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Intelligent coordinated self-optimizing handover scheme for 4G/5G heterogeneous networks

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Abstract

Mobile connections and applications are growing unprecedentedly with the advent and increasing popularity of wireless services worldwide, which greatly increases the demands on data traffic. This led to considering millimeter-wave bands and ultra-dense deployment as part of the key enabler solutions in fifth-generation (5G) networks. However, these solutions radically increase the number of handovers (HOs), thus increasing the rate of unnecessary HO and dropping call probabilities. In this regard, optimizing HO control parameters appropriately is the main factor that can efficiently address HO issues during user mobility. This paper proposes a fuzzy-coordinated self-optimizing HO scheme to achieve a seamless HO while users move in multi-radio access networks. The proposed scheme resolves the conflict between mobility robustness and load balancing functions by utilizing a fuzzy system considering three input parameters: signal-to-interference-plus-noise ratio, cell load and UE speed. Simulation results show that the proposed scheme manages to control the mobility optimization in terms of ping-pong HO, radio link failure and HO latency over different mobile speed scenarios. Moreover, the proposed scheme reduces the outage probability compared to other schemes from literature.

Keywords: Self-optimization; Handover; 5G; HetNets

1. Introduction

The massive deployment of small cells in next-generation networks is expected to boost overall network performance. Deploying small cells is also a solution to increase the capacity and coverage where it is an important concern for telecommunication operators. However, this new mode of deployment, from a technical perspective, adds many new challenges that need to be tackled in the 5G network. Stand alone (SA) and non-SA (NSA) are the two stages that have been introduced as standard-based paths to 5G network deployment [1]. In the NSA stage, 5G is deployed along with long-term evolution (LTE) mainly for increasing data rate, enhancing mobile broadband, and ensuring reliable connectivity. The SA stage is deployed once the technology matures and all 3GPP specifications are ratified. Communication performance in 5G systems and future heterogeneous networks (HetNets) is dramatically affected by the introduction of new radio (NR) bands. The full-scale development of the 5G NR has been introduced in Release 16 [2]. The 5G NR can operate in low- and high-frequency bands ranging from 4.5 GHz to 6 GHz (sub 6 GHz) and from 24.25 to 52.6 GHz (millimeter wave (mmWave)) [3]. However, the high-frequency band provides small coverage because of the extremely short wavelengths. In small area coverage, user mobility and network deployments

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have important roles in communication performance and are intertwined with the channel model [4]. Given the small range of mmWave cells, the deployment is dense and requires frequent access point updates, thus increasing the probability of handover (HO), HO failure (HOF), HO ping pong (HOPP), and radio link failure (RLF) effect [5]. The HO scenario occurs according to signal quality and channel conditions related to user equipment (UE) behavior and HO control parameters (HCPs): time to trigger (TTT) and HO margin (HOM). Thus, investigating communication performance during user mobility in HetNets is crucial to improve user experience.

HCPs are optimized independently in the mobility robustness optimization (MRO) and load balancing optimization (LBO) functions, leading to a conflict issue between these functions. Such issues can hinder overall HO performance and increase RLFs. According to literature, resolving this conflict remains an open issue, and recent studies have still not found optimum solutions. Recent research has focused on addressing the MRO function, and solutions for optimizing either HOM, TTT or both have been proposed [6–8]. In [6], the authors proposed a fuzzy logic control (FLC) scheme to adapt the HOM based on a radio channel quality and user velocity in 4G HetNets. In [7], the authors investigated the effectiveness of HCPs in 5G networks. Various HCP settings are studied with several mobile speed scenarios. The simulation results demonstrated that there is a trade-off between HO performance metrics. The work in [8] presented another solution by disabling the LBO function and integrating the cell load into the MRO function for carrier aggregation in LTE-Advanced (LTE-A) systems. Although these proposed solutions have exhibited improvement in reducing RLFs, the optimum solution remains far from being achieved. In addition, these solutions are inapplicable to ultra-dense HetNets, where the number of HOs increases due to the small size of cells. Nonetheless, addressing this issue and obtaining an optimum solution is possible by coordinating MRO and LBO functions to adjust HCPs in an appropriate manner.

