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Handover in LTE networks with proactive multiple preparation approach and adaptive parameters using fuzzy logic control

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Abstract

High data rates in long-term evolution (LTE) networks can affect the mobility of networks and their performance. The speed and motion of user equipment (UE) can compromise seamless connectivity. However, a proper handover (HO) decision can maintain quality of service (QoS) and increase system throughput. While this may lead to an increase in complexity and operational costs, self-optimization can enhance network performance by improving resource utilization and user experience and by reducing operational and capital expenditure. In this study, we propose the self-optimization of HO parameters based on fuzzy logic control (FLC) and multiple preparation (MP), which we name FuzAMP. Fuzzy logic control can be used to control self-optimized HO parameters, such as the HO margin and time-to-trigger (TTT) based on multiple criteria, viz HO ping pong (HOPP), HO failure (HOF) and UE speeds. A MP approach is adopted to overcome the hard HO (HHO) drawbacks, such as the large delay and unreliable procedures caused by the break-before-make process. The results of this study show that the proposed method significantly reduces HOF, HOPP, and packet loss ratio (PLR) at various UE speeds compared to the HHO and the enhanced weighted performance HO parameter optimization (EWPHPO) algorithms.

Keywords: Multiple preparation, multiple criteria, handover parameters, fuzzy logic control, ping pong handover, handover failure

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1. Introduction

The effective delivery of data at high mobility in long-term evolution networks (LTE) is the main challenge to overcome when trying to enhance network performance. Maintaining a session while the user equipment (UE) moves from one evolved node base-station (eNB) to another is known as handover (HO). The Third Generation Partnership Project (3GPP) specified that there should be hard handover (HHO) for LTE, where the connection with the current eNB is removed first before a new connection is made with the next eNB. The decision on which eNB a UE should be connected to next solely depends on the reference signal received power (RSRP) mechanism [1]. Several parameters, including handover margin (HOM), time-to-trigger (TTT), and layer 3 filtering, have been included in the LTE HO decision-making process to support accurate HO decisions [2]. However, the selection of a good combination of HO parameters is not easy because it depends on the radio network condition, network load, and UE speeds. Monitoring the system after manually changing the HO parameters is laborious and can lead to inaccurate HO decisions. Moreover, when any new features are added to enhance system performance this can increase the complexity and physical size of the system. Therefore, a sophisticated self-optimization HO algorithm is needed to address these drawbacks. The self-organization network (SON) has been used in the European Framework Project FP7 SOCRATES [3], next-generation mobile networks (NGMNs) [4], LTE [5], and LTE-Advanced [6] as it shows promise in terms of minimizing the operational effort and improving the quality of the network. The SON can provide self-configuration, self-healing, and self-optimization mechanisms. These can reduce the need for human intervention in network operations, and thus achieve significant reductions in operational and capital expenditure [3]. Self-optimized HO parameters enhance network performance by reacting to the auto-tuning process in the network.

In the present study, we propose an algorithm that considers a set of multiple criteria and uses fuzzy logic control (FLC) to optimally set the HO parameters (HOM and TTT). This method weighs the tradeoff between HOF and HOPP at various UE speeds. The multiple preparation (MP) technique [7] is used with FLC to overcome the problem of HHO delay and it also enables further adjustment of the HO parameters at all UE speeds. This process is accomplished by reducing the delay in the re-establishment of the radio resource control (RRC) connection and by allowing FLC to apply a wider range of adjustments to the HO parameters. Multiple HO preparations establish RRC connections with multiple eNBs simultaneously. The RRC must be reconfigured if a UE fails to connect with the target eNB. This process can significantly minimize HO delay and thus reduce packet loss. Therefore, the main contribution of this paper is the development of a method, which we name FuzAMP, to enhance the HO mechanism in LTE networks. In FuzAMP, the HO parameters are automatically tuned according to the HOF, HOPP and UE speed that reflect the network condition. This algorithm seeks a minimized balanced tradeoff between HOF and HOPP, and both are used with the UE speed as feedback to the FLC in the upcoming transmission time interval (TTI). With this setup, the HO parameters can be optimally balanced and a very low HOF and HOPP can be achieved. Prior to this balanced state, MP is used to minimize the HO delay, which decreases the packet loss ratio (PLR). This work is implemented on a system-level simulation and the results show its superior performance compared to the HHO and EWPHPO algorithms in significantly reducing HOF, HOPP and PLR.

The rest of this paper is organized as follows: Section 2 presents a review of related work. Section 3 describes the HO procedures in LTE. Section 4 explains the system model, including HO parameters, MP, radio link performance, and FLC. Section 5 presents the proposed algorithm. Section 6 describes the system analysis. Section 7 introduces the simulation setup. Section 8 presents the results and discussion. Section 9 provides the conclusion.

2. Related Work

Several studies have focused on the process of enhancing system performance through self-optimizing HO parameters. The FLC approach has been widely used as a self-optimizing mechanism for the automatic adjustment of network parameters. In [8-12] FLC was employed for load balancing, while in [13-17] FLC was used for HO optimization. Both strands of research show that FLC is a powerful tool for auto-tuning parameters because it can translate linguistic terms into a set of simple, logical rules.

Another mechanism, mobility robustness optimization (MRO), was first introduced in [5] for LTE Rel.9 to overcome HO failure (HOF) and HO ping pong (HOPP). Incorrect HO parameter settings, even when they do not result in radio link failure (RLF), may seriously degrade the user experience. A secondary objective of MRO was to avoid the ping pong effect. Many studies, such as [18-22], have been conducted to fulfill the MRO objectives. The authors in [18-21] proposed adjusting only HOM without considering the impact of TTT, but this may cause an increase in HOPP. In contrast, the authors in [23] proposed tuning only TTT and ignoring the effect of HOM, but this may result in increased HO delay, which leads to increased HOF. The authors in [17] proposed using FLC to adapt HOM for different network conditions while maintaining only two limited values for TTT. However, they did not consider the quality of service (QoS); rather they investigated the grade of service (GoS). The authors in [22] proposed the enhanced weighted performance HO parameter optimization (EWPHPO) algorithm, which considers both HO parameters, HOM and TTT. The EWPHPO enhanced the weighted performance HO parameter optimization (WPHPO) algorithm [24]; the enhancement arises from a rearrangement of the weighted parameters and their priorities. Although the authors in [25] considered all the HO parameters, they lost a certain degree of generality because they assumed that UE speeds are fixed rather than variable. These aforementioned sub-optimal schemes have their limitations, particularly at high speeds, when making tradeoffs between HOF and HOPP.

