

Research Article

Effectiveness of Handover Control Parameters on Handover Performance in 5G and beyond Mobile Networks

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Mobility management is essential in mobile communication networks to provide a smooth connection during users' mobility. Handover control parameters (HCPs), such as handover margin (HOM) and time-to-trigger (TTT), are major and essential factors in mobility management that must be defined carefully to make efficient handover (HO) procedures. Their impact becomes more critical with the deployment of fifth-generation (5G) mobile networks and beyond (B5G). This is due to the different characterizations of next mobile networks, such as the use of millimeter-wave (mmWave) bands, the ultradense deployment of small base stations (BSs), large mobile connection traffic growth, and other more critical factors. The case becomes more sensitive with the high mobility speed scenarios. This study proposes different HCP system settings to be investigated and analyzed over B5G networks. They will be investigated with various mobile speed scenarios to illustrate their impact on the network performance. Various key performance indicators (KPIs) are considered to evaluate and validate system performance, such as reference signal received power (RSRP), HO probability (HOP), HO ping-pong (HOPP), radio link failure (RLF), HO interruption time (HIT), and HO failure (HOF). Results show that the various system settings provide different and significant impacts on the performance of B5G networks. Furthermore, the setting of HCP1 obtained the best performance in RSRP and RLF with -69.7 dBm and 4.8%, respectively, while the optimum performance of HOPP, HIT, HOP, and HOF is achieved in the HCP6 setting with 0%, 0.02 ms, 0.05%, and 0%, respectively. Moreover, the overall outcome of all HCP settings is 54.94%. These results indicate a tradeoff between RLF and HOPP with various HCP settings in B5G mobile networks. Thus, the HCP system settings must be adjusted carefully considering other factors, such as mobile environment and use case.

1. Introduction

The massive increase of mobile-connected users, mobile applications, various types of connected devices, and other services greatly increases mobile data traffic growth. Hence, the fifth-generation (5G) of the mobile communication networks and beyond (B5G) have developed to meet this great

demand of mobile data traffic growth in the future. This new mobile technology is promising to provide various mobile communication services with a high data rate, wider bandwidth, high traffic capacity, wider coverage, and low latency [1]. Although this new technology will bring several advantages in many areas, issues regarding mobility management are still a big challenge that needs to be solved in

the future B5G mobile networks. The outstanding issues include the challenges related to mobility routing, handover (HO) decisions, HO authentication, handover control parameters (HCPs) settings, and more other mobility issues [2, 3].

Handover (HO) is one of the main techniques in mobile communication networks that enable the mobile user equipment (UE) to connect with the serving networks during its mobility. The process is performed by switching its connection from one base station (BS) to another during its mobility without interruption in the ideal case [4]. The HO process uses different HO parameters and HO decision algorithms to control the HO occurrence. These considered algorithms and parameters have a significant effect on the HO performance. Therefore, setting these parameters properly and utilizing the suitable HO decision algorithm provide optimal HO performance. This study will be focusing on the HCP settings, which are the parameters that control the decision-making of HO. HCPs are major and critical factors used in mobility management to control HO decisions. For that, they must be defined carefully to ensure efficient HO procedures. The most significant HCP settings are the handover margin (HOM) and time-to-trigger (TTT) [5, 6].

HOM parameter, also known as the hysteresis margin, is one of the main parameters that control the HO process between two cells. It controls the HO decision algorithm by adding a margin level that prevents the HO decision from being taken and initiated before fulfilling this requirement. For example, the HO is initiated if the link quality of the target candidate cell is better than the current link quality by a HOM level. The actual values usually vary between 0 and 12 dB, with an interval of 0.5 dB between the steps. For that, HOM can contribute positively or negatively to enhancing or degrading HO performance. For example, the HOM settings can be adjusted to prevent the frequent occurrence of HOP and HO ping-pong (HOPP) probability [7]. This performance metric can be performed if a higher HOM setting has been defined. However, this case may lead to increasing radio link failure (RLF). From another aspect, the HOM setting can be used to reduce RLF, which can be performed by defining lower HOM settings. However, this event may increase the HO probability (HOP) and HOPP probability. Thus, the HOM setting must be defined carefully.

TTT parameter is another significant parameter used to control the HO process. During this time, the specific criteria for an event need to be met to make the HO decision. In other words, TTT can be defined as an interval of time determined in the system to be used for investigating the measured received signal power several times before making the HO. The range of TTT intervals is broad, which provides different HO performances. TTT intervals that are defined by the 3rd generation partnership project (3GPP) fall within one of the following values: 0, 40, 64, 80, 100, 128, 160, 256, 320, 480, 512, 640, 1024, 1280, 2560, and 5120 ms [8]. These intervals can be selected manually or automatically based on the system function operation. The various TTT intervals cause different performances, the same as the different HOM settings do. For example, the high TTT settings can prevent the frequent occurrence of HOP and HOPP proba-

bility. But this case may lead to increasing the RLF. From another aspect, the lower TTT setting can be used to reduce the RLF rate. However, this setting may also lead to an increase in the HOP and HOPP. Accordingly, the TTT setting also must be defined carefully.

Consequently, the optimal HCP settings lead to enhanced HO performance, whereas the inappropriate HCP settings lead to degradation of the HO performance. Their impact becomes more critical with the deployment of B5G mobile networks. The reason is the different characterizations and technologies introduced in the next mobile networks, such as the use of millimeter-wave (mmWave) bands, the ultradense deployment of small BSs, large mobile connection traffic growth, huge number of connected applications, and other more critical factors. The characteristics of mmWave provide a very small coverage area of up to 200 m, and the ultradense deployment of small BS increases the number of HOs. Moreover, the large connected mobile devices to the network increase a load of BS, which increases the HOP. The case becomes more sensitive with the high mobility speed scenarios, particularly as the support of high mobility speed is one of the main requirements that the B5G network should provide. Therefore, studying the effectiveness of HCP settings over the B5G network is a significant topic that needs to be conducted with various deployment and mobile speed scenarios.

This study proposed different HCP system settings (different TTT and HOM settings) to be investigated and analyzed over B5G networks. They will be investigated with various mobile speed scenarios to illustrate their impact on the network performance. Various key performance indicators (KPIs) are considered to evaluate and validate the system performance, such as reference signal received power (RSRP), HOP, HOPP, RLF, HO interruption time (HIT), and HO failure (HOF). Also, the study considered six mobile speed scenarios up to 200 km/h. Therefore, according to the investigation results, there are no optimal fixed settings of HCP that can be achieved with optimal HO performance in all HO KPIs. Thus, advanced automatic and intelligent HO algorithms, such as [9–13] (discussed in a subsection of related works), could be a superior solution to provide optimal overall HO performance. Overall, this investigation study will help the developers to understand the impact of the setting of HCP on the HO performance on B5G networks (mmWave) and give them an excellent sight when determining the range of HCPs in the system, especially in the scenarios of highway and high speeds.

The rest of the paper is organized as follows. Section 2 provides a background on the related research topic. Section 3 presents the system model, simulation setting, and performance metrics. Subsequently, Section 4 provides the results and discussion. Finally, Section 5 concludes our study.

2. Background

The 5G and B5G mobile system is the latest term used for an enhanced mobile communication network that offers several services, enhancements, new applications, and ubiquitous connectivity. B5G provides a significantly higher

performance level than the previous mobile generations in terms of data rate, network capacity, system latency, connectivity, and flexibility. 5G is designed to provide a new type of connectivity and applications, such as automotive communications, large video download, and remote control with haptic style feedback, which needed ubiquitous connectivity. 5G has also been developed to provide a very low data rate to satisfy the requirements of several applications, such as sensors and Internet of Things (IoT) applications. In other words, 5G enables a broad range of applications, from those that require a low data rate to applications that need a very high data rate with low latency. Nevertheless, one of the significant issues in B5G networks that should be studied carefully is mobility management. This matter is an essential issue that needs to be solved to ensure a seamless/smooth connection for UE with the serving network while moving within the network coverage area [2].

2.1. Mobility Management in B5G. One of the essential functions of cellular networks is mobility management. Figure 1 shows the identification and tracking of changes in user location for user connectivity to cellular network service. The access mobility function (AMF), N2 is responsible for the mobility management tasks and connection, and Xn is for managing HO between B5G next-generation node BS/base stations (gNBs). This specific feature provides network connectivity to users at any location, and users can avail of this function to smoothly access the network at a new location. In short, mobility management provides users with an uninterrupted and reliable connection, communication, and service [14]. In a B5G system, the importance of mobility management is significantly increased as many applications are very connectivity sensitive to the networks.

