IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received November 25, 2019, accepted December 9, 2019, date of publication December 20, 2019, date of current version January 2, 2020.

Digital Object Identifier 10.1109/ACCESS.2019.2961186

Auto Tuning Self-Optimization Algorithm for Mobility Management in LTE-A and 5G HetNets

ABDULRAQEB ALHAMMADI [1], (Graduate Student Member, IEEE), MARDENI ROSLEE [1], (Senior Member, IEEE), MOHAMAD YUSOFF ALIAS [1], (Senior Member, IEEE), IBRAHEEM SHAYEA [2], (Member, IEEE), SADDAM ALRAIH [3], (Graduate Student Member, IEEE), AND KHALID SHEIKHIDRIS MOHAMED [1], (Graduate Student Member, IEEE)

[1]Faculty of Engineering, Multimedia University, Cyberjaya 63100, Malaysia
[2]Electronics and Communication Engineering Department, Istanbul Technical University, 34467 Istanbul, Turkey
[3]Electrical and Electronic Engineering Department, National University of Malaysia, Bangi 43600, Malaysia

Corresponding author: Mardeni Roslee (mardeni.roslee@mmu.edu.my)

This work was supported by the Telecom Malaysia Research and Development Sdn. Bhd. (TM Research and Development) under Grant MMUE/170014.

ABSTRACT Ultra-dense networks represent the trend for future wireless 5G networks, which can provide high transmission rates in dense urban environments. However, a massive number of small cells are required to be deployed in such networks, and this requirement increases interference and number of handovers (HOs) in heterogeneous networks (HetNets). In such scenario, mobility management becomes an important issue to guarantee seamless communication while the user moves among cells. In this paper, we propose an auto-tuning optimization (ATO) algorithm that utilizes user speed and received signal reference power to adapt HO margin and time to trigger. The proposed algorithm aims to reduce the number of frequent HOs and HO failure (HOF) ratio. The performance of the proposed algorithm is evaluated through simulation with a two-tier model that consists of 4G and 5G networks. Simulation results show that the average rates of ping-pong HOs and HOF are significantly reduced by the proposed algorithm compared with other algorithms from the literature. In addition, the ATO algorithm achieves a low call drop rate and reduces HO delay and interruption time during user mobility in HetNets.

INDEX TERMS Ultra-dense, heterogeneous networks, handover, self-optimization.

I. INTRODUCTION

Next generation of cellular network technologies is expected to improve wireless services, such as data rates, latency, quality, and mobility. In recent years, heterogeneous networks (HetNets) with different deployment scenarios have played a key role in increasing network performance in terms of system capacity and network coverage. However, HetNets become complex due to the deployment of a massive small cells within macro cells. The deployment of a huge number of small cells in 5G networks is expected to boost total system performance by enhancing coverage and improving user experience [1], [2]. From a technical perspective, however, such deployment introduces new challenges that should be addressed in the next 5G network. Non-stand-alone (NSA) and stand-alone (SA) are two stages of deployment in the next-generation 5G network [4]. Thus, NSA is considered for the initial stage of 5G technology, where ultra-dense small cells are routed to 4G macro cells. The major rising issue in 4G/5G HetNet deployment is addressing user mobility, which produces a high rate of handover (HO) probability (HOP), HO ping-pong (HOPP), and radio link failure (RLF) [3], [6]. Thus, system performance is degraded due to the high frequency of call drop rate (CDR) and long interruption time (IT). Accordingly, this issue must be solved to guarantee that next-generation networks will provide seamless communication during user movement among different deployment scenarios. Many survey studies have investigated mobility management issues and HO optimization [7]. These studies have identified the reasons that can lead to HO failure (HOF) and the limitations of available HOF solutions. Mobility robustness optimization (MRO) has been initially introduced in Long-Term Evolution Advanced (LTE-A) as part of a self-organizing network (SON). It adjusts HO control

The associate editor coordinating the review of this manuscript and approving it for publication was Miguel López-Benítez.

parameters (HCPs), namely, HO margin (HOM) and time to trigger (TTT), to maintain communication links during user movement with minimal operator intervention [8].

Conditional HO has been recently introduced in several technical documents, such as [9]–[11]. It focuses on the threshold of measurement reports without periodically adjusting HCPs in accordance with user experience. Several studies, such as [3], [12]–[14] have proposed various MRO algorithms to reduce HOF by improving HO performance in HetNets. Although these algorithms slightly improve HO performance, interesting and relevant HO problems still need to be addressed, particularly when these algorithms are implemented for small cells.

The major contribution of this paper is to optimize HCPs in MRO to minimize the HOF rate and maintain connection links between serving evolved node B (eNB) and mobile user equipment (UE). To achieve this objective, HCPs are adjusted contentiously after each measurement report, reducing HOPP, HO delay, IT, and CDR. An auto-tuning optimization (ATO) algorithm is proposed to perform as a controller that adapts HCPs (HOM and TTT) on the basis of the reference signal received power (RSRP) and UE speed. The ATO algorithm is evaluated with numerous macro eNBs (MeNBs) and small eNBs (SeNBs) based on 3GPP TS36.839 [15]. The performance of the proposed algorithm is analyzed and compared with those of other algorithms. Simulation results show that the proposed algorithm outperforms the other algorithms in all performance metrics with different speed scenarios.

The remainder of this paper is organized as follows. Section II presents existing studies on HetNets. Section III discusses the challenges of mobility optimization in HetNets. System model, proposed solution, and HO performance metrics are provided in Section IV. Simulation and performance evaluation are presented in Section V. Finally, the paper is concluded in Section VI.

II. RELATED WORKS

Many studies have focused on HO optimization, and they have introduced algorithms and schemes to improve network performance. The work in [13] optimized HCPs on the basis of enhanced mobility state estimation, which considers two parameters, namely, UE velocity and HO types, to select the optimal TTT value. Meanwhile, the authors in [12] introduced an adaptive algorithm that selects different values of HOM and load balancing for each UE in the HetNet. HO decision in the proposed algorithm utilizes the signal-to-interference-plus-noise ratio (SINR) instead of the received signal strength indicator to calculate the actual level of HOM. In other studies, such as [16], the authors used the reinforcement learning concept to detect HO in a network. Effective session HOs lead to low CDR and also reduce HOF and HOPP. However, this technique only supports UE mobility speed of up to 120 km/h.

The authors in [17] proposed an algorithm that mitigates frequent HO for ultra-dense HetNets. This algorithm adjusts HCPs on the basis of ping-pong UE, where UE is handed over to the MeNB in high mobility speed. In our previous work [18], we proposed a dynamic HCP (D-HCP) algorithm to investigate and evaluate HO types that cause HOF (too early HO, too late HO, and HO to wrong cell). The D-HCP algorithm adjusts the values of HCPs in accordance to these HO types to decrease the rates of RLF and HOPP. The results showed that the D-HCP algorithm achieved lower RLF and HOPP rates compared with those of HCPs with fixed values. However, the proposed algorithm is insufficiently robust because it only adjusts HCPs on the basis of HO types while disregarding UE speed, which significantly affects system performance.