The major contributions of this paper can be summarized as follows:

1. We develop an intelligent coordinated scheme that utilizes a FLC system to adjust HCPs smoothly in accordance with the input parameters: signal-to-interference-plus-noise ratio (SINR), cell load and UE speed.
2. We propose a HO decision algorithm to manage the HO process between serving and target base stations.
3. We evaluate and compare the performance of the proposed scheme using various HO performance metrics with the most existing related work.

This paper is organized as follows. Section 2 describes the system model and simulation environment. Then, the proposed dynamic coordinated HO scheme is explained in Section 3. The performance evaluations of the proposed scheme are discussed in Section 4. Finally, the paper concludes in Section 5.

Table 1
Simulation parameters.

Parameter	Value	
	4G cell	5G cell
Cell radius (m)	500	200
Number of eNB	61	183
Carrier frequency (GHz)	2.1	28
System bandwidth (MHz)	20	500
Transmit power (dBm)	46	30
Inter-HO preparation time (ms)	60	
Measurement time (ms)	50	
Intra-HO preparation time (ms)	10	
UE height (m)	1.5	
SINR threshold (dB)	−10	

2. System model

The system model consists of 61 4G macro hexagonal cells and 183 5G small cells covering an area of 8 × 8 km^2. The small cells are uniformly arranged at the middle of each macro cell's sector. Non-overlapping coverage is assumed for all small cells. This system model is introduced in our previous works [5]. Each sector and small cell is equipped with directional and omni-directional antennas, respectively. The network model supports radio access technology, allowing a UE to connect to a single eNB at the medium access control layer.

The UEs receive their requested traffic over either the small or macrocells. In this work, no restrictive assumptions about any obstacles are considered (i.e. trees, buildings and mountains). Thus, all the monitored UEs are equally moving in various directions with line-of-sight link communications in each simulation time. During HO procedures, the cells directly communicate with each other via the X2 interface [9]. The HO procedure is primarily supported by an X2 interface that can interchange parameter configurations, operational reports, and RLF status. Most of the computational procedures are performed at the base station and other few parts can be performed at the UE side. But when the HO is needed to change the central management unit so it can perform part of the necessary computational procedures. A distributed self-optimization network gathers HO information at each small and macro cell to optimize the HCPs. When a UE moves from a serving cell to an adjacent cell, the status of the UE is monitored by a measurement report that the UE periodically sends to the serving cell. Then, the serving cell makes a HO decision to a target cell according to Algorithm 1. The simulation parameters of this work are listed in Table 1.

3. Proposed handover scheme

Existing HO solutions are uncoordinated in terms of the aspects in which the predicted HCP values optimized by the MRO and LBO functions contradict one another. This contradiction eventually leads to inferior system performance by increasing the rate of RLFs and the probability of outage [10]. Moreover, this issue may become worse in ultradense networks and high-speed mobile users. Thus, existing solutions should

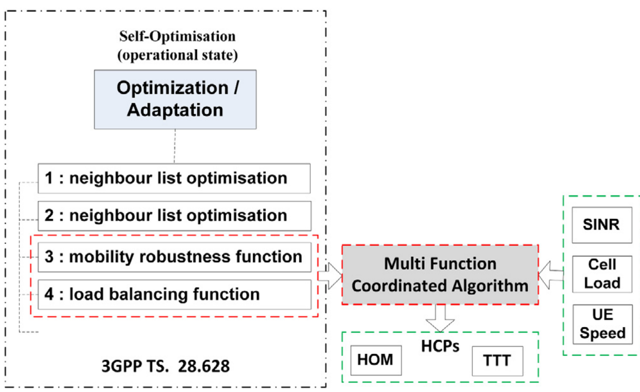

Fig. 1. Framework of the proposed solution scheme.

be improved further to meet the requirements of seamless HO and quality of service. To address this issue, the LBO function is disabled and its input parameter (cell load) is replaced in the proposed dynamic coordinated scheme. The proposed scheme is an intelligent coordinated scheme that utilizes a fuzzy logic control system to adjust HCPs smoothly in accordance with the input parameters: SINR, cell load and UE speed. Fig. 1 illustrates the framework of the proposed scheme. As shown in the figure, the MRO and LBO functions are combined in the proposed scheme to estimate appropriate values for HCPs. In this manner, the conflict issue is eliminated and the complex relation is also reduced.

