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A Novel Power-Efficient BS Operation Scheme for Green Heterogeneous Cellular Networks

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ABSTRACT

Power-efficient base station (BS) operation is one of the important issues in future green cellular networks. Previously well-known BS operation schemes, *the cell zooming scheme* and *the cell wilting and blossoming scheme*, require tight cooperation between cells in cellular networks. With the previous schemes, the non-cooperative BSs of a serving cell and neighboring cells could cause coverage holes between the cells, thereby seriously degrading the quality of service as well as the power saving efficiency of the cellular networks. In this paper, we propose a novel power-efficient BS operation scheme for green downlink heterogeneous cellular networks, in which the networks virtually adjust the coverage of a serving macrocell (SM) and neighboring macrocells (NMs) without adjusting the transmission power of the BSs when the SM is lightly loaded, and the networks turn off the BS of the SM when none of active users are associated with the SM. Simulation results show that our proposed scheme significantly improves the power saving efficiency without degrading the quality of service (e.g., system throughput) of a downlink heterogeneous LTE network and outperforms the previous schemes in terms of system throughput and power saving efficiency. In particular, with the proposed scheme, macrocells are able to operate independently without the cooperation of a SM and NMs for green heterogeneous cellular networks.

Key Words : Load management, virtual coverage management, green communication, system throughput, power saving efficiency, heterogeneous cellular network

Ⅰ. Introduction

With the spread of smartphones, there is a limit to accommodate the rapidly increasing demand of mobile data traffic in traditional homogeneous cellular networks. Heterogeneous cellular networks can cope with the increasing traffic demand, in which macrocells are overlaid with small cells including microcells, picocells and femtocells with lower-power base stations, and heterogeneous networks can achieve coverage extension, throughput enhancement, and load balancing between cells by offloading the data traffic from macrocells to small cells[1-6].

Green communication technology for energy saving is also an important issue for future mobile cellular networks considering global environment effects. The energy consumption ratio and the energy consumption gain have been studied for high-speed downlink packet access cellular networks

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when reducing the cell size without degrading the quality of service[7]. Moreover, the effect of the cell size on energy saving and system capacity in mobile cellular networks has been investigated and shown that small-cell based communication networks can effectively accommodate high-rate data traffic with less CO2 emissions[8]. Some research issues and techniques to achieve energy efficient base stations for green heterogeneous cellular networks have been comprehensively explored in [9]. Power is mainly consumed by base stations (BSs), mobile switching centers, and core transmissions in cellular communication networks, in which BSs occupy the largest portion (about 60 percent) of power consumption in mobile cellular networks[10,11].

To reduce the power consumption of BSs, several power-efficient BS operation schemes, including *the cell zooming BS operation scheme* and *the cell wilting and blossoming BS operation scheme* have been introduced in [12,13]. With the cell zooming scheme, a serving cell reduces its coverage by gradually decreasing the transmission power of its BS, and also neighboring cells extend their coverage by increasing the transmission power of their BSs, consequently; UEs in the serving cell hand over to the neighboring cells, and the BS of the serving cell is switched off when none of the active UEs camp on the serving cell[12]. The cell wilting and blossoming scheme is similar to the cell zooming scheme, in which a serving macrocell (SM) in heterogeneous cellular networks operates with a sleep mode. In particular, the scheme gradually reduces the transmission power of the SM when the traffic load of the SM is light and turns off the BS transmitter of the SM when none of the active users stay in the SM, whereas neighboring macrocells (NMs) accommodate users handed over from the SM by gradually increasing the transmission power of the NMs[13].

The previous power-efficient BS operation schemes can achieve good performance in power saving efficiency and load balancing between cells in mobile cellular networks. With the cell zooming scheme, however, when a SM and NMs in heterogeneous cellular networks are not cooperatively operated, a coverage hole could be caused, thereby degrading the quality of service (e.g., system throughput) as well as the power saving efficiency. A virtual coverage management scheme (VCMS) with an adaptive handover threshold was introduced for WCDMA and LTE cellular networks[14-16], in which with decreasing the handover threshold in a SM reduces the coverage of the SM whereas the coverage of NMs is virtually extended without adjusting the transmission power of BSs in the SM and NMs.

Dynamic BS operation and user association mechanisms were proposed for BS energy saving of homogeneous cellular networks, in which a theoretical framework was developed with dynamic load-aware BS on/off operation scheme and an optimal energy-efficient user association policy[17]. However, the dynamic BS operation scheme has not been considered traffic management methodology, i.e., how to transfer mobile users of low-load macrocells to neighboring macrocells or femtocells in heterogeneous cellular networks. Furthermore, a joint algorithm for BS switching-on/off and user association in heterogeneous networks was introduced[18], in which the algorithm was designed to balance the energy consumption of overall network and the revenue of cellular networks, and the networks consist of both cellular networks using a licensed band and wireless local area networks operating in an unlicensed band. Also, a power-efficient BS operation scheme for green downlink heterogeneous cellular networks has recently been presented, and its performance of the BS operation scheme was compared with those of the previous cell zooming and normal schemes1), in terms of the total system throughput and power saving efficiency in the heterogeneous cellular networks[19].

In this paper, we propose a VCMS-based power-efficient BS operation (VPBO) scheme with BS switch-off for green heterogeneous LTE cellular

1) Note that the idea "normal scheme" hereinafter means that any special BS operation scheme, i.e., any special coverage management technique is not used in the heterogeneous cellular networks.

networks, in which UEs in a SM are handed over early to NMs and the femtocells deployed in the SM and NMs by applying the VCMS to the networks when the SM is lightly loaded, i.e., a few number of UEs are associated with the SM, and the BS transmitter of the SM is turned off when none of the active UEs are connected with the SM. Therefore, with our proposed VPBO scheme, each cell can independently operate without cooperation between a SM and NMs in heterogeneous cellular networks. Note that the VCMS was originally introduced to manage traffic overloading in WCDMA[14] and heterogeneous LTE[15,16] cellular networks, where mobile users in an overloaded SM are easily handed over to NMs and the femtocells overlaid with the SM and NMs. On the other hand, the VCMS in this study is used for BS power saving with the VPBO scheme in the networks. We also evaluate the performance of BS operation schemes, such as the proposed scheme, the previous cell zooming scheme and the normal scheme, and then investigate the effect of system parameters related to the BS operation schemes. Simulation results show that our proposed scheme outperforms both the cell zooming scheme and the normal scheme in power saving efficiency without degrading the system throughput in a downlink heterogeneous LTE cellular network.

