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Inteference Mitigation in Femtocellular Networks

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ABSTRACT

Femtocells can significantly boost up wireless cellular network capacity by reducing communication distances to user equipment and also by reusing resources already utilized in the macrocell network on which they overlay. However, the deployment of femtocells within a macrocell coverage area, causes severe interference between the femtocell and the macrocell, which may have an impact on the overall performance of the femtocells. Avoiding such interference is very important for the effective co-existence of femtocell and macrocell. This paper proposes an algorithm to mitigate cross-tier interference between a femtocell and a macrocell using adaptive power control. The proposed approach is modeled and simulated using MATLAB. The impact on the performance of the femtocell using the proposed algorithm is analysed. Results show that the proposed adaptive power control algorithm has tremendously reduced the negative effects on the system throughput, delay and outage probability for voice and data traffics.

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1. INTRODUCTION

With an increased usage of smart mobile phones and mobile dongles nowadays, the need of improving coverage, enhancing capacity and data rates in cellular wireless networks becomes more and more crucial. In 2010 the amount of global mobile data traffic nearly tripled for the third year in a row [1]. By 2015, nearly one billion people are expected to access the Internet exclusively through a mobile wireless device [1]. It is obvious that the traditional cellular network, cannot keep pace with this data explosion through the expensive and incremental methods of the past: namely increasing the amount of spectrum or by deploying more macro base stations. This rapid increase in mobile data activity has raised the stakes on developing innovative new technologies and cellular topologies that can meet these demands in an energy efficient manner. A number of technologies and standards have been developed to cope with this increasing demand. These include 3rd Generation Partnership Project (3GPP) standards, High Speed Packet Access (HSPA), Long Term Evolution (LTE) and LTE advanced; 3GPP2s Evolution-Data Optimised (EVDO), Ultra Wide Band (UWB) and Worldwide Interoperability for Microwave Access (WiMAX) have been developed to provide high speed communication to end users [2].

However with the growing demand of innovative 3G services, most industrial critics see significant potential for the use of femtocells in addressing the challenge of limited indoor coverage [2]–[7]. Femtocells, also known as home base stations are small, low power access points and visually look like an ordinary wireless router. These indoor access points are installed by the users, which creates a small wireless coverage area and connect a User Equipment (UE) to the cellular core network through subscribers broadband internet access. Femtocells are envisioned as a mean of providing better voice and data coverage in the home, especially indoors where many subscribers experience poor signal quality. Femtocells are also primarily viewed as a cost-effective means of offloading data traffic from the macrocell network. By the start of 2011, an estimated 2.3 million femtocells were already deployed globally, and this is expected to reach nearly 50 million by 2014 [8]. Femtocells, along with WiFi offloading, are expected to carry over 60% of all global data traffic by 2015 [9]. Femtocells are also expected to substantially reduce the operator CAPital EXpenditure (CAPEX) and Operational EXpenditure (OPEX) [10], [11], which explains the great interest shown by cellular operators deploying femtocells.

Furthermore, the deployment of Femtocell Access Points (FAPs), has affected cellular network architecture which now consists of two tiers or layers [12], [13], [14], [15]. The first tier or layer is the conventional macrocellular network while the second tier or layer is the femtocell network. The new architecture is thus called two-tier or two-layer network architecture. The new layer, called the femtocell layer is an unplanned and random distribution of femtocells. The femtocell is preferred to be deployed in co-channel fashion, which is using the same frequency bands as the macrocell, to achieve higher capacity.

This in return, gives rise to severe interference management challenges [4], [16]. The interference introduced by femtocells can negatively impacts on the network performance. This interference which is normally between a femtocell and a neighbouring femtocell, or a femtocell and a macro-cell needs to be reduced or completely avoided in order to improve indoor coverage and hence system capacity. Adding to that is the characteristic of ad-hoc deployment, which might elevate interference to unbearable levels, rendering the network inefficient and sometimes unusable. Finally the distributed nature of the femtocell network makes it even more challenging. Interference mitigation between neighbouring femtocells and between the femtocell and macrocell is considered to be some of the major challenges in femtocellular networks because femtocells share the same licensed frequency spectrum with the macrocell. Moreover, the conventional radio resource management techniques for hierarchical cellular system are not suitable for femtocell networks since the position of the femtocells is random depending on the users' service requirement.Two main types of interference exist in a two-tier network architecture: co-tier interference and cross-tier interference.