The UEs can execute uninterrupted HO with the help of B5G. Additionally, B5G offers various beneficial features, including delivering a high data rate, handling a greater volume of data, expanding B5G devices' market, lower latency, better quality of experience for end-users, and more energy conservation. B5G makes use of the ultradense network (UDN) technique that helps to fulfill the data traffic requirements of users with its feature of greater network bandwidth.

In short, mobility management allows B5G networks to successfully cater to user needs and hence holds a significant position in the mobile wireless system [15].

2.2. Problems of Mobility Management in B5G. Mobility management solutions designed for prospective wireless networks may face a number of issues [3, 16]. These issues include those associated with higher density (because of the large variety of user access points). Other issues are associated with heterogeneity (because of compatibility with diverse types of radio access technologies (RATs)) and issues with the programmability of the network or environment. All these issues call for the formulation of effective mobility management techniques to provide enhanced mobility management to users for ensuring their connectivity and service continuity in dynamic wireless network environments [17].

B5G networks usually employ UDNs, which are different from the traditional networks. The UDN executes HO rap-

idly and frequently because it entails numerous small cells, allowing a user to pass through a greater number of cells with lesser time spent within each cell along the path [18]. Consequently, the HO cost has a considerable risk which affects the average throughput and ultimately the performance of mobile users. This risk in HO cost may be attributed to the fact that the user resources are mostly exhausted in HO executions than the data traffic, leading to a considerable fall in the quality of service [19]. However, these issues can be resolved by improving the designs of HO techniques used for mobility management in UDN.

B5G mobility management should provide high speed for UE, such as highway speed (above 80 km/h) and high-speed rail (up to 500 km/h). Similar to any technology, the high mobility of wireless communication terminals has its own set of pros and cons. The designing, modeling, and assessment of future communication systems are significantly affected by high mobility. In addition, developers can use the features offered by high mobility to develop a better system design leading to improved system performance. From another aspect, various drawbacks associated with the design of high mobility communication systems include the following [19]:

- (i) Fast fading
- (ii) Channel estimation errors
- (iii) Doppler diversity
- (iv) High penetration loss
- (v) More frequent and quick HO

2.3. HCPs. As previously mentioned, two important HO HCPs are the TTT and HOM. Both have a significant effect on HO. Two criteria must be met for the execution of HO. The first criterion requires the received signal strength (RSS) of the serving BS to be outshined by the RSS of a potential cell, whereas the second criterion requires the fulfillment of the first condition within the time specified in the TTT parameter [20, 21].

Several researchers focused on the HCPs to study the HO performance. In [22], the author introduced HCPs that investigate user experiences to modify HCPs and make a HO choice in a self-optimizing way. Dynamic HCPs are categorized HOF into three types: too late, too early, and erroneous cell HO. Then, HCPs are modified based on the prevailing HOF. The study dealt with the issue of a significant number of small cells in upcoming next-generation mobile networks to meet 5G standards. Mobility management is one of the critical challenges that must be addressed in heterogeneous networks (HetNets), where 5G ultradense small cells coexist with present fourth-generation (4G) networks. Furthermore, an efficient HO mechanism was implemented to mitigate this issue and enhance mobility management by modifying the HCPs, specifically TTT and HO margin. A simulation was carried out on the proposed algorithm based on 3GPP evaluation using MATLAB. The findings demonstrated that the proposed D-HCP algorithm adaptively optimized the HCPs and surpassed existing literature algorithms. In

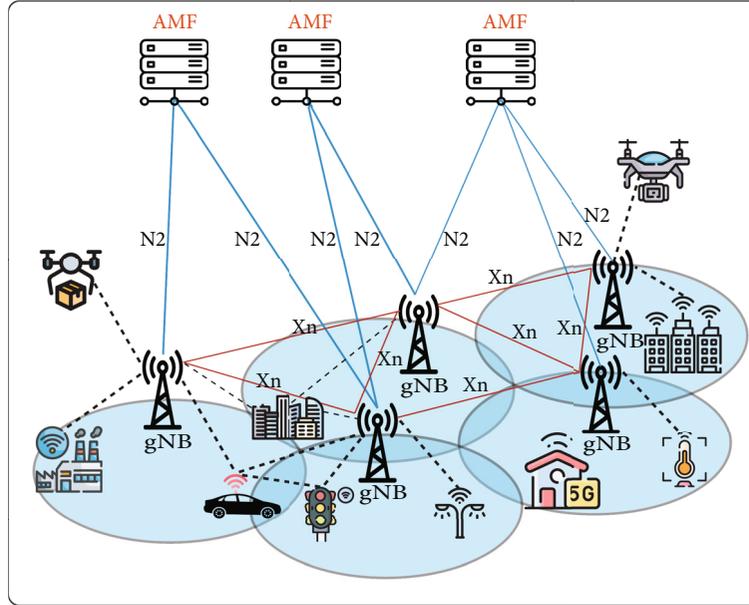


FIGURE 1: Mobility management in ultradense networks (UDNs) with the existing B5G technologies.

comparison to all mobile speeds, the algorithm almost decreased the rate of HOs, HOPP, and RLF ratio.

In [23, 24], the authors focused on assessing RLF, HOPP, and HOP brought about by site separation, TTT, and UE speed. Closed-form expressions for the HO execution probabilities were inferred as a component of entombing site separation and UEs' speed. Although the articulation is evident, the suspicion that small cell inclusion is a round shape should be discussed in respect to the HetNet scenario. Considering that asymmetry transmits an intensity of various levels, the passage purpose of a HO condition is diverse when a user enters from various headings of a smart BS.

2.4. Problem of Fixed HCPs in B5G System. As the HO algorithms are developed by adjusting the two HCPs (TTT and HOM), notably, the performance of the HO and consequently that of the wireless network may be affected if the values of these parameters are fixed. The reason is that the constancy of these values may lead to high HOPP and RLF rates. In addition, mobile wireless systems, specifically 4G and B5G, do not keep the TTT and HOM values fixed in HO. Thus, the values of TTT and HOM must be open for timely adjustment to allow adjusting these values higher (in the case of slow UE for preventing high HOPP and prolonged HO) and lower (in the case of faster UE to avoid delayed HO and high RLF).

B5G networks are incompatible with the fixed HCP technique as uninterrupted HO and virtually zero lost connection are essential for B5G networks. Hence, various techniques and algorithms for better HO execution have been developed by experts.

In [25], the authors suggested an X2-based HO application in a partly simulated software-defined networking-based (SDN-based) long-term evolution (LTE) architecture. Meanwhile, in [26], the authors suggested an SDN-based HO approach to generate a delayed duration of shorter than

1 ms as a B5G network should continuously provide a connection service to the users. Furthermore, a shorter execution duration was required for this approach compared with UE, in which a direct HO was conducted as a result of the management of cells by the SDN controller. Then, in [27], the authors incorporated a three-dimensional N-tier downlink network and identified the relation possibilities and inter/intrastier HO degrees through the instruments from stochastic geometry. Meanwhile, an emerging vehicular network architecture was combined with 5G mobile communication technologies, followed by the proposal of SDN [28]. Furthermore, the fog cell was suggested to be the solution of the HO, which often occurred between the vehicles and roadside units. However, the HO among vehicles remained a problem in the multihop relay link in a fog cell. With a high number of vehicles being exchanged between the adjacent fog cells, the HO would be simultaneously developed for the multihop relay links and fog cells.

The fundamental difference of B5G networks to the current 4G/5G network implementation is the adoption of machine learning methods. In [29], mobility management for fog computing has been proposed for the internet of vehicles. Furthermore, the cost prediction model can estimate the potential fog nodes at a specific location and determine the temporal and geographical patterns in the data. Moreover, [30] suggested a two-tier machine learning-based scheme to manage the HO in vehicular networks. The researchers also implemented a recurrent neural network model, which predicted an access point to determine the HO trigger through the receiving signals. Additionally, a stochastic Markov model was also applied to select the subsequent access point.

