RESEARCH ARTICLE OPEN ACCESS

Small-Cell Zooming Scheme for Energy Efficient Two-Tier Hybrid Green Cellular Networks

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Abstract:

The dynamic growth of Information and Communication Technology (ICT) have considerably increased the energy requirements and also contribute a growing fraction to CO_2 emissions, thereby creating a need for wireless communications to be more energy-efficient. In this paper, Cell Zooming concept is implemented for reducing the overall power consumption of the network The Green small-cell base station (GSBS) has emerged as a promising technology to improve the network coverage of a macro-cell base station (MBS) for green communications. With the plug-and-play property and without the auto-configuration ability, GSBSs are installed un plannedly and unequally. Under such an occasion, it is important to reduce the energy consumption in two-tier MBS-GSBS networks. In addition, reducing carbon dioxide emissions is a globally common goal. In this paper, an energy saving small-cell zooming scheme is proposed to be employed in the two-tier cellular network. The proposed scheme allows GSBSs to be smartly switched on/off and zoomed in/out, according to dynamically fluctuating traffic loads, while maintaining pre-determined data-rate requirements of all users. Finally, it is observed from simulation results that the presented scheme has a much better energy-saving ability, compared with that of conventional ones..

Keywords — ***ICT, small-cell cell zooming, energy-efficient, next-generation networks*.**

I. INTRODUCTION

There is an enormous rapid growth in wireless cellular networks due to the explosive increase in traffic volumes as a consequence of the exponential rise in subscriber numbers. Network providers are doing their best to fulfill user requirements. In the exponentially growing world energy consumption is becoming a vital issue, also usage of energy sources are creating larger negative impact on the environment with global warming because of the carbon emission. For example, a standard 3G base station to produce 40W of output RF power requires 500W of input power, with 12,000 base stations it consumes more than 50GWh of input power every year in a network.The carbon foot print from the base stations is also growing exponentially because of the diesel power generators that are used as backhaul for electrical grids. This evidently indicates the biggest power issue that is concerning cellular networks is the power consumed by base stations. This shows that "Green cellular network". deployment needs a primary focus on power consumption reduction in base stations.The various traffic application demands has brought great challenges to existing cellular networks of much lower capacity and coverage.

A simple-yet-effective method to solve this problem is to make the transmitter and the receiver to be close [1]. The deployment of Green Small-cell Base Stations (GSBSs), such as femto-cell BSs (FBSs) [2], which are low power and low cost BSs with smaller coverage ranges, in the coverage area of Macro-cell BSs (MBSs) to increase the indoor coverage and provide the high-speed data service is a prospected way to tackle this issue.The report from the Informa Telecoms & Media [3] anticipates that the small-cell market will experience significant growth over the next few years. It will reach over 49 million SBSs in the market by 2014 and 114 million users accessing mobile networks through GSBSs during these years. Nowadays, the deployment of GSBSs is not well planned, which are plugged in unplanned ways that may cause serious energy consumption if there are no efficient energy-saving schemes to be employed. However, the way of designing such an energy-saving scheme for those unplanned SBSs is not the same as that for traditional MBSs. As a result, it will be a challenge to develop algorithms for improving the energy efficiency of those unplanned GSBSs.

Most of existing energy-saving schemes have concentrated on the energy efficiency of MBSs, such as [4-6]. In [4], Zhou *et al.* proposed an algorithm of dynamically switching off cer-tain MBSs when the traffic load is low. The main idea was to use the traffic distribution information, considering both the space and the time dimensions of the whole network, to make the power-on/off decision for MBSs. In [5], Peng *et al.* ap-proximated the network energy proportionality by using non-load MBSs to leverage the temporal-spatial traffic diver-sity and the deployment heterogeneity. In [6], Marsan *et al.* studied simple analytical models for the energy-aware man-agement of cellular access networks to characterize the amount of energy. It reported that the energy could be saved by reduc-ing the number of active MBSs during the period of light traf-fics. However, the above results were only focused on MBSs not concerning on the issue for GSBSs.

The study in [7-8] proposed a multi-objective heuristic algorithm based on a genetic algorithm for a centralized self-optimizing femto-cell network. The main idea was to optimize the cover-age based on the current statistics of both the global traffic distribution and the interference level between neighboring GSBSs. Nevertheless, because the genetic programming gener-ally needs a long time to calculate the fitness in each genera-tion, it may be not suitable to make exact decision in an ac-ceptable short time interval in practice.

