An Optimal Energy Efficiency of a Two-tier Network in Control-Data Separation Architecture

Zaid Mujaiyid Putra Bin Ahmad Baidowi and Xiaoli Chu
Department of Electronic and Electrical Engineering, The University of Sheffield, Sheffield S1 4ET, United Kingdom
Email: {zmpahmadbaidowi1, x.chu}@sheffield.ac.uk

Abstract—In this paper, we propose to maximize the Energy Efficiency (EE) of a two-tier network by jointly optimizing the number of active small cell base stations (SBSs) and the user-cell association. We apply the concept of signaling and data separation where a macro cell base station (MBS) provides full coverage while the SBSs provide high data transmission. First, we model the spatial distributions of the SBSs and mobile users following two independent Poisson Point Processes (PPP) and derive the expressions for the Signal-to-Interference Ratio (SIR), user cell associations, power consumption and energy efficiency of the Heterogeneous Network (HetNet). Then, we formulate the EE maximization problem and solve it by proposing the Switching off Decision and User Association (SODUA) algorithm. The algorithm associates a mobile user to an SBS that offers the highest SIR and calculates the load of each SBS. The algorithm, then, decides to switch off the SBSs that have fewer mobile users than a threshold value, where the mobile users will be offloaded to a nearby SBS that offers the highest SIR. Finally, we calculate the EE of the HetNet. We compare the EE achieved by the proposed algorithm (i.e. after offloading) and that "without offloading". The results show that the proposed algorithm improves the EE of the HetNet and that the EE cannot be further improved by switching off more SBSs than a certain number.

Index Terms—Energy efficiency, separation architecture, CDSA, repulsive switching off

I. Introduction

Energy Efficiency (EE) of a network is one of the hot topics among researchers in wireless communications. The HetNet which consists of various types of base stations (BSs) with different transmit power has been proven to improve the EE. The existence of small cells helps a lot in reducing power consumption due to their low-powered radio communications' equipment. Nevertheless, due to the mobility of the mobile users, many small cell base stations (SBSs) are lightly loaded but they still consume some amount of energy. To avoid coverage holes, the low-powered SBSs cannot be turned off to guarantee the coverage of the network but resulting to energy inefficiency. To solve this problem, we propose to apply Control-Data Separation Architecture (CDSA) [1] which helps to split between control signaling and data transmission. The macro cell base station (MBS) controls the whole network activities including the SBSs. Nevertheless, the data transmission, that is provided by the SBSs, can be more flexible due to uncertainty of traffic load, the distance to the SBSs and the Signal-to-Interference Ratio (SIR). Consequently, by applying CDSA, the SBSs can be switched off when necessary and this would certainly save the energy and leads toward EE.

A. Literature Review

The CDSA or also known as separation architecture was introduced several years ago to guarantee the coverage of the network [2]-[4]. The architecture allows the MBS to control the SBSs' activities in order to improve the EE of the Heterogeneous Network (HetNet) [4]. The MBS provides high coverage as it operates on low capacity and low frequency bands with good quality propagation capabilities [1]. Whilst, the SBSs offer high capacity and more spectrum resources as it operates on high frequency bands [3]. The separation of control signaling and data transmission allows the MBS to dynamically readjust the network via its control. As a main controller, the MBS switches off the SBSs due to the low traffic load in SBSs. This, apparently, could save the energy consumption of all BSs in the network. The flexibility, that the architecture offers, allows changes to the network such as addition of more SBSs and thus, the network is reconfigurable. By applying CDSA in the network, the MBS can switch off the SBSs when the SBSs do not meet certain criteria such as if no user is found within the coverage area [2].