The co-tier interference refers to the interference caused by network elements that belong to the same tier or layer of the network [4]. In the case of femtocells, it is the interference caused to a femtocell by another femtocell. Usually the femtocells causing interference to each other are immediate neighbouring femtocells, as they are close to each other. In case of dense deployment, where there might be a number of neighbouring femtocells interfering, the overall interference observed at a femtocell can be very high. The co-tier interference is more severe in closed access as compared to the open access [17].

On the other hand, the cross-tier interference is caused by network elements that belong to different tier or layer of the network. For example, an FAP can cause interference to the downlink of a Macrocell User Equipment (MUE) nearby. Femtocells would cause large amount of interference to neighbours that are using macrocell services for indoor purpose. This problem becomes more severe in the case of closed access mode [17].

All these factors lead to a basic question in cellular network management: how can cross-tier and co-tier interferences be mitigated in a cellular network? Any interference management scheme strongly depends on the radio access technology (e.g CDMA or OFDMA) and access mode (open access or hybrid access) being used. Techniques like adaptive power control, resource allocation, interference cancellation and beam-forming for multiple antenna transceivers can be of help in having an efficient interference management scheme. Furthermore, hybrid schemes such as joint power control and resource allocation can also be very helpful. These interference management techniques are broadly categorized into three: Interference Cancellation, Distributed Interference Management and Interference Avoidance.

Many previous works have dealt with one or the aspect of such techniques to resolve interference problems caused by the deployment of femtocells. For instance, a distributed power control algorithm is proposed in [18] for the closed access mode. The paper derives a relation which provides the largest feasible cellular SINR values if a set of feasible SINR values for femtocells were given. In order to reduce the cross tier interference, a distributed utility based SINR approach at the femtocell BS was also proposed, where the power of femtocells causing strong interference was gradually reduced [19]. Moreover, a Distributed Dynamic Inter-Cell Interference Avoidance (DDIIA) scheme was proposed in [20]. The algorithm introduces the concept of Inter-Cell Interference (ICI) link and two tier scheduling due to which it is able to harmonise all base stations with users adaptively. Another interesting study, done in [21], shows that femtocells were able to decode the BS control channel and make decisions related to transmission based on the scheduling and resource allocation of the macrocell system. Moreover, in [22] an adaptive pilot power model is introduced for femtocells to adapt the transmission power based on position of the users. One such scheme is proposed in [23], where a decentralised power control algorithm that considers loads of individual femtocell is proposed for closed access femtocell networks. In addition, spectrum splitting was suggested in [24] to cope with cross-tier interference.

Even though power control has been identified as a key technique in interference avoidance, especially in dense femtocell deployment [24], much contributions have not been done in this direction. This paper addresses the interference mitigation between macrocells and femtocells in a Third Generation (3G) cellular network by modeling a co-channel femtocell and macrocell in a 3G commercial environment and implementing adaptive power control algorithm to handle the interference mitigation.

2. RESEARCH METHOD

The method starts with the design of a femtocell-macrocell deployment scenario followed by the proposed algorithm and pathloss model considerations.

2.1. Cross-tier design

For the purposes of this study, a femtocell is deployed within the same channel as a macrocell, thus co-channel deployment. The interference zone as highlighted in figure 1 by the red dashed line, is considered for the uplink interference from the Femtocell Access Point (FAP) to the Macrocell Base Station (MBS) only. Figure 1 shows that the considered cross-tier interference scenario involves a FAP, MBS and UE.

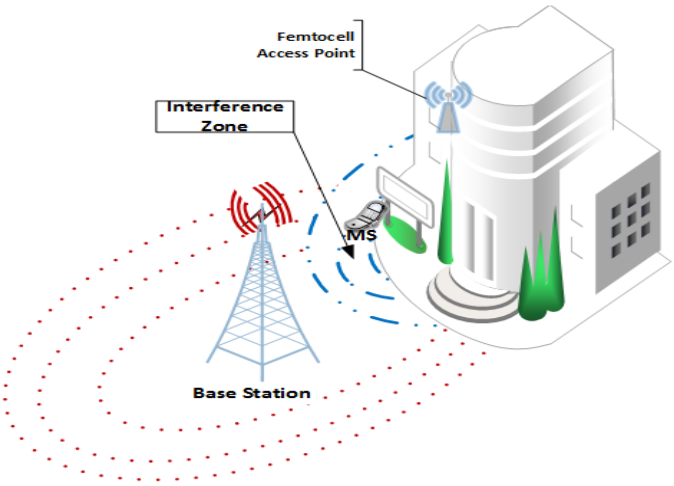

Figure 1. Proposed Cross-tier Interference Scenario

2.2. Pathloss Model

The Okumura-Hata model for pathloss is considered in simulating the pathloss between the Mobile Base Station (MBS) and the Femtocell User Equipment (FUE). The pathloss equation is given as follows :