Thousands of SBSs deployed in macro-cells may increase energy consumption if the traffic load is light and SBSs are always active. In recent years, many researchers have paid much attention to the energy consumption issue on SBSs, such as [9-12]. In [9], Ashraf *et al.* proposed an energy-efficient transmission scheme for FBSs via the user activity detection by introducing the idle mode[2] to the normal FBS operation. It allowed the FBS to completely switch off its radio transmissions and associated processes, when not involved in an active call. In [10], the 3rd Generation Partnership Project defined potential energy-saving solutions for multi-tier cellular net-works, which indicated that certain cells could be totally deactivated in case of light or no traffics. In [11], by introducing the *cell zooming* concept, the cell size of the FBS was able to beenlarged by dynamically adjusting its *transmission power*. Recently, a handover decision policy for femtocell networks was proposed in [12].

Nevertheless, the energy-saving transmission problem for BS transceivers in two-tier MBS-GSBS cellular networks has not fully been investigated yet. Consequently, the work focus-ing on how to efficiently and effectively minimize the total energy consumption of plenty of transceivers in all kinds of BSs is still an open issue.

The rest of this paper is divided into five sections as fol-lows. In Section II, the considered system model of a two-tier MBS-SBS cellular network and its problem description are detailed. Next, Section III presents an energy-saving small-cell zooming scheme to be employed in the system model, and then, Section IV elaborates the considered transmission power consumption model. Following that, simulation results are demonstrated in Section V. Finally, Section VI concludes this paper

II.PROBLEM DESCRIPTION

A. System Model

Definition 1*:* Green Silent SBS (GSSBS)

An SBS is called a Green Silent SBS (GSSBS) if the SBS is in the idle mode. An SSBS is possibly considered to wake up and provide service if a device arrives at its coverage.

Definition 2: Green Active SBS (GASBS)

An ABS is called an Green Active SBS (ASBS) if the SBS is in the ac-tive mode. An ASBS is able to enlarge its coverage area to cover/heal the coverage hole.

Consider there are *N*GSBSs being densely deployed within the *ring* bounded by the outer radius R and the inner radius R_0 of an MBS, as illustrated in Fig. 1. The dotted circle indicates that the GASBS enlarges its normal coverage area. Throughout this paper, the MBS is assumed always active. For convenience, we refer to the overall coverage area of the two-tier network as the *two-tier cell*. All kinds of BSs (i.e., MBS and GSBSs) are connected to the core network via broadband backhauls and assumed to operate on a licensed band.

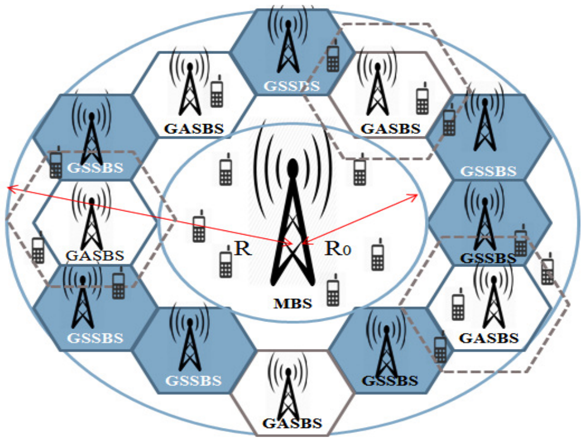

Fig. 1. Illustration of the considered two-tier MBS-GSBS model, where ten GSBSs deployed is given as an instance.

Assume there is a *Small-cell Control Server (SCS)*, which is a virtual entity for controlling the small-cell turn-on/off and zoom-in/out procedure, being implemented in the MBS. The *SCS* is responsible for sensing the network configuration in-formation by specific control messages. After collecting the information, the *SCS* will decide whether to make the SBS become the GSSBS or the GASBS. Moreover, the Orthogonal Frequency-Division Multiplexing (OFDM) technique is adopted as the underlying transmission scheme in the physical layer for its robustness against the multi-path fading and bandwidth scalability. Furthermore, let B denote the system bandwidth.

B. Goal

The goal of this paper aims to minimize the total power consumptions for all kinds of BSs' transceivers in the consid-ered model, while guaranteeing that the required signal is cov-ered over the considered hole up to the hilt. As a result, the problem for managing the power consumption of the network intends to reduce the overall system capacity by deactivat-ing/adjusting transceiver powers of some GSBSs or adjusting the transceiver power of the MBS, according to the dynamic traffic situation. In other words, the problem attempts to figure out a coverage set from those configurations with the minimum power consumption, while the coverage requirement for the hole is satisfied.