The rest of this paper is organized as follows. The system model with a two-tier downlink heterogeneous LTE cellular network is described in section II. The proposed VPBO scheme is presented in section III. Simulation results are discussed in section IV. Finally, our conclusions are given in section V.

Ⅱ. System Model

We consider a two-tier downlink heterogeneous LTE cellular network shown in Fig. 1, in which multiple femtocells are overlaid with macrocells and use the same spectrum as the macrocells.

In the heterogeneous network, evolved NodeBs (eNBs) are located at the center of the macrocells and home eNodeBs (HeNBs) of the femtocells are randomly located in each macrocell. The femtocells

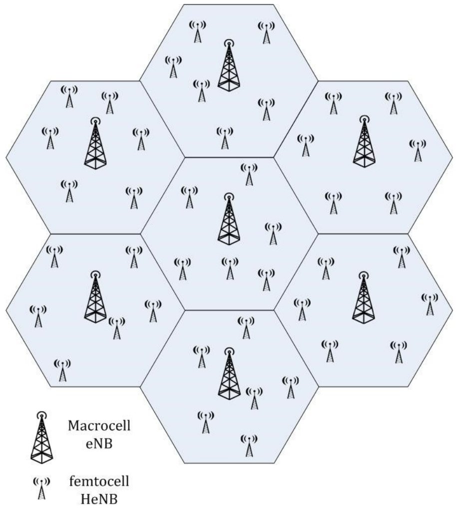

Fig. 1. Illustration of a two-tier heterogeneous LTE cellular network.

are operated in an open access mode so that the user equipment (UEs) in the macrocells and femtocells can use the radio resources of the femtocells when the UEs stay in the femtocell zone.

Ⅲ. Proposed Power-Efficient BS Operation Scheme

BS power consumption in heterogeneous cellular networks can normally be saved by turning off the BS of an unused macrocell without any cell coverage management when none of the active UEs are associated with the macrocell, which is hereinafter referred to as the normal BS operation scheme. Furthermore, the transmission power of BSs in the heterogeneous networks can be saved with the previous cell zooming BS operation scheme, which is similar to the concept of the cell wilting and blossoming BS operation scheme; hereafter referred to as the cell zooming scheme[12,13].

With the cell zooming scheme, the wireless coverage of a serving macrocell (SM) is reduced by decreasing the BS transmission power of the SM, and the coverage of neighboring macrocells is concurrently extended by increasing the BS transmission power of the NMs when the traffic load of the SM is lower than a predefined traffic load threshold, and the SM turns off its BS transmitter when none of the active UEs camp on the SM. Note that with the cell zooming scheme, the power saving efficiency can be enhanced only when both the lightly-loaded SM and NMs are cooperatively operated in heterogeneous cellular networks, whereas if tight cooperation between the SM and NMs is not ensured, then coverage holes between the cells are predictable thereby degrading the quality of service (QoS) such as the system throughput of the heterogeneous cellular networks.

3.1 The Concept of the Virtual Coverage management Scheme (VCMS)

Handover decisions in LTE cellular networks are performed with two threshold parameters, such as the handover hysteresis margin (HOM) and the time-to-trigger (TTT) timer, expressed as (1)[20]:

$$RSRP_t - RSRP_s > HOM$$
$$HO_{Trigger} \geq TTT, \qquad (1)$$

where $RSRP_s$ and $RSRP_t$ are the reference signal received power from the serving cell and the target cell, respectively, and $HO_{Trigger}$ is the handover trigger timer counting when the first criterion in (1) is satisfied.

Fig. 2 shows the concept of the VCMS for heterogeneous cellular networks. The VCMS was originally proposed to alleviate traffic overloading in WCDMA[14] and heterogeneous LTE[15,16] cellular networks, where the coverage of an overloaded SM and NMs are virtually shrunk and expanded, respectively, by decreasing the predefined threshold value of HOM in (1), namely, HOM = HOM - $\triangle HOM$. Hence, mobile users in the SM are easily handed over to NMs and the femtocells overlaid with the SM and NMs. Note that with the VCMS, the transmission power of base stations is not changed; instead, a predefined HOM value is adjusted by $\triangle HOM$, and thus the coverage of cells is virtually adjusted by changing the HOM value, namely, the real coverage of the cells is not changed regardless of the adjusted HOM value.

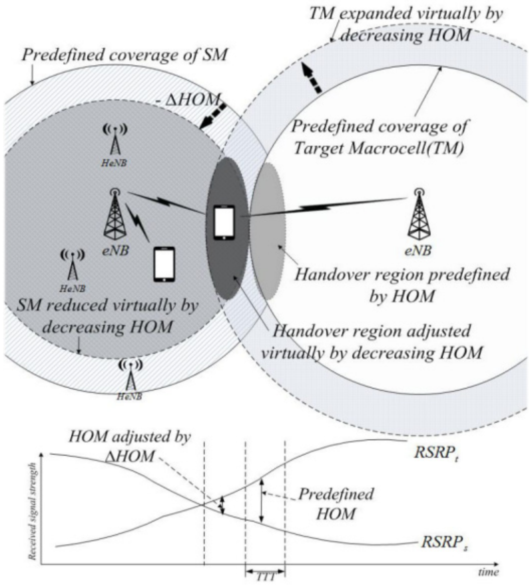

Fig. 2. The concept of the virtual coverage management scheme.

