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Power Efficient Group Communication in Small Cell Networks

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Abstract

Small Cell Networks (SCNs) constitute a new promising way for increasing coverage, boosting data rates and lowering capital and operating expenditures (CAPEX and OPEX) of today's mobile networks. In this paper, we deal with the problem of efficient power control in SCNs. We propose and evaluate an efficient power control mechanism for SCNs, which efficiently controls the available power resources of the network, while on the other hand guarantees home users' Quality of Service. We introduce the methodology of Priority Grouping, in which home users in the topology, are assigned to one of a number of predefined groups, with different priorities, in terms of traffic requirements. Furthermore, the mechanism dynamically updates the power setting of home base stations, based on the topology of the macro and home users in real time.

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Keywords: Small Cells; Power Control; Radio Resource Allocations; Radio Resource Management; LTE; Femto cell

1. Introduction

Small Cells represent an effective way to improve efficiency, cell coverage and network capacity of next-generation mobile networks, while on the other hand the deployment cost for the service provider is kept in extremely low level [1]. Although Small Cell Networks (SCNs) provide several benefits for operators and users alike, their massive deployment comes with a number of technical challenges. Notably, an important and detrimental problem facing SCNs is the presence of interference among neighboring SNCs, and between the SNCs and the macrocell Long Term Evolution (LTE) network [2]. Several solutions are presented in the bibliography about how to mitigate interference in co-channel femto-to-macro Downlink (DL) interference [3][4][5][6]. These studies have consistently shown that a coverage-hole exists when co-channel femto cells are

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deployed in a macrocell overlay network. Additionally, the studies have shown that although a femto cell can cause interference to other users in the system, the interference can be well controlled on both the downlink and uplink, if proper interference management techniques are used [6][8].

A major portion of the existing literature has investigated the interference management issues of integrated LTE and Small Cell deployments [3][4][5][6][6][8]. However, the area of Power Control in SCNs is not thoroughly investigated in the literature. A joint admission and power control algorithm, where the small cells can determine jointly their admissibility and transmit power autonomously is introduced in [10]. Authors in [11] present a study of Power control in two-tier femto cell networks, where an algorithm that reduces transmission power of the strongest femto cell interferer is proposed. A distributed algorithm for downlink resource allocation in multicarrier small cell networks is also introduced in [12]. In this algorithm, each home base station selects the allocation strategy to maximize a surplus function comprising both, own cell utility and interference prices.

Although the above presented approaches provide an adequate solution to the problem of power control and interference management in SCNs, they present a number of drawbacks that make difficult their widespread adoption in SCNs, since they don't cover all the possible topology and traffic scenarios that can be realized in SCNs. In this paper, we propose a power control mechanism for efficient power allocation in SCNs. The mechanism dynamically updates the Home evolved Node B (HeNB - home base station) power setting in real time, based on the topology of the macro and home users, the requested traffic scenario by the users, as also takes into consideration both macro and home users' mobility. To achieve this, we introduce the methodology of Priority Grouping, in which each Home User Equipment (HUE) in the topology is assigned to one of a number of predefined groups with different priorities in terms of power requirements and requested traffic load. The mechanism performs power control per group and thus a more efficient usage of the available power resources of HeNB is achieved. In each group, the most appropriate algorithm which meets the traffic requirements of each group is selected each time. The usage of Priority Grouping can result in a combined usage of more than one power control algorithms at HeNB, depending on the traffic scenario. Furthermore, depending on the examined traffic scenario, the mechanism can provide better protection (in terms of interference) either on macro users or on home users. The proposed mechanism is evaluated through a user-friendly graphical tool designed to reproduce and calculate the optimal transmission parameters, via a graphical representation of the entire topology for a highly customizable network configuration.

2. Power Control in Long Term Evolution Small Cell Home Base Stations

In this section, we focus on the description of a number of power control algorithms which can be used on a Frequency Division Duplex LTE Small Cell HeNB. A typical topology of such a network is presented in Fig. 1. In the LTE terminology, HeNBs are also known as femto cells, thus the terms HeNB and femto cell will be used interchangeably in this paper.