C. Problem Formulation

Let the N SBSs be indexed by i, i=1,2,…,N. Define Ω as the set of all combinations of configurations for activa-tions/deactivations of the N SBS transceivers. What's more, we define $[a_1^{(z)}, a_2^{(z)}, \ldots, a_N^{(z)}]$ as the*status vector*of transceiverconfigurations for the N SBSs, where z is the index for the employed configuration in Ω , z=1,2,…, |Ω| . It follows that | Ω |= 2^N. Notice that given a specific configuration$z$, if SBSi is activated, $a_i^{(z)}$ =1; otherwise, $a_i^{(z)}$ =0. Next, we define key parameters for the power consumption of all kinds of BSs' transceivers. Define p_{SBS} as the basictransceiver power of an GSBS. Let$\aleph^{(z)}$ and$p^{(z)}_{trans,i}$ denote the set of SBSs and the transmission power from GSBS i in configuration z, respectively. Without loss of generality, $p_{trans,i}{}^{(z)}$ isconsumed only when $a_i^{(z)}$ =1. In turn, define p_{MBS} andp_{MBS_trans}as the basic transceiver power and the transmissionpower for the MBS, respectively. In addition, denote maximum allowable transmission powers of anGSBS and the MBS by$p_{SBS_trans_max}$ and $p_{MBS\_trans\_max}$, respectively.

Moreover, we define two different binary decision indica-tors x_i and y_i^{ℓ} . First, x_i means whether the transmission power of SBS i is consumed. If $p_{trans,}{}^{(z)}{}_i$ is consumed, x_i =1; otherwise, x_i =0. Next, y_i^{ℓ} represents whether the selectedposition ℓ in the considered hole is covered by the transmis-sion power from GSBS i. If the position ℓ is supported by $p_{trans,}{}^{(z)}{}_i$,y_i^{ℓ}=1; otherwise,y_i^{ℓ}=0. For mathematically model-ing the complete coverage of the considered hole, we introduce the set ϒ of dense measurement positions. Additionally, de-fine φ as the total power consumption of all kinds of BSs'transceiver in the considered model. Let C_j and $C^{min}{}_j$ denote the obtained data rate of user-j and its minimum require-ment, respectively. Let ℜ denote the set of all users.

Mathematically, the considered optimization problem can be rigorously formulated as

Minimize

$$\varphi = p_{SBS} \cdot |\aleph^{(z)}| + \sum_{i \in \aleph^{(z)}} p^{(z)}_{trans,i} + p_{MBS} + p_{MBS\_trans} \quad (1)$$

subject to

$$z \in \Omega, \quad (2)$$

$$\sum_{i \in \aleph^{(z)}} x_i \, y_i^{\ell} \geq 1 ,\ell \in \Upsilon, \quad (3)$$

$$p^{(z)}_{trans,i} \leq p_{SBS\_trans\_max}, i=1,2,\ldots,N, \quad (4)$$

$$P_{MBS\_TRAS} \leq P_{MBS\_TRANS\ MAX} \quad (5)$$

$$C_j > C_{min}, \quad j \in \Re \quad (6)$$

The objective function in (1) is to minimize φ by activating/deactivating or adjusting powers of all kinds of BSs. The first constraint in (2) means the allowed configuration set. The second constraint in (3) is to guarantee the full coverage for the hole. The next two constraints in (4)-(5) are transmission power limitations for the GSBSs and the MBS respectively.The last constraint in (6) states minimum data-rate requirements for all users.

In order to provide a realistic way to operators for their possible operations in practice, we herein pay our attention to developing an efficient method to tackle this problem. Consequently, we next attempt to propose an alternatively simple-yet-effective power management strategy in the two-tier hybrid network to be recommended to operators for their references.

III.ENERGY SAVING SMALL CELL ZOOMING SCHEME

It is noted that once the number of users increases in the two-tier cell, it will lead to higher blocking probability. Mean-while, users in the macro-cell edge may cause larger consumption for transmitting power than that of users in the central area, if SBSs are not properly planned and managed. Therefore, it is crucial to determine whether to switch on/off SBSs, based on traffic loads. On the premise that all users must achieve their minimum data-rate requirements, we adopt the factor, the number of users, to perform the call admission control for the MBS.

If the number of users does not exceed the threshold H, all users are served by the MBS. Otherwise, users are geographically classified into two parts for corresponding connections. Users within the range of radius R_0 are served by the MBS, while users out of this area (i.e., within the *ring*) are served by the nearest GSBSs[3]; meanwhile, other GSBSs are switched off. On the other hand, if users make handovers, it may cause link interruption or/and delay. If the handover is made many times, it will make the BS switch on/off repeatedly, which, in turn, will make the BS break down easily. To avoid causing high-frequency handovers, the speed threshold is defined. If the user speed exceeds V, he/she will be served by the MBS. The flow chart for the scheme operation is shown in Fig. 2.

