Fuzzy-Logic-Based Handover Algorithm for 5G Networks

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***Abstract*—A traditional 4G handover algorithm that performs well in a macro-cell-only network could not be employed in the 5G network with the random distribution of small base stations due to the irregular change of the signal-to-interference-plus-noise ratio (SINR) of a moving user equipment (UE). Besides, the fuzzy logic is a well-known method to translate the domain knowledge of a human expert into a set of basic rules and to formalize the uncertainty judged by the human expert. In this paper, based on the fuzzy logic, we make the first attempt to propose a handover algorithm for a UE in 5G networks. Simulations show that our algorithm has a good performance in terms of the radio link failure (RLF) rate and the ping-pong rate in a 5G network, as compared with the state-of-the-art methods.**

***Index Terms*—5G network, handover, fuzzy logic.**

I. Introduction

The average data rate of a 5G network will reach 575 Megabits per second by 2023 [1]. To achieve such high data rate, network densification is a key feature in a 5G network [2], where millimeter-wave base stations (called small base stations) are densely deployed for the spatial reuse to cooperate with the traditional microwave base stations (called macro base stations). As compared to a 4G network, a moving user equipment (UE) experiences the handover of base stations more frequently in a 5G (heterogeneous) network. Many applications on UEs, such as phone calls, live streaming services, and online games, require continuous receipt of data to provide smooth user experience. Thus, a handover algorithm should be able to prevent disconnections and unnecessary handovers. However, a traditional 4G handover algorithm that performs well in a macro-cell-only network cannot be employed in a 5G network [3]. In this paper, we undertake the development of handover algorithms in a 5G network.

According to the Third Generation Partnership Project (3GPP) specification [4], a handover for a UE may be triggered by the serving base station after the serving base station receives the measurement report, which includes the reference signal received powers (RSRPs) of nearby base stations, from the UE, where the measurement report can be submitted periodically with a cycle time from 120 ms to 30 min [5]. However, to reduce the signaling overhead, the submission of a measurement report is more often to be triggered by a handover event. A typical handover event occurs once the RSRP of some neighboring base station has become an offset (called handover margin) greater than that of the serving base station for a certain period (called time to trigger). In actual practice, the settings of high and low handover margins could increase the number of disconnections between a UE and its serving base station and the number of unnecessary handovers, respectively. This dilemma presents the challenge to choose an appropriate handover margin.

In recent years, many handover algorithms are proposed to reduce the number of disconnections and unnecessary handovers. In [6], the serving base station utilizes the awareness of the future trajectory of a UE (which is a drone there) and the sites of nearby base stations to determine the handover timing and the target base station of the UE. This method, however, is not suitable for the current 5G network since the base station cannot be aware of the future location of the UE. In [7] and [8], methods are proposed for a base station to determine the handover margin of all UEs served by the base station. The determined handover margin is in turn broadcast to all UEs served by the base station. Such methods are so-called UE-assisted network-controlled since UEs obey the configuration sent from the base stations to submit their measurement reports. However, the handover margin determined by a base station is hard to be appropriate to all UEs in the base station since the UEs usually have different moving speeds and directions and receive different RSRPs of nearby neighboring base stations, which introduces the proposal of methods for a UE to determine the individual handover margin of the UE (called UE-controlled handover algorithms).

Note that the implementation of the UE-controlled handover algorithms has no need to change the 3GPP handover procedure executed in base stations, thus the UE-controlled handover algorithms are compatible with the 3GPP specification. In the literature, many UE-controlled handover algorithms are proposed [9]–[13]. In [9], [10], each UE utilizes the reinforcement learning to decide the handover timing and the target base station. However, these proposed methods are not compatible with the 3GPP specification which specifies that the target base station is determined by the serving base station. In [11]–[13], the UE-controlled handover algorithms are proposed based on the fuzzy logic, where the fuzzy logic is a method to translate the domain knowledge of a human expert into a set of basic rules (that map the inputs to an output in linguistic terms) and formalize the uncertainty judged by the human expert [14].

Note that unlike the distribution of macro base stations that are installed in a hexagonal grid, the distribution of small

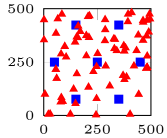


Fig. 1: Example of the 5G network scenario of the dense urban, where the blue square (or red triangle) denotes the macro (or small) base station.

base stations can be perceived as a random drop since the deployment of small base stations has no fixed pattern due to that small base stations can be deployed in the indoor premises or public hotspots independently. Thus, the change of the signal-to-interference-plus-noise ratio (SINR) of a moving UE in a 5G network is considerably irregular due to the uncertain number of neighboring base stations of the UE. It is also noted that a UE needs to keep connected with the serving base station to accomplish a handover. According to [15], the occurrence of a disconnection between a UE and a base station is determined by the condition that the block error rate of the transmission between the UE and the base station is greater than 10%, where the block error rate is a function of SINR. Thus, the future SINR of a UE has a significant impact on the timing of triggering a successful handover. This implies a handover algorithm in an attempt to have good performance in a 5G network should consider the SINR change of a UE.