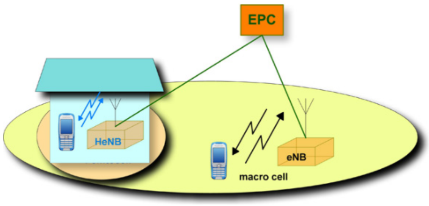

Fig. 1. Topology of an FDD LTE Small Cell HeNB

The most common power algorithms for HeNB Power Control as defined by the 3GPP are presented below:
Algorithm 1. Fixed HeNB power setting mode [8]

Algorithm 2. Smart power control based on interference measurement value from macro NodeB [8], [13]

Algorithm 3. HeNB power control based on HeNB-MUE path loss [8]

In **Algorithm 1**, Network Operator typically sets HeNB transmission power manually. HeNB power can be adjusted by the network operator, if necessary.

In **Algorithm 2**, HeNB adjusts its maximum DL transmit power in relation to air interface measurements to avoid interfering with macro cell UEs. The HeNB adjusts its maximum transmit power according to the following formula:

$$P_{tx} = \max(\min(\alpha \times (CRS\,\hat{E}_C + 10\log(N_{RB}^{DL} \times N_{SC}^{RB})) + \beta, P_{\max}), P_{\min}) \tag{1}$$

where: parameters P_{max} and P_{min} is the maximum and minimum HeNB transmit power settings, $CRS\ \hat{E}_c$ is measured in dBm, which refers to the RSRP per resource element present at the Home BS antenna connector received from the strongest co-channel macro cell. N_{RB}^{DL} is the number of downlink resource blocks in the HeNB channel. N_{sc}^{RB} is the number of subcarriers in a resource block ($N_{sc}^{RB} = 12$). Parameter α is a linear scalar that allows altering the slope of power control mapping curve, β is a parameter expressed in dB that can be used for altering the exact range of $CRS\ \hat{E}_c$ covered by dynamic range of power control. Parameters P_{min}, α, and β are considered to be HeNB configuration parameters, and P_{max} refers to the HeNBs maximum transmition power.

According to **Algorithm 3**, HeNB adjusts the downlink transmit power by considering the path loss between the HeNB and an outdoor neighbor MUE including penetration loss in order to provide better interference avoidance for the MUE while maintaining sufficient HeNB coverage for HUEs.

HeNB sets the transmit power of reference signal P_{tx} as follows:

$$P_{tx} = \text{MEDIAN}(P_m + P_{offset}, P_{tx\_upp}, P_{tx\_low})[dBm] \tag{2}$$

where: P_m (dBm) is RSRP from the nearest Macro evolved NodeB (MeNB) measured by the HeNB. P_m is dependent on path loss, which includes the penetration loss between the nearest MeNB and the HeNB. P_{offset} (dB) is the power offset described in equation 3 in detail and P_{tx_upp}/P_{tx_low} (dBm) is the upper/lower limit value for the transmit power of the reference signal [9].

P_{offset} above should be defined as the path loss which may consist of indoor path loss between the HeNB and cell edge of HeNB cell and the penetration loss. Therefore, P_{offset} should be formulated as follows:

$$P_{offset} = \text{MEDIAN}(P_{offset\_o} + K{*}LE, P_{offset\_max}, P_{offset\_min}) \tag{3}$$

where: P_{offset_o} (dB) is a predetermined power offset value corresponding to the indoor path loss. Typical value range between 50 and 100dB. K is an adjustable positive factor which can be determined by the priority of HeNB operation. This value should be high to increase the total transmit power (macro NodeB is more acceptable to higher interference) and low to reduce the interference to macro NodeB operation. LE (dB) is estimated penetration loss as below. $P_{offset\_max}/P_{offset\_min}$ (dB) is the maximum/minimum value of the P_{offset} by which the estimated and calculated P_{offset} can be prevented from being too large or too small. This value is dependent of the actual wall penetration loss plus P_{offset_o}. The typical wall penetration loss ranges between 10 and 30dB.

