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Interference Management in Femtocells by the Adaptive Network Sensing Power Control Technique

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Abstract: The overlay integration of low-power femtocells over macrocells in a heterogeneous network (HetNet) plays an important role in dealing with the increasing demand of spectral efficiency, coverage and higher data rates, at a nominal cost to network operators. However, the downlink (DL) transmission power of an inadequately deployed femtocell causes inter-cell interference (ICI), which leads to severe degradation and sometimes link failure for nearby macrocell users. In this paper, we propose an adaptive network sensing (ANS) technique for downlink power control to obviate the ICI. The simulation results have shown that the ANS power control technique successfully decreases the cell-edge macro user's interference and enhances the throughput performance of macro users, while also optimizing the coverage and capacity of the femtocell. When compared with the Femto User Equipment (FUE)-assisted and Macro User Equipment (MUE)-assisted power control technique, the proposed technique offers a good tradeoff in reducing interference to macro users, while maintaining the quality of service (QoS) requirement of the femtocell users.

Keywords: adaptive network sensing; femto user assisted; macro user assisted; power control inter-cell interference; path loss

1. Introduction

The exponentially increasing demand for high data rate and capacity in mobile communications has created a real challenge for wireless communication network operators, as a large percentage of indoor users suffer from a poor quality of service (QoS) [1]. The current mobile system should be equipped to cope with these demands. The third-generation partnership project long-term evolution-advance (3GPP-LTE-A) is a promising technology in this regard, whose objective is to increase spectral efficiency, coverage, capacity and offload traffic from the macrocell. LTE-A is a progressively evolving technology that adapted generic and novel technologies of orthogonal frequency division multiplexing (OFDM) and multiple input, multiple output (MIMO), in order to accomplish future demands [2].

The overlay integration of low-power femtocells over MIMO in a heterogeneous network (HetNet) is widely discussed [3] as a feature that will achieve the expected user-demand in terms of coverage, data rate, capacity and quality. The femtocell is a short-range wireless access point, also called femto access point (FAP), which is linked to broadband Internet backhaul and uses the licensed frequency spectrum. Femtocells are specifically developed for an indoor environment (i.e., home, schools, airports and offices) to increase coverage area and to provide a higher data rate [4]. It has been predicted that, in the near future, the origination of indoor data and voice traffic will be increased by up to 90% and 60% respectively [5].

The two-tier, macro–femto heterogeneous system, where the primary system is the macro base station (MBS also called eNB) and the secondary system, represented by the user-installed femtocell

(HeNB), ignore their mutual presence, while both systems work in a frequency reuse fashion [6]. In such an operating scenario, the downlink (DL) transmission of HeNB causes inter-cell interference for the cell-edge macro user.

The deployment of the femtocell in HetNets plays a significant part in causing interference in the MUE (Macro User Equipment). The user-deployed, low-power femtocell has no coordination with the macrocell and it is not controlled by the operator. When the deployment of the femtocell is inadequate and in ad-hoc style and users can change the position from one place to another, this can drastically degrade the performance of the whole system and cause interference with the nearby MUE. The interference is crucial in MUE, as the received signal from the macrocell has lower power due to path loss and from shadowing the signal from the femtocell. The interference can lead to errors such as a loss of data packets, a delay in connection and transmission and link failure, which significantly decrease the QoS. The mitigation of interference cannot be accomplished by using the customary resource management and nominal cell planning. Rather, adaptive and cognitive techniques are the advanced solution.

The access style of user equipment (UE) has a massive impact on the overall femtocell network, in terms of interference [7]. The deployment of the femtocell depends on three different access modes. Closed access mode is where only authorized UE has access to a femtocell [8]. Open access mode is deployed by the operator to maximize the capacity, where all UE has access. Hybrid access mode is where some UE is prioritized over other UE and it is a user-deployed mode. The different modes serve different mechanisms to network users. The Inter-cell interference (ICI) is much harsher in the closed access mode as compared to the open access mode [9]. Consequently, dynamic management of resources is difficult for operators. The optimization of performance in the femtocell is most reliant on its allocation of resources and position in an indoor environment. It also requires an effective and vigorous approach to sense its adjacent surroundings and has dynamic techniques to diminish any interference [10].

