Base Station Operation Based on Affinity Propagation in Cellular Networks

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***Abstract*—Wireless communication network requires a network design that can cope with peak mobile traffic. The mobile traffic fluctuates over time. It is known that the energy consumption of base stations (BSs) accounts for a large percentage of the overall network energy consumption. Recently, small cell base stations (SBSs) are deployed at high density to cope with the increasing amount of mobile traffic. However, activating all SBSs during non-peak hours of traffic leads to a decrease in energy efficiency. BS sleep strategy has been considered to improve energy efficiency. In this paper, affinity propagation (AP) based BS sleep technology is proposed. AP does not need to determine the number of clusters in advance. The computer simulation results show that the proposed scheme can reduce the outage probability of user equipment (UE) compared to the conventional scheme.**

***Index Terms*—green cellular networks, energy-efficient operation, base station sleep, clustering, affinity propagation**

I. INTRODUCTION

In recent years, with the spread of mobile devices such as mobile phones and notebook computers equipped with communication functions, the amount of mobile data traffic on the network has increased dramatically. Multimedia-rich content represented by YouTube has a large capacity, so the amount of downlink traffic, which is communication from a base station (BS) to a user equipment (UE), requires large communication capacity. Furthermore, with the explosive spread of social networking services (SNS) such as Facebook and Twitter, the amount of uplink traffic that is communication from UE to BS is increasing. The amount of mobile traffic varies significantly over time [1].

Cellular networks need to be designed to accommodate mobile traffic volume that fluctuates over time. For this reason, only a part of radio resources (frequency and time slot) are used in each BS when traffic volume is relatively low such as dawn and midnight. For example, BS power amplifiers (PA) are designed to maximize efficiency at maximum transmit power when all frequency resource blocks (RBs) are used. Therefore, if only a part of the frequency RB is used, the transmission power is smaller than the maximum transmission power, and the efficiency of the PA is reduced. Furthermore, BS operation requires power that is independent of transmission power. It is defined as the energy consumption required to transmit one bit[1]. The energy use efficiency [J/bit] is lower than that during the peak.

If a BS operates in the same way as during peak hours when mobile traffic is low, the energy utilization efficiency of the entire network significantly degrades. For this reason, many studies have been conducted to improve the energy utilization efficiency of the entire network during non-peak hours. BSs consume about 60% of the energy consumption of the entire network [2]. For this reason, BS sleep technology [3] that reduces the energy consumption of the entire network by placing a low-utilization BS in a low power consumption mode (sleep mode) during non-peak hours of mobile traffic has attracted attention in recent years.

There are several previous studies related to this technology [3] [4]. In [3], a small cell BS (SBS) sleeping strategy has been proposed for a heterogeneous network (HetNet) where macro BS (MBS) and SBS coexist. Two methods, a random sleep method that randomly sleeps each SBS and a strategic sleep method that sleeps depending on the traffic load, have been studied. The computer simulation reveals that the random sleep method can improve energy efficiency (EE) by about 30 %. Although the strategic sleep method is more complex than the random sleep method, it can improve EE by about 15 %. In [4], green network design using Affinity Propagation (AP) [5], which is one of the clustering methods, is proposed. It is formulated as an optimization problem consisting of a combination of "whether BS is in active mode or sleep mode" and "which UE should be connected to which BS". Channel-based BS clustering between BS and UE is performed. As a result, it became clear that the energy consumption of BS was reduced by more than 50 % compared with the conventional method.

In [4], the state of BS, whether each BS is active or sleep, is determined after AP is executed. At this time, the state of the BS remains constant until the next AP execution. However, since the traffic volume varies with time, if the traffic volume increases, the load on one BS increases or the throughput of UEs in the coverage hole decreases.

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[1] For example, there are the following indicators. [bit/J] representing the amount of data per joule, $E_{\mathrm{Largecell}}/E_{\mathrm{Smallcell}}$ representing the energy consumption gain in heterogeneous networks and performance index *PI* that is evaluated using different parameters in the suburbs and the city center, as defined by the European Telecommunications Standards Institute (ETSI).

In this paper, a BS activation strategy to improve the communication quality in the network by setting which BS to be active mode until the next AP execution. This makes it possible to respond flexibly to traffic that fluctuates after AP execution.