3. Proposed Mechanism Supporting Power Efficient Group Communication

In this section, we present a power control mechanism that makes efficient use of the above presented algorithms so as to provide an efficient solution to the problem of power control in future SCNs. A block diagram of the mechanism is presented in Fig. 2. Our mechanism senses the topology and traffic scenario requirements in real time and selects each time the algorithm(s) that best fit to the current topology instance and traffic scenario. We introduce the methodology of Priority Grouping, in which each HUE in the topology is assigned to one of the available groups, with different priorities in terms of power requirements and traffic load. The use of Priority Groups can result in a combined usage of more than one power control algorithms from the HeNB, depending on the traffic scenario. This in turn means that HeNB performs a more efficient power allocation and interference management.

More specifically, the scheme consists of four distinct operation phases. These are: **Initialization phase**, **Algorithm Selection phase, Power** Computation **phase**, and **Group Assignment phase**. HeNB is the responsible node of the SCN architecture for the operation of this mechanism.

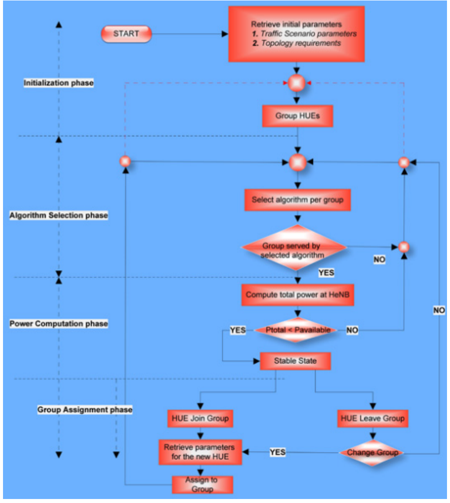

Fig. 2. Block diagram of the proposed mechanism

Regarding the **Initialization phase** (Fig. 2), at first, the mechanism categorizes HUEs that reside in the topology based on their traffic requirements, to a predefined number of N_G priority groups. In each of those groups, a target mean HUE throughput (Th_{target}) is set. For example, a HUE with heavy traffic requirements (ex real time streaming) is categorized to a priority group with high value of Th_{target}, while a HUE with reduced traffic requirements (ex. http browsing) is categorized to a priority group with low value of Th_{target}. What we want to achieve with this categorization is to distinguish between the HUEs that their traffic scenario require increased power resources and those HUEs that have reduced power requirements. In addition, we assume that the maximum available power ($P_{available}$) is known to the HeNB.

In **Algorithm Selection phase**, the power control algorithm that will firstly be adopted by each of the N_G groups is selected. At this stage, the mechanism selects the algorithm that requires minimum initial power as the starting algorithm of the group. Following this, in each group the mechanism checks if the starting algorithm could serve the dedicated for the group traffic load, taking into account the mean HUE throughput per group (Th_{target}), the number of HUEs in each group as well as their location within the femto cell. In each group, if the selected algorithm has enough power to support the traffic requirements of the group, the mechanism enters the **Power Computation phase**. Alternatively, the mechanism selects another starting algorithm(s) for the group(s) that their traffic load cannot be served by the previously selected starting algorithm(s).

In **Power Computation phase**, the total power (P_{total}) is calculated in HeNB, as a sum of the required power in each of the N_G priority groups. Following this, P_{total} is compared to $P_{available}$ in order to secure that the system's total power is kept in an acceptable level. If $P_{total} < P_{available}$ the mechanism enters the stable state which means that all users in the topology are served well with respect to their traffic requirements. In case where $P_{total} > P_{available}$, the mechanism need to reduce the system's total power either by proceeding to the reselection of the power control algorithm per group or by performing a total system regrouping. On **stable state**, in each group, the algorithm that results in minimum total power of the HeNB is selected with respect to the performed priority grouping. In other words, in each group, the selected algorithm requires the minimum acceptable power in order to serve the total throughput of the HUEs that constitute each group.

