# An Energy-Efficient Macro-assisted Sleep-Mode Scheme in Heterogeneous Networks

Xuhui Yang[1], Wen'an Zhou[1], Da Li[1]
[1] Beijing University of Posts and Telecomunications Beijing, China
jimmyyoung24@outlook.com, zhouwa@bupt.edu.cn, freedani@bupt.edu.cn

**Abstract.** Ultra-dense small cell deployment is seen as a necessary means to address the explosive mobile traffic growth in the near future. However, a large-scale small cell deployment can substantially increase the network energy consumption with strong ecological and economic implications. In this article, we introduce an energy-efficient macro assisted sleep mode scheme in heterogeneous networks to reduce cellular networks' power consumption. The designed scheme takes into account that (i) macro base station's power consumption is varying with the load, (ii) macro starts a UE-small cell connection procedure as soon as a connected UE is required to start receiving data is potentially suboptimal in terms of energy consumption. Furthermore, we present the procedures of the proposed macro assisted sleep mode scheme. By our calculation and analysis, our scheme can yield a further 5% energy savings with respect to the amount of energy savings obtained with existing schemes.

## 1 Introduction

Fueled by the popularization of mobile devices and the increased number of broadband services, wireless traffic experienced an exponential growth in recent years. Such growth is very likely to continue in the near future owing to new cloud-based services and data-hungry applications [1]. In order to be able to serve such a big amount of traffic, wireless networks shall increase their capacity.

Ultra-dense small cell deployment is seen as a necessary means to address the huge capacity demand [2], [3]. However, as base stations are responsible for the large amount of energy consumed in cellular networks, deploying such large number of small cells poses two main challenges: the cost of the network infrastructure and its environmental footprint. Both issues can be solved by designing an energy efficient mobile network: the decrease of the network energy consumption will result in lower operational cost for the infrastructure and lower greenhouse gas emissions.

While there are various distinctive approaches to reduce energy consumptions in a mobile cellular network, adopting renewable energy resources or improving design of certain hardware is often prohibitive due to the cost of replacing, and installing new equipment. By comparison, sleep mode techniques, does not require changes to current network architecture, and takes advantage of changing traffic patterns on daily

 
L. Barolli et al. (eds.), *Advances on Broad-Band Wireless Computing, Communication and Applications*, Lecture Notes on Data Engineering and Communications Technologies 2, DOI 10.1007/978-3-319-49106-6_8

or weekly basis. Hence, sleep mode have the potential to save a significant amount of energy, as shown in various studies.

Decoupling coverage and capacity provisioning could make it easier to deploy and manage a large number of small cells. DOCOMO proposes the concept of Phantom Cell which gives the ideas of high-frequency small cells configured no Cell specific Reference Signal (CRS) [4]. In the Phantom Cell Concept, the control plane (C-plane) and the (U-plane) are separated [5], as shown in Figure 1. In such systems, effective macro-assisted energy savings schemes based on sleep mode techniques can be implemented with minimal additional signaling. Thus, in this paper we introduce an energy efficient macro assisted sleep mode scheme in heterogeneous networks.

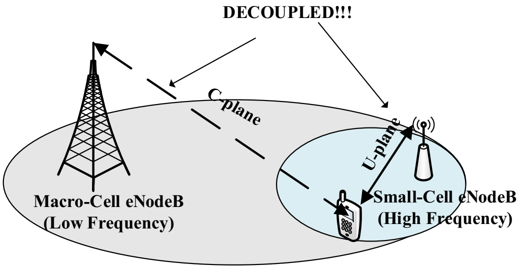


**Fig. 1.** Heterogeneous networks with the C-plane and the U-plane are separated.

We note that there are several previously published papers, for example [6], [7], which already studied the base stations sleep mode in heterogeneous networks. However, only a few papers considered macro assisted scenarios. Among these, we cite [9], where the authors show that in macro-controlled small cells, effective macro-assisted energy savings schemes can be employed to reduce the network energy consumption at practically no additional cost to the network and no hit to user quality of service (QoS). However, [9] does not consider that:

- The energy consumed by macro cell is not constant, but rather variable with the traffic load (approximately linearly);
- When a small cell is switched off, the macro cell assumes the load of that small cell, hence the macro cell energy consumption increases.
- Macro cells have data capacity, thus, in some case a connection to a small cell is not needed: the macro cell base station could handle the transmission of the arriving file with its own resources, especially when the file is relatively small.