Base station sleeping have been proven to be energy efficient [5] and energy saving [6]. The strategies that are commonly used are random and strategic [7] [8]. In random sleeping, information like traffic load and cell's location are not required. Besides, the random sleeping allows any SBSs to be switched off with equivalent probability and hence, it can be implemented easily. This strategy was implemented by [4] via vertical offloading where the mobile users that served by SBSs were offloaded to MBSs. Whilst, [7] applied horizontal offloading where the mobile users were offloaded between the MBSs only since it was implemented in homogeneous network. The most popular strategy is the strategic sleeping BSs which was implemented by [7] in addition to the random strategy. In this sleeping strategy, the MBSs that had low traffic load were switched off. This method was studied by [9], [10] but the BSs were sent to sleeping mode rather than switching them off if

Manuscript received January 12, 2020; revised May 28, 2020.
This research is under a joint scholarship of Ministry of Education Malaysia (MoE) and Universiti Teknologi MARA (UiTM) Malaysia. This work has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 734798.
Corresponding author email: zmpahmadbaidowi1@sheffield.ac.uk
doi:10.12720/jcm.15.7.545-550

the number of mobile users were less than the threshold value.

According to [11] sleeping mode consumes 10% of the power consumption but switching off mode consumes none of the power consumption. However, in this paper, we consider repulsive switching off strategy [4] to be deployed on SBSs that controlled by MBS in CDSA environment. The strategy allows the SBSs that are in the switching off area to be switched off.

B. Motivation

EE is a crucial topic in saving the energy and to ensure the energy is used at an optimal level. Recently, many studies were carried out in this area. To the best of our knowledge, less work was carried out in CDSA to find an optimal number of SBSs in maximizing the EE of a HetNet. Therefore, we propose an algorithm to be applied in the CDSA environment to maximize the EE in a HetNet by switching off the SBSs that have low traffic load.

C. Contributions

In this paper, we propose the Switching off Decision and User Association (SODUA) algorithm to find the optimal number of SBSs and the user-cell associations that maximize EE of the HetNet. The contributions of this work can be summarized as the following:

- Model the spatial distribution of the SBSs and the mobile users as two independent Poisson point process (PPP). Whilst, the single MBS is located at the center of the network to control the SBSs' activities in the CDSA environment,
- Derive the expressions for the SIR, user-cell associations, power consumption and EE of the HetNet,
- Formulate the EE maximization problem and solve it by using the proposed algorithm. The proposed algorithm considers the traffic load of each SBS and switching off strategy that could improve the HetNet, and
- Show that the combination of various SIR, the random SBSs' transmit power, and the SBSs switching off in CDSA environment could give a significant result toward the EE of the HetNet.

The remainder of this paper is organized as follows. In Section II, we describe the proposed system model. In Section III, we describe the proposed algorithm, develop the problem formulation and solve the problem. In Section IV, we present the result of the proposed algorithm and validate the result through numerical values. Lastly, we make a conclusion and the future works in Section V.

II. System Model

The proposed network deployment consists of a two-tier network that consist of one macro cell network (MCN) and a number of small cell networks (SCNs). The MBS, *0*, is located at the center of the network while the SBSs are arranged according to an independent PPP, $\mathcal{S}$. The mobile users are arranged according to another independent PPP, $\mathcal{U}$. The number of SBSs and mobile users are denoted by *S* and *U*, respectively.

Each mobile user is associated with one SBS that offers the highest received signal strength. The mobile users are located in Voronoi cell. We apply the concept of signaling and data separation as introduced by [12] or known as CDSA where the MBS controls the SBSs and transmits the signaling information separately. The main objectives of the CDSA are providing full coverage and high data transmission by MBS and SBSs, respectively.

The users are connected to the MBS first for signaling control. The MBS calculates the SIR of all possible communications between the users and the SBSs. For each user, the highest SIR is selected for association between the user and the SBS. For the data transmission, the users are always connected to the SBSs as the MBS acts as a main controller for the signaling. On top of that, the MBS determines which SBSs to be switched off due to the low traffic and offloads the users from the inactive SBSs to the selected active SBSs.