A fuzzy logic-based scheme that adjusts HOM on the basis of UE speed and radio channel quality was presented in [19]. The scheme aims to reduce the number of HOs and HOF rate during UE movement in dense small cells. The simulation results demonstrated that the scheme reduces HOF rate, particularly ultra-dense small cells, but neglected the effect level of HOPP below 1%. Another approach that aims to minimize the number of unnecessary HOs (UHOs) and reduce signaling overhead in HetNets was demonstrated in [20] wherein a multiple-attribute decision-making approach was proposed. The HO decision in this approach depends on the technique for order of preference by similarity to ideal solution (TOPSIS), which selects the appropriate target eNB. The authors modified the TOPSIS approach on the basis of two methods to adapt it for HO management in HetNets. These methods, which were represented by standard deviation and entropy weighting techniques, were used to score the importance of each HO metric and HO metric weighting, respectively. The simulation results showed that the proposed approach can effectively reduce the number of frequent HOs and RLFs and improve the mean UE's throughput. In another work [21], the authors utilized the analytic hierarchy process-TOPSIS technique to introduce an intelligent scheme for optimal eNB selection. In addition, the Q-learning approach was adopted to optimize HCPs after selecting the optimal eNB. However, the authors focused only on two HO performance metrics, namely, HOPP and HOF, and disregarded other metrics, such as RLF, HOP, and CDR.

III. MOBILITY ROBUSTNESS OPTIMIZATION

In wireless mobile communication, mobility management is essential for providing seamless communication at different mobility levels. Radio resource management is responsible for maintaining radio link connection between UE and eNB within the coverage area by handing over UE from one cell to another. HO is a process of establishing a new radio link connection from the source to the target base station (BS) [22], [23]. Therefore, in non-heterogeneous wireless networks, mobile UE maintains its radio connection when it moves within cells by performing an HO process from the serving eNB to another eNB that provides better signal quality. However, HO not only maintains connection in HetNets but also improves the performance of an entire network and

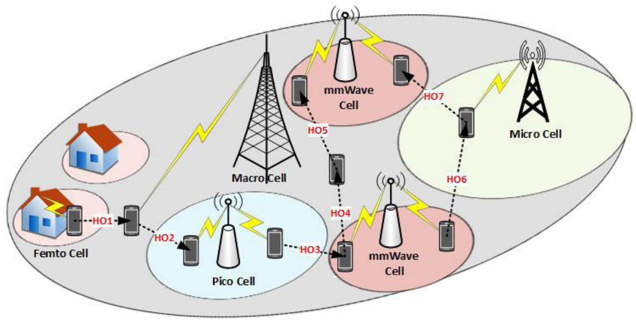

FIGURE 1. HO concept in HetNets.

TABLE 1. Types of HO during UE mobility according to Fig. 1.

HO No.	HO cell type	Type of HO	RAT
HO1	Femto to Macro	Horizontal	No
HO2	Macro to Pico	Horizontal	No
HO3	Pico to mmwave	Vertical	Yes
HO4	mmwave to Macro	Vertical	Yes
HO5	Macro to mmwave	Vertical	Yes
HO6	mmwave to Micro	Vertical	Yes
HO7	Micro to mmwave	Vertical	Yes
HO8	Micro to Macro	Horizontal	No

UE's quality of service (QoS). Fig. 1 illustrates vertical and horizontal HOs, where an active UE handed over from one BS to another passes through several eNBs in HetNets. Multi-radio access technology (RAT) is a convenient technology for HetNets because it requires intelligent techniques to perform seamless communication. Table 1 lists the types of HO in HetNets that can occur during UE mobility based on Fig. 1. Therefore, an efficient HO algorithm can support service continuity and enhance QoS without any service interruption. LTE-A systems introduce several features to enhance system performance, such as improved HO mechanisms that provide short IT. In addition, mobility speeds of approximately 500 km/h are supported by LTE-A communication systems [24].

The HO algorithm can be divided into three categories: RSRP-based, RSRP with threshold, and HOM- and TTT-based. In the RSRP-based algorithm, the HO decision algorithm is considered only on the basis of the received signal strength (RSS), and it launches the HO process as soon as the serving RSS degrades less than the target RSS. Meanwhile, in RSRP with threshold, the HO decision algorithm depends on the RSS pulse as a predefined threshold level. Two conditions, namely, the serving RSS should be less than a predefined threshold and the target RSS should be stronger than the serving RSS, must be satisfied before HO decision is made. By contrast, HO decision in the HOM- and TTT- or HCP-based algorithm initiates once the target RSS is greater than the serving RSS plus the HOM for a specific time interval of TTT. HOM and TTT can be fixed or dynamic values, and their units are dB and ms, respectively. These values are highly sensitive for making a robust HO decision, which in turn, contributes to enhancing overall system performance. Apparently, the HCP-based algorithm is the most practical and efficient technique used for making a HO decision during user mobility [25], [26]. Moreover, a hybrid technique (i.e., the combination of two or more techniques) contributes to reducing the establishment of RLF and UHO (i.e., prevent the ping-pong effect). In general, the HO decision algorithm that is selected on the basis of RSS with HOM level is used for the conventional HO decision algorithm in LTE/LTE-A systems [27], [28]. This HO decision in conventional algorithm, which depends on RSRP, is presented mathematically as follows:

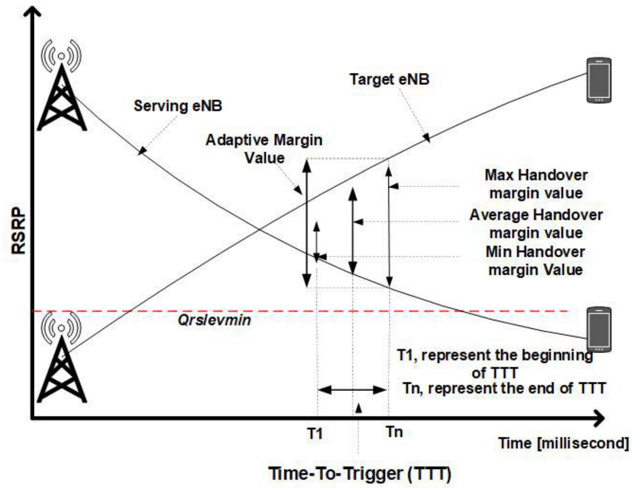

FIGURE 2. HO decision in LTE-A.

$$RSRP_{Target} > RSRP_{Serving} + \Delta_{HOM}$$

where $RSRP_{Serving}$ and $RSRP_{Target}$ denotes the RSRP of serving eNB and target eNB, respectively. The purpose of Δ_{HOM} is to reduce the HOF and HOPP when the UEs are continuously handed over between two eNBs during UEs mobility in HetNet.

To make a HO decision, the serving RSRP should be continuously less than the target RSRP plus the HOM level during a TTT interval . Fig. 2 shows the effectiveness of varying values of HOM level and TTT interval on HO decision. These values can be adaptively adjusted or fixed. The latter means that the HCP values are fixed for the entire transmission interval. Meanwhile, the former indicates that the HCPs values are automatically adjusted depending on several network factors.

IV. SYSTEM MODEL AND PROBLEM FORMULATION

A. NETWORK MODEL

We consider a two-tier HetNet that comprises LTE-A and 5G networks. The LTE-A network consists of a set number of MeNBs N_m, and the 5G network consists of a set number of SeNB N_s. Fig. 3 presents an example of one macro

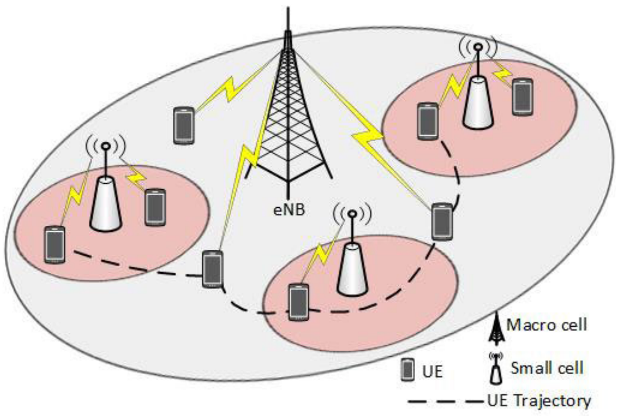

FIGURE 3. System model in HetNets.

cell with small cells in the network deployment scenario. The macro LTE-A cells operate at a frequency band below 5 GHz, and the small 5G cells operate at mm-wave bands. The reuse frequency factor in both networks is assumed to be one. The number of users is generated randomly in every macro and small cell, and it moves across the considered geographical area during time t. We define a user as u, where $u \in 1, 2, ..., |U|$. Meanwhile, U represents all set of UEs. Every user $u \in U$ moves in a random direction $\Theta_u \in [0, 2\pi]$, where u travels with an average velocity $V_u \in [v_{min}, v_{max}]$.

