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Energy efficiency scheme for relay node placement in heterogeneous networks

Aziemah Athirah As'ari[1], Nur Ilyana Anwar Apandi[1], Nor Aishah Muhammad[2], Rozeha A. Rashid[2], Mohd Adib Sarijari[2], Jamaliah Salleh[3]
[1]Faculty of Electrical Engineering, Universiti Teknologi Malaysia, Melaka, Malaysia
[2]Telecommunication Software and Systems (TeSS) Research Group, Department of Communication Engineering, School of Electrical Engineering, Universiti Teknologi Malaysia, Johor Bahru, Malaysia
[3]Wireless Communication Centre, Universiti Teknologi Malaysia, Johor Bahru, Malaysia

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ABSTRACT

Relay node (RN) placement expands the network coverage and capacity and significantly reduces the energy consumption of heterogeneous networks (HetNets). Energy efficiency is the system design parameter in HetNets as it determines network operators' energy consumption and economic value. Relay is one of the energy-saving methods, where it can reduce the transmit power by breaking a long transmission distance into several short transmissions. However, placing an RN without a proper transmission distance may lead to a waste of energy. Thus, investigating an optimum RN placement in HetNets is crucial to ensure energy efficiency and maintain network performance. This paper presents an energy efficiency scheme for the RN based on four commonly used network topologies of indoor HetNets. The minimum energy consumption algorithm is proposed based on a comparison of distance and links of the RN. The results show that the circular network topology is an optimal network model with an efficiency factor increase of 6% that can be used to design the energy efficiency indoor HetNet.

Corresponding Author:

Nur Ilyana Anwar Apandi
Faculty of Electrical Engineering, Technology Malaysia University
Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
Email: ilyana@utem.edu.my

1. INTRODUCTION

The rapid evolution of wireless services, such as high-definition video streaming, e-education, has led to an explosive demand for mobile data. According to the recent virtual networking index report [1], the global mobile speed was 13.2 Mbps in 2018 and is expected to grow more than triple by 2025. Although many advanced technologies in the existing fourth-generation system, it is anticipated that only incremental improvements may not be sufficient to meet the future data speed demands [2]. Therefore, the fifth-generation (5G) development has attracted growing attention among researchers in both academia and industry in recent years [3], [4].

One potential solution to meet the substantial increase in network capacity is adapting the heterogeneous network (HetNet). HetNet comprises a mixture of low power base stations (BSs), such as picocells, femtocells, relays and remote radio heads (RRHs), underlying the conventional homogeneous macrocells [5]. HetNet expands the indoor and cell-edge coverage and enhances the user throughput and the network spectral efficiency. There are several research efforts on the performance evaluation of HetNets [3], [6]–[12]. Specifically, coordinated joint transmission schemes have been proposed in [11] to investigate the downlink coverage and throughput performances of the HetNet with non-coordinated non-orthogonal multiple access. The work in [12] proposed a load-aware approach for the downlink coordinated multi-point joint transmission scheme in a dense HetNet consisting of several BSs. However, the works in [5], [11], [12] mainly focused on the coverage and throughput performance. Meanwhile, the work in [11] focused on energy efficiency by investigating the issue of power management and energy-efficient user scheduling. Surender *et al.* [13] presented a survey on rectenna systems and analyzed their performance and how the implementation of rectenna systems affects the environment. Recently, [7], [8], [14]–[16] also studied the potential applications in HetNet that can overcome energy efficiency issues. Thiagarajah *et al.* [8] discussed the architecture and technical challenges of the cooperative HetNets to optimize and balance the networks' spectrum efficiency, energy efficiency, and quality of service (QoS). A deep learning algorithm in [17], [18] is a promising energy efficiency solution for HetNet. It adds another challenge to ensure high-energy details when requiring super-resolution multi-image sources. However, the existing works in [7], [13], [14], [17]–[19] are based on the single criteria of direct communication between a BS and the user, where there is no additional node used to convey the signal and information to the receiver which adds a challenge to a highly populated area.

