Database-aided Energy Savings in Next Generation Dual Connectivity Heterogeneous Networks

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***Abstract*—This paper studies potential energy savings that can be realized in dual connectivity heterogeneous networks (HetNets) with densely deployed small cells. Using the Phantom Cell Concept (PCC) as a reference architecture, a novel database-aided mechanism is introduced to provide macro cell-controlled sleep mode functionality to small cells. System level simulations show that a system with this capability can yield energy savings of up to 40% and throughput gains of about 25% in dense deployment scenarios compared to a system where no energy savings scheme is implemented.**

I. Introduction

The proliferation of smartphones and other internet-enabled portable devices is currently putting a strain on many wireless networks. Still, the data rate and quality of experience (QoE) demands expected in the future is expected to drive global traffic in wireless networks to unprecedented levels. By 2015, it is expected that the global amount of wireless traffic will reach 15 to 30 times the 2010 levels, and by 2020, a 1000-fold increase with respect to 2010 levels is expected [1] [2].
To fulfil these stringent requirements, wireless network researchers are exploring two potential avenues, namely network densification, *i.e.,* increasing the amount of deployed small cells, and spectrum extension, *i.e.,* using new frequency bands to transmit wireless signals. Both of these approaches can be found in the dual connectivity heterogeneous network (HetNet) architecture, where a user equipment (UE) is both connected to a macro base station (BS) as well as to a small cell BS. Such a scheme can be used to transmit the control plane (C-plane) signalling on the macro BS, providing a continuous reliable cell coverage layer to users at a lower frequency band, and to transmit the user data plane (U-plane) traffic on the small cells using a higher frequency band, offering high capacity and throughput. This is the case in the Phantom Cell Concept (PCC), a dual connectivity HetNet system developed by NTT DOCOMO, Inc. in Japan [3].
In practical deployments, the achievable capacity of such ultra-dense networks can deteriorate because of severe interference from many neighbouring small cells. Additionally, these networks consume a significant amount of energy due to the operation of a large number of small cells. The impact of high energy consumption is not only environmental, since it is estimated that the ICT industry is responsible for 2% of the global CO_2 emissions [4], but also economic, since it results in high operating expenses for network operators. Therefore, energy efficiency is a very important aspect to consider.
It has been suggested that significant energy savings in dual connectivity ultra-densely deployed networks can be achieved by enabling the small cells to be put to sleep or turned off when not in use [5]. Furthermore, the level of interference in the small cell network is also expected to be reduced, due to the fact that reducing the number of active small cells also reduces the number of interferers.
Several schemes have been proposed to put small cells in a *sleep* state when not in use in order to achieve energy savings, such as in [6] or [7]. In state of the art schemes, the action of turning *on* or *off* the small cells is generally performed by signalling on the small cell radio link, such as in the schemes proposed in [6]. One scheme is based on uplink (UL) signalling, where the radio frequency (RF) receiver chain of the small cell is kept on even when the cell is in *sleep* mode, and the other one is based on downlink (DL) signalling where the RF transmitting chain of the small cell has to be turned on periodically in order to transmit beacon signals. However, these schemes are suboptimal in terms of energy consumption due to the overhead created by leaving one of the RF chains *on* even when the small cell is in *sleep* mode. Additionally, small cell activation procedures implemented in these schemes require some signalling overhead which can lead to delays of up to 400 ms, thereby degrading end user QoE [8].
In this paper, we introduce a QoE-aware implementation of the PCC, where the macrocell is equipped with a database storing data regarding the channel quality so that UEs can obtain an estimation of a small cell channel even when both the RF receiving and transmitting chains of the small cell are completely deactivated, *i.e.,* when the small cell does not monitor UE signals and does not transmit pilot symbols.

II. System Concept and Architecture

In this section, we introduce the architecture of the considered system, based on the PCC architecture as defined in [3].