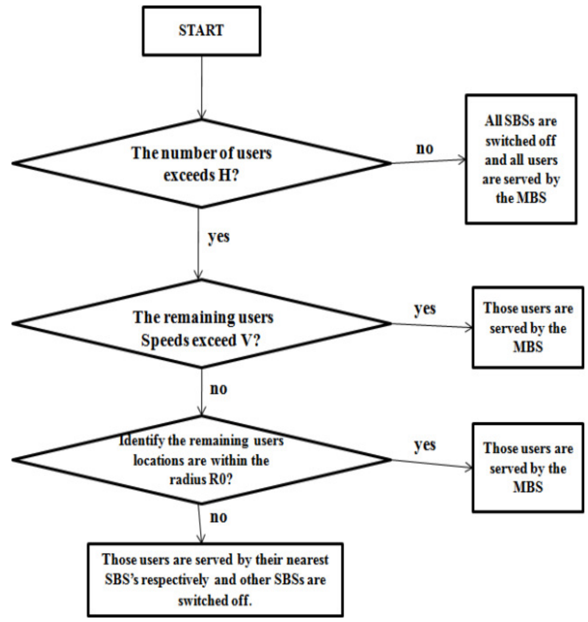

Fig. 2. Flow chart for the operation of the proposed energy-saving small-cell zooming scheme.

Since the edge users are served either by the deployed SBSs or the MBS based on the above design, it is assumed that the spectrum of the MSB can be reused by the SBSs. For each ASBS in configuration z, it is arranged for the bandwidth of B /| $\aleph^{(z)}$ | . The bandwidth is further equally divided for users Located in the same ASBS This connection configuration approach is able to improve the energy-saving performance, which will be verified in Section V.

IV.TRANSMISSION POWER CONSUMPTION MODEL

In what follows, we describe how to calculate the transmission power consumption. Based on the well-known Shannon's formula [14], to achieve $C^{\min}{}_j$, the required transmission power can be expressed as

$$p = \frac{bN_0}{G}\left(2^{\frac{C_j^{min}}{b}} - 1\right) \qquad (7)$$

provided that the interference is ignorable due to the fact that the OFDM technology is adopted. In (7), b means the occupied bandwidth, N_0 denotes the noise power spectral density, and G is the corresponding channel gain.

Here, we employ the simplified path-loss model [15] as the underlying channel model for study, and G is modeled by

$$G = \alpha(d_o/d)^v \qquad (8)$$

Note in (8) that α represents the path-loss factor,v stands for the path-loss exponent, d_0 is the close-in distance, and d means the Euclidean distance between the designated user and the MBS/A SBS

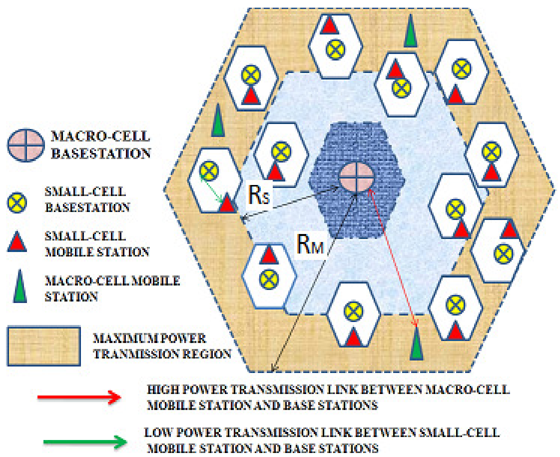

Fig3. Graphical representation of Hetrogenous networks where small cells are uniformly distributed across the macrocell.In this setup macrocell mobile users are still transmitting with maximum power.

Type	Typical Range	Typical Output Power
Macro-Cell	1km - 70km	20W - 60W
Micro-Cell	0.1km - 1+km	5W - 10W
Pico-Cell	In - Building	0.1W – 0.5W
Femtocell	In - Room	0.02W – 0.1W

Table I: Power consumption of cells include Macro-cell(Rural,highway),Micro-cell(urban,street),

V.SIMULATION RESULTS

In this section, the energy consumption performance with the proposed energy-saving small-cell zooming scheme in the considered model, as conceptually depicted in Fig. 1, are ex-amined and compared with that of two conventional ones. The two ones are set as baselines as follows: *baseline scheme 1:* the same as the proposed scheme except that all the GSBSs are al-ways active; *baseline scheme 2:* the same as baseline scheme 1 except that the GSBSs are not able to zoom in/out. For demon-strating results, we Pico-cell(in buildings), Fermtocell(In-Room) let the average number of users be a varia-ble. The performance is assessed by conducting computer simulations with MATLAB. Simulation time is set equal to 24h.