A. The Switching Off Strategy

We apply repulsive scheme where the SBSs can only be switched off if the SBSs reside in the switching off radius, r_{so} , that is within the MBS's coverage radius, D . Similar to [4], the average switching off ratio, Λ, can be calculated based on the switching off area to the MBS's coverage area as follows:

$$\bar{\Lambda} = \frac{\pi r_{so}^2}{\pi D^2} \tag{1}$$

B. Channel Model

The proposed HetNet has two different parameters of the transmit powers. The transmit power of the MBS and SBSs are denoted by P_0 and P_i , respectively. We describe the received power at a typical mobile user that is connected to one of the SBSs in the distance r_i as $P_i h_i r_i^{-\alpha}$ h_i represents the channel fading coefficients of the SBSs and it is assumed to follow exponential distribution $h_i \sim \exp(c\mu)$. The r_i is the distance from the mobile user u to the associated SBS i . In this paper, the path loss exponent is assumed to be $\alpha > 2$.

C. Signal-to-Interference Ratio (SIR)

In CDSA, both MBS and SBSs use different spectrum. Hence, a mobile user u that is served by SBS i is experiencing interference from other SBSs only. We consider interference-limited environment due to the small noise power (i.e. $\sigma \to 0$) as compared to the interference coming from other SBSs. This can be expressed as

$$\gamma_{iu} = \frac{P_i\, h_i\, r_i^{-\alpha}}{\sum_{s \in \mathcal{S} \setminus i} P_s\, h_s\, r_s^{-\alpha}} \tag{2}$$

D. Achievable Downlink Rate

The achievable data rate of a mobile user u that is associated with SBS i, R_{iu} can be expressed as follows

$$R_{iu} = W_{iu}\log_2\left(1+\gamma_{iu}\right)a_{iu}\ ; \forall i \in \mathcal{S}, u \in \mathcal{U} \qquad (3)$$

where W_{iu} is the bandwidth of each communication between i and u while a_{iu} is the indicator variable for the user association which will be explained in the next subsection. In this paper, we assume that the bandwidth is equally allocated [2], [13] to all mobile users in the network. Therefore, the bandwidth of each communication can be defined as $W_{iu} = B/U$, where B is the system bandwidth. The total achievable data rate of all mobile users in the network, that are associated to their respective SBSs, can be expressed as

$$R^{tot} = \sum_{i\in\mathcal{S}}\sum_{u\in\mathcal{U}} W_{iu}\log_2\left(1+\gamma_{iu}\right)a_{iu} \qquad (4)$$

E. User Associations

If no user is associated with SBS i, the user-association variable a_{iu} is equal to 0. Therefore, the MBS will switch off the SBS and there will be no energy consumption at all [2]. In this case, $P_i^{stat} + P_i = 0$ when $a_{iu} = 0; \forall u \in \mathcal{U}$ of that particular SBS. The P_i^{stat} is the static power consumption of the SBSs.

Each mobile user in $\mathbb{A}$ can be associated with one of the SBSs only. If the SBS i is not in the set of active SBSs, $\mathcal{S}^{act}$, the user association is set to 0 for all users since it cannot serve any mobile users. Therefore, we can represent this situation as $\mathbb{A}_{\mathcal{S}^{act}} = \{a \mid \forall u \in \mathcal{U}, a_{iu} = 1$ if $i \in \mathcal{S}^{act}$ and $a_{iu} = 0$ if $i \notin \mathcal{S}^{act}\}$. The MBS is always in active mode due to controlling the SBSs [14]. To keep the power consumption at an optimum level, the SBSs with low traffic load will be turned off.

F. Power Consumption Model

The total power consumption of the MBS, P_0^{tot}, and the SBSs, P_i^{tot}, can be expressed as

$$P_0^{tot} = P_0^{stat} + P_0 \qquad (5)$$

$$P_i^{tot} = \sum_{i\in\mathcal{S}}\left(P_i^{stat} + P_i\right)a_{iu} \qquad (6)$$

P_0^{stat} is the static power consumption of the MBSs and P_i is the transmit power of SBS i.

