Evaluation of Femtocells Interference Mitigation Techniques over ICIC Coordinated LTE-A Networks

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***Abstract*—Femtocells offer an attractive solution to locally improve the data rates and coverage of mobile networks, however interference issues may rise when they are deployed to nearby non-subscribed macro users. Power control and radio management are the most prominent ways to tackle the problem. In this work, we provide a simulation framework that is capable to simulate the behaviour of femtocells deployment over Long Term Evolution Advanced (LTE-A) macrocells networks. With the help of the tool, we evaluate several available interference mitigation techniques for femtocells, when applied in Inter-Cell Interference Cancellation (ICIC) macrocell environments.**

***Index Terms*—simulation, interference, femtocells, ICIC, LTE**

I. Introduction

Long Term Evolution Advanced (LTE-A), delivers the 4G target performance, utilizing Orthogonal Frequency Division Multiple Access (OFDMA) technology and incorporating features such as Heterogeneous Networks (HetNet). OFDMA, based on orthogonal channel division through subcarriers, provides robustness against intra-cell interference, but is vulnerable against inter-cell interference, experienced mostly by cell edge users. On the other hand, heterogeneous networks support, although useful in terms of enhanced coverage and spectral efficiency may result in both severe intra-cell interference and inter-femtocell interference.

Many techniques have been discussed for the mitigation of the interference phenomenon, mainly based on radio management techniques, hybrid access femtocells, and/or power control. An overview of the available approaches is found in LTE-A specification [1]. Radio management of femtocells deployed over Soft Frequency Reuse (SFR) coordinated macrocell environment is studied in [2], while dynamic allocation of resources is examined in [3] and [4]. The optimal power allocation for femtocells' Base Stations (FBS) is investigated in [5] when deployed over OFDMA systems that utilize fractional Frequency Reuse (FR). The work in [6] presents a strategy for hybrid access at femtocell service, allowing open access on default CSG femtocells under specific conditions.

A power control method ensuring constant femto Base Station (BS) coverage is introduced in [7], while a collective quantitative comparison of several power control algorithms is presented in [8], where simulations results showcase the advantages and disadvantages of the most common approaches.

Despite the extensive investigation, there has been no quantitative comparison of the interference mitigation approaches that can be incorporated by femtocells, in order to decide the most appropriate in relation to the network's parameters and the desired achieved performance. To this end, we designed a high configurable simulation framework capable of reproducing custom user-defined femtocells/macrocells heterogeneous networks. Two notable relevant simulation tools that provide solid system simulations for LTE-A environments are [9] and [10]. However, we focus especially on femtocells and custom ICIC scenarios. Facilitated by the framework, we evaluate radio management and power control femtocell techniques, and decide the optimal selection regarding overall throughput, probability of service unavailability and Signal to Interference plus Noise Ratio (SINR) of cell-edge users for various macro layer ICIC environments and femtocell deployment densities. The framework and the outcomes of the paper may be used for guidelines on investigating network's topology and planning, estimation of systems' performance and proper femtocell configuration. The tool is available online [11].

The structure of the paper is as follows. Section II presents the functionality of the simulator. In Section III, the evaluation is taking place with the experimental results. Finally, Section IV concludes the paper and suggests future enhancements.

II. Framework Functionality

In this section, we present the functionality of the framework and the scenarios that were incorporated and examined.

Fig. 1 shows an example of the tool's interface. Based on the inputs, the network is generated and depicted graphically.

When a femtocell is deployed, a self configuration process occurs to configure transmission parameters. This configuration may include femtocell resource allocation in regards to traffic or to ICIC schemes in macro level, or control of power transmission depending on sensed environment parameters. For our simulation, we considered full buffer traffic model, since it is the worst case interference scenario and cannot be tackled by scheduling techniques. The scenarios examined in the simulator are:

Scenario 1. Co-channel operation. The worst case of cross-tier interference, where no frequency partition or power control is enforced and both femto-macrocells use the same spectrum.

Scenario 2. IFR aware. When Integer FR of factor 3 (IFR3) is employed by Macro BSs, femtocells use measurements (i.e. Reference Signal Received Power-RSRP) to determine the