A. *Parameter Setting*

The setting of key parameters is listed in Table II.

TABLE II
THE SETTING OF KEY SIMULATION PARAMETERS

Parameter	Value
R	1 km
R_0	700 m
N	35
B	5 MHz
P_{SBS}	5 Watt
P_{MBS}	500 Watt
N_0	-150 dBm
H	20
V	50 km/h
C^{min}_j	1 Mbps
α	–31.54 dB
v	2
d_0	1
user-location distribution	spatially uniform distribu-tion in the two-tier cell
user mobility	random direction
user moving speed	truncated normal distribu-tion with mean equal to 10 km/h
SBS-deployment distribu-tion	spatially uniform distribu-tion in the *ring*
arrival traffic pattern	always backlogged
user-number distribution	truncated normal distribu-tion with means equal to 5, 10, 20, 30, 40, and 50, respectively
period for executing scheme	10 min

B. *Results of Energy Consumption Performance*

Fig. 3 shows total energy consumption results of all the MBS and SBSs with the three considered schemes (i.e., the proposed scheme, baseline scheme 1, and baseline scheme 2) under various user numbers. It is seen in Fig. 3 that the pro-posed scheme has the best energy-saving performance which can reduce the total energy consumption by up to around 27%, compared with that of the two baseline schemes. The reason is that the proposed scheme can smartly turn on/off GSBSs, when the traffic load is relatively light. This fact is verified in

Fig. 4 which focuses on energy consumption results of all the GSBSs. In Fig. 4, we can find that the proposed scheme has significant improvement in reducing energy consumption from GSBSs. In addition, it can be seen in Fig. 3 that the result difference be-tween the two baseline schemes is little, because all the SBSs are always active in these two schemes. Since the GSBSs in baseline scheme 1 have the zooming ability to help the MBS cover/heal the hole, its performance is slightly better than that of baseline scheme 2, when the traffic load is relatively heavy, as shown in Fig. 3. Therefore, we believe that with the smart activation/deactivation ability, GSBSs can be used for increasing network capacity in an energy-efficient manner.

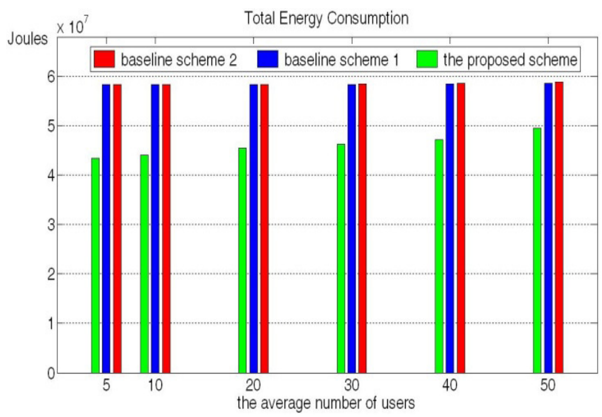

Fig. 3. Comparison of total energy consumption of all the MBS and GSBSs between the proposed scheme, baseline scheme 1, and baseline scheme 2.

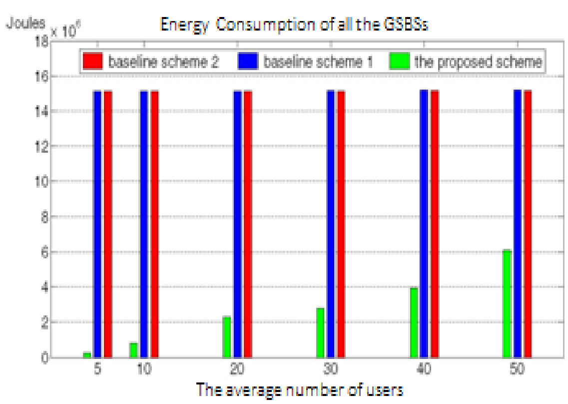

Fig. 4. Comparison of energy consumption of all the GSBSs between the proposed scheme, baseline scheme 1, and baseline scheme 2.

VI. CONCLUSIONS

In this study, we have completely formulated the power minimization problem for transmissions in two-tier cellular networks. Meanwhile, a smart energy-saving scheme has successfully been proposed for solving this problem. The pro-posed scheme can improve energy efficiency in the network environment and users can achieve their required data rates. In view of all the findings, we conclude that the proposed scheme should be a good approach to be recommended for cellular operators

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