UE receives its requested traffic over either SeNB or MeNB cells. The cells use the X2 interface to communicate with one another during the HO process. This process is basically supported by the X2 interface, which can exchange operational reports, parameter configurations, and RLF status. At each SeNB and MeNB, a distributed SON collects HO information to optimize HCPs. HO is executed when UE moves from serving cells to neighboring cells. Serving cells decide to hand over UE to target cells following the measurement reports that UE periodically sends to serving cells.

B. CHANNEL MODEL

The large-scale channel model $PL_{u,k}$ for different frequencies in HetNets in urban area for a link between an eNB,k and an UE $u \in U$, in dB [29], is

$$L(u, k, l) = 20 \log_{10}(\frac{4\pi r_0}{\lambda_l}) + 10\, n \log_{10}(\frac{r_{u,k}}{r_0}) + \chi_l, \quad (1)$$

$$eNB = \begin{cases} SeNB, & if \quad l = 1 \\ MeNB, & otherwise, \end{cases} \quad (2)$$

where r_0 and $r_{u,k}$ denote the reference distance and distance between the UE u and eNB k, respectively, where $r_{u,k} \geq r_0$. n represents the path loss exponent, λ_l is the wavelength at carrier frequency ($f_{c,l=1} = 28GHz$ and $f_{c,l=2} = 2.1GHz$),and χ is a Gaussian random variable with zero mean and variance σ^2.

The calculation of path loss depends on the type of serving eNB. A variable l = 1 if UE u is set to associate with SeNB k; otherwise, UE u associates with MeNB m. Maximum QoS requirements are used to limit interference by reducing RLF. Notably, the performance of each UE should meet its minimum data rate requirement for QoS satisfaction. For channel modeling, the SINR experienced by u is modeled as [30]:

$$\Gamma_{u,k,l} = \frac{p_{u,k,l} g_{u,k,l} b_{ij}}{\sum_{i \in K \setminus \{k\}} \sum_{j \in U \setminus \{u\}} p_{ij} g_{u,k,l} + P_{AWGN}}, \quad (3)$$

where $p_{u,k,l}$ is the received signal power at u, $g_{u,k,l}$ is the channel gain experienced by UE u at k, b_{ij} is the binary association indicator of user u in which $b_{ij} = 1$ indicates user $u$associates with one eNB; otherwise $b_{ij} = 0$. p_{ij} represents the interference received signal power by UE u at k, and P_{AWGN} is the additive white Gaussian noise (AWGN) power.

C. PROBLEM FORMULATION

Adjusting HCPs is a crucial process during UE mobility. An inappropriate configuration of HCPs causes HOF that leads to service interruption. Setting HCPs to high values can cause too-late or wrong cell HO (i.e., high mobility), which results from a delay in HO decision. In such case, the HOF rate can be decreased. However, as the HOF rate decreases, the HOPP rate increases. By contrast, too-small values can cause too-early or wrong cell HO (i.e., low mobility), which decreases HOPP but increases the HOF rate [11]. Therefore, an adaptive technique is required to adjust HCPs in accordance with UE status during mobility. In this work, the adjustment values of HCPs depend on UE speed and RSRP. For example, when UE is moving at a very high speed, several SeNBs and MeNBs are crossed. This condition necessitates a relatively low TTT value to prevent late HO. By contrast, low-speed UE undergoes improved signal quality over short distances, necessitating a relatively high TTT value to prevent early HO. Therefore, this study aims to address this mobility issue and minimize the probability rate of HO performance metrics, such as HOPP, RLF, and HOF, which can occur during the HO process. The minimization of the HO problem can be formulated as follows:

$$\underset{\mathcal{T},\mathcal{M}}{\text{argmin}} \quad P(\mathcal{T}, \mathcal{M}) \quad (4a)$$

$$Subject \quad to: \quad \sum_{j=1}^{N} b_{ij} = 1, \forall_j \quad (4b)$$

$$\zeta \leq \zeta_{th} \quad (4c)$$

$$TTT_{\min} \leq \mathcal{T} \leq TTT_{\max} \quad (4d)$$

$$HOM_{\min} \leq \mathcal{M} \leq HOM_{\max} \quad (4e)$$

$$b_{ij} \in 0, 1, \forall_{ij} \quad (4f)$$

where P refers to the probability of HOPP, RLF and HOF which control by a proper selection of TTT $\mathcal{T}$ and HOM $\mathcal{M}$. Constraint (4b) ensures that each UE u is associated with one eNB k; (4c) guarantees that the HOF rate of each u is less than the threshold ζ_{th}; (4d) and (4e) ensure that the selected $\mathcal{T}$ and $\mathcal{M}$ are not out of range and (4f) is the binary constraint on the user association indicators.

UE periodically measures the RSRPs of all serving eNBs and reports the measurements, indicating whether HO is triggered if certain conditions are met or to continue link connection with the serving eNB. In this work, we consider all the events in [31] that trigger HO on the basis of measurement reports using a realistic environment.

D. PROPOSED SOLUTION

We propose a novel distributed ATO algorithm that automatically tunes HCPs on the basis of user speed and RSRP. An entity of distributed SON is equipped at each eNB to collect related data and periodically optimize HCPs for each UE in accordance with its condition. Algorithm 1 summarizes the process for updating the $\mathcal{T}$ and $\mathcal{M}$ according to following conditions:

Condition 1: $\delta_S > \delta_T + \theta_{th}$

$$\begin{cases} \hat{\mathcal{M}}_{u,t} = \mathcal{M}_{u,t-1} + \beta, \; \hat{\mathcal{T}}_{u,t} = \mathcal{T}_{u,t-1} + \alpha & \text{if } V_{u,t} < V_r \\ \hat{\mathcal{M}}_{u,t} = \mathcal{M}_{u,t-1} + \beta, \; \hat{\mathcal{T}}_{u,t} = \mathcal{T}_{u,t-1} + \alpha & \text{if } V_{u,t} = V_r \\ \hat{\mathcal{M}}_{u,t} = \mathcal{M}_{u,t-1} - \beta, \; \hat{\mathcal{T}}_{u,t} = \mathcal{T}_{u,t-1} - \alpha & \text{if } V_{u,t} > V_r \end{cases} \tag{5}$$

Condition 2: $\delta_S < \delta_T + \theta_{th}$

$$\begin{cases} \hat{\mathcal{M}}_{u,t} = \mathcal{M}_{u,t-1} - \beta, \; \hat{\mathcal{T}}_{u,t} = \mathcal{T}_{t-1} - \alpha & \text{if } V_{u,t} < V_r \\ \hat{\mathcal{M}}_{u,t} = \mathcal{M}_{u,t-1} - \beta, \; \hat{\mathcal{T}}_{u,t} = \mathcal{T}_{u,t-1} - \alpha & \text{if } V_{u,t} = V_r \\ \hat{\mathcal{M}}_{u,t} = \mathcal{M}_{u,t-1} - \beta, \; \hat{\mathcal{T}}_{u,t} = \mathcal{T}_{u,t-1} - \alpha & \text{if } V_{u,t} > V_r \end{cases} \tag{6}$$

