

Received March 25, 2022, accepted April 26, 2022, date of publication May 9, 2022, date of current version June 14, 2022.

Digital Object Identifier 10.1109/ACCESS.2022.3173255

Performance Evaluation of Mobility Robustness Optimization (MRO) in 5G Network With Various Mobility Speed Scenarios

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This work was supported in part by Al-Furat Al-Awsat Technical University (ATU), Engineering Technical College-Najaf, Iraq.

The authors also acknowledge the benefit from the Scientific and Technological Research Council of Turkey (TÜBİTAK) Project No. (118C276) conducted at Istanbul Technical University (ITU). Also, this work was supported in part by the Universiti Teknologi Malaysia (UTM), Research University Grant Scheme Tier 2, Grant Reference Number PY/2019/00325.

ABSTRACT The massive deployment of small-sized cells for the Fifth Generation (5G) mobile network will increase the Handover Probability (HOP), potentially causing higher Handover Ping-Pong Probability (HPPP) and/or Radio Link Failure (RLF). Inappropriate usage of Handover Control Parameter (HCP) settings may further exasperate this issue. Therefore, Mobility Robustness Optimisation (MRO) has been introduced and further developed as a significant Self-Optimisation Network (SON) function in the 5G network and beyond. The main aim of MRO is to address Mobility Management (MM) issues during user mobility between cells to ensure a smooth connection. Although various algorithms were suggested in the literature, they mostly cater to 4G networks which may not be effective for the 5G network due to different network characterisations. This paper analyses the performance of various MRO algorithms with various system settings and scenarios for the 5G network. The investigated algorithms from the literature include the Distance (Dis), Cost Function (CF), Fuzzy Logic Controller (FLC) and Handover Performance Indicator (HPI). Validation has been accomplished for different mobility conditions in the 5G network. A simulation based on the MATLAB software has been conducted using various system tools. The evaluation analysis is in terms of Signal to-Interference-plus-Noise-Ratio (SINR), HPPP and RLF effects since these are major indicators in assessing system performance and selecting the handover decision during user mobility. The simulation outcomes show that the HPI algorithm performance is more reactive to mobile speed scenarios over time, significantly reducing the HPPP compared to the other algorithms which do not provide large reactions in the same conditions. Simultaneously, the HPI algorithm exhibits the highest RLF and SINR from among the other algorithms. The distance algorithm is the best in terms of RLF and SINR, achieving an acceptable level in terms of HPPP. These results point to that the MRO algorithm that operate based on distance is the most robust compared to the other investigated algorithms, confirming the potential of the Dis approach for the 5G network.

INDEX TERMS Self-organising networks (SONs), mobility robustness optimisation (MRO), mobility management (MM), handover (HO), handover optimisation, handover control parameters (HCPs), load balancing (LB), fifth generation (5G) network.

The associate editor coordinating the review of this manuscript and approving it for publication was Binit Lukose.

I. INTRODUCTION

The massive growths in smartphone, mobile applications, connected devices and other related factors have led to the

rapid surge in demands for mobile broadband services with high data rates and excellent Quality of Service (QoS). Mobile networks must establish crucial steps to manage this exponential mobile data traffic growth and spectrum gap in future [1]. The 5G mobile networks and beyond will meet the requirements of User Equipment (UE), from millions of mobile connected devices and fixed sensors to bullet trains that operate at speeds of over 500 km/h. The need for higher reliability and lower latency represents the key requirements for Fifth Generation (5G) networks and beyond compared to current mobile network generations [2]. The significant presence of users necessitates the construction of a robust 5G mobility architecture. The 5G cellular network must be an integrated network that ensures a seamless connection and good user experience with high communication quality. This is to satisfy higher data rates and more system capacity among huge numbers of connected users' equipment. The deployment of small cells like (Pico, Femto, Mirco) cells has been introduced to contribute for enhancing system capacity. Also, it supports high data rate and enlarge the coverage area for the perceived 5G mobile network [3]–[5]. In the near future networks, a massive number of small cells will be deployed overlapping with the existing mobile networks. These small cells, along with unplanned deployment dynamics, will make the network's manual formation to become extremely difficult. The parameters of system are attuned physically (manually) in the current mobile networks to reach at high operational performance levels. This manual adjustment has become difficult with rapid network developments [6], [7] to improve network performance. The system parameters are adaptively adjusted according to network status [8], [9].

The Mobility Robustness Optimisation (MRO) is one of the important Self-Optimisation Network (SON) components introduced via the 3rd Generation Partnership Project (3GPP) [10]–[14]. It uses to address mobility management difficulties in Fourth Generation (4G) and 5G mobile networks [11]–[14]. It is also known as the Handover Parameter Self-Optimisation (HPSO) in the 4G system, which tends to be more advanced in the 5G system. Generally, SON functions/algorithms are classified into three categories: centralised, distributed and hybrid functions. Under SON there are various functions have been introduced, like MRO, Mobility Load Balancing (MLB), Interference Management (IM) and Frequent Handover Mitigation (FHM) to help small cells provide adequate performance to carrier class [15]–[18].

Load balancing is an important function in SON. It represents the Handover (HO) adjustment area to allow UEs on the edge of the cell to migrate from high cell loads to adjacent cells with fewer loads. This effectively increasing the utilisation rate of resources. MRO is another essential function in SON as it can detect HO issues by gathering information on UEs. Accordingly, the MRO and load balancing functions are two different and independent functions in SON. On the other side, the similarity between them is that they both functions

adjust the same handover control parameters but for different purposes [19], [20].

MRO enhances the performance of user mobility by optimising the parameters related to HO. The key objective of MRO is to reduce Radio Link Failure (RLF) and HPPPs via automatically optimising HO parameters. This is because the reliable contact is directly linked to the quality of experience between users [21]–[23]. The adjusted HO parameters by MRO include the individual displacement of the cell, Time-To-Trigger (TTT), etc. When the parameters are not appropriately set, RLFs and HPPP will occur if utilizers in the service move from cell to cell. This is indicated to as HO [24].

MRO has acquired much interest from the research community. This is demonstrated by the numerous HO optimisation techniques applied to various radio access technology found in the literature. For instance, optimisation solutions have been proposed with soft-HO in Wideband Code Division Multiple Access (WCDMA) system to address mobility issues [12], [25]–[29]. But, the Next Generation Wireless Networks (NGWNs) rely on hard-HOs where at a specific time, the UEs are connected to a single cell. Several performance analyses of LTE HOs within frequency have been described in [30]–[32]. However, determining optimal HO parameter settings using SON algorithms are not found in these studies. In [33]–[35], the authors proposed a handover SON solution to optimize HCP. But only one parameter has been considered. The techniques to modulate both HOM and TTT have been proposed in [36], [37]. However, no additional effects on user velocity were examined.

Machine learning-based algorithms have been suggested in [38]–[41] to provide a more flexible method for tuning HO parameters. Thus, these algorithms are limited to HO optimisation. Other algorithms in [38], [40] can adjust hysteresis and TTT, ignoring cell-individual offsets. The algorithms in [39], [41] can adjust HO offset without TTT modification. It has been assumed that the user speeds mentioned in [40], [42] are so accurately estimated that their algorithms do not apply to generic environments in practice. A distributed MRO algorithm has been suggested in [43] to reduce the probability of HOFs. This may resulted due to the occurrence of RLFs by tuning two HCPs, which are the offset and TTT parameters. This proposed algorithm takes into account the HOFs of every neighbouring cell and individually adjusts the HO parameters. The suggested algorithm adaptively optimises parameters by simulation. Moreover, it outperforms previous algorithms in different mobile environments.

On the top of that, the FLCs have been introduced widely applied for optimising HCPs in mobile networks [27], [44]–[47]. From these references, it can be concluded that FLCs approach are also effective method for optimising HCPs network automatically in mobile networks. The rules represent the assigning of inputs to basic steps of the output. These include collecting and evaluating data as well as performing a control action. An algorithm has also been

developed according to the Fuzzy Logic theory where various levels of HO parameter optimisation have been implemented at the network-level, cell level and cell-range, taking in the effect of measurement errors within the computation. The key advantage of the proposed FLC solution is that it permits for numerical issues to be addressed from the perspective of human thought, making it easier to translate the network operator's experience into the system control. FLC has been suggested in [39] to adaptively modify the HOM settings automatically while the TTT is set to a fixed value. The HOM level is adjusted through FLC according to two control measures: the Handover Ratio (HOR) and the Drop Call Probability (DCP). In [48], the HCP settings are also adjusted based on the average HPI thought Weighted Performance on the basis of Handover Parameter Optimisation (WPHPO) algorithm, which is operating as a function of HPPP, DCP and Handover Failure Probability (HFP).

