Energy Savings in Heterogeneous Networks with Clustered Small Cell Deployments

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***Abstract*—Ultra dense small cell deployments will play a critical role in addressing future capacity requirements in dense urban outdoor and indoor environments such as train stations and shopping malls. Effective interference and energy management schemes will be needed to make such deployments technically and economically viable. In this paper, we demonstrate the benefits of a database-aided energy savings scheme for clustered small cell deployments. System-level simulations demonstrate that the proposed scheme can yield energy savings of up to 30% even when the network is heavily utilized, and offer throughput gains of up to 25% in case few users are present in the network, with respect to a conventional small cell deployment without the energy savings feature.**

I. INTRODUCTION

By 2015, global traffic is expected to reach 15 to 30 times the level of 2010, and by 2020, a 1000-fold increase with respect to 2010 levels is expected [1] [2]. To address this capacity requirement in the radio access network, a combination of network densification, spectrum extension and higher spectrum efficiency techniques will be required [3]. This combination can be found in dual connectivity heterogeneous networks (HetNets), where a user equipment (UE) is both connected to a macro cell base station (BS) and to a small cell BS. While macro cells offer a ubiquitous and reliable cell coverage to users in lower frequency bands, small cells offer high capacity and throughput to users in higher frequency bands with high bandwidths. Thus, the compromise between capacity and coverage, present in traditional network deployments, can be avoided. Such systems have been proposed by NTT DOCOMO, Inc. as the Phantom Cell Concept (PCC) [4] and by Ericsson as the Soft-cell Approach [5].

Another trend in small cell deployments is portrayed by the high need for capacity in public urban hotspots and other indoor locations with high traffic concentration, such as shopping malls, train stations or airports. In order to provide the required capacity to users in these public urban centres, small cells have to be locally deployed in a certain area, in a highly densified fashion. Such an area is known as a small cell cluster. Provisions for small cell cluster-based deployments have been considered by the 3rd Generation Partnership Project (3GPP) in the latest Release 12 of the Long Term Evolution (LTE) standard [6].

While the idea of dense small cell deployments sounds promising, its practical implementation is challenged by several factors. First of all, the fact of having multiple small cells close to each other increases the interference issues, thereby degrading the achievable capacity. Furthermore, increasing the number of small cells leads to an increase of the global energy consumption of the system. A high energy consumption is not desirable, not only due to the environmental impact, but also due to the economic impact, since it results in higher operating expenses for network operators.

Energy savings schemes for dual connectivity HetNets have been proposed in the past, enabling small cells to go into a *sleep* mode (also called *sleep state*), in which they consume a reduced amount of energy [7]. However, these state of the art schemes are based on signalling procedures on the small cell radio link, requiring to keep on the transmitting or receiving parts of the radio frequency (RF) circuitry of the small cell, which is suboptimal in terms of energy consumption.

In order to further reduce the energy consumption of the small cells, an innovative database-aided energy saving scheme was proposed in [8]. In the proposed scheme, a macro cell is equipped with a database, which stores geographic-based channel quality information for all small cells under the control of the macro cell. This allows small cells to remain discoverable even when they are put into a deeper *sleep* mode in which both the transmitting and receiving RF circuitry of the small cell are turned off.

In [8], the performance gains of the database-aided energy savings scheme were demonstrated for uniformly deployed small cells and users, assuming worst-case interference scenarios. It was shown that energy savings of up to 40% could be obtained in high utilization scenarios, and that the UE throughput could be doubled when only few users are present in the network.

In this paper, we investigate the potential gains that can be achieved in clustered small cell deployments, which more realistically model typical use cases for small cells, assuming more realistic interference scenarios. We show that under this realistic setting, the proposed scheme still yields significant energy savings of 30% in high utilization scenaros and offers throughput gains of up to 25% in case few users are present in the network.

II. SYSTEM CONCEPT

A. System Architecture

The system concept introduced in this paper is illustrated in Figure 1. We consider a system comprised of two overlaid networks:

- The macro cell network, comprised of macro cell BSs, operating in lower frequency bands (*e.g.,* 2 GHz), using legacy standards, such as 3GPP LTE Release 10, guaranteeing backwards compatibility for legacy UEs, *i.e.,* UEs which only support legacy standards;
- The small cell network, comprised of small cell BSs, operating in higher frequency bands (*e.g.,* 3.5 GHz), and connected to a macro cell through a backhaul link.