A. System Architecture

The architecture of the system is illustrated in Figure 1. The system concept is comprised of two overlaid networks:

- C-plane, comprised of control plane base stations (C-plane BSs) or *macro cells*, operating in legacy frequency bands (*e.g.,* 2 GHz) and using standardized systems (*e.g.,* 3GPP Long Term Evolution (LTE)), guaranteeing backwards compatibility for legacy UEs, *i.e.,* UEs which just support legacy standards;
- U-plane, comprised of user data plane base stations (U-plane BSs), also called *small cells*, operating in higher frequency bands (*e.g.,* 3.5 GHz), and connected to one C-plane BS through a backhaul link.

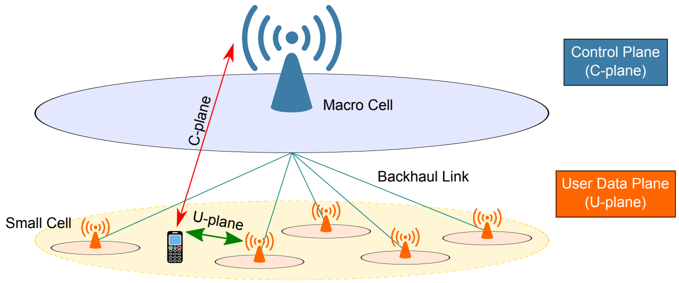

Figure 1. Representation of the considered system architecture

Two modes of operation are considered:

- *legacy mode*, in which the macro cell takes care of the transmission of both control signals and user data signals, and where the small cells are not in use. This mode is used either to support legacy UEs, which are not able to connect to small cells, or to support a low number of small cell-compatible UEs (which we henceforth refer to as newer UEs) with very high mobility or with lower data rate requirements;
- *small cell (SC) mode*, only accessible to newer UEs, in which the macro cell is responsible for C-plane communication, and the small cells for U-plane communication. This is the same utilization mode as envisaged in the PCC [3].

B. Issues Arising when Putting Small Cells to Sleep

At a given time, it is assumed that a small cell can be in one of two states, namely the *on* state and the *sleep* state.

- In the *on* state, small cells are fully operational and send both user data to connected UEs and pilot symbols to enable other UEs to connect. Pilot symbols sent by the small cells enable the users to differentiate each small cell and to estimate the channel between them and the small cells.
- In the *sleep* state, the small cell is in a stand-by mode where it can neither send nor receive any signal over the radio link, but where it can be woken up by the macro cell through the backhaul link, and operational again almost instantly (in about 1 ms).

In state of the art *sleep* mode schemes for small cells [6] or [7], the RF receiving and/or transmitting chains of the small cell needs to be kept on even when the cell is in *sleep* mode, which potentially leads to an energy consumption overhead. In order to maximize energy savings, an alternative solution is to turn off both the RF transmitting and receiving chains of a small cell. However, this leads to two major issues.

- If the RF receiving chain of small cells is turned off, UEs cannot autonomously connect to small cells by sending signals on the radio interface, but need the assistance of the macro cell to do so.
- Additionally, if the RF transmitting chain of small cells is off, UEs cannot detect small cells since small cells stop transmitting pilot symbols. Furthermore, the lack of pilot symbols makes it impossible to estimate the current channel between UEs and small cells in *sleep* state.

In effect, putting small cells to sleep deprives UEs of the information they need to make optimal cell association decisions.

C. Database at the C-plane BS

In order to cope with the discovery and channel estimation issues discussed in section II-B, we propose a system to enable UEs to connect to small cells based on their geographic location information. However, the small cell which can offer the best channel quality is not necessarily the closest small cell to the user. Therefore, we propose to equip each macro cell with a database that can help any UE to choose the most appropriate small cell within the macro cell's coverage area. This database is divided into several partitions, where one partition corresponds to one small cell connected to the macro BS. In each partition, Signal to Noise Ratios (SNRs) of the UE-small cell links are stored, mapped to sets of geographical coordinates (x, y), as shown in Figure 2.