3.1.1 Proposed VCMS-based BS operation Scheme

We here propose a VCMS-based power-efficient BS operation (VPBO) scheme, in which the VCMS is applied to a lightly loaded SM of heterogeneous cellular networks shown in Fig. 3. Specifically, with the proposed scheme, when the downlink load of a SM L_k, approaches a predefined traffic load threshold, L_{th}, identifying a low load situation (i.e., $L_k < L_{th}$), the VCMS is applied to the heterogeneous LTE networks.

That is, the predefined HOM value is decreased by $\triangle HOM$ (i.e., HOM = HOM - $\triangle HOM$), and thus UEs in the SM are handed over early to the NMs, i.e., macrocell-to-macrocell handover, and to the femtocells overlaid with the SM and NMs, namely, macrocell-to-femtocell handover. When none of the active UEs are associated with the SM k, i.e., L_k = 0, the eNB of the SM is turned off. Note that in the proposed scheme, $RSRP_s$ is the reference signal received power from the SM and $RSRP_t$ is the reference signal received power from the SM or from the femtocells overlaid with the SM and NMs.

Meanwhile, if UEs in the offed SM try to access an eNB, an appropriate scheme such as the cell

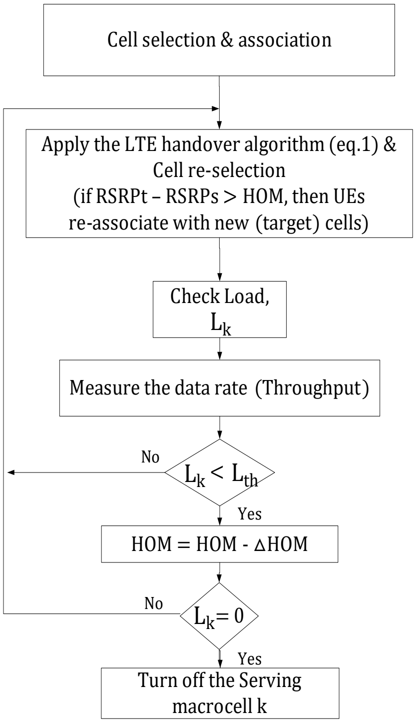

Fig. 3. The proposed VPBO scheme for green heterogeneous LTE cellular networks.

discovery technique[22,23] can be used for switching on the eNB of the SM in heterogeneous cellular networks densified with small cells. Note that $\triangle HOM$ in the proposed scheme affects a virtual coverage of SM and NMs in heterogeneous cellular networks, while $\triangle Ptx$ in the cell zooming scheme directly influences a real coverage of SM and NMs in the heterogeneous cellular networks.

3.1.2 Performance Metrics

The proposed VPBO scheme can be applied to heterogeneous LTE cellular networks without degrading QoS in the networks, and thus, we considered the total system throughput and power saving efficiency (PSE) as the performance metrics for the proposed scheme as well as for the normal and cell zooming schemes. The total system throughput of a heterogeneous cellular LTE network can be obtained by (2) as follows:

$$Total\ system\ throughput = \sum_{SM}\sum_{NMs}\sum_{femtos} R_i \tag{2}$$
$$R_i = 0.7 \times W \times \log_2(1 + SINR_i),$$

where W is the system bandwidth, and $SINR_i$ is the signal-to-interference plus noise power ratio received by the *ith* user.

The PSE means the ratio of the BS transmission power after and before applying a BS operation scheme to the heterogeneous cellular network. As previously described, the transmission power of the eNB in a SM is not adjusted with both the proposed scheme and the normal scheme regardless of the traffic load in the SM, and thus, the real coverage of the SM is not changed. Therefore, only the SM is considered for the PSE of both the normal and proposed schemes shown in Fig. 4(a). The PSE of the proposed scheme can be formally expressed as (3), which is the same as that of the normal scheme.

$$PSE = \frac{P_{tx}(T_{end} - T_{start}) - P_{tx}(T_{SM-Off} - T_{start})}{P_{tx}(T_{end} - T_{start})} \times 100 \tag{3}$$

On the other hand, with the cell zooming scheme the transmission power of a lightly-loaded SM, P_{tx}^{SM}, is decreased by $\triangle Ptx$ shown in Fig. 4(b), and the transmission power of NMs, P_{tx}^{SM}, is also increased by $\triangle Ptx$ shown in Fig. 4(c). Therefore, the PSE of the cell zooming scheme is more appropriate to consider both the PSE of the SM PSE_{Zoom}^{SM} and the PSE of the NMs, PSE_{Zoom}^{NMs} which is given by (4).

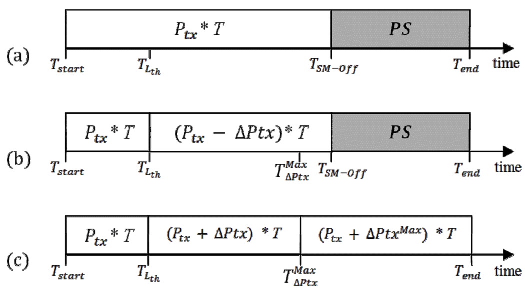

Fig. 4. Illustration of the power saving efficiency for the proposed and normal schemes (a), and the cell zooming scheme (b and c) (where, $P_{tx} = P_{tx}^{SM} = P_{tx}^{NM}$).