The downlink transmission power level of the femto base station (FBS) affects the users in its vicinity, which have no access to the femtocell. The high downlink transmission power of the femtocell provides more coverage and good signal quality; at the same time, it creates terrific interference to other cell-edge users of the other femtocell or macrocell networks. In this paper, we proposed an adaptive network sensing (ANS) technique for downlink power control, to avoid ICI. The simulation results show that the ANS power control technique successfully decreases the cell-edge macro user's interference and enhances the throughput performance, whilst also optimizing the femtocell coverage and capacity. When compared to the femto user equipment (FUE)-assisted and MUE-assisted power control technique, the proposed technique provides a good tradeoff in reducing interference in MUE and maintaining the QoS requirement of the femtocell users.

The paper is divided further into the following sections. Related work has been discussed in Section 2. In Sections 3 and 4, we describe the system model and power control techniques (previous and proposed techniques), respectively. In Section 5, we analyze the simulation results. Finally, in Section 6, we draw our conclusion.

2. Related Work

Recently, there has been innovative research to design and develop multiple novel approaches, techniques and strategies for an adaptive and cognitive femtocell, used for reducing the ICI between the MUE and the femtocell. An algorithm presented in [11] mitigates the ICI in a two-tier macro and femtocell network. The power control modelled with unity function and every macro BS and femto BS, separately capitalizes its utility function by dynamically regulating the transmit power of its existing subchannels and chooses the appropriate power setting in the firefly algorithm (FA) iteration optimization technique. This algorithm provides a good tradeoff between the performance of the FUE and the MUE by fine-tuning the coefficient value of the utility function. The tradeoff is between the macrocell user's and femtocell user's performance, as discussed in [12]. The QoS of macrocell users is

increased, while the QoS of the femtocell users is not degraded. HeNB and eNB decide to increase or decrease their transmission power, based on the estimated SINR (signal to interference plus noise ratio) of MUE and FUE. Fair allocation of resources in the distributed power adjustment algorithm [13] for the heterogeneous mobile network is when a BS relies on the signal power received from the adjacent BS and adjusts its transmission power. An established threshold SINR value or predetermined value for interference is not used for power tuning. The researcher presents a technique in [14] to alleviate the downlink interference of macro UE, received from the femto BS. The femto BS has the capability to sense the spectrum and obtain essential information, such as the usage of macrocell downlink radio resources and information about cell-edge MUE. The femto BS then allocates transmit power to each channel effectively, so the overall system throughput increases, while still satisfying the MUE outage constraint. The smart femto base station algorithm (FBSA) and downlink power-control algorithm (DPCA) in [15] are two techniques presented to lessen the interference between the femto BS and macro BS by using power control. The FBSA distributes femto users to the non-interfered femto BS, to bypass interference and enhance the achievable data rate. When the SFSA is unable to resolve this issue, DPCA is engaged, which improves the achievable data rate (ADR) of all femto users. A stochastic approximation (SA) algorithm proposed in [16] for downlink transmit power control in femto BS networks is based on the essential channel measurement feedback report in macrocell signaling. The femto BS can adjust the transmitted power by listening to the feedback report from the cell-edge MUE to macrocells, such as channel quality indicator (CQI) and ACK/NAK signals. This does not need any extra backhaul signaling from the macro BS. A power optimization algorithm in [17] optimizes the transmission power of the femtocell in a decentralized manner, to reduce the interference in an adjacent cell and user equipment. When applying particular schedulers such as maximum (max) and minimum (min), proportional fair, and resource fair, the optimum power enhances the average throughput of the system and its fairness and efficiency. To increase the system throughput of the femtocell, the distributed Dynamic Power Control Algorithm (DPCA) [18] is used, which dynamically regulates the downlink transmission power of the femtocell based on the feedback report received from its users. This technique can be effectively used on random network topology with minimum overhead. Cooperative optimal power control theory in [19] is used to manage interference in the femto BS. In the first phase, it measures the downlink transmit power by assuming all sub channels, while in the next phase, the selection of sub channels can be employed for an additional reduction in interference. In game theory [20], a sophisticated base transmits a power control technique, which generates opportunities to reuse the spectrum between mutually interfering femto BSs. This power control technique is based on the generalized Nash equilibrium (NE) problem. The author proposed a distributed channel-aware power control algorithm to create opportunities to reuse the spectrum for the interfering femto BSs.