On the other hand, a relay is a node that connects the transmission from a BS to users, especially in long-distance transmission [20]–[24]. The relay-node (RN) is also suitable for being placed in highly populated areas to support network capacity [25]–[27]. Proper RN deployment is required to significantly reduce energy consumption and boost data transmission speed in HetNets [25]. Bagaa *et al.* [26] proposed an optimal solution to locate the RNs in a specific position while increasing the network throughput and QoS. The proposed solution also was found to reduce the latency of the data transfer. The work in [6], [9] considered massive multiple-input multiple-output HetNet in their analysis. Specifically, the authors in [9] investigate the energy-efficient resource allocation in two-tier HetNets with wireless backhaul by considering two hybrid analogue/digital precoding schemes. This study maximizes the system's energy efficiency with limited wireless backhaul and QoS constraints. Xu *et al.* [6] proposed a robust hybrid design in both MBS and femtocell BS. Recently, a heuristic method known as whale optimizer has been proposed in [21] to solve the problem regarding RN placement and energy efficiency in the HetNet. However, the works in [8], [20]–[23], [25], only considered the downlink transmission and the connection within the range of capacity constraints, whereas energy consumption performance did not consider in the RN placement.

This paper proposes the energy efficiency scheme by deriving the network system model based on considering the RN network topology for highly populated indoor HetNets. The aim is to minimize total energy power consumption by leveraging the efficiency ratio optimization [28], [29]. Unlike the works in [21] which omit minimizing total power consumption, we consider the downlink transmission network to design the optimal system model for RN placement based on the energy efficiency formulation [30]. We also consider the RN placement for the building so that the number of indoor user devices may still grow exponentially. Moreover, to achieve minimum power consumption for indoor HetNet, unlike in [28], [29], with the assumption of optimal network deployment, we investigate an energy efficiency performance by selecting the most appropriate RN placement based on the arrangement of suitable network topologies.

2. SYSTEM MODEL

In this section, we derive the minimum total power consumption based on the energy efficiency formulation [30]. Firstly, we describe the primary network system model, which is a replicate model of the real system model of HetNet that consists of M BSs, R RNs, and N users, with at least one u that must be connected either with BS, b or RN, r, which is denoted by $b = \{b_1, b_2 \dots b_M\}$, $r = \{r_1, r_2, \dots r_R\}$ and $u = \{U_1, U_2, \dots U_N\}$, respectively. Denote by G (V, E) the routing in the constructed system model. Let V as the vertex set $V = (b \cup r \cup u)$ that includes all the nodes in the model. E_{ru}, E_{br} and E_{bu} represent the sets of links from a RN to a user, from a BS to a RN, and from a BS to a user, respectively. Let the subscripts i,j as two different nodes in vertex set V and e_ij is the notation for link between nodes i and j. All connections in the network model are in the downlink transmission, and the Cartesian coordinate system is used to locate all position.

In HetNet, energy efficiency is defined by selecting the appropriate RN placement location based on the minimum total power consumption. Let L_{ij} as a data that is transmitted from i to j, simplified through link ij. Let ϵ_{ts} and ϵ_{rv} as the power transmit and receive, respectively, power ber bit between BS and RN. We let the distance between nodes i and j, represented by d_{ij}^2. While power consumption for the HetNet represents the total power consumption in each link. Each link consists of nodes i and j within the vertex set V. The power involved in each link consists of basic power, which is the power transmit and power receive in idle mode. Let P_{ts}^{ij} and P_{rv}^{ji}, as the power transmited and received, respectively, is calculated in each link ij

based on [14]. ϵ_t and ϵ_r refer to the power transmitted and received per bit, respectively. L_{ij} is the amount of data transmitted through link ij. As the quantity of data transmission cannot be assessed, value one indicates the symbol for each link's successful data transmission. Hence, the total transmitting power at node i, P_{ts}^{i} and receiving power at node j, P_{rv}^{j} are respectively, given by:

$$P_{ts}^{i} = \sum_{j=1}^{j=N} \epsilon_{ts} L_{ij} d_{ij}^{2} \tag{1}$$

$$P_{rv}^{j} = \sum_{i=1}^{i=N} \epsilon_{rv} L_{ji} d_{ji.}^{2} \tag{2}$$

3. METHOD

In this section, we describe the methodology used to achieve the minimum energy consumption of the proposed network. For simplification, we consider that only one b can serve all users, where is randomly distributed for the u location, while the location of each b and r is fixed at a certain coordinate. The arrangement of BS for various topology structures, namely tree, hexagonal and circular model, as shown in Figure 1 and set within the constraints of coordinate (10,10).