G. Energy Efficiency

We formulate the EE of the HetNet as the total achievable data rate of the SBSs over the total power consumption of the MBS and the SBSs. The equation can be expressed as follows

$$\mathrm{EE}(\mathcal{S}, a_{iu}) = \frac{R^{tot}}{P_0^{tot} + P_i^{tot}} \qquad (7)$$

III. Proposed Switching Off Decision and User Association Algorithm

In this section, we will discuss further on the problem formulation of the proposed algorithm i.e. SODUA. The objective of this algorithm is to decide whether or not the SBSs should be switched off based on the traffic load. If the SBSs are switched off, the users that associated with them will be offloaded to the other active SBSs that offer the highest SIR. Thus, this algorithm finds the best SBSs to be associated with the users subject to some constraints in order to achieve a higher EE.

A. Problem Formulation

The proposed SODUA problem can be formulated as follows

$$\begin{aligned}
&\max_{\mathcal{S},\, a_{iu}} \mathrm{EE}(\mathcal{S}, a_{iu}) = \frac{R^{tot}}{P_0^{tot} + P_i^{tot}} \\
&\text{subject to} \\
&\mathrm{C1}: \sum_{u\in\mathcal{U}} R_{iu} \geq R_i^{min}\ ; \forall i \in \mathcal{S}^{act} \\
&\mathrm{C2}: P_0^{min} \leq P_0 \leq P_0^{max} \\
&\mathrm{C3}: P_i^{min} \leq P_i \leq P_i^{max}\ ; \forall i \in \mathcal{S}^{act} \\
&\mathrm{C4}: \sum_{i\in\mathcal{S}} a_{iu} \leq 1; \forall u \in \mathcal{U} \\
&\mathrm{C5}: a_{iu} \in \{0,1\} \\
&\mathrm{C6}: \sum_{u\in\mathcal{U}} a_{iu} \geq \underline{U}\ ; \forall i \in \mathcal{S}^{act} \\
&\mathrm{C7}: \mathrm{count}\left(\sum_{u\in\mathcal{U}} a_{iu} \geq \underline{U}\right) \leq \overline{\Lambda}; \forall i \in \mathcal{S}^{act}
\end{aligned} \qquad (8)$$

where C1: The total data rate of each active SBS, $\mathcal{S}^{act}$, must be larger than the minimum data rate of each SBS, C2: The transmit power of the MBS must be between the minimum and the maximum allowable transmit power, C3: The transmit power of each active SBS must be between the minimum and the maximum allowable transmit power, C4: One mobile user can only be connected to a single SBS, C5: The user association indicator, a_{iu}, is a binary digit variable, C6: The number of mobile users of each SBS must be larger than the minimum number of mobile users of each SBS, $\underline{U}$. This is to allow the SBS to remain active, and C7: The average number of SBSs active must be less than the average switching off ratio, $\overline{\Lambda}$.

B. Problem Solving

The proposed algorithm, that generates $M = 1000$ times samples, is shown in Algorithm 1. First, we generate the SIR randomly, γ_{iu}, for all possible connections between the users and the SBSs in $U \times S$ matrix. Then, we find the highest SIR, γ_{ij}^{max} for each user where j is the index of the user that received the highest SIR, $j \in \mathcal{U}_{\gamma}^{max}$. We need to copy γ_{iu} to a new variable γ_{iu}^{2} for offloading purpose later.

Then, to associate the users and their SBSs respectively, we assign the user-cell association variable to 1, $a_{iu} = 1$. Otherwise, let the user-cell association variable be 0, $a_{iu} = 0$. By using γ_{ij}^{max}, we calculate the data rate of each user, R_{ij}. We set zero to the elements in the array γ^{2} for finding the highest SIR if we need to offload to the other active SBSs.