Efficient mobility management is a significant part of 5G technology so as to achieve the drawn requirements. The key continuation in this paper is to study and investigate various MRO algorithms that dynamically optimise HCP settings to reduce the HOF rate, tackle the problems associated with increased HPPP and/or RLF and drastically reduce HCPs by adjusting settings after every measurement report. This will also reduce the SINR, HPPP and RLF probability. The key contributions of this manuscript can be summarised as:

- (a) The mobility management problem related to MRO is assessed and formulated in the 5G network with various system setting scenarios.
- (b) The performances of several MRO algorithms are investigated and validated in the 5G network for different mobile speed scenarios.
- (c) The performance of the selected MRO algorithms is evaluated and compared for efficiency and functionality according to the UE state for different mobile speed scenarios by focusing on three key performance measures: SINR, HPPP and RLF.

The rest of this research paper is arranged as in the following: Section II briefly highlights the related studies. Section III presents the path loss, fading and interference model. Section IV focuses on key metrics for evaluating HO performance. Section V presents the system model for the simulation scenario utilized in this work and discusses the simulation analysis and the evaluation of performance. Finally, Section VI displays the conclusion of this work.

II. RELEVANT STUDIES

The functions of self-optimisation aim to reduce operational spending (for instance, MRO). At high speeds, mobile phone users or mobile networks pose challenges that may lead to deeply degraded network performance and user experience. Thus, the goal of MRO is to automatically adjusting HCPs to enhance the total network performance, provide an enhanced end user experience and increase the capacity of network. This is achieved through automatically adapting the HCPs parameters of cell according to the

feedback from various considered performance indicators. This will reduce human interference in network management and optimisation tasks. Several studies have focused on HO optimisation by introducing schemes and algorithms for enhancing network performance [1], [11], [13], [14], [33], [38], [40], [43], [49]–[53].

The authors in [53] proposed an MLB technique according to cell reselection which operates based on the MRO function. When the UE is on idle mode for Radio Resource Control (RRC), the algorithm adjusts the cell reselection parameters to allow it to hang over the cell that lightly-loaded. Once the UEs switch into RRC connected mode, it will belong to the lightly loaded cell that is set to idle.

The authors in [43] proposed a small-cell network distributed MRO algorithm to reduce the RLF number that can occur from HOs through adjusting the TTT and offset parameters. The algorithm classifies handover failure (HOF) into three categories based on the cause of failure: too early, too late and false cell. It simultaneously optimises three HO parameters based on the predominant failure. The algorithm takes into account the HOFs of every neighbouring cell and individually adjusts HO parameters. The proposed algorithm demonstrates the adaptively optimised parameters and outperforms the previous algorithms in different mobile environments.

Another scaling and cost function method according to the MRO scheme has been suggested for Long Term Evolution (LTE) femtocell in [1]. The overhead signals of the system have been analysed. The developed scheme depends on MRO to adjust the HO parameter and reduce UHOs and RLFs resulting from wrong HO, too late HO or too early HO in open access femtocells. A cost function method including Unnecessary Handovers (UHOs) and wrong HOs was also introduced to achieve MRO. Later, an MRO scheme was proposed based on the gradient algorithm for femtocell networks [54], [55]. The simulation outcomes refer that the suggested scheme has the best execution in terms of the fixed parameters method, successfully reducing the number of HOFs and UHOs with limited signal adjustments.

In [33], the authors proposed an algorithm for HO parameter optimisation that can be utilised for dramatic changes in UE mobility without the need for additional functions to estimate UE mobility. SON has attracted attention as it is an efficient method for reducing operating expenses. The main feature of the suggested algorithm is mobility robustness, which means that the HO performance is resilient with changes in UE mobility. To achieve mobility robustness, the suggested algorithm adaptively adjusts HO parameters by taking into account the reason for HOF, attaining the ability to track any changes in UE mobility. The suggested algorithm reduces the high HOF rates below 0.2% by confirming mobility robustness.

In [40], the authors developed SON for Cellular Cognitive Network (CCN) by adding perceptions that enable SON functions to independently recognise the desired optimal configurations. This is accomplished by the generalised

framework of Q-Learning for CCN functions. The framework fits into the general control loop of the SON function and then applies the framework to two functions in MRO and MLB. The results reveal that the MRO function learns to optimise HO performance, while the MLB function learns immediate intercellular load distribution.

In [38], the authors presented the Fuzzy Q-Learning based MRO scheme to provide a general basis for enabling self-optimising and self-healing network operations. This approach allows HO parameters to independently adapt to local conditions of the cell sector, where HO parameters are set in a specific manner within a cell pair. The performance of the suggested approach has been compared with the reference scenario for the HO optimisation scheme based on the trend and scheme that allocates TTT values according to speed estimates. The outcomes show that the suggested approach clearly outperforms the other studied schemes, particularly regarding HOFs and HPPPs where optimal performance has been investigated. However, it is not possible to achieve performance improvements with regard to all cell sectors.

In [56], the authors have suggested a self-organising HO procedure of LTE network according to the SON concept where the two adjusted HO parameters are the TTT and Hysteresis (Hys). The simulation results demonstrate that network performance is best after TTT and Hys are optimised. Thus, the performance of the LTE network exhibited significant improvements in network delay, jitter and throughput.

In [39], the authors conducted a sensitivity analysis of two key HO parameters, the TTT and HO Margin (HOM), for various levels of system load and velocities of user in the LTE network. Next, the FLC was designed to adaptively adjust HOMs to optimise HO. In this state, the levels of various optimisation parameters (at the network level, at the cell level and at the cell scale) are considered with the effect of measurement errors. The simulation outcomes of the sensitivity analysis revealed that adjusting HOMs is an efficient solution for optimising HO in LTE networks. The FLC further proved to be an efficient method for adapting HOM to various network conditions so that the signal load of the network is reduced while achieving an acceptable level of dropped calls. In this work, the FLC is suggested to independently optimise HOM in the simulated scenario. It has been precisely designed for providing a better response. In contrast to [37], the effect of user velocity was also analysed in this work.

The number of HOs and RLF dramatically rises because of increase in Ultra-Dense Small Cells (UDSC) within the network. To enhance system performance, Mobility Management (MM) has become a key function in SON. The authors in [11] proposed a speed-based self-optimisation algorithm for tuning HCPs in 4G/5G networks. The proposed algorithm utilizes the power and speed received through the utilizer for tuning the HOM and TTT during mobility of user in the network. The simulation outcomes indicate that the proposed algorithm significantly achieves lower HPPP rate

and RLF, thus outperforming existing algorithms for all HO performance measures.

In [57], the authors linked real-world urban area detection with proactive load balancing by having proposed urban events to predict changes in cellular hotspots according to twitter data and enable context awareness. The strategy of proactive 5G load balancing has been simulated while taking into account the prediction of hot points that are irregularly distributed in urban areas. The context-aware proactive load balancing strategy has been optimised through predicting the better activation time.

In [58], the authors introduced a common Aware User Association and Resource Allocation (AURA) in 5G optimisation framework to provide an ideal solution for user inter-connection. They formulated a user correlation strategy as a Mixed Integer Linear Program (MILP) aimed to maximise the total network rate while optimising bandwidth assignment and choosing the access point. Using this framework, a new comparative research of all studied scenarios was conducted based on the total network throughput and performance versus the baseline scenario and system fairness. The simulation results demonstrate that the optimal solutions for AURA-5G do improve the performance of various network scenarios based on total network throughput and system justice comparison with the basic scenario.

The current work concentrates on formulating HO performance as an objective function for the general HO optimisation problem, which is later resolved according to certain presumptions using various MRO algorithms from the literature. Unlike most previously mentioned methods, the main contribution of this work is to study the performance of different MRO algorithms that dynamically optimise HCP settings in the 5G network to reduce the HOF rate and conserve communication links between the servings evolved Node B (eNB) and the mobile UE. To achieve this goal, this paper presents four different optimisation algorithms from the literature. The algorithms are examined to set the optimal behaviour of the suggested system according to the SINR and different mobile user speeds.