Additionally, each macro cell is equipped with a database containing information about connected small cells. The database purpose and contents are explained in Section II-B.

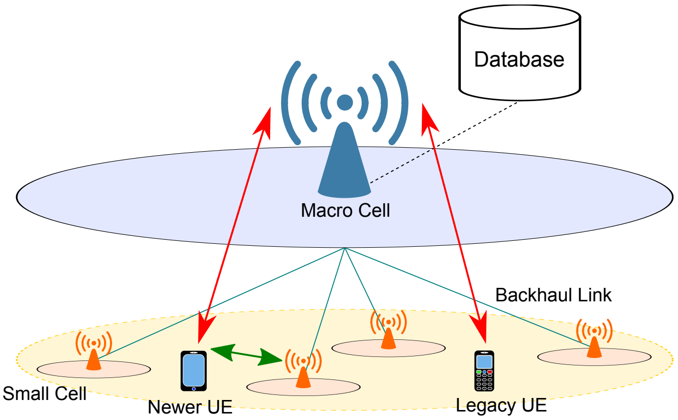

Figure 1. System architecture of a heterogeneous network where UEs support dual connectivity

Two connectivity modes are assumed for this system. A single connectivity mode where UEs are only served by a macrocell, and a dual connectivity mode where UEs are served by both a macro cell and a small cell. While newer UEs support both connection modes, legacy UEs only support the single connectivity mode.

While it is technically possible for a UE to have single connectivity to a small cell, this scenario would lead to significant network signalling overhead and a higher rate of link failures, due to frequent handover procedures necessary to provide seamless mobility for relatively fast-moving UEs. As a result, we do not consider the case of single connectivity to a small cell within the scope of this paper.

B. Database-aided Energy Savings Scheme

To realize the most energy savings, it is desirable to turn off both transmitting and receiving components when the small cell is in sleep mode. However, doing this could lead to a cell discovery issue since the cell does not transmit any pilots and does not detect any UE uplink (UL) signalling [8]. In order to overcome this discovery issue, we propose to use a database-aided scheme, in which each macro cell is equipped with a database which stores geographic-based information about channel quality for all small cells under the control of the macro BS. [8].

The database is divided into several partitions, where a partition corresponds to a certain small cell connected to the macro cell. In each partition, Signal to Noise Ratio (SNR) values of the UE-small cell links are stored, mapped to sets of geographical coordinates (x, y). This way, the most suitable small cell to serve a user can be determined at the macro cell, based on a geographic location report from this user. If necessary, the best selected small cell can also be woken up by the macro cell via the backhaul link. SNR is used as a measure of the channel quality because it provides a good balance between the required information that must be stored and the necessary computational effort to discover a suitable small cell to serve a given UE [8]. Two variants of databases are considered based on the type of SNR value stored

- *Perfect* database, where the SNR values in the database are perfectly estimated for instantaneous channel conditions. This represents an ideal scenario.
- *Trained* database, where the SNR values which approximate the medium to long-term channel quality are obtained through a training procedure [8] and may not represent instantaneous channel conditions.

C. Small Cell Power Consumption States

While the macro cells are considered to be transmitting all the time to guarantee a ubiquitous coverage for users, three different states are considered for the small cells:

- The *on* state, in which a small cell is fully operational and sends both user data to connected UEs and pilot symbols to enable other UEs to connect.
- The *sleep* state, in which a small cell is in a standby mode and can neither send nor receive any signal over the radio link, but can be woken up by the macro cell through its backhaul link. In order to enable almost instantaneous transition to the *on* state, some components of the small cell are not fully switched off. Indeed, several elements of the small cell BS hardware, such as the power supply and baseband processing components take a non-negligible time to be activated [8]. The power consumption breakdown for various BS sizes can be found in [9]. Assuming that a small cell has the size of a pico cell or a femto cell, the power consumption of a small cell in *sleep* state when only the power amplifier and the RF components are deactivated is between and 48% and 55% of the power consumption of small cell in *on* state.
- The *off* state, in which a small cell is completely deactivated, with almost all of its circuitry components switched off. Only some components on the backhaul remain active in order to be able to receive an activation signal from the macro cell. In the *off* state, the small cell consumes a negligible amount of power compared to the *on* or *sleep* states, but with current technology, it takes a non

negligible amount of time to transition from the *off* to the *on* state.

An overview of these three small cell states and their transitions is represented in Figure 2. Note that the transition between the *sleep* state and the *off* state is not considered within the scope of this paper.