In [21], the authors presented a process of improving MRO [5], but there are inefficient parameter adjustments because the TTT is considered fixed. The algorithm converges slowly in response to network changes because it requires a large number of HOs to trigger the adjustment. Although [22] presents a method with a faster convergence time, the authors considered only UE with fixed speeds.

In [26], a cost-based adaptive HOM scheme was presented as a self-optimization method. The authors considered the cost function, which consists of many factors that affect only the HOF, in order to adapt HOM accordingly. Even though the method achieved a reduced HOF, the TTT was fixed, resulting in high HOPP. A similar approach was used for heterogeneous networks [27], [28]. In [29] the authors were only interested in reducing HOPP by using HOM and TTT, which are assumed to have fixed values. These two values are chosen based on HOPP feedback from the network at a fixed UE speed. This may lead to a high HOF ratio and degrade network performance due to large HO delays. Consequently, this delay will make the UE stay at non-optimum cells for a longer time, thus increasing interference. The authors in [30] proposed a self-optimized HO to reduce HOPP by adjusting the HO parameters. They assumed that there is no overlapping among cells, so the algorithm optimizes the HO parameters by comparing the number of cell-boundary crossings and the number of HOs that the UE executes. However, this method is inefficient because it ignores HOF. Moreover, generality is lost because there is no overlapping among cells.

It is clear from the above that researchers have not yet been able to design and verify a robust algorithm for HO optimization in which the best tradeoff between HOPP and HOF can be achieved when the algorithm considers HO parameters, full traffic load and various UE speeds in a more realistic environment. Thus the results of the current study demonstrate the significance of the proposed algorithm, FuzAMP, as a powerful solution for HO optimization that improves on existing works.

3. Handover Procedure

A typical HO procedure consists of three phases. The first is the preparation phase when the UE begins sending measurement reports to the serving eNB. Based on the reference symbol, the UE measures the RSRP and reference signal received quality (RSRQ) to indicate to the serving eNB the current network radio condition. If the signal strength of the neighboring eNB is better than the serving eNB event, then event A3 will take place. Event A3 is defined as a triggering event that occurs when a neighbor cell, which is superior to the serving cell, turns into an offset value [2]. Handover preparation involves signaling exchanges between the serving eNB and the target eNB and the UE admission control to the target eNB. These signaling exchanges are accomplished through X2, which is the communication interface between the serving and the target eNB [31].

The second phase is the execution phase, which occurs after the successful preparation of the HO. The HO decision is issued by the serving eNB, the HO command is then sent to the UE, and the serving eNB releases the connection with the UE. The UE then attempts to synchronize and access the target eNB by using the random access channel (RACH). The third phase is the completion phase, which occurs after the UE is successfully synchronized with the target eNB. The UE responds with a RRC HO confirmation message (generated by the RRC layer), which notifies the completion of the HO procedure [1].

4. System Model

4.1 HO parameters

The values of HO hysteresis or HOM and TTT have been specified in the discussion on 3GPP in [2]. The HOM is a parameter used to enter and leave an event condition that initiates the measurement reporting condition. This is shown in **Fig. 1** at points 3 and 4, where its value varies from 0 dB to 10 dB. The TTT is a duration that varies from 0 s to 5.120 s, during which the particular criteria for the event must be fulfilled to trigger a measurement report [2]. This paper uses HOM and TTT as the HO parameters. Equations (1) and (2) represent the entering and the leaving conditions of the cell area, respectively. When the RSRP of the serving eNB drops below the signal-to-interference-plus-noise ratio (SINR) threshold by HOM, the UE enters the HO region. Then the UE in the HO region begins sending measurement reports to the serving eNB. The serving eNB then finds the target eNB. If the RSRP of the serving eNB becomes better than the SINR threshold by HOM, then the UE stops sending measurement reports to the serving eNB.

$$RSRP_i - HOM < SINR_{TH} \tag{1}$$

$$RSRP_i + HOM > SINR_{TH} \tag{2}$$

where $RSRP$ is the reference signal received power and i and j indicate the serving and target eNB, respectively. $SINR_{TH}$ is the threshold value of the signal to interference plus noise ratio. The HO decision is taken according to Eq. (3) for the selected TTT based on the applied algorithm.

$$RSRP_j > RSRP_i + HOM \tag{3}$$

Optimizing HOM and TTT may shift the HO region to an improved radio network operation. However, choosing the optimal HO parameter is not an easy task. Indeed, it may lead to a worse operation region, such as that the red outlined area shown in **Fig. 1**. An increase in TTT results in an increase in HO delay, while an increase in HOM leads to degradation in the quality of the radio connection before the condition of Eq. (3) is satisfied, which may lead to HOF. Therefore, we expect that the self-optimization of HO parameters can reduce HOPP and HOF.

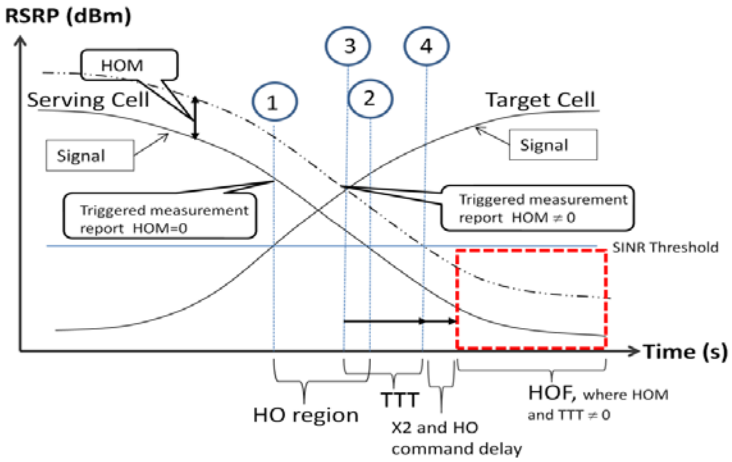


Fig. 1. HO mechanism

4.2 Multiple preparation (MP)

The MP technique is a well-known part of the HO procedure that has been implemented in LTE [7], [32]. The serving eNB in MP can trigger HO preparation in multiple candidate eNBs, although only one of the candidates is indicated as the actual target. This approach speeds up RLF recovery; if the UE fails to connect with the target eNB, it can connect with one of the other prepared candidate eNBs instead. Multiple preparation reduces HO delay and decreases PLR. The source eNB receives only one "RELEASE_RESOURCE" message from the final selected eNB [32]. This process gives users the fair use of resource blocks (RBs) and prevents wastage of radio resources. The RB for the physical RB is the smallest unit of bandwidth assigned to the UE by the eNB scheduler. It contains 12 consecutive subcarriers for one slot of 0.5 ms in the time domain and 180 kHz in the frequency domain [33].

