World Academy of Science, Engineering and Technology
International Journal of Electronics and Communication Engineering
Vol:15, No:8, 2021

Neighbour Cell List Reduction in Multi-Tier Heterogeneous Networks

Mohanad Alhabo, Naveed Nawaz

***Abstract*—The ongoing call or data session must be maintained to ensure a good quality of service. This can be accomplished by performing handover procedure while the user is on the move. However, dense deployment of small cells in 5G networks is a challenging issue due to the extensive number of handovers. In this paper, a neighbour cell list method is proposed to reduce the number of target small cells and hence minimizing the number of handovers. The neighbour cell list is built by omitting cells that could cause an unnecessary handover and/or handover failure because of short time of stay of a user in these cells. A multi-attribute decision making technique, simple additive weighting, is then applied to the optimized neighbour cell list. The performance of the proposed method is analysed and compared with that of the existing methods. Results disclose that our method decreases the candidate small cell list, unnecessary handovers, handover failure and short time of stay cells compared to the competitive method.**

***Keywords*—** Handover, HetNets, MADM, small cells.

I. Introduction

THE vast growing number of smart user equipments (UEs) connected to the fifth generation (5G) networks has lead to the need for coverage and capacity expansion. The already deployed macrocell (MC) base stations are not efficient enough to satisfy the user demand for capacity and coverage. Ultra-dense deployment of small cell (SC) base stations is a key technology to enhance the network coverage and capacity. However, considering large number of SCs can cause huge signalling overhead due to the unnecessary handover (HO). In order to perform a HO to a proper cell, a list of cells is stored in each cell in a list called neighbour cell list (NCL), which contains the neighbouring cells. Upon performing the HO to this cell, the UE gets the NCL. Then, the UE measures the signal quality of the cells stored in this NCL for the next HO [1]. With ultra dense SC deployment in 5G networks, it is not proper to use a NCL which has a huge number of SCs. A reduced NCL means lower signal overhead, efficient SC utilization and faster HO.

In terms of HO, there were many literature works that dealt with reducing the number of HOs aiming to reduce signalling overhead. In [2], a novel HO method is proposed. This method is based on RSS estimation and the gathered SINR values. This method minimized the unnecessary HOs and failure probability and improved the achieved throughput. In [3], authors proposed a three-steps mobility-aware technique. The HO probability is derived according to the target cell location, UE moving trajectory and speed. Authors in [4] presented a HO method for HetNets. Interference and signalling overhead of cell boundary UEs sufficiently reduced through the deployment of coordinated multiple points (CoMP) policy. Moreover, combining with self-optimisation strategy, the interference adjustment and HO performance are enhanced. In [5], an energy efficient technique is proposed to mitigate the radio link failure (RLF) and unnecessary HO for HetNets at the cost of system complexity. Authors in [6] presented a green HO method to mitigate the UE power consumption and minimize the unnecessary HOs. This method refuses a HO request for high speed UE (using call admission control policy) and permits HO request that does not cause an increase in the target cell transmission power. Authors in [7] presented a HO method for HetNets. This method utilized HO history policy and measurement reports. Following mobility status, UEs are defined as either high speed UEs or ping pong UEs. High speed UEs are obliged to HO to MC, while ping pong UEs do a HO metrics adjustment to HO to a proper cell. If ping pong is not possible, UEs are connected with the MC. In [8], a HO method for load balancing in HetNets is proposed. The interference is considered to force UE offloading from a congested cell. This method deploys a modified A3 HO triggering event taking into account cell load and interference. Results show a good performance in terms of load balancing and throughput improvement. In [9], a method to minimize the number of target SCs and reduce unnecessary HOs in HetNet is presented. A SC NCL is formed by utilizing the distance between the UE and the SC and the user's angle of movement. High speed UEs are not permitted to HO to SCs. In [10], a technique that permits a cell to change its transmission power following its data traffic load is presented. To avoid going into off mode, base stations have the ability to control their transmission power. In [11], a method that takes into consideration the UE association and power control in HetNets is proposed. The joint optimization problem is formed utilizing log-utility model. An improvement in the utility energy efficiency compared to the conventional method is observed.

