Cell Throughput based Sleep Control Scheme for Heterogeneous Cellular Networks

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ABSTRACT

The mobile traffic continuously grows at a rapid rate driven by the widespread use of wireless devices. Along with that, the demands for higher data rate and better coverage lead to increase in power consumption and operating cost of network infrastructure. The concept of heterogeneous networks (HetNets) has been proposed as a promising approach to provide higher coverage and capacity for cellular networks. HetNet is an advanced network consisting of multiple kinds of base stations, i.e., macro base station (MBS), and small base station (SBS). The overlay of many SBSs into the MBS coverage can provide higher network capacity and better coverage in cellular networks. However, the dense deployment of SBSs would cause an increase in the power consumption, leading to a decrease in the energy efficiency in downlink cellular networks. Another technique to improve energy efficiency while reducing power consumption in the network is to introduce sleep control for SBSs. This paper proposes cell throughput based sleep control which the cell capacity ratio for the SBSs is employed as decision criteria to put the SBSs into a sleep state. The simulation results for downlink communications demonstrate that the proposed scheme improves the energy efficiency, compared with the conventional scheme.

Keywords: Heterogeneous Cellular Network, Sleep Control, Cell Capacity Ratio, Energy Efficiency, Small Base Station

1. INTRODUCTION

Currently, the user demands mobile data traffic continuously grow at a rapid rate in wireless communication systems. This is because various kinds of mobile communication devices, such as tablets and smartphones, have been developed and then the number of mobile broadband data subscribers increases rapidly. This rapid mobile traffic growth also causes the data-traffic congestion in cellular networks. From these facts, most of network services operators make a large effort to meet these user demands by providing the sufficient wireless networks with the large system capacity under the low cost of network infrastructure [1].

Up to today, various solutions and strategies have been proposed to handle this problem. The conventional homogeneous cellular networks (HoNets) are formed with base stations and a collection of user equipment (UE), in which all the base stations have the same transmission power level, antenna parameters, receiver noise floor, etc. across wide geographical areas. Moreover, all the base stations offer unrestricted access to UEs in the network and serve roughly the same number of UEs, all of which carry similar data flow with similar QoS requirement. To accommodate spatially concentrated traffic demand, heterogeneous cellular network (HetNet) is one of the low-cost effective solutions [2].

HetNets include multiple different kinds of base stations, referred to macro base stations (MBSs) and small base stations (SBSs). The MBSs provide radio coverage to a large area of mobile network extended to several kilometers with high transmission power usually in a range of tens of watts, and the SBSs provide small radio coverage from 10 to 200 meters with lower transmission power. Since SBSs have smaller coverage area, they do not suffer from the high propagation losses which arise at MBSs. Furthermore, inter-cell interference in the downlink can be reduced by operating the SBSs on the dedicated higher frequency bands, thus leading to an improvement in spectral efficiency [3]. The use of such bands for SBSs can lead to a significant capacity enhancement since they can offer larger bandwidth while reducing inter-cell interference. Hence, HetNets can eliminate black hole or dead zone with high user demand while also offering traffic offloading from the MBSs with large traffic demands [4].

However, the dense and random deployment of SBSs within the macro coverage causes the various negative effects, such as an increase in the inter-cell interference due to the use of the same frequency at many SBSs, and also an increase in power consumption due to the installation of additional SBSs. Nev-

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ertheless, various strategies have been proposed to reduce power consumption and improve energy efficiency in the HetNets. One of the effective techniques for energy efficiency improvement and power consumption saving is to introduce sleep control into the BSs. In [5], the sleep control scheme is applied for the SBSs, in which the number of users connected to the SBS is employed as decision criteria to put the SBS into the sleep state. Then the users connected to the sleeping SBSs are forced to hand over to one of other active base stations, and this handover makes a significant impact on communication performance at users due to the reduction of the assigned frequency bandwidth and signal quality at users. This is because the remaining active base stations have to take responsibility for providing service to the users also after their connecting BSs put into a sleep state. However, the number of connected users can be inappropriate as decision criteria for sleep control because some SBSs may have large cell throughput in spite of the small number of connected users. Therefore, the decision criteria need to be considered carefully for the sleep control of SBSs.