$$PSE\ of\ the\ zooming\ scheme = PSE_{Zoom}^{SM} + PSE_{Zoom}^{NMs} \quad (4)$$

where, $PSE_{Zoom}^{SM} =$

$$\left[1 - \frac{P_{tx}^{SM}(T_{L_{th}} - T_{start}) + (P_{tx}^{SM} - \triangle P_{tx})(T_{SM-Off} - T_{L_{th}})}{P_{tx}^{SM}(T_{end} - T_{start})}\right] \times 100$$

$$PSE_{Zoom}^{NMs} = \left[1 - \sum_{NMs} \frac{\Gamma + \Phi + \Theta}{\Omega}\right] \times 100,$$

$$\Gamma \equiv P_{tx}^{NM}(T_{L_{th}} - T_{start}),$$
$$\Phi \equiv (P_{tx}^{NM} + \triangle P_{tx})(T_{\triangle P_{tx}}^{Max} - T_{L_{th}}),$$
$$\Theta \equiv (P_{tx}^{NM} + \triangle P_{tx}^{Max})(T_{end} - T_{\triangle P_{tx}}^{Max}),$$
$$\Omega \equiv P_{tx}^{NM}(T_{end} - T_{start}).$$

In (4), T_{Lth}, $T_{SM\text{-}Off}$, and $T_{\triangle P_{tx}}^{Max}$, respectively, represent the times such that the traffic load in a SM approaches the traffic load threshold L_{th} ; the eNB of a SM is turned off, and the decrement (or increment) of the transmission power $\triangle Ptx$ reaches the maximum value of $\triangle Ptx$.

Ⅳ. Simulation Results and Discussion

4.1 Evaluation Methodology

To evaluate the performance of our proposed VPBO scheme, we consider a downlink heterogeneous LTE cellular network, in which the network consists of a 7-macrocell with a centered SM and 6 adjacent NMs, and the SM is also overlaid with several femtocells2) . In addition, the femtocells are uniformly distributed in the SM. We also consider a 7-cell wrap around model[24], and the inter-site distance between two eNBs is 1.4 *Km*, and they are disposed in the center of hexagonal cells. Each HeNB is operated in an open-access mode; UEs entering a femtocell will remain there until their calls end. The proposed scheme has been implemented in a simulation taking into consideration both link-level and system-level characteristics, in which the Shannon capacity considers 30 percent overhead information for the link-level characteristics. That is, we assume 70 percent of the Shannon capacity can be achieved from the link-level of the LTE cellular network. The performance of the proposed scheme is compared to those of both the normal and cell zooming schemes.

We assume that 35 UEs are uniformly distributed in a SM, whereas 50 UEs are randomly distributed in each NM to consider different traffic load situations in the SM and NMs. In addition, UEs constantly move at varying speed between 5 *Km/h* and 50 *Km/h*, and travel in random directions that range from 0 to 360 degrees. We also assume a full queue data traffic model for all UEs in the macrocells and femtocells. Only two kinds of handovers are enabled; macrocell-to-femtocell and macrocell- to-macrocell handovers. The handover decision criteria in (1) for macrocell-to-macrocell handovers are herein activated regardless of the speeds of UEs, whereas the decision criteria for macrocell- to-femtocell handovers are applicable to only the UEs travelling at speeds which are lower than the velocity threshold V_{th}.

We here introduce the relative traffic load (RTL) in a SM for a traffic load measure expressed as the number of UEs in the SM relative to the average number of UEs in NMs, given by (5).

$$RTL\ in\ SM \equiv \frac{Number\ of\ UEs\ in\ SM}{Average\ Number\ of\ UEs\ in\ NMs}. \quad (5)$$

The traffic load threshold L_{th} ranging from 0.1 to 0.3 is used to apply the proposed scheme (i.e., the VCMS) and the cell zooming scheme to the heterogeneous LTE network. Moreover, a HOM value of 2 dB, a $\triangle HOM$ value of 0.1 *dB*, and a maximum $\triangle HOM$ value of 5 *dB* are used for the proposed scheme; in the same manner, a $\triangle Ptx$ value of 0.1 *dBm* and a maximum $\triangle Ptx$ value of 5 *dBm* are assumed for the cell zooming scheme. Therefore, when the traffic load in the SM approaches a predefined load threshold value, the HOM value is decreased by $\triangle HOM$ value until the sum of the decreased value reaches the maximum $\triangle HOM$ value, whereas the transmission (TX)

2) Note that for the sake of simulation simplicity, 150 femtocells are overlaid with only the SM in the considered heterogeneous LTE network. In addition, different numbers of UEs are distributed in both the SM and NMs for the situation of a traffic load imbalance.

power of the eNB of the NMs, Ptx, is decreased by the $\triangle Ptx$ value until the sum of the decreased value reaches the maximum $\triangle Ptx$ value.

4.2 Numerical Results and Discussion

Power-efficient BS operation schemes for green heterogeneous cellular networks should be able to enhance the power saving efficiency without degrading the QoS (e.g., system throughput). To compare the performance of the proposed, normal, and cell zooming schemes, we evaluate the total system throughput and PSE of the downlink heterogeneous LTE cellular network with several system parameters given in Table I[20,21]. The total system throughput of the heterogeneous network is obtained by (2).

The total system throughput can be obtained from a SM, NMs and the femtocells overlaid with the SM

Table 1. System Parameters.

Parameters		Value
System	Bandwidth	10 *MHz*
	Simulation time	300 *sec*
	TTI	1 *msec*
	Scheduling scheme	Proportional Fair
Macrocell	Number of macrocells	7
	Radius	0.8 *Km*
	Inter-site distance	1.4 *Km*
	Tx power of eNB (*Ptx*)	43 *dBm*
	Load threshold (*Lth*)	0.1, 0.2, 0.3
	$\triangle Ptx$, maximum $\triangle Ptx$ (for zooming scheme)	0.1 *dBm*, 5 *dBm*
Femtocell	Number of femtocells	150
	Tx power of HeNB	20 *dBm*
Propagation model	Path-loss = 120.35 + 37.6 * log(*d*) *d* : distance between UE and BS	
Mobility model	Velocity (*Vmin*, *Vmax*)	(5 *Km/h*, 50 *Km/h*)
	Vth (for M-to-f handover)	45 *Km/h*
	Moving direction	[0, 360°]
Traffic model	Number of UEs in (SM, NM)	(35, 50)
	Data traffic	a full queue
Handover parameters	HOM, $\triangle HOM$, Maximum $\triangle HOM$	2 *dB*, 0.1*dB*, 5 dB (*Max.*)
	TTT	200 *msec*

given by (6). We evaluate the performance of the proposed VPBO scheme and compare it to the performances of the other two schemes: the normal scheme and the cell zooming scheme. We first investigate the effect of various system parameters on the performance of the proposed and cell zooming schemes and then choose the optimum parameter values for the schemes through simulations of the downlink heterogeneous LTE cellular network.