III. PATH LOSS, FADING AND INTERFERENCE MODEL

A. PATH LOSS MODEL AND FADING

The Path Loss (PL) model for the various bands in the urban area between the base station and the utilizer is demonstrated as follows [59]:

$$PL_{u,m,v} = 20 \log_{10} \left(\frac{4\pi r_0}{\lambda_v} \right) + 20 \log_{10} \left(\frac{d_{u,m}}{d_0} \right) + \chi \quad (1)$$

where ($v = 1$) if the BS has small cell k , while otherwise for the macro cell. d_0 and $d_{u,m}$ is the reference distance and the distance between the UE and BS m , respectively, ($d_{u,m} \geq d_0$; d_0 is assumed to be 50 m). λ_v represent the wavelength at the carrier frequency $f_{c,v}$. χ is a Gaussian random variable with zero mean and variance σ^2 .

In addition, we considered shadow fading model using Gaussian-distributed random variable with zero mean and

TABLE 1. Simulation parameters [10], [66]–[69], [24], [70], [71].

Parameter	value
Cell deployment	61 Hexagonal cells, with three sectors in each cell
Coverage area	3 km ²
Carrier frequency	28 GHz
System bandwidth	500 MHz
Cell radius (R)	200 m
eNB number	61
UE number per eNB	200
Time of simulation	150 s
Shadow Fading Model	Gaussian-distributed random variable with zero mean and σ_{dB} standard deviation in dB
Shadowing standard deviation	8 dB
Transmitted Power	23 dBm
Mobility model	Random direction
UE speed	(40, 80, 120, 160, and 200) km/h
Noise figure of UE	9 dB
Density of white noise power	-174 dBm/Hz
Thermal noise power	-127 dB

σ_{dB} standard deviation in dB (as stated in table 1 the shadowing is 8 dB). The PL model is appropriate for scenarios in the urban and suburban areas, where the height of buildings almost uniform. Thus, the path loss in such environments can be expressed as follows [60], [61]:

$$L = 58.8 + 37.6^* \log_{10}(d) + 21^* \log_{10}(f_c) \quad (2)$$

where d is the distance between eNB and served UE in kilometers, f_c is the operating carrier frequency in MHz. Shadow fading model defined as a Gaussian-distributed random variable with zero mean and standard deviation σ_{dB} in dB expressed as [60], [61]:

$$\psi_{dB}(\omega, \mu_{dB}) = \frac{\xi}{\omega \times \sigma_{dB} \times \sqrt{2\pi}} e^{-\left[\frac{(10 \log_{10}(\omega) - \mu_{dB})^2}{2\sigma_{dB}^2}\right]} \quad (3)$$

where $\xi = 10/\ln(10)$, μ_{dB} is the mean value of received signal power in dB, it depends on the building properties and path loss in the considered area, σ_{dB} is the standard deviation of ω_{dBm} in dB, and ω represents the transmitted-to-received power ratio ($\omega = P_t/P_r$), which is estimated empirically.

B. INTERFERENCE MODEL

We considered interference model based on co-channel interference in the first tier from six neighboring eNBs, whereas the adjacent channel interference is neglected. Thus, three interference signals from each neighboring eNB interfere with the serving eNB. Moreover, the UE can receive interference from the other sectors in the same serving eNB in which case intra-eNB interference is in place. The total interference signals received by the served UE can be expressed mathematically by denoting the total instantaneous

interference signal power as (I_n^{Total}) which is received by the UE from i^{th} neighboring eNB and sector number s as follows [52]:

$$I_n^{Total} = \sum_{i=1}^H \sum_{s=1}^{N_{Sec}^{eNB}} P_{int_n}(i, s) + \sum_{s=1}^{N_{i=sec}^{eNB}} P_{int_n}(s) \quad (4)$$

where H is the number of neighbors' eNBs in the first tier around the serving eNB. N_{sec}^{eNB} is the total number of sectors per eNB. P_{int_n} is the instantaneous interference signal power received by UE. $N_{i=sec}^{eNB}$ represents the number of sectors under the serving eNB that cause interference to the served UE.

IV. HO PERFORMANCE EVALUATION METRICS

To evaluate the HO network performance, we considered three aspects of the Performance Evaluation Metrics (PEMs): SINR Estimation, HPPP and RLF. These metrics have been chosen due to their importance. They represent the key criteria typically utilised in assessing the wireless networks performance through mobility of user. Accordingly, the outcomes are displayed and discussed in the next section. The three PEMs measured in this paper are illustrated as follows.

A. SINR

The requirements of maximum QoS minimise interference through reduce the RLF. The performance of every UE must fulfil the minimum data rate requirements in order to meet the QoS. The path loss computation based on the type of service eNB. We define a user as u where $u \in 1, 2, \dots, |N|$. Simultaneously, N represents each group of UEu where each user $u \in N$ moves in a random direction. The UEu receives a required movement through small or macro cells. Therefore, for channel modelling, the SINR received by UEu can be defined for every user as follows [62], [63]:

$$SINR_{u,m,v} = \frac{P_{u,m,v} G_{u,m,v} b_{ij}}{\sum_{i \in M/(m)} \sum_{j \in N/(u)} P_{ij} G_{u,m,v} + P_N} \quad (5)$$

where $P_{u,m,v}$ is the received signal power at u , while $G_{u,m,v}$ refers to the channel gain which expresses through the UEu at m . Also, b_{ij} is the binary correlation pointer of user u , where if $b_{ij} = 1$ this refers to user u which connects with one eNB; otherwise $b_{ij} = 0$. Meanwhile, P_{ij} indicates the power of the interference signal received by UEu at m , and P_N refers to the power of additive white Gaussian noise (AWGN), respectively.

B. HPPP

The HPPP is the probability of UHO produced from the user's mobility. This can occur for several reasons such as incorrect HCP settings or inexact the decision of HO. If this condition appears through mobility of user, it will lead to unstable and poor quality of connection. Because this is a critical problem in wireless networks, it is considered in this study as one of the key PEMs typically utilised to evaluate the performance of wireless network through mobility of user within cells. The HPPP can be mathematically expressed where if a call is

delivered to a new cell and returned to the cell of source in less than the critical time (T_c), the resulting HO is considered to be HPPP. Thus, the HPPP ratio represents the number of ping-pong handovers (M_{PPH}) divided by the total number of HOs; i.e., the M_{PPH} , the number of HOs where no ping-pong occurs (M_{NPPH}) and the number of Handover Failures (M_{HOF}), given as follows [49], [64]:

$$\overline{HPPP} = \frac{M_{PPH}}{M_{PPH} + M_{NPPH} + M_{HOF}} \quad (6)$$

C. RLF

The RLF is generally considered to be an essential PEM commonly utilised to compute the performance of wireless network through mobility of user. It is recorded as the rate of connection drops through the user mobility because of degradation in the Reference Signal Reception Power (RSRP) level is also registered if the serving RSRP falls below a certain threshold level before the mobile phone switches contact to a new Base Station (BS). Usually, the threshold level is determined through a criterion that varies from system to system. This is due to user mobility which can lead to a quick change in the strength of the received signal. Dropped calls may result before the connection reaches a new cell because of the quality of poor signal or unavailable resources in some cases. This problem can also be caused by inaccurate HCP settings or an incompatible HO decision algorithm. The RLF usually occurs when the UE disconnects from the eNB and fails to maintain the connection link. In spite of the primary source of RLF involves HOF or disconnection states in a connection link. Thus, the average RLF probability (\overline{RLF}) can be obtained for all UE (M_{UE}) as follows [65]:

$$\overline{RLF} = \frac{\sum_{i=1}^{M_{UE}} RLF_i}{M_{UE}} \quad \forall i^{th} U \quad (7)$$

V. SIMULATION EVALUATION AND PERFORMANCE ANALYSIS

A. SYSTEM ENVIRONMENT AND SIMULATION MODEL

This work is an extension of our previous research [49]. In this paper all system settings, mobility model, network environments and systems models are developed based on the specifications of 5G networks referring to 3GPP specifications. Simulation models have been developed mainly for studding mobility management in 5G mobile network. A real 5G network with single frequency and SON has been considered by developing a simulation model to evaluate different MRO algorithms taken from the literature. The algorithms are validated through simulations, with the assumption that the environment of network will be small cells within urban and suburban areas. The small cell base stations are the eNBs in the 5G network which can connect to each other. This communication mainly supports the HO procedure through exchanging operational reports, parameter configurations and RLF indications. In this network, every