Condition 3: $\delta_S = \delta_T + \theta_{th}$

$$\begin{cases} \hat{\mathcal{M}}_{u,t} = \mathcal{M}_{u,t-1} + \beta, \; \hat{\mathcal{T}}_{u,t} = \mathcal{T}_{u,t-1} + \alpha & \text{if } V_{u,t} < V_r \\ \hat{\mathcal{M}}_{u,t} = \mathcal{M}_{u,t-1}, \qquad \hat{\mathcal{T}}_{u,t} = \mathcal{T}_{u,t-1} & \text{if } V_{u,t} = V_r \\ \hat{\mathcal{M}}_{u,t} = \mathcal{M}_{u,t-1} - \beta, \; \hat{\mathcal{T}}_{u,t} = \mathcal{T}_{u,t-1} - \alpha & \text{if } V_{u,t} > V_r \end{cases} \tag{7}$$

where δ_s and δ_T are the severing and target RSRP, respectively. θ_{th} denotes the threshold level which is assumed to be *2dB*. $V_{u,t}$ and V_r denote the UE speed level at time t and reference speed that is assumed to be at medium range ($V_r = 70 - 90$ km/h), respectively. $\hat{\mathcal{M}}_t$ and $\hat{\mathcal{T}}_t$ are the adaptive *HOM* and *TTT*, respectively. α and β depicts the step levels to set both the *TTT* and *HOM*, which are approximately 50 ms and 1 dB, respectively. These steps are implemented when HO condition is encountered. The values of the HOM level and TTT interval are standardized as an enumerated parameter [31].

Subsequently, $\hat{\mathcal{M}}_t$ and $\hat{\mathcal{T}}_t$ are periodically updated for each active mobile UE in cells to avoid RLF and HOF threshold ζ_{th} =1% is monitored [32]. This algorithm is based on meta-heuristic algorithms, wherein the solution is not the best solution (global optimal). However, it improves the quality of solution to find the suboptimal solution with low computational complexity [33].

The proposed algorithm adjusts HCPs for each UE in accordance with these conditions in each simulation time.

Algorithm 1 Proposed ATO Algorithm

```
Initialize systems' parameters
Inputs: δ_S, δ_T, V_{u,t}
Outputs: M̂_t, T̂_t
if Simulation time t=1 then
    HODecision ⟵ false
else
    Calculate the HOF according to (15)
    while HOF ζ > ζ_th do
        if δ_S > δ_T + θ_th then
            Updating M̂ and T̂ according to (5)
            HODecision ⟵ True
            Updating M̂ and T̂
        else if δ_S < δ_T + θ_th then
            Updating M̂ and T̂ according to (6)
            HODecision ⟵ True
            Updating M̂ and T̂
        else
            Updating M̂ and T̂ according to (7)
            HODecision ⟵ false
            Updating M̂ and T̂
        end if
    end while
    Update HOF
end if
```

Each distributed UE has a different condition, such as SINR and speed. Assigning the same HCP values to all distributed UE will result in inferior network performance. Thus, in our proposed algorithm, the eNB assigns different values of HCPs to each UE depending on its current status conditions during mobility. The reestablishment procedure of radio resource control (RRC) is a process initiated to recover radio link connection once UE loses connection. Thus, UE attempts to find a suitable target eNB and then performs RRC reestablishment toward this target eNB. The reestablishment process shall select a suitable target cell and recover connection within the maximum allowed time for connection recovery, denoted as T310 (maximum interval to perform connection reestablishment procedure) [31].

The proposed algorithm continues monitoring the HOF rate in each simulation time and adjusts HCPs when $\zeta > \zeta_{th}$. Each UE sends a measurement report to the serving eNB every 50 ms to monitor the RSRP level. Then, the serving RSRP is compared with the target RSRP plus the threshold, and one of the three conditions (Equations 5-7) is applied. Once a condition is applied, HCPs adjust with respect to each UE speed by increasing or decreasing the current $\mathcal{T}$ and $\mathcal{M}$. For example, when UE moves at high speed, the current $\mathcal{T}$ and $\mathcal{M}$ decease by one step (α and β) to avoid late HO, which causes RLF. By contrast, the current $\mathcal{T}$ and $\mathcal{M}$ increase by one step (α and β) when UE moves at low speed to avoid early HO, which causes HOPP.

E. HANDOVER PERFORMANCE METRICS

Several performance metrics or key performance indicators (KPIs) are frequently defined in wireless networks to characterize QoS. Therefore, the proposed algorithm is investigated using these metrics compared with previous algorithms. Four main KPIs are used for the investigation:

The first KPI is HOP. It measures how HO frequently happens between serving and target eNBs. It is also the probability of interchanging links between serving and target eNBs. HOP is obtained as follows:

$$HOP_{u,t}(\delta_T, \delta_S) = P_r[\delta_T - \delta_S \geq \hat{\mathcal{M}}] \tag{8}$$

The average of HOP in each simulation time over all UEs in the network can be given by the following equation:

$$\overline{HOP} = \frac{\sum_{j=1}^{N_u} HOP}{N_u} \quad \forall\ j^{th} U, \tag{9}$$

where N_u is the total number of users in the entire simulation.

The second KPI is HOPP. It is an important indicator that determines UHOs between two neighbor cells. It counts when UE disconnects its communication links from the serving eNB, establishes a new connection with the target eNB, and then bounces back to the serving eNB within a period that is shorter than the critical ping-pong interval T_c, which is assumed to be 2 s. T_c is defined as a short period required to calculate UHO between neighboring eNB cells. HOPP should be considered if the following conditions are satisfied.

$$P(HOPP) = P_r[T_i \leq T_c], \tag{10}$$

$$T_i = T_L - T_{hb}, \tag{11}$$

where T_i depicts the time taken by the UE to connects back to the serving eNB. T_L denotes the time taken to establish the HO from the serving eNB, and T_{hb} defines the time needed to reconnect to the same eNB. It is useful to mention that the HO is taken as HOPP for each UE in the network, T_i is less than $T_c(T_i < T_c)$ when the user is connected back to serving eNB. The following equation obtains the average HOPP probability in every simulation time.

$$\overline{P(HOPP)} = \frac{N_{HOPP}}{N_{RHO}}, \tag{12}$$

$$N_{RHO} = N_S + N_F, \tag{13}$$

where N_{HOPP} represents the number of occurring HOPP overall simulation time. N_{RHO} is the total number of requested HOs, N_F and N_S are failed and successful HO, respectively.