4.2.1 An optimum $\triangle Ptx$ for the cell zooming scheme

We here investigate the optimum $\triangle Ptx$ value, i.e., the increment or decrement of the BS transmission power for the cell zooming scheme in the heterogeneous LTE network. Fig. 5 shows the total system throughput achieved by a SM, NMs, and the femtocells of the downlink heterogeneous LTE network applied the cell zooming scheme, depending on the increment or decrement value of the BS transmission power $\triangle Ptx$, namely,

$$total\ system\ throughput = \sum_{SM}\sum_{NMs}\sum_{femto} R_i .$$

With the cell zooming scheme, the real coverage of a SM is shrunk and those of NMs are expanded by increasing $\triangle Ptx$, and thus, a number of UEs are handed over to the NMs increasing the interference to the UEs, thereby degrading the total system throughput. In particular, the degradation in the total system throughput is increased in the case in which a larger value of $\triangle Ptx$ (e.g., above 5 *dBm*) is set

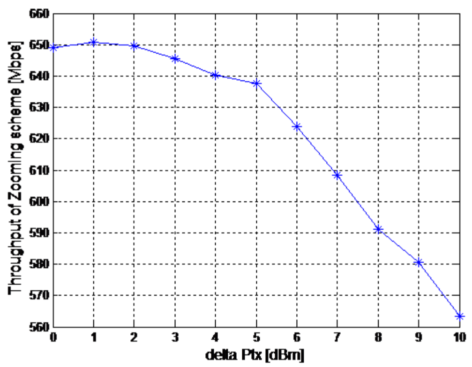

Fig. 5. The total system throughput of the cell zooming scheme depending on $\triangle Ptx$ in the downlink heterogeneous LTE network.

for the cell zooming scheme compared to a case with a smaller value of $\triangle Ptx$.

Fig. 6 shows the power saving efficiency obtained by (3), when the cell zooming scheme is applied to the downlink heterogeneous LTE network according to the increment or decrement value of the BS transmission power $\triangle Ptx$. The PSE of a SM shows improvement over those of both the SM and NMs. This improvement is increased with larger values of $\triangle Ptx$. For example, the improvement in the PSE of the SM ranges from 9 to 10 percent when the value of $\triangle Ptx$ increases from 8 to 9 *dBm* and from 4 to 5 *dBm*, respectively. Meanwhile, the total system throughput of the cell zooming scheme in the case of 5 dBm for the $\triangle Ptx$ is higher than that in the case of 9 *dBm* for $\triangle Ptx$, and thus, 5 *dBm* is chosen as the optimum value of $\triangle Ptx$ used throughout the simulations for the cell zooming scheme.

We hereinafter investigate the effects of system parameters related to the proposed VPBO scheme on the performance of the downlink heterogeneous LTE network.

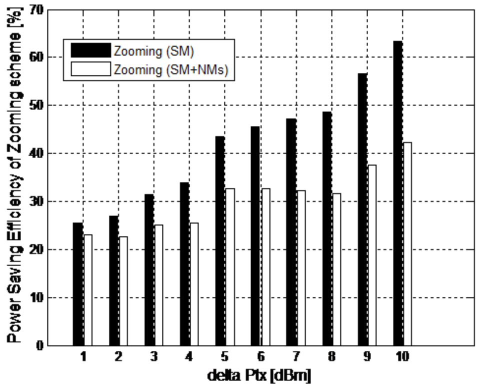

Fig. 6. The power saving efficiency of the cell zooming scheme according to $\triangle Ptx$ in the downlink heterogeneous LTE network.

4.2.2 The virtual coverage adjustment value △HOM

Fig. 7 shows the total system throughput achieved by a SM, NMs and femtocells of the downlink heterogeneous LTE network, namely, $total\ system\ throughput = \sum_{SM}\sum_{NMs}\sum_{femto} R_i$, depending on the increment or decrement value of the virtual coverage (i.e., $\triangle HOM$) when the proposed scheme is applied to the heterogeneous network. As the value of $\triangle HOM$ increases, the HOM value decreases (HOM = HOM - $\triangle HOM$), and thus, the virtual coverage of a SM is shrunk, thereby decreasing the system throughput obtained by the SM, whereas the system throughput by the NMs and femtocells is improved by quickly inducing UEs in the SM to hand over toward the NMs and femtocells of the heterogeneous network.

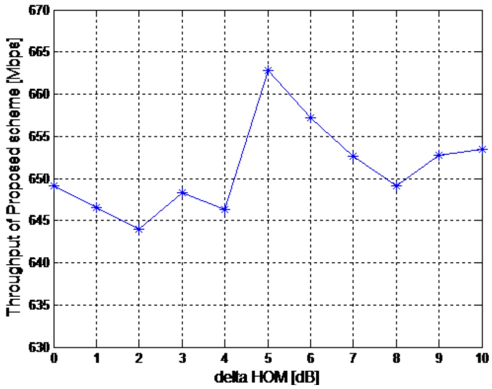

Fig. 7. The total system throughput of the proposed scheme for $\triangle HOM$ in the downlink heterogeneous LTE network.