From the above background, this paper proposes a cell throughput based sleep control for SBSs in HetNets by introducing a cell capacity ratio as decision criteria to put the SBSs into a sleep state for downlink communications [6]. The salient of the proposed sleep control scheme is to put the SBSs with small cell throughput into a sleep state and to keep the active state at the SBSs with large cell throughput. By using the above decision criteria, the proposed sleep control scheme can improve the overall energy efficiency and also increase the system capacity in downlink communications compared with the conventional sleep control scheme.

The remainder of this paper is organized as follows. Section 2 presents related work to the sleep control for HetNets. Section 3 introduces the proposed cell throughput based sleep control scheme by using the decision criteria of cell capacity ratio. Section 4 presents the system model employed in performance evaluation for downlink communications through computer simulation. The simulation results are presented to verify the effectiveness of the proposed scheme in Section 5. Finally, Section 6 draws some conclusions.

2. RELATED WORK

Several techniques for reducing the power consumption in HetNets have been proposed. Reference [7] introduces three different strategies sleep control for small base stations, controlled by small cells, controlled by UEs, and controlled by the core network. The proposed algorithm allows the hardware components in the base stations to be switch off in idle conditions. Furthermore, the strategic sleep control by core network provides higher energy savings than the UE and small cell control methods.

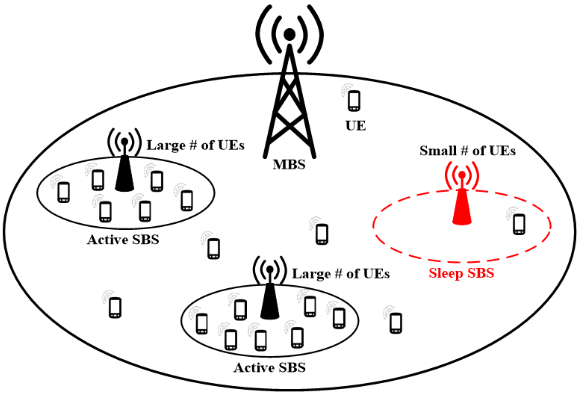

Fig. 1: *Conventional Sleep Control Scheme for Small Base Station.*

Reference [8] proposes the sleep mode activation scheme for small cells by the core network, which activates the sleeping SBS with the smallest large-scale channel fading to the active user. This scheme uses the advantage of the spatial correlation in large-scale fading and formulates the channel estimation method as a linear mean square. The result obtained in the paper shows the effectiveness of channel estimation method to estimate large-scale fading and saves transmit power over small cell networks.

Another fundamental work has been studied. In [9], the authors model sleeping strategy and apply the tool from stochastic geometry to analyze the impact of load-aware sleeping strategy for homogeneous macro cell and heterogeneous networks. Then the paper finds its performance to be at least as well as a network without using sleep control. In [10], the authors propose a distributed learning algorithm using notions of regret learning, which the base stations autonomously choose their optimal transmission strategies by considering the current traffic load and network environment. Reference [11] utilizes stochastic geometry by modeling the switching of base station operation. Two sleep mode strategies are investigated, namely random sleeping and strategic sleeping. Then the paper obtains analytical results for the coverage probabilities and the area spectral efficiency under different cell sleeping strategies.

Finally, in the conventional work [5] as shown in Fig. 1, the conventional sleep control scheme is applied to the small base stations in downlink communications network. The conventional sleep control scheme focus on the number of UEs connected to the SBS. In other words, the number of UEs connected to the SBS is used as the decision criteria to put the SBS into a sleep state. Based on this decision criteria, when the number of UEs N_{con} connected to the SBS is less than or equal to a sleep threshold N_{sleep}, the SBSs have to be put into a sleep state. Otherwise, the SBSs keep active state with large number of UEs connected.

Although the conventional sleep control scheme can achieve lower power consumption, the energy efficiency performance does not improve significantly because some SBSs may have large cell throughput in spite of the small number of connected UEs. That means the number of connected UEs does not always correlate with cell throughput. Here, it should be noted that the sleeping SBSs may have higher cell throughput than those for the active SBSs. Therefore, the conventional sleep control scheme can achieve lower power consumption with the cost of degradation in system throughput for downlink wireless communications. From the above problem, the decision criteria need to be considered carefully for sleep control of the SBSs.