In our proposed algorithm, we use random transmit power to the active SBSs, P_i. After that, we count the number of mobile users that attached to each SBS, a^{tot}. Next, we find the average number of mobile users that each SBS serves in the whole network. This becomes the benchmark of the minimum number of mobile users that each SBS should serve, $\underline{U}$. Then, we identify the SBSs to be switched off, $\mathcal{S}_{k}^{ina}$, and to be active, $\mathcal{S}^{act}$, where k is the index of the inactive users. We count the number of active SBSs, S_{sbs}^{act}, the number of inactive SBSs, S_{sbs}^{ina}, and the number of mobile users in the inactive SBSs, S_{user}^{ina}. If the number of inactive SBSs, S_{sbs}^{ina}, is larger than the average switching off ratio, $\overline{\Lambda}$, switched on back the last few SBSs. This is not our focus, but we can only switch off the number of SBSs not exceeding $\overline{\Lambda}$.

Algorithm 1: Switching Off Decision and User Association (SODUA) Algorithm

START
while $m < M$ **do**
  $\gamma_{iu} = \mathrm{rand}(U, S)$
  $\gamma_{ij}^{max} = \max \gamma_{iu};\ j \in \mathcal{U}_{\gamma}^{\max}$
  $\gamma_{iu}^{2} = \gamma_{iu}$
  while $j \in \mathcal{U}_{\gamma}^{\max}$ **do**
    $a_{ij} = 1$
    $R_{ij} = W_{iu} \log_2(1 + \gamma_{ij}^{max})$
    $\gamma_{ij}^{2} = 0$
    END
  $P_i = \mathrm{rand}(1, S)$
  $a^{tot} = \sum_{j \in \mathcal{U}_{\gamma}^{max}} a_{ij};\ \forall i \in \mathcal{S}$
  $\underline{U} = \mathrm{average}(a^{tot})$
  Offloading Section
  $\mathcal{S}_{k}^{ina} = \mathrm{find}(a^{tot} < \underline{U})$
  $\mathcal{S}^{act} = \mathrm{find}(a^{tot} \geq \underline{U})$
  $S_{sbs}^{ina} = \mathrm{count}(\mathcal{S}_{k}^{ina})$
  $S_{sbs}^{act} = \mathrm{count}(\mathcal{S}^{act})$
  $S_{user}^{ina} = \mathrm{count}(\sum_{u \in \mathcal{U}} a_{iu} = 1;\ \forall i \in \mathcal{S}_{k}^{ina})$
  if $S_{sbs}^{ina} > \overline{\Lambda}$ **then**
    $P_{last} = 1$
    END
  $\gamma_{ik}^{max2} = \max \gamma_{iu}^{2}$
  $R_{ik}^{ina} = W_{iu} \log_2(1 + \gamma_{ik}^{max});\ \forall k \in \mathcal{U}_{\gamma}^{max}, i \in S_{k}^{ina}$
  $R_{ik}^{act} = W_{iu} \log_2(1 + \gamma_{ik}^{max2});\ \forall k \in \mathcal{U}_{\gamma}^{max2}, i \in S^{act}$
  $R_{ij}^{new} = R_{ij} + \sum_{k \in \mathcal{U}_{\gamma}^{max2}} R_{ik}^{act} - \sum_{k \in \mathcal{U}_{\gamma}^{max}} R_{ik}^{ina}$
  END
$EE = \frac{R_{ij}^{new}}{P_0^{tot} + P_{act}^{tot}}$
END

Before offloading, we find the highest SIR, γ_{ik}^{max2}, of the inactive SBSs from γ_{iu}^{2}. Next, we calculate the data rates of the users that associated with the inactive SBSs, R_{ik}^{ina} and the users that associated with the active SBS, R_{ik}^{act}. These will be used for calculating the new total data rates, R_{ij}^{new}, of the whole network. Finally, we calculate the EE of the HetNet.

IV. RESULTS

In this simulation, we set the number of users, U, to be 200 while the number of SBSs, S, to be 30 in the whole network. For all cases, we fixed the value of the SBSs' transmit power to 0.75 Watt, unless stated otherwise.