In [31], the authors emphasized the reduction of the blocking error of HO at the cell boundary of the BSs. The placement of the mobile node at the cell boundary and the HO management was conducted using geolocation data

presented by the global positioning system (GPS). Meanwhile, in [32–35], the researchers suggested various HO algorithms for LTE-Advanced/5G HetNets. The authors of [36, 37] suggested self-optimization algorithms of HO to decrease the use of energy in the network. Moreover, to improve the cross-tier HO performance in the 5G heterogeneous UDN, the authors of [38] implemented the analytical results of cross-tier HO based on the stochastic process and suggested a fuzzy logic multiattribute cross-tier HO decision algorithm. A notable HO scheme was suggested in [39], which combined the benefits of fuzzy logic and multiple attributes' decision-making algorithms to create a HO process at the intended time and link to the optimal neighboring BS. To improve the proposed scheme performance, the subtractive clustering method, through historical data, was implemented to identify the optimal membership functions in the fuzzy system.

In significantly dense cellular networks, an adaptable HO scheme was suggested by [40] to reduce HO delay. The HO procedure was skipped through this scheme with several BSs throughout the users' trajectories. The assessment and examination of this scheme execution for the single HO skipping have significant advantages in various practical phenomena. Meanwhile, in [41], the authors presented a modern review of various HO schemes and algorithms in the scenario related to high-speed mobile to classify and discuss the different HO schemes. A review of HO management in LTE and 5G new radio (5G NR) was conducted by [42] to emphasize the major contrasts between the essential HO phenomena. Moreover, the article suggested and discussed enhancing techniques for HO management.

2.5. Related Works. Most of the existing works considered HCPs, either TTT, HOM, or both, in developing their algorithms. This subsection discusses a part of the previous related studies.

In [9], the authors investigated the optimization of HO in next-generation mobile communication networks. The study also presented a dynamic HO optimization (DHO) strategy motivated by data to address issues in mobility, such as needless HO, HO to the wrong cell, too late HO, too early HO, and HOPP. The DHO technique has four key components: (1) identifying mobility problems, (2) designing KPIs, (3) estimating KPI functions, and (4) optimizing HO parameters. LTE-Sim, an open-source framework designed to model LTE networks, was utilized as the primary computer model to assess the outcomes. The HO parameters, including the HOM and TTT, were adjusted based on the model for better performance measurement expressed as a weighted average of multiple ratios of mobility problems. The simulation results showed that the proposed DHO approach could effectively minimize mobility problems and enhance connectivity.

In [10], the authors investigated the cumulative effect of HCP, such as HOM, $A3_{\text{offset}}$ (event A3, when the *RSRP* of the serving cell plus HOM is worse than the *RSRP* of the neighbor cell), and TTT. They also performed an analysis in connection with the angle of UE movement and intersite

distance. Following the analysis, a regression-based prediction (RBP) model was introduced for HCP configuration. The framing rules were not dependent on expert knowledge. The paper performed testing and simulation and showed that the proposed model's performance excelled other evaluated techniques in relation to eNB service coverage and zones for successful HO. A comparison was also made to three considered literature techniques, where the developed RBP model was found to be capable of improving the performance for both measures. HO performance was consistent as the proposed solution depended on network and UE-based distance-related metrics. Overall, HO performance was significantly improved when contrasted to a dedicated HCP setup.

In [11], the author investigated the HCPs, including TTT, HOM, and offset. The technique used to adapt the HCPs is called particle swarm optimization (PSO). Moreover, the author considered a self-organized network to improve the system performance by tuning the mobility load balancing and PSO. The evaluated HO performance metrics are HOPP and HOF in traffic loads and dynamic user mobility. According to the simulation results, the HOPP and HOF are greatly improved compared with the considered literature techniques.

In [12], the author proposed two techniques, which are carrier aggregation deployment scenarios and weight performance function, to improve the HO performance. The techniques are aimed at adapting the HCPs automatically. The results illustrate a remarkable enhancement in the UE's spectral efficiency and low outage probability.

In [13], the authors introduced a unique HO optimization algorithm for LTE networks. The proposed algorithm worked by experimenting with different HOM and TTT values monitoring the output performance that corresponded to the values of these parameters and then choosing values that provided the best performance. Simulations were used to assess the performance of the presented HO optimization method. The simulation results were compared to the basic LTE HO algorithm under various UE speed scenarios as well as other reference works, which later revealed that the proposed Q-learning technique effectively enhanced network performance (i.e., minimum HO, maximum system throughput, and minimum system delay).

3. System Model

This section provides the simulation environment and the parameters used in the simulation. Moreover, this section discusses the performance matrices used to evaluate the system.

3.1. Simulation Setup. The simulation environment has been developed in MATLAB R2020b to test the effectiveness of HCPs in the HO performance for the B5G network. The simulation parameters are adjusted according to 3GPP Release 16 [43–45] and illustrated in Table 1. As shown in Figure 2, 61 gNBs are deployed in a (3 km × 3 km) simulation environment (coverage area), and the distance coverage of each BS is 200 m. The UEs are set to move straight but

TABLE 1: Simulation parameters.

Parameter	Assumption
Cell layout	Hexagonal grid
Number of gNBs	61
Number of sectors	3
Number of measured UEs	20
Number of traffic UEs	200/cell
Cell radius	200 m
Carrier frequency	28 GHz
System bandwidth	500 MHz
White noise power density	-174 dBm/Hz
Path loss	Release 16, 3GPP UMi model
gNB noise figure	10 dB
UE noise power	10 dB
gNB height	10 m
UE height	1.5 m
UE speeds	[20, 40, 80, 120, 160, 200] km/h
UE power	23 dBm
Transmit power	35 dBm
Mobility model	8 straight directions [45°]

randomly in the green bounded circle with eight directions (45°) within the simulation environment. They are supposed to pass through BSs with six different scenario speeds, 20, 40, 80, 120, 160, and 200 km/h. Once a UE reaches the edge of the green area, it randomly changes its movement direction. In addition, different system settings of investigated HOM and TTT, as presented in Table 2, are applied in the simulation. The setting values for TTT and HOM are selected as low, medium, and high levels. Figure 3 illustrates the flow-chart of the general simulation model with the HO decision algorithm. $RSRP_s$, $RSRP_t$, and T represent the RSRP from a gNB source, RSRP from a gNB target, and simulation time, respectively.

3.2. Performance Metrics. The following subsections present the used performance matrices. To investigate the HCPs' performance in B5G networks, we have used the HOPP, RLF, RSRP, HIT, HOP, and HOF as performance matrices.

3.2.1. RSRP. RSRP indicates the power level (or simply strength of signals) received in cellular networks, including B5G and LTE. The average signal strength or average RSRP indicates the power level or strength associated with a particular reference signal.

RSRP is evaluated in LTE networks by obtaining an average of the overall strength of all resource elements that transmit the cell-specific reference signals. From another aspect, RSRP for B5G networks (also known as secondary synchronization SS-RSRP) is calculated based on secondary synchronization signals. These synchronization signals, which are specific to each cell, are transmitted using the source elements.

The significance of the metric of RSRP in LTE and B5G networks cannot be denied because it is used extensively

during cell selection, HO, power control, and cell reselection procedures [46].

RSRP is associated with the measurement of the signal strength associated with the downlink channel or, in other words, the signals directed toward UE. The 3GPP community classified the RSRP into three categories as follows: weak RSRP (ranging between -160 and -95 dBm), moderate RSRP (ranging between -100 and -73 dBm), and strong RSRP (ranging from -80 to -20 dBm) [47, 48].

3.2.2. HOPP. The HOPP (Figure 4) is the frequent HO that happens between two neighbor cells. The frequent movement of the UE between the boundaries of the two neighbor cells results in a ping-pong effect because of high signal fluctuations [5].

The HOPP ratio is calculated as the number of HOPP divided by the total number of HO, as in the following:

$$N_{\text{HOPP}} = \frac{N_{\text{HOPP}}}{N_{\text{HO}}}, \quad (1)$$

where N_{HOPP} is the HOPP ratio, while N_{HO} is the total number of HOs (HO failure + successful HO).

The instantaneous average HOPP probability ($\overline{\text{HOPP}}$) over every UE can be given as follows:

$$\overline{\text{HOPP}} = \frac{\sum_{i=1}^{N_{\text{UE}}} N_{\text{HOPP}}(i)}{N_{\text{UE}}}, \quad (2)$$

where i is the corresponding number of the measured user and N_{UE} the total number of measured UEs.