3. CELL THROUGHPUT BASED SLEEP CONTROL SCHEME

This section proposes cell throughput based sleep control to overcome the problem with the conventional sleep control mentioned in the previous section.

Figure 2 shows the proposed cell throughput based sleep control scheme for downlink communications in HetNets. In the proposed scheme, the cell capacity ratio is newly introduced as decision criteria to put the SBSs into the sleep state, instead of the number of connected UEs employed in the conventional scheme.

The cell capacity ratio R^i_{cell} for the i-th SBS can be obtained from the current cell throughput S^i_{cell} [bps] normalized by cell capacity C_{cell} [bps], which is expressed by;

$$R^i_{\mathrm{cell}} = \frac{S^i_{\mathrm{cell}}}{C_{\mathrm{cell}}} \tag{1}$$

where C_{cell} denotes maximum achievable cell throughput when using whole bandwidth assigned to the target SBS. The S^i_{cell} is current cell throughput at the i-th SBS obtained by summing the user throughput S^j_{UE} at all the UEs connected to the SBS. The S^i_{cell} can be expressed by;

$$S^i_{\mathrm{cell}} = \sum_{j=1}^{N^j_{\mathrm{con}}} S^j_{\mathrm{UE}} = \sum_{j=1}^{N^j_{\mathrm{con}}} \{B^j_{\mathrm{UE}} \log_2(1+\gamma^i_{\mathrm{UE}})\}, \tag{2}$$

where B^i_{UE} is the frequency bandwidth allocated to the j-th UE, and γ^i_{UE} is the received signal to interference plus noise ratio (SINR) at the j-th UE, and N^i_{con} is the number of UEs connected to the i-th SBS.

For determining the operation state for the SBSs; sleep or active state, the proposed scheme employs a threshold-based control for the cell capacity ratio R^i_{cell}. Then, the operating state OP^i of the i-th SBSs is determined by;

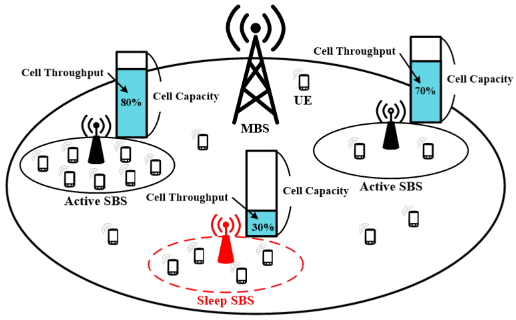

Fig.2: *Proposed Sleep Control Scheme with Constant a Threshold.*

$$OP^i = \begin{cases} sleep & ; \quad R^i_{cell} \le \alpha \\ active & ; \quad R^i_{cell} > \alpha \end{cases}, \tag{3}$$

where α is a pre-defined threshold value for the cell capacity ratio. From Eq. (3), it can be observed that when R^i_{cell} is less than or equal to α, the SBSs are put into the sleep state. Otherwise, SBSs keep active state.

This paper proposes two types of the threshold values for determining the operating state for the SBSs;

i) Constant threshold for all SBSs
This threshold takes a constant value and is the same for all the SBSs: $\alpha = c$, where c is a predefined value.

ii) Distance-based threshold
This threshold value depends on the distance dSBStoMBS from a given SBS to the MBS at the cell to which the SBS belongs. This paper proposes the threshold α which is defined by a linear function and can be expressed by;

$$\alpha = -m \cdot d_{\mathrm{SBStoMBS}} + c, \tag{4}$$

where m is a slope of the function and c is a constant, and both parameters are predefined.

The idea behind this threshold setting is as follows: one of the major factors which affect the user throughput is the distance between the UE and its connecting base station. This is because the user throughput is determined by the SINR as shown in Eq. (2) and the SINR is directly affected by the distance. Considering the user throughput for the UEs after hand over due to the sleeping of the connecting SBS, the UEs locating near the MBS have more potential obtaining larger user throughput from the MBS after their handover from the sleeping SBS to the MBS. From this consideration, the sleep state is more applicable for the SBSs near the MBS than those far from the MBS. Therefore, the threshold α should be larger for the SBSs near the MBS than those far from the MBS.