The third KPI is RLF which occurs when UE disconnects from an eNB and fails to maintain the communication link. However, the primary source of RLF includes HOF cases or disconnections in the communication link. That is, N_{UE}, as the average RLF of all UE, can be obtained as follows:

$$\overline{P(RLF)} = \frac{\sum_{j=1}^{N_u} P(RLF)}{N_u} \quad \forall\ j^{th} U \tag{14}$$

The forth KPI is HOF which typically occurs after the HO request is sent to the target eNB. Two different cases may cause HOF during HO. The first case is the lack of available target resources. It occurs when HO is initiated, but its establishment remains incomplete due to insufficient resources available for the target eNB. In the second case, HOF occurs due to UE moving out of the coverage area of the target eNB before completely establishing HO. The total ratio of HOF is calculated as a total ratio of HOF divided by the submission of the total number of HOF and successful HO, which can be expressed as follows:

$$HOF = \frac{N_F}{N_S + N_F} \tag{15}$$

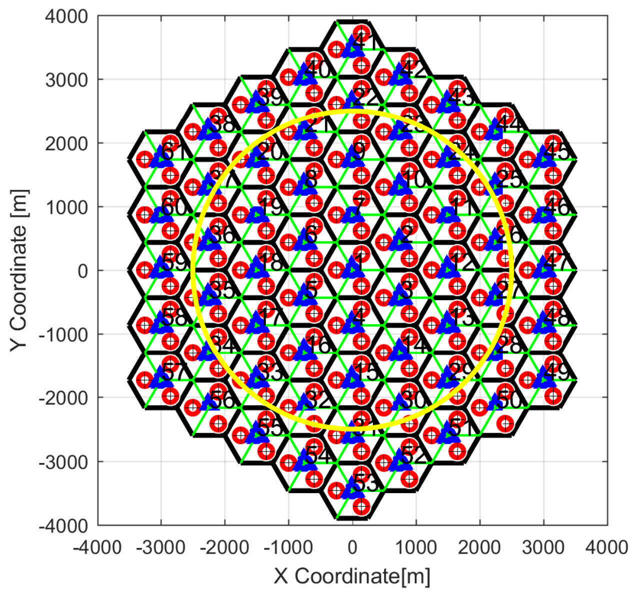

FIGURE 4. Simulation environment.

V. SIMULATION AND PERFORMANCE EVALUATION

A. SIMULATION ENVIRONMENT

This research is an extension of our previous work [18]. We consider a HetNet that consists of 61 MeNBs and 183 SeNBs with an area of 8x8 km^2. Each MeNB is composed of 3 SeNBs that are located at the middle of each MeNB cell's sector. Fig. 4 illustrates the simulation environment for HetNet, where the simulation area is within the bouncing circle (yellow circle). We consider a deployment scenario in which MeNBs and SeNBs operate at different carrier frequencies to avoid interference between them. The network model enables RATs, which allow UE to connect to one BS (MeNB/SeNB) at the medium access control (MAC) layer. Thus, UE receives its traffic demand over either 4G or 5G bands. A random direction mobility model [0^o 360^o] in which UEs are randomly distributed over the area at a time frame T, is considered for this network, wherein only one speed scenario is considered at each time frame T. In addition, we do not consider restrictive assumptions about any obstacles, such as buildings, trees, and mountains . Thus, all the UEs are moving equally in different directions in each

TABLE 2. Simulation parameters [1]–[3], [29].

Parameter	Value	
	MeNB	SeNB
Carrier frequency (GHz)	2.1	28
System bandwidth (MHz)	20	500
Number of eNB	61	183
Cell radius (m)	500	200
Number of UEs/eNB	100	200
Transmit power (dBm)	46	30
Shadowing standard deviation (dB)	6	7.8
Correlation distance of shadowing (m)	25	
T310 (s)	1	
Simulation time (s)	1000	
UE speed (km/h)	40, 80, 120, 160	
HO preparation time (ms)	50	
HO execution time (ms)	40	
Noise figure (dB)	9	
Thermal noise density (dBm/Hz)	-174	

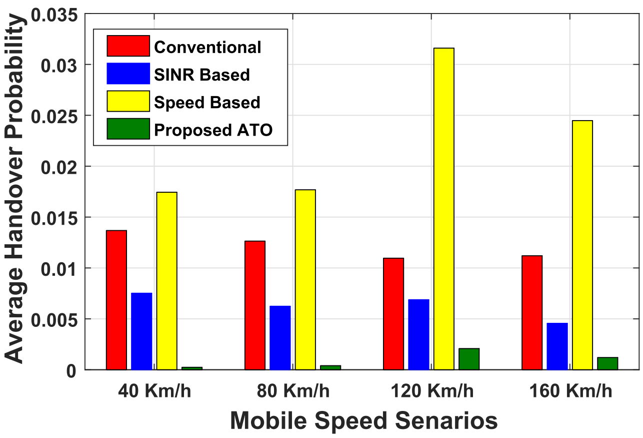

FIGURE 5. Average HOP versus mobile speed scenarios.

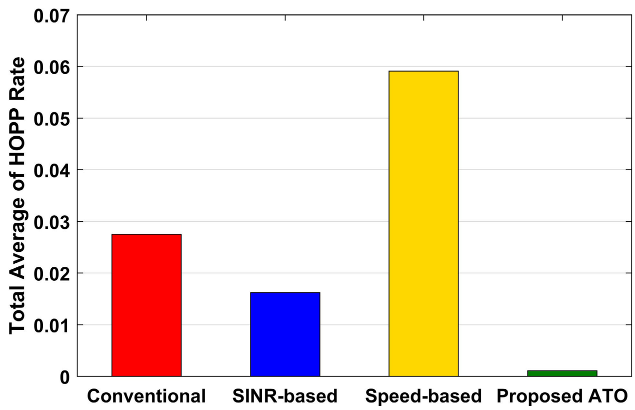

FIGURE 6. Average probability of HOPP versus different optimization algorithms.

time frame. Other simulation parameters are summarized in Table 2.

To evaluate and validate the proposed ATO algorithm, simulations are performed using MATLAB. We consider four different UE speeds that represent low, medium, and high speeds: 40, 80, 120, and 160 km/h. These speeds represent the typical speeds of vehicles in urban and suburban areas and are assumed for theoretical investigation.

B. PERFORMANCE EVALUATION

To analyze the performance of the proposed ATO algorithm, simulations are performed by considering different UE speeds. The proposed algorithm is then compared with different optimization algorithms: conventional, speed-based [12] and SINR-based [13] algorithms. We evaluate the overall simulation time of the proposed ATO algorithm using six KPIs: HOP, HOPP, RLF, CDR, HO delay, and IT.

Fig. 5 shows an average HOP versus different UE speeds scenarios, wherein the performance of the ATO algorithm is compared with those of conventional, SINR-based, and speed-based algorithms. The simulation results show that the ATO algorithm reduces the average HOP for all speed scenarios compared with the other algorithms. The overall average HOP achieved by the ATO algorithm is approximately 82%, 73%, and 92% lower than those achieved by the conventional, SINR-based, and speed-based algorithms, respectively, for all mobile speed scenarios.

Fig. 6 depicts the average rate of HOPP versus different optimization algorithms for all mobile speed scenarios and the entire simulation time. The HOPP rate obtained by the proposed algorithm is relatively lower than those obtained by the other algorithms for all mobile speed scenarios. This result can be justified by stating that the inappropriate optimization of HCPs by MRO algorithms, i.e., conventional, speed-based, and SINR-based algorithms, increases HOPP or UHO. Moreover, a high HOP may lead to a high HOPP and HOF, whereas a significant reduction in HOP will reduce the HOPP rate.