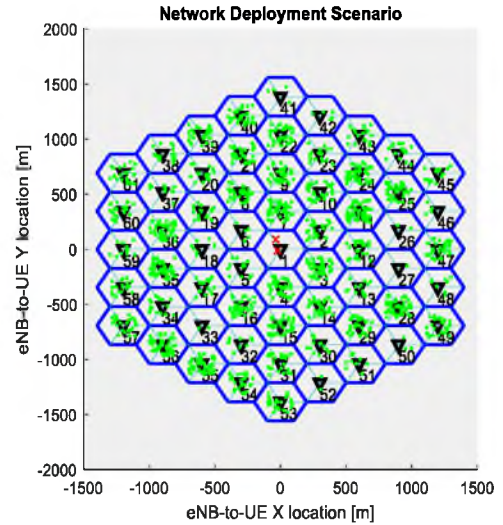


FIGURE 1. The 5G network deployment scenario.

hexagonal cell is made up three sectors, with a cell radius R (m) and one eNB located in its centre. In each eNB, the distributed SON continues to collect HO information and optimise the HCPs. The HO action is performed when the UE moves from a service cell to an adjacent cell. Figure 1 presents parts of the simulation environment for the deployment scenario of 5G network utilized in this work with several small hexagonal cells. We consider 5G network that consists of 61 Hexagonal cells with an area of 3 km². Thus, the users move within this limited coverage area for data measurements. The green cross is the UE, whilst the black triangular shape refers to the eNB. A random direction mobility model is considered where the UEs move in any eight directions in the range of [0°- 360°] selected randomly in every simulation time. However, considering various mobile speed scenarios at same simulation time is not a proper way to evaluate the network performance. Thus, only one mobile speed scenario is taken into account at each complete simulation time in order to evaluate the network performance in accordance with speed user. Initially, 200 randomly distributed mobile users are created within each hexagonal cell to represent the real 5G network environment. The traffic load of each eNB is changed randomly and periodically in every cell through the simulation cycles to replicate the real environment.

To assess and validate the suggested algorithms, simulations are made by use the MATLAB software. We considered five various UE velocities in this work to refer to low, medium and high velocities (40, 80, 120, 160 and 200 km/h). These velocities are typical vehicle speeds in urban and suburban areas, and they were hypothesised for the sake of theoretical investigation. The average value outcomes of service SINR, Cumulative Distribution Function (CDF) probability for user SINR, HPPP and RLF for all 15 users in each simulation cycle were calculated in this work because they move in parallel across different intracellular tracks.

The data collection was collected from each monitored user every 50 ms corresponding to each mobile speed scenario. Table 1 summarises the simulation parameters.

B. DISCUSSION OF SIMULATION RESULTS AND PERFORMANCE ANALYSIS

This section provides the outcomes for the study of simulation. The performance outcomes of the MRO algorithm are discussed and subsequently comparison with four other algorithms a selection of literature: Dis, CF, FLC and HPI. The algorithms have been assessed using five different mobile phone speed scenarios (40, 80, 120, 160 and 200 km/h) to determine their performance in various circumstances. The evaluation and validation of the algorithms are based on simulations through used the 5G network. Performance was independently measured for every utilizer in each 50 ms simulation cycle. After that, the average value was recorded for all users evaluated in every simulation period. All displayed outcomes are the average values of 15 utilizers considered in the measurements. It should be noted that in our work, the frequency is not varying, where there is only one assumed frequency band considered for all comparison results. Thus, there is no any comparison can be discussed in term of various frequency bands.

The MRO is compared according to the Dis [15]–[17], CF [72], FLC [39] and WPHPO (named HPI in the figures) [48]. These algorithms were selected from the literature because they focus mostly on MRO function development comparison with other algorithms. The displayed outcomes demonstrate the influence of the developed algorithms according to the SINR and HPPP. Thus, on the basis of these PEMs, the outcomes are displayed and discussed in the three following subsections.

1) SIMULATION RESULTS FOR AVERAGE SERVING SINR AND CDF PROBABILITY OF USER'S SINR

Figures 2 and 3 present the SINR in the average serving form and in the form of the CDF probability of all measured users. For the simulations, the user speeds of the proposed algorithms were randomly chosen within specific ranges (between 40 and 200 km/h) with a step equal to 40 km/h for modelling the pedestrian environment.

The HPI outperformed the other algorithms, as shown in Figure 2, where performance consecutively oscillates for different time values. The CF and FLC converge to a higher SINR level while the Dis smoothly converges. If the HPI is taken into account, the minute average differences between the minimum and maximum levels are 40, 47, 45, 48 and 34 dBm for 40, 80, 120, 160 and 200 km/h, respectively. However, the average improvement values are not very high. The HPI algorithm achieved the worst result for 160 km/h. If the HPI is not considered, a reasonable result can be achieved with only slight differences between the other proposed algorithms. On the other hand, it was noticed that the Dis optimisation also acquired the worst result, while the other two algorithms (CF and FLC) exhibited similar

performance based on the average serving SINR results for mobile speed scenarios of 40, 80 and 120 km/h with only a small variation. Thus, we can conclude from this observation that most utilizers, if not all, do reach the target SINR which is QoS satisfaction.

Figure 3 presents the CDF for the probability of users' SINR values after the initial temporary response of different HO self-optimisation algorithms. The displayed results highlight the performance of several automatic self-optimisation algorithms for various scenarios of mobile speed. The outcomes prove that no particular algorithm that can provide the highest SINR level for all scenarios of mobile speed. The proposed HPI algorithm did not achieve significant improvements for 40, 60 and 80 km/h speeds compared with other measurement algorithms from the literature. However, for maximum mobile speed scenarios (i.e., 160 and 200 km/h), the proposed algorithms (HPI and FLC) provide significant improvements compared to the Dis and CF measurement algorithms. Thus, the simulation outcomes reveal that HPI appears to be an efficient method for optimising HO in various network conditions, reducing the signal load in the network while achieving an acceptable level of dropped calls.

2) SIMULATION RESULTS OF AVERAGE PPHP

A trade-off may be present between the RLF and HPPP reduction [42], therefore, the HPPP rates of the proposed existing algorithms are compared (It is defined as the proportion of the total number of ping-pongs to the total number of experimental HOs across the network). Figure 4 presents the average HPPP rate for a selected time over all measured utilizers with various scenarios of mobile speed and various optimisation algorithms. In this figure, the presented outcomes are 7% from the total results (Figure 4 (a)). The x-axis scale is equal to 10 s, which represents one part from the total results. This outcome may initially be a good result, however, it inversely changes with the increase in time. For the case where the x-axis scale is equal to 150 s (Figure 4 (b)), all results (equivalent to 3000 readings) are displayed. The findings indicate that the suggested HPI algorithm produces a variable HPPP that rapidly fluctuates with time for different scenarios of mobile speed compared to the FLC, CF and Dis algorithms. Figure 4 demonstrates that the average HPPP rates for all optimisation algorithms increase as the RLF rate decreases and time increases. This demonstrates that the HPI algorithm provides the lowest average HPPP rate comparison with other algorithms. With the exception of HPI, the other algorithms have a strong trade-off between the RLF and HPPP reduction. For instance, the performance of the FLC algorithm is the worst when it comes to HPPP rates but better in RLF rates, while the HPI performs better in both the RLF and HPPP rates.