The use of MP in the HO decision process leads to an improved HO procedure with increased QoS and quality of user experience (QoE) as a result of reduced RLF. The QoE is related to the user's perception of the acceptability of service quality and judgment processes experienced by the user [34]. The message exchange during HO preparation includes the following steps [7], which are also shown in **Fig. 2**:

1- Based on the measurement report, HO preparation is initiated by transmitting an HO request from the serving eNB to the indicated candidate HO targets, eNB1 and eNB2, which prompt the RRC connection to be set up.
2- An admission control is conducted on the target base stations, eNB1 and eNB2. This process indicates the successful re-establishment of an RRC connection. The HO is initiated by transmitting an HO request acknowledgment from the target base stations, eNB1 and eNB2, to the serving eNB.

3- The HO request acknowledgment includes feedback information that represents the admission control on the target eNBs and the RRC reconfiguration.
4- The UE is updated with the information on the target eNB selected and finally sends an HO command.

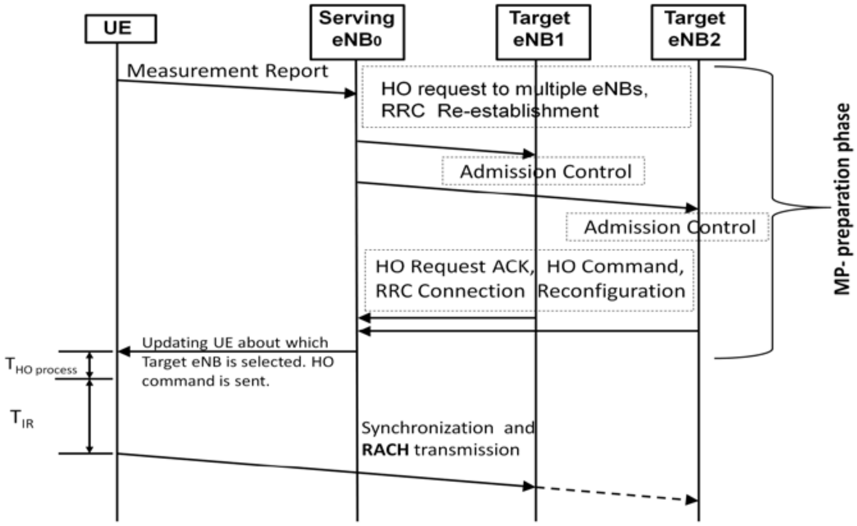


Fig. 2. MP process [7] and HO interruption time T_{IR}

The HO procedure has been explained in section 3. The execution phase begins with an HO command sent by the serving eNB. Interruption in the L1/L2 layers, random access, time alignment, and UL/DL resource assignment occur in this phase. **Fig. 2** shows that the interruption time (T_{IR}) is defined as the duration from the instant when the previous subframe ends to the instant when the UE initiates RACH transmission, as expressed in Eq. (4). This transmission indicates the start of the HO command in the physical downlink shared channel from the serving eNB, which should not exceed the following [35]:

$$T_{IR} = T_{search} + T_{IU} + 20ms \tag{4}$$

where T_{search} is the target cell search delay when the target cell is not known during the reception of the HO command by the UE. $T_{search} = 0$ for known target cells, and the signal quality is sufficient for successful cell detection. Otherwise, $T_{search} = 80$ ms for unknown target cells. The target cell is identified when the cell search requirements are fulfilled in the last 5 s; otherwise, the cell is considered unknown. T_{IU} is the uncertainty of the interruption in acquiring the first available physical random access channel (PRACH) occasion in the target eNB. T_{IU} can reach up to 30 ms [36].

4.3 Radio link performance

The small total latency requirements in LTE constrain the time available for preparing and reporting the measurements and conducting the HO. Enhanced mobility procedures are needed to overcome these challenges. One essential feature of mobility is cell searching, which is needed to identify the unique physical cell identities. The requirements for cell identification are specified in terms of the maximum permissible cell identification delay, which consists of the time needed to detect and synchronize a cell (**Fig. 3**), which depends on RSRP or RSRQ. The HO delay is the total RRC procedure delay in addition to the T_{IR} [35].

The re-establishment of the RRC connection begins when a UE loses its RRC connection in the RRC_CONNECTED state (e.g., because of RLF, HOF, or RRC connection reconfiguration failure) [2]. An RLF occurs when the SINR lies below the threshold of the duration of T310 [37]; the RLF timer is shown in **Fig. 3**. A HOF occurs when the SINR falls below the threshold of the HO execution. There are three main types of HOF, based on the timeliness of their occurrence: 1) an HO may occur too early, that is, shortly after a successful HO; 2) an HO may occur too late, that is, before the HO is initiated or during the HO; and 3) an HO can enter the wrong cell, as in the case of a connection failure shortly after the HO is completed, and the UE attempts to re-establish a new eNB other than the source and the target eNB [38]. HOPP is a successful but unwanted HO because of the increased signaling overhead, delay, and PLR. A HOPP occurs when the UE is returned to the same source eNB within 5 s. The PLR is the ratio of lost packets during HO to the total number of transmitted packets [39].

Fig. 3 illustrates the radio link performance of the serving eNB. When the UE detects a few consecutive "out-of-sync" indications, known as N310, it initiates a network-configured RLF timer T310. By default, the number of N310, 200 ms interval, out-of-sync pulses is 1. Assuming that some consecutive "in-sync" indications called N311 are reported through the UE's physical layer, then timer T310 is stopped. Otherwise, T311 starts when the UE tries to re-establish the RRC connection with the strongest eNB signal. A successful RRC re-establishment implies that the UE can send the "RRCConnectionReestablishmentRequest" message within $T_{re\text{-}establish\_delay}$, and it entails a delay in obtaining the uplink grant used to direct the message along with $T_{UE\text{-}re\text{-}establish\_delay}$. This delay is delineated as the delay from the time when the UE detects the need for RRC re-establishment until a RACH is transmitted to the target eNB. The total delay in re-establishing the RRC is expressed as in Eq. (5):

$$T_{re-establish\_delay} = T_{UL\_grant} + T_{UE\_re-establish\_delay} \qquad (5)$$

where T_{UL_grant} is the time required to acquire and process the uplink grant from the target cell. The uplink grant is required to transmit the "RRCConnectionReestablishmentRequest" message. The UE re-establishment delay may be expressed as follows:

$$T_{UE\_re-establish\_delay} = 50ms + N_{freq} \times T_{search} + T_{SI} + T_{PRACH} \qquad (6)$$

where 50 ms represents the HO delay, including 15 ms of RRC connection. N_{freq} is the total quantity related to the carrier frequencies that are accessible to the RRC re-establishment. T_{SI} is the time needed to read the target cell system information (SI). T_{PRACH} is the delay caused by the random access procedure [35], [36]. The UE's estimation of the downlink radio link quality is compared with the "out-of-sync" and "in-sync" thresholds, Q_{out} and Q_{in}, respectively, to monitor the radio link. These thresholds are stated with reference to the block error rate of a hypothetical physical downlink control channel transmission from the serving eNB [36]. An out-of-sync occurs when no discontinuous reception (DRX) is configured, particularly when the downlink radio link quality calculated through the last 200 ms period becomes poorer than the threshold Q_{out}. The in-sync also occurs without DRX when the downlink radio link quality calculated through the last 100 ms period becomes better than the threshold Q_{in} [35].