3.2.3. RLF. An RLF is identified when the backward HO signaling with the source cell cannot function properly. In such a condition, the failure implies that despite favorable radio conditions for decoding measurement reports received from the UE by the source gNB and the consequent signals to the target cell for the execution of HO, the UEs are unable to decode the HO command received from the source gNB. When an RLF is identified during a HO, the UEs execute a recovery procedure. In this process, the RLF timer is switched on as soon as UE detects the radio link issues. The RLF timer is usually set at 500 or 1000 ms [49]. The service provider adjusts the RLF timer based on drive tests within the network. Once the RLF time expires, UE sends a connection request to another target cell without disconnecting from the existing cell. UE manages to connect to the target cell if the source gNB has already organized the target cell on receipt of the measurement report from the UE. This process is more time-consuming than the backward HO procedure leading to prolonged service interruption. However, this procedure prevents the loss of temporarily stored data within the source gNB because of the features of data forwarding and in-order delivery. In Figure 5, RLF is illustrated. The following equation calculates the instantaneous average RLF probability (RLFP) for all UEs:

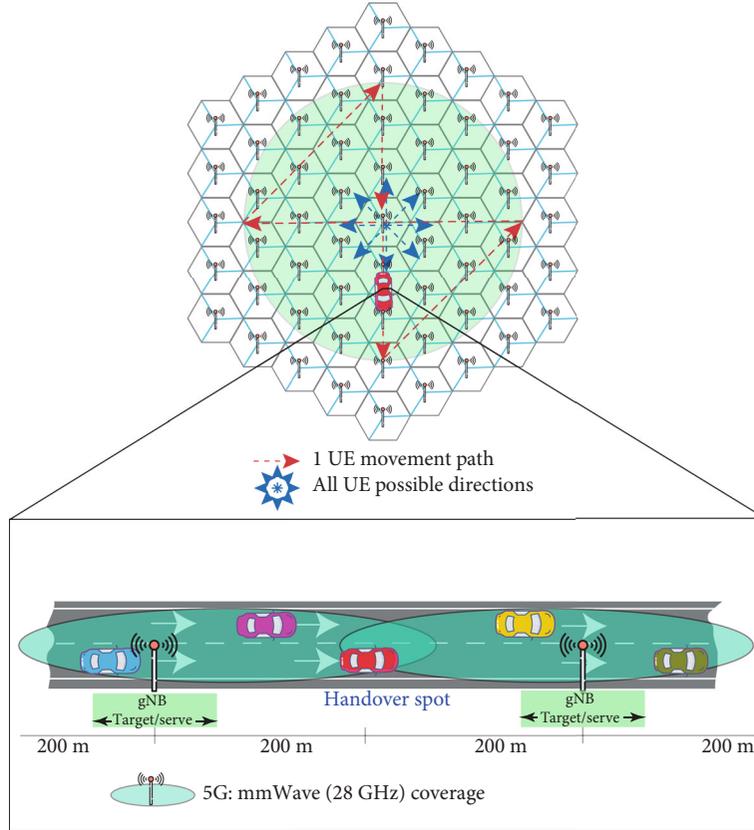


FIGURE 2: B5G network deployment scenario.

TABLE 2: HCP setting.

System number	HOM (dB)	TTT (ms)
HCP1	0	0
HCP2	8	60
HCP3	2	320
HCP4	5	320
HCP5	8	320
HCP6	8	4800

$$\overline{\text{RLFP}} = \frac{\sum_{i=1}^{N_{\text{UE}}} \text{RLFP}(i)}{N_{\text{UE}}}, \quad (3)$$

where i is the corresponding number of the measured user and N_{UE} the total number of measured UEs.

3.2.4. HIT. The HIT is the instant during the execution of HO when an interruption occurs in the user data exchange between source and target cell by the mobile terminal. This notion suggests that HIT is the minimum time supported by a cellular network in the course of HO.

The HIT ranges from 30 to 60 ms for a 4G LTE deployment [50]. The factors affecting this HIT include HO and radio conditions. The 3GPP community is aimed at reducing the HIT in the future to allow the effective use

of B5G wireless technologies in future applications. The HIT can be precisely reduced to around 0 ms in B5G networks [51].

3.2.5. HOP. HOP is the probability of HO when the UE moves from one cell to another. Similarly, HOP represents the percentage of HO occurring. One of the cases that increase the HOP is the HOPP.

Increasing HOP leads to an increase in the system complexity and affects the overall performance. The average of HOP in the network in each simulation cycle and overall UEs is calculated in the following expression:

$$\overline{\text{HOP}} = \frac{\sum_{i=1}^{N_{\text{UE}}} P_i(\text{HO})}{N_{\text{UE}}}, \quad (4)$$

where N_{UE} is the number of UEs.

3.2.6. HOF. HOF probability (HOFPP) is an important metric that evaluates the system's performance. HOFPP is the probability of the unsuccessful HO. HOFPP increases as the HOP increases. Moreover, HOFPP can be defined as follows:

$$\overline{\text{HOF}} = \frac{\text{Number of unsuccessful HO}}{\text{Total Number of HO}}. \quad (5)$$

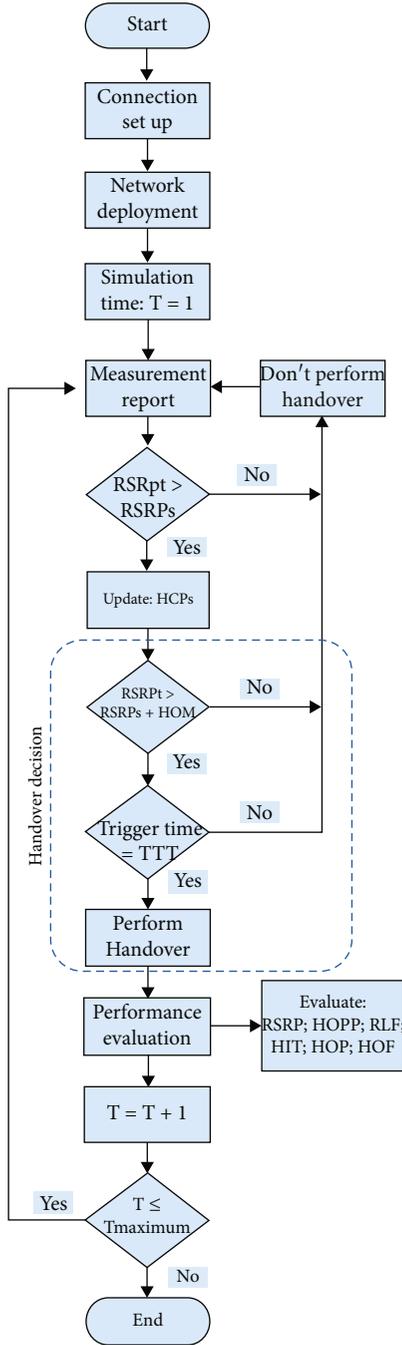


FIGURE 3: Simulation flowchart with HO decision algorithm in the developed simulation model.

4. Results and Discussions

In this section, the results of the fixed HCP investigation are presented. Various fixed HCPs have been studied to investigate the effectiveness of the HO performance in the B5G system. Several HO performance metrics have been considered, such as RSRP, HOPP, RLF, HIT, HO rate, and HOF over different speed scenarios.

4.1. RSRP. RSRP is an important factor in making HO's decision to switch a radio link connection from one cell to

another. Figure 6 shows the effect of different fixed HCP values over mobile speeds and overall measured UEs. The HCP1 appears the highest RSRP levels when the HCPs are set to very small values, whereas HCP6 achieves the lowest RSRP levels when the HCPs are set to high values. The RSRP level slightly decreases as the UEs' speed increases for all HCP settings. Increasing values of the HCPs enable the UE to stay connected to the source cell longer. Thus, UE remains away from the source until the signal weakens. Overall, the speeds do not significantly affect the RSRP when HCPs are set at very low, low, and moderate levels. RSRP is considerably affected when the values of HOM and TTT are very large, HCP6. Also, as shown in HCP3, HCP4, and HCP5, the performance of the RSRP is almost similar; this is when the TTT is fixed at 320 ms, and HOM is changed. Consequently, RSRP performance is highly affected by TTT greater than by HOM. Moreover, the results indicated that setting HCP at low values keeps the connection of UE to gNB with strong RSRP due to UE changing its connection to new gNB fast before the signal drop. However, changing UE's connection between the cells increases the HOPP probability, as observed and discussed in the HOPP subsection. Therefore, setting HCPs properly is essential to avoid the conflict between the different HO performance metrics.