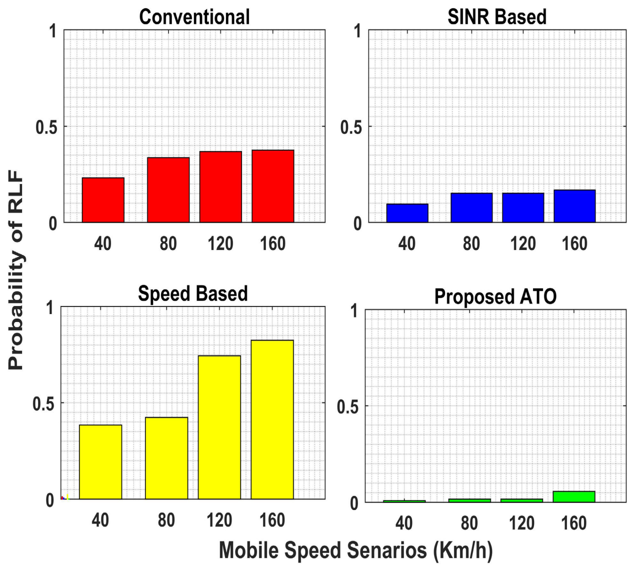

FIGURE 7. Radio link failure probability with varying speeds.

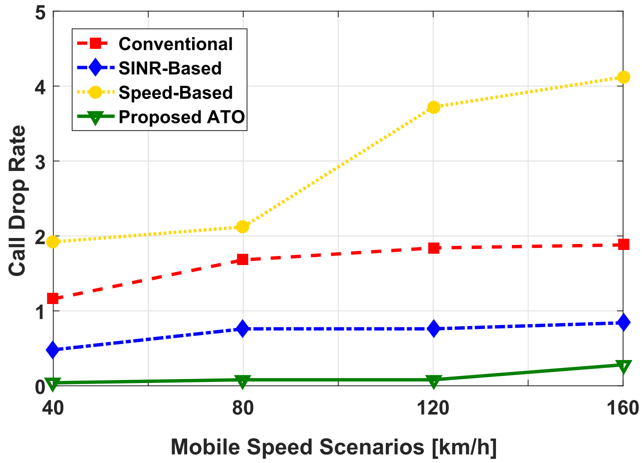

FIGURE 8. Call-dropped rate.

Fig. 7 illustrates the average rate of RLF probability versus different optimization algorithms for varying mobile speed scenarios. The average rate of RLF probability is calculated for each mobile speed scenario over all monitored mobile users and the entire simulation time. The RLF rate obtained by the ATO algorithm is significantly reduced compared with those obtained by the other algorithms. The use of inappropriately adjusted UE speed to optimize HCPs (i.e., speed-based algorithm) may lead to high RLF rates. Therefore, HCPs should be periodically adapted on the basis of each UE's experience independently. Furthermore, the Doppler effect accompanied by poor connections increases the RLF rate in accordance with UE speed. Nevertheless, the proposed ATO algorithm achieves approximately 93%, 65%, and 87% average RLF rates compared with the conventional, speed-based, and SINR-based algorithms, respectively.

An important metric for evaluating system performance is the CDR of UE. Hence, we specifically examine the average dropped call ratio over the entire simulation time. Fig. 8 shows CDR with varying UE speeds. The ATO algorithm obtains remarkable reduction in CDR compared with the other algorithms for all mobile speeds. Increasing the number of HOs due to UE being handed over to ultra-dense SeNBs increases the potential source of CDR. Furthermore, a high failure rate occurs for outbound mobility crossing small cells in high-speed scenarios. However, dropped calls directly affect the QoS of a network, whereas other HO types indirectly affect QoS. Thus, decreasing HOF and RLF should be highly prioritized in MRO.

Fig. 9 illustrates the evaluation of the HOPP effect with different UE speeds for a selected time. The proposed algorithm obtains lower HOPP rates than the other algorithms due to the appropriate setting of HCPs and connection to the best target eNB. However, the other algorithms also obtain low HOPP rates during a specific period, particularly in high-speed scenarios. A high HOPP rate causes considerable resource block waste due to the back-and-forth switching of UE data. The HOPP effect of the conventional and speed-based algorithms at a speed of 40 km/h is high compared with in the other speed scenarios. Received signals fluctuate more at a low speed, and thus, HOPP rate is high. However, at medium and high speeds, UE connection with the target eNB is fast, leading to a low HOPP rate. The proposed algorithm achieves remarkable reduction in HOPP rate in all the mobile speed scenarios compared with the other algorithms. It monitors UE speed and RSRP during UE mobility and then set appropriate HOM and TTT values to satisfy all the requirements for performing a successful HO process. Therefore, the ATO algorithm reduces HOPP rate by approximately 96%, 93.21%, and 98.14% compared with the conventional, SINR-based, and speed-based algorithms, respectively.

HO delay and IT are also important factors in network performance. Figs. 10 and 11 show the HO delay and IT in different mobile speed scenarios, respectively. A long HO delay will increase HOP and HOPP rates (Figs. 5 and 7) because the transmission of several packets is disabled during vertical HO in HetNets. Thus, the network experiences additional time delay due to the IT included in the process. Therefore, ATO achieves low HOPP and HOP because of the efficient HCP values in accordance with UE speed. Accordingly, HO delay is significantly reduced. Moreover, the ATO algorithm reduces IT by 90% more compared with the other algorithms.

Fig. 12 depicts the total average rate of HOF versus the other optimization algorithms over the entire simulation time. The speed-based algorithm obtains a higher HOF rate than the other algorithms due to same issue mentioned in Fig. 7, wherein RLF and HOF are related to each other. HOF can occur immediately after a successful HO, resulting in failure link connection between UE and the target eNB, and eventually, call drops. However, the proposed algorithm achieves lower HOF rate than the conventional, SINR-based, and speed-based algorithms by approximately 95.9%, 83.1%, and 92.5%, respectively.

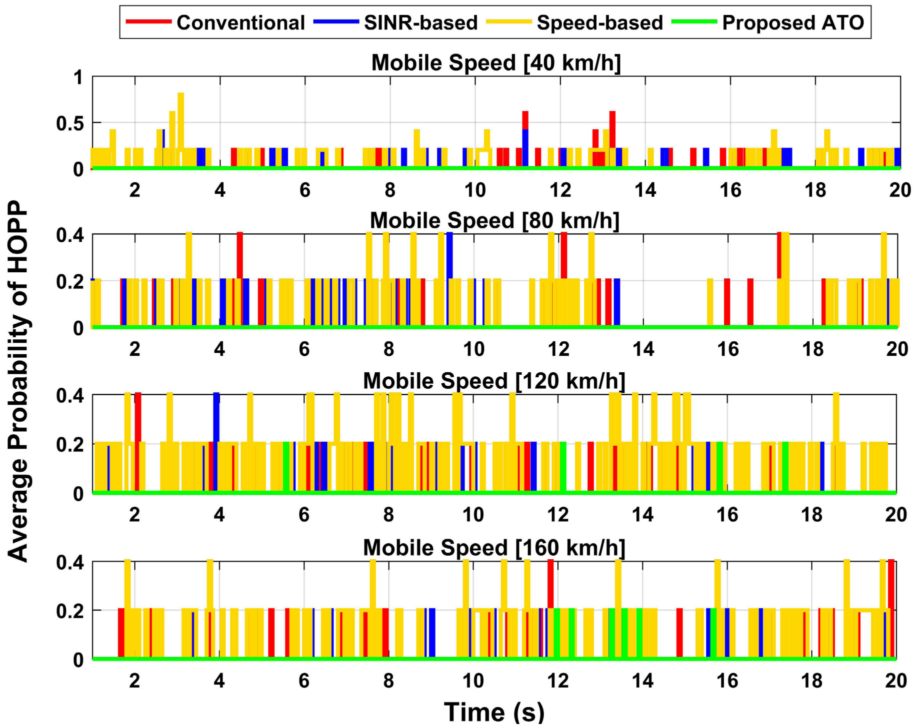

FIGURE 9. Average HOPP probability varying with mobile speeds.

TABLE 3. The overall of performance metrics with different MRO algorithms.