3. System Model

We considered an inadequately deployed femtocell in a heterogeneous network, with overlays integrated with the eNB. The two systems, i.e., the eNB as the primary system and the femtocell as the secondary system, work in a frequency reuse fashion and have no coordination among them, so neither system pays attention to their respective mutual presence. The only information that the eNB shares with the HeNB is the scheduled information of the macro-cell by using backhaul link. In such an operating scenario, the downlink transmission of the HeNB causes inter-cell interference to the cell-edge macro user. To take into account worst-case interference, we considered that the eNB and HeNb use the same carrier frequency, f = 2 GHz and the same bandwidth. The access mode used in the HeNB has an efficient effect on the whole interference scenario, as shown in Figure 1. Only authorized UE has access to the femtocells deployed in the close access mode; therefore, the MUE in the vicinity of the femtocell has no access to subscribe to the services [21]. We take into account path loss using the path loss model for urban deployments in the 3GPP LTE-A [22].
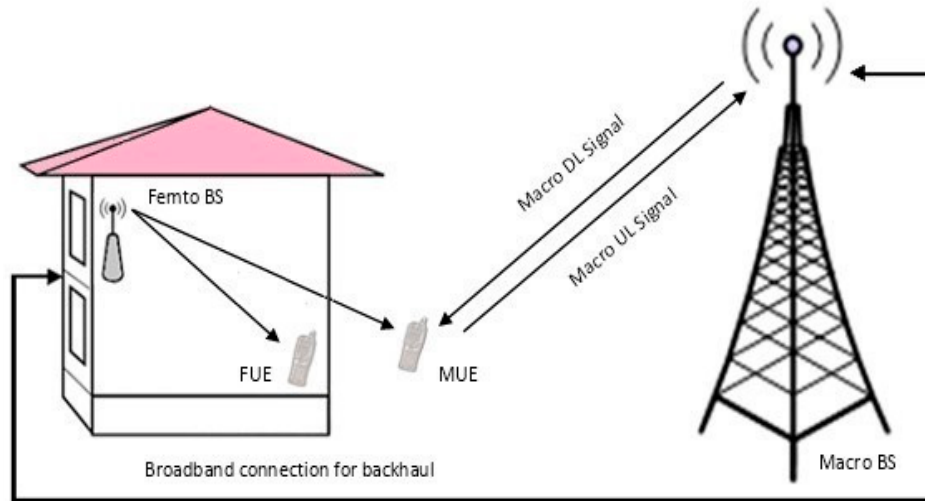
Figure 1. Interference scenario in the Primary and Secondary System.

3.1. Path Loss Model

The path loss models set by the 3GPP LTE-Advanced for urban deployments in [22], between the macro BS and UE, is given as:

$$PL_{Macro}(dB) = \begin{cases} 15.3 + 37.6 \log_{10} R & \text{(outdoor UE)} \\ 15.3 + 37.6 \log_{10} R + L_{OW} & \text{(indoor UE)} \end{cases} \tag{1}$$

where the distance between the macro BS and UE is "*R*" and the outdoor wall penetration loss is *Low*.

The path loss between the femto BS and UE indoor or outdoor in an apartment is calculated by using:

$$PL_{Femto}(dB) = \begin{cases} 38.46 + 20 \log_{10}(R) & \text{(outdoor UE)} \\ \max(15.337.6 \log_{10}(R), \ 38.46 + 20 \log_{10}(R)) + L_{OW} & \text{(indoor UE)} \end{cases} \tag{2}$$

3.2. Link-Level Performance Model

The link-level performance in this paper is evaluated using the throughput as the performance measure. The Truncated Shannon Bound (TSB) optimally approximates the actual throughput function for an arbitrary set of coding schemes and modulation schemes [23], so the link capacity can be treated as a function of the SINR [24]. The TSB equations approximate the throughput over a channel, with the SINR that the user experiences in reception given as:

$$Thr_{TSB} = \begin{cases} \text{Thr} = 0 & \text{for} \quad \text{SINR} < \text{SINR}_{min} \\ \text{Thr} = B_w \alpha \log_2(1 + SINR) & \text{for} \quad \text{SINR}_{min} < \text{SINR} < \text{SINR}_{max} \\ \text{Thr} = \text{Thr}_{max} & \text{for} \quad \text{SINR} > \text{SINR}_{max} \end{cases} \tag{3}$$

where B_w is the bandwidth and SINR_{min} is a lower limit on the SINR below which throughput is zero and SINR_{max} is an upper limit associated with the throughput of the highest rate coding/modulation. To match the link-level performance, α has been used [23].