The scheme introduced in this paper considers the aforementioned aspects, and thus minimizes the energy consumption in heterogeneous networks and provides a more energy efficient as well as a more realistic sleep mode scheme.

The rest of this paper is organized as follows. In Section 2, we introduce the macro-controlled heterogeneous networks architecture and the energy model considered within the scope of this paper. In Section 3 we propose our macro assisted sleep mode scheme. Section 4 provides numeric analysis of the proposed scheme and illustrate energy savings. Section 5 concludes the paper.

# 2 System Model

## 2.1 System Architecture

The system in this paper is macro-controlled small cells heterogeneous networks, such as the PCC architecture [5], and the Macro-assisted Data-Only Carrier System in [11]. Such macro-controlled system advocates the separation of the C-plane and the U-plane. Such system, illustrated in Figure 2, is comprised of two overlaid heterogeneous networks:

- A macro cell network, whose primary objective is to offer a C-plane coverage to users. These macro cells operate in lower frequency bands (e.g., 2 GHz);
- A small cell network with small cell BSs, responsible for delivering a high throughput to connected users. These small cells operate in higher frequency bands (e.g., 3.5 GHz), and are connected to a macro cell through a backhaul link.

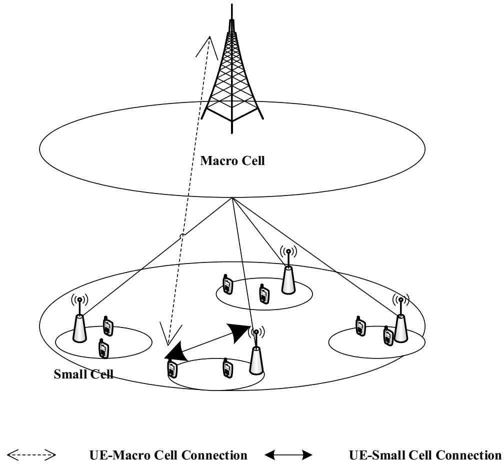


**Fig. 2.** System architecture of macro-controlled small cells, a heterogeneous network.

Additionally, we consider two small cell states, namely on and sleep. In the on state, all hardware components in the small cell base station are fully switched on, small cells consume the highest amount of energy. In the sleep state, some of the hardware components are either completely switched off or operated in low-power modes. The exact components to be switched off are a function of the specific hardware architecture and the particular energy saving algorithm.

### 2.2 Energy Model

In order to evaluate the potential of the system energy efficiency, an appropriate base station power consumption model is needed. The energy model we consider in this paper is introduced in [8], based on the following assumptions:

- The power consumption of a macro base station is equal to $a\ell + W_M$, where $\ell \in [0,1]$ is the traffic load of the macro base station normalized to its maximum capacity, and $W_M$ is the power consumption when $\ell$ = 0, $a$ is a constant value;

$$P_M = a\ell + W_M \tag{1}$$

- The power consumption of a small base station is constant (independent from the traffic load variations) and equal to $W_S$ .

$$P_S = W_S \tag{2}$$

## 3 Energy Efficient Macro Assisted Sleep Mode Scheme

### 3.1 Problem Description

The goal of sleep mode technology is to minimize the energy consumption while guaranteeing that the QoS requirements of each user are fulfilled. At a given time granularity, this system optimization problem can be formulated as follows:

$$\text{Minimize} \quad \sum_{n=1}^{N}[C_n E_S^{on} + (1-C_n)E_S^{sleep}] + E_M \tag{3}$$

$$\text{Subject to:} \quad R_k \geq \rho_k, \forall k \in \{1,...,K\}, \tag{4}$$

$$C_n \in \{0,1\}, \tag{5}$$

where N is the total number of small cells deployed in the coverage of macro cell, K is the number of users in the system, $E_S^{on}$ is the energy consumed by a small cell in the on state, $E_S^{sleep}$ is the energy consumed by a small cell in the sleep state, $E_M$ is the energy consumed by the macro cell, $R_k$ is the throughput (or data rate) obtained by UE k, $\rho_k$ is the data rate requirement of user k,

$$\text{and} \quad C_n = \begin{cases} 1 \text{ if small cell n is in the on state} \\ 0 \text{ if small cell n is in the sleep state} \end{cases}$$