Figure 5 displays the average HPPP rate and final average HPPP rate results across all scenarios of mobile speed over the entire simulation period for various optimisation

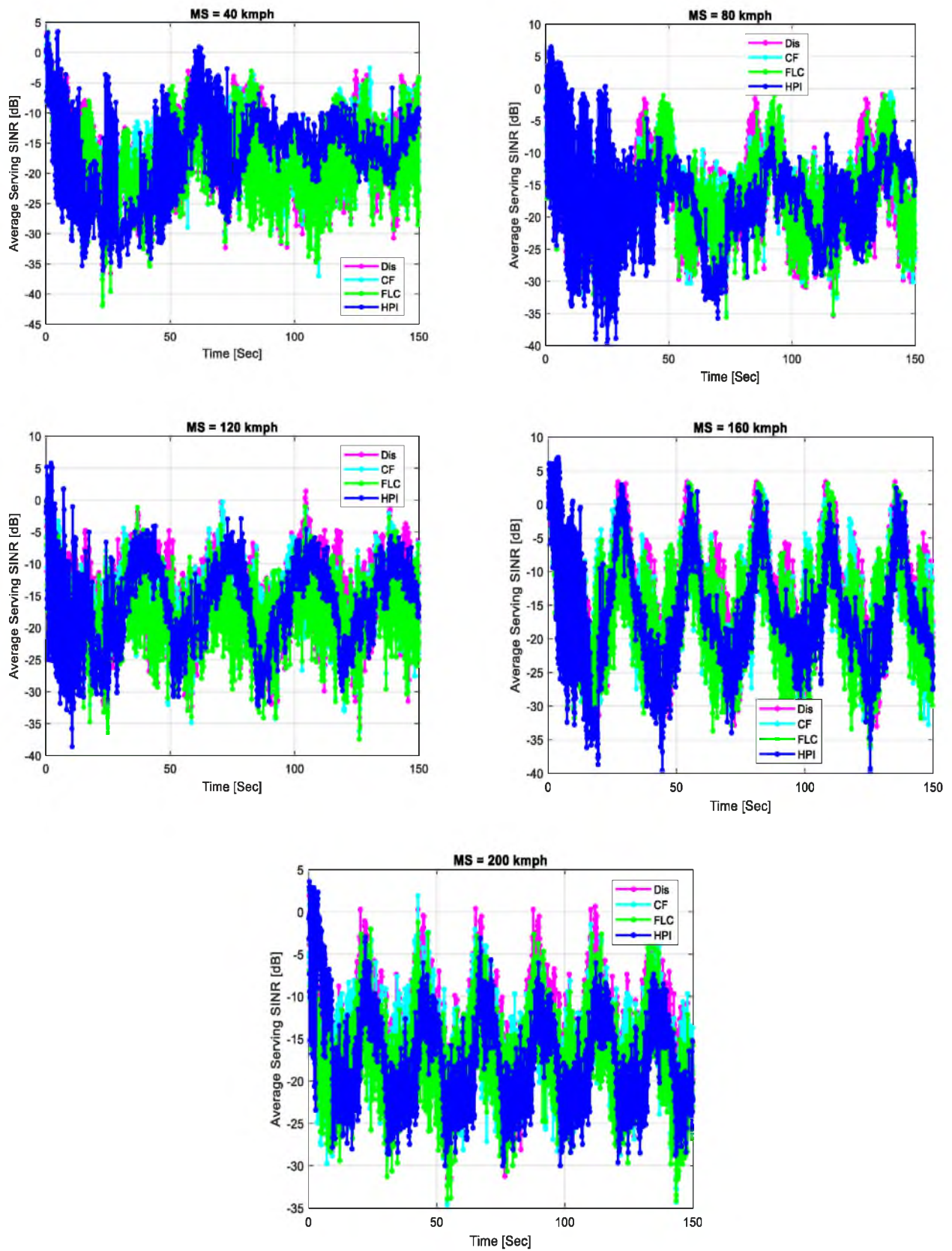


FIGURE 2. Average serving SINR vs. time for various mobile speed scenarios.

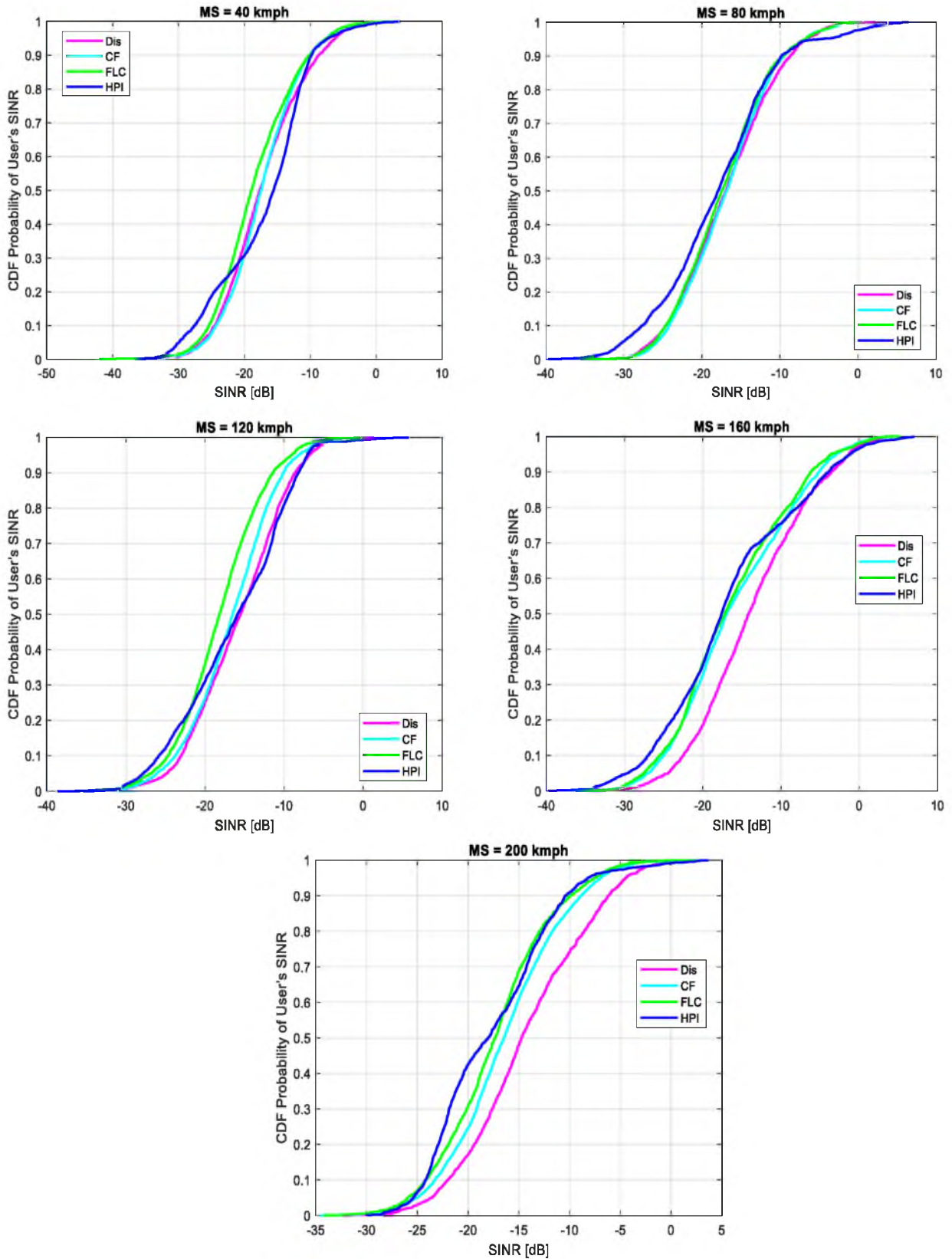


FIGURE 3. Average CDF probability of users' SINR for various mobile speed scenarios.

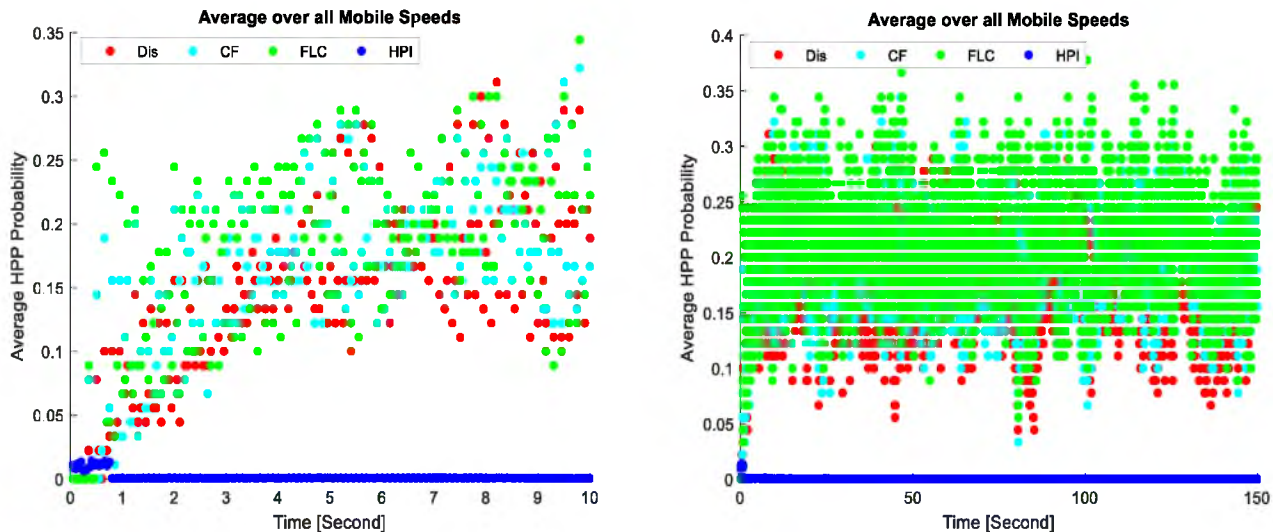


FIGURE 4. Average HPPP rate versus time for all measured users with different scenarios of mobile speed.