Fig. 2 displays the block diagram of the proposed scheme. The proposed scheme dynamically self-optimizes the HCPs according to the input parameters of the fuzzy system. The scheme also mitigates the MRO and LBO conflict by considering the cell load parameters in the estimation process of HCPs.

The proposed self-optimization scheme depends on three bounded functions: SINR $f(\gamma)$, cell load $f(\iota)$, and user velocity $f(\nu)$. These functions represent the fuzzy system's inputs, and the weight of each bounded function is utilized to estimate precise values of the HCP (HOM levels and TTT interval) for each UE individually. The weight function $f(\gamma,\iota,\nu)$ for the HCPs can be expressed as follows:

$$f(\gamma,\iota,\nu) = \Omega_\gamma \times f(\gamma) + \Omega_\iota \times f(\iota) + \Omega_\nu \times f(\nu), \tag{1}$$

where Ω_γ, Ω_ι and Ω_ν are the normalized weight of SINR, cell traffic load (TL) and user velocity, respectively. The normalized weights can be given as:

$$\Omega_\gamma = \frac{\omega_\gamma}{\omega_t},\ \Omega_\iota = \frac{\omega_\iota}{\omega_t},\ \Omega_\nu = \frac{\omega_\nu}{\omega_t}, \tag{2}$$

$$\omega_t = \omega_\gamma + \omega_\iota + \omega_\nu, \tag{3}$$

where ω_γ, ω_ι and ω_ν represent the weights for SINR, cell TL, and user velocity, respectively. These weights are assumed constants with a range of values used in the literature according to the functions defined by [10].

3.1. Input linguistic variables

The first function is SINR $f(\gamma)$: it assists the base station to make a HO decision based on indication level of received power at UE and can be expressed as:

$$f(\gamma) = \frac{\gamma_T - \gamma_S}{\gamma_{max}}, \tag{4}$$

where γ_S and γ_T denote the SINR over the target and serving BSs, respectively. γ_{max} denotes the maximum expected level of SINR that can be measured at UE (assumed to be 30 dB) [11]. The fuzzy membership functions have three and four different levels of input and output, respectively, which are defined as:

$$\gamma_T = \gamma_S = \{\text{"}weak\text{"}, \text{"}moderate\text{"}, \text{"}strong\text{"}\},$$
$$\omega_\gamma = \{\text{"}low\text{"}, \text{"}average\text{"}, \text{"}high\text{"}, \text{"}very\ high\text{"}\}.$$

Second function is the cell TL $f(\iota)$: This function represents the LBO which balances the cell load by adjusting the HOM values and TTT intervals to produce appropriate HO decision (HOD) to a target eNB. The second function can be expressed as:

$$f(\iota) = \frac{\iota_T - \iota_S}{\iota_{max}}, \tag{5}$$

where ι_T and ι_S denote the cell load of the target and serving eNBs, respectively. ι_{max} represents the maximum cell load. The FLC of cell load has two fuzzy sets (ι_T and ι_S) inputs and one output set ω_ι, where its membership function consists of three and four different levels for input and output sets, respectively, and can be expressed as follows:

$$\iota_T = \iota_S = \{\text{"}low\text{"}, \text{"}medium\text{"}, \text{"}high\text{"}\},$$
$$\omega_\iota = \{\text{"}low\text{"}, \text{"}average\text{"}, \text{"}high\text{"}, \text{"}very\ high\text{"}\}.$$

Third function is UE velocity $f(\nu)$: The velocity function is also an important parameter to adapt the HCPs in accordance with the UE speed. It aims to assign the adaptive values of the HOM values and TTT intervals in accordance with the UE speed to avoid unnecessary HO that might occur during UE mobility. An unbound function for adjusting the UE velocity is introduced by [12], where it is expressed as:

$$f(\nu) = \log_2(1 + \nu_t). \tag{6}$$

This function is improved further to fit the proposed scheme of this work and can be expressed as:

$$f(\nu) = 2\log_2\left(\frac{\nu_t + \nu_{max}}{\nu_{max}}\right) - 1, \quad -1 \le f(\nu) \le 1 \tag{7}$$

