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Femtocell Sleep Mode Activation Based Interference Mitigation in Two-Tier Networks

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Abstract

The deployment of femtocells in conventional macrocells is expected to solve the indoor coverage problems in a cost effective manner. However the key requirement for efficient co-channel macro/femto cell deployment is the suppression of interference. This paper proposes a sleep mode activation procedure for femtocell base stations based on the interference mitigation for macrocell user equipments (MUEs) results of the system level simulation with realistic LTE-A system parameters have shown that the proposed procedure improves the signal quality for the MUEs and reduces the number of blocked MUEs up to 60% compared to no sleep mode scenario. Moreover, the algorithm presents power consumption saving opportunities of approximately 55% in femtocell networks with respect to no sleep mode activation scenario.

Keywords: Femtocell, macrocell, sleep mode, active mode, interference

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1. Introduction

The explosive growth of indoor voice and data usage creates a great challenge for the wireless communication operators to overcome the in-building coverage problems. Femtocell technology provides a promising solution to the network operators to enhance their indoor network performance, and offers brand new services and applications. Femtocell also known as Home enhanced NodeB (HeNB) in the 3rd Generation Partnership Project (3GPP)

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standardization, is a small size, low power, and low cost base station, with a short service range and can support under ten users simultaneously [1]. Femtocells can be easily installed by the end users, they utilize the users existing broadband internet access as a backhaul to communicate with the mobile operator core network [2].

Femtocell will result in a win-win situation, with enhanced indoor coverage and high data rates for end users. On the other hand lower network capital expenditure (CAPEX) due to the reduction of site built cost. Also the reduction of backhaul and site maintenance cost will cause a significant saving in the operational expenditure (OPEX) [3].

However the dense deployment of femtocells gives rise to several technical challenges. The major one is the interference between femtocell and macrocell, particularly in co-channel deployment scenarios. In downlink transmission, a macrocell user equipment (MUE) located at the cell edge may experience a severe co-channel interference from nearby femtocells due to high path loss and shadowing effects [4]. Although femtocells are low power base stations, the massive deployment of them will result in increasing the total energy consumption of the network, therefore efficient methods such as cell-zooming and sleep mode are required to reduce energy consumption while maintaining the performance of femtocells [5].

The effects of a joint macro and femto cell deployment on the network energy efficiency have been investigated in [6]. Simulation results have shown that femtocell can improve energy efficiency of the network; however this comes with the cost of performance degradation due to interference, which is particularly severe in dense deployment scenarios. However the energy consumption metrics used in this study do not take into account the variable loads in different base stations and other factors such as backhaul power consumption is not considered. A novel idle mode approach for femtocell base stations is improved in [7], which enables switching off the unnecessary hardware component when not involved in an active call. However this algorithm will result in increasing in core network signalling.

Energy efficient sleep mode algorithms for small cell base stations are introduced in [8]. Three different strategies for algorithm control are discussed, relying on small cell driven, core network driven, and user equipment driven approaches. The algorithms have been shown to offer approximately 10-60 percent energy savings in the network compared to no sleep modes in small cells. The solutions for reducing the number and size of macrocells following traffic load conditions in both homogeneous and heterogeneous networks are investigated in [9]. Results show that using sleep mode at base stations in low to medium traffic load conditions combined with the deployment of small cells offers energy reduction gains especially in heterogeneous networks. These studies focus on the use of sleep mode for small cells to reduce the energy consumption with the constraint that the base station is not occupied or in an active session. However in this study we propose a sleep mode procedure for femtocells in response to the interference on macro users (MUEs). This is expected to reduce the energy consumption of the network besides mitigating the interference from femtocells to MUEs, so as to guarantee a minimum number of blocked MUEs.

The rest of this paper is organized as follows: section 2 presents the system model. Section 3 provides details about the sleep mode activation algorithm. Section 4 describes the simulation scenario. Section 5 is dedicated to the performance evaluation results and discussion. Concluding remarks are given in section 6.

2. System model

The system model is used to study the interference impact on the performance of MUEs and home user equipments (HUEs), in terms of signal to interference plus noise ratio (SINR) and the number of blocked MUEs due to the introduction of the sleep mode for femtocell base stations.