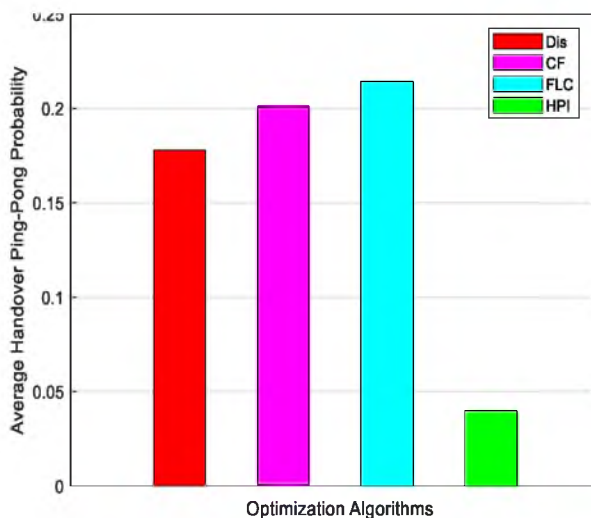
algorithms considered. The outcomes demonstrate that the suggested HPI algorithm provides remarkable reduction gain in the HPPP rate, particularly when compare it to the FLC, CF and Dis algorithms for all scenarios of mobile speed. These results can be justified through mentioning this allocation by the MRO algorithms (i.e., FLC, CF and Dis algorithms) is inappropriate for HCPs since they increase HPPP or UHO. The outcomes also reveal that in the initial operating period, the HPPPs are low, and then gradually increase with the increase in time for all mobile speed scenarios (Figure 5 (a)). This phenomenon

happens due to network start up according to the initially selected HCP settings. After a period, the studied algorithms automatically optimise and update the HCP settings. This has a varied effect on HPPP which differs according to the resilience and reaction of the optimisation algorithm used.

It can be generally noted that the HPPP rate achieved using the HPI approach is slightly less than that of FLC, CF and Dis for all scenarios of mobile speed due to appropriate HCP settings and better target eNB connection. The other algorithms achieved low HPPP rates through a specified



(a) Average HPPP rate.



(b) Final average HPPP rate

FIGURE 5. Average HPPP rate and final average HPPP rate for all scenarios of mobile speed and different optimisation algorithms.

period, especially in scenarios of high speed where elevated HPPP rates caused significant waste of resource blocks because of the back-and-forth switching of UE data. The received signals further oscillate at low velocity, so the rate of HPPP is high. At medium and high velocities, the communication between the UE and target eNB is fast, which leads to a low HPPP rate.

A higher HPPP rate occurs when the Handover Parameter Optimisation (HPO) function does not properly optimise the HCP algorithms (as in FLC, CF and Dis), leading to suboptimal HCP estimation. Accordingly, increasing the amount of UHOs outcomes in higher HPPP, especially at higher mobility speed. A drop in the HPPP rate is sometimes a good indicator as it signifies the utilize of effective MRO algorithms that estimate optimal HCP settings. The

suggested HPI algorithm monitors the UE’s speed and RSRP through UE mobility and then selects the proper HCP values to meet all requirements for executing a successful HO operation. Thus, the FLC algorithm acquires a higher average HPPP rate through mobile speeds. The HPI approach reduces the overall effect of the HPPP rate by 83%, 80% and 77% compared to the FLC, CF and Dis algorithms, respectively.

Nevertheless, the HPI presents the lowest HO rate in relation to the average across all scenarios of mobile speed, however, this is not a good indicator of HPI. Sometimes, the lowest HPPP rate can be regarded as a bad sign due to the trade-off between HPPP and RLF. In the HPPP framework, the service of the user is successfully maintained during it’s back and forth movement between two adjacent cells through

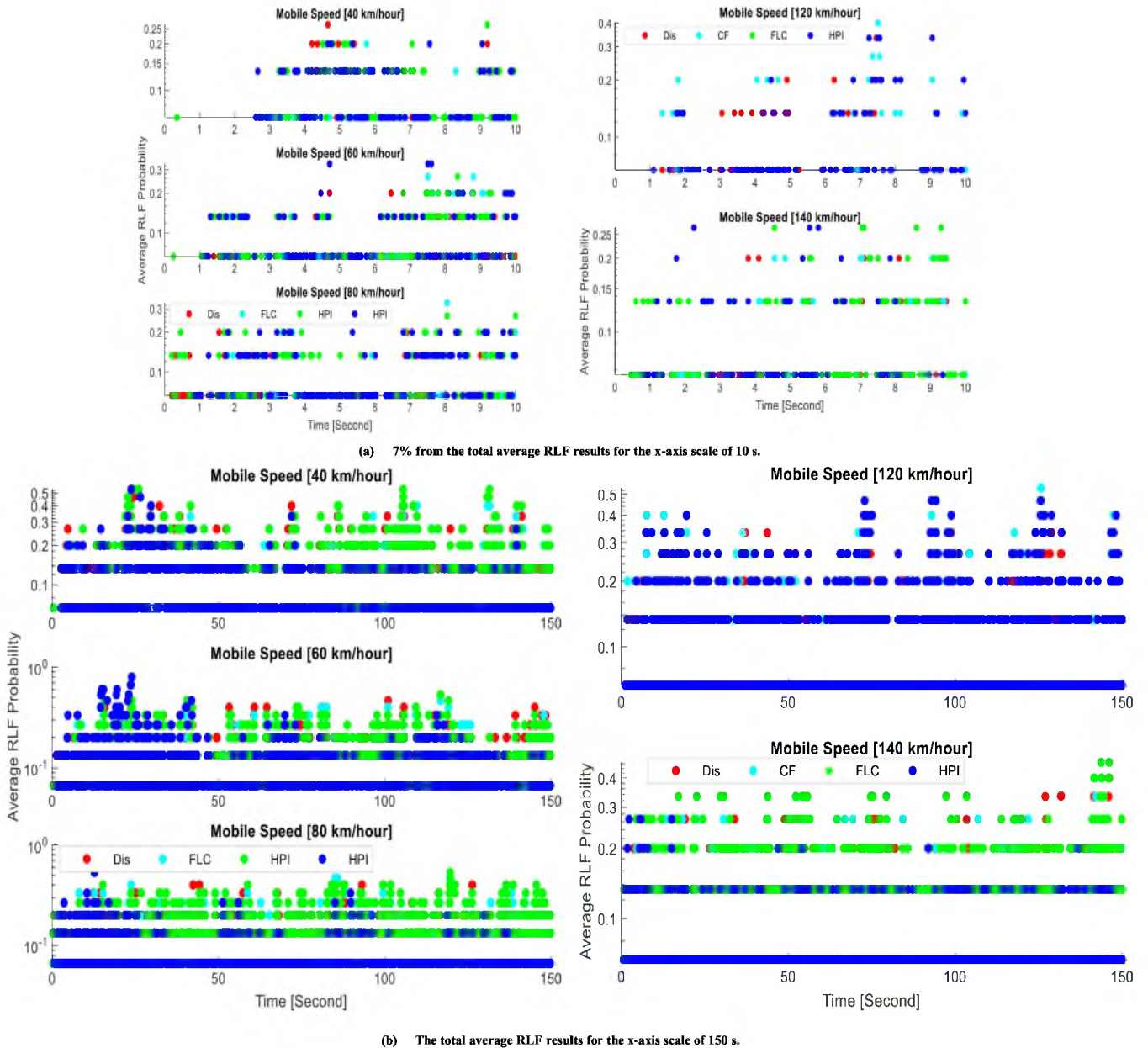


FIGURE 6. The RLF rate vs time for various scenarios of mobile speed.

a short period of time, called the minimum state time. Since HPPP only affects the signal load of the network, the impact on the QoS will be less than the RLFs. The key objective of MRO is to reduce RLFs through optimising HO parameters. The RLF causes the UE to physically lose wireless connection, requiring an additional retransmission or reconnection which interrupts the service of the user and wastes network resources.