From Fig. 7, we can observe that the maximum value of the total system throughput is obtained when a $\triangle HOM$ of 5 *dB* is set for the proposed scheme. Note that $\triangle HOM$ rises by 0.05 *dB* with every 100 *msec* in the simulation, and it takes 10 seconds for the $\triangle HOM$ to reach 5 *dB* and 18 seconds for 9 dB, respectively, and thus, the effect of $\triangle HOM$ on the PSE of the downlink heterogeneous network is minimal considering the entire simulation time is only 300 seconds.

4.2.3 The traffic load threshold *Lth*

We here investigate the effect of the traffic load threshold L_{th} on the PSE and the total system throughput of the downlink heterogeneous LTE network using the proposed scheme and considering that the total system throughput of the proposed scheme increases with a larger value of $\triangle HOM$ shown in Fig. 7.

Fig. 8 shows the total system throughput achieved by a SM, NMs, and femtocells of the heterogeneous

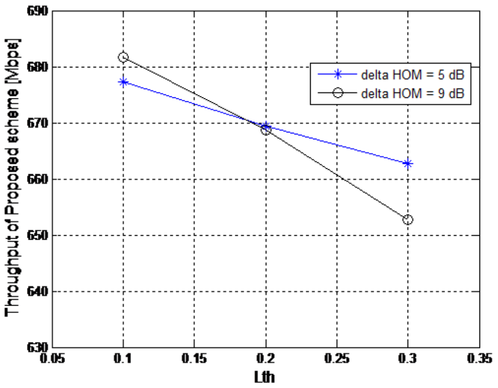

Fig. 8. The total system throughput of the downlink heterogeneous LTE network with the proposed scheme according to the traffic load threshold L_{th}.

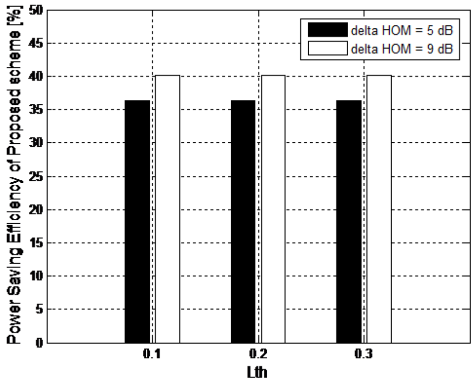

Fig. 9. The power saving efficiency of the proposed scheme according the traffic load threshold L_{th}.

LTE network depending on the L_{th} and $\triangle HOM$, when the proposed scheme is applied to the heterogeneous network.

When traffic is lightly loaded in the SM, e.g., L_{th} is less than 0.2, the total system throughput in the case of $\triangle HOM$ = 9 *dB* is higher than that in the case of $\triangle HOM$ = 5 *dB*. On the other hand, with L_{th} = 0.3, the total system throughput in the case of $\triangle HOM$ = 5 dB is higher than that in the case of $\triangle HOM$ = 9 *dB*. That is, when traffic is low in the SM, the proposed scheme with a larger value of $\triangle HOM$ quickly induces the handovers of UEs in the SM to other cells such as the NMs and femtocells of the heterogeneous network, and thus, the total system throughput is not degraded.

Whereas, with a larger value of L_{th}, namely, in the case for which traffic is not lightly loaded in a SM, the proposed scheme with a larger value of $\triangle HOM$ forces even the UEs receiving higher signal power in the SM to be handed over to other cells such as the NMs and femtocells of the heterogeneous network, thereby degrading the total system throughput. Therefore, when a relatively large number of UEs are associated with a SM in the heterogeneous network, with a smaller value of $\triangle HOM$, e.g., 5 *dB* in this case, the virtual coverage of the SM and NMs is gradually adjusted, and thus, the signal power received by UEs in the SM is not rapidly dropped.

Fig. 9 shows the PSE of the heterogeneous network according to the traffic load threshold L_{th} when the proposed scheme with 5 and 9 *dB* of $\triangle HOM$, respectively, is applied to the network.

The PSE is irrelevant to the value of L_{th} and the PSE in the case of $\triangle HOM$ = 9 *dB* is better than that of $\triangle HOM$ = 5 *dB*. Note that with the proposed scheme, if traffic in a SM approaches the predefined traffic load threshold L_{th}, the VCMS is applied to the heterogeneous network; namely, a predefined HOM value is decreased by $\triangle HOM$ (i.e., HOM = HOM - $\triangle HOM$). In addition, $\triangle HOM$ rises by 0.05 *dB* every 100 msec in the simulation, and it takes 10 seconds for the $\triangle HOM$ value to reach 5 dB and 18 seconds for 9 *dB*, respectively, and thus, the effect of L_{th} on the PSE of the heterogeneous network is minimal when considering the entire simulation time is 300 seconds. Consequently, the PSE of the proposed scheme is nearly irrelevant to the value of L_{th}.

From Figs. 8 and 9, we can observe the following: when traffic is lightly loaded in a SM, the proposed scheme with a larger value of $\triangle HOM$ (e.g., 9 *dB*) can improve the PSE without degrading the total system throughput (i.e., QoS) of the heterogeneous network, whereas in the case that traffic is not low in a SM, the proposed scheme with a larger value of $\triangle HOM$ (e.g., 9 *dB*) can enhance the PSE but degrade the total system throughput of the network compared to the proposed scheme with $\triangle HOM$ = 5 *dB*.