2.1. Interference Scenario

In the downlink the received signal at the UE contains the OFDMA transmitted symbols of the serving base station plus the interference induced by nearby base stations. Fig. 1 shows the interference scenario which consists of two types of interference: (i) Cross-tier interference between macrocell and femtocell, in which the cell-edge MUE may suffer from severe interference. (ii) Co-tier interference between the femtocells.

2.2. Propagation models and SINR calculations

In this study we adopt 3GPP LTE-A path loss models for urban deployments [10]. In which the path loss between the eNB and the UE is calculated as follows:

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

where R is the distance between the UE and eNB in meters and L_{ow} is the penetration loss of an outdoor wall, which is 20 dB.

While the path loss between HeNB and UE within or outside an apartment is formulated as:

$$PL_{femto}(\mathrm{dB}) = 127 + 30\log_{10}\left(R/1000\right) \tag{2}$$

where R is the distance between HeNB and UE in meters.

In [10] the shadowing effect is considered in all the links between eNB/HeNB and the UE, which is added to the path loss as a Gaussian distributed random variable (in dB) with a standard deviation σ.

The SINR of the MUE in the downlink is given by:

$$SINR_{MUE} = \frac{PT_m g_{mj}}{\sum_{f \in F} PT_f g_{fj} + N} \tag{3}$$

where PT_m, PT_f are the transmit power of eNB and HeNB respectively, and F is the number of HeNBs, g_{mj} and g_{fj} are the signal loss factors for macrocell and femtocell respectively and N is the additive white Gaussian noise.

The SINR of the HUE in the downlink is given by:

$$SINR_{HUE} = \frac{PT_f g_{fh}}{\sum_{\substack{k \in F \\ k \neq f}} PT_k g_{kh} + PT_m g_{mh} + N} \tag{4}$$

where PT_f and PT_k are the transmit power of the serving and interferer HeNBs respectively.

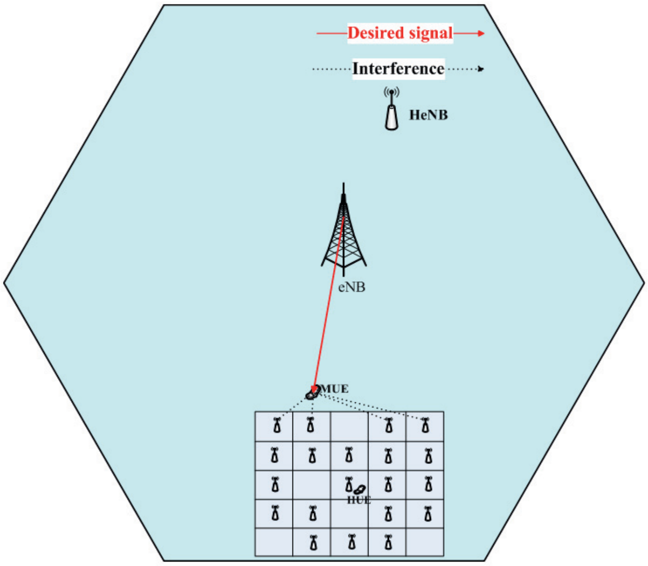

Fig. 1. Interference scenario.

3. Sleep mode activation algorithm

In this study we assume that femtocell (HeNB) resides exactly in one of the following modes at any time: (i) Active mode: in which the HeNB served all the allowed users in its coverage area. (ii) Sleep mode: in this mode the HeNB is switched off.

Fig. 3 shows the operational flow chart of the sleep mode activation procedure for HeNBs. Initially the HeNB resides in the active mode. The macro UE performs received power measurements on eNB downlink band, if the SINR of the MUE decreased under a predefined threshold (considered as -6 dB here), then the MUE must detect the strongest HeNB interferer; the transition of this HeNB to sleep mode is conditioned by the occupation of the cell as shown in Fig.2. After the distance between the victim MUE and the aggressor HeNB becomes double (double the initial distance at time of activation of sleep mode), the HeNB is set back to active mode to maintain a good performance for HeNB while mitigating interference to MUEs.

4. Simulation scenario

The downlink macrocell/femtocell scenario as in Fig.1 is considered with the eNB at the center of the cell. A typical 5×5 grid scenario of a dense urban area for femtocells with 25 houses each house has the size of 10m×10m is located at the edge of the macrocell. Twenty HeNBs are dropped randomly and uniformly in the houses.