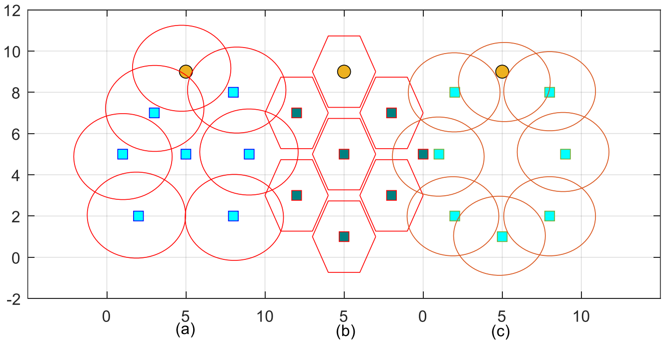


Figure 1. Arrangement of BS, b (illustrated as circle marker) and RN, r (illustrated as square) for (a) tree, (b) hexagonal grid, and (c) circular network topology structure with $r = 7$ and $b = 1$

For the proposed system model, we consider 1 BS, 2 RNs and 5 users. Figure 2 illustrates an example of the coordinates of nodes and their respective label of links within the maximum coordinate (10,10). To investigate the appropriate RN, r placement in the proposed network model there are additional three assumptions that have been made, i.e., i) the shortest link between nodes will provide reduction in the power consumption than a random fixed distance, ii) adding more RN to the network system does not efficiently lower power consumption to the optimal level for the network, and iii) decreasing the number of users will decrease power consumption. Then, total power transmitted, P_{ts}^{i} and received, P_{rv}^{j} are also calculated. From these assumption and Figure 2, we have three sets of links as follows:

$$E_{ru} = \{E_{r1u1}, E_{r1u3}, E_{r1u4}, E_{r1u5}, E_{r2u2}, E_{r2u3}, E_{r2u4}, E_{r2u5}\} \tag{3}$$

$$E_{br} = \{E_{br1}, E_{br2}\} \tag{4}$$

$$E_{bu} = \{E_{bu1}, E_{bu2}\} \tag{5}$$

we first calculate using various distance settings for each power consumption in each link ij, and total power consumption in the network model, P_{ts}^{i} and P_{rv}^{j}. Two conditions of distance are applied to determine the link ij distances, that is, by setting the links with the fixed distance and choosing the shortest distance of each link ij. Based on (1) and (2), the total transmits and receive power are computed in both directions. The power consumption is observed based on the selected condition for various number of r. The RN iteration number keeps increasing until the calculated power value reaches the best possible state. The first set number of RN that reached constant value will be chosen. Meanwhile, the number of randomly distributed users tested is fixed, and we conducted a few set numbers of users. To trace the location of links ij, the shortest link for each user, u is recorded based on Monte Carlo simulation and ensure that all u tested have at least one connection. Let l_j^i as the link i that is connect to each set j, and N_j is the total number of j connection. Thus, the percentage of the location can be computed as:

$$L\% = \frac{\sum_{i=1}^{i=N} l_j^i}{N_j} \times 100 \tag{6}$$

to investigate the optimal network system model for RN placement, suppose that each RN, r served the node that is within its range of constraints, where the position of BS, b is fixed for all type of the network model. By referring to all the constructed models and based on (1) and (2), respectively, the total power transmitted, P_{ts}^i and received, P_{rv}^j is calculated. The power consumption from the system network has also been evaluated. As a result, the network model which gives the lowest possible value of total P_{ts}^i and P_{rv}^j is selected as the optimal model for the RN placement. The distribution trend between BS, b, RN, r and users u is analysed by comparing the selected optimal network model and the proposed model to observe the distribution trend from both network models. Here, we expected that each type of topologies resulted in different total power consumption. Therefore, it is assumed that the selected optimal network model caused in equivalent distribution of BS, RN and users that can impact to the energy efficiency of the network system. Thus, based on (1) and (2), the total energy consumption in the link ij is denoted by E_{ij} can be written as:

$$E_{ij} = \left(P_{ts}^{ij} + P_{rv}^{ji}\right)\Delta t \tag{7}$$

where Δt is a one time slot of difference. Based on (7), the minimum energy consumption for the indoor network connection, E_min in all links can be expressed as:

$$E_{min} = \min \sum_{i\in V, j\in V} x_{ij} E_{ij} + P_{basic}^b \Delta t \tag{8}$$

where P_{basic}^b is a basic power at the BS, b. In this computation, the minimum power consumption that consists of basic power of BS and the total energy consumption in link ij within a time slot Δt. Besides, let x_{ij} as the binary variable to denote which link ij selected in the computation. In this study, we consider x_{ij} to be in the similar as distance, d_{ij}^2. We also consider the link ij which had the shortest distance for the final calculation of minimum power consumption. Let $\overline{D}$ as the average amount bandwidth required by each user, u. Based on (8), the energy efficiency in the network system model denoted by E_e, can be expressed as:

$$E_e = \frac{\bar{D}u}{E_{min}} \tag{9}$$

Finally, to analyze the difference between each selected network model, a performance comparison in terms of total minimum energy consumption, E_{min} and energy efficiency, E_e is investigate.

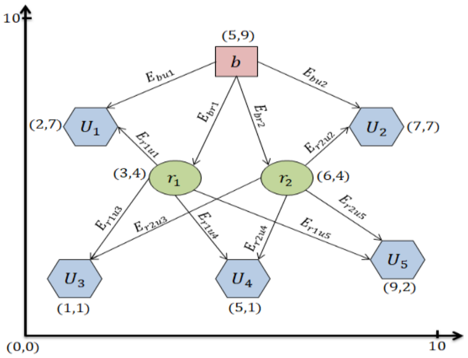


Figure 2. Illustration of coordinates and label of links in the proposed network model

4. RESULT AND DISCUSSION

This section provides the results based on the proposed design in section 3. To evaluate the performance of the power consumption in (7), under different distance settings, we first set up two RNs,

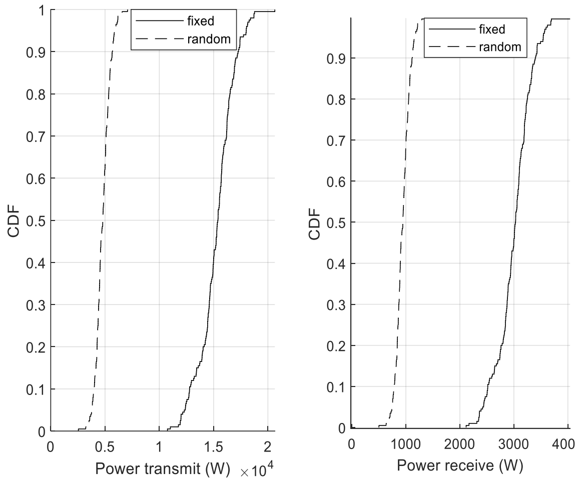
$r = \{r_1, r_2\}$ with $N = 10$ random users, $u = \{U_1, U_2, \ldots U_{10}\}$ and then obtain the total transmit and receive power based on (1) and (2), respectively. We compare two different distance settings that is the connection between u and r. For both distance settings, we set the coordinate of r_1 and r_2 to be (3,4) and (6,4), respectively, while u are in random location. For a fixed distance, link ij is set to be connected to node i and j without considering how far the position between r and u. For simplification, we let r_1 is connect to $u = \{U_1, U_3, U_4, U_5, U_7, U_8, U_9\}$ while r_2 is connect to $u = \{U_2, U_3, U_4, U_5, U_7, U_8, U_{10}\}$. In contrast, for the random distance, we set a random position of u and the same coordinate of r_1 and r_2, which only enable to compute the power consumption for distances between r and u that are close to each other. Finally, the network parameters are summarized in Table 1, where the values of the parameters are based on [25].