A degraded quality of service (QoS) is recorded when a user connects to a cell for very short time (ToS $<$ Time threshold) resulting in unnecessary HO and/or HO failure. This is a very big issue in multi-tier HetNets. In order to minimize the impact of this issue on the QoS delivered to the end user, we aim to reduce the number of target SCs in the NCL so that the user can have a short listed cell candidates. The reduced NCL is obtained by omitting the cells that could cause a short ToS. Then, the simple additive weighting (SAW) multiple attribute decision making (MADM) technique [12] is applied on the optimized NCL to perform HO to the best candidate cell. In this paper, the signal to interference plus noise ratio (SINR) is used with the predicted ToS in SAW cells ranking.

This paper is organized as follows. The system model is given in Section II, while Section III presents the proposed method. In Section IV the performance of the proposed method and results are analysed. Finally, Section V concludes the paper.

II. System Model

System model in this work considers a three-tier HetNet (Macrocell, picocell and femtocell), which consists of SCs overlaid

Mohanad Alhabo is currently with the Informatics and Telecommunication Public Company/Iraqi Ministry of Communications (e-mail: mohanad.alhabo@gmail.com).

Naveed Nawaz is currently with the University of Engineering and Technology, Lahore, Pakistan.

under the coverage area of the MC, as depicted in Fig.1. The MC is deployed as a hexagonal with three sectors (120^o each). The SCs are distributed randomly based on a uniform distribution. The minimum distance constraint between the MC tier and SC tier is considered to mitigate the impact of interference and hence enhance the anticipated capacity of the SCs. The minimum distances in meters are set as follows [13]: MC site to SC site is 75m and MC to UE is 35m. The UE mobility follows a Gauss

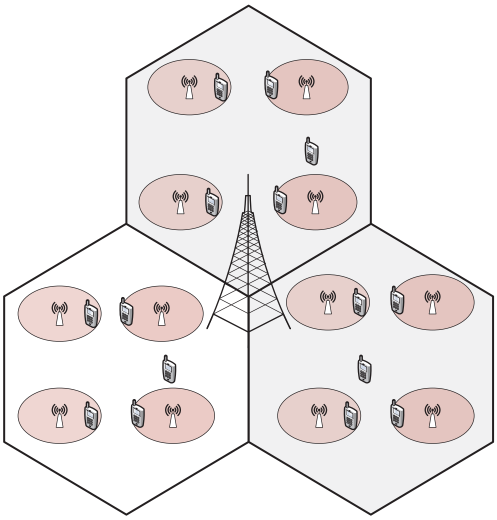

Fig. 1 Network system model

mobility model which can be expressed by using two parameters: direction, θ, and velocity, V. The two parameters can be expressed as Gaussian distribution and are updated as [14]

$$V = \mathcal{N}(v_m, v_{std}), \quad (1)$$

$$\theta = \mathcal{N}(\theta_m, 2\pi - \theta_m \tan(\frac{\sqrt{V}}{2})\Delta t), \quad (2)$$

where v_m is the mean velocity of the user, v_{std} is the standard deviation of the UE velocity, θ_m is the previous direction of the user, Δt is the period between two updates of the mobility model, and $\mathcal{N}(x, y)$ is a Gaussian distribution with mean x and standard deviation y.

The propagation model between the MC and the UE is expressed as in [15] by

$$\delta_m = 128.1 + 37.6 \ \log_{10}(d_m) + \xi, \quad (3)$$

where d_m is the distance between the user and the MC base station in kilometres, and ξ is a Gaussian distribution random variable with zero mean and 12 dB standard deviation [15].
For picocell, the path loss is defined as [15] [16]

$$\delta_{pc} = 38 + 30 \ \log_{10}(d_{pc}) + \xi, \quad (4)$$

where d_{pc} is the distance between the user and the picocell base station in metres. And its path loss from the femtocell to the user is expressed as [15] [16]

$$\delta_{fc} = 37 + 20 \ \log_{10}(d_{fc}) + \xi, \quad (5)$$

where d_{fc} is the distance between the user and the femtocell base station in metres.