In this simulation we consider the cell-edge MUEs only, which are the users that suffer from severe interference induced by femtocells. The HUEs are dropped randomly and uniformly inside the femtocells. Indoor and outdoor UEs move at a speed of 1 m/s. Table 1 shows the main simulation parameters confirmed with 3GPP TR 36.814 [10].

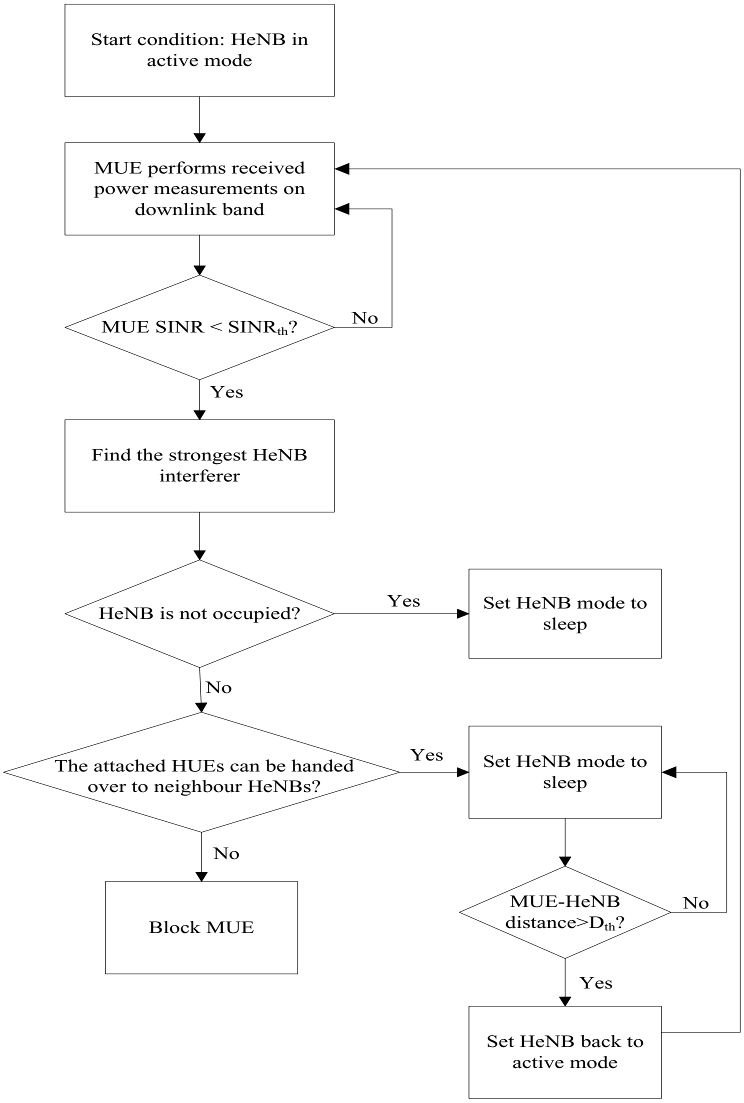

Fig. 2. Sleep mode algorithm flow chart

Table 1. Simulation parameters

Parameter	Macrocell	Femtocell
Cell radius	500 m	10 m
HeNB transmitter power	46 dB	20 dB
HeNB antenna gain	14 dBi	5 dBi
Log normal shadowing standard deviation	8 dB	10 dB
Carrier frequency	2.0 GHz	
Bandwidth	10 MHz	
Antenna pattern	Omnidirectional	
Thermal noise	-174 dBm/Hz	

5. Results and discussion

System level simulation is conducted to evaluate the SINR of the macro UEs. Fig. 3 shows a clear improvement in the SINR of MUEs with the usage of sleep mode for HeNBs. That is due to the reduction of interference from the nearby femtocells.

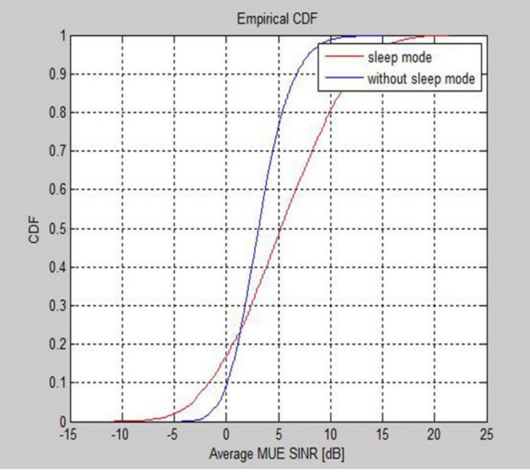

Fig. 3. Average SINR of MUEs

A slight degradation in the SINR of HUEs is shown in Fig. 4. The reason for that is some of the HUEs are not served by their best HeNB; instead they have been handed over to their neighbouring HeNBs to deactivate the strongest interfere to MUEs.