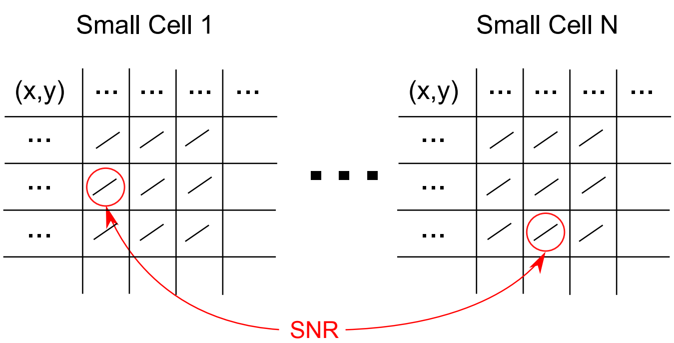

Figure 2. Representation of the macro cell database contents

This way, UEs can always obtain an estimation of a small cell channel, even when the small cell is in *sleep* mode. The geographical coordinates necessary to retrieve the SNR values from the database at the appropriate UE location, can be obtained using standard LTE positioning techniques, such as Assisted-GPS or Observed Time Difference of Arrival [9]. Even though the Signal to Interference plus Noise Ratio (SINR) provide a better measure of the channel quality than the SNR, it depends on the actual network conditions and therefore requires a lot of memory to store all possible network states. As a result, SNR values, which represent only a single network state, are stored in the database instead. Nevertheless, SINR values can still be derived from the stored SNRs using the formula

$$\mathrm{SINR}_i = \frac{\mathrm{SNR}_i}{1 + \sum\limits_{j \neq i} \mathrm{SNR}_j} \tag{1}$$

using linear values of SNRs and SINRs, where i represents the desired source and $j \neq i$ the interfering sources, *i.e.,* other small cells which are *on*.

The best small cell to serve a UE can then be determined from the estimated SINRs using pilot symbols for turned on small cells and from the computed SINR from database values for small cells in *sleep* mode. If the best small cell is in sleep mode, the small cell can be woken up so that its connection procedures with the UE can be initiated. Note that the decision regarding the best small cell can be made either by the UE or by the macro cell depending on the implementation. The question of which of these alternatives is the most efficient is however out of the scope of this paper.

In order to obtain accurate SNR values in the database, the system has to go through a training phase. During the training phase, UEs perform channel estimation measurements on the small cell links and report their results to the macro cell, along with their geographical position. The database is also equipped with an Exponential Moving Average (EMA) system. When an element of the database is empty, the measured SNR is stored directly in the database. However, when a value is already present, it is updated using the forumla

$$s_t = \alpha x_t + (1 - \alpha) s_{t-1} \tag{2}$$

where x_t represents the measured value, s_{t-1} and s_t the previously stored and new stored values, respectively, and α represents the EMA smoothing factor. In our case, we set this smoothing factor to 0.5 so that the measured value and the previously stored value have as much influence on the updated value. More details regarding the database training process are discussed in section III-A of this paper.

D. Maximum SINR *Connection Procedure*

Whenever UEs are required to connect to small cells, they use what we call the *maximum SINR* connection procedure. The basic principle behind this procedure is that UEs always try to connect to the small cell offering the best SINR, regardless if it is already *on* or in *sleep* mode. SINR values are either directly measured from the channel by pilot symbols for U-plane BSs in *on* state, or computed from SNR values retrieved from the macro BS database using equation (1) for U-plane BSs in *sleep* state. The *maximum SINR* connection procedure is represented on Figure 3.

E. Achievable Energy Savings in Sleep Mode

One of the requirements for the system we develop here is that it requires a very high dynamicity since small cells need to be available almost instantly. Therefore, their activation time needs to be very short, of the order of magnitude of a radio subframe, *i.e.,* ca. 1 ms. In state of the art BSs, it is possible to leave the power amplifier at its lowest working point. Such