4. Power Control Techniques

4.1. FUE-Assisted Power Control Technique

In a real scenario, the HeNB instructs all the FUE to measure the received signal power from the neighboring interferer BS and send a feedback report [25]. The femtocell uses the information

received from the FUE and makes some necessary adjustments in downlink transmission power. The FUE-assisted power can be expressed as:

$$P_{FUE.Assist.} = \max(P_{min},\ \min(P_0, P_{max}))\tag{4}$$

In (4), P_{min} is the minimum transmission power and P_{max} is the maximum transmission power of the femtocell.

$$P_0 = \max(I_{FUE_i} + PL_{FBS \rightarrow FUE_i}) + \varepsilon_0\tag{5}$$

where ε_0 is set to maintain the necessary QoS of femto users in (5).

4.2. MUE-Assisted Power Control Technique

In this technique, the femtocell tunes its transmission power based on the measured information sent by the macro user via the macrocell [25]. This is due to the non-existence of a direct interface between the femtocell and MUE [26], which brings an extra signaling overhead. To mitigate interference with the MUE, the optimal transmit power of the femtocell is given as:

$$P_{MUE\ .Assist.} = \max(P_{min},\ \min(P_1, P_{max}))\tag{6}$$

$$P_1 = 10\log\left(10^{S_{MUE}+\varepsilon_1)/10} - 10^{I/10}\right) + PL_{FBS \rightarrow MUE}\tag{7}$$

In (7), interference to the MUE from different femto BSs is I. The received power at the MUE from the macro BS is denoted as S_{MUE} and ε_1 is the necessary QoS requirement for the MUE. The path loss from the femtocell to MUE $PL_{FBS \rightarrow MUE}$ is given as:

$$PL_{FBS \rightarrow MUE} = \max(15.3 + 37.6\log_{10}(R), 38.4620\log_{10}(R)) + L_{ow}\tag{8}$$

where L_{ow} is the outdoor wall penetration loss, which is 10 dB.

4.3. Proposed Power Control Technique

The proposed ANS power control technique is where the MUE will measure the interference level from the femtocell and compare it with the threshold interference level, which is the minimum required value to maintain the necessary QoS. When the interference is higher than the threshold interference, MUE will send a CQI message to the macrocell, along with the information of the femtocell. The macrocell will send back a message to the MUE and then, the MUE will forward it to the femtocell [27]. The interference threshold on i^{th} MUE can be given as:

$$I_i = P_t \psi (R)^{-\beta}\tag{9}$$

$$x_k = \begin{cases} 0, & I \le I_{threshold} \\ 1, & Otherwis \end{cases}\tag{10}$$

In (9), the path loss is denoted by $(R)^{-\beta}$; log-normal shadowing is Ψ. R is the distance from the interferer BS to the user equipment. In (10), a function x_k is used, which indicates whether the interference is lower or higher than the threshold interference. The MUE will decide to send a CQI message to the macrocell, on the basis of function x_k.

When the femtocell receives the message from the macrocell, it makes necessary adjustments to control the transmission power. The femtocell will measure the received signal power of the macrocell and assume that the nearby MUE in its coverage area is also receiving the same power. Using this statement, the femtocell then efficiently tunes its transmission power as:

$$P_{ANS} = \max(P_{min},\ \min(P_f, P_{max}))\tag{11}$$

$$P_f = P_{macro} - PL_{MBS \to FBS} + PL_{Femto}(R_1) + \varepsilon_2 \tag{12}$$

In (12), $PL_{MBS \to FBS}$ is the macrocell-to-femtocell path loss. The line of sight (LOS) path loss is $PL_{Femto}(R_1)$ with the cell range R_1. The downlink SINR for any user can be calculated using:

$$SINR = \frac{P_{tx}^s PL^s}{\sum_{i=1}^{N} x_i I_i + \sum_{i=1}^{N} P_{tx}^t PL^t + P_n} \tag{13}$$

where P_{tx}^s is the transmit power from the serving BS (either the macrocell or the femtocell) to UE; from the serving BS to the UE, the path loss is denoted as PL^s. Similarly, P_{tx}^t and PL^t is the transmission power of the interferer BS and path loss, respectively. In (13), the total number of interferers is denoted as N and the thermal noise density is denoted as P_n.