Figure 7 demonstrates the average serving RSRP overall measured UEs and overall mobile speeds regarding simulation times for 30 seconds. The average serving cell of RSRP decays as the simulation time increases. As seen in HCP6, the average RSRP is dramatically decreased as the simulation times increase since the HCPs are set with large values. In other words, the strongest RSRP can be obtained by setting the HCPs with low values, which allows the UE to make HO in a short time. Furthermore, as the simulation times increase, the UE moves away from the serving cell.

4.2. HOPP. HOPP probability is another important performance metric that has been investigated in fixed HCPs. Figure 8 shows the HOPP probability over different mobile speeds for all HCPs.

Generally, the average probability of HOPP decreases as the mobile speeds increase for all HCPs. This can be explained since the UE moves to the target cell faster as the speeds increase and the potential of the link to reconnect to the serving cell is low. The highest HOPP probability is seen in HCP1, with zero HOM and TTT values. In addition, a zero probability is shown with HCP6, which has very large values for TTT and HOM. The second-highest ratio appears for HCP2, which has a small value of TTT and a large HOM level. The other HCPs, such as HCP3, HCP4, and HCP5, demonstrate very low HOPP probabilities, approximately below 70% at 20 km/h and gradually decrease to 0% as the mobile speeds increase. Furthermore, the setting of the TTT level affects the HOPP probability more than HOM does, as shown in HCP3, HCP4, and HCP5. The TTT level was fixed with one value (320 ms), whereas the HOM varied with different values (2, 5, and 8 dB).

Figure 9 demonstrates the average HOPP probability of overall users and mobile speed scenarios for a simulation

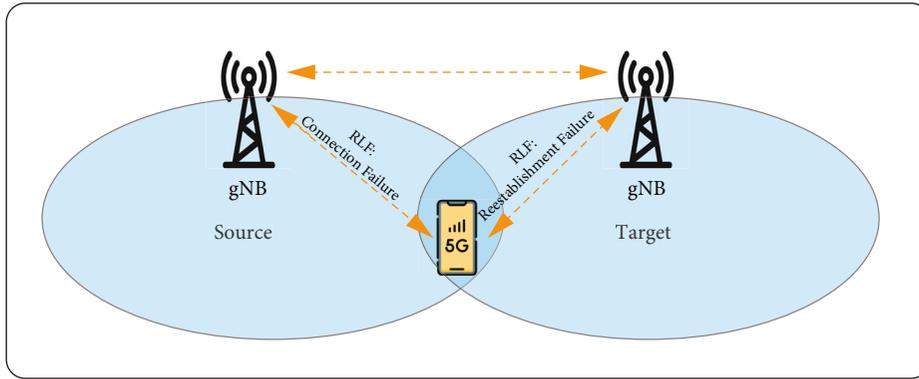


FIGURE 4: Illustration of HOPP occurrence at the cell edge of BS coverage.

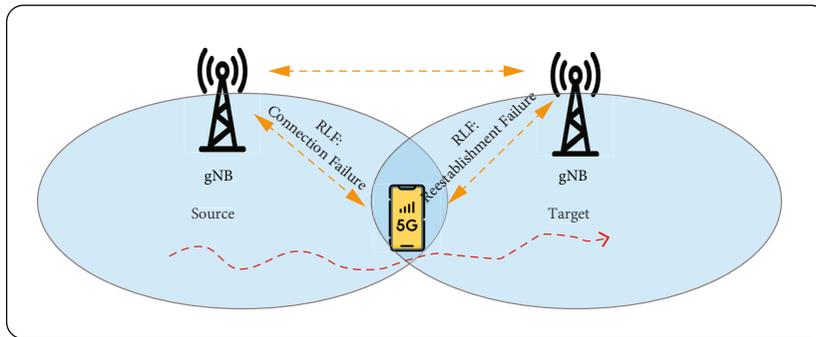


FIGURE 5: Illustration of RLF occurrence during mobility of UEs.

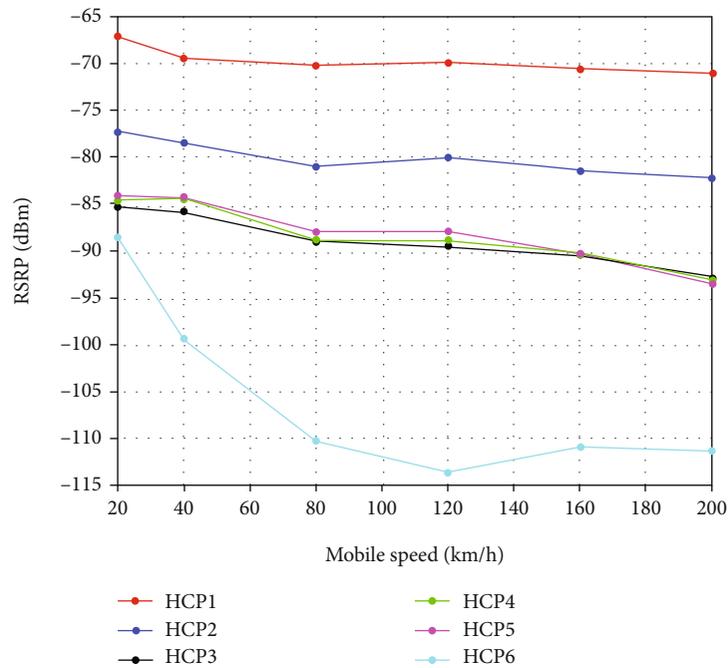


FIGURE 6: Impact of mobile speeds in RSRP.

time of 30 seconds. All the HCPs display smooth fluctuation probabilities along the simulation time except HCP6. The probabilities started from zero and sharply increased, as

shown in HCP1 and HCP2, until 0.5 seconds. Then, the fluctuations continued almost steady. In HCP6, the HOPP probability is persistent at 0% along with all simulation time.

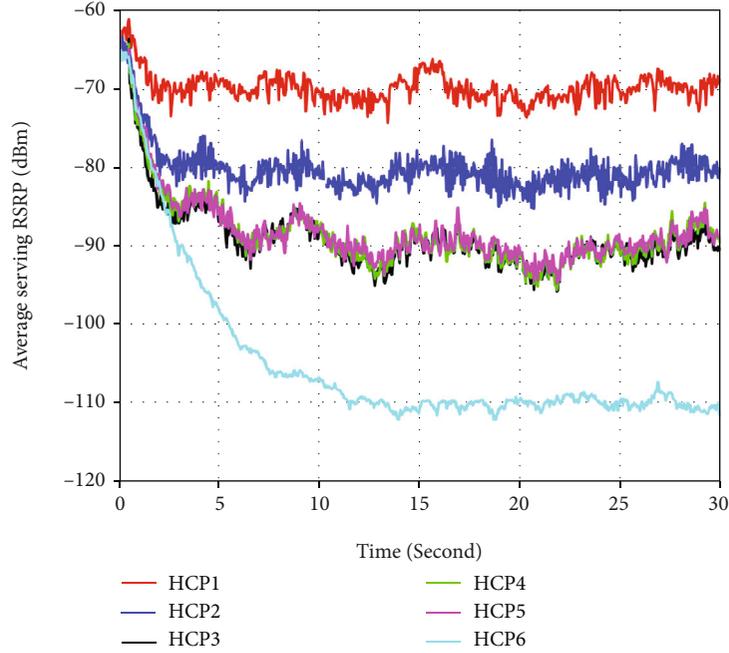


FIGURE 7: Average RSRP probability overall users and mobile speeds vs. simulation times.

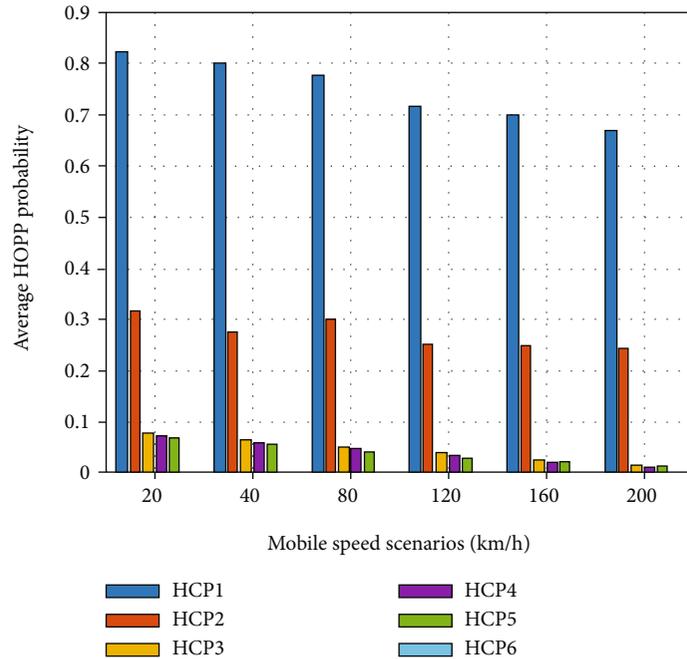


FIGURE 8: HOPP probability versus mobile speed scenarios.