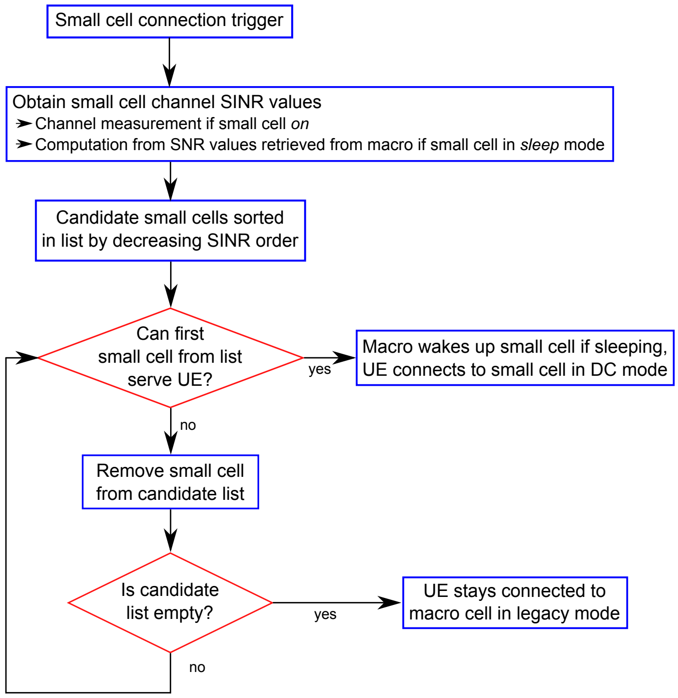

Figure 3. Flow chart representing the *maximum SINR* connection principle

a scheme is called *Micro Discontinuous Transmission (DTX)*, enabling BSs to go to sleep and wake up in about 30 μs [10]. The *sleep* state we assume in the proposed scheme should not be confused with a complete small cell shut down, where almost all the components of the small cells are turned off. A BS in *sleep* mode still consumes a non-negligible amount of energy due to the fact that only parts of its circuitry are turned off. Micro DTX schemes can reduce the energy consumption of macro BSs by about 70% compared to their fully operational energy consumption levels [10]. However, for the smaller BSs we propose to implement as small cells, which approximately have the size of picocells or femtocells, the power amplifier only represents a small fraction of the total energy consumption of the BS [11]. Hence, only 30% reduction in energy consumption is expected when small cell BSs are put to sleep using state of the art *Micro DTX* techniques.

III. System Model and Simulations

The system model used for the evaluation of our proposed scheme is based on 3GPP assumptions on small cell enhancements [12]. A single macro cell site with three sectors and a cell radius of 290 m is considered. A given number of small cells and UEs are uniformly dropped within each sector. The channels between the macro cells and the UEs as well as the channels between the small cells and the UEs are generated according to the 3GPP Spatial Channel Model (SCM). The main parameters used are provided in Table I.

The number of small cells and UEs dropped in the simulation scenario, as well as the required minimal distances between macro cells, small cells and UEs are given in Table II.

Table I
MAIN PARAMETERS FOR THE BSS AND UES

Parameters	Macro cell	Small cell	UE
System bandwidth [MHz]	10	10	-
Carrier frequency [GHz]	2.0	3.5	2.0/3.5
Total BS transmit power [dBm]	46	37	-
Antenna height [m]	25	10	1.5
Receiver antenna gain [dBi]	-	-	0
Receiver noise figure [dB]	-	-	9
3GPP SCM variant	UMa	UMi	-
Moving speed [km/h]	-	-	3

Table II
ADDITIONAL SIMULATION PARAMETERS

Number of small cells	20 per macro cell sector
Number of UEs	Variable, max. 60 per macro cell sector
Minimum distances	Small cell-Small cell: 20 m Small cell-UE: 5 m Macro cell-Small cell: 75 m Macro cell-UE: 35 m

Two simulation steps are performed. In the first step, the training of the macro cell database is performed. In the second step, actual data transmission based on a simplified LTE radio access model is simulated.

A. Initial Database Training Phase

Before a usable database can be obtained, the system has to go through a training process. To obtain a properly trained database, *i.e.,* to obtain clean SNR values of the small cell channels uncontaminated by interference, it is necessary to perform measurements by keeping only one U-plane BS *on* at a time.

The training phase is performed after the system initiliazation and consists of the following steps performed over multiple iterations:

- Some UEs are randomly dropped according to a uniform distribution;
- Channels between small cells and UEs are initialized, according the the 3GPP SCM parameters [13];
- Each UE estimates the offered SNR on each small cell channel, ignoring interferences from other small cells. The measured SNRs are then stored in the database.