Expression (4), imposing that the data rate requirement of each UE in the system be fulfilled, means that each BS in the system need to have enough bandwidth to fulfil the data rate requirement of all the UEs it is serving. Thus, it is possible to rewrite expression (4) as:

$$\sum_{k=1}^{K} \frac{\rho_k}{\omega_{n,k}} \alpha_{n,k} \leq B_{total,n}, \quad \forall n \in \{1,...,N\}, \tag{6}$$

$$\sum_{k=1}^{K} \frac{\rho_k}{\omega_{macro,k}} \left(1 - \sum_{n=1}^{N} \alpha_{n,k}\right) \leq B_{total,macro}, \tag{7}$$

$$\sum_{n=1}^{N} \alpha_{n,k} \leq 1, \qquad \forall k \in \{1,...,K\}, \tag{8}$$

$$\alpha_{n,k} \in \{0,1\}, \quad \forall n \in \{1,...,N\}, k \in \{1,...,K\}, \tag{9}$$

where $\omega_{n,k}$ ($\omega_{macro,k}$) is the spectral efficiency of the link between small cell n (macro cell) and user k, in bit/s/Hz, $B_{total,n}$ ($B_{total,macro}$) is the total bandwidth available on small cell n (macro cell), in Hz,

and $\alpha_{n,k} = \begin{cases} 1 \text{ if small cell n is serving user k} \\ 0 \text{ if small cell n is not serving user k} \end{cases}$

To minimize the total power consumption of the system, a small cell should be in sleep state whenever it is not serving any user, but in the on state when serving at least one user. This means $C_n$ can be expressed as follows:

$$C_n = \begin{cases} 1 \text{ if } \sum_{k=1}^{K} \alpha_{n,k} \geq 1 \\ 0 \text{ if } \sum_{k=1}^{K} \alpha_{n,k} = 0 \end{cases} \quad \forall n \in \{1,...,N\} \tag{10}$$

Additionally, for a given time granularity, expression (3) can be rewritten as follows, according to the energy model introduced in Section 2 (expression (1) and expression (2)).

$$\sum_{n=1}^{N} [C_n W_S + (1 - C_n) W_S^{sleep}] + a\ell + W_M \tag{11}$$

It has been shown in [9] that problems of this form are not guaranteed to exist a unique optimal solution. In this paper, we propose a heuristic macro-assisted sleep mode scheme based on the following heuristics:

- To minimize the power consumption of small cells, we have to minimize the total time that small cells spend in the on state.
- As we considered heterogeneous network that comprised of macro cell and small cells, we should take into account the macro cell energy consumption increase when a small cell is switched off.

The first heuristic can be achieved by finding and switching on the best small cell for user to connect to, so that the transmission of files from each small cell to users can be finished quickly to be able to put small cells to sleep state as soon as possible. A good way to find the best small cell for a user to connect to is to find small cell which providing the highest SINR to that user. To utilize the second heuristic, when a file arrives for a specific user, if the macro identifies there are UE-associated small cells in the sleep state, the macro cell can make the decision to make the UE connect to the small cell network or not based on the traffic load variation of macro base station. At a given timeslot, the power consumption that make the UE not connect to the small cell can be expressed as:

$$\sum_{m=1}^{M} W_S + a\left(\ell + \Delta\ell\right) + W_M \quad (12)$$

where M is the total number of small cells in the on state, $\Delta\ell$ is the traffic load variation of macro because of the macro cell assumes the load of the arrived file. The power consumption that make the UE connect to small cell is:

$$\sum_{m=1}^{M+1} W_S + a\ell + W_M \quad (13)$$

Therefore, we have:

$$\Delta E = W_S - a\Delta\ell \quad (14)$$

$\Delta E$ is the power consumption difference between UE connect to the small cell network and not. Thus the macro can make the decision to make the UE connect to the small cell network if $W_S < a\Delta\ell$ , vice versa.