MRO algorithms	HO performance metrics					
	HOPP	RLF	CDR	HOF	Delay(ms)	IT(ms)
Conventional	0.028	0.328	1.640	6.836	6.836	2.210
SINR Based	0.016	0.142	0.710	3.690	3.690	1.220
Speed Based	0.059	0.594	2.970	12.897	12.900	4.215
Proposed ATO	**0.001**	**0.024**	**0.120**	**0.561**	**0.651**	**0.185**

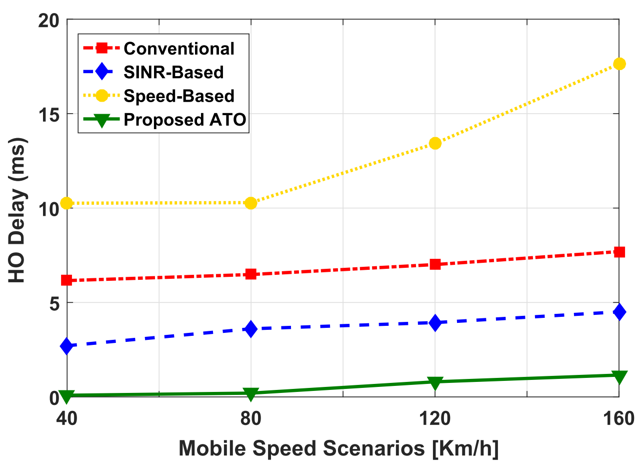

FIGURE 10. HO delay versus mobile speed.

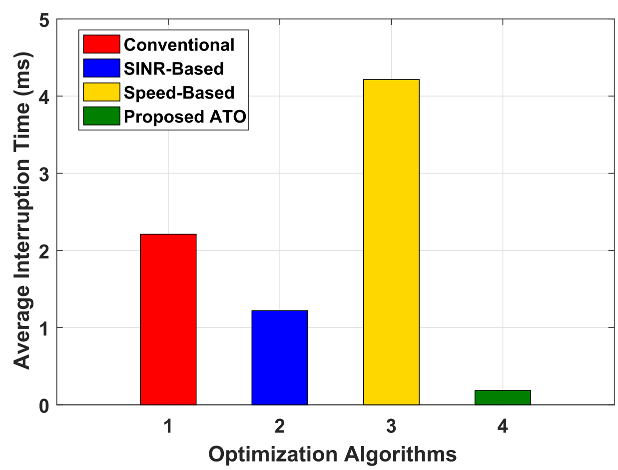

FIGURE 11. Average IT versus optimization algorithms.

The overall performance metrics of the proposed and other benchmark algorithms is provided in Table 3. As expected from the previous results, the conventional and speed-based algorithms exhibit the worst performance for all the performance metrics due to their inefficient manner of handling the HO decision. The SINR based algorithm performs slightly

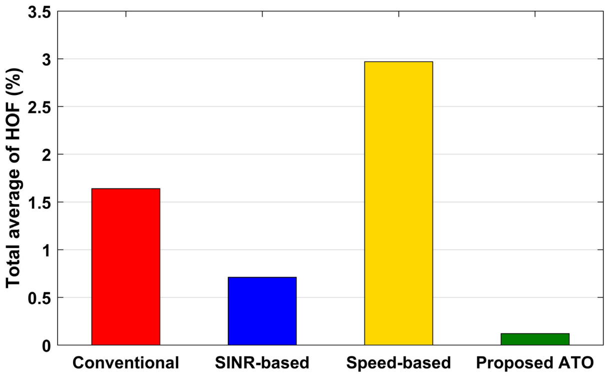

FIGURE 12. Total average of HOF over entire simulation.

better because it considers the distributed SON algorithm. However, it does not fully address the HO issue because it must still consider UE speed to further improve network performance. The proposed algorithm demonstrates the best performance and outperforms all the other algorithms because it controls HO on the basis of SINR and speed, reducing the major KPIs, namely, HOPP and RLF. Moreover, reducing HOPP and RLF leads to the remarkable performance of other KPIs, such as CDR, HOF, HO delay, and IT.

VI. CONCLUSION

In this paper, we propose a HO self-optimization algorithm for HetNets to improve network performance. The proposed ATO algorithm periodically adjusts the values of HCPs on the basis of UE speed and RSRP. It is investigated and evaluated through a two-tier model simulation consisting of 4G and 5G networks. The simulation results show that the ATO algorithm improves overall system performance and outperforms all the other compared algorithms. In addition, our algorithm reduces the total rate of all the performance metrics by more than 80% compared with the other state-of-the-art algorithms. Therefore, adjusting HCPs in accordance with UE conditions is an efficient and effective technique for mobility management. In future work, the proposed algorithm can be extended to include additional parameters, such as SINR, UE mobile speed and cell traffic load, which affect the network performance during the HO process. Investigating these additional parameters might further enhance the HO performance.