5. Simulation Results and Discussion

The simulation carried out in MATLAB is based on the simulation parameter set out in [28] and some selected simulation parameters are listed in Table 1. In this simulation, we used an urban model, a single floor building, as shown in Figure 1. We also used the closed access mode HeNB, one of the favorite access modes of domestic subscribers of femtocell services, where only authorized users have access to the services of the femtocell; the MUE in the vicinity of the femtocell has no access to the femtocell.

Table 1. Simulation parameters.

Parameters	Values/Range
Bandwidth	10 GHz
Carrier frequency	2 GHz
Transmit power of macrocell	43 dBm
Transmit power of femtocell	20 dBm (maxi) 0 dBm (mini)
Macrocell radius	500 m
Femtocell radius	10 m
Thermal Noise Density.	−174 dBm/Hz
Penetration Loss.	20 dB
Lognormal shadowing the standard deviation (macrocell)	10 dB
Lognormal shadowing the standard deviation (femtocell)	4 dB
Noise figure in user	9 dB
Minimum separation from Users Equipment(UE) to HeNB	20 cm

The main aim of power controlling in the HeNB is to uphold the FUE coverage and identify potential downlink throughput, while mitigating the ICI experienced by the nearby macro users. Figure 2 shows the macro user's downlink throughput CDF (Cumulative Distribution Function). The simulation of "No Power Control" is carried out as a baseline, when there is no power control technique activated in the femtocell; in other words, the femtocell transmits with the maximal transmit power. The femto user-assisted and macro user-assisted power control techniques have almost identical effects in enhancing the throughput performance of the nearby MUE, whereas the simulation results show that the ANS power control technique has a good tradeoff in reducing interference in the MUE and maintaining the QoS requirement of the femtocell users.