This paper is organized as follows: Section II introduces the considered system architecture, radio propagation model, and performance metrics. Section III first summarizes the AP and then describes how to determine the strategic BS behavior. Section IV gives the simulation results. Finally, Section V provides concluding remarks.

II. SYSTEM MODEL

A. System Architecture

Consider a typical cellular network, where UEs and BSs are distributed according to Poisson point process (PPP) of intensity λ_{BS} $[/\mathrm{km}^2]$ and λ_{UE} $[/\mathrm{km}^2]$, respectively. It is assumed that a UE receives the pilot signal from the BSs and feeds back the received signal strength (RSS) to the BSs. Once BS clustering is performed based on AP, BSs selected as exemplars (the detail is explained in Section III) continue to be active mode and the other BSs enter sleep mode. Each UE generates a packet that follows a Poisson distribution with a packet generation rate of intensity λ_{pckt} [packet/s] and starts uplink communication. When multiple UEs connect to the same BS, the number of connected UEs is calculated for each transmission frame, and an equal orthogonal bandwidth is assigned to each UE.

B. Selection of BS to which UE connects

Each UE is connected to the active mode BS with the highest channel gain. Let us denote the set of active BSs by $\mathcal{J}_{\mathrm{active}}$ and that of BSs in sleep mode by $\mathcal{J}_{\mathrm{sleep}}$, respectively. In other words, $\mathcal{J}_{\mathrm{active}} \cup \mathcal{J}_{\mathrm{sleep}} = \mathcal{J}$ and $\mathcal{J}_{\mathrm{active}} \cap \mathcal{J}_{\mathrm{sleep}} = \emptyset$ hold. UE i connects to BS $j_i^\star$ given by the following equation:

$$j_i^\star = \underset{j \in \mathcal{J}_{\mathrm{active}}}{\arg\max}\, \gamma_{j,i}, \tag{1}$$

where $\gamma_{j,i}$ is the channel gain between BS j and UE i. When handover (HO) is not performed, UEs always connects to the same BS while continuing to transmit packets and while transmitting packets are stored in the transmission buffer. On the other hand, when HO is performed, even if UEs are transmitting a packet, UEs switch the connected BS if the neighboring BS changes from the sleep mode to the active mode. In addition, a UE is in outage if the RSS does not exceed a certain RSS threshold [10].

C. Radio Propagation Model

For the channel between UEs and BSs, we considered distance-dependent path loss [8] and shadowing loss with spatial correlation [9]. RSS $P_{j,i}$ from BS j to UE i is expressed by the following equation:

$$P_{j,i} = P_{\mathrm{tx}} D_{j,i} \psi, \tag{2}$$

where P_{tx} is the transmission power of BSs, $D_{j,i}$ is the path loss from BS j to UE i, and ψ is shadowing loss with spatial correlation.

D. Throughput of UEs

The transmission rate of UE i, C_i is calculated from Shannon's channel capacity equation expressed by the following equation:

$$C_i = \min\{\log_2(1 + \mathsf{SINR}_i),\ R_{\max}\}, \tag{3}$$

where $R_{\max}$ is the maximum transmission rate of the system. The signal-to-interference plus noise power ratio (SINR), SINR_i, is given by

$$\mathsf{SINR}_i = \frac{P_{\mathrm{Hz}} \gamma_{j_i^\star,i}}{\dfrac{1}{N_{j_i^\star}} \displaystyle\sum_{i' \in \mathcal{I} \setminus \mathcal{N}_{j_i^\star}} \alpha_{i'} P_{\mathrm{Hz}} \gamma_{j_i^\star,i'} + \sigma^2}, \tag{4}$$

where α is an indicator variable that represents the state of UE i, P_{Hz} is the power spectrum density of UE, $j_i^\star$ is the index of the BS to which UE i is connected, $N_{j_i^\star}$ is the number of UEs connected to BS $j_i^\star$, and σ is the power spectral density of thermal noise.