Table I shows the parameters that we used to run our simulation. We ran the simulation until 5 iterations to see the consistency of the proposed algorithm.

TABLE I: PARAMETER VALUES

Parameter	Value	Parameter	Value
B_m	20 MHz	B_s	20 MHz
P_m^{stat}	130 W	P_m	106.4 W
P_s^{stat}	4.8 W	P_s	0.75 W
r_{so}	30 km	D	40 km

The result shows that the "After Offloading" is always above the "Before Offloading" as shown in Fig. 1. Technically, when we switched off the SBSs that offered the highest SIR, γ_{ij}^{max}, and offloaded to the other active SBSs that offered the subsequent highest SIR, γ_{ik}^{max2}, the total data rates would be decreased. However, this scenario could increase the EE of the network. The reason was that the data rates slightly decreased but a fair amount of the power consumption decreased, and this caused the EE increased. The SBSs that had less user would be switched off before offloading. Then, the users would be connected to the SBS that offered γ_{ik}^{max2}. In conclusion, the dropped in the power consumption and the data rates would maximize the EE.

The proposed algorithm produced $\underline{U} = 7$ for the average minimum number of users, $S_{sbs}^{act} = 16$ for the number of active SBSs and $S_{sbs}^{ina} = 14$ for the number of inactive SBSs. As a result, the above three parameters $\underline{U} = 7$, $S_{sbs}^{act} = 16$ and $S_{sbs}^{ina} = 14$ produced the highest EE as compared to the others (Fig. 2). However, if we increased $\underline{U}$ by 1 (from 7 to 8), the EE would be increased because the more chances SBSs will be switched off too. Nevertheless, this case did not correspond to the average switching off ratio, $\overline{\Lambda}$, where

$S_{sbs}^{ina} > 17$. If we decreased $\underline{U}$ by 1 (from 7 to 6), the EE would be decreased because the less chances SBSs will be switched off. As a conclusion, decreasing $\underline{U}$ would reduce the EE but would just waste the energy. Whilst, increasing $\underline{U}$ would enhance the EE but exceeding $\bar{\Lambda}$. Hence, the best $\underline{U}$ is 7 that would maximize the EE subject to the predefined constraints.

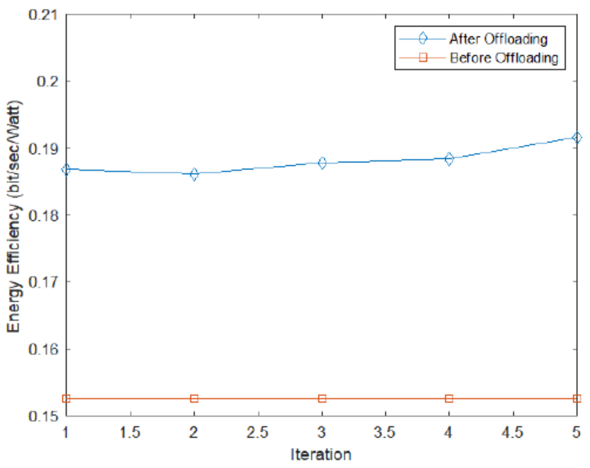


Fig. 1. Energy efficiency vs. Iteration.

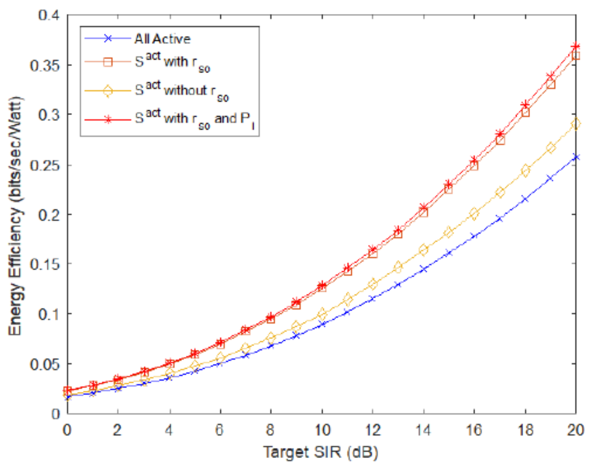


Fig. 2. Energy efficiency vs. SIR with various number of active SBSs.