From this control mechanism, the proposed sleep control scheme can achieve better energy efficiency than the conventional one which considers the num-

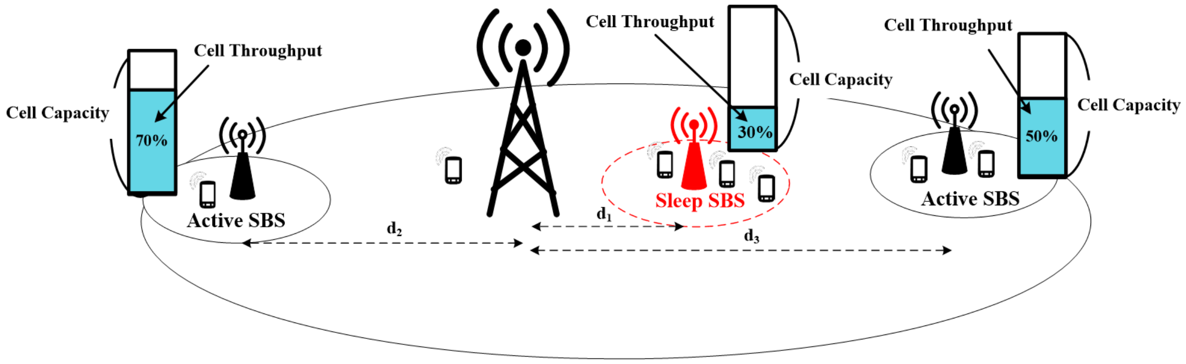

Fig.3: *Proposed Sleep Control Scheme with Distance a Threshold.*

ber of UEs connected to the SBS as the decision criteria. This is because the large cell throughput at the active SBSs can increase the system throughput, leading to improvement in the energy efficiency.

4. SIMULATION MODEL

This section describes the system model and the performance metrics used in the performance evaluation for the proposed sleep control scheme in the downlink communications of HetNets.

4.1 System Model

The MBSs are located at the centers of 7 hexagonal cells with one ring layout. The cell radius of the MBS is 500 meters. The N_{SB} SBSs and N_{UE} UEs are uniformly distributed in each MBS cell (coverage) area. The UEs are stationary without any mobility. The radio access technique is assumed to be orthogonal frequency division multiple access (OFDMA), in which MBS and SBS have the same amount of the frequency bandwidth W[Hz]. The allocated frequency band to the MBSs is different from that to the SBSs. Thereby, no interference occurs within a cell and between the MBS cells and SBS ones, and the total interference received by the j-th UE on the downlink is caused only from the same kind of base stations transmitting on the same carrier frequency band. Each base station assumes to generate the data traffic with a full buffer.

In the propagation model, the path loss due to the distance attenuation, and shadow fading attenuation are assumed. Therefore, the received signal power P^j_{rx}[dB] at the j-th UE can be expressed by;

$$P^j_{\mathrm{rx}} = P^j_{\mathrm{tx}} - (PL^j + \psi^j), \tag{5}$$

where P^j_{tx} [dB] is the transmission power at the connecting base station, PL^j[dB] is the path loss due to distance attenuation from the connecting base station to the j-th UE and ψ^j is the shadow fading attenuation at the j-th UE, which occurs due to various obstacles between transmitter and receiver [12]. Here the shadow fading attenuation ψ^j is modeled by a log-normal distribution, which can be given by;

$$P(\psi^i_{dB}) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left[-\frac{(\psi^j_{dB} - \mu_{dB})^2}{2\sigma^2_{dB}}\right], \tag{6}$$

where μ, σ^2[dB] are mean and variance of the distribution respectively.