## 3.2 An Energy Efficient Macro Assisted Sleep Mode Scheme

**Best Small Cell Selection and Small Cell Sleep to On Procedure**

The small cell base stations can be configured to reside in the sleep state by default and move to the on state as explained next. The flow chart of our macro-assisted sleep mode scheme is illustrated in Figure 3 and the decision-making process is:

The transition of small cell from sleep to on state is controlled by the macro via the backhaul. In the macro-controlled small cells, UE first connect to the candidate macro cell. After connecting to the candidate macro cell, the UE will get time and frequency synchronization with the macro. In energy savings schemes presented in the literature, when there is any UE-associated small cell in sleep state, it is generally assumed that the macro changes an appropriate small cell to the on state and starts a UE-small cell connection procedure as soon as a connected UE is required to start receiving data [6], [7], [8], [9]. In this paper, we propose that this behavior is potentially suboptimal in terms of energy consumption, since in some cases a connection to a small cell is not needed. In our scheme, macro decide whether the UE connect to the small cell network or not based on expression (14): if $W_S < a\Delta\ell$ , which means the power consumption that make the UE connect to the small cell network is less than make the UE stays connected to macro cell, and vice versa.

If macro decide to make UE connect to small cell network, the best small cell select procedure is performed. The decision is performed using the SINR values of UE small cell links, which can be obtained by information reporting from the small cells via their backhaul links. Then, macro builds a list of small cell candidates for the UE, and sorting them by UE-small cell link SINR values. Finally, chose the first small cell of the sleep list as the small cell for UE to connect to.

It should be noted that, $\Delta\ell$ which stands for the traffic variation of macro cell can be obtained by based on the size of the file to be received. Nevertheless, the size of a file is an application-layer piece of information, only available to the two ends of the communication, thus we maybe need cross-layer information exchange or obtaining the file size information via UE.

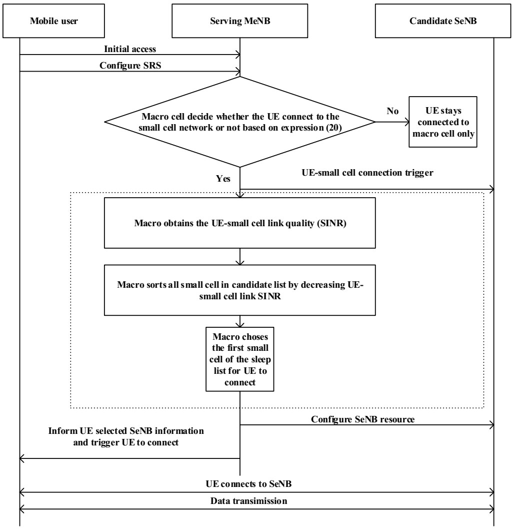


**Fig. 3.** Procedures of the proposed macro assisted sleep mode scheme used to determine the best small cell for a UE to connect to.