4.2.4 Number of deployed femtocells

Fig. 10 shows the total system throughput obtained by the heterogeneous LTE network depending on the number of femtocells deployed in the network when the proposed scheme with 5 and 9 *dB* of △*HOM*, respectively, is applied to the network. The total system throughput improves as the number of femtocells increases. This improvement in the system throughput increases when the proposed scheme with a relatively smaller value of △*HOM* (e.g. 5 *dB*) is applied to the heterogeneous network deployed with a larger number of femtocells. For example, a slightly higher total system throughput is achieved with △*HOM* = 9 *dB* and with less than 90 femtocells, whereas the total system throughput is enhanced with △*HOM* = 5 *dB* and with more than 90 femtocells. This means that as the number of femtocells deployed in the heterogeneous network increases the number of UEs handed over to the femtocells also increases, and thus, a smaller value of △*HOM* is more suitable for improving the total system throughput of the proposed scheme.

Fig. 11 shows the PSE according to the number of femtocells deployed in the heterogeneous network when the proposed scheme with 5 and 9 *dB* of △*HOM*, respectively, is applied to the network. The PSE is enhanced as the number of femtocells is increased. In particular, the PSE is more improved when the proposed scheme with a larger △*HOM* (i.e., 9 *dB*). This means that with a larger value of

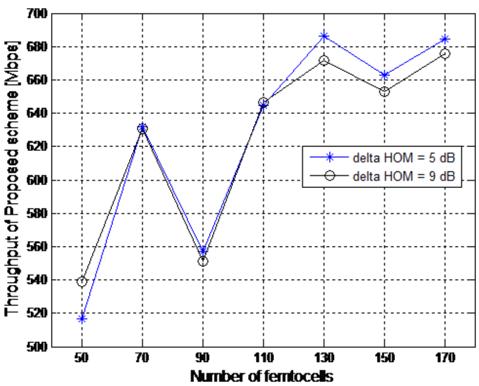

Fig. 10. The total system throughput of the proposed scheme for the number of femtocells.

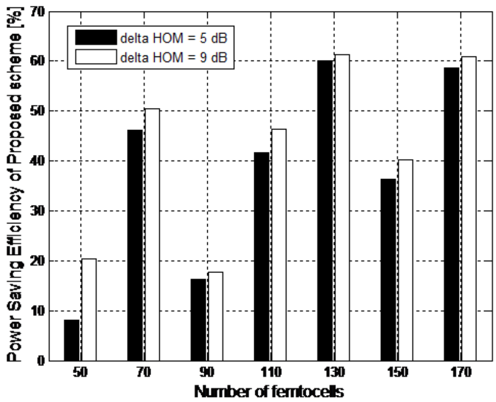

Fig. 11. The power saving efficiency of the proposed scheme for the number of femtocells.

△*HOM*, UEs camping on a SM can be handed over early to the femtocells, and thus, the PSE can be improved.

4.2.5 The virtual coverage adjustment value △*HOM*

We have observed that both the PSE and total system throughput of the proposed scheme can be improved by forcing UEs in a SM to be handed over to the femtocells and NMs when fewer femtocells are deployed in the heterogeneous network. We also investigate the effect of the virtual coverage adjustment value △*HOM* on the system throughput of the proposed scheme.

Fig. 12 shows the system throughput, respectively, achieved by only a SM and femtocells in the heterogeneous LTE network using the

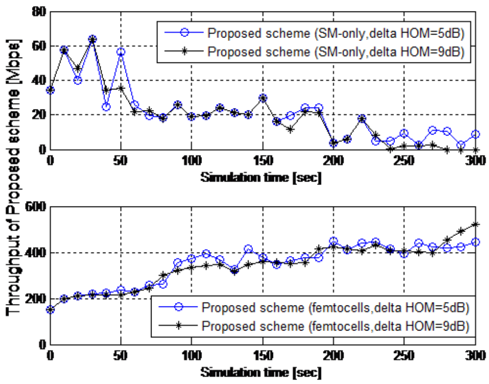

Fig. 12. The total system throughput of the proposed scheme for △*HOM*.

proposed scheme depending on $\triangle HOM$. As the simulation time progresses the system throughput of the SM diminishes, whereas the system throughput obtained by the femtocells increases. In particular, the system throughput of the femtocells in the range of 70 seconds and 270 seconds is slightly higher with $\triangle HOM$ = 5 dB, whereas the system throughput after over 270 seconds (i.e., SM is offed) is slightly higher with $\triangle HOM$ = 9 *dB*. From the investigations on the performance of the proposed scheme, shown in Figs. 7-12, we can observe that the total system throughput in the case of the proposed scheme with $\triangle HOM$ = 5 *dB* is higher than that in the case of $\triangle HOM$ = 9 *dB*, whereas the PSE in the case of $\triangle HOM$ = 9 *dB* is more improved than that in the case of $\triangle HOM$ = 5 *dB*.

4.2.6 Performance comparison of the BS operation schemes

We hereinafter compare the performance of the BS operation schemes with 5 *dBm* and 5 *dB* as the optimum values of $\triangle Ptx$ and $\triangle HOM$ for the cell zooming scheme and proposed scheme, respectively.

Fig. 13 shows the total system throughput achieved by a SM, NMs, and femtocells of the downlink heterogeneous LTE cellular network according to the traffic load threshold L_{th}. The BS transmission power of the NMs is increased with the cell zooming scheme, and thus, the interference affecting the other cells such as adjacent macrocells and femtocells is also increased, thereby significantly reducing the total system throughput obtained by the heterogeneous network. The reduction in the total system throughput is exacerbated as the traffic load threshold is increased. On the other hand, the BS transmission power of NMs as well as a SM is not adjusted with the proposed scheme, and interference is not generated; hence, the total system throughput of the heterogeneous network is nearly not reduced compared to the cell zooming scheme.

Therefore, the total system throughput of the proposed scheme outperforms those of both the normal and cell zooming schemes. In particular, the total system throughput of the cell zooming scheme is inferior to the other schemes because the *SINR* of UEs located nearby the SM could be degraded by increasing the transmission power of the NMs by $\triangle Ptx$, and thus, the number of macrocell-to-femtocell handovers may be reduced. Furthermore, from Fig. 13, the total system throughput of the proposed scheme improves when a smaller value of the traffic load threshold is set for the SM. This is because when a smaller value of the L_{th} is used for the SM in the heterogeneous network, the number of UEs handed over compulsively to other cells diminishes, thereby reducing the degradation of the total system throughput.