Table 1. The network parameter values

Parameter	L_{ij}	ϵ_{ts}	ϵ_{rv}	P_{basic}^{b}	Δt
Value	1	170.2 pJ/bit/m^2	33.5 pJ/bit/m^2	1500 W	1 s

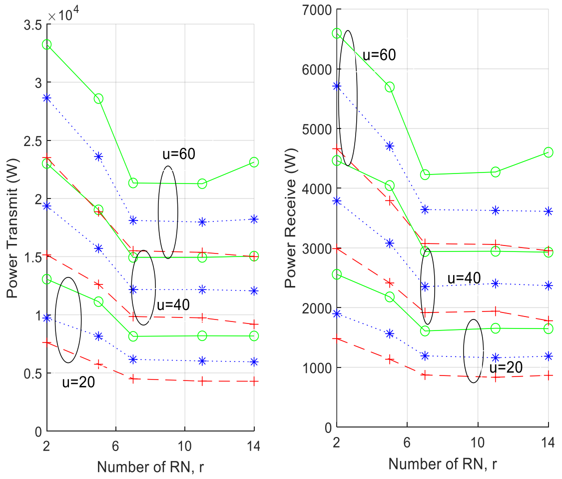
Figures 3(a) and (b), respectively, presents cumulative distribution function (CDF) comparison performance for both power transmit, P_{ts}^{i} and power receive, P_{rv}^{j} from the two different distance comparisons, that is between fixed and random distances setting for link ij. It is observed in both Figures 3(a) and (b) that the shortest distance between r and u has less power compared to a fixed distance, which implies that the shortest distance link ij uses a low power consumption and less energy in transmitting data. This result also demonstrates that an appropriate placement of r leads to an improvement of the energy efficiency in HetNets.

Next, we compute (1) and (2) using a different set number of r to reach an optimal power consumption for various number of RN, r. The main aim is to observe that the power consumption in the network system model will reach the optimal number of RN. Figure 4 reveals the power consumption performance as a function of r for various values of r, and u. It is seen in both Figures 4(a) and (b), respectively, that the transmit and receive power decrease with r and reach a constant value when r is 7. The same observation is found in all cases of u. Moreover, the trendline illustrated with a dash, dots, and solid line, respectively, for a minimum, average and maximum value of power consumption are almost the same for all set of u. The results show that although the number of users increases, the total number of 7 RNs in the network system is sufficient to minimize power consumption. Hence, adding more RN to the network system is unnecessary and will waste expense and energy. This is inlign with results shown in [22], whereas using a reasonable number of RNs gives better performance to the network without the need to add more relays.



(a) (b)

Figure 3. Comparison of power (a) transmits and (b) receives consumption for $u = 10$ with various distance settings



(a) (b)

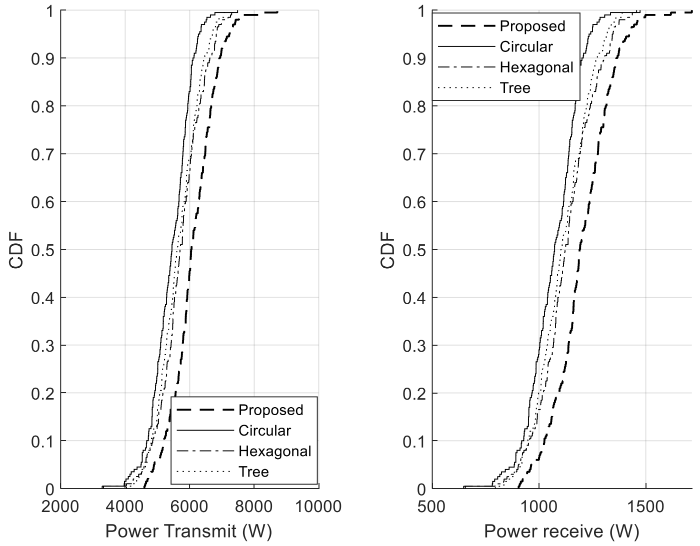
Figure 4. Performances of power (a) transmits and (b) receives for various number of RNs