The result in Fig. 2 shows four different cases, (i) All Active where all SBSs were considered active but no offloading was considered, (ii) S^{act} with r_{so} where the SBSs would be switched off if $\sum_{u \in \mathcal{U}} a_{ij} < \underline{U}$. The number of SBSs that should be active was 16 and switched off was 14. This corresponded with the average sleeping ratio, $\bar{\Lambda}$, (iii) S^{act} without r_{so}. Similar to (ii), we switched off the SBSs that have fewer number of users, S_{user}^{ina}, than the average minimum number of users but here we did not restrict the number of SBSs that can be switched off, and (iv) S^{act} with r_{so} and P_i. Here, we applied our proposed algorithm where the major differences were that the transmit power of the SBSs (i.e. $P_i = [0\ 0.75]$) were randomly applied and we restricted the average maximum number of SBSs that can be switched off must not be larger than $\bar{\Lambda}$. The algorithm switched off 14 SBSs and this corresponded to the $\bar{\Lambda}$. It showed that the proposed algorithm outperformed the others.

V. Conclusion and Future Works

In this work, we have maximized the EE of a HetNet by jointly optimizing the number of active SBSs and the user-cell associations. We proposed the SODUA algorithm in CDSA environment to determine which SBSs to be switched off in order to achieve a higher EE for the HetNet. The simulation results showed that the proposed algorithm outperformed the other algorithm. In our future work, we will include overloaded SBSs as one of the constraints to achieve a higher EE. If the SBS is overloaded, the users that are attached to the SBS will be offloaded not only to the other SBSs but also to the MBS.

Conflict of Interest

The authors declare no conflict of interest.

References

[1] R. I. Ansari, H. Pervaiz, C. Chrysostomou, S. A. Hassan, A. Mahmood, and M. Gidlund, "Control-Data separation architecture for dual-band mmwave networks: A new dimension to spectrum management," *IEEE Access*, vol. 7, pp. 34925–34937, 2019.

[2] Y. Zhu, Z. Zeng, T. Zhang, L. An, and L. Xiao, "An energy efficient user association scheme based on cell sleeping in lte heterogeneous networks," in *Proc. International Symposium on Wireless Personal Multimedia Communications (WPMC)*, 2014, pp. 75–79.

[3] A. I. Abubakar, M. Ozturk, S. Hussain, and M. A. Imran, "Q-learning assisted energy-aware traffic offloading and cell switching in heterogeneous networks," in *Proc. IEEE 24th International Workshop on Computer Aided Modeling and Design of Communication Links and Networks (CAMAD)*, 2019, pp. 1–6.

[4] S. Zhang, J. Gong, S. Zhou, and Z. Niu, "How many small cells can be turned off via vertical offloading under a separation architecture?" *IEEE Transactions on Wireless Communications*, vol. 14, no. 10, pp. 5440–5453, 2015.

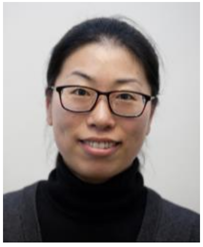
[5] L. Li, M. Peng, C. Yang, and Y. Wu, "Optimization of base-station density for high energy-efficient cellular networks with sleeping strategies," *IEEE Transactions on Vehicular Technology*, vol. 65, no. 9, pp. 7501–7514, 2016.

[6] J. Kim, H. W. Lee, and S. Chong, "Traffic-aware energy-saving base station sleeping and clustering in cooperative networks," *IEEE Transactions on Wireless Communications*, vol. 17, no. 2, pp. 1173–1186, 2017.