where ν_t and ν_{max} are the UE speed at time t and the maximum UE speed (assumed as 160 km/h) in typical vehicles in urban and suburban areas, respectively. The velocity function is limited by the lower and upper bound (−1,1) where a fast vehicle speed at ν_{max} leads to the maximum upper bound level of $f(\nu)$, whereas a slow vehicle speed leads to the minimum lower bound level of $f(\nu)$. Parameters (ν_t and ν_{max}) are fed as inputs into $f(\nu)$. The FLC of velocity has a single input ν and output ω_ν fuzzy set, where its fuzzy membership function has five and four different levels of input and output sets, respectively, which are defined as:

$$\nu = \{very\ slow, slow, moderate, fast, very\ fast\},$$
$$\omega_\nu = \{\text{"}low\text{"}, \text{"}average\text{"}, \text{"}high\text{"}, \text{"}very\ high\text{"}\}.$$

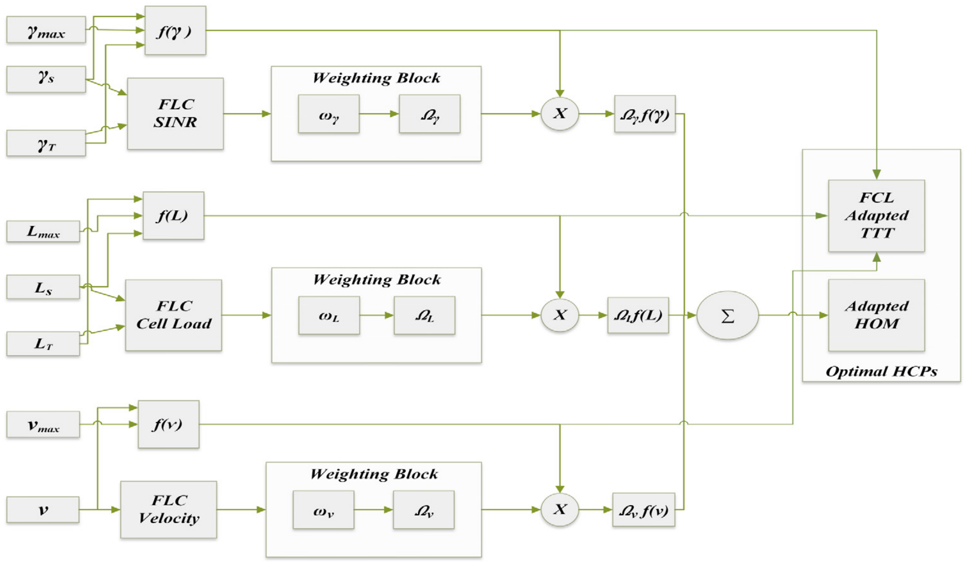

Fig. 2. Block diagram of the proposed scheme.

3.2. Output linguistic variables

The output variables are the main aim of designing the proposed scheme, where they refer to the estimated HOM levels and TTT intervals in accordance with the input functions. The first output is the adapted HOM, $\Delta(HOM)$, it is expressed as the multiplication of the $f(\gamma,\iota,\nu)$ and the $\overline{HOM}$ or HOM_{max}. This output also depends on the SINR level of the target and serving eNBs with respect to the SINR threshold γ_{th}. The estimated value of $\Delta(HOM)$ can be expressed as:

$$\Delta(HOM) = \begin{cases} \overline{HOM}(f(\gamma,\iota,\nu)), \text{if } \gamma_{T,S} \le \gamma_{th} \parallel \gamma_{T,S} \ge \gamma_{th}, \\ HOM_{max}(f(\gamma,\iota,\nu)), \text{if } \gamma_T \le \gamma_{th} \& \gamma_S \ge \gamma_{th}, \\ f(\gamma,\iota,\nu), \text{if } \gamma_S \le \gamma_{th} \& \gamma_T \ge \gamma_{th}, \end{cases} \tag{8}$$