The location for each link ij is being tracked to determine the number of N users connected to b or RNs $r = \{r_1, r_2, \dots, r_6, r_7\}$. Table 2 presents the distribution percentage of link ij between b, r for different number of u, which shows that the highest distribution percentage is at r_2 and the lowest is at b. The same findings can be observed for all cases of u. It is also found that the patterns of distribution percentage for all cases of u are similar. However, it is still an inappropriate arrangement because they are not equivalent for each node, which will affect the power consumption in the network. Therefore, an optimal model of RN distribution is required. To choose the most applicable placement for RN, we first select the most suitable network topology to apply in the indoor connection. We compare the power consumption between four types of network system models as shown in Figure 1. The comparison aims to see which network model had the distribution of link ij that achieved the optimal state. This simulation is run under 200 iteration environments for the fixed location of $b = 1, r = 7$ with the fixed coordinate and random located users, $u = 20$.

Table 2. The distribution percentage for link ij between b, r and various u

Node (%)	b	r_1	r_2	r_3	r_4	r_5	r_6	r_7
$u = 20$	1.30	1.85	3.21	1.52	1.57	1.93	2.67	2.66
$u = 40$	2.63	3.49	6.34	3.07	2.97	3.99	5.42	5.36
$u = 60$	3.90	5.33	9.68	4.54	4.51	6.39	8.31	7.33

Figure 5(a) and (b), respectively, compares power transmits and receieves consumption performance between those network system models mentioned in section 3. Both Figures 5(a) and (b) shows that the circular arrangement of the proposed network model gives the lowest total power consumption among other types of the network model. In this case study, we observe that the circular network topology is the most suitable and optimum network model for the RN placement. Meanwhile, Table 3 shows the distribution trend of link ij for various types of networks. On average, the circular network model is more suitable and appropriate than the distribution in other network models. Its distribution trend placement is because each RN in the circular network topology model can serve the users equivalently. While the number of users will grow, the distribution pattern can be maintained equivalently as long as the nodes in the circular network are still in an appropriate place. This result indicates that with this network topology structure arrangement, we can minimize energy consumption at each node level and reduce the remote redundancy of connection between nodes and all users. Thus, energy efficiency in the area coverage is ensured.



(a) (b)

Figure 5. Comparison of power (a) transmits and (b) receives consumption for various network model

To analyse the minimum energy consumption by selecting the location of RN placement, we compare, E_{min} and E_e between the optimal network model based on (9). Here, the total minimum energy consumption and energy efficiency are compared between the proposed network model and the most optimal network model, which is a circular network topology model. The computation used $u = 20$ with the average bandwidth required for each user is 300 kbps [22]. From Table 4, the circular network topology model achieves lower energy consumption and has a higher efficiency than the proposed model by an average factor of 1.056. Hence, the circular network topology can increase the energy efficiency in the system and maintain the network performance since the interference between each node is minimal for this type of network. Hence, this indicates that the circular network topology is an appropriate network model that can be used in designing the optimal network system model.

Table 3. The distribution percentage of link ij for various types of network topologies model

Node (%)	b	r_1	r_2	r_3	r_4	r_5	r_6	r_7
Circular	11.80	13.51	11.29	13.23	12.3	13.08	10.77	14.03
Proposed	7.80	11.10	19.22	9.09	9.41	11.52	15.97	18.93
Hexagonal	10.84	15.76	16.66	9.65	11.20	14.70	14.20	7.00
Tree	9.25	12.31	13.50	9.88	13.13	9.63	16.30	16.00

Table 4. Comparison of energy performance for various network model

	Circular (Factor Efficiency Increase)	Proposed
E_{min}	39778 (×1.0566)	42018
E_e	150.784 (×1.0556)	142.785

5. CONCLUSION

This paper presented the energy efficiency scheme by selecting and designing the most appropriate RN placement based on the arrangement of suitable network topologies. In this study, an acceptable r placement is represented by a scenario with the lowest total power consumption realized in the suggested network model. This study also discovered that the circular network topology of the node is the most effective configuration for an RN in an indoor network connection after considering the distance between nodes and the distribution of each node that can further improve the QoS to users. Furthermore, the efficiency factor ensures an improvement that can be utilised in building the energy efficient indoor HetNet. Building structures and designs must be considered in the future while creating the energy efficient indoor HetNet.