3) SIMULATION RESULTS OF THE AVERAGE RLF

The RLF is other important pointer to evaluate the performance of network. Like to the HPPP with various orientations, the RLF occurs from near-optimal HCP settings. This leads to late HO which may later lead to an

increase in RLF in some cases, particularly for mobile utilizers who move at high speeds or are located at cell edges. This will significantly waste network resources and reduce the performance of network. The RLF must be reduced as possible to maintain the resources of network. Figures 6 and 7 display the average RLF probability recorded versus various optimisation algorithms taken from the literature. The average RLF probability rate for each scenario of mobile speed is computed across all monitored mobile device utilizers during the whole simulation time.

Figure 6 illustrates the RLF probability as the average rate of the various optimization algorithms for all measured utilizers at various mobile speed scenarios. The average

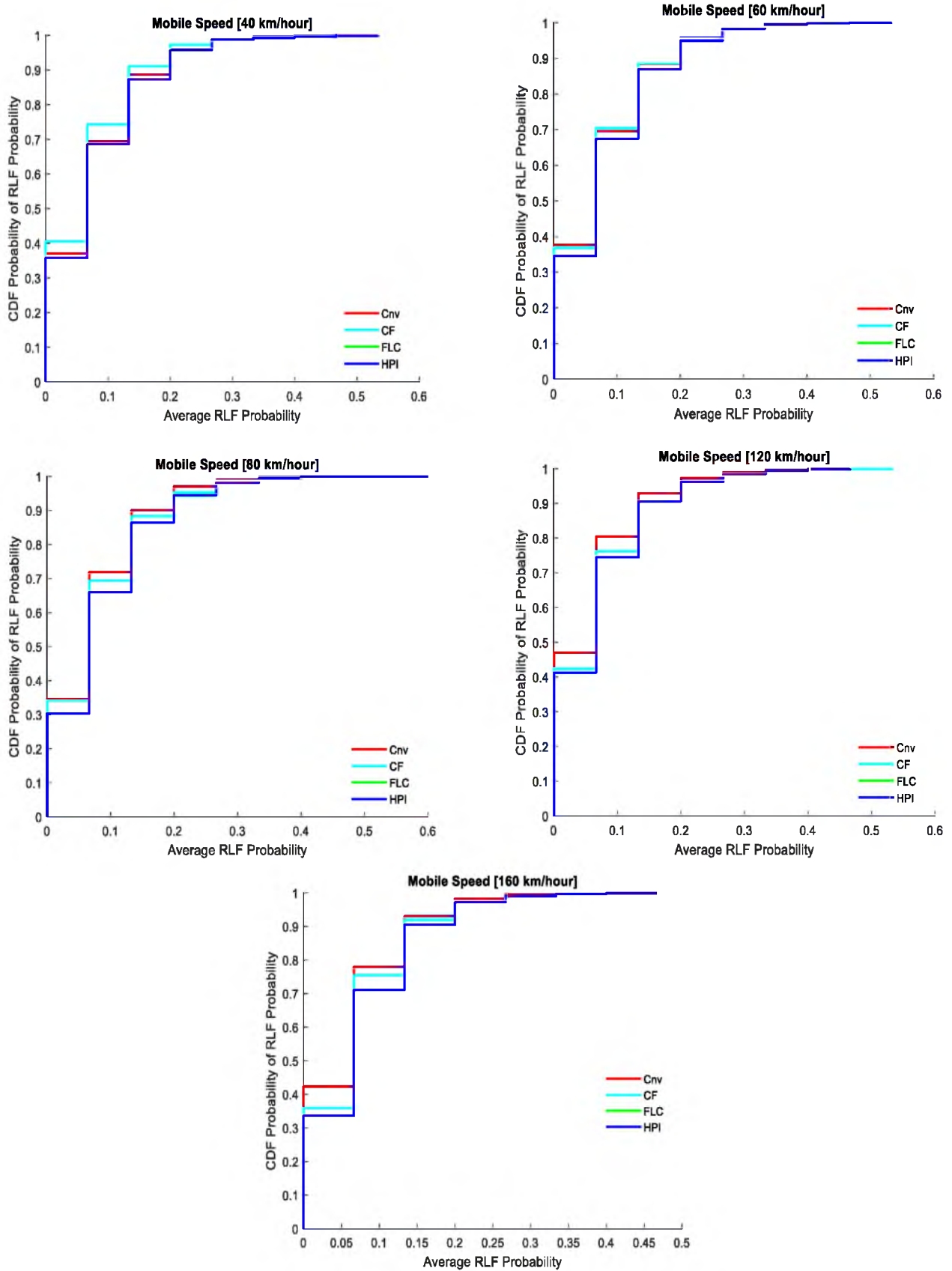


FIGURE 7. The CDF probability of the RLF rate for different scenarios of mobile speed.

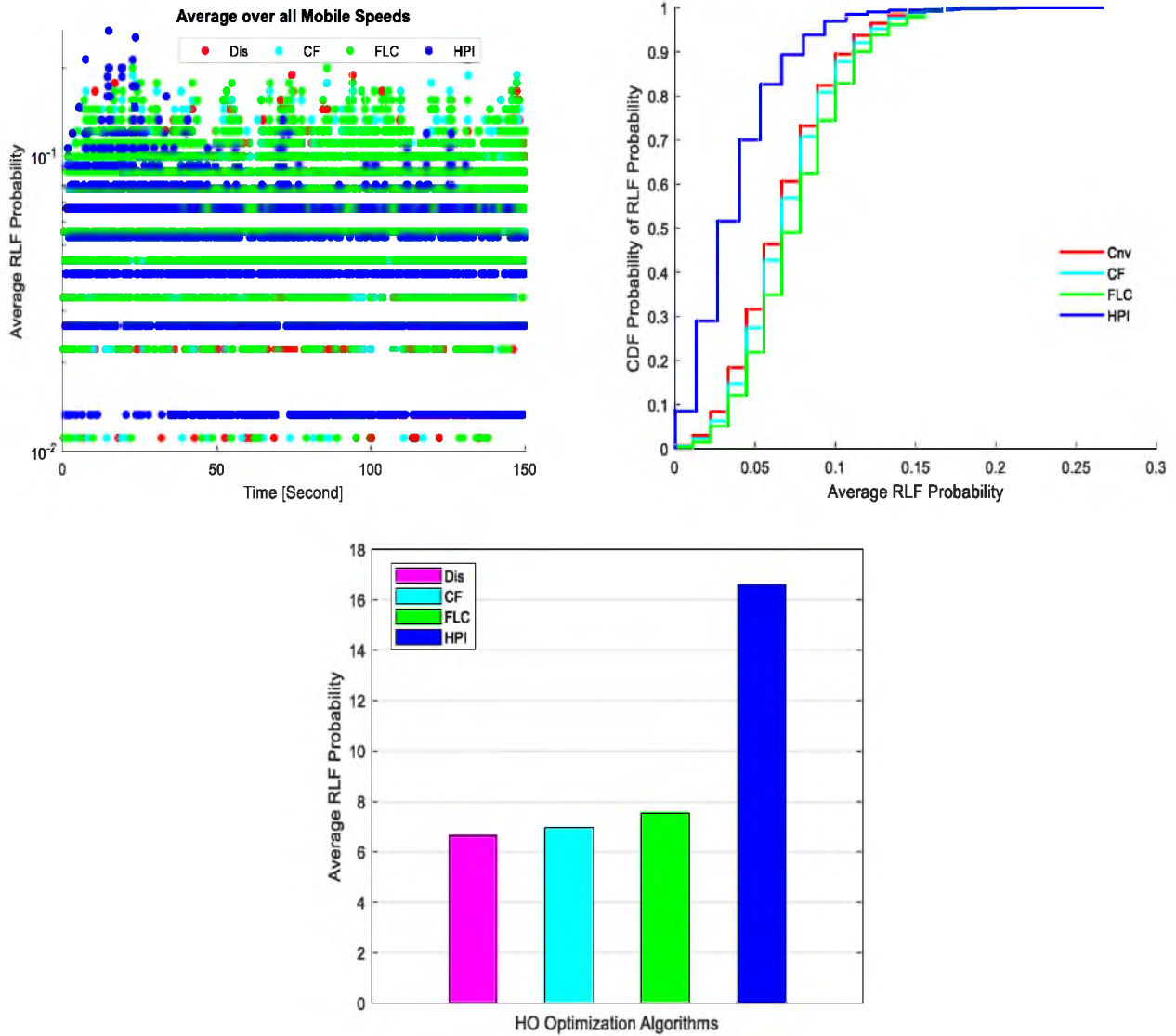


FIGURE 8. The final average RLF during all scenarios of mobile speed vs time.