Group Assignment phase is dedicated to perform the assignment of HUEs to the available priority groups. For any new HUE that is activated within the coverage area of the Home eNB, the mechanism performs an HUE assignment to the available priority groups depending on the traffic requirements of the new HUE. On the contrary, if an HUE leaves the coverage area of the home environment, the mechanism removes the corresponding HUE from the priority group that was assigned. Since HUEs are characterized by mobility and depending of the traffic requirements of an HUE, the mechanism could move an HUE from a priority group to another in order to secure the efficient power management of the whole system.

4. Performance Evaluation

4.1. Experiment Results

The simulation parameters that are necessary for the conduction of the experiment are presented in Table 1. The SCN topology consists of multiple adjacent macro cells, multiple femto cells that are uniformly distributed in the network and multiple macro and home users. Macro users as well as home users are uniformly distributed in the topology and they can move to any direction within macro cell and home area respectively. The source code of the implemented mechanism is available in [15].

Table 1.Simulation parameters

Parameter	Units	Value
Inter-site distance	m	500
Channel model		3GPP Typical Urban
Path loss	dB	Cost 231 Hata Model
BS transmit power	dBm	43
HeNB power between	dBm	[-10 dBm, 10 dBm]
Antenna Gain	dBi	14
Fixed Power for Algorithm 1	dBm	-3
HeNB operation mode		Closed Subscriber Group
N_G (priority groups)		3
Group 1/Group2/Group3 Th_{target} for experiment 1	Mbps	1.2/ 0.2/0.05
Group 1/Group2/Group3 Th_{target} for experiment 2	Mbps	1.2/ 0.65/0.05

For the needs of results' presentation, we conducted two experiments. In both experiments, we consider a 9 macrocell and 10 femto cell network with 150 MUEs, 50 initial HUEs and approximately additional 120 HUEs gradually distributed in time domain (Fig. 3). Additionally, HUE population is increased with a constant low rate (about 5% of HUEs population) throughout the first half of each simulation, while in the second half, HUE population increased rapidly (about 10% of HUEs population). Finally, in order to evaluate the ability of our mechanism to efficiently handle HUEs transition from one group to another, we extended the simulation time of the second experiment. During that period (steps 20-25 in Fig. 5a and Fig. 5b), 60% of group 2 users are moved to group 3. In the remaining of this section, the proposed mechanism is also referred as algorithm 4.

4.1.1. First experiment

Fig. 3 displays an overview of the entire SCN topology. In order to efficiently present the results, we focus on femto cell number 13 of the topology depicted on Fig. 3. Fig. 4a presents the comparison of the mean throughput achieved by all HUEs that reside in femto cell 13, as also the mean throughput achieved by each group of the algorithm 4 (proposed mechanism) in the same femto cell. Furthermore, Fig. 4b depicts the evolution of HeNB transmit power for each power control algorithm, as well as the HUE population evolution per group in time domain. Additionally, Fig. 4b presents the algorithm that is selected each time, for each group, by our mechanism in order to perform efficient power allocation at HeNB.

By combining the subplots of Fig. 4b, we can assume that algorithm 4 (proposed mechanism) selects algorithm 3 for serving group 1 on steps 0-1 and then chooses algorithm 2 for the rest of the experiment. This happens because in steps 0-1, group 1 has small HUE population and most of the HUEs are located in femtocell edge, so high power is needed in order to achieve the target mean throughput of the group (1.2 Mbps see Table 1). One step later, even if HUE population of the group 1 starts rising, most of these HUEs are located in the center of femto cell 13. This means that less power is needed to support group 1 users and thus the proposed mechanism performs an algorithm switch from algorithm 3 to algorithm 2 (as shown in Fig. 4b).