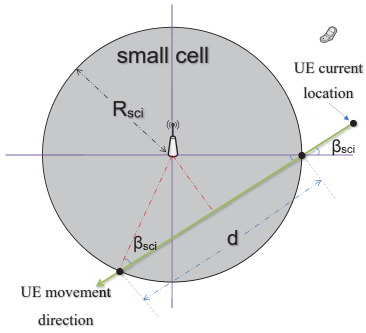

Fig. 2 UE ToS measurement

The downlink reference signal received power (RSRP) is measured as

$$P_i^r = p_i^t + g_{bs} - \delta_i - \xi_i, \quad (6)$$

where P_i^r is the computed RSRP of the candidate cell, p_i^t is the transmitting power of cell i, g_{bs} is the antenna gain, δ_i is the path loss between the user and cell i, and ξ_i is the shadow fading with a log-normal distribution with zero mean and 3 dB standard deviation [17].

The estimated user ToS can be expressed utilizing the velocity, V, and the predicted distance that a user will reside in the base station coverage area as depicted in Fig. 2.

The angle β_{sc_i}, which is the user's angle of entry to SC, can be defined as a random variable, which is uniformly distributed and restricted to interval $[\frac{-\pi}{2}, \frac{\pi}{2}]$. This random variable has a constant density over that interval i.e., has a probability density function (PDF) $f_{\beta_{sc_i}}(\beta_{sc_i})$, as illustrated in Fig. 3 and (7).

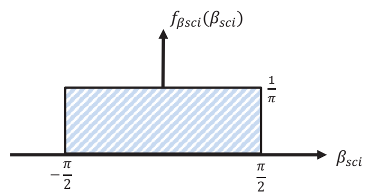

Fig. 3 PDF of β_{sc_i}

$$f_{\beta_{sc_i}}(\beta_{sc_i}) = \begin{cases} \frac{1}{|\frac{-\pi}{2} - \frac{\pi}{2}|} & \text{if } \frac{-\pi}{2} \leq \beta_{sc_i} \leq \frac{\pi}{2} \\ 0 & \text{otherwise} \end{cases} \quad (7)$$

Therefore, the ToS for a user in SC i can be expressed as

$$\begin{aligned} \mathrm{E}\Big[ToS_{ue,i}\Big] &= \mathrm{E}\Bigg[\frac{2R_{sc_i}\cos(\beta_{sc_i})}{V}\Bigg] \\ &= \int \frac{2R_{sc_i}\cos(\beta_{sc_i})}{V} f_{\beta_{sc_i}}(\beta_{sc_i}) d\beta_{sc_i} \\ &= \int_{\frac{-\pi}{2}}^{\frac{\pi}{2}} \frac{2R_{sc_i}\cos(\beta_{sc_i})}{V}\frac{1}{\pi} d\beta_{sc_i} \\ &= \frac{4R_{sc_i}}{\pi V}, \end{aligned} \quad (8)$$

where R_{sc_i} is the radius of SC i.

The estimated ToS, $ToS_{ue,i}$, for the user in cell i is used to build the NCL. This is done by comparing $ToS_{ue,i}$ with time threshold, which means that the SC will be excluded from the NCL if the

ToS is less than the predefined time threshold as depicted in the following

$$\mathrm{E}\Big[ToS_{ue,i}\Big] < T_{threshold} \tag{9}$$

In order to keep service continuity for the user, it should receive a minimum signal strength of $RSRP_{th}$.

The received SINR from cell i at the user side can be written as

$$\gamma_i^r = \frac{P_i^r}{\sum_{j=1,j\neq i}^{N_{bs}} P_{bs_j}^r + \sigma^2}, \tag{10}$$

where $P_{bs_j}^r$ is the RSRP from the interfering cell, σ^2 is the noise power and N_{bs} is the total number of base stations in the network.

III. Proposed Method

The aim of this paper is to optimize the NCL so that the extensive number of unnecessary HOs and HO failure are reduced. This is accomplished by estimating the ToS that a user spends inside the coverage area of a SC. The optimized NCL is then used to select the proper candidate cell for HO using SAW weighted technique. The proposed method procedures are listed in Algorithm 1.