$$PL(dB) = 69.55 + 26.16\log(f_c) - 13.82\log(h_b) - a(h_u) + B\log(d)$$

Where:

$$B = 44.9 - 6.55\log(h_b)$$
$$a(h_u) = \begin{matrix} 8.92\log(1.5 \times h_u)^2 - 1.1, \text{for } f \le 400\text{MHz} \\ 3.2\log(11.75 \times h_u)^2 - 4.97, \text{for } f > 400\text{MHz} \end{matrix}$$

fc is the carrier frequency in MHz
hb is the height of the base station antenna
hu is the height of the user equipment
d is the distance of separation in kilometers

However for the evaluation of the pathloss between a Femtocell User Equipment and the Femtocell Access Point (FAP), the following pathloss model is introduced where window and wall losses are considered:

$$PL_{femto} = \max\left(15.3 + 37.6 \times \log(d), 3 + 20 \times \log(d)\right) + q \times w \times L_{ow}$$

With:
d is the distance between user equipment and FAP
q is the number walls between the user equipement and FAP
w the losses induced by the walls
L_{ow} the losses induced by the windows

2.3. Proposed Adaptive Power Control Algorithm

Figure 2 shows the flowchart that is used in achieving the adaptive power control scheme. The algorithm developed in this paper is based on power control mechanism at the FAP level. The algorithm consists of evaluating the power transmitted by the FAP to reach the Mobile Station (MS), which is defined as a function of distance, pathloss, fading and shadowing effect. We then derive the real SNIR (SINRreal) and compared it to a defined threshold SINR (SINRthres). If the evaluated SINR is less or equal to the defined threshold, transmission is done and communication proceed. Conversely, if the SINRreal becomes greater than the SINRthres, the FAP starts transmitting with a predefined power scheme called adaptive power. The adaptive power is a predefined value that is calculated and inserted in the algorithm. It corresponds to the minimum required transmission power to reach the mobile station. While transmitting with the adaptive power, the corresponding SINR is also evaluated taking in consideration all the necessary factors. This SINR, known as adaptive SINR (SINRadapt) is then compared with the predefined threshold and if it is less than the SINRthres, transmission is performed using the adaptive power. On the other hand, if the SINRadapt is greater than SINRthres , the minimum between SINRreal and SINRadapt is determined and transmission follows with the corresponding power.

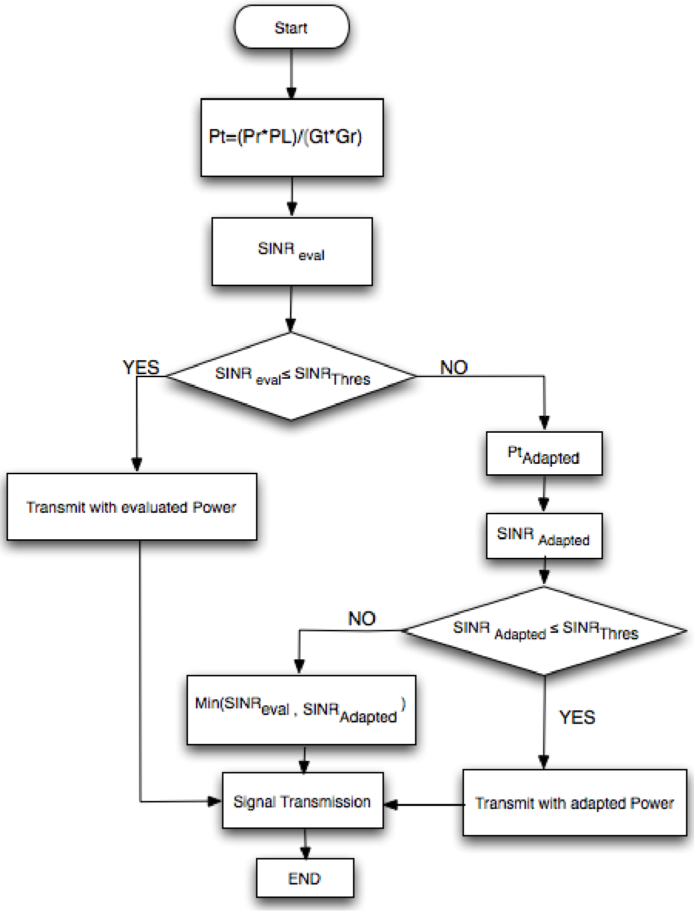

Figure 2. Proposed Adaptive Power Algorithm

The received power Pr by the Femtocell access point is defined as:

$$P_r = \frac{P_t \times G_t \times G_r}{P_L}$$

Where:
P_t is the FAP transmitted power
G_t is the transmitter antenna gain
G_r is the receiver antenna gain