Overall, large values of HCPs provide a steady and low HOPP probability. However, RLFP is increased, as shown and discussed in the next subsection.

In summary, the characteristics of the mmWave, which provides short coverage and deployment of small dense cells, affect the HOPP. In other words, the HOPP increases as the number of cells increases. However, using mmWave and SDNs is the primary key to fulfilling the growing number of connected devices and massive traffic

requirements. The setting of HCPs with low values results in increasing the HOPP probability. The justification of this phenomenon is that low values of HCPs lead to making an early and unnecessary HO process. Additionally, giving zero TTT and HOM means zero waiting time for HO decisions. Furthermore, HOPP may increase when the UE stays at the cell edges for a long time. Therefore, adjusting adequately HCPs helps reduce the HOPP probability and enhance the overall system performance.

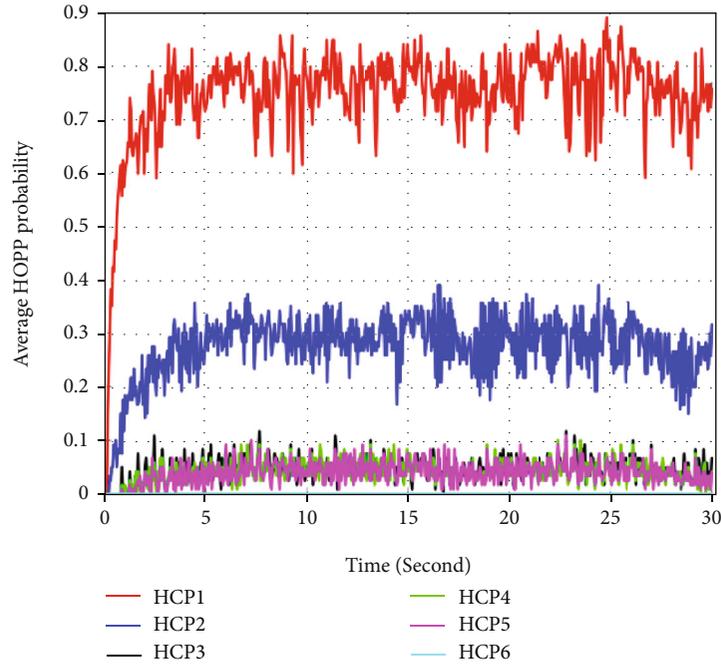


FIGURE 9: Average HOPP probability overall users and mobile speeds vs. simulation times.

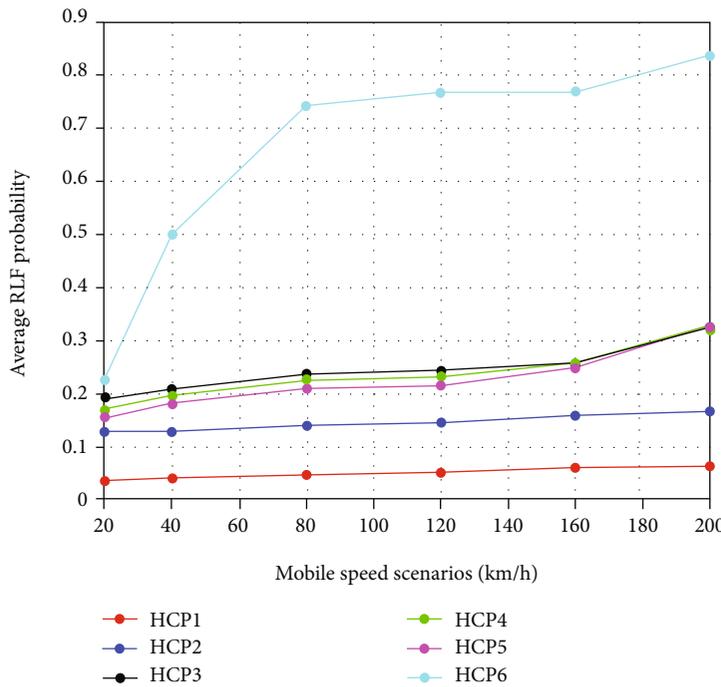


FIGURE 10: RLF probability over different mobile speed scenarios.

4.3. *RLF*. Network quality mainly depends on the RLF performance. Figure 10 presents the average RLFP versus six mobile speeds scenarios for the six HCPs. The lowest RLFP is seen in HCP1, 2%, with zero values for TTT and HOM. By contrast, the HCP6 achieves the highest RLFP, up to 84% at 200 km/h, with very large TTT and HOM values with 4800 ms and 8 dB, respectively. In addition, the RLFP for HCP6 dramatically increases at speeds of 20, 40, and

80 km/h and almost remains steady for the rest of mobile speeds, with a slight increase at 200 km/h. Concisely, the RLFP increases as the mobile speed increases, which means a positive relationship between the RLFP and mobile speeds. Furthermore, the increase in the RLFP is a faint increase except in HCP6, which has very large TTT and HOM values.

In Figure 11, the results show the average RLFP overall users and mobile speeds scenarios for simulation times of

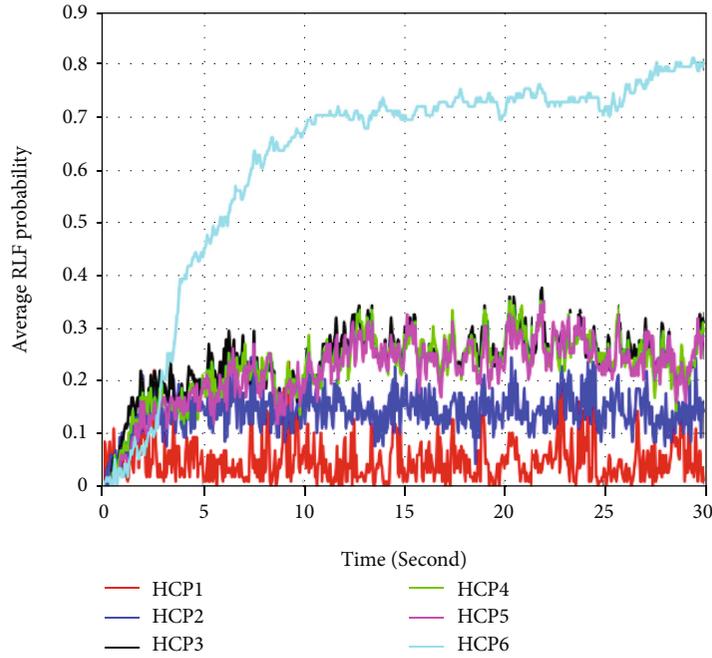


FIGURE 11: Average RLF probability overall users and mobile speeds vs. simulation times.

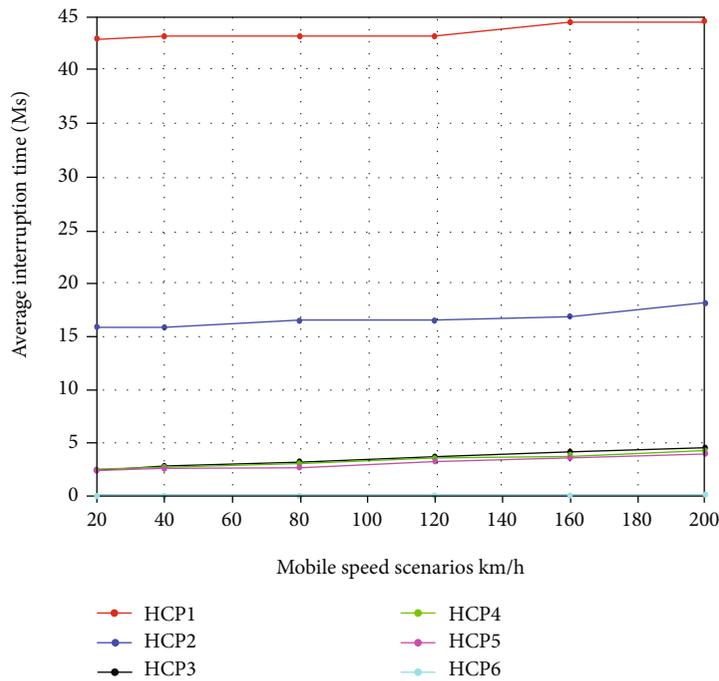


FIGURE 12: Average HIT probability overall users with mobile speeds.