The C-plane BS database has a granularity of 5 m for the x and y coordinates, which means that measured SNRs will be stored in discreet elements with $\pm$ 2.5 m accuracy regarding the positions of UEs, in order to take into account potential positioning errors from the geolocation equipment.

B. Data Transmission Phase

The data transmission phase of the simulation starts after database training. We assume a non-full buffer bursty traffic model using the File Transfer Protocol (FTP) model 1, as defined in [14], with an arrival rate $\lambda = 0.5$ and a file size of 2 MB. Note that only DL traffic is simulated, UL traffic is not considered.

Each user present in the system only receives data from BSs when its data buffer is not empty. Otherwise, it is considered to be in idle state and is therefore neither connected to any small cell nor to a macro cell. Active users can either receive data from a macro cell if connected in *legacy* mode, or from a small cell if connected in *SC* mode.

Furthermore, each UE possesses a data rate requirement drawn from a Rayleigh distribution with scale parameter σ_{req}. Within the context of this paper, we fix the σ_{req} parameter to 1 Mbit/s, which corresponds to a conventional LTE minimum data rate requirement [15].

Resource allocation and scheduling procedures are performed independently in each macro cell and small cell BS. UEs are only allocated resources on a small cell if they are connected in *SC* mode. In the macro cell, UEs connected in *SC* mode are allocated a very small number of resource blocks (RBs) in order to receive the additional C-plane signalling required by the dual connectivity. The rest of the RBs in the macro cell is allocated to users connected in *legacy* mode, scheduled according to a standard proportional fair (PF) mechanism.

In each small cell, the implemented scheduler performs the resource allocation procedure in a PF manner as well, while keeping track of the number of *available RBs*, corresponding to the total number of RBs minus the number of RBs required by all connected users to meet their data rate requirements.

Note that we consider that a small cell can only serve a user if the number of RBs it requires does not exceed the number of available RBs available on the small cell. This required RBs number can be calculated based on the estimated channel SINR using a Channel Quality Indicator (CQI) mapping table. The corresponding CQI determines the Modulation and Coding Scheme (MCS) used, and hence, the achievable data rate per RB. In this paper, the standard LTE CQI table is used [16].

IV. SIMULATION RESULTS

After running data transmission simulations for a sufficient number of runs, we obtain results for three specific metrics, namely the achieved energy savings by our proposed scheme with respect to a PCC system where all small cells are permanently *on*, the percentage of UEs for which the data rate requirement is satisfied, and the average achieved UE throughput. In addition to assessing the performance of the proposed scheme, we also simulate a system without small cells where users are only served by macro cells for benchmarking purposes.

Figure 4 shows the percentage of achievable energy savings with the proposed scheme. As explained in section II-E, using state of the art *sleep* mode techniques enables to reduce the energy consumption of a small cell in *sleep* mode to 0.7 times the energy consumption of a small cell in *on* mode. However, future technological improvements in BS hardware are expected to further increase the achievable energy savings in *sleep* mode for individual BSs. For this reason, we also analyse situations in which the a small cell in *sleep* mode consumes 0.5, 0.3 or 0 times the power of a small cell in *on* mode.

It can be observed that the amount of achievable energy savings scales well with the number of UEs present per macro cell. For the high *sleep* mode energy consumption of 0.7, the achieved energy savings range from 25% for a low number of UEs im the system, to about 10% in case of high utilization. For the upper-bound case of zero *sleep* mode energy consumption, energy savings as high as 40% can be obtained in dense utilization scenarios.