The MP factor "*n*" in FuzAMP is assumed to represent the carrier frequencies that are already prepared through MP. In other words, it can be defined as the unknown number of frequencies that are known after MP is configured into multiple target cells. This configuration increases the amount of known carrier frequencies *n* that can be detected by the serving cell. The target cell searching delay is consequently minimized by [40]:

$$n \times T_{search} \qquad (7)$$

Thus, Eq. (6) can be rewritten as follows:

$$T_{UE\_re-establish\_delay} = 50ms + \left(N_{freq} - n\right) \times T_{search} + T_{SI} + T_{PRACH} \qquad (8)$$

This reduction of delay results in a significant reduction of PLR, as demonstrated in the simulation discussed below.

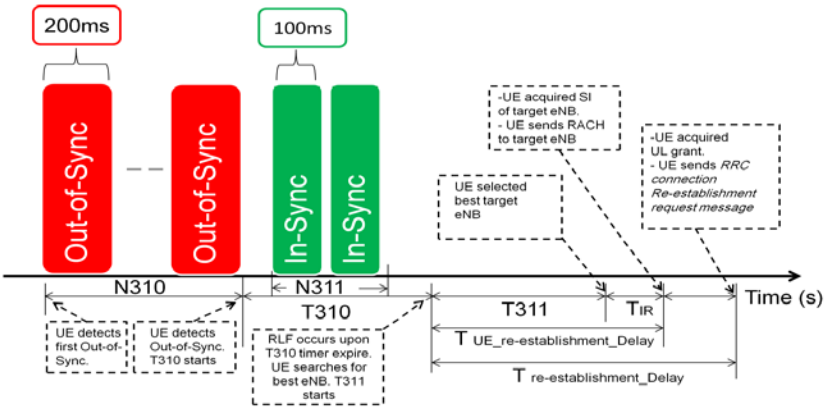


Fig. 3. Radio link performance

4.4. Fuzzy logic control (FLC)

Fuzzy logic (FL) refers to a problem-solving control system methodology (multi-valued logic) that easily reaches a certain conclusion based on vague, ambiguous, imprecise, noisy, or missing input information. Fuzzy logic can be used in hardware or software applications, or in a combination of both. The FL approach to the control problem mimics the way people make decisions in a quick manner and in computer programming [41]. It integrates an easy, rule-based approach (IF X AND Y THEN Z) to solve a control problem instead of modeling a mathematical system. The quantity and the complexity of the rules are determined by the quantity of the input parameters that need to be processed and the quantity of fuzzy variables that are linked to every parameter. The membership function, in which the triangle function is common, is a graphical representation of the magnitude of the participation of each input at the fuzzifier. It assigns a weight to each of the inputs that are processed and defines the functional overlap between the inputs. The fuzzy inference engine develops a decision according to the fuzzy rule-based table. The defuzzifier ultimately determines the output response [42]. **Fig. 4** shows a typical FLC system configuration.

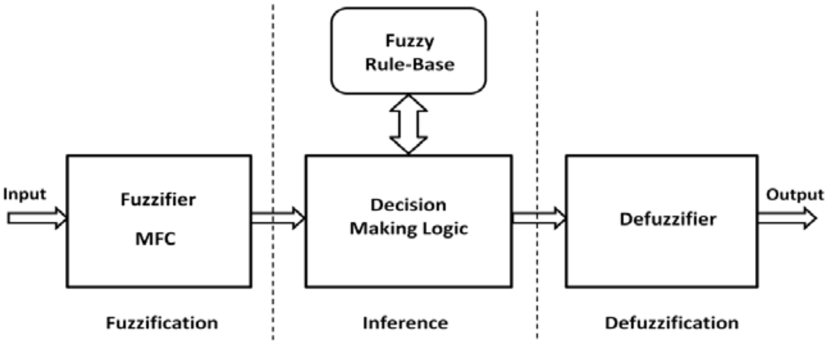


Fig. 4. FLC system configuration

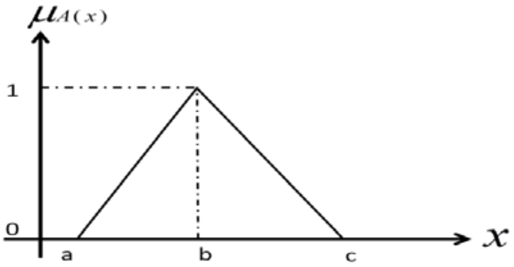
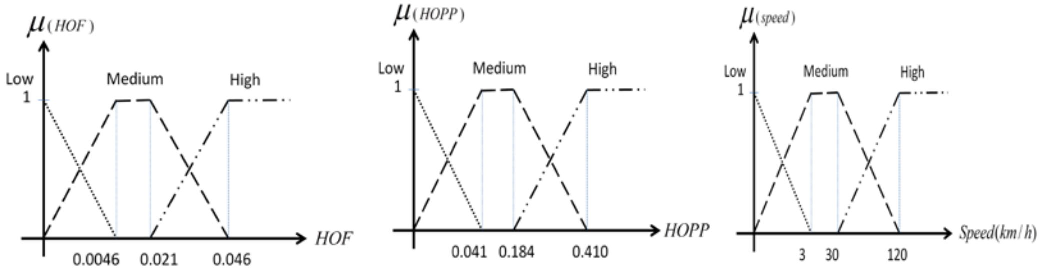


Fig. 5. Triangular membership function at the defuzzifier

$\mu_{A(x)}$ in **Fig. 5** is the degree of membership of element *x* in fuzzy set *A*, and *x* is the FL parameter. The functional mapping is expressed by:

$$\mu_{A(x)} \in [0,1] \tag{9}$$

The triangular membership functions in FuzAMP are illustrated in **Fig. 6(a–c)**. In FuzAMP, multiple criteria, such as HOF, HOPP and UE speed, in addition to the conventional HHO criterion, RSRP, are considered to evaluate the HO decision. The proposed method utilizes triangular fuzzy membership for its simplicity, shorter computational time, and ability to immediately comply with the relevant optimization criteria [43] for the HO decision. **Fig. 6** shows the instantaneous values of these criteria set as a dynamic mapping, to adapt to HO parameters. These values vary according to network behavior and fuzzy membership definition.