Fig. 14 shows the power saving efficiency of the downlink heterogeneous LTE cellular network

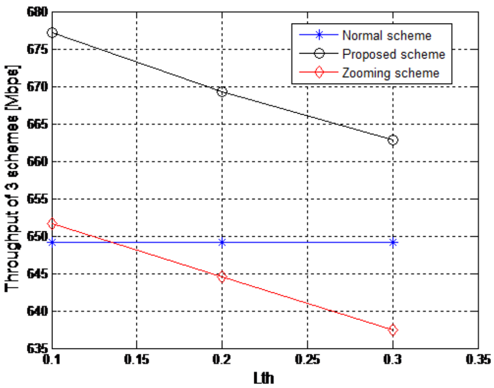

Fig. 13. Comparison of the total system throughput for BS operation schemes depending on the traffic load threshold L_{th}.

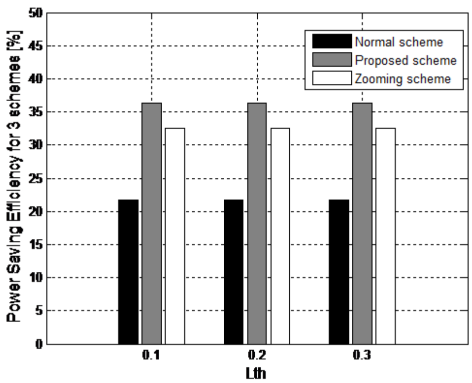

Fig. 14. Comparison of the power saving efficiency for BS operation schemes according to traffic load threshold L_{th}.

according to the traffic load threshold L_{th}. The power saving efficiency of the proposed scheme shows an improvement compared to those of both the normal and cell zooming schemes. For example, with the proposed scheme, the improvement in the power saving efficiency is about 15 percent compared to the corresponding values of the normal scheme and 5 percent compared to that of the cell zooming scheme. In particular, this improvement is almost irrelevant to the values of L_{th}.

This is because both the proposed and cell zooming schemes operate when the traffic load in a SM approaches a predefined load threshold value, i.e., L_{th} = 0.1, 0.2, and 0.3, and thus, too short of a time is required to reach the maximum values of $\triangle HOM$ and $\triangle Ptx$ for the two schemes, respectively. Note that it takes only 18 seconds for the maximum value of $\triangle HOM$ to reach 5 *dB* and for the maximum value of $\triangle Ptx$ to reach 5 *dBm*, respectively, and this time is too short compared to the 300 seconds of the entire simulation (operation) time.

Fig. 15 plots the total system throughput obtained by a SM, NMs and femtocells according to the number of femtocells deployed in the heterogeneous LTE network. The total system throughput is enhanced as the number of deployed femtocells increases. In particular, the total system throughput of our proposed scheme can achieve more benefits than the cell zooming scheme in the case of densely deployed femtocells. Therefore, we can infer that femtocells in the case of the proposed scheme can have a more important role (e.g., macrocell-to-femtocell handover) to increase the total system throughput, compared to that of the cell zooming scheme.

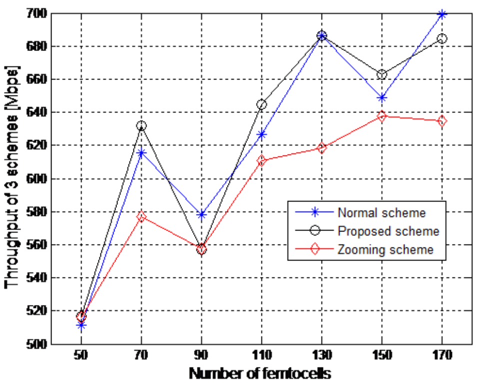

Fig. 15. Comparison of the total system throughput for BS operation schemes depending on the number of femtocells.

V. Conclusion

Energy saving technology is one of the important issues for green heterogeneous cellular networks. Several power-efficient BS operation schemes have previously been introduced to reduce the power consumption of base stations which occupy the largest portion of power consumption in cellular mobile communication networks. However, previously-known BS operation schemes such as both the cell zooming scheme and the cell wilting and blossoming scheme require concurrent operations of a SM and NMs in heterogeneous cellular networks, and thus, cellular networks without cooperation between a serving and neighboring macrocells could cause coverage holes between the cells, thereby seriously degrading the QoS as well as the power saving efficiency in the networks.

In this paper, we have proposed a novel power-efficient BS operation scheme for green downlink heterogeneous LTE cellular networks, in which the networks virtually shrink the coverage of a SM and virtually extend the coverage of NMs by changing the HOM value when the SM is lightly loaded; consequently, UEs in the SM are easily handed over to the femtocells overlaid with the SM and NMs, and the proposed scheme turns off the SM when none of the active UEs are associated with the SM. In particular, with the proposed scheme, the heterogeneous cellular network does not need to adjust the transmission power of BSs, whereas the previous schemes manage the coverage of cells by changing the transmission power of BSs.

We have investigated the performance of the proposed, normal, and cell zooming schemes in terms of system throughput and power saving efficiency for a two-tier downlink heterogeneous

LTE cellular network. Simulation results showed that our proposed VPBO scheme improves the power saving efficiency without degrading the total system throughput of the heterogeneous cellular network. In particular, this improvement is significantly increased by the appropriate values for the traffic load threshold and HOM adjustment, and by the number of femtocells deployed in the heterogeneous cellular network. Furthermore, the proposed BS operation scheme outperforms both the previous cell zooming and normal schemes in terms of power saving efficiency and total system throughput. With the proposed scheme, macrocells are able to operate independently without cooperation between cells for green heterogeneous cellular networks.

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