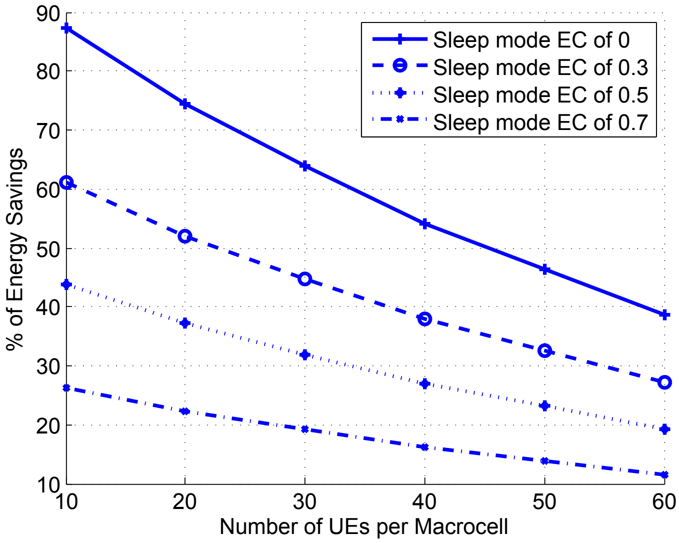

Figure 4. Achieved energy savings by the proposed database-assisted scheme when assuming a *sleep* mode energy consumption (EC) for the small cells of 0.7, 0.5, 0.3 or 0 times the energy consumption of a small cell in *on* mode.

Figure 5 illustrates the satifsaction rate of the network, *i.e.,* the percentage of UEs for which the data rate requirement has been met. Even though the average data rate requirement for each UE is as low as 1 Mbit/s, which is equivalent to a minimum data rate requirement in a LTE system [15], it can be observed that such a requirement cannot be sustained in a conventional LTE network without the help of small cells. Using small cells, however, allows the system to keep a satisfaction rate greater than 70%, even when a large number of UEs is present in the system. Using the proposed database-aided scheme further increases the satisfaction rate by 5-10%. This phenomenon can be explained by the following: although a small cell in the *on* state can help the network to serve more users and hence reduce the load on other cells, it is considered as an interferer for other small cells because of the data it transmits. Therefore, putting a small cell to sleep when no user is connected to it reduces the amount of interference on other small cells' links. This enables other small cells to transmit data using a better MCS, thereby increasing the achieavable data rate and thus the probability that the users' data rate requirement is satisfied. Note that in the considered system, we assume a worst-case interference scenario, *i.e.,* small cells are assumed to always transmit at their maximum output power level when in the *on* state.

It can be argued that the energy consumption and the interference level of the small cells can be reduced by deploying a conventional PCC network with a reduced number of small cells instead of implementing the proposed database-aided scheme. Assuming an energy consumption for small cells in *sleep* mode of 0.5 times the energy consumption of *on* mode, it can be observed that ca. 45% of energy savings are achieved on average when considering 10 UEs per small cell. The equivalent number of deployed small cells per macro cell in a PCC system which would consume the same amount of energy is $20 \times 45\% = 11$ small cells. Similarly, the equivalent number of deployed small cells for the case of 20, 30, 40, 50 and 60 users per macro cell is 12, 13, 14, 15 and 16 small cells, respectively. However, such a scenario consuming an equivalent amount of energy with respect to the database-aided scheme does not reach the performance benefits offered by our proposed scheme. Figure 5 suggests that reducing the number of deployed small cells further degrades the performance of the system. Reducing the number of deployed small cells does not allow the system to obtain the same level of flexibility as obtained with the proposed database-aided scheme.

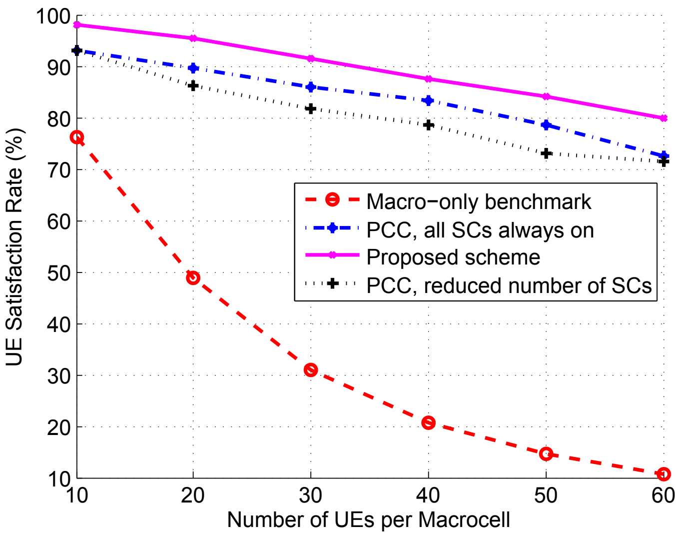

Figure 5. UE satisfaction rate, *i.e.,* percentage of UEs for which the data rate requirement is satisfied. Results are displayed for the benchmark macro cell-only system, for the PCC system where all small cells (SCs) are always on, for the proposed database-assisted energy savings scheme, as well as for the PCC system with a reduced number of deployed small cells (SCs) consuming an equivalent amount of energy to the database-assisted scheme.