E. Energy Consumption Model

1) UE: Each UE consumes power in uplink transmission to the BS. These include bandwidth dependent power $P_{\mathrm{UE,RF}}$ and independent power $P_{\mathrm{UE,const}}$ [11]. Also we assume that the UE consumes standby power P_{wait} when the channel condition is poor and the UE cannot connect to the BS. The total energy consumption $E_{\mathrm{UE},i}$ required for UE i to finish sending one packet is expressed by the following equation:

$$E_{\mathrm{UE},i} = T_{\mathrm{wait}} P_{\mathrm{wait}} + T_{\mathrm{f}} \left(\sum_{q=0}^{Q_i - 1} \left(P_{\mathrm{UE,const}} + \underbrace{\frac{1}{N_{j_i^\star}} P_{\mathrm{UE}}}_{P_{\mathrm{UE,RF}}}\right) \right), \tag{5}$$

where T_{wait} is waiting time, P_{wait} is standby power, expressed as ηP_{c} with coefficient η $(0 < \eta \leq 1)$, T_{f} is the frame length, Q_i is the number of frames needed for the UE i to finish sending one packet, and P_{UE} is UE transmission power.

2) BS: Each BS also consumes power in uplink transmission from a UE. These include power $P_{\mathrm{BS,c}}$ consumed by the RF chain during communication with the UE and power $P_{\mathrm{BS},0}$ (baseband processing, battery backup, cooling, etc.) consumed regardless of whether or not it is in communication [12]. Therefore, energy consumption of the BS $E_{\mathrm{BS},j}$ per frame at the time of reception is given by

$$E_{\mathrm{BS},j} = T_{\mathrm{f}}(\beta_j M P_{\mathrm{BS,c}} + P_{\mathrm{BS},0}), \tag{6}$$

where β_j is an indicator variable that represents the state of BS j and M is the number of antennas. Since this study assumes only uplink transmission, the transmission power of BS is not considered.

III. STRATEGIC BS BEHAVIOR DETERMINATION USING RESPONSIBILITY MATRIX

In this section, we describe how to select which BS to be active mode by reusing the responsibility calculated by AP. First, AP will be explained, and then the values used in AP will be described in detail. After that, the algorithm of BSs mode transition is described.

A. Affinity Propagation [5]

Clustering splits a set of nodes into multiple subsets of nodes that have strong interconnection or interdependency. k-means [6] is one of the clustering methods. Although k-means is simple, it has the disadvantage that the clustering result strongly depends on the initial selection of a randomly selected center of each cluster. To overcome this disadvantage, k-means++ has been proposed [7]. However, it is necessary to determine the number of clusters in advance for both k-means and k-means++. AP is a clustering method that overcomes all these disadvantages. All nodes are the candidates for the cluster center that is called an *exemplar*. The clusters are automatically formed without determining the number of clusters in advance. In AP, a value called a *message* is exchanged between nodes to maximize the similarity. This message exchange repeats until the cluster center is determined. Since the similarity is determined for all nodes, if the total number of nodes is Q, it can be defined as similarity matrix $\mathbf{S}$ with the similarity between each pair of nodes as an element as follows:

$$\mathbf{S} = \begin{bmatrix} s(1,1) & \cdots & s(1,k) & \cdots & s(1,Q) \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ s(q,1) & \cdots & s(k,k) & \cdots & s(q,Q) \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ s(Q,1) & \cdots & s(Q,k) & \cdots & s(Q,Q) \end{bmatrix}, \tag{7}$$

where $s(q,k)$ represents the similarity between node q and node k. In similarity matrix $\mathbf{S}$, diagonal elements $s(k,k)$ are called preferences. Diagonal component $s(k,k)$ often takes the minimum value of non-diagonal component $s(q,k)$. In addition to the similarity, three values are used in AP to maximize the similarity between nodes.

Similarity
It is expressed as $s(q,k)$, where q and k are elements of $\mathcal{Q}$, which is a set of nodes. It indicates how similar node q and k are. Any value can be used as long as it takes a high value if the two nodes are similar and a low value if they are dissimilar.

Responsibility
It is expressed as $r(q,k)$. It indicates how appropriate for node k to be as an exemplar of node q.

Availability
It is expressed as $a(q,k)$. It indicates how appropriate for node q to become a member of node k.

Criterion
It is expressed as $c(q,k)$ that is the sum of $r(q,k)$ and $a(q,k)$.