High downlink transmission power of the femtocell provides good signal quality and better coverage to the FUE, though concurrently it creates massive interference to other cell-edge users. The power control techniques, such as the MUE-assisted power control technique, focus on alleviation of interference to macro users; at the same time, they lessen the femto user's performance. Figure 3 shows that the ANS power control scheme provides the best tradeoff mitigation of interference in cell-edge users and maintains also the necessary QoS of femto users.
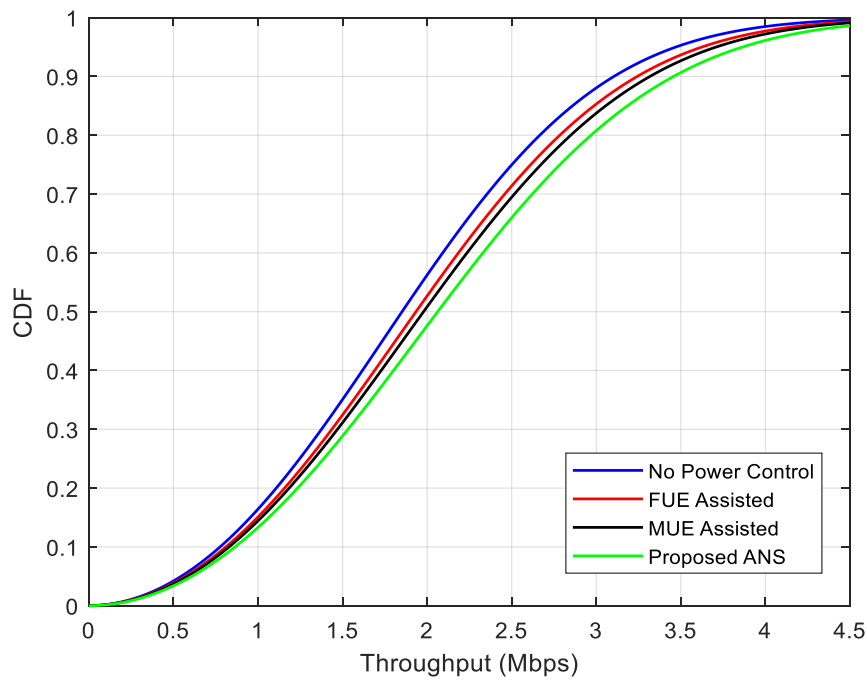
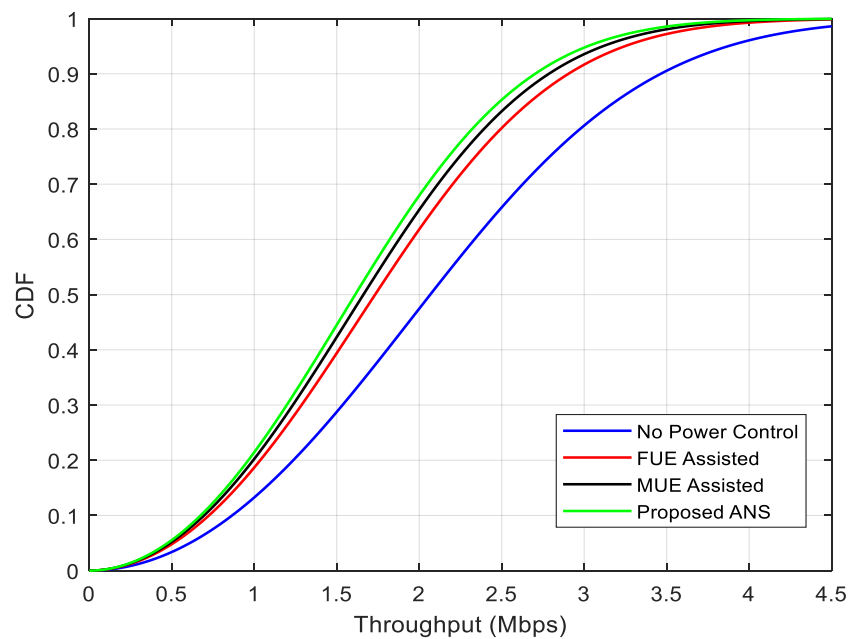**Figure 2.** Macro User's throughput Cumulative Distribution Function (CDF).

Figure 3. Femtocell User's throughput CDF.

To summarize, the proposed ANS power control technique effectively and efficiently balances the throughput performance by reducing the interference to the MUE in the vicinity of the HeNB and optimizes the femtocell coverage and capacity. In Table 2, a comparison of average throughput for macro users and femto users is shown, under the existing and proposed power technique.

Moreover, the ANS technique is a reactive power control technique, as it reacts only when the interference indication function indicates that the interference level is higher than the threshold level in the MUE and receives a message from the macrocell, whereas other above-listed techniques are proactive. In the proactive power control technique, the femtocell depends on the measured value of

RSRP (Reference Signal Received Power) to set its downlink transmission power, irrespective of the presence of a victim macro user in its coverage area. Thus, the reactive power control technique can competently deter the irrelevant tuning of transmission power.

Table 2. Performance Comparison.

	FUE (Femto User Equipment) Assisted Power Control Technique	MUE (Macro User Equipment) Assisted Power Control Technique	ANS (Adaptive Network Sensing) Power Control Technique
Macro User Throughput (Mbps)	1.69	1.8	1.93
Femto User Throughput (Mbps)	5.07	4.97	4.81

6. Conclusions

In this paper, we have proposed an interference mitigation technique for an inadequately deployed lower power femtocell. The proposed technique is as follows: the femtocell uses the information from the macrocell and tunes the downlink transmit power. We presented an interference indication function, which compares the interference level with the threshold value and then sends CQI feedback via the MUE to the macrocell. The macrocell then instructs the femtocell to take the necessary steps to adjust its transmission power and reduce interference to cell-edge macro users, satisfying the necessary QoS requirement of femto users. The simulation results show that the proposed ANS power control technique efficiently decreases the cell-edge macro user's interference and enhances the throughput performance of the macro user, while also optimizing the femtocell coverage and capacity.

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