Moreover, the path loss PL^j in Eq. (5) is generally modeled by the Okamura-Hata model [13], although the path loss may be less for rural areas with flat terrain than urban and suburban areas with buildings. In addition, the path loss depends on the conditions for signal propagation, such as carrier frequency, antenna height, and so on. Therefore, the path loss PL^j_{MB}[dB] for the MBSs with the carrier frequency of 2000 MHz, the antenna height of 15 meters and nearby buildings of uniform height can be given by;

$$PL^j_{\mathrm{MB}} = 128.1 + 37.6 \log_{10} r^j, \tag{7}$$

where r^j [km] is the distance from the j-th UE to its connecting base station. The path loss PL^j_{SB}[dB] for SBSs can be given by;

$$PL^j_{\mathrm{SB}} = 140.7 + 36.7 \log_{10} r^j, \tag{8}$$

As for the SINR at the j-th UE γ^j_{UE} in Eq. (2), it can be expressed by;

$$\gamma^j_{\mathrm{UE}} = \frac{P^j_{\mathrm{rx}}}{I^j + N_0 B^j_{\mathrm{UE}}}, \tag{9}$$

where N_0 is the noise power density, and I^j is the co-channel interference at the j-th UE from other active base stations except its own connecting base station, which is represented by;

$$I^j = \sum_{\substack{n=1 \\ n \neq j}}^{N} P^n_{\mathrm{rx}}, \tag{10}$$

where N is the number of active base stations in the network, and P^n_{rx} is the received power from the n-th interfering base station.

The power consumption of the base stations consists of two factors. The first factor describes the static power consumption P_{static}[W] which indicates the power consumption of base station independent from the dynamic resource allocation, such as transmission power and bandwidth allocation. The dynamic power consumption P_{dynamic}[W] is the second factor and is the function of transmission power . Hence, the overall power consumption P_{all}[W] can be given by;

$$P_{\mathrm{all}} = P_{\mathrm{static}} + P_{\mathrm{dynamic}}, \tag{11}$$

This paper considers the instantaneous power consumption and focuses on the power consumption only at the base stations, which does not include the power consumption at the users. The power consumption P_{MB}[W] at the MBSs is assumed to be constant and that P_{SB}[W] at the SBSs is assumed to be different depending on their operating state: the active state P_{ON}[W] with signal transmission, the active state P_{NTX}[W] without signal transmission, and the sleep state P_{SL}[W]. Hence, the overall power consumption P_{all}[8] can be expressed by;

$$\begin{aligned} P_{\mathrm{all}} &= (N_{\mathrm{MB}} \cdot P_{\mathrm{MB}}) \\ &+(N_{\mathrm{ON}} \cdot P_{\mathrm{ON}} + N_{\mathrm{NTX}} \cdot P_{\mathrm{NTX}} + N_{\mathrm{SL}} \cdot P_{\mathrm{SL}}) \end{aligned}, \tag{12}$$

where N_{MB} is the number of active MBSs, N_{ON}, N_{NTX} and $N_{\mathrm{SL}}$are the number of SBSs in the active state with signal transmission, the active state without signal transmission, and the sleep state, respectively.

4.2 Evaluation Metrics

The energy efficiency EE [bps/W], system throughput S_{sys}[bps] and overall power consumption P_{all}[W] are evaluated throughput computer simulation.

The energy efficiency EE is defined as an achievable system throughput over the overall power consumption P_{all} in the system [14], which can be expressed by;

$$EE = \frac{S_{\mathrm{sys}}}{P_{\mathrm{all}}}, \tag{13}$$

where S_{sys} is the system throughput, which is given by the summation of the cell throughput at all the MBSs and SBSs in HetNets. The S_{sys} can be expressed by;

$$\begin{aligned} S_{\mathrm{sys}} &= \sum_{i=1}^{N_{\mathrm{MB}}} S_{\mathrm{Mcell}}^{i} + \sum_{i=1}^{N_{\mathrm{SB}}} S_{\mathrm{cell}}^{i} \\ &= \sum_{i=1}^{N_{\mathrm{MB}}} \sum_{j=1}^{N_{\mathrm{Moon}}^{i}} \left\{ B_{\mathrm{UE}}^{j} \log_2(1+\gamma_{\mathrm{UE}}^{i}) \right\} \\ &+ \sum_{i=1}^{N_{\mathrm{SB}}} \sum_{j=1}^{N_{\mathrm{con}}^{i}} \left\{ B_{\mathrm{UE}}^{j} \log_2(1+\gamma_{\mathrm{UE}}^{i}) \right\} \end{aligned}, \tag{14}$$

where S_{Mcell}^{i} is the cell throughput at the i-th MBS, N_{SB} is the number of the SBSs in the active state, and $N_{\mathrm{Mcon}}^{i}$is the number of the UEs connected to the i-th MBS.