30 seconds. The overall probability for all HCPs is between 0% and 20%. HCP1 has a considerable fluctuation along the time. Furthermore, HCP6 drastically increases at 2 seconds and continues rising. Unlike HOPP, RLF obtains better performance when the HCPs are setting at low levels and low mobile speeds. In addition, high levels of HCPs increase RLFP dramatically, up to 80% in HCP6, and may affect the overall system performance.

In summary, RLF is a critical metric that should be considered when evaluating the HO performance. As the RLF results show, the large HCP values increase in the RLFP. Nevertheless, RLFP is reduced as the HCPs are reduced, which explains that these small values of HCPs make the HO decision performs early, whereas the signal is still good. The large values of HCPs delay the HO decision, which keeps the link longer, and simultaneously, the

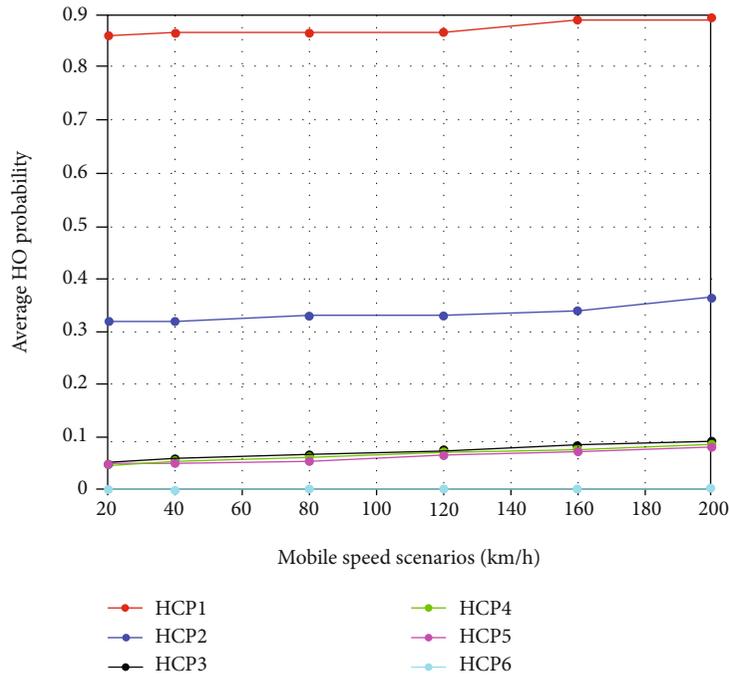


FIGURE 13: The HO probability at different mobile speeds.

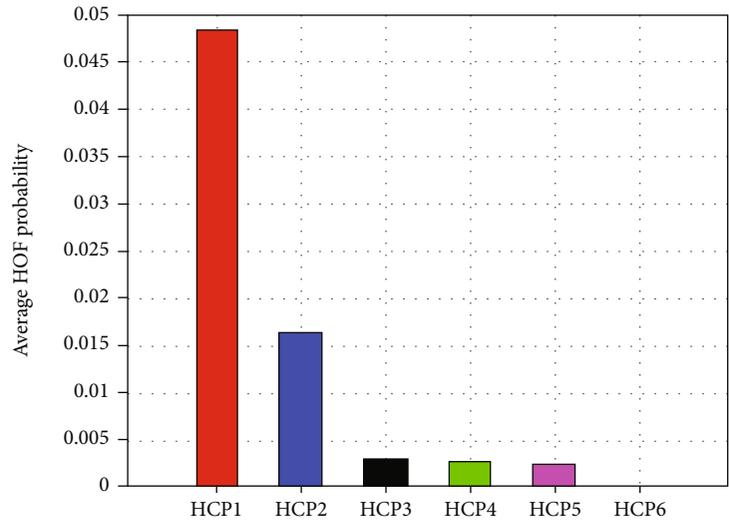


FIGURE 14: HOF probability overall mobile speed scenarios and simulation times.

UE moves away from the serving cell. Moreover, the RLF and HOPP have a conflict in their performance. In other words, the large values of HCPs reduce the HOPP and simultaneously increase the RLF. Therefore, developing algorithms that can appropriately adjust the HCPs and make the best tradeoff between the different HO KPIs are vital in B5G networks to provide optimum system performance.

4.4. HIT. The HIT investigates the duration between a stop and resumes UE transmissions through U-plane. If the HO execution phase starts or RLF is detected, its connection is stopped. Figure 12 illustrates the average HIT versus mobile

speed scenarios. HCP1 indicates the worse average HIT with an average value of 43 ms overall speeds since the HCPs are set with large values. On the contrary, HCP6 attains the lowest HIT, approximately 0.02 ms, because it is set with zero values of TTT and HOM. Hence, increases in the HCP values lead to an increase in the HIT and vice versa. HCP3, HCP4, and HCP5 almost have the same HIT because of the same TTT setting for all three HCPs, 320 ms, regardless of HOM values. In addition, HCP2 that has TTT = 60 ms, larger than HCP1 and smaller than the TTT of the rest, shows lower HIT than HCP1 and larger than the other three HCPs. Overall, similar to HOPP, HIT is improved as the HCPs are set with large levels and achieved the optimum

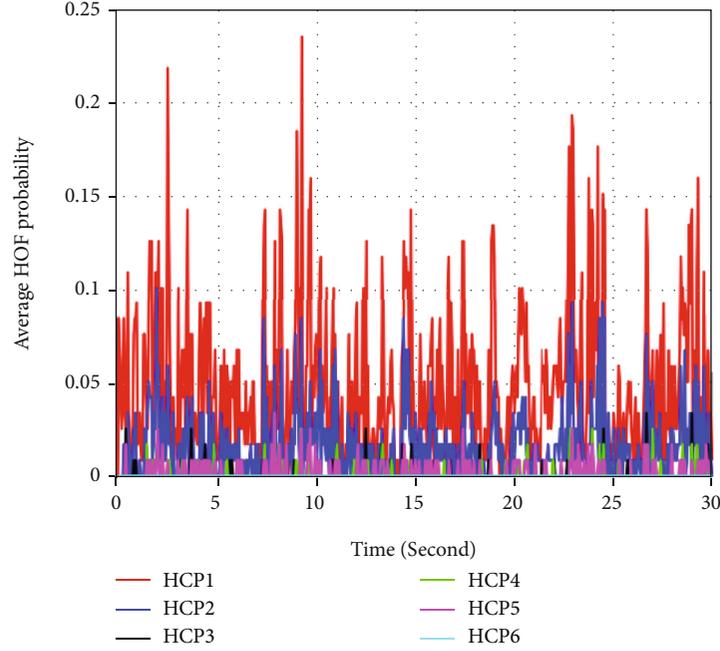


FIGURE 15: Average HOF probability overall users and mobile speeds vs. simulation times.

TABLE 3: Comparison of HO performance for all HCPs.

	HCP1	HCP2	HCP3	HCP4	HCP5	HCP6	Average
RSRP (dBm)	-69.7	-80	-88.8	-88	-87.9	-105.7	-86.68
HOPP (%)	74.8	27	4.5	4	3.8	0	19.01
RLF (%)	4.8	14	24	23	22	64	25.30
HIT (ms)	43.5	16.5	3.4	3.2	3	0.02	11.60
HOP (%)	87	33	6.9	6.5	6	0.05	23.24
HOF (%)	4.8	1.6	0.29	0.26	0.23	0	1.19

TABLE 4: Average HO performance gain for all HCPs compared to the best system performance considering HCP1 and HCP6 as the benchmark.