2.4. Simulation parameters

Tables 1 and 2 show respectively, the macrocell and femtocell simulation parameters considered:

Table 1. Macrocell Simulation parameters

Parameters name	Values
Carrier frequency	200 MHz
Carrier bandwidth	5 MHz
BS Antenna Gain	14 dBi
BS Noise Figure	5 dBi
Total BS Tx Power	43 dBm

Table 2. Femtocell Simulation parameters

Parameters name	Values
Distribution of FAP	Random
Min Separation between FAP & MBS	35 m
Penetration Loss of Exterior Wall	10, 30 dB
BS Noise Figure	8 dB
Upper Limit/Lower Limit of Tx Power	20/-20 dBm
Number of Active Femtocell	1
Min distance between FAP & FUE	5m

2.5. Performance measures

In order to determine the impact of the mitigated interference on the system or network, the following performance measures were investigated.

- **System or Network Throughput (b/s)**

This refers to the volume of data that can pass through the network. The Shannon Capacity formula is used in calculating the throughput which is always a fraction of the total capacity in a fading channel.
The system capacity is given as:

$$\mathrm{C} = \mathrm{B} \times \log_2(1 + \mathrm{SINR})$$

Where B is the system bandwidth
However, the signal to noise plus interference ratio is given as:

$$\mathrm{SINR} = \frac{\mathrm{SignalPower}}{\mathrm{NI}}$$

where NI is noise plus interference and is evaluated as follow:

$$\mathrm{NI} = \frac{\mathrm{T_{macro}}}{\mathrm{PL_{macro}}} + \frac{\mathrm{T_{femto}}}{\mathrm{PL_{femto}}} + \mathrm{N_{th}}$$

Where:
T_{macro} is the transmit power of the active macrocell
PL_{macro} is the propagation loss from the macrocell to the femtocell
T_{femto} is the transmit power of the femtocell
PL_{femto} is the femtocell to macrocell propagation loss
N_{th} is the Thermal Noise

- Delay

The delay experienced by a data unit sent from the FAP to the UE is given as:

$$d(UE) = \frac{1}{f\big(SINR(UE)\big)}$$

where $f\big(SINR(UE)\big)$ gives the instantaneous transmission rate on the channel from the UE the FAP which is expressed in the data units per seconds.

- Outage probability

This performance metric indicates the possibility of a UE falling into a deadzone asa result of high interference coming from the deployed femtocell. The outage probability is calculated by using the Erlang B formula which is defined as follow:

$$P_b = \frac{\frac{A_m}{m!}}{\sum_{i=0}^{m} \frac{A_i}{i!}}$$

Where A is the traffic intensity or load and m is the Number of trunked channels.

3. RESULTS AND ANALYSIS

The simulation results for various QOS parameters have been presented and discussed in this section.

3.1. Network Throughput

The throughput of the simulated system, both with and without interference mitigation, as illustrated by figure 3, gradually diminishes as the traffic ratio increases. However, the reduction is more severe when the interference introduced by the deployment of the FAP is not mitigated. With the adaptive power control algorithm proposed, the throughput of the system is improved by a percentage ranging from 2% to 24% depending on the traffic ratio the system.

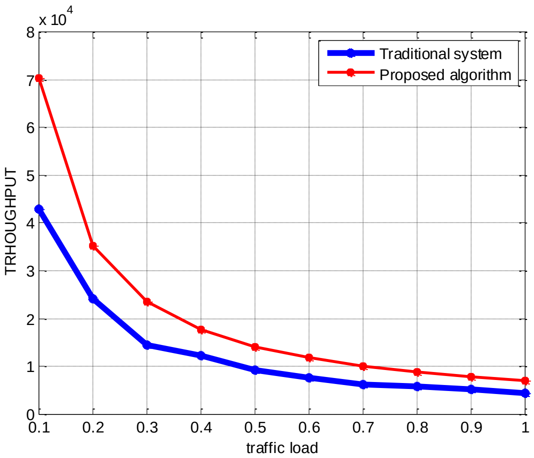

Figure 3. Throughput of voice system vs Traffic load

3.2. Delay

This is another performance measure which is impacted by the mitigation of interference in a femtocell – macrocell cross-tier network.