REFERENCES

[1] T. Bilen, B. Canberk, and K. R. Chowdhury, "Handover management in software-defined ultra-dense 5G networks," *IEEE Netw.*, vol. 31, no. 4, pp. 49–55, Jul. 2017.
[2] M. Polese, M. Giordani, M. Mezzavilla, S. Rangan, and M. Zorzi, "Improved handover through dual connectivity in 5G mmWave mobile networks," *IEEE J. Sel. Areas Commun.*, vol. 35, no. 9, pp. 2069–2084, Sep. 2017.
[3] D. Castro-Hernandez and R. Paranjape, "Optimization of handover parameters for LTE/LTE-A in-building systems," *IEEE Trans. Veh. Technol.*, vol. 67, no. 6, pp. 5260–5273, Jun. 2018.
[4] *Technical Specification Group Services and System Aspects; Release 15 Description*, document 3GPP TR 21.915, 3GPP, 2019.
[5] *NR; User Equipment (UE) Radio Transmission and Reception; Part 1: Range 1 Standalone*, document 3GPP TR 38.101, 3GPP, 2018.
[6] H. Zhang, W. Huang, and Y. Liu, "Handover probability analysis of anchor-based multi-connectivity in 5G user-centric network," *IEEE Wireless Commun. Lett.*, vol. 8, no. 2, pp. 396–399, Oct. 2018.
[7] A. A. Ahmed and A. A. Alzahrani, "A comprehensive survey on handover management for vehicular ad hoc network based on 5G mobile networks technology," *Trans. Emerg. Telecommun. Technol.*, vol. 30, no. 3, p. e3546, 2019.
[8] F. B. Tesema, A. Awada, I. Viering, M. Simsek, and G. Fettweis, "Evaluation of context-aware mobility robustness optimization and multi-connectivity in intra-frequency 5G ultra dense networks," *IEEE Wireless Commun. Lett.*, vol. 5, no. 6, pp. 608–611, Dec. 2016.
[9] *Conditional Handover*, document 3GPP TSG-RAN WG2 Meeting #97bis, Tdoc R2-1704087, Ericsson, Qualcomm, Hangzhou, China, May 2017.
[10] *Performance Evaluation of Conditional Handover*, document 3GPP TSG RAN WG2 Meeting #103bis, Tdoc R2-1814052, Chengdu, China, Intel Corporation, Oct. 2018.
[11] *Baseline Handover: Basic HO vs. Conditional HO*, document 3GPP TSG-RAN WG2 Meeting #102, Tdoc R2-1807674, ETRI, Busan, South Korea, May 2018.
[12] R. P. Ray and L. Tang, "Hysteresis margin and load balancing for handover in heterogeneous network," *Int. J. Future Comput. Commun.*, vol. 4, no. 4, p. 231, 2016.
[13] S. Nie, D. Wu, M. Zhao, X. Gu, L. Zhang, and L. Lu, "An enhanced mobility state estimation based handover optimization algorithm in LTE-A self-organizing network," *Procedia Comput. Sci.*, vol. 52, pp. 270–277, Jan. 2016.
[14] A. Awada, B. Wegmann, I. Viering, and A. Klein, "A SON-based algorithm for the optimization of inter-RAT handover parameters," *IEEE Trans. Veh. Technol.*, vol. 62, no. 5, pp. 1906–1923, Jun. 2013.
[15] *Universal Mobile Telecommunications System (UMTS), Mobility Enhancements in Heterogeneous Networks*, document 3GPP TR 36.839, 2015.
[16] S. Chaudhuri, I. Baig, and D. Das, "Self organizing method for handover performance optimization in LTE-advanced network," *Comput. Commun.*, vol. 110, pp. 151–163, Sep. 2017.
[17] M. M. Hasan, S. Kwon, and S. Oh, "Frequent-handover mitigation in ultra-dense heterogeneous networks," *IEEE Trans. Veh. Technol.*, vol. 68, no. 1, pp. 1035–1040, Jan. 2019.
[18] A. Alhammadi, M. Roslee, M. Y. Alias, I. Shayea, and S. Alraih, "Dynamic handover control parameters for LTE-A/5G mobile communications," in *Proc. Adv. Wireless Opt. Commun. (RTUWO)*, Riga, Latvia, 2018, pp. 39–44.
[19] K. Da Costa Silva, Z. Becvar, and C. R. L. Frances, "Adaptive hysteresis margin based on fuzzy logic for handover in mobile networks with dense small cells," *IEEE Access*, vol. 6, pp. 17178–17189, 2018.
[20] M. Alhabo and L. Zhang, "Multi-criteria handover using modified weighted TOPSIS methods for heterogeneous networks," *IEEE Access*, vol. 6, pp. 40547–40558, 2018.
[21] T. Goyal and K. Sakshi, "Handover optimization scheme for LTE-advance networks based on AHP-TOPSIS and Q-learning," *Comput. Commun.*, vol. 133, pp. 67–76, 2019.
[22] *UTRAN Functions, Examples on Signalling Procedures Release 16*, document TR.25.931, 3GPP, Valbonne, France, 2019.
[23] *Vocabulary for 3GPP Specifications, Release 16*, document TR.21.905, 3GPP, 2019.
[24] *Modified RRH Arrangement for HST SFN*, document R4-154516, Ericsson, 2017.
[25] S. Barbera, K. I. Pedersen, C. Rosa, P. H. Michaelsen, F. Frederiksen, E. Shah, and A. Baumgartner, "Synchronized RACH-less handover solution for LTE heterogeneous networks," in *Proc. Int. Symp. Wireless Commun. Syst. (ISWCS)*, Brussels, Belgium, 2015, pp. 755–759.
[26] P.-C. Lin, L. F. G. Casanova, and B. K. S. Fatty, "Data-driven handover optimization in next generation mobile communication networks," *Mobile Inf. Syst.*, vol. 2016, p. 11, Jul. 2016.
[27] *Overall Description, Release 15*, document TS 36.300, 3GPP, France, 2019.
[28] *Evolved Universal Terrestrial Radio Access (E-UTRA); Requirements for Support of Radio Resource Management, Release 15*, document TS 36.133, 3GPP, France, 2019.
[29] *5G; Study on Channel Model for Frequencies From 0.5 to 100 GHz*, document 3GPP TR 38.901, 3GPP, 2018.

[30] O. Semiari, W. Saad, M. Bennis, and B. Maham, "Caching meets millimeter wave communications for enhanced mobility management in 5G networks," *IEEE Trans. Wireless Commun.*, vol. 17, no. 2, pp. 779–793, Feb. 2018.
[31] *Universal Mobile Telecommunications System (UMTS), Radio Resource Control (RRC) Protocol Specification*, document TS 36.331, 3GPP, 2019.
[32] M. T. Nguyen, S. Kwon, and H. Kim, "Mobility robustness optimization for handover failure reduction in LTE small-cell networks," *IEEE Trans. Veh. Technol.*, vol. 67, no. 5, pp. 4672–4676, May 2018.
[33] X.-S. Yang, *Engineering Optimization: An Introduction With Metaheuristic Applications*. Hoboken, NJ, USA: Wiley, 2010.

ABDULRAQEB ALHAMMADI (GS'14) received the B.Eng. degree in electronic majoring in telecommunications and the M.S. degree in wireless communication from Multimedia University, Malaysia, in 2011 and 2015, respectively, where he is currently pursuing the Ph.D. degree in wireless communication. He is the author of more than 20 articles in international journals and conferences. His main research interests include heterogeneous networks, mobility management, D2D communication, cognitive radio networks, localization, and propagation modeling. He is a member of professional institutes and societies, such as IEICE, IACSIT, and IAENG. He is also a member of more than ten program committees at international conferences or workshops.

MARDENI ROSLEE (SM'14) is a registered Chartered Engineer with the Engineering Council United Kingdom and a member with the Institution of Engineering and Technology (IET), United Kingdom. As a Chartered Engineer, he brings a diversified range of engineering experience in design and amp; development and engineering management. His experiences include the consultation, professional institution, and academic sectors. His current research interests include wireless mobile communication and radar communication systems. He is a Senior Member of IACSIT.

MOHAMAD YUSOFF ALIAS (SM'10) received the B.Sc. degree in engineering (electrical engineering) from the University of Michigan, Ann Arbor, in May 1998, and the Ph.D. degree from the School of ECS, University of Southampton, U.K., in December 2004. He is currently a Professor with the Faculty of Engineering, Multimedia University, Malaysia. His research interests include wireless communications, especially in OFDM, multiple antenna systems, multiuser detection, genetic algorithms in communications, multimedia applications, and visible light communications.

IBRAHEEM SHAYEA (M'15) received the B.Sc. degree in electronic engineering from the University of Diyala, Baqubah, Iraq, in 2004, and the M.Sc. degree in computer and communication engineering and the Ph.D. degree in mobile communication engineering from the National University of Malaysia, Universiti Kebangsaan Malaysia (UKM), Malaysia, in 2010 and 2015, respectively. From January 2011 to February 2014, he worked as a Research and Teaching Assistant with UKM. Then, from January 2016 to June 2018, he joined the Wireless Communication Center (WCC), University of Technology Malaysia (UTM), Malaysia, and worked there as a Research Fellow. He has been a Researcher Fellow with Istanbul Technical University (ITU), Istanbul, Turkey, since September 2018. His main research interests include wireless communication systems, mobility management, radio propagation, and the Internet of Things (IoT).

SADDAM ALRAIH received the B.Eng. degree in telecommunication engineering from the University of Science and Technology (UST), Yemen, in 2011, and the M.Eng. degree in telecommunication engineering from Multimedia University (MMU), Malaysia, in 2016. He is currently pursuing the Ph.D. degree with the Department of Electrical, Electronic and System Engineering, National University of Malaysia (UKM), Malaysia. His current research interests include mobility management and handover techniques in 5G.

KHALID SHEIKHIDRIS MOHAMED (GS'15) received the B.Eng. and M.Eng. degrees in telecommunication from Future University, Sudan, in 2011, and Multimedia University, Malaysia, in 2014, where he is currently pursuing the Ph.D. degree in telecommunication. His research interests include cellular communication, LTE, 5G, and interference management in heterogeneous networks.