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# Measurement-based coverage function for green femtocell networks

Anna Dudnikova [*], Daniela Panno, Antonio Mastrosimone

*Department of Electrical, Electronics and Computer Engineering, University of Catania, Catania, Italy*

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## ABSTRACT

In this paper, we propose a self-optimized coverage function for LTE femtocells embedded in a macrocell area. Each Femto Base Station (FBS) adapts its pilot power, and thus the coverage, to the on-site traffic demand. Under low traffic conditions the FBSs, whose presence is not essential for the proper operation of the network, reside in a low power Listen Mode. In this way a relevant energy saving on entire femtocell network can be achieved. In a high-load scenario, FBSs dynamically create high capacity zones under interference constraints. This permits to improve system capacity and offload more traffic from the nearby macrocell and, in the same time, to minimize co-channel interference in the femtocell tier.

## 1. Introduction and related works

Femtocell concept has found a place in the architecture of LTE networks as a cost-effective solution designed to improve both the coverage and the user throughput indoors (where mobile users spend most of time), as well as the overall system capacity by offloading data traffic from macrocells. Femtocells were originally conceived to be installed by terminal consumers without network preplanning in private households. At present time, it is increasing the adoption of femtocells from the enterprise segment, which is a key focus for a growing number of operators.

According to the researches of “Informa Telecoms & Media”, the 9.6 million femtocells in operation today make up 56% of all base stations (BSs) globally and they will continue to outnumber all other types of cells with an expected 86% of the total BS market in 2016 [1]. Due to the massive deployment of these additional BSs the wireless network energy consumption might be significantly increased. This problem becomes especially acute in public areas (e.g. airports, shopping malls, etc.) characterized by a large number of mobile users, which require high data rates. In these environments, the capacity of a macrocell is not enough and a very high femtocell density is expected. Let’s also note that the user number is highly variable. For this reason the use of the static pilot power configuration, in which FBSs are required to transmit pilot signals continuously and to do the related processing even when they are not serving any users, would lead to considerable energy waste for entire femtocell network under low traffic load conditions. Therefore, energy saving techniques need to be exploited by designing efficient mechanisms to enable sleep modes in FBSs.

Another significant issue arises from the fact that femtocells are typically configured to use the same licensed frequency band as macrocells with which they coexist. This is spectrally efficient, but can cause interference issues that become more challenging in dense FBS

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[*] Corresponding author.

*E-mail addresses:* anna.dudnikova@dieei.unict.it (A. Dudnikova), daniela.panno@dieei.unict.it (D. Panno), antonio.mastrosimone@dieei.unict.it (A. Mastrosimone).

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deployments (e.g. in enterprise environments), where femtocells are very likely to be overlapped. The increased level of interference leads to a significant performance degradation of the overall femtocell network.

For the success of dense femtocell networks, both the issues of energy efficiency and intercell interference mitigation should be addressed together optimizing the potential conflicts while, at the same time, trying to minimize the intervention of network operator/user.

Many works in the literature (e.g. [2–6]) have dealt with the above issues separately, neglecting the impact of their simultaneous optimization. In [2–4] only the energy saving issue is addressed, while the interference between adjacent femtocells is not taken into account. These works assume a constant femtocell radius in the downlink irrespective of surrounding radio frequency (RF) environment and femtocell deployment topology, and they propose to switch off unnecessary hardware components of FBSs when not involved in an active call. In [5,6] adaptive coverage control schemes are presented, but the energy saving issue is not addressed.

Other works have proposed solutions aiming at optimizing the two objectives simultaneously. In [7], the scheme includes UE-controlled sleep mode for FBSs in order to reduce power consumption. The FBS that receives the strongest wake-up signal, broadcasted by UEs, is chosen by Femtocell Management Unit to be waken-up. Then each active FBS adapts its transmission power as a function of UEs positions. In [8] FBSs use user activity detection in order to save energy. Active FBSs adjust their pilot power levels in order to minimize co-tier interference following commands of a Femtocell Interference Unit. Both these proposals operates in a centralized fashion which envisages a local femtocell management unit. So, they exploit the advantage of the centralized knowledge of the overall state of the network to implement the optimization strategy. However this results in an increased complexity of the system, mainly due to the need of a central controller and to the information exchange between femtocells and the controller itself, which may cause signaling overhead. Moreover, centralized implementations typically suffer of low scalability and robustness, thus making them not attractive for practical use in expected large-scale femtocell deployment.

In this paper we deal with these problems by proposing a distributed self-configuration approach. It aims at addressing both energy consumption reduction and femto–femto interference issues without requiring a leader or a central control unit, neither information exchange between the base stations of the network. In the proposed algorithm (an improved version of the one presented in [9,10]) we make use of radio measurements integrating in each FBS automatic and autonomous procedures of configuration and optimization of coverage according to the detected on-site user activity. The adaptive nature of the coverage algorithm allows to increase the capacity and the Energy Efficiency (EE) of the overall network. The simulation results show the flexibility, the scalability, the robustness and the stability of our method. Furthermore, we make use of a component-based model to quantify the energy saving achieved by our algorithm taking into account a typical diurnal traffic pattern in a public area.

The paper is organized as follows: in Section 2, the network model and the problem formulation are defined; in Section 3 the detailed description of the proposed power control algorithm is given; in Section 4 the performance of our algorithm is evaluated by MATLAB simulations. Concluding remarks are given in Section 5 and are followed by the Appendix which is dedicated to the decision-making parameters for our algorithm.

## 2. Network model and problem formulation

In the following a two-tier heterogeneous network comprising a single macrocell embedded with a set of FBSs is considered (Fig. 1). Both FBSs and the Macro Base Station (MBS) are assumed to operate using the same OFDMA technology and to use the same licensed frequency band. We assume that the MBS ensures complete coverage, as this is the case in dense public areas where femtocells are likely to be deployed as hotspots of large capacity for the purpose of increasing the throughput and offloading traffic from macrocells. Femtocells are deployed without cell pre-planning and all BSs are equipped with omni-directional antennas. For convenient analysis, some assumptions are made and are listed below.

**Assumption 1.** There is no intra-cell interference in the downlink.
**Assumption 2.** For FBSs the open access mode is adopted, i.e. FBSs behave as regular BSs and are accessible by any UE. This access mode is considered to be used widely for enterprise deployments, in shopping malls, cafes and other public areas [11,12].
**Assumption 3.** Each UE can be served by at most one BS. Cell selection is based on a maximum downlink received power of pilot signal.
**Assumption 4.** FBSs operate in two modes: Listen Mode and Active Mode [4].

Based on "Assumptions 2 and 3", the macro–femto interference is less acute than femto–femto interference. In fact in this scenario UEs which are causing or suffering from interference can be handed over freely between the macro and femtocells [13]. Furthermore, specific macro–femto interference mitigation approaches (e.g. [14–17]) can be additionally applied without deteriorating the performance of our power control scheme. For this reason we focus only on the problem of interference in the femtocell tier.

In regard to the femto–femto interference avoidance schemes, there are two different approaches: those that use intelligent allocation of spectral resources (Physical Resource Blocks (PRBs) in the LTE specifications) [18–20] and those that apply the femtocell pilot power calibration to minimize femtocell overlapping [21,22]. We follow the second approach, therefore we do not take into account the allocation of PRBs to single active UEs' connections. However, the strategies of intelligent resource allocation can be used together with our pilot power control so as to improve the quality of both. In this paper we propose an algorithm that performs a self-optimization coverage

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