Algorithm 1 Proposed Method

Start
User **moves** to SC coverage area
for $i \leftarrow 1, N_{bs}$ **do**
  Predict $ToS_{ue,i}$
  if $\mathrm{E}\big[ToS_{ue,i}\big] > T_{threshold}$ **then**
    Save SC i in the new NCL N_{bs}^*
  end if
end for
Calculate γ_i^r for all N_{bs}^*
Generate the decision matrix D based on $ToS_{ue,i}$ and γ_i^r
Apply the **SAW** steps on the decision matrix **D**
Perform HO to the cell with the **highest rank**
end

The proposed method begins by omitting SCs that may result in short ToS, i.e., SCs with ToS below the time threshold, $T_{threshold}$, resulting in a NCL, denoted as N_{bs}^*, which can be expressed as

$$N_{bs}^* = \Big\{ i \in N_{bs} \mid \mathrm{E}\big[ToS_{ue,i}\big] > T_{threshold} \Big\}. \tag{11}$$

Then, the proposed method uses SAW technique for best cell selection. The HO metrics deployed to rank the candidate cells are: the estimated ToS ($ToS_{ue,i}$) and the SINR of the candidate cell (γ_i^r).

Now, the user has a set of N_{bs}^* candidate cells $m = \{1, 2, \cdots, N_{bs}^*\}$ with a set of HO metrics $n = \{1, 2\}$ and attributes weighting vector **w**. The SAW procedures can be briefed as:

Step 1: The decision matrix, **D**, is built by mapping the cells against HO metrics as

$$\mathbf{D} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \\ a_{31} & a_{32} \\ \vdots & \vdots \\ a_{m1} & a_{m2} \end{bmatrix}, \tag{12}$$

where each row represents one cell and the columns represent their correspondent HO metrics, $n = 1, 2$, $m = 1, 2, \cdots, N_{bs}^*$, a_{ij} represents the value of the j^{th} HO metric for the i^{th} cell. In this work, $a_{i1} = ToS_{ue,i}$ and $a_{i2} = \gamma_i^r$.

Step 2: The decision matrix is normalized as

$$a_{ij}^{norm} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^{m} a_{ij}^2}}, \quad a_{ij}^{norm} \in [0, 1], \tag{13}$$

where a_{ij}^{norm} is the j^{th} normalized HO metric of the i^{th} cell.

Step 3: The weighting vector **w** must be computed to consider the importance of each HO metric. The weighting of HO metrics plays an important role in decision making. In this paper, we deploy the standard deviation weighting (SD) technique [18]. The SD technique computes the weights of each HO metric in terms of standard deviation. If a HO metric has an equal values on all available cells in N_{bs}^*, then it has no important influence on HO decision, therefore its weight is null.

The weighting vector $\mathbf{w} = [w1 \;\; w2]$ represents the weights of $ToS_{ue,i}$ and γ_i^r respectively. The SD weighing vector can be computed as

$$w_j^{sd} = \frac{\lambda_j}{\sum_{k=1}^{2} \lambda_k}, \tag{14}$$

$$\lambda_j = \sqrt{\frac{1}{m} \sum_{i=1}^{m} (a_{ij}^{norm} - \mu_j)^2}, \tag{15}$$

$$\mu_j = \frac{1}{m} \sum_{i=1}^{m} a_{ij}^{norm}, \tag{16}$$

where λ_j and μ_j are respectively the standard deviation and the mean value of the j^{th} normalized HO metric.

Step 4: The candidate cells are then evaluated using SAW as

$$A_i = \arg\max_{i \in m} \sum_{j=1}^{n} w_j \; a_{ij}^{norm} \quad ; \quad i = 1, 2, \cdots m \tag{17}$$

IV. Performance and Results Analysis

The performance of the proposed method is evaluated and compared against the conventional method in terms of the number of SC in NCL, short ToS rate, number of HOs and HO failure probability. Simulation parameters are given in Table I [15].