(a) (b) (c)

Fig. 6. Membership function of each input variable: (a) HOF, (b) HOPP, and (c) UE speed

The rule base used to describe fuzzy sets with multiple inputs and outputs can be stated as follows: IF (set of conditions are satisfied) THEN (set of consequences can be inferred):

$$\text{IF x is A AND y is B AND z is C THEN w is D} \tag{10}$$

where *A* and *B* are sets of conditions that have to be satisfied and *C* is a set of consequences that can be inferred [44]. The antecedent for each rule is computed using a product operator, particularly by applying the basic operations defined for fuzzy sets. In this case, the antecedent is AND. To calculate the inference output value, we use a Sugeno model [45]:

$$\beta_q = \mu_x(HOPP).\mu_y(HOF).\mu_z(speed) \tag{11}$$

where β is the degree of truth of rule *q*. The final stage of the FLC is defuzzification or the conversion of the fuzzy form into a non-fuzzy value. The defuzzifying output membership function is the centroid method, which is the most prevalent method.

The main concern in FuzAMP is to avoid the time-consuming part of the defuzzification method, which is why a Sugeno model is used. Each rule in a Sugeno model has a crisp output given by a function. Therefore, the overall output is obtained through a weighted average defuzzification [46] for our method as shown in Eq. (12):

$$FLC_{output} = \frac{\sum_{i=1}^{q} \beta_i . k_i}{\sum_{i=1}^{q} \beta_i} \tag{12}$$

where q is the number of rules and k is the centroid of each membership function.

5. Proposed FL and MP-based HO

In LTE, only a HHO is possible, which causes a delay that entails a short T_{IR}, as depicted in **Fig. 2**. The conventional HHO and other later improvement algorithms reported in section 2 are not able to optimize HO procedures because they consider only one HO parameter at a time. Even when they consider both HOM and TTT together, one of the parameters is fixed while the other is adjusted. Moreover, previous works only consider UE with fixed speeds. Therefore, in the present study, we propose a new self-optimization HO algorithm that can tune the HO parameters HOM and TTT simultaneously, as outputs of FLC. These outputs are inferred by FLC taking into consideration HOF and HOPP ratios at various UE speeds as input variables. These inputs reflect network performance and can be updated every 1 ms. We designed our FuzAMP algorithm based on FLC multiple criteria and also applied MP to the HO. By monitoring these input variables continuously, the automatic selection of HO parameters can be performed to reduce HOF and HOPP. The optimal HO parameter value is achieved through FLC that encourages or discourages HO. The MP technique is incorporated in our method to reduce the time taken to re-establish the connection of RRC when a HOF occurs, which reduces the total HO delay. All FLC phases and computations have been described in section 4.4. To test our method, FuzAMP was implemented in a system-level LTE-Sim simulation. The default HHO criterion, RSRP, was used at the beginning to trigger the FuzAMP algorithm. The system keeps updating the need for HO every TTI, which is set to 1 ms. The network constantly evaluates the HOF, HOPP, and UE speeds to be used as inputs in FuzAMP. When the UE indicates that it needs to perform an HO, FuzAMP assesses the HO decision. **Fig. 7** shows the FuzAMP algorithm.

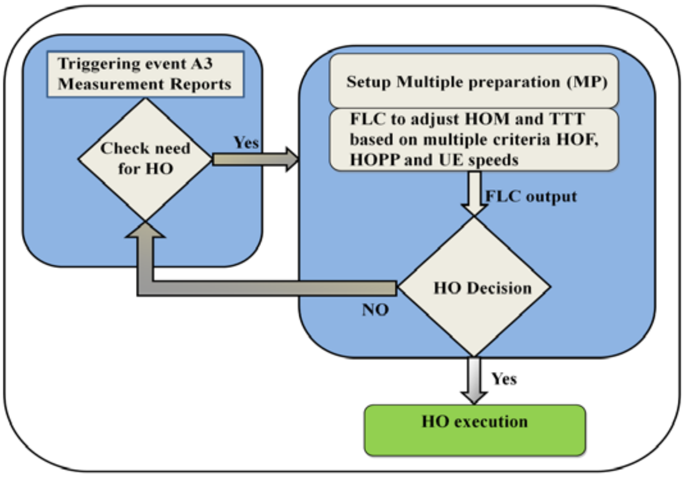


Fig. 7. Proposed FuzAMP algorithm

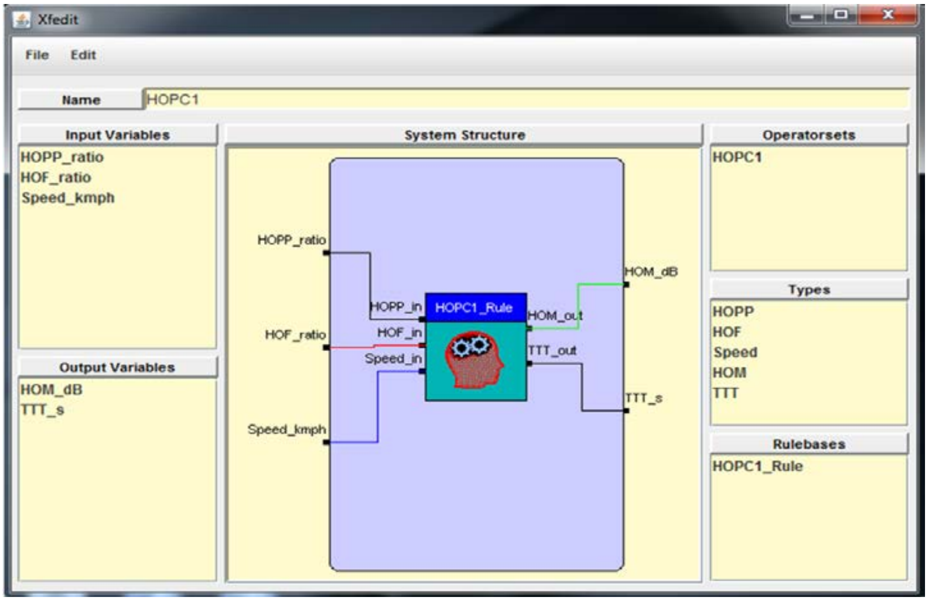
Self-optimization is achieved by the FLC, in which the input parameter values are assigned a weight between [0-1], as explained in section 4.4. Table 1 shows all the possible values for an input and output at three different levels (fuzzy sets; i.e., low, medium, and high). The main control algorithm is the fuzzy inference engine. The (IF THEN) fuzzy rule bases are proposed carefully for use by the fuzzy inference engine, as expressed in Eq. (11), where the decision-making phase takes place. Finally, in the defuzzification stage, the output values of FLC are HOM and TTT, which are used to optimize the HO decision, as shown in Eq. (12). This process is updated every TTI, and the new input parameter values reflect in the current network condition, and accordingly the FLC automatically adjusts the new HOM and TTT values.