In addition, to be superior to the existing handover algorithms [11]–[13], we believe that a handover algorithm must meet two properties: p1) a handover of a UE should be avoided as the SINR change of the UE is non-negative, and p2) a handover of a UE should be triggered as the future SINR of the UE will fall below the out-of-synchronization threshold which incurs a disconnection. In this paper, we make the first attempt to propose a UE-controlled fuzzy-logic-based handover algorithm that takes the SINR change of a UE into account and meets the above two properties for a 5G network.[1] Our goal is to minimize the number of disconnections and reduce the number of unnecessary handovers at the same time.

II. Preliminary

A. Scenario

We consider the 5G network scenario of the dense urban depicted in the 3GPP technical report [16], where 7 macro base stations are located in a hexagonal grid with the inter site distance (ISD) 200 m in a 500×500 m^2 square area and 10-30 small base stations are uniformly and randomly located in each macro base station, as shown in Fig. 1. And, each macro (or small) base station operates at the carrier frequency 4 (or 30) GHz. In addition, ITU-R P.1238 [17] is used as the path loss model between a macro/small base station and a UE, where $l(f,d) = 20\log_{10}(f) + 29.6\log_{10}(d)$, in which l, f, and d denote the path loss (dB), the carrier frequency (MHz), and the distance between a macro/small base station and a UE, respectively. Moreover, each small base station is set to have the maximum transmit power 46 dBm. According to [18], the receiver sensitivity of a UE at 30 GHz is -98 dBm. Since the received power of a UE from a small base station is $46 - l(30000, 70) \approx -98$ dBm when the UE is 70 m away from the small base station, the transmission range of a small base station is around 70 m. And, to fully cover the entire simulation area while reducing the interference between base stations, the transmit power of each macro base station is set to 25 dBm. According to [19], the receiver sensitivity of a UE at 4 GHz is -107 dBm. Hence, the transmission range of a macro base station is around 105 m. Moreover, 10 UEs are in a base station in average, including 80% indoor and 20% outdoor UEs. Each indoor (or outdoor) UE moves at the speed 3 (or 30) $\mathrm{km/h}$.

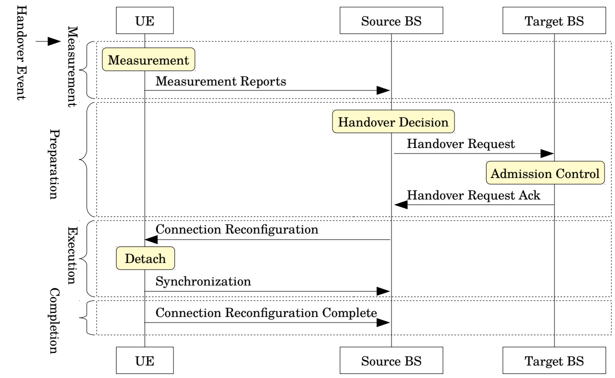


Fig. 2: Overview of the handover procedure.

B. Handover Procedure

The handover procedure is divided into four phases: Measurement, Preparation, Execution, and Completion, as shown in Fig. 2. At first, a UE proceeds to the phase of Measurement once the handover procedure is triggered by a handover event that the RSRP of some neighboring base station is greater than that of the serving base station by a handover margin (HOM). And, if the handover event lasts for a period of time, called time to trigger (TTT), the UE sends the measurement reports concerning the reference signal received powers (RSRPs) and reference signal received qualities (RSRQs) of the nearby base stations (including the serving base station) to the serving base station, and then proceeds to the phase of Preparation. According to the measurement reports, the serving base station designates a target base station for the UE, and sends a handover request to the target base station. If the target base station admits the handover request, it responses a handover request acknowledgment to the serving base station. Then, the handover procedure proceeds to the phase of Execution. At the

[1] A fuzzy-logic-based algorithm can construct a small number of inference rules via the expert domain knowledge; thus, a fuzzy-logic-based handover algorithm can trigger a necessary handover after a smaller inference delay using lower power consumption, as compared to machine-learning-based algorithms. Since the SINR of a moving UE changes over time, the longer the inference delay, the higher the probability that a moving UE experiences a handover failure. In addition, since a UE is usually power-sensitive, a UE-controlled algorithm demands low power consumption. Thus, a fuzzy-logic-based algorithm is addressed in this paper.