Responsibility and availability are calculated recursively until convergence. Without loss of generality, let us consider the ith update ($i > 0$) of the values between node q and node k. The update of responsibility $\tilde{r}(q,k)$ and availability $\tilde{r}(q,k)$ are calculated as follows. Firstly, the following variables are calculated:

$$\tilde{r}(q,k) = \begin{cases} s(q,k) - \max\limits_{k' \in \mathcal{Q} \backslash k} \left\{ a^{(i-1)}(q,k') + s(q,k') \right\} \\ \hfill (q \neq k) \\ s(q,k) - \max\limits_{k' \in \mathcal{Q} \backslash k} \left\{ s(q,k') \right\} \hfill (q = k) \end{cases} \tag{8}$$

and

$$\tilde{a}(q,k) = \begin{cases} \min \left\{ 0, r^{(i)}(k,k) + \sum\limits_{k' \in \mathcal{Q} \backslash k} \max \left\{ 0, r^{(i)}(q',k) \right\} \right\} \\ \hfill (q \neq k) \\ \sum\limits_{k' \in \mathcal{Q} \backslash k} \max \left\{ 0, r^{(i)}(q',k) \right\} \hfill (q = k) \end{cases}, \tag{9}$$

where the initial value of availability, $a^{(0)}(q,k)$, is set to 0. Then, to prevent two message values, $r^{(i)}(q,k)$ and $a^{(i)}(q,k)$, from oscillating in a recursive computation, the windowing is applied as follows:

$$r^{(i)}(q,k) = (1 - \lambda_{\mathrm{df}}) r^{(i-1)}(q,k) + \lambda_{\mathrm{df}} \tilde{r}(q,k) \tag{10}$$

and

$$a^{(i)}(q,k) = (1 - \lambda_{\mathrm{df}}) a^{(i-1)}(q,k) + \lambda_{\mathrm{df}} \tilde{a}(q,k), \tag{11}$$

where λ_{df} ($0 \leq \lambda_{\mathrm{df}} \leq 1$) is a damping factor (DF), which is often empirically obtained.

Finally, the convergence condition of AP is described. AP is terminated if the number of iterations reaches a predetermined number, I_{AP}, or the following condition is satisfied:

$$\max_{q,k \in \mathcal{Q}} \frac{\left| c^{(i)}(q,k) - c^{(i-1)}(q,k) \right|}{\left| c^{(i-1)}(q,k) \right|} \leq \epsilon, \tag{12}$$

where $c^{(i)}(q,k) = r^{(i)}(q,k) + a^{(i)}(q,k)$ and ϵ is a positive small number. After the convergence of AP, exemplar k_q of node q is selected as follows:

$$k_q = \arg\max_{k \in \mathcal{Q}} c^{(i)}(q,k). \tag{13}$$

B. Strategic BS Behavior Determination

In this manuscript, the correlation coefficient of RSS value between BSs is taken as the similarity value. The correlation coefficient $r_{q,k}$ between BS q and BS k is calculated as follows:

$$r_{q,k} = \frac{\frac{1}{n} \sum\limits_{j=1}^{n} (P_{q,j} - \overline{P_q})(P_{k,j} - \overline{P_k})}{\sqrt{\frac{1}{n} \sum\limits_{j=1}^{n} (P_{q,j} - \overline{P_q})^2} \sqrt{\frac{1}{n} \sum\limits_{j=1}^{n} (P_{k,j} - \overline{P_k})^2}}, \tag{14}$$

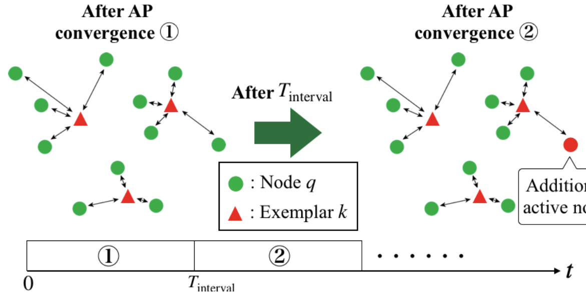

Fig. 1. BS behavior after AP convergence

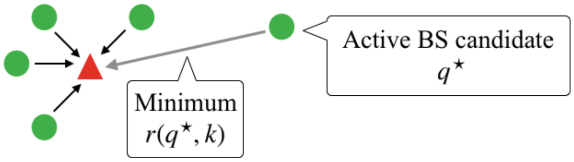

Fig. 2. Strategic BS behavior determination of proposed method

where n is the number of UEs that can be connected to BS q and k, P_q is the average RSS [mW] from BS q to UE that can connect to BS q and $P_{q,j}$ is the RSS from BS q to UE j.