The maximum achievable throughput per unit frequency bandwidth of R_{max}[bps/Hz] is assumed. The R_{max} takes a different value between the MBSs and the SBSs due to the difference in their carrier frequency and propagation conditions.

5. SIMULATION RESULTS

In this section, various computer simulations are conducted to evaluate the performance of the proposed sleep control scheme, compared with the conventional sleep control scheme, in term of the energy efficiency EE, system throughput S_{sys}, and overall power consumption P_{all} in downlink communications. The main simulation parameter settings used in the following evaluation are summarized in Table 1. The total number of SBSs N_{SB} per macro cell coverage is 5-50, the total number of UE N_{UE} per macro cell coverage is 50, and the frequency - bandwidth W is 20 MHz, which is the same bandwidth for MBSs and SBSs. The different carrier frequency band is used, 2.0 GHz for MBSs, and 3.0 GHz for SBSs. The transmission power is 43 dBm and 30 dBm for MBSs and SBSs, respectively.

Table 1: *Simulation Parameters [15], [16]*

Parameters		Value
No. of small base stations per cell N_{SB}		5-50
No. of user equipment per cell N_{UE}		50
Macrocell radius		500 m
Frequency bandwidth W		20 MHz
Carrier frequency	MBS	2.0 GHz
	SBS	3.5 GHz
Transmit power P_{tx}	MBS	43 dBm
	SBS	30 dBm
Shadow fading std.	MBS	8 dB
	SBS	10 dB
Noise power density N_0		-174 dBm/Hz
Maximum throughput per unit frequency bandwidth R_{max} for MBSs,SBSs		2.5, 4.4 bps/Hz
Power consumption $P_{\mathrm{MB}}, P_{\mathrm{ON}}, P_{\mathrm{NTX}}$ P_{SL}		150, 30, 25, 15 W

The threshold α for the cell capacity ratio employed in the proposed scheme with the constant threshold is set so that the proposed scheme provides the same P_{all} performance as the conventional sleep control scheme, which employs the number of connected UEs as decision criteria. For the threshold employed in the proposed scheme with the distance based threshold, the linear function shown in Fig.4

is employed for determining the α depending on the distance d_{SBStoMBS}, which provides the best energy efficiency EE performance among several simulation evaluations varying the parameter settings of m and c.

Figure 5 shows the energy efficiency EE when changing the number of the SBSs per macro cell coverage. From the figure, it can be observed that both of the proposed sleep control schemes can achieve higher EE performance than the conventional sleep control scheme, and the proposed sleep control scheme with the distance based threshold has superior EE performance to with the constant threshold when the is over 25. These improvements come from the fact that the SBSs with small cell throughput put into a sleep state, while the SBSs with large cell throughput is always keeping in the active state.

Figure 6 shows the system throughput S_{sys} when changing the number of the SBSs per macro cell coverage. From the figure, it can be observed that the system throughput for both of the proposed sleep control schemes is higher than that for the conventional sleep control scheme. Moreover, the proposed sleep control scheme with distance-based threshold can achieve the highest performance, and it also shows a little bit superior the scheme without sleep control.

Figure 7 shows the overall power consumption P_{all} when changing the number of the SBSs per macro cell coverage. As the number of the SBSs per macro cell coverage increases, the overall power consumption of the network also increases. In the figure, the conventional without sleep control has highest power consumption due to all the SBSs keeping the active state. From the figure, it can be observed that the proposed sleep control scheme can achieve almost the same power consumption as the conventional sleep control scheme. Compared with the conventional without sleep control, both of the proposed sleep control schemes can drastically reduce power consumption in the network. However, the proposed sleep control scheme with the distance based threshold increases the power consumption slightly, compared with the constant threshold, although the gap in the power consumption between these two schemes is quite small.