TABLE I
SIMULATION PARAMETERS

Parameter	Value
MC radius	500 meters
Picocell radius	100 meters
Femtocell radius	25 meters
Number of SCs (pico & femto)	100
Bandwidth	20 MHz
MC transmission power	46 dBm
Pico cell transmission power	20 dBm
Femtocell transmission power	10 dBm
Small cell antenna gain	0 dBi
Small cell transmit power	2 dBm
MC Shadowing standard deviation	8 dB
SC Shadowing standard deviation	10 dB
UE velocity	{10, 20, 30, 40, 50} km/h
$RSRP_{th}$	-70 dBm
$\gamma_{threshold}$	5 dB
T_{exe}	1 sec
$T_{threshold}$ for femtocell	5 sec
$T_{threshold}$ for picocell	10 sec

The conventional method builds the NCL by including all cells with an RSRP greater than $RSRP_{th}$. This implies that there will be a very long time needed to choose the candidate cells. The NCL for the conventional method, denoted as NCL_{conv}, is written as

$$NCL_{conv} = \Big\{ i \in N_{bs} \mid \; P_i^r \; > \; RSRP_{th} \Big\}. \tag{18}$$

Differently, the proposed method forms the NCL based on the estimated ToS. According to the definition of density metric in [19], the SC density in a given coverage area is expressed by density metric, D_{bs}, as

$$D_{bs} = \frac{\mid N_{bs} \mid \pi R_{sc}^2}{\pi R_m^2}, \tag{19}$$

where R_{sc} and R_m are respectively the SC and MC radii. The denominator is the MC coverage area. When the density metric of SC, D_{bs} is 1, this implies that the deployment of the SCs occupies the complete zone of the MC coverage area. Additionally, a higher than 1 value implies that SCs are covering the complete zone of MC and an overlapping exists among SCs.

The probability that a user resides in the coverage areas of cell i is defined as

$$\mathbb{P}_{ue \text{ inside } i} = \mathbb{P}\Bigg[P_i^r \; \geq \; RSRP_{th} \Bigg]. \tag{20}$$

The probability of short ToS occurrence can be defined as

$$\mathbb{P}_{ToS} = \mathbb{P}\Big[\mathrm{E}\big[ToS_{ue,i} \big] \leq T_{threshold} \Big]. \tag{21}$$

The HO failure probability happens when a user starts HO process but an interruption terminates the process before finishing (before the expiry of HO execution time) as a result of the degraded SINR from the source and the target cells. Thus, the HO failure probability can be expressed as

$$\mathbb{P}_{HOF} = \mathbb{P}\Big[\gamma_i^r < \gamma_{threshold} \; \wedge \; \gamma_{serving}^r < \gamma_{threshold} \text{ for } t < T_{exe} \Big], \tag{22}$$

where $\gamma_{serving}^r$ is the serving cell SINR and T_{exe} is the time required to complete the HO process (including HO preparation and HO execution and is defined as 1 second [1]).

Fig. 4 depicts the number of SCs in NCL for the proposed and conventional methods. Clearly, the number of SCs in the NCL in both methods reduces as the velocity increases. However, the proposed method outperforms the conventional one for all velocities due to the reduced size of NCL as a result of omitting SCs that cause short ToS for the user. Obviously, at 30 km/hr, the curve of the proposed method sharply goes down because the NCL for high speed users will be highly reduced.

Fig. 5 illustrates the short ToS rate. The short ToS means an increased number of unnecessary HOs and hence high signalling overhead. Clearly, the proposed method sharply goes down in terms of short ToS compared to the conventional method, which gives high short ToS at all velocities.

The number of HOs with respect to velocity is depicted in Fig.6. The number of HOs for the conventional method sharply increases with velocity because the conventional method does not optimize the NCL prior to HO process. Differently, the proposed method shows a reduced number of HOs and the number of HOs sharply goes down at 30 km/hr due to the reduced number of SCs in NCL meaning that high speed users will not HO to short ToS SC.