Since the calculation of the similarity matrix affects the clustering results, the similarity among nodes becomes similar if RSS information of all UEs is used. Thus, in this paper, ρ % of the number of UEs within the simulation area is used for similarity matrix calculation.

Once the exemplars are determined, those exemplars are set to active mode. Thus, they become $\mathcal{Q}_{\mathrm{active}}$ and the other BSs become $\mathcal{Q}_{\mathrm{sleep}}$. As shown in Figure 1, an additional BS is activated at every T_{interval}. To decide which BS needs to be activated next, we propose to use the responsibility matrix that has been calculated during the AP. A small responsibility value $r(q,k)$ indicates that node k is not suitable as an exemplar candidate for node q (Fig. 2). Therefore, it is possible to move the BS of the entire network efficiently by setting the BS with the smallest responsibility to the active mode. This not only provides wide coverage for UEs but also reduces the amount of calculation by reusing the calculation results. The procedure is shown in Algorithm 1.

IV. SIMULATION RESULTS

The simulation parameters are shown in Table I and II. As shown in Table I, the system bandwidth set to 20 [MHz], and each UE transmits a packet with the size of 1 [MBytes] via uplink transmission with a transmission power of 23 [dBm]. The packet generation intensity λ_{pckt} is set to 10 [packet/sec] for each UE. The transition interval T_{interval} for BS is set to every 1000 [frames]. In addition, damping factor of AP λ_{df} is set to 0.5. Finally, maximum number of iterations in AP I_{AP} is set to 1000 and threshold for AP termination ϵ is set to be 10^{-3}.

Figure 3 shows the impact of ρ, which is the ratio of the number of UEs used for similarity calculation, on the UE outage probability. When a UE cannot find a BS with RSS greater than or equal to -93.3 [dBm], the UE is considered to be in an outage. Here, intensity of BS λ_{BS} is set to 4 [/km^2]. The proposed strategy that sequentially activates the sleeping BS to active based on the responsibility matrix is labeled "Prop." in the figure. For reference, the strategy that randomly selects one sleeping BS to be active mode every T_{interval} is labeled "Conv.". This outage probability is calculated for each additional number of active BSs N_{act} after AP convergence. "$N_{\mathrm{act}} = 0$" means that only the BS that become exemplar after AP convergence is in active mode. It can be seen that the outage probability can be minimized by setting $\rho = 0.1$ to 0.2, that is, 10% to 20% of the total number of UEs. This can be explained as follows. When ρ is set to large, the similarity values are averaged due to information from a large number of UEs being used for similarity calculation. Thus, in the following, we set $\rho = 0.2$.