According to figure 4, the delay of the system increases as traffic ratio increases. However, when the adaptive power control algorithm is employed, there was a significant decrease from 2.3×10^{-4} to 1.4×10^{-4} for 100% traffic ratio. The delay with voice traffic is thus improved. Figure 5, further confirms this improvement by using data.

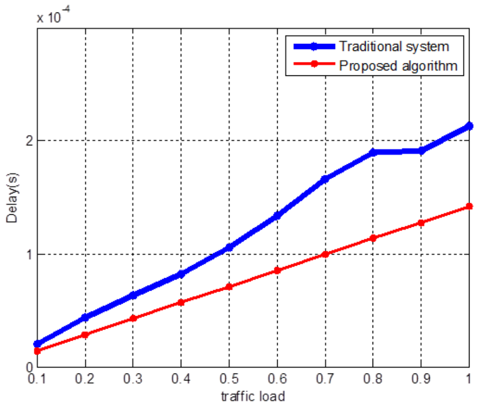

Figure 4. Delay of Voice System vs Traffic load

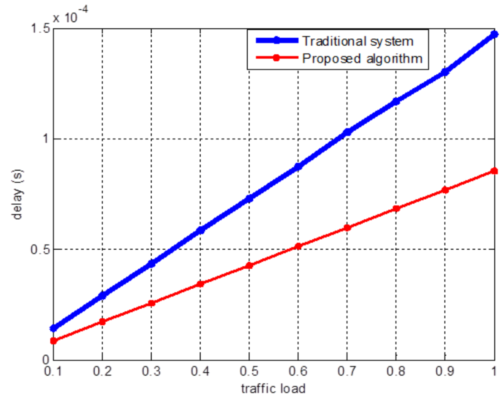

Figure 5. Data System Delay vs Traffic load

3.3. Outage probability

The tendency of a UE falling into a deadzone as a result of non-mitigated high interference coming from the deployed femtocell. Figure 6 and 7 show that with the employment of the adaptive power algorithm which reduces interference, the probability of a UE falling into deadzone reduces considerably. Thus a voice call can be sustained longer in face of interference because of mitigating measure.

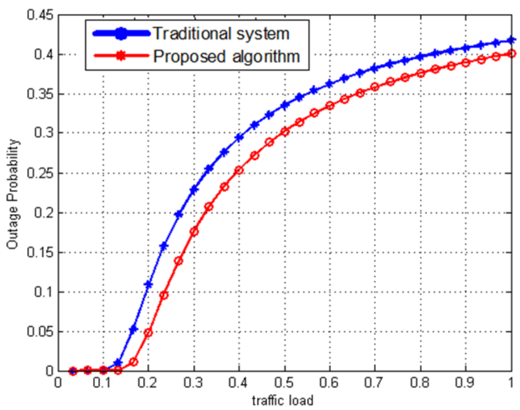

Figure 6. Voice Outage Probability vs Traffic load

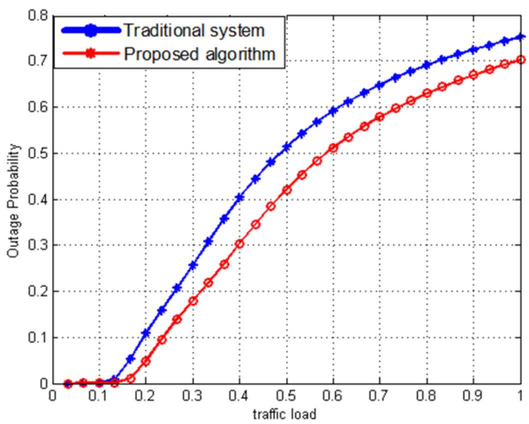

Figure 7. Voice Outage Probability vs Traffic load

Comparing Figures 6 and 7, it is obvious that probability of outage of data services is higher compared to voice services. However, for the same channel conditions, the adaptive power control algorithm improves the outage of data services by 5% at 100% traffic load.

4. CONCLUSION

This study covered the modeling and simulation of a cross-tier, co-channel femtocell and macrocell deployment in a 3G commercial environment. Simulations with the help of MATLAB show that the deployment of femtocells come with interference and if not mitigated, this can severely impact on performance measures such as throughput, delay and outage probabaility. However, the implementation of the above described algorithm, yield prominent results in terms of improvement of throughput, delay and outage probability for different types of traffic including voice and data. The proposed algorithm, therefore reduces considerably the interference level. This in the long run, increases indoor coverage which happens to be the primary objective of deploying femtocells.

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