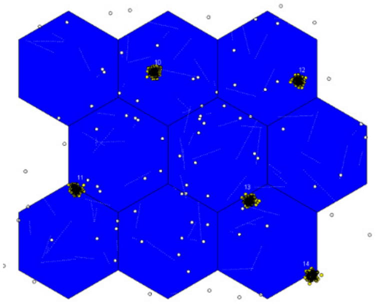

Fig. 3 Topology of the experiments

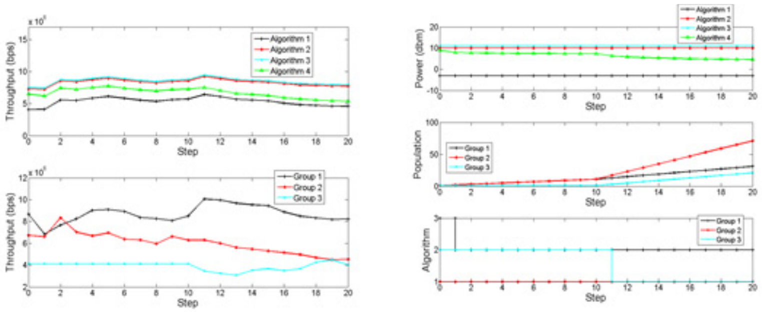

Fig. 4 (a) Achieved throughput for cell 13–Experiment 1; (b) Power selection for cell 13–Experiment 1

Regarding group 3, the mechanism chooses algorithm 2 for serving the HUEs on steps 0-11 and then chooses algorithm 1 for the rest of the experiment. That happens because on steps 0-11, there are only few HUEs on group 3, while on steps 11-20, the population of HUEs starts rising with a higher rate and also, the vast majority of the HUEs of the group for second half of the simulation are located near the center of the femtocell 13. This means that less power is needed to support group 3 users and thus, the proposed mechanism performs an algorithm switch from algorithm 2 to algorithm 1 (as shown in Fig. 4b), so as to efficiently use the power resources. Group 2 users are efficiently served by algorithm 1 throughout the whole duration of the simulation.

Moreover, combining Fig. 4a and Fig. 4b, we can say that even if algorithm 1 achieves the lowest power from all the other algorithms, the mean throughput it achieves (approximately 5Mbps average) is lower than the target throughput needed to support the traffic load of group 1 (approximately 9Mbps average). This means that the specific traffic scenario cannot by served by the solely usage of algorithm 1, throughout the whole duration of the simulation. On the other hand, algorithms 2 and 3 are capable to serve the HUEs with respect to the target throughput, but there is waste of power resources if we compare them with the proposed mechanism (algorithm 4). Our mechanism (algorithm 4) is capable to achieve the target throughput per group, while on the other hand optimally handles the available power resources of HeNB. To conclude, the proposed mechanism results in mean power saving at HeNB over 35% compared to algorithm 2 and over 42% compared to algorithm 3.

4.1.2. Second experiment

Fig. 3 displays the overview of the entire SCN topology for the second experiment. In this experiment, we want to evaluate the ability of our mechanism to handle the transition of home users from one group to another. For this purpose, we have modified the traffic scenario of the first experiment as follows: we have increased the target throughput of group 2 from 0.2 to 0.65 Mbps and we have extended the simulation time to 25 steps. In particular, HUE population is increased with a constant low rate (with a rate 5%) during steps 1-10 of the simulation, while during steps 11-20, HUE population increased rapidly (with a rate 10%). Finally, in the last 5 steps (period 20-25 Fig. 5a and Fig. 5b), 60% of group 2 users are moved to group 3. In order to better present the results, we focus on femto cell number 13 of the topology depicted on Fig. 3. Fig. 5a presents the comparison of the mean throughput achieved by all the HUEs which reside in femto cell 13, as also the mean throughput achieved by each group of the algorithm 4 (proposed mechanism) in the same femto cell. Furthermore, Fig. 5b depicts the evolution of HeNB transmit power for each power control algorithm, as well as the HUE population evolution per group in time domain. Additionally, Fig. 5b presents the algorithm that is selected each time, for each group, by our mechanism in order to perform efficient power allocation at HeNB.

