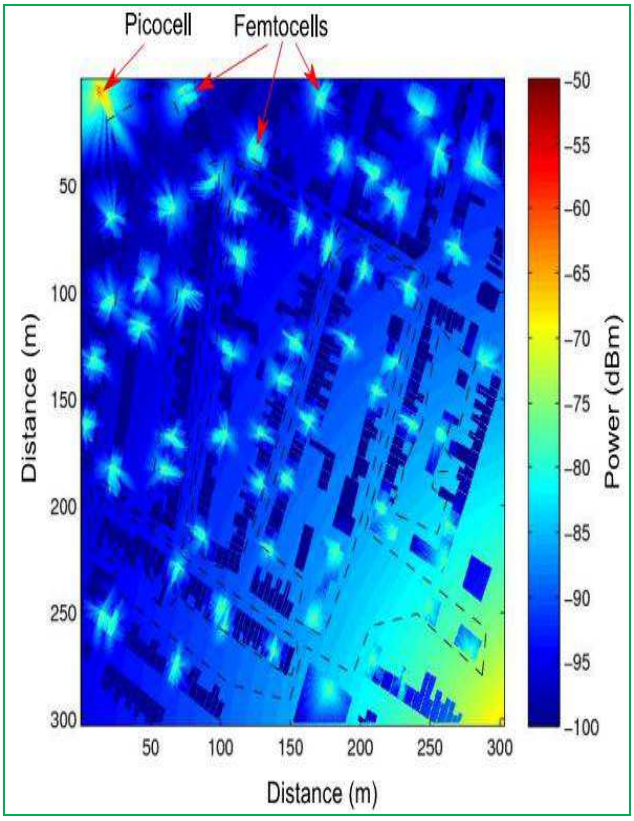

Fig. 2: Simulation Set up

Figure 3 illustrates the SINR of a pedestrian user when passing by the front door of two different houses hosting a femtocell.

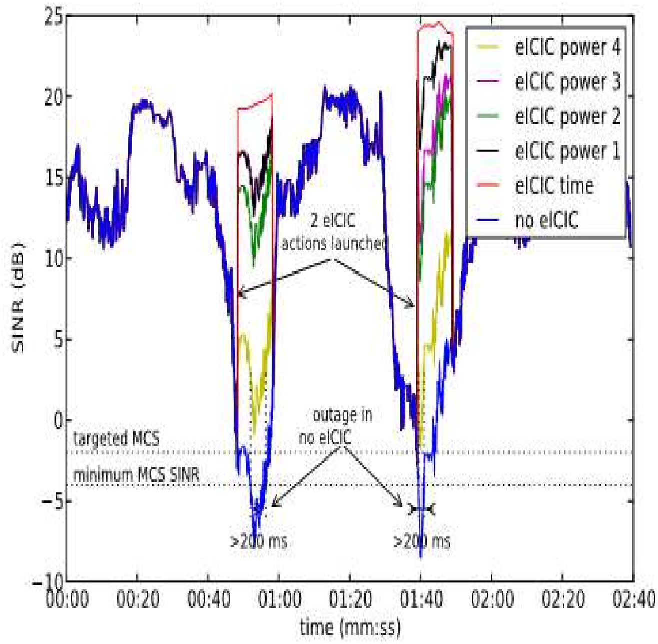

Fig. 3: SINR versus time of a victim MUE when passing close to two houses.

It can be seen from the figure that when no action is taken at the femtocells, the SINR of the pedestrian user falls significantly due to the cross-tier interference, thus resulting in UE outage [9]. Conversely, when eICIC is applied, the MUE SINR recovers and outages vanish. This implies that when MUEs report low signal quality using channel quality indicators, an eICIC action is triggered by the macrocell in the femtocells.

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V. Conclusion

The following conclusions are deducted from the work:

- Interference is a major issue in LTE Networks. Solution techniques implemented at the terminal end can be very much effective, both for end users and LTE operators.
- HetNets have the potential to significantly boost network performance, benefiting from transmitter-to-receiver distance reduction and enabling better spatial reuse of the spectrum.
- The work reviews the major advantages of HetNets and their technical challenges.
- Measures to avoid cross-tier interference are also considered owing to its crucial role in the operation of multi-tier networks.
- The main eICIC techniques currently under discussion in 3GPP have been evaluated through realistic system-level simulations.

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