Table 1. Fuzzy rule sets for HO

No.	IF HOPP	IF HOF	IF Speed	THEN HOM	THEN TTT
0	Low	Low	High	Low	Low
1	Medium	Low	High	Medium	Medium
2	High	Low	High	Medium	High
3	Low	Medium	High	Low	Low
4	Medium	Medium	High	Medium	Low
5	High	Medium	High	High	Low
6	Low	High	High	Low	Low
7	Medium	High	High	Medium	Low
8	High	High	High	Medium	Low
9	Low	Low	Medium	Low	Low
10	Medium	Low	Medium	Low	High
11	High	Low	Medium	Medium	Medium

12	Low	Medium	Medium	Low	Low
13	Medium	Medium	Medium	Low	Low
14	High	Medium	Medium	Medium	Medium
15	Low	High	Medium	Low	Low
16	Medium	High	Medium	High	Low
17	High	High	Medium	Medium	Medium
18	Low	Low	Low	Low	Low
19	Medium	Low	Low	High	High
20	High	Low	Low	High	High
21	Low	Medium	Low	Low	Low
22	Medium	Medium	Low	Medium	Low
23	High	Medium	Low	High	Medium
24	Low	High	Low	Low	Medium
25	Medium	High	Low	Medium	Medium
26	High	High	Low	High	Medium

Multiple preparation is also initiated when event A3 is triggered, to provide rapid RLF recovery and to enable the serving eNB to simultaneously send HO requests to multiple target eNBs, although only one will be used [7]. Multiple preparation minimizes the delay $T_{\text{re-establish\_delay}}$ in re-establishing the connection, as shown in **Fig. 3**, if the preferred target eNB fails to connect. Time is saved in terms of total HO delay, including the RRC connection procedures, by minimizing the scanning time required to re-establish the RRC connection. Time saving is expressed by Eq. (7). In practice, this equation means that UE may save battery power as searching time is reduced. Multiple preparation also enables the algorithm to assign similar weights, unlike in [22], for all criteria, HOF and HOPP ratios and UE speeds. Therefore, FLC has more flexibility in selecting HOM and TTT values without losing the best tradeoff between HOPP and HOF. FuzAMP can minimize the delay that results from an increase in TTT, which is needed to reduce HOPP. For example, at a low UE speed, HOPP is high, but when TTT is increased, HOF is low. Minimizing HOPP results in a higher HOF because of the extra delay. Multiple preparation acts as a delay compensator by way of multiple connections to two target eNBs, as explained in section 4.2. It improves the tradeoff between HOPP and HOF at different UE speeds. Therefore, the FLC system is proposed as a way to auto-tune the HO parameters. Fuzzy logic control is a very useful tool because it can translate linguistic terms into basic fuzzy sets of rules. Proportional–integral–derivative (PID) controllers were used in [46] because they overcome the irregular response of the discontinuous and continuous controller. However, FLC has an advantage over PID because it can easily be built for non-linear systems. We use an extra simulation tool called Xfuzzy3.0 [47], as shown in **Fig. 8**, to design an FLC for our algorithm and integrate the output C++ code within the main simulation tool, the LTE-Sim [48]. One of the key features of FuzAMP is its relatively fast convergence time, which is attributed to Xfuzzy3.0, as proven in [49].



Name: HOPC1

Input Variables:
- HOPP_ratio
- HOF_ratio
- Speed_kmph

Output Variables:
- HOM_dB
- TTT_s

Operatorsets:
- HOPC1

Types:
- HOPP
- HOF
- Speed
- HOM
- TTT

Rulebases:
- HOPC1_Rule

Fig. 8. Xfuzzy3.0 configuration

6. System Analysis

The performance metrics for FuzAMP include HOPP, HOF, and PLR, which were defined in section 4.3. We can thus write the formula to evaluate them as follows:

$$HOPP(\%) = \frac{N_{HOPP}}{N_{SuccessfulHO} + N_{HOF}} \tag{13}$$

where the ratio of HOPP indicates the number of HOPPs relative to the total number of HOs (successful HO and HOF) and where the successful HO includes the total number of normal HOs (non-ping pong) and HOPPs. In the same manner, the ratio of HOF is expressed by:

$$HOF(\%) = \frac{N_{HOF}}{N_{SuccessfulHO} + N_{HOF}} \tag{14}$$

The PLR is calculated by:

$$PLR = 1 - \frac{N_{received\_packets}}{N_{transmitted\_pakets}} \tag{15}$$

Fig. 9 shows that the performance of the FLC part of FuzAMP is evaluated in terms of the HO parameters with HOPP and HOF ratios at different UE speeds. **Fig. 9(a–c)** illustrates how the FLC controls the adjustment of HOM and TTT in an autonomous manner. **Fig. 9a** shows that, at low speeds, when TTT increases HOPP approaches zero. However, TTT has less effect on HOF except at high TTT values that lead to a large delay. An explanation is given later in this section. In contrast, HOM exerts a strong effect on HOF, except at low speeds, when HOM increases the HOF remains almost constant and the number of HOs decreases. **Fig. 9b** shows that, at medium speeds, as TTT increases, HOF increases exponentially. FuzAMP then reacts to decrease TTT to avoid the large delay that causes high HOF. At the same time, FuzAMP increases the HOM to control HOPP because of the decrease in TTT. **Fig. 9c** shows that, at high speeds, when TTT decreases HOPP gradually increases. As in the case of medium speed, FuzAMP then reacts to increase the HOM, except that HOF is more sensitive at high speeds than HOPP. In all the aforementioned cases, good combinations of TTT and HOM give reduced HOPP and HOF. We also considered how quickly these changes could be achieved. The HO parameter range can be implemented according to the 3GPP [2] standard range.