$$\overline{HOM} = \frac{HOM_{max} - HOM_{min}}{2}, \tag{9}$$

where HOM_{min} and HOM_{max} denote the minimum and maximum HOM, which carry values of 0 dB and 12 dB, respectively. The second output is the TTT which produces a tunable value between 0 to 650 ms by adding a new FLC called TTT-FLC with three inputs and one output of fuzzy sets. The TTT-FLC adjusts the TTT interval according to the outputs of the bounded functions. The fuzzy membership function of TTT-FLC has three and four levels of input and output sets, respectively. It can be defined as:

$$f(\gamma), f(\iota), f(\nu) = \{\text{"}low\text{"}, \text{"}moderate\text{"}, \text{"}high\text{"}\},$$

$$\Delta(TTT) = \{\text{"}short\text{"}, \text{"}average\text{"}, \text{"}long\text{"}, \text{"}very\ long\text{"}\}.$$

After updating the $\Delta(HOM)$ and $\Delta(TTT)$, the HOD is taken in accordance with reference signals received power (RSRP) for serving cell $RSRP_S$ and target cell $RSRP_T$. Algorithm 1 illustrates the process of the HO triggering and decision.

Algorithm 1 HO Triggering and Decision

Calculate SINR, cell TL and UE speed
if $RSRP_T > RSRP_S + \Delta(HOM)$ **then**
  if $Trigger\ timer \ge \Delta(TTT)$ **then**
    $HO\ Decision \longleftarrow True$
    Send HO Request
  else $HO\ Decision \longleftarrow false$
    Run Trigger Timer
  end if
else $HO\ Decision \longleftarrow false$
  Reset Trigger Timer
end if

4. Performance evaluation

The performance of the proposed scheme is analyzed and discussed in terms of HOPP, RLF, and HO latency. Simulations are run in MATLAB to investigate and validate the proposed scheme. For network performance evaluation, five mobile speed scenarios were considered: 10 km/h, 40 km/h, 80 km/h, 120 km/h, and 160 km/h. The adjusted values of TTT and HOM during the evaluation of the proposed scheme are investigated. The simulation starts with initial values of 5 dB and 480 ms for HOM and TTT, respectively. These initial values will be adjusted if needed during user measurement when simulation time ($t > 1$). The adjusted values of HOM and TTT estimated by the proposed scheme in accordance with speed scenarios. Moreover, the proposed scheme is compared to the existing scheme (Souza scheme) in [6] that is based on the FLC system.

Fig. 3 shows the average HOPP probability of the proposed and Souza schemes varying respects to various mobile speeds. These results are taken overall monitored users and simulation time. It can be observed that the proposed scheme reduces the HOPP rate comparing with Souza scheme for all the mobile

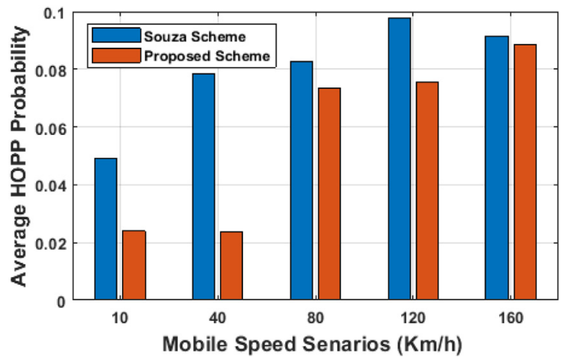

Fig. 3. Average HOPP probability of the proposed and Souza schemes with respect to the mobile speeds.

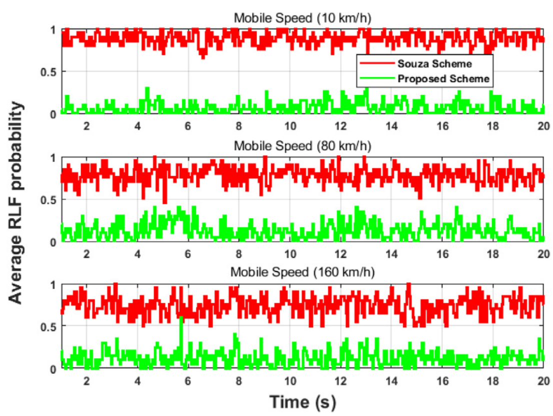

Fig. 4. Average probability of RLF with respect to the mobile speed scenarios.