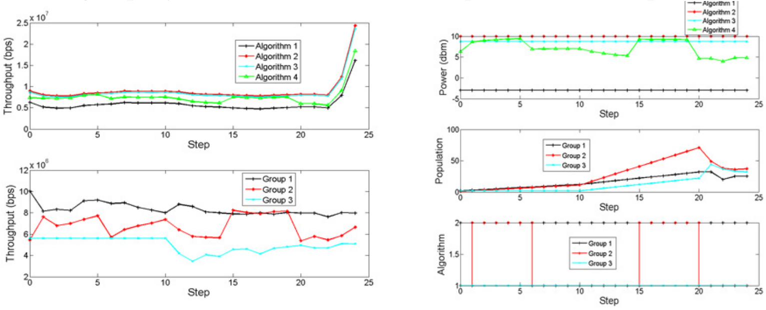

Fig. 5 (a) Achieved throughput for cell 13–Experiment 2; (b) Power selection for cell 13–Experiment 2

Fig. 5b shows that the proposed mechanism (algorithm 4) selects algorithm 1 for serving group 3 and algorithm 2 for serving group 1, throughout the whole duration of the experiment. The analysis of the behavior of our mechanism for these two groups is identical to the analysis presented in the previous section. However, we want to focus the analysis on the last part of the simulation (steps 20-25), where the transition of HUEs from group 2 to group 3 has taken place. Just before the abrupt transition of group 2 HUEs to group 3 (step 20), group 2 is served by algorithm 2, while group 3 by algorithm 1. The abrupt transition of HUEs from group 2 to group 3 results in a significant decrement of the mean throughput achieved by group 2 HUEs (target mean throughput for each group 2 HUE is 0.65 Mbps see Table 1), as presented in the second plot of Fig. 5. Our mechanism responds to this change by performing an algorithm switch from algorithm 2 to algorithm 1 for the group 2, since the number of group 2 HUEs is significantly reduced. Thus, less power is needed to support group 2 users and there is no need to waste power keeping algorithm 2 active. As shown in Fig. 5b, the mean power saving at HeNB during the last five steps of the experiment is over 50% compared to algorithms 2 and 3. Concerning group 1 HUEs, even if its number is significantly increased during the last five steps of the experiment, the mechanism (algorithm 4) continues to use algorithm 1 as the active algorithm for the specific group. This happens because the low value of target throughput of group 3 HUEs (target mean throughput for each group 3 HUE is 0.05 Mbps) doesn't result in a significant change in the total group 3 throughput as presented in second plot of Fig. 5a.

5. Conclusions And Future Work

In this paper, a power control mechanism for Small Cell Networks is presented. The mechanism efficiently controls the available power resources in HeNB, while guarantees home users' QoS. To achieve this, the methodology of Priority Grouping is introduced. With Priority Grouping, home users are assigned to one of the predefined available groups with different priorities in terms of power requirements and requested traffic load. The mechanism performs power control per group. In each group, the most appropriate algorithm which meets the traffic requirements of each group is selected each time. The use of Priority Grouping results in a combined usage of more than one power control algorithms from the HeNB depending on the traffic scenario. The results prove that the proposed mechanism results in significant power saving at HeNB, compared to existing approaches, where only one power control algorithm is utilized by HeNBs. In particular, by enabling HeNBs to use more than one power control algorithms simultaneously, this could lead to power gain up to 30% compared to existing approaches. The steps that follow this work include the evaluation of the mechanism through additional simulation scenarios, so as to estimate the algorithm switching points of the mechanism. This information could be used as feedback to the mechanism in order to improve its performance. Furthermore, the complexity that the mechanism inserts in HeNB due to its dynamic and periodic nature could be investigated.

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