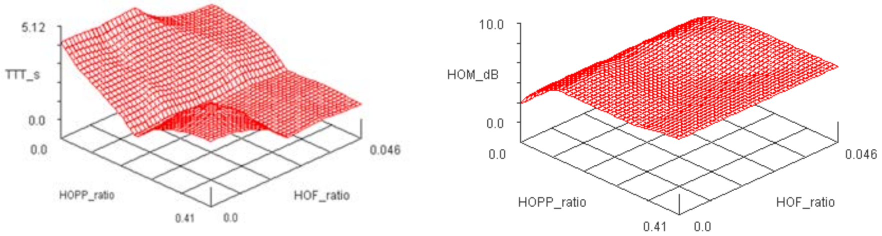


Fig. 9a. HOPP, HOF vs HOM and TTT with low speed 3 km/h

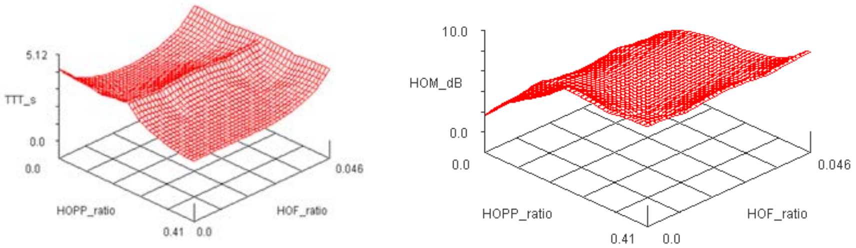


Fig. 9b. HOPP, HOF and HOM vs TTT with medium speed 30 km/h

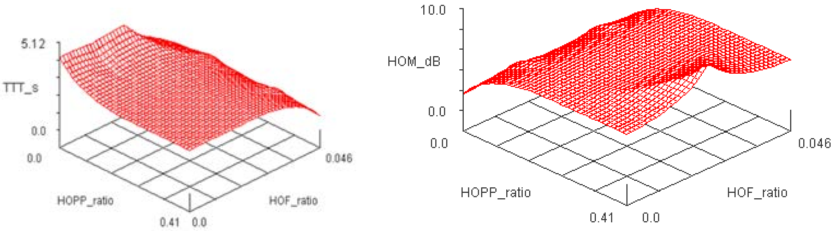


Fig. 9c. HOPP, HOF and HOM vs TTT with high speed 120 km/h

Fig. 9. FLC performance

As mentioned above, our proposed method was implemented in a system-level LTE-Sim simulation in which all UEs moved within the coverage area during the simulation time. The UE speeds and direction varied; 3 km/h for a pedestrian scenario and 30 km/h and 120 km/h for vehicular scenarios with a random direction model. The simulation environment consisted of 19 cells each with a radius equal to 1 km. Each cell could accommodate up to 20 users. For the traffic load, real-time video streaming flows were considered [50]. The channel model in the simulations included a macro-cell urban model, path loss, shadowing, and interference effects [51]. **Table 2** describes all the simulation parameters.

Table 2. Simulation parameters

Parameter	**Value**	**Parameter**	**Value**
Physical details		**Scenario details**	
Bandwidth	5 MHz	Cell layout	1 km
Transmitted power	43dBm	Max delay (end-to-end)	0.1 s
Number of RBs	25	Subframe length (TTI)	1 ms
Subcarriers per RB	12	Number of cells	19
Number of subcarriers	300	Number of simulations	10
Subcarrier spacing	15 kHz	Number of UEs	20
Carrier frequency	2 GHz	Channel model	
Duration of simulation	2000 s	Propagation model	Macro-Cell Urban Model
Frame structure	FDD	Path loss	$PL = 128.1 + 37.6 * Log_{10}(r)$ [51]
Traffic models		Shadow fading	Log-normal distribution (mean = 0 dB, standard deviation = 8 dB) [51]
Real-time (video) type:	H264 [50]	RLF timer N310, N311, T310	1, 1, 200 ms, respectively [37]
Bit rate	264 kbps	UE noise figure	2.5 dB
Mobility		Required uplink SINR	-4 dB
Mobility model	Random direction [52]	Thermal noise level	-174 dBm

8. Results and Discussion

This section compares the FuzAMP results with those of conventional HHO, enhanced MRO [21], and EWPHPO [22], respectively. The results show that our proposed method outperforms the other two methods. First, in HHO, the decision to perform an HO is based only on RSRP, which is insufficient when large-scale fading (shadowing) is considered. The HHO also suffers from increased delay, unreliable break-before-make procedures, and consequently a high HOF ratio. Static HO parameters cannot help in finding the optimal choice to overcome system degradation, particularly for a wide range of UE speeds. Therefore, FuzAMP is a suitable FLC to automatically tune the HO parameters. Furthermore, multiple criteria measurements are made to serve as inputs into the system to inform the HO decision. Second, the enhanced MRO is considered fixed at TTT = 265 ms and relies only on HOM adjustment. Such inefficient adjustable parameters are not desirable because of the increase in HOF at low speeds, extra late HO, and increased HOPP at high speeds, which are exacerbated by the shadowing effects. Third, EWPHPO improved the WPHPO algorithm, that is, the slow convergence time of WPHPO at the cost of increased HOPP. The improvement was achieved by assigning a higher weight to HOF over that of HOPP. In contrast, FuzAMP overcomes the problem of slow convergence time and reduces both HOF and HOPP, leading to a decrease in PLR.

Fig. 10 shows that, at a low speed of 3 km/h, the HOF is low for HHO relative to those at high speeds. In this situation, FuzAMP slightly increases the HOM to keep the UE anchored to the best eNB. The results show that the HOF ratio is almost zero because the Doppler shift has only a minimal effect at low speeds, thus minimizing delay by Eq. (7). The optimum value of HOM is not affected by the modulation and coding scheme (MCS). As the UE moves slowly away from the eNB, the signal quality of the connection is not significantly affected. At the same speed, FuzAMP increases the TTT to minimize the HOPP ratio and prevents the HOF ratio from increasing. This is possible because the MP strategy, where multiple connections are made prior to HO, saves searching time, as highlighted earlier. At a medium UE speed of 30 km/h, the HOF ratio increases. FuzAMP assigns a new specific percentage of increment or decrement to HOM and TTT to verify the proposed values presented in **Table 1** and demonstrated in **Fig. 9(a–c)**. On the other hand, the EWPHPO assigns a fixed weight to each criterion and this slows the convergence time of HO parameter adjustment. This process becomes worse at high speed. It is clear that FuzAMP is smoother than EWPHPO because the latter fluctuates more due to its slow response to changes in the network condition. The most serious challenge is at a high speed of 120 km/h because the UE moves away quickly from the eNB and the connection quality deteriorates. At this speed, the HOPP ratio is low because the UE penetrates further into the target eNB, and the HO is triggered and completed relatively quickly. Therefore, FuzAMP reduces TTT when HOPP is low and increases HOM judiciously because a high HOM triggers the adjustment of the MCS to fulfill the bit rate service, which requires more RBs. The admission control is typically dependent on the availability of RBs. The results show that the reduction of HOF through FuzAMP over conventional the HHO algorithm is approximately 60%, 65%, and 66% at 3 km/h, 30 km/h, and 120 km/h, respectively, and over the EWPHPO algorithm it is approximately 30%, 46%, and 50% at 3 km/h, 30 km/h, and 120 km/h, respectively.