Algorithm 1 BS $q \in \mathcal{Q}$ operation decision algorithm

```
Set $q = 1$
while $q \le |\mathcal{Q}|$ do
  if $q \in \mathcal{Q}_{\mathrm{sleep}}$ then
    $m(q) \Leftarrow \arg\max_{k \in \mathcal{Q}_{\mathrm{active}}} r^{(i)}(q,k)$
  end if
  $q \Leftarrow q + 1$
end while
$q^\star = \arg\min_{q \in \mathcal{Q}_{\mathrm{sleep}}} m(q)$
$\mathcal{Q}_{\mathrm{active}} \Leftarrow \mathcal{Q}_{\mathrm{active}} \cup q^\star$
$\mathcal{Q}_{\mathrm{sleep}} \Leftarrow \mathcal{Q}_{\mathrm{sleep}} \backslash q^\star$
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TABLE I
SYSTEM PARAMETERS

Intensity of BS	$\lambda_{\mathrm{BS}} = 3, 4$ [/km^2]
Intensity of UE	$\lambda_{\mathrm{UE}} = 100$ [/km^2]
Simulation Area	2×2 [km^2]
Bandwidth	$W = 20$ [MHz]
Transmit packet size	$B_{\mathrm{REQ}} = 1$ [MBytes]
Maximum transmission rate	$R_{\max} = 6$ [bps/Hz]
BS transmission power	$P_{\mathrm{tx}} = 30$ [dBm]
UE transmission power	$P_{\mathrm{UE}} = 23$ [dBm]
UE fixed power	$P_{\mathrm{UE,const}} = 5$ [dBm]
UE standby power factor	$\eta = 1$
Number of BS antennas	$M = 1$
Circuit power of the corresponding RF chain	$P_{\mathrm{BS,c}} = 6.1$ [W]
Non-transmission power	$P_{\mathrm{BS,0}} = 2.6$ [W]
Minimum UE reception sensitivity [10]	-93.3 [dBm]
Thermal noise power spectral density	$N_0 = -174$ [dBm/Hz]
Frame length	$T_{\mathrm{f}} = 10$ [ms]
Intensity of UE packet generation	$\lambda_{\mathrm{pckt}} = 10$ [packet/s]
BS mode transition interval	$T_{\mathrm{interval}} = 1000$ [frames]

Figure 4 shows the UE outage probability as a function of N_{act}, which is the number of activated BSs in addition to the exemplars selected by AP. As a benchmark, the UE outage probability when N BSs are randomly set to be active mode without using AP are shown. It can be seen from the figure that the proposed strategy can reduce the UE outage probability compared to the conventional random strategy irrespective of λ_{BS}. For the conventional strategy, there is a possibility that

TABLE II
AP PARAMETERS

Damping factor	$\lambda_{\mathrm{df}} = 0.5$
Maximum number of iterations	$I_{\mathrm{AP}} = 1000$
Threshold for AP termination	$\epsilon = 10^{-3}$
Ratio of the number of UEs used for similarity calculation	$\rho = [0.01, 1]$

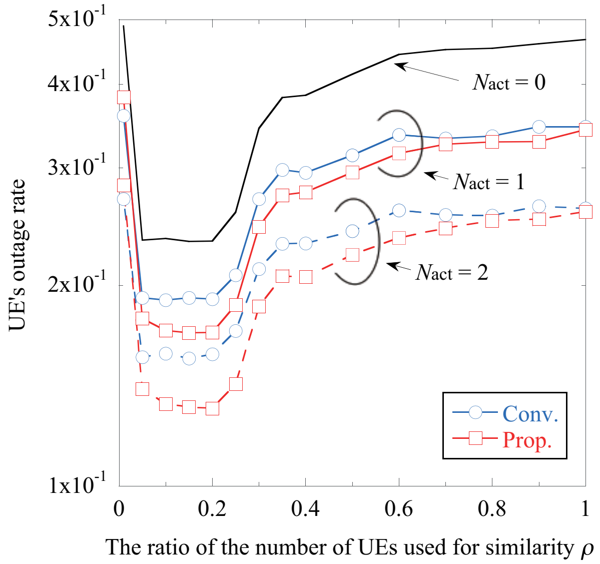

Fig. 3. The impact of ρ on the UE outage probability ($\lambda_{\mathrm{BS}} = 4$).