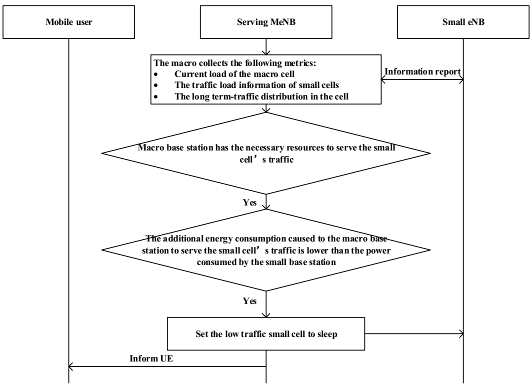


**Fig. 4.** Small cell On to Sleep Procedure

**Small cell On to Sleep Procedure**

A small cell may be putted to sleep state as soon as: (i) the macro base station has the necessary resources to serve the small cell's traffic; (ii) the additional energy consumption caused to the macro base station to serve the small cell's traffic when it is sleeping is lower than the power consumed by the small base station. The main characteristic of our macro assisted sleep mode scheme is that the state of the small cell can be determined by the macro cell which is different from the current LTE system. Macro cell can take into account the long-term traffic distribution in the cell, the state and capacity of small cells, and the moving speed of terminals. Thus, the optimized centralized decision can be achieved. The flow chart of our small cell on to sleep procedure we proposed is illustrated in Figure 4.

## 4 Evaluation Results

This Section focuses on the performance of the proposed scheme by estimation based on the research result. We consider specific values of the parameters introduced in Sections 2 and 3 according to [8]. According to [12], the number of pico base stations for a given capacity is shown in Table 1. According to [8], the parameters is shown in Table 2.

**Table 1.** Density of small cell base stations.

| System Capacity (GB/H/km$^2$) | Small cell Density (BSs/km$^2$) |
|---|---|
| 50 | 35 |
| 100 | 190 |
| 150 | 300 |
| 200 | 500 |
| 250 | 1000 |

**Table 2.** System Parameters values.

| Parameter | Value |
|---|---|
| $W_M$ | 800W |
| a | 500W |
| $W_S$ | 13W |
| $W_0$ | 4.3W |

Using the traffic model provide in [8], we can calculate the data volume percentage of different traffics. Big files that satisfies $W_S < a\Delta\ell$ represented by FTP traffic currently take up to 22% of the total data volume. We choose random arrival traffic for study. Three schemes are compared: a) traditional no sleep scheme; b) macro starts a UE-small cell connection procedure as soon as a connected UE is required to start receiving data, as presented in the state-of-art sleep mode schemes [9], [10]; c) macro decides whether UE connect to small cells network or not based on the traffic load variation of macro cell, which is proposed in Section 3 in this paper

Figure 5 shows the energy per $km^2$ consumed in one day for the three considered schemes varying the capacity requirements. We notice that the use of sleep mode reduces the system energy consumption. Moreover, the proposed macro assisted sleep mode scheme in this paper gives a further reduction in the system energy consumption. Figure 6 shows the percentage of power savings by schemes b) and c) with respect to the fully on small cell scheme a). We notice that our scheme can yield energy savings of up to 10% compared to not using sleep mode, and can yield a further 5% energy savings with respect to the amount of energy savings obtained with existing sleep mode schemes.

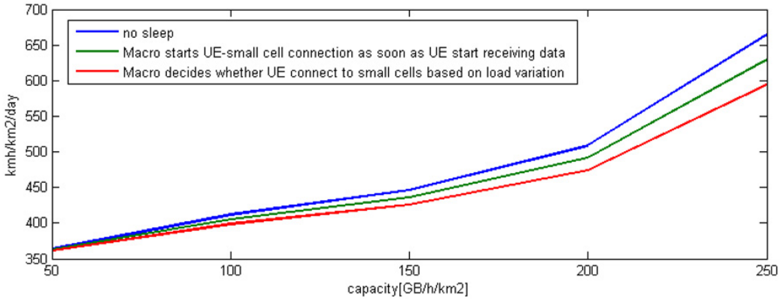


**Fig. 5.** Energy consumed for the three considered schemes varying the capacity requirements.

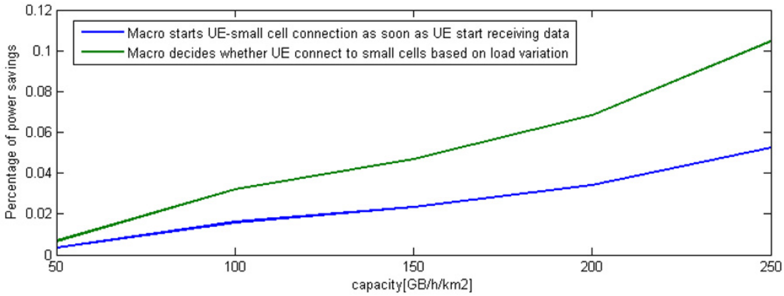


**Fig. 6.** Percentage of power savings by schemes b) and c) with respect to the fully on small cell scheme a).

Finally, we have to notice the fact that the power consumption of macro base stations has a significant dependency on the traffic load [8], assuming a constant macro base station power consumption leads to an overestimation of the energy savings with the use of sleep mode technology.