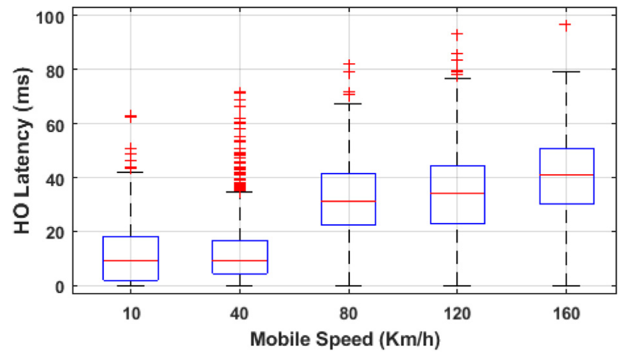

Fig. 5. Average HO latency of the proposed scheme with respect to the mobile speed scenarios.

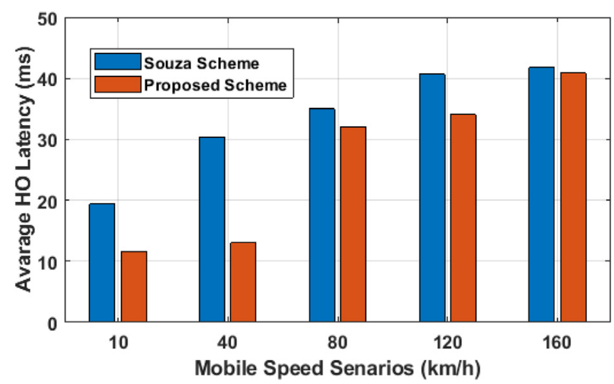

Fig. 6. Average HO latency of different schemes with respect to mobile speed scenarios.

speed scenarios. This is due to the conflict coordination of MRO-LBO functions and optimized HCPs. The significant reduction is mainly attributed to the effective control of the HO operation by avoiding conflict between LBO and MRO. However, the reduction in the HOPP rate reduces the waste in network resources due to the reduction in overhead signaling.

Fig. 4 illustrates the average RLF probability of the proposed and Souza schemes versus time for three different UE speeds. The result exhibits reduction in the RLF rate at low UE mobile speed compared to high speed scenarios. By comparing the results in Fig. 3 with Fig. 4, it can be deduced that a low rate of HOPP may increase the rate of RLF. By contrast, a high rate of HOPP will result in overhead signaling which may decrease the rate of RLF. Therefore, setting proper HCPs values are mitigated by the trade-off between HOPP and RLF.

Fig. 5 demonstrates the boxplot of HO latency versus mobile speed scenarios over all monitored users. It can be observed that the proposed scheme reduces the HO latency further at low speed scenarios (10 km/h and 40 km/h) compared to high speed scenarios. A similar median of HO latency is obtained at high speed scenarios (120 km/h and 160 km/h). The reduction in the HO latency can be attributed to the good coordination between optimization functions. Fig. 6 displays a comparison between the proposed and Souza schemes varying with the mobile speed scenarios. The proposed scheme outperforms Souza scheme for all mobile speeds. This remarkable performance provides better connectivity and reliable network services. Moreover, network resources are reserved by reducing the HOPP rates, as shown in Fig. 3. However, increasing the rate of HO latency leads to transmission of several packets which is disabled during the HO process. Thus, the network experiences an additional time delay in the HO process. Fig. 7 demonstrates the overall outage probability of the proposed and Souza schemes overall monitored users and mobile speeds. The outage probability increases when the UE speed increases. It reduces when the UE moves at a low speed due to selecting the best target eNB with strong SINR and low load. It can be observed that the proposed scheme achieves a smaller outage probability over time than the other schemes. The outage probability gain can be explained by the outage probability event that occurs when the signal strength over the serving eNB fades away below a threshold value. Overall, the proposed scheme achieves a reduction in all HO performance metrics. Thus, the enhancement achieved by the scheme results in a remarkable reduction in the outage probability.