[7] Y. S. Soh, T. Q. S. Quek, M. Kountouris, and H. Shin, "Energy efficient heterogeneous cellular networks," *IEEE Journal on Selected Areas in Communications*, vol. 31, no. 5, pp. 840–850, 2013.

[8] R. Cai, W. Zhang, and P. C. Ching, "Cost-efficient optimization of base station densities for multitier heterogeneous cellular networks," *IEEE Transactions on Wireless Communications*, vol. 15, no. 3, pp. 2381–2393, 2016.
[9] Y. Kang, S. Dong, and J. Zhang, "An energy-efficient user offloading algorithm for cellular network in base station sleep mode," in *Proc. 8th International Conference on Wireless Communications & Signal Processing (WCSP)*, 2016, pp. 1–4.
[10] Y. Li, H. Zhang, J. Wang, B. Cao, Q. Liu, and M. Daneshmand, "Energy efficient deployment and adaptive sleeping in heterogeneous cellular networks," *IEEE Access*, vol. 7, pp. 35 838–35 850, 2019.
[11] F. H. Panahi, F. H. Panahi, S. Heshmati, and T. Ohtsuki, "Optimal sleep & wakeup mechanism for green internet of things," in *Proc. 27th Iranian Conference on Electrical Engineering (ICEE)*, 2019, pp. 1659–1663.
[12] A. Capone, A. F. Dos Santos, I. Filippini, and B. Gloss, "Looking beyond green cellular networks," in *Proc. 9th Annual Conference on Wireless On-Demand Network Systems and Services (WONS)*, 2012, pp. 127–130..
[13] L. An, T. Zhang, and C. Feng, "Stochastic geometry based energy-efficient base station density optimization in cellular networks," in *Proc. IEEE Wireless Communications and Networking Conference (WCNC)*, 2015, pp. 1614–1619.
[14] Y. Wang, J. Zhang, and P. Zhang, "Energy-efficient power and subcarrier allocation in multiuser ofdma networks," in *Proc. IEEE International Conference on Communications (ICC)*, 2014, pp. 5492–5496.

Zaid Mujaiyid Putra Bin Ahmad Baidowi is a senior lecturer at the Universiti Teknologi MARA (UiTM) Malaysia. He serves Faculty of Computer and Mathematical Sciences, Shah Alam but seconded at Center of Foundation Studies, Dengkil, Selangor, Malaysia. He is currently doing his PhD at The University of Sheffield, United Kingdom under a joint scholarship of the Ministry of Education Malaysia (MoE) and UiTM. He received the Diploma in Computer Science from UiTM in 2001, the B.Sc. (Hons.) (Data Communications and Networking) from UiTM in 2004, and the Master of Computer Science (Information Security) from Universiti Teknologi Malaysia (UTM) in 2010.



Xiaoli Chu is a Professor in the Department of Electronic and Electrical Engineering at the University of Sheffield, UK. She received the B.Eng. degree in Electronic and Information Engineering from Xi'an Jiao Tong University in 2001 and the Ph.D. degree in Electrical and Electronic Engineering from the Hong Kong University of Science and Technology in 2005. From 2005 to 2012, she was with the Centre for Telecommunications Research at King's College London. Xiaoli has co-authored over 150 peer-reviewed journal and conference papers. She is co-recipient of the IEEE Communications Society 2017 Young Author Best Paper Award. She co-edited/co-authored the books "Heterogeneous Cellular Networks – Theory, Simulation and Deployment" (Cambridge University Press 2013), "4G Femtocells: Resource Allocation and Interference Management" (Springer 2013), "Ultra Dense Networks for 5G and Beyond" (Wiley 2019), and "Fog-Enabled Intelligent IoT Systems" (Springer 2020). She is Senior Editor for the IEEE Wireless Communications Letters, Editor for the IEEE Communications Letters, and received the IEEE Communications Letters Editor Award in 2018.