	HCP1	HCP2	HCP3	HCP4	HCP5	HCP6	Average
RSRP (%)	100	87.13	78.49	79.2	79.29	65.94	81.68
HOPP (%)	25.2	73	95.5	96	96.2	100	80.98
RLF (%)	100	34.29	20	20.87	21.8	7.5	34.07
HIT (%)	0.05	0.12	0.59	0.63	0.67	100	17.01
HOP (%)	0.06	0.15	0.72	0.77	0.84	100	17.09
HOF (%)	95.2	98.4	99.71	99.74	99.77	100	98.80
Overall outcome (%)	53.42	48.85	49.17	49.54	49.91	78.91	54.94

case with HCP6, which has TTT = 480 seconds and HOM = 8 dB. However, other HO KPIs, such as RLF and RSRP, are contrary affected.

4.5. HOP. HOP is one of the HO performance metrics that evaluate a user's probability to HO, that is, a radio communication link from serving gNB to targeting gNB. Figure 13 shows the average HOP for all selected HCPs at different mobile speeds. HCP1 achieves the worse HOP with around

90% at a mobile speed of 200 km/h, whereas HCP6 obtains the best HOP with approximately 0.05% for all mobile speeds. This result can be explained due to HCP1 and HCP6 being set by small and high values of TTT 4800 ms and TTT 60 ms, respectively. HCP2 ranks as the second-highest HOP with an average of 30%. Other HCPs (HCP3, HCP4, and HCP5) attain approximately similar HOP below 10% because of a similar setting of TTT values and a slight change in HOM. Moreover, the mobile speeds have a slight

TABLE 5: Summary of HCPs on HO performance with different KPIs.

UE speed	HOM (dB)	TTT (ms)	RSRP		HOPP		RLF		HIT		HOP		HOF	
			I/D	P	I/D	P	I/D	P	I/D	P	I/D	P	I/D	P
Increase	0	0	Decrease	Best	Decrease	Worse	Increase	Best	Increase	Worse	Increase	Worse	Increase	Worse
Increase	8	60	Decrease	Good	Decrease	Good	Increase	V.Good	Increase	Good	Increase	Good	Increase	Good
Increase	2	320	Decrease	Good	Decrease	V.Good	Increase	Good	Increase	V.Good	Increase	V.Good	Increase	V.Good
Increase	5	320	Decrease	Good	Decrease	V.Good	Increase	Good	Increase	V.Good	Increase	V.Good	Increase	V.Good
Increase	8	320	Decrease	Good	Decrease	V.Good	Increase	Good	Increase	V.Good	Increase	V.Good	Increase	V.Good
Increase	8	4800	Decrease	Worse	Decrease	Best	Increase	Worse	Increase	Best	Increase	Best	Increase	Best
Decrease	0	0	Increase	Best	Increase	Worse	Decrease	Best	Decrease	Worse	Decrease	Worse	Decrease	Worse
Decrease	8	60	Increase	Good	Increase	Good	Decrease	V.Good	Decrease	Good	Decrease	Good	Decrease	Good
Decrease	2	320	Increase	Good	Increase	V.Good	Decrease	Good	Decrease	V.Good	Decrease	V.Good	Decrease	V.Good
Decrease	5	320	Increase	Good	Increase	V.Good	Decrease	Good	Decrease	V.Good	Decrease	V.Good	Decrease	V.Good
Decrease	8	320	Increase	Good	Increase	V.Good	Decrease	Good	Decrease	V.Good	Decrease	V.Good	Decrease	V.Good
Decrease	8	4800	Increase	Worse	Increase	Best	Decrease	Worse	Decrease	Best	Decrease	Best	Decrease	Best

I, D, P, and V. represent increase, decrease, performance, and very, respectively.

TABLE 6: List of abbreviations.

Abbreviation	Definition
3GPP	The 3rd Generation Partnership Project
4G	Fourth generation
5G	Fifth generation
AMF	Access and mobility management function
B5G	Fifth generation and beyond
BS	Base station
eNB	eNodeB
gNB	gNodeB: 5G next-generation base station
GPS	Global positioning system
HCP	Handover control parameter
HetNet	Heterogeneous network
HIT	Handover interruption time
HO	Handover
HOF	Handover failure
HOPF	Handover failure probability
HOM	Handover margin
HOP	Handover probability
HOPP	Hanover ping pong
IoT	Internet of Things
Km/h	Kilometer per hour
KPIs	Key performance indicators
LTE	Long-term evolution
m	Meter
mmWave	Millimeter wave
ms	Millisecond
PSO	Particle swarm optimization
RATs	Radio access technologies
RBP	Regression-based prediction
RLF	Radio link failure
RLFP	Radio link failure probability
RNN	Recurrent neural network
RSRP	Reference signal received power
RSRQ	Reference signal received quality
RSS	Received signal strength
SDN	Software-defined networking
SS-RSRP	Secondary synchronization-RSRP
TTT	Time to trigger
UDN	Ultradense network
UE	User equipment

effect on the HOP for all HCPs. Additionally, the probabilities of HO for all six HCPs are slightly increased as the mobile speeds increase.

In summary, HOP increases as the number of cells increases and increases with high mobility speeds. Furthermore, increasing the HOP increases the HOPF, which decreases the overall system performance. Moreover, B5G networks that use mmWave and small cell deployment face the challenge of increasing HOP. Large values of HCPs may reduce the number of HOs but simultaneously increase the

RLF. Thus, advanced and intelligent HO algorithms are greatly needed with B5G systems to optimize the HCPs perfectly and address the challenges of mobility management, which is significantly increased with the use of mmWave.

4.6. *HOPF*. HOPF is another important metric that indicates HO performance; increasing HOPF affects system performance and vice versa. Figure 14 depicts HOPF overall speed scenarios and simulation times. The low level of HCPs leads to an increase in the HOPF, as shown in HCP1 when both values of HCPs were set to zero. However, the large values of HCPs result in mitigating the HOPF. Moreover, when HCP6 is set with a high level of TTT and HOM (TTT = 4800 ms and HOM = 8 dB), the achieved HOPF is almost zero, resulting in a negligible probability of HO. Additionally, there is a positive relationship between HOP and HOPF; for example, HOPF increases as HOP increases and conversely.

Figure 15 illustrates HOPF overall users and mobile speed scenarios for simulation times of 30 seconds. HOPF decreases as the values of HCPs increase and vice versa. For example, when the HCPs are set with zero values, HOPF achieves the highest probability. From another aspect, giving a high level of HCPs decreases the HOPF. The fluctuation of all HCP performances along the simulation times represents the increasing and decreasing number of HO and HOF ratios.

Table 3 provides the HO performance for all HCPs, while Table 4 illustrates the average HO performance improvement for all HCPs compared to the best system performance, using HCP1 and HCP6 as a benchmark. Table 5 summarizes the effectiveness of the HCPs on HO performance for the different performance metrics. Also, it shows the relationship between the UE speed (increase/decrease) and various HO performance metrics. For example, if the HCPs are set with zero, RSRP and HOPP decrease as the UE speeds increase (a reverse relationship), whereas the RLF, HIT, HOP, and HOF increase as the UE speed increases (a positive relationship). Table 6 provides the abbreviation list.

5. Conclusion

This study has investigated the effectiveness of HCPs on HO performance in the 5G mobile networks by proposing different HCP system settings. The results are evaluated utilizing different HO KPIs, such as RSRP, HOP, HOPP, RLF, HOPF, and HIT. The results show that the HO performance impacted significantly by the various HCP settings has been investigated. For example, the HOPP probability is highly affected by TTT more than HOM. Moreover, utilizing a high system setting for TTT and HOM, such as 4800 ms and 8 dB, leads to a significant reduction in HOPP probability to approximately 0%. However, the RLF is dramatically increased as TTT and HOM are increased due to the late HO decision. Selecting the ideal HCP settings is essential to provide optimal HO decisions.

Furthermore, sophisticated HO algorithms that can provide accurate HO performance are necessary for mobile

wireless networks, particularly in B5G mobile networks with unique applications, such as high data rate, low latency, and wide bandwidth, compared with the legacy networks. The future mobile networks will use very high-frequency bands (such as mmWave, TeraHertz, and visible light), which provide a very short coverage cell area (i.e., up to 200 m with 28 GHz). Thus, HOP and HOPP will increase further. Furthermore, to achieve a seamless and fast HO, the HCPs must be set appropriately.

The investigation study contributes to the understanding of HCP effectiveness on the HO performance in 5G mobile networks and beyond. That also helps to design efficient HO algorithms. This work will be extended in our future research study by considering further assumptions, system settings scenarios, more KPIs, B5G new use case, and higher mobile speeds in our next phase of study work.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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