the BS similar to an exemplar may become active. On the other hand, the sleeping BS dissimilar to an exemplar is activated by the proposed strategy; therefore, the better coverage can be provided to the UEs. In particular, for λ_{BS} = 3, the UE outage probability when there are five additional active BSs is improved by about 18.2%. For λ_{BS} = 4, when there are six additional active BSs, the UE outage probability is reduced by about 26.5%.

Figure 5 shows the UE throughput at 50% and 98% of cumulative distribution function (CDF). It can be seen that "Prop." shows higher throughput than "Conv.". Especially at the 98% point of CDF, the proposed strategy can improve the throughput by about 4.1% from the random strategy. This is because the proposed strategy can efficiently activate the sleeping BS that has a lower similarity value from the BSs that are already activated.

Figure 6 and 7 shows the BS and UE energy consumption at 50% of CDF, respectively. "All active" means that all BSs in the network are set to active mode without using AP. The energy consumption of BS is calculated as the energy consumption of all BS per frame. On the other hand, the UE energy consumption is calculated as the energy consumption required to transmit one packet. For a BS, it can be seen that using AP can significantly reduce the energy consumption of BS regardless of "Conv." or "Prop.". For a UE, it can also be seen that using AP can reduce the energy consumption of UE. Furthermore, it can be seen that "Prop." can reduce energy consumption more than "Conv." by about 4.5%.

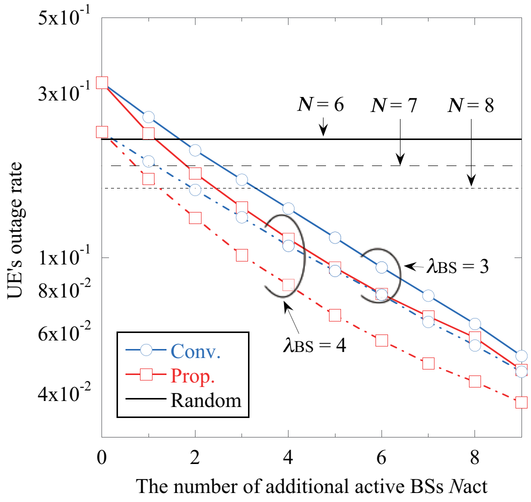

Fig. 4. The impact of N_{act} on the UE outage probability.

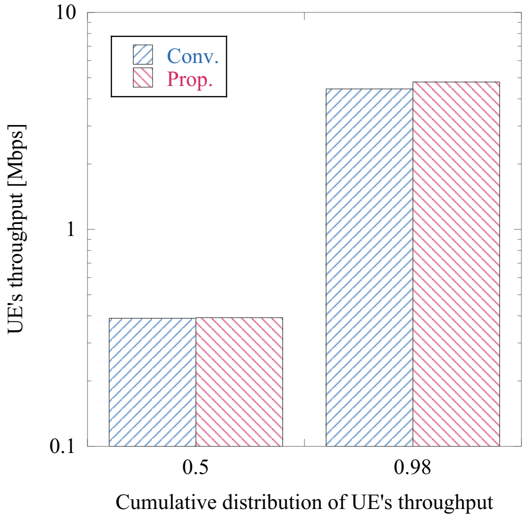

Fig. 5. UE's throughput at the 50% and 98% of cumulative distribution function (CDF) ($\lambda_{\mathrm{BS}} = 4$).

V. CONCLUSION

In this paper, a BS sleeping-and-activation strategy has been proposed to improve network performance. Clusters of BSs are formed based on affinity propagation (AP). Then, the responsibility value is used to activate the sleeping BS to provide better communication quality sequentially. The simulation results have shown that the proposed strategy could reduce the UE outage probability compared to the conventional random strategy.

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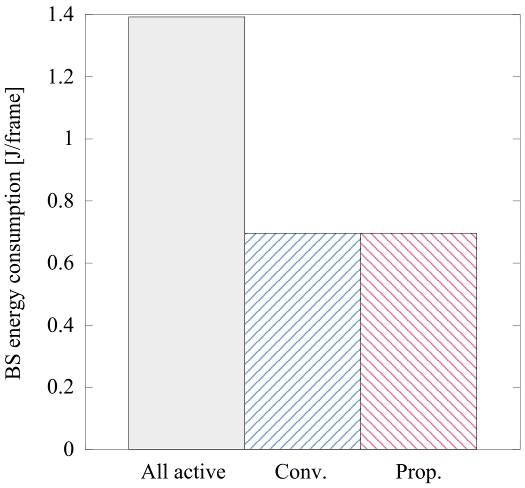

Fig. 6. BS energy consumption at the 50% of CDF ($\lambda_{\mathrm{BS}} = 4$).

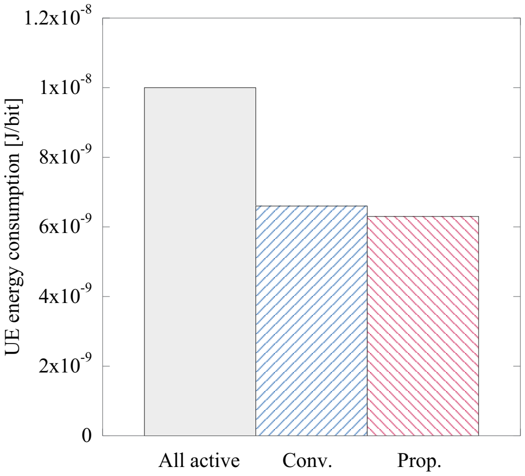

Fig. 7. UE energy consumption at the 50% of CDF ($\lambda_{\mathrm{BS}} = 4$).

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