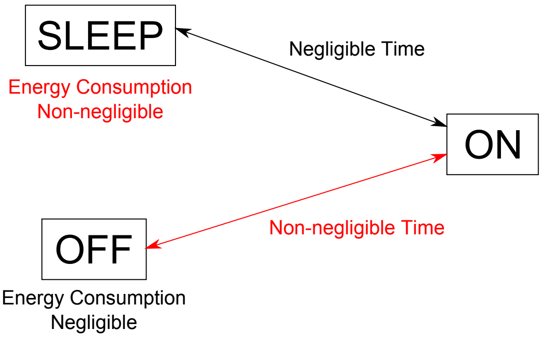

Figure 2. Overview of the small cell states and their transitions.

III. System Model and Simulations

A. Channel Model and Simulation Parameters

The considered channel model is the ITU-R IMT-Advanced MIMO Channel Model (ITU-R), widely used for system-level simulations involving small cells and HetNets [6] [10]. Depending on the radio link, different channel model scenarios are considered. For the UE-macro cell channel, the ITU-R non line-of-sight (NLoS) urban macro (UMa) scenario is chosen, and for the UE-small cell channel, the ITU-R line-of-sight (LoS) urban micro (UMi) scenario is selected.

The main simulation parameters are summarized in Table I. Most of these values are aligned with the 3GPP assumptions for small cell enhancements [10]. A single site with three macro cell sectors and a cell radius of 290 m is considered. Note that we consider that each macro cell, small cell and UE is equipped with a single antenna. Multiple-input and multiple-output (MIMO) aspects are outside the scope of this paper. Although the antenna gains for small cells and UEs are omnidirectional, the antenna gain for macro cells is variable, following the antenna pattern described in [11], choosing 14 dBi as the maximum (boresight) gain.

Table I
MAIN SIMULATION 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	-
ITU-R channel model scenario	UMa NLoS	UMi LoS	-
Antenna height [m]	25	10	1.5
Transmitter antenna gain [dBi]	max. 14	5	-
Receiver antenna gain [dBi]	-	-	0
Receiver noise figure [dB]	-	-	9
Moving speed [km/h]	-	-	3

A cluster-based deployment scenario (see [12] for details), where small cells are dropped in a locally aggregated fashion, inside *clusters*, represented by circular areas of a given diameter, and where UEs are partly dropped into the clusters, partly uniformly, is considered. The number of clusters is chosen so that a specific number of small cells per cluster is dropped. A schematic representation of a cluster based-deployment scenario is represented in Figure 3. The deployment parameters, *e.g.,* the various numbers of nodes as well as the deployment constraints, are provided in Table II.

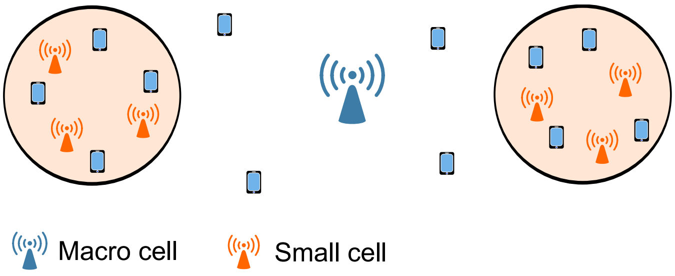

Figure 3. Schematic representation of a cluster-based deployment of small cells and UEs, displaying only 3 small cells per cluster. Small cell clusters are represented by circles

Table II
DEPLOYMENT PARAMETERS

Number of clusters	2 clusters per macro cell sector
Number of small cells	10 small cells per cluster
Number of UEs	Variable, max. 60 per macro cell sector 2/3 uniformly dropped inside clusters 1/3 uniformly dropped inside macro area
Radius for dropping inside cluster	Small cell dropping: 50 m UE dropping: 70 m
Minimum distances	Small cell-Small cell: 20 m Small cell-UE: 5 m Macro cell-Cluster centre: 75 m Macro cell-UE: 35 m Cluster centre-Cluster centre: 100 m

The simulation procedure consists in a downlink only data transmission on both the macro-UE and the small cell-UE links. A non-full buffer File Transfer Protocol (FTP) traffic model with an arrival rate $\lambda = 0.5$ and a file size of 2 MB is considered [13].

The LTE physical time-frequency resource structure is assumed [14]. In our system, the throughput on any given link is determined by a combination of the number of resource blocks (RBs) allocated, the channel quality and the used Modulation and Coding Scheme (MCS). A Signal to Interference plus Noise Ratio (SINR) to Channel Quality Indicator (CQI) mapping is performed to determine the best MCS to use for a given channel quality.