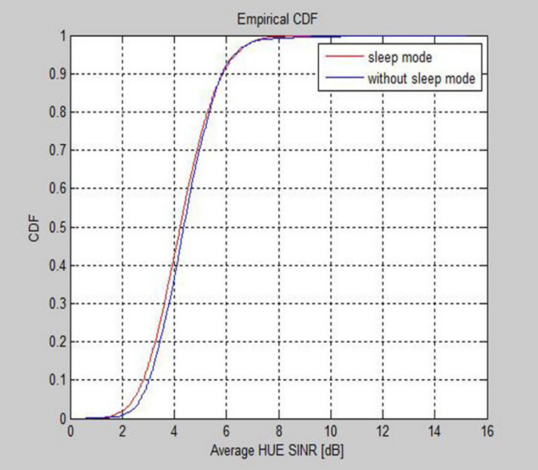

Fig. 4. Average SINR of HUEs

The probability of blocking the cell-edge MUEs is high as a result of high path loss and shadowing effects. However the activation of sleep mode for nearby HeNBs in response to interference on MUEs reduces the number of blocked MUEs up to 60% compared to no sleep mode scenario as presented in Fig.5.

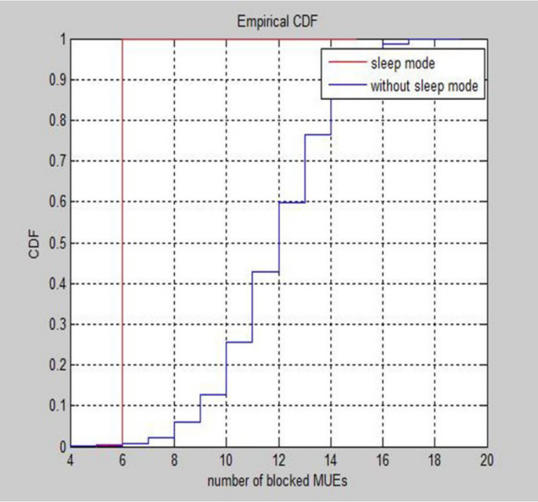

Fig. 5. Number of blocked MUEs

The usage of sleep mode for HeNBs allows a greener deployment by reducing the total power consumption of the femtocell network. This reduction is presented in this study as the total transmitted power of the femtocells network. Fig. 6 shows up to 55% reduction compared to no sleep mode scenario.

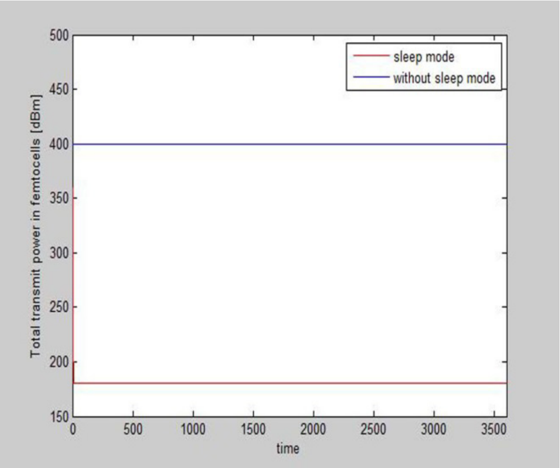

Fig. 6 Total transmit power in femtocells [dBm]

6. Conclusion

The emergence of femtocells within macrocells creates new opportunities and challenges for the wireless network operators. In co-channel deployment scenarios, femtocells will cause interference to macrocells. This effect will be severe for cell-edge MUEs. In this work a sleep mode activation procedure for HeNBs has been introduced. In response to the interference on MUEs, the strongest HeNB interferer is set to sleep mode on condition of the occupation of the HeNB. The proposed algorithm is evaluated to mitigate the interference for MUEs. Moreover the algorithm can guarantee a minimum number of blocked MUEs. Additionally reducing the number of active HeNBs offers high power consumption savings.

Acknowledgements

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