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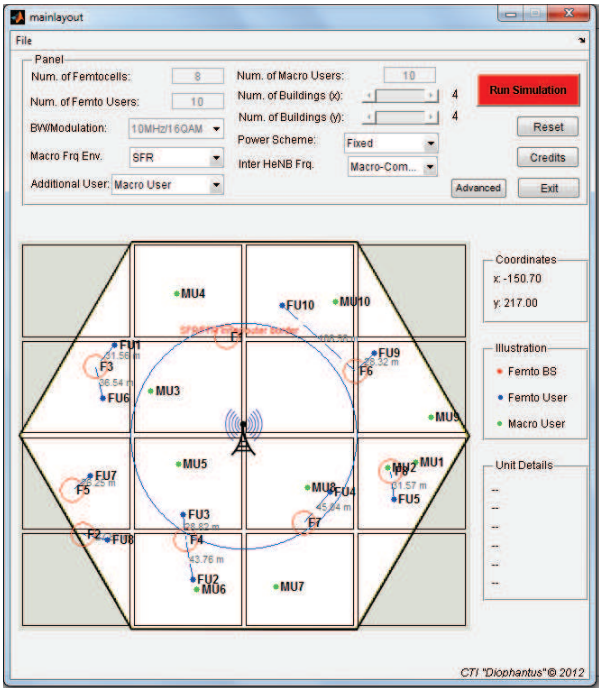

Fig. 1: Interface of the simulation tool.

TABLE I: Simulation Parameters.

Parameter	Value
Cell Radius	250 m
Bandwidth (MHz)	20MHz
Modulation Mode	64QAM
Subcarriers bandwidth	15 KHz
Carrier frequency	2 GHz
Correlation distance	40 m
Macro BS TX power	46 dBm
Femto BS default TX power	11 dBm

sub-bands of the lowest priority to schedule their transmissions. Since IFR3 allocates different sub-bands for adjacent macrocells, femtocells result using the frequencies allocated to the neighbouring macrocells of the cell they are located.

Scenario 3. SFR aware. When macro BS enforce SFR schemes, femtocells, when capable, utilize the sub-bands that are not used in the cell zone they are located. In SFR the available bandwidth is distributed non-uniformly between the inner region of the cell, around to the macro BS and the outer one. That means that same frequencies are allocated in cell-edge macro users and cell-centre femto users, and vice versa.

Scenario 4. IFR/SFR unaware. The case when ICIC is incorporated, but femtocells are unaware of their surroundings and are not configured properly, thus transmitting to entire bandwidth, is similar to co-channel operation of scenario 1.

Scenario 5. Power control. The femtocell configures its downlink transmit power by taking into account the path loss between the femtocell and the macro BS including penetration loss, in order to maintain constant femtocell coverage independently of its location [7].

III. Experimental Results

Table I summarizes the network parameter's values during the simulation, while Fig. 2 presents the data rate map of the investigated schemes. In the co-channel scenario (Fig. 2a), macro users located close to femtocells suffer from inadequate service provision. Furthermore, cell-edge users experience additional inter-macrocell interference. Power control (Fig. 2b) provides some protection to macro users, adjusting femto transmit power in respect to received power from macro BS.

Fig. 2c shows how important is for femtocells to be aware of ICIC schemes. If not, the combination of the spectrum division with the femtocells co-channel operation, results in severe SINR degradation. In SFR with aware femtocells, the only interference originates from femtocells near the regions' borders, and their coverage extends over the other side (Fig. 2d).

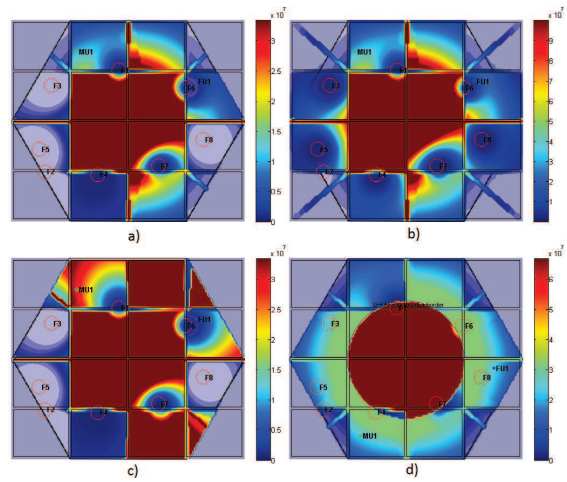

Fig. 2: Macro-user's data rate map for a) Co-channel operation b) Power control c) IFR with femtocells utilizing the entire bandwidth d) SFR with adapted femtocells.

Fig. 3 presents a comparison of all methods, versus the number of femtocells. Simple power control behaves best in overall performance, since no bandwidth fragmentation takes place. However, as femtocells' number increases, its edge decreases, and finally diminishes for over 35 femtocells. Moreover, no provision (co-channel operation) becomes worse than FR methods when femtocells' number exceeds 22. This means that macrocell small spectrum utilization in ICIC is compensated in terms of overall performance, for large femtocell deployment, maintaining system's spectral efficiency.