B. Reduced Transmit Power for Small Cells Serving No User

In order to evaluate gains in practical deployments, a realistic interference model is used in this paper. We assume that a small cell in the *on* state but not serving any user only sends a limited number of signals in order to be discoverable, namely pilot symbols and broadcast signals. In the LTE/LTE-Advanced (LTE-A) standard, three types of signals need to be taken into consideration [14]:

- Cell-specific Reference Signals (CRS), used to estimate the channel quality
- Primary Synchronization Signals (PSS) and Secondary Synchronization Signals (SSS), used for synchronization purposes
- Physical Broadcast Channel (PBCH) signals, containting basic information about physical characteristics of the channel

The LTE/LTE-A downlink (DL) frame structure is comprised of several RBs, each RB having a time duration of 0.5 ms, and a frequency span of 180 kHz. Each RB is further divided into 84 resource elements (REs), 4 of which are CRS pilot symbols [14]. Computing the proportion of the total frame structure used for CRS yields that 4.7619% of all the DL signals are pilot symbols.

Similarly, PSS and SSS are each transmitted twice per radio frame for a duration of 1 RE, and PBCH is transmitted once per frame for a duration of 4 REs, all on a frequency span of 6 RB out of the 50 RB frequency span of the considered 10 MHz bandwidth for the small cell channel [14]. The total proportion of the radio frame used for PSS, SSS and PBCH can be computed as 0.6857%.

CRS, PSS, SSS and PBCH all together then constitute 5.4476% of the radio frame. Therefore, it is a reasonable approxiamation to consider that the transmitted signal level by a small cell not serving any user is equal to **5%** of the maximum signal power transmitted by a small cell serving at least one user.

C. Considered Simulation Schemes

Five simulation schemes are considered.

- The first is a *macro only* scheme, where small cells are not deployed and users are only served by a macro cell.
- In the second, called *conventional* HetNet scheme, small cells are deployed and are considered to be *on* all the time. Small cells not connected to any user are still *on*, but transmit with a reduced signal power as explained in Section III-B.
- The third scheme is the database-aided scheme using the *perfect* database defined in Section II-B, in order to evaluate the upper bound system performance.
- The fourth scheme is the database-aided scheme using the *trained* database defined in Section II-B. Due to estimation errors and channel variations, the values of this database are potentially erroneous or out-of-date and can therefore lead to errors in the best small cell selection procedure. However, this scheme more accurately reflects a realistic scenario.
- Finally, in the fifth scheme, we consider a conventional HetNet scheme with a *reduced* number of deployed small cells that consumes as much energy as the database-aided scheme when the small cells are put to *sleep*.

Whereas the conventional HetNet scheme does not yield any energy savings, the other three HetNet schemes can realize some potential energy savings.

IV. SIMULATION RESULTS

System level simulations are used to evaluate the performance of the various considered schemes in Section III-C. Two different metrics are analysed, namely the achievable energy savings and the average achieved UE throughput.

Energy savings performance results are displayed on Figure 4. Three series of results are considered:

- *Non-energy savings (ES) scheme*, which represents a conventional system where small cells are always in the *on* state. Therefore, the percentage of achievable energy savings remains zero, independently of the number of UEs present in the network;
- *ES-schemes,* sleep *mode*, which represents the energy savings obtained by the database-aided schemes where unused small cells are put to *sleep*. Based on the state of the art (see Section II-C), small cells in *sleep* state are assumed to consume 50% of the energy used by a small cell in the *on* state;
- *ES-schemes,* off *mode*, which represents the energy savings obtained by the database-aided schemes where unused small cells are turned *off*. Small cells in *off* mode are assumed to consume a negligible amount of power, which corresponds to 0% of the power used by a small cell in the *on* state.

It can be observed that the percentage of achievable energy savings is inversely proportional to the number of UEs in the network, since more operational small cells are needed when more users need to be served by the network. Furthermore, there is a significant difference between the realizable energy savings in *sleep* state and in *off* state. State of the art techniques make it only possible to realize *sleep* state for a reasonable activation delay. However, in order to achieve the most energy savings, it is important to push the boundaries of technology to realize negligible activation delays even in the *off* state.

