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On improving SINR in LTE HetNets with D2D relays

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ABSTRACT

Femtos, with frequency reuse one, can be deployed in hotspots, offices and residences alike to provide high indoor data rates and reduce traffic load on Macro. However, arbitrarily deployed Femtos could decrease SINR significantly because of inter-cell interference and obstacles present in the building. Hence, to attain a desirable SINR Femtos have to be placed efficiently. At the same time, minimizing the power leakage from indoor Femtos in order to improve the SINR of outdoor users in the high interference zone (HIZone) around building areas is also important. To guarantee minimum SINR to both indoor UEs (*IUEs*) and outdoor UEs in HIZone (*HIZUEs*), we apply the concept of device-to-device (D2D) communication wherein free/idle IUEs act like UE-relays for HIZUEs. We first formulate a D2D MILP model which establishes D2D pairs between free/idle *IUEs* and *HIZUEs* and also guarantees certain SINR threshold ($SINR_{th}$) for both *IUEs* and *HIZUEs*. As D2D MILP model takes more computation time, it is not usable in real-world scenarios for establishing D2D pairs on the fly. Hence, we propose a two-step D2D heuristic algorithm for establishing D2D based relay pairs. In step one (called as hDPRA), it efficiently chooses potential D2D based relay pairs and allocates radio resources to them. In step two (called as hDPA), a Linear Programming (LP) model is formulated for power control of D2D links. We have evaluated the performance of the proposed D2D heuristic algorithm for different scenarios (i.e., 500 topologies) by varying densities of IUEs and HIZUEs. From our evaluation, we find that the proposed algorithm maintains almost the same SINR as that of *Full Power Femto scheme* (i.e., Femto transmits with maximum power) for *IUEs* and also guarantees certain minimum $SINR_{th}$ for *HIZUEs*. Our simulation results show that in comparison to the *Optimal Femto Power* (OptFP; Sathya et al., 2014) scheme (i.e., Femto transmits with optimal reduced power), it improves SINR of IUEs by 40%. However, the degradation in SINR of IUEs is only 1.6% when compared to the *Full Power Femto scheme*.

1. Introduction

The increased use of mobile devices has led to an increase in the demand for data services over cellular networks. This is partly addressed by intensifying the deployment of Macro Base Stations (MBSs) in the Long Term Evolution (LTE) cellular networks. The mobile operators can boost data rates for outdoor user equipments (*OUEs*) but are not able to increase the data rates for indoor user equipments (*IUEs*). This is because it is difficult for electromagnetic signals to penetrate through walls and floors. Thus, the *IUEs* suffer with low signal strengths. To demonstrate this, let us consider a single-floor building with a single MBS (interchangeably used as Macro in rest of this paper) placed at a distance of 350 m [2] on the south west side of the building. By taking into account path losses due to walls and floors, the region up to which the signal from MBS can penetrate into the building is then measured and shown in Fig. 1. This figure shows the radio environmental map (REM) of the building where *Z*-axis is used to list out signal to noise ratio (SNR) values at various sub-regions (X, Y) inside the building. Owing to the walls inside the building, *IUEs* on average receive low SNR (e.g., −8 dB, −9 dB) compared to *OUEs* (e.g., 4, 2, 0, −1 dB).

Cisco VNI Mobile Forecast [3] (2014–2019) tells that although only 3.9% of mobile connections were LTE based they accounted for 40% of the mobile traffic and this will rise to 51% by 2019, by which the mobile data usage will grow 11 fold to over 15 exabytes per month. Reports by Cisco and Huawei [4] tell that 70% of the traffic is caused by indoor users (*IUEs*). Hence, it is very important for telecom operators to improve coverage of indoor areas and boost data rates of *IUEs*. To achieve this, one can deploy a large number of low power nodes (LPNs) a.k.a. small cells (e.g., Picos and Femtos [5]) under an umbrella MBS coverage and thereby form an LTE heterogeneous network (HetNet). This increases spectrum

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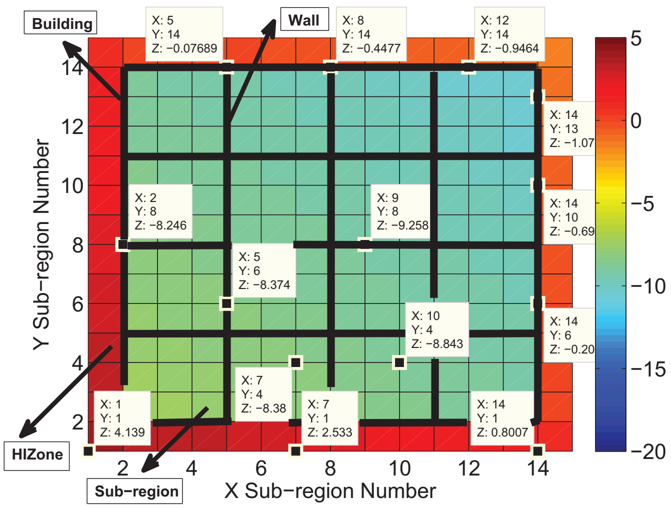

Fig. 1. REM of sub-regions inside building without any Femto cells deployed indoor.