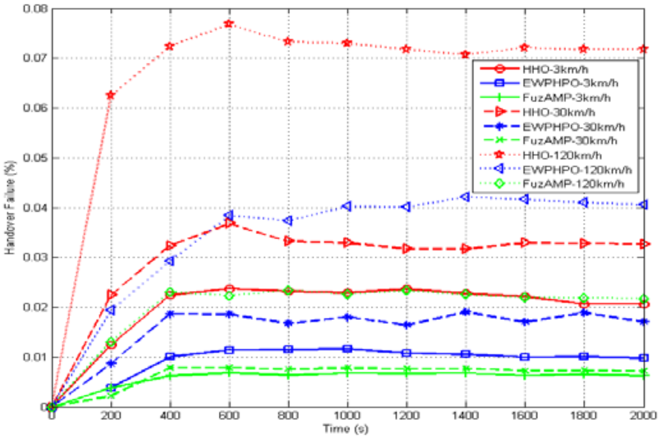


Fig. 10. HOF performance for FuzAMP, EWPHPO and HHO at 3 km/h, 30 km/h and 120 km/h

Fig. 11 shows that, at a low speed of 3 km/h, TTT must rapidly increase to decrease the high HOPP ratio and keep the UE anchored to the serving eNB. The HOPP ratio is more dependent on TTT than on HOM, whereas the HOF ratio is more dependent on HOM than on TTT. Furthermore, the HOPP ratio is high because of signal fluctuation, whereas the HOF ratio is high because of the weakness of the connection. FuzAMP significantly reduces the HOPP ratio at 30 km/h and 120 km/h. This reduction can be attributed to the fast convergence time of FLC in determining the proper value of the HO parameters, the MP that reduces searching time, and the relatively reliable radio connection. The results demonstrate that the reduction of the HOPP ratio by the FuzAMP algorithm relative to that of the conventional HHO algorithm is approximately 54%, 44% and 69% at 3 km/h, 30 km/h and 120 km/h, respectively, and to the EWPHPO algorithm it is approximately 38%, 33% and 65% at 3 km/h, 30 km/h and 120 km/h, respectively.

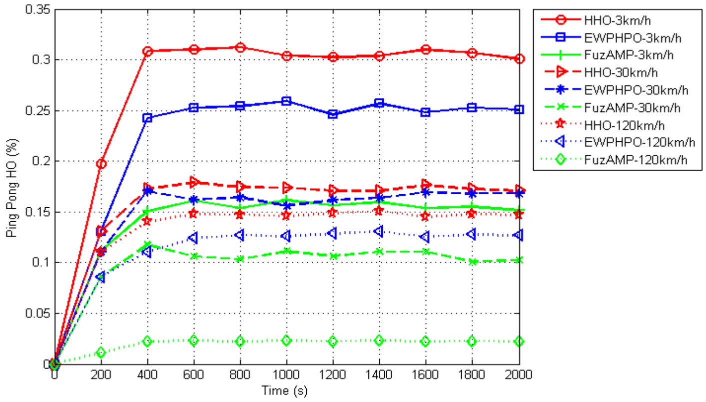


Fig. 11. HOPP performance of FuzAMP EWPHPO, and HHO at 3 km/h, 30 km/h and 120 km/h

Fig. 12 shows the PLR, which is very high with HHO, worsens with an increase in load and UE speed. There are two main types of packet loss: 1) network packet losses, which arise mainly because of network congestion (i.e., router buffer overflow), RLF and rerouting, and transmission errors and 2) losses caused by discarded packets arising from excessive delays [53]. Clearly, FuzAMP combats the two main sources of PLR, namely, RLF and delay that causes HOF. Moreover, the sending of packets back and forth rapidly due to HOPP is overcome as well. The PLR at high load is reduced compared to HHO by approximately 67%, 59% and 68% at 3 km/h, 30 km/h and 120 km/h, respectively, and EWPHPO by approximately 52%, 35% and 48% at 3 km/h, 30 km/h and 120 km/h, respectively.

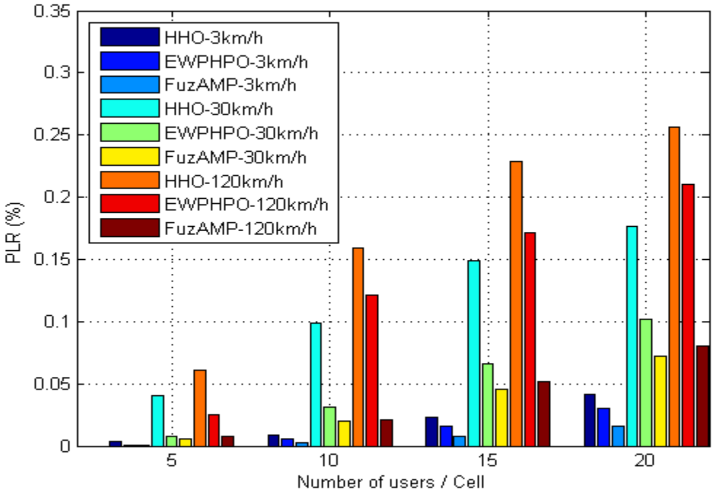


Fig. 12. PLR performance for FuzAMP, EWPHPO and HHO at 3 km/h, 30 km/h and 120 km/h

9. Conclusion

In this study, the FuzAMP, a self-optimization handover scheme to automate HO parameters was proposed for seamless HO. The FuzAMP is aimed at minimizing HOF, HOPP and PLR. A thorough analysis of HO parameters was carried out at different UE speeds and the results compared with those for previous algorithms. The results demonstrated that FuzAMP provides an effective tradeoff between HOF and HOPP, reducing PLR significantly. Our algorithm speeds up the HO process with high accuracy because it uses multiple criteria to make HO decisions. Fuzzy logic control is an important part of the proposed algorithm as it accelerates the convergence time and combines HOM and TTT in an optimum manner. The MP strategy is also used to reduce the HO delay length caused by interruptions. Here, we have argued that sub-optimality is an inefficient method to minimize both HOF and HOPP and showed that FuzAMP outperforms HHO and EWPHPO, both in terms of time convergence and full optimization of HO parameters to reduce HOF, HOPP and PLR at different UE speeds.

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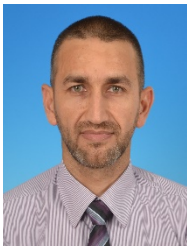

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