Figure 5 illustrates the achievable average user throughput offered by the various schemes introduced in Section III-C. First of all, regardless of the small cell scheme considered, it can be observed that the macro-only benchmarking scheme performs really poorly in comparison, affirming the unavoidable need for small cell deployments in next generation networks.

Secondly, performance gains of up to 13% for the trained database scheme and up to 25% for the perfect database scheme can be observed when the number of users per macro cell is low, compared to the conventional dual connectivity scheme. As seen on Figure 4, high energy savings can be obtained by these database-aided schemes in this situation. This indicates that less small cells are *on*, hence reducing the global level of interference in the network. This increases the UE-small cell channel SINRs, thereby enabling small cells to transmit data with a better MCS.

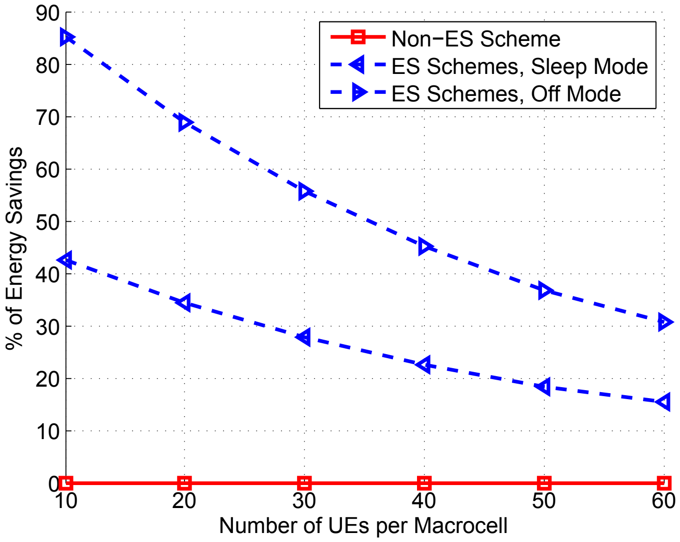

Figure 4. Achievable energy savings by the various simulated schemes. For energy savings generating schemes, it is assumed that small cells are either put to *sleep*, or turned *off*

Figure 5 also displays the performance results obtained with the scheme using only a reduced number of deployed small cells. Although this scheme yields the same energy savings as the database-aided scheme while offering an almost identical throughput performance as the conventional scheme, it is not realizable in practice since the number of reduced small cells to deploy changes depending on the number of users in the network. While such a scheme would be interesting for deployments where the user traffic is rather constant, it is not practical in dense urban network environments, where the number of users and the network utilization rate greatly varies depending, *e.g.,* on the time of the day. Finally, it is also important to note that this scheme does not offer the throughput gains obtained with the database-aided scheme.

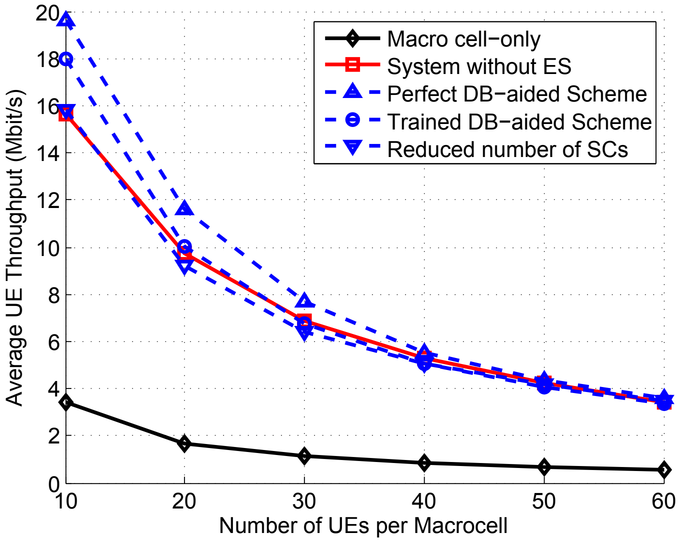

Figure 5. Average UE throughput in Mbit/s for the various simulated schemes

V. CONCLUSION AND FUTURE WORK

In this paper, we have demonstrated the benefits of the database-aided scheme introduced in [8] in clustered small cell and user deployment scenarios, under realistic interference situations. Energy savings of up to 30% for highly utilized networks and throughput gains of up to 25% in case few users are present in the network, with respect to conventional dual connectivity HetNet systems, can potentially be achieved.

In the near future, we will investigate the impact of signalling delays due to small cell connection procedures on the performance of the database-assisted scheme.

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