efficiency by allowing spatial reuse of the same spectrum. Small cells can be installed by end users in residences and in large office environments and hotspots. But, co-tier interference among Femtos can occur, if they are placed arbitrarily and the operator tries to reuse the same spectrum, which would decrease the system capacity. In order to make the usage of spectrum more efficient for *IUEs*, placement of Femtos needs to be optimal. Optimal placement of Femtos ensures good SINR and thereby improves system capacity. In this work, we apply the Minimize Number of Femtos (MinNF [1]) model (explained in detail in Section 4) to determine the optimal count and the optimal placement of Femtos and hence reduces operator's CAPEX and OPEX. Hence, we expect that large scale enterprises could benefit from MinNF model based deployment. However, in some scenarios, operator's may need to go for sub-optimal or arbitrary deployment (due to physical constraints) which will lead to deployment of more number of Femtos than that in MinNF to ensure that there are no coverage holes. Even optimal placement of Femtos inside a building leads to power leakage at the edges/corners of the building. This degrades the performance of the *OUEs* (i.e., Macro connected) in high interference zone (HIZone) around the building area because both Macros and Femtos operate at the same frequency due to reuse one in LTE HetNets. In our work we specifically refer the *OUEs* in *HIZone* as *HIZUEs*.

To guarantee certain minimum SINR to both *IUEs* and *HIZUEs*, we apply the concept of device to device (D2D) communication in LTE HetNets. In D2D, devices (i.e., UEs) communicate directly with each other while the serving BS assists in setting up of D2D links and managing the control plane, authentication, handovers, etc. D2D helps in improving the cellular network capacity and power efficiency. In our work, we make use of idle *IUEs* as relays between Femtos and *HIZUEs* through *D2D* as an underlay to the LTE HetNet. We formulate a Mixed-Integer Linear Programming (*MILP*) model that chooses D2D pairs, and assigns radio resources and transmission power to each of D2D pairs. To reduce the time complexity, we propose a two-step heuristic algorithm. In step one, we find the sub-optimal D2D pairs and assign the radio resources for them. In step two, a Linear Programming (*LP*) model is used to determine the transmit power for D2D pairs.

Table 1 shows notations used in this work. Rest of the paper is organized in the following manner. Section 2 describes the related research works. Proposed LTE HetNet system architecture with D2D links is presented in Section 3. In Section 4, proposed placement MILP model which minimizes number of Femtos to be deployed, D2D MILP model and D2D heuristic algorithm are discussed. Performance results are explained in Section 5. Finally, Section 6 contains concluding remarks.

Table 1
Notations used in our work.

Notation	Abbreviations
D2D	Device-to-device
HIZUE	*OUE* in *HIZone*
HIZone	High interference zone
IUE	Indoor UE
LPN	Low power node
LP	Linear Programming
MBS	Macro Base Station
MILP	Mixed Integer Linear Programming
MinNF	Minimize the Number of Femtos
OptFP	Optimal Femto Transmission Power
PRS	Position Reference Signal
RB	Resource block
SINR	Signal-to-interference plus noise ratio
$SINR_{th}$	Threshold SINR
SON	Self Organizing Network
UE	User Equipment

2. Related research work

Many approaches to placing Femtos have been discussed in literature with sufficient insight, keeping in mind various parameters such as building dimensions, interference from Macro BSs and other Femto BSs. In [6], small cell locations are optimized in an airport environment depending upon the traffic demand. In [7,8], Guo et al. suggested an automated small cell deployment model which attempts to find the optimal location of a new cell, subject to knowledge about the locations of existing cells, UEs and the building environment. A closed-form equation is given for the new cell's deployment location which is a function of transmit power, transmission scheme and path loss parameters. In [9], the authors investigated a joint Femto placement and power control optimization problem in enterprise buildings with the aim to prolong UEs' battery life. They proposed a novel two-step reformulation approach to convert the original mixed-integer non-convex problem (MINCP) into a MILP and then devised a global optimization algorithm by utilizing the MILP. But their system model did not consider co-tier and cross-tier interferences. In [10], Femtos are optimally placed in a multi-storey enterprise building by not considering co-tier and cross-tier interferences. In [11], the authors proposed an iterative algorithm for optimizing deployment locations of cells based on a novel utility function (i.e., area proportional fairness utility which accounts for both user distribution and fair resource allocation) while accounting for mutual interference. Authors in [12] proposed an algorithm which gives the optimal transmission power of each of the Femtos deployed in a HetNet scenario by guaranteeing $SINR_{th}$ for IUEs and lesser degradation for *HIZUEs*. However, Femto power adaptation has not factored in occupancy level of *HIZUEs* outside the building.

In one of our previous works [13], an optimization problem is formulated for Femtos deployment which guarantees $SINR_{th}$ inside the building by considering co-tier interference, cross-tier interference and impedance caused by walls. We also varied the $SINR_{th}$ depending on average user density in each region inside the building. This resulted in improving spectral efficiency of Femtos deployed in indoors. However, *HIZUEs* suffered degradation in SINR due to cross-tier interference between Macros and Femtos. In [1], optimal placement of Femtos and dynamic control of their transmit powers are studied by solving two optimization models, namely MinNF and OptFP. MinNF determines the minimum number of Femtos