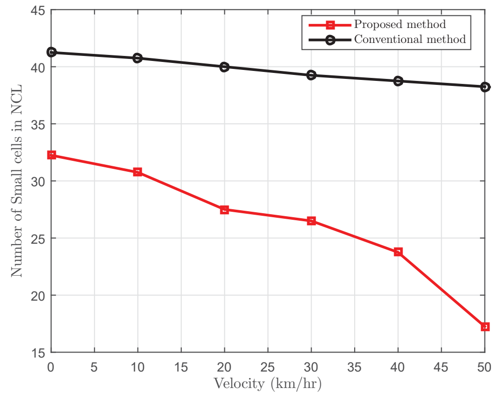

Fig. 4 Number of small cells in NCL

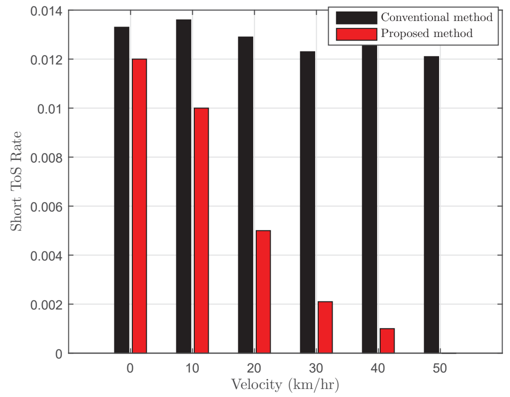

Fig. 5 Short ToS rate

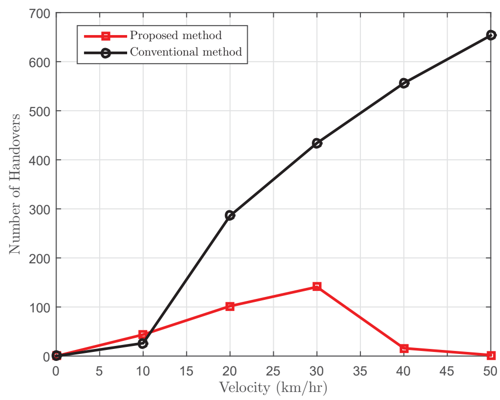

Fig. 6 Number of handover

The probability of HO failure is illustrated in Fig. 7. When the user passes through a short ToS SC, the HO will be initiated but will be interrupted due to the user departing the SC coverage area before HO completion. Therefore, the HO failure increases as in the conventional method. However, the proposed method outperforms the conventional for all velocities.

V. Conclusion

In this paper, we proposed a NCL reduction method to minimize the unnecessary HO and HO failure resulted from short ToS inside SCs coverage area. The proposed method considers a multi-tier

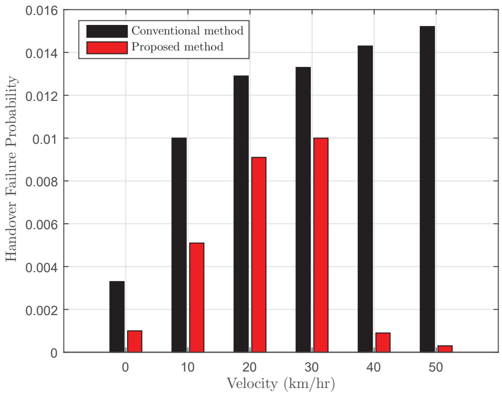

Fig. 7 Handover failure probability

HetNets with dense SCs deployment. The NCL is optimized by estimating the ToS that a user could stay in a specific cell, where the cell is omitted from the list if its ToS is less than a predefined threshold. The optimized candidate cells are then used for HO. Users can perform HO to the best cell in the optimized NCL after applying the multiple attribute decision making SAW technique. The proposed method is evaluated and compared against the conventional method where no optimization for NCL is considered. The proposed method outperforms the conventional method for all evaluation metrics. For example, when the velocity is 30 km/hr, the proposed method gives %32, %84, %65 and %25 reduction in the number of short ToS, NCL size, number HOs and HO failure respectively compared to the conventional method.

References

[1] E. U. T. R. Access, "Radio resource control (rrc)," *Protocol specification*, vol. 290, 2013.

[2] H. Kalbkhani, S. Yousefi, and M. G. Shayesteh, "Adaptive handover algorithm in heterogeneous femtocellular networks based on received signal strength and signal-to-interference-plus-noise ratio prediction," *IET Communications*, vol. 8, no. 17, pp. 3061–3071, 2014.

[3] S. Kapoor, D. Grace, and T. Clarke, "A base station selection scheme for handover in a mobility-aware ultra-dense small cell urban vehicular environment," in *2017 IEEE 28th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC)*. IEEE, 2017, pp. 1–5.

[4] H. Zhang, C. Jiang, J. Cheng, and V. C. Leung, "Cooperative interference mitigation and handover management for heterogeneous cloud small cell networks," *IEEE Wireless Communications*, vol. 22, no. 3, pp. 92–99, 2015.