IFR compared to SFR presents slightly worse behaviour, since SFR is characterized by greater spectral efficiency. One last observation on the figure is the catastrophic consequences of not adaptable femtocells. Fig. 4 presents the CDF of data rate when 15 femtocells have been scattered in the cell. Power control behaves best for the majority of users but is unable to guarantee service to all. On the other hand, FR schemes protect the worst case macro users, but deprive bandwidth for many users located in otherwise unproblematic areas.

Fig. 5 demonstrates the average throughput experienced by

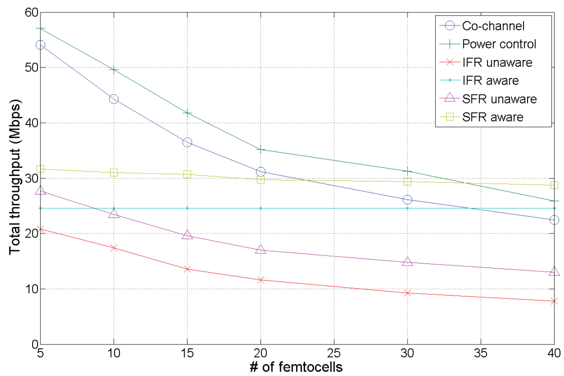

Fig. 3: Average throughput performance for macro users.

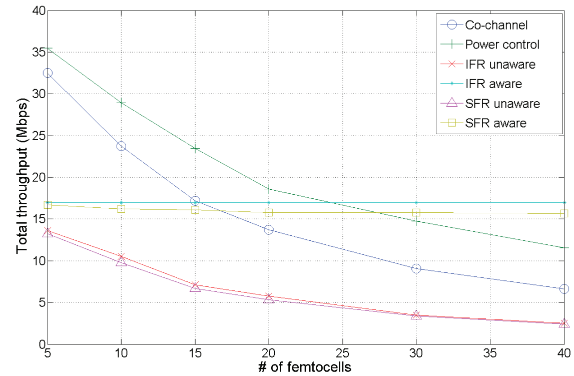

Fig. 5: Throughput for macro users at cell's borders.

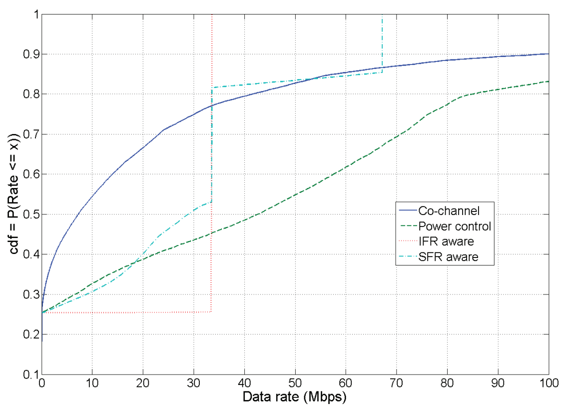

Fig. 4: CDF of throughput for different scenarios.

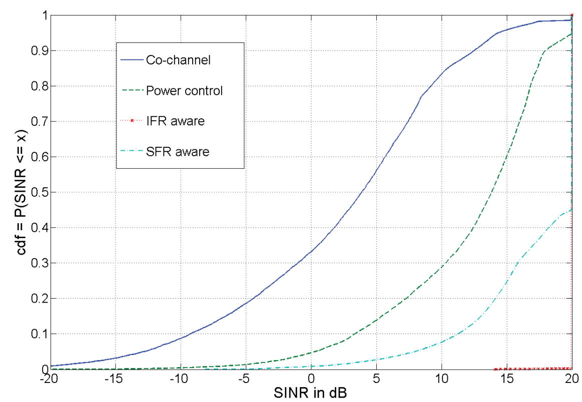

Fig. 6: CDF of SINR at cell's borders for different scenarios.

a cell - edge user. Due to weak signal received, it is the area where an increased femtocell density is expected.

The trends are similar with total cell throughput, but the points where a scheme is preferred have shifted. Frequency partition methods (IFR, SFR) demonstrate the best performance when the number of femtocells is over 25, and surpasses the co-channel scenario for 15 femtocells and beyond.

Fig. 6 demonstrates the CDF of the SINR for cell - edge users when 15 femtocells have been scattered over the cell. It can be observed that without allocating dedicated bandwidth to macro users, a portion of macro users will have not access to service at all. SFR and IFR instead ensure the protection of every macro user in the cell.

IV. Conclusion & Future Work

In this paper, we designed a simulation framework to evaluate the most prominent techniques for mitigation of interference caused by femtocells in ICIC coordinated LTE-A networks. For small penetration rates of femtocells, we concluded that power control is adequate for interference cancellation for the majority of macro users. For a large penetration rate, the extended use of femtocells compensates for the reduced spectral efficiency of frequency partition methods.

A step that follows this work could be the inclusion of techniques that target both control and data channels.

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