5. Conclusion

This paper introduces a dynamic coordinated HO scheme for LTE-A/5G HetNets that aims to resolve the MRO–LBO conflict. This scheme is based on the weight optimization function, which is evaluated based on input weighted fuzzy and bounded functions. Three FLCs are considered in this scheme, namely SINR, cell load and user velocity, to estimate HCPs for each user independently. An appropriate setting for

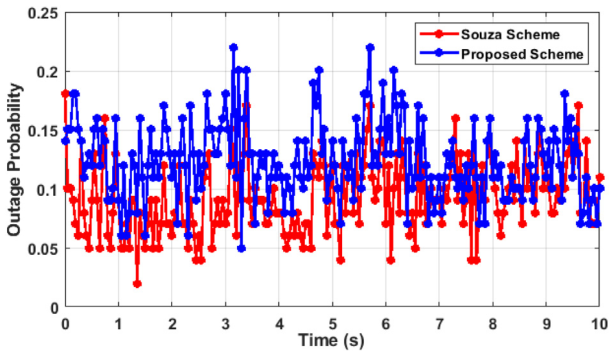

Fig. 7. Overall outage probability versus time.

HCPs leads to accurate HOD, and consequently, improves HO performance. The simulation results demonstrate that the proposed scheme exhibits better performance in terms of cell edge spectral efficiency, HO latency and outage probability. Moreover, it reduces the complex relation between the MRO and LBO functions, providing seamless HO in inter-RAT networks. This finding implies that the considered input parameters and coordination approach are essential for designing intelligent HO schemes for dense urban HetNets to boost total network performance whilst users move amongst cells.

CRediT authorship contribution statement

Abdulraqeb Alhammadi: Concept, Design, Analysis, Writing, Revision of the manuscript. **Wan Haslina Hassan:** Concept, Supervision, Revision of the manuscript. **Ayman A. El-Saleh:** Concept, Supervision, Design, Analysis. **Ibraheem Shayea:** Concept, Design, Analysis, Revision of the manuscript. **Hafizal Mohamad:** Writing, Revision of the manuscript. **Wasan Kadhim Saad:** Concept, Design, Revision of the manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] 3GPP, NR and NG-RAN overall description; stage 2," 2018, Tech. Rep. TS 38.300, 2018.
[2] 3GPP, NR base station (BS) radio transmission and reception, Tech. Rep. TS 38.104, 2018.
[3] 3GPP, Study on channel model for frequencies from 0.5 to 100 GHz, Tech. Rep. TR 38.901, 2019.
[4] M. Tayyab, X. Gelabert, R. Jäntti, A survey on handover management: From LTE to NR, IEEE Access 7 (2019) 118907–118930.
[5] A. Alhammadi, M. Roslee, M.Y. Alias, I. Shayea, S. Alraih, K.S. Mohamed, Auto tuning self-optimization algorithm for mobility management in LTE-A and 5G HetNets, IEEE Access 8 (2019) 294–304.
[6] D.D.S. Souza, R.F. Vieira, M.C.D.R. Seruffo, D.L. Cardoso, A novel heuristic for handover priority in mobile heterogeneous networks, IEEE Access 8 (2019) 4043–4050.
[7] W.K. Saad, I. Shayea, B.J. Hamza, H. Mohamad, Y.I. Daradkeh, W.A. Jabbar, Handover parameters optimisation techniques in 5G networks, Sensors 21 (15) (2021) 5202.
[8] I. Shayea, M. Ergen, A. Azizan, M. Ismail, Y.I. Daradkeh, Individualistic dynamic handover parameter self-optimization algorithm for 5G networks based on automatic weight function, IEEE Access 8 (2020) 214392–214412.
[9] 3GPP, Optimized handover procedures and protocols between E-UTRAN access and CDMA2000 HRPD access; Stage 3, Tech. Rep. TS 29.276, 2017.
[10] I. Shayea, M. Ismail, R. Nordin, M. Ergen, N. Ahmad, N.F. Abdullah, A. Alhammadi, H. Mohamad, New weight function for adapting handover margin level over contiguous carrier aggregation deployment scenarios in LTE-advanced system, Wirel. Pers. Commun. 108 (2) (2019) 1179–1199.
[11] 3GPP, E-UTRA; Physical layer procedures (Release 15), Tech. Rep. TS 36.213, 2019.
[12] M.I. Anwar, A. Khosla, N. Sood, A mobility improvement handover scheme for mobile-WiMAX, Int. J. Comput. Appl. 11 (3) (2010) 28–31.