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BIOGRAPHIES OF AUTHORS

Aziemah Athirah As’ari received her B.Eng degree (Hons) in Mechatronic Engineering from Universiti Teknikal Malaysia Melaka (UTeM), Malaysia in 2021. She was a Student Research Assistant under Center for Research Innovation Management (CRIM), Universiti Teknikal Malaysia Melaka (UTeM) in 2020. Currently, she is an Automation Engineer at Flex Ltd. in Pelabuhan Tanjung Pelepas, Johor, Malaysia. Her research interest includes data communication and energy efficiency. She can be contacted at email: aziemahasari@gmail.com.

Nur Ilyana Anwar Apandi received her B.Sc. degree (Hons.) in Industrial Mathematics from Universiti Teknologi Malaysia (UTM), Malaysia, in 2002, and the M.Sc degree in Modeling in Applied Mathematics from the University of East Anglia, Norwich, U.K., in 2004. She obtained her PhD degree from the School of Electrical and Information Engineering, The University of Sydney, Australia, in 2017. Currently, she is a Senior Lecturer at the Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka (UTeM). Her research interest includes system modelling, applied engineering mathematics, and wireless telecommunications applications. She can be contacted at email: ilyana@utem.edu.my.

Nor Aishah Muhammad received her B.Eng. and M. Eng. degrees in Electrical Engineering (Telecommunications) from the Universiti Teknologi Malaysia, Malaysia, in 2009 and 2012, respectively. From Mac 2011-May 2011, she was a visiting researcher at Computer Laboratory, University of Cambridge, United Kingdom. She obtained her Ph.D degree from the School of Electrical and Information Engineering, The University of Sydney, Australia in 2019. She was a tutor (2009-2017) and a Postdoctoral fellow (2019-2021) at the Wireless Communication Centre (WCC), Universiti Teknologi Malaysia. Currently, she is a Senior Lecturer in the School of Electrical Engineering, Universiti Teknologi Malaysia. Her research interests include applications of stochastic geometry, millimeter-wave and microwave communications, wireless propagation, channel modeling, and channel measurement. She can be contacted at email: noraishahm@utm.my.

Rozeha A. Rashid received her B. Sc. degree in electrical engineering from the University of Michigan, Ann Arbor, USA and her M.E.E. and PhD degrees in telecommunication engineering from Universiti Teknologi Malaysia (UTM). She is an associate professor in the Department of Communication Engineering, School of Electrical Engineering, Universiti Teknologi Malaysia and is currently the head of Telecommunication Software and System (TeSS) research group. Her current research interests include wireless communications, sensor network, cognitive radio and internet-of-things. She can be contacted at email: rozeha@fke.utm.my or rozeha@utm.my.

Mohd Adib Sarijari obtained his Ph.D in Delft University of Technology in Telecommunication Engineering in 2016. He received his Bachelors in Engineering degree, and the Master of science in Electrical Engineering from UTM. He is now an Academic IT fellow in IoT technology with UTM digital, as well as the founder and advisor to UTM Jazari Innovation Club, Jazari. He can be contacted at email: madib@utm.my.

Jamaliah Salleh obtained her B.Sc. degree in Electrical engineering (Telecommunication) and the Master of Electrical Engineering from Universiti Teknologi Malaysia in 2009 and 2012, respectively. Currently she is Research Officer at Wireless Communication Centre, Universiti Teknologi Malaysia. Her research interest includes mobile communication system, RF-EMF measurement, and 5G use cases. She can be contacted at email: jamaliah_s@utm.my.