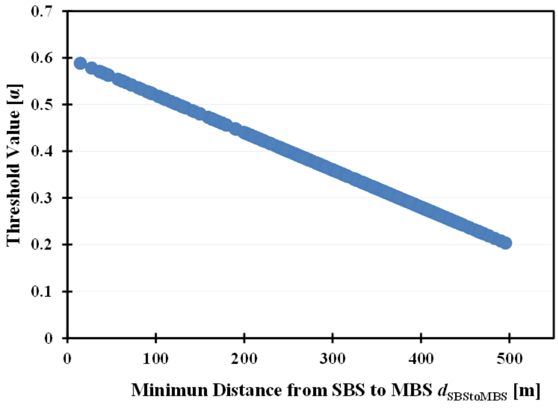

Fig.4: *Distance based Threshold by Using Linear Function.*

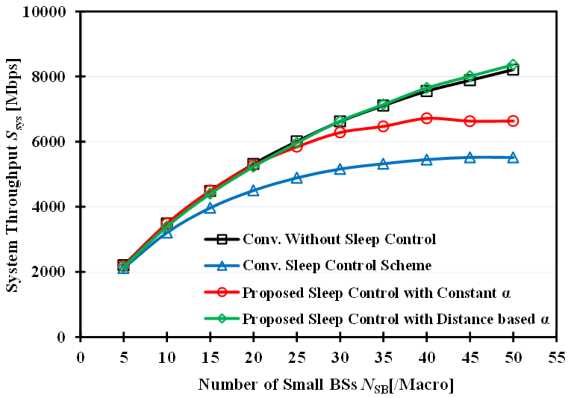

Fig.6: *The System Throughput when Changing the Number of Small BSs.*

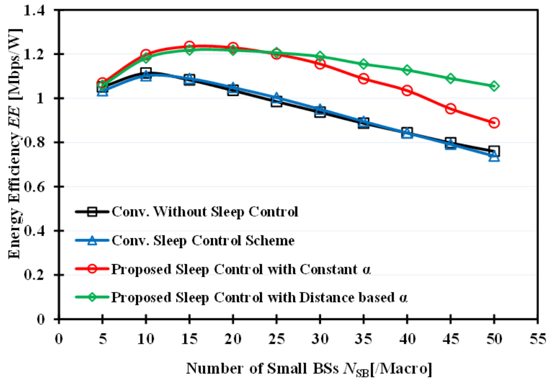

Fig.5: *The Energy Efficiency when Changing the Number of Small BSs.*

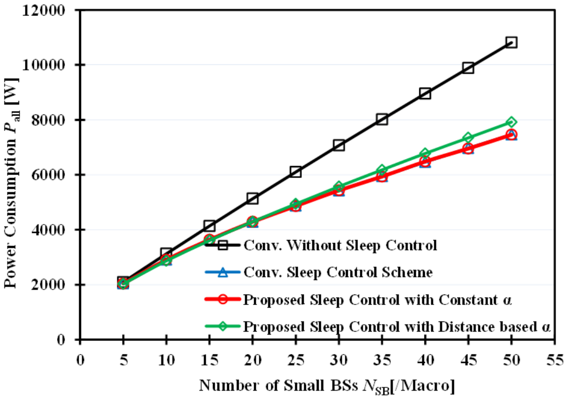

Fig.7: *The Power Consumption when Changing the Number of Small BSs.*

6. CONCLUSIONS

This paper discussed the sleep control technique applied to the SBSs for the downlink communications of HetNets, and then proposed the sleep control scheme which introduces the cell capacity ratio as decision criteria to put the SBSs into a sleep state. Since the decision criteria affect the system performance largely, this paper investigated two kinds of threshold control for the cell capacity ratio.

From the evaluation results through computer simulation, this paper shows that the proposed sleep control scheme with the distance based threshold can achieve better energy efficiency and higher system throughput, compared with other sleep control schemes. Therefore, the proposed sleep control with the distance based threshold is effective as sleep control for the downlink communications in HetNets.

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