The third set of results, displayed by Figure 6, shows the average throughput of users in the system. This metric is obtained by measuring the instantaneous data rate whenever a user is transmitting a packet, and then averaging the measurements over the number of measured packets. First of all, it can be noted that the presence of small cells drastically increases the average achieavable throughput. For a system with 30 UEs per macro cell, the average data rate offered by the PCC with 20 small cells without energy savings scheme is about five times the data rate offered by the macro-only system.

Interestingly, it can be observed that the throughput can be further increased by implementing a *sleep* mode for small cells, especially when the number of users in the system is low (*i.e.,* when a lot of small cells are in *sleep* mode). Nevertheless, even in high utilization scenarios, *i.e.,* with a large number of users present in the system, significant gains can be obtained: in the 60 UEs per macro cell case, the average throughput when using the previously introduced energy savings scheme is about 40% higher than the average throughput achieved when all small cells are left fully on.

Figure 6 also shows that deploying more small cells is always beneficial from a throughput perspective. Specifically, a PCC with 20 small cells deployed and database-aided sleep mode activated always performs better than a PCC with fewer number of small cells which consumes an equivalent amount of energy.

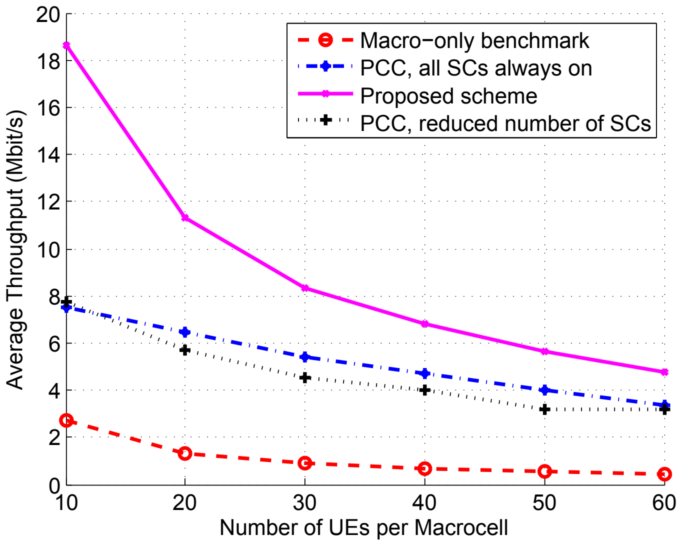

Figure 6. Average UE throughput in Mbit/s. Results are displayed for the benchmark macro cell-only system, for the PCC system where all small cells (SCs) are always on, for the proposed database-assisted energy savings scheme, as well as for the PCC system with a reduced number of deployed small cells (SCs) consuming an equivalent amount of energy to the database-assisted scheme.

V. Conclusion and Future Work

This paper introduces an efficient way to put small cells to sleep without having to keep the RF receiving or transmitting chains of small cells on. The implemented database-aided connection procedure enables us to solve the small cell discovery issue which arises when small cells do not transmit pilot symbols. The simulation results show that the maximum SINR connection procedure offers multiple benefits. The scheme not only enables to reduce the overall system energy consumption of the network, but also allows the users in the system to achieve a significantly higher throughput on average.

We are aware of the limitations of our current simulation assumptions, regarding *e.g.,* the fact that we do not take the delays induced by the BS hardware or by the required signalling procedures into consideration, or that a worse-case interference scenario is always assumed when small cells are *on*. For this reason, we plan to investigate the impact of these assumptions on the performance of the proposed scheme in the near future.

Additionally, we plan to train the database with other metrics, such as SINR or signal strength, which are easier to obtain in a real network situation, and to compare the performance of the proposed scheme to other small cells on/off schemes.

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