## 5 Conclusions

In this paper we have presented an energy efficient macro assisted sleep mode scheme in the macro-controlled heterogeneous networks. From the results of our analysis, we showed that the power consumption of macro base station has a significant dependency on the traffic load. Moreover, it is important to model the dependency of the macro base station power consumption on the traffic load to correctly determine whether the UE connect to the small cell network or not. By our calculation and analysis, our scheme can yield energy savings of up to 10% compared to not using sleep mode, and can yield a further 5% energy savings with respect to the amount of energy savings obtained with existing sleep mode schemes.

However, the proposed scheme in this paper is based on the assumption that the size of each arriving file is known by the macro cell serving the UE to which the file needs to be sent. This is difficult to implement in practice in the current LTE standard. In addition, energy-aware load balancing between macro and small cells still needs further study

## Acknowledgement

This work is supported by the National Science and Technology Major Project (No. 2015ZX03001025).

## References

1. H. Peng et al., “Ultra Dense Network: Challenges, Enabling Technologies and New Trends”, China Communications, Feb. 2016
2. N Bhushan, J Li, D Malladi et al., “Network densification: the dominant theme for wireless evolution into 5G”, Commun. Mag. IEEE. 52(2), 82–89 (2014)
3. PK Agyapong, M Iwamura et al., “Design considerations for a 5G network architecture”, IEEE Commun. Mag. 52(11), 65–75 (2014)
4. Kishiyama, Y.; Benjebbour, A.; Nakamura, T.; Ishii, H., “Future steps of LTE-A: evolution toward integration of local area and wide area systems,” Wireless Communications, IEEE, vol.20, no.1, pp.12, 18, February 2013
5. H Ishii, Y Kishiyama, H Takahashi, in Globecom Workshops (GC Wkshps), 2012 IEEE. A novel architecture for LTE-B: C-plane/U-plane split and Phantom Cell concept (Anaheim, CA, 2012), pp. 624–630
6. I. Ashraf, F. Boccardi, and L. Ho, “Sleep mode techniques for small cell deployments,” IEEE Commun. Mag., vol. 49, no. 8, pp. 72-79, Aug. 2011
7. S. Cai, L. Xiao, H. Yang, J. Wang, and S. Zhou, “A cross-layer optimization of the joint macro and picocell deployment with sleep mode for green communications,” in Proc. 22nd WOCC, May 2013, pp. 225-230
8. P. Dini, M. Miozzo, N. Bui, and N. Baldo, “A model to analyze the energy savings of base station sleep mode in LTE HetNets,” in Proc. IEEE GreenCom, IEEE iThings/CPSCom, Aug. 2013, pp. 1375-1380

9. E. Ternon, P. Agyapong, and A. Dekorsy, “Performance Evaluation of Macro-assisted Small Cell Energy Savings Schemes,” 2015, accepted for Publication to EURASIP Journal on Wireless Communications and Networking
10. Chang Liu et al., “Performance analysis of macro-assisted data-only carrier system in 5G energy-efficient heterogeneous networks,” IEEE GreenCom, Nov. 2014, pp. 1-6
11. Xing Zhang; Jiaxin Zhang; Wenbo Wang; Yan Zhang; Chih-Lin I, “Macro-assisted Data-only Carrier for Small Cell Enhancement in 5G Cellular Systems,” IEEE Commun. Mag., vol. 53, no. 5, pp. 223-231, May 2015
12. K.Hiltunen, “Comparison of different network densification alternatives from the lte downlink performance point of view,” in IEEE Vehicular Technology Conference (VTC Fall) 2011, San Francisco, US, Sept. 2011