RLF probability rate across all monitored UEs is calculated independently through the whole simulation time in the system network for every scenario of mobile speed. Thus, the presented outcomes are 7% from the total RLF probability results for the x-axis scale equal to 10 s (Figure 6 (a)) and the total RLF probability result for the x-axis scale equal to 150 s (Figure 6 (b)). Generally, the RLF probability is subject to change over time for all mobile speed scenarios, as well revealing that all algorithms constantly interact with the passage of time. The RLF has been averaged independently across all UEs in the system and across all simulation times for every scenario of mobile speed. The outcomes clearly indicate that there are obvious variations among these different algorithms. Also, the rate of RLF probability obtained by the Dis algorithm is greatly reduced for all speeds of UE compared to that obtained by other

suggested optimization algorithms. This is due to the effective way of dealing with the HO decision, where the HO is controlled on the basis of SINR and speed to improve the performance of network further, which leads to a reduction in the RLF. On other hand, the outcomes in this figure demonstrate that the probability of RLF increases with increasing UE speed because the UE whose speed is high stays in the cell for a short time and needs HO to target BS to avoid RLF. Therefore, the Dis algorithm reduces adaptively the values of HCPs (i.e., HOM and TTT) for rapid HO performance and avoidance the too late HO. Nevertheless, the highest priority should be given to the reduction of RLF in MRO.

This paper explained the results in more details through adding further results for the CDF probability of the RLF rate. The results presented with various mobility speed scenarios

to show the impact of different algorithms in more details. Thus, Figure 7 displays the CDF probability of the RLF rate after the initial transient response of the various HO algorithms. The outcomes shown highlight the performance of many self-optimization algorithms for various mobile speed scenarios. The outcomes showed that no specified algorithm can provide the highest level of CDF probability for the lower mobile speeds scenarios (i.e. 40 and 60) km/hour. However, for higher mobile speed scenarios (i.e. 80, 120 and 160) km/hour, the Dis algorithm (which represents Cnv in these figures) provides significant enhancements compared with other measurement algorithms. Therefore, the simulation outcomes show that Dis algorithm seems to be an effective method to optimize HO in different conditions of network compare with other algorithms, in addition to reduce signal load in the network with achieve an acceptable level of lost calls.

Moreover Figure 8 presents the final RLF vs. time as an average probability to all users who have been measured for mobile phone speed scenario, the final CDF probability for RLF rate and the final average RLF probability vs. different HO optimization algorithms. This figure displays the recurring rate of separation of radio links between BSs and the mobility of the UE. The average RLF probability rate is got from the total simulation time for every UE velocity. The outcomes indicate that the RLF rate obtained using the HPI algorithm is significantly increased compared to that of other algorithms in all scenarios of mobile speed. Using inappropriately modified UE velocity to optimise HCPs may result in high RLF rates than other algorithms because only HOM is tuned based on the speed of the UE.

Thus, HCPs should be periodically adapted to manage the decision of HO based on the independent experience of every UE. Moreover, the Doppler impact associated with connections of weak radio link increase gradually the RLF rate based on the UE speed for all compared algorithms. Overall, the outcomes show that the average reduction gains realized using the proposed Dis algorithm are approximately 6%, 17% and 62% less than that of CF, FLC and HPI algorithms, respectively, for all respective speeds of mobile. This represents an important achievement for the proposed Dis algorithm, indicating that it can contribute significant enhancements compared to other examined algorithms. In spite of HPI algorithm yields a higher rate of RLF than Dis, CF and FLC algorithms, but this algorithm achieve lower rates of HPPP because of the lower values of HOM and TTT. In general, the reduction in the RLF rate is a good indicator since it is because of the utilize of effective MRO algorithms that estimate optimal HCP settings where a trade-off performance between HPPP and RLF is present. On the other hand, a reduction in the rate of RLF is not always a good indicator since using lower HCP settings can lead to a reduced RLF rate. This will concomitantly cause early HO which, in turn, leads to an increase in HPPP.

TABLE 2. The total performance metrics with various investigated MRO algorithms.

MRO algorithm	HO performance metrics	
	HPPP	RLF
Dis	0.18	6.8
CF	0.2	7.15
FLC	0.22	7.8
HPI	0.04	16.8

Table 2 presents the general performance measures for the standard algorithms chosen from the literature. As shown from the above outcomes, the CF and FLC algorithms had the worst performance results for the HPPP rate since they inefficiently handle the HO decision. The Dis algorithm performed somewhat better since it is considered to be a distributed SON algorithm. However, it does not completely address the problem of HO as it still has to take into account the speed of the UE to further improve the performance of network. The examined HPI algorithm exhibited enhanced performance results and outperformed the other algorithms since it controls HO based on SINR and velocity, which reduces the main PEM (namely, HPPP).

VI. CONCLUSION

This paper investigated various MRO algorithms for the 5G network at different mobility speeds and system setting scenarios. The MRO algorithms periodically adjust the HCP settings based on a different method in order to enhance mobile network performance. Performance evaluation of the examined MRO algorithms was accomplished to set the optimal demeanour of the suggested system based on the SINR, HPPP and RLF at various mobile speeds and system setting scenarios. The simulation outcomes revealed that the investigated HPI algorithm does improve the overall system performance by reducing the HPPP rate for different mobile speed scenarios of more than 75% as compared to other algorithms. It simultaneously provides the highest RLF and SINR in contrast with other examined MRO algorithms. The algorithm based on distance is the best in terms of RLF and SINR, further providing an acceptable level in terms of HPPP. This means that the trade-off between HPPP and RLF carried out through the use of the examined Dis algorithm is better than the other algorithms. These outcomes indicate that the MRO algorithm based on the distance is the most resilient. The optimisation algorithm has a robust design that withstands changes in UE mobility. The investigated Dis algorithm has much potential in the 5G network. The presented outcomes indicate that the Dis algorithm appears to be an effective method for optimising HO throughout various network conditions, thereby reducing the signal load of the network.

VII. ABBREVIATIONS

The abbreviations utilized in this paper and their interpretations are demonstrated below:

Abbreviations	Interpretations
3GPP	3rd Generation Partnership Project
4G	Fourth Generation
5G	Fifth Generation
AURA	Aware User Association and Resource Allocation
BS	Base Station
CCN	Cellular Cognitive Network
CDF	Cumulative Distribution Function
CF	Cost Function
DCP	Drop Call Probability
Dis	Distance
eNB	Evolved Node B
FHM	Frequent Handover Mitigation
FLC	Fuzzy Logic Controller
HCP	Handover Control Parameter
HFP	Handover Failure Probability
HO	Handover
HOF	Handover Failure
HOM	HO Margin
HOP	Handover Probability
HOR	Handover Ratio
HPI	Handover Performance Indicator
HPO	Handover Parameter Optimisation
HPPP	Handover Ping-Pong Probability
HPSO	Handover Parameter Self-Optimisation
Hys	Hysteresis
IM	Interference Management
LTE	Long Term Evolution
MILP	Mixed Integer Linear Program
MLB	Mobility Load Balancing
MLB	Mobility Load Balancing
MM	Mobility Management
MRO	Mobility Robustness Optimisation
NGWNS	Next Generation Wireless Networks
PEMs	Performance Evaluation Metrics
QoS	Quality of Service
RLF	Radio Link Failure
RRC	Radio Resource Control
RSRP	Reference Signal Reception Power
SINR	Signal to-Interference-plus-Noise-Ratio
SON	Self-Optimization Network
Tc	Critical Time
TTT	Time To Trigger
UDSCs	Ultra-Dense Small Cells
UE	User Equipment
UHO	Unnecessary Handover
WCDMA	Wideband Code Division Multiple Access
WPHPO	Weighted Performance Handover Parameter Optimization

ACKNOWLEDGMENT

The authors submit their sincere thanks and gratitude to the Ministry of Higher Education and Scientific Research, Engineering Technical College Najaf, Al-Furat Al-Awsat Technical University (ATU), Iraq, for awarding a Postdoctoral Research Fellowship to work as visiting researchers at Istanbul Technical University (ITU), Turkey.

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