[5] K. Kanwal and G. A. Safdar, "Energy efficiency and superlative ttt for equitable rlf and ping pong in lte networks," *Mobile Networks and Applications*, vol. 23, no. 6, pp. 1682–1692, 2018.

[6] G. Araniti, J. Cosmas, A. Iera, A. Molinaro, A. Orsino, and P. Scopelliti, "Energy efficient handover algorithm for green radio networks," in *Broadband Multimedia Systems and Broadcasting (BMSB), 2014 IEEE International Symposium on*. IEEE, 2014, pp. 1–6.

[7] M. M. Hasan, S. Kwon, and S. Oh, "Frequent-handover mitigation in ultra-dense heterogeneous networks," *IEEE Transactions on Vehicular Technology*, vol. 68, no. 1, pp. 1035–1040, 2018.

[8] M. Alhabo and L. Zhang, "Load-dependent handover margin for throughput enhancement and load balancing in hetnets," *IEEE Access*, vol. 6, pp. 67 718–67 731, 2018.

[9] ——, "Unnecessary handover minimization in two-tier heterogeneous networks," in *Wireless On-demand Network Systems and Services (WONS), 2017 13th Annual Conference on*. IEEE, 2017, pp. 160–164.

[10] A. Merwaday and I. Güvenç, "Optimisation of feicic for energy efficiency and spectrum efficiency in lte-advanced hetnets," *Electronics Letters*, vol. 52, no. 11, pp. 982–984, 2016.

[11] X. Huang, W. Xu, H. Shen, H. Zhang, and X. You, "Utility-energy efficiency oriented user association with power control in heterogeneous networks," *IEEE Wireless Communications Letters*, vol. 7, no. 4, pp. 526–529, 2018.

[12] L. Wang and G.-S. G. Kuo, "Mathematical modeling for network selection in heterogeneous wireless networksŮa tutorial," *IEEE Communications Surveys & Tutorials*, vol. 15, no. 1, pp. 271–292, 2013.

[13] X. Chu, D. López-Pérez, Y. Yang, and F. Gunnarsson, *Heterogeneous Cellular Networks: Theory, Simulation and Deployment*. Cambridge University Press, 2013.

[14] J. Zhang and G. De la Roche, *Femtocells: technologies and deployment*. John Wiley & Sons, 2011.

[15] E. U. T. R. Access, "Mobility enhancements in heterogeneous networks," 3GPP TR 36.839, Tech. Rep., 2012.

[16] 3GPP, "HNB and HNB-Macro Propgation Models," 3rd Generation Partnership Project (3GPP), Tech. Rep. R4-071617, 2007.

[17] T. Jansen, I. Balan, J. Turk, I. Moerman, and T. Kurner, "Handover parameter optimization in lte self-organizing networks," in *Vehicular Technology Conference Fall (VTC 2010-Fall), 2010 IEEE 72nd*. IEEE, 2010, pp. 1–5.

[18] Y.-M. Wang and Y. Luo, "Integration of correlations with standard deviations for determining attribute weights in multiple attribute decision making," *Mathematical and Computer Modelling*, vol. 51, no. 1, pp. 1–12, 2010.

[19] N. Bulusu, D. Estrin, L. Girod, and J. Heidemann, "Scalable coordination for wireless sensor networks: self-configuring localization systems," in *International Symposium on Communication Theory and Applications (ISCTA 2001), Ambleside, UK*, 2001.

Mohanad Alhabo Received the B.Sc. degree in computer and information engineering from the Faculty of Electronics Engineering, University of Mosul, Mosul, Iraq, in 2007, and the M.Sc. degree in computer network administration and management engineering from the University of Portsmouth, Portsmouth, UK, in 2009, and the Ph.D. degree with the School of Electronic and Electrical Engineering, University of Leeds, Leeds, UK, in 2018. He was a Network Engineer for over four years. His research interest includes mobility management, handover and interference management for heterogeneous networks. Dr Alhabo is currently with the Informatics and Telecommunication Public Company/Iraqi ministry of communications.

Naveed Nawaz Received his PhD in Electrical Engineering from University of Leeds, UK and is currently serving as Assistant Professor at UET Lahore, Pakistan. Before this, he also worked on telecommunication systems with Huawei Technologies, Pakistan. His research interests are within the domain of next generation networks, IoT and Fog computing.