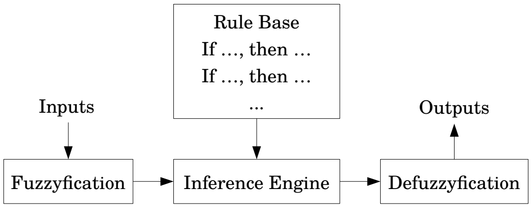
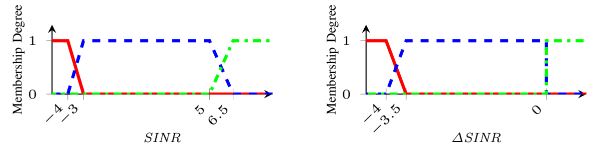


Fig. 3: The architecture of a fuzzy logic system.



(a) (b)

Fig. 4: The membership functions (a) $\mu_B(\mathit{SINR})$, $\mu_M(\mathit{SINR})$, and $\mu_G(\mathit{SINR})$, and (b) $\mu_P(\mathit{\Delta SINR})$, $\mu_F(\mathit{\Delta SINR})$, and $\mu_N(\mathit{\Delta SINR})$ shown in red solid, blue dashed, and green dashdotted lines, respectively, where $\mu_F(\mathit{\Delta SINR}) = 0$ and $\mu_N(\mathit{\Delta SINR}) = 1$ if $\mathit{\Delta SINR} = 0$.

start of the phase of Execution, the serving base station sends a connection reconfiguration to the UE to inform the UE to reconnect to the target base station. The UE in turn detaches itself from the serving base station, and starts to synchronize with the target base station. Finally, if the synchronization is successful, the UE proceeds to the phase of Completion, and sends a connection reconfiguration complete message to the target base station, completing the handover procedure.

Note that if the UE disconnects to the serving base station in the phase of Measurement, the serving base station cannot receive the measurement reports. And, if the UE disconnects to the serving base station in the phase of Preparation or at the start of the phase of Execution, the UE cannot receive the connection reconfiguration. In addition, if the UE disconnects to the target base station in the phase of Execution, the UE cannot synchronize with the target base station. In such cases, the handover procedure fails.

III. The Fuzzy-logic-based Algorithm

A. The Algorithm

According to [15], a UE is more likely to disconnect to the serving base station if the SINR of the UE is worse. Therefore, when the SINR of a UE is low, the HOM of the UE is good to set low in order that the UE can trigger the handover procedure easily. This leads us to take the SINR of a UE as one input of our algorithm. Besides, a handover of a UE is more likely to fail in the phases of Measurement and Preparation (which can be accomplished in 200 ms as TTT is set to 80 ms according to [20]) if the SINR of the UE is worse during the future 200 ms. Therefore, when the SINR of a UE is low during the future 200 ms, the HOM of the UE is good to set low in order that the UE can trigger the handover procedure early. However, the future SINR of a UE is unknown. Fortunately, in a short while, the variation of the change of SINR of the UE is negligible. Thus, we can estimate the SINR of a UE during the future 200 ms according to the change of the SINR of the UE during the past 200 ms. This leads us to take the change of the SINR of a UE during the past 200 ms as another input of our algorithm.

Our algorithm dynamically determines HOM according to the SINR of a UE (denoted by SINR) and the change of the SINR of a UE during the past 200 ms (denoted by $\mathit{\Delta SINR}$) of a UE by means of fuzzy logic. A fuzzy logic system, which can be perceived as a function that takes the numerical inputs SINR and $\mathit{\Delta SINR}$ and returns a numerical output HOM, consists of four parts: fuzzyfication, rule base, inference engine, and defuzzyfication, as shown in Fig. 3. In the fuzzyfication part, each input x is assigned into one or more predetermined fuzzy sets, and the degree of x with respect to a fuzzy set A (called membership degree) is calculated by a predetermined membership function $\mu_A(x)$ of the fuzzy set A. In our algorithm, there are three fuzzy sets GOOD, MODEST, and BAD (or $\mathit{NONFALL}$, FALL, and PLUNGE) for the input SINR (or $\mathit{\Delta SINR}$). The membership functions $\mu_G(\mathit{SINR})$, $\mu_M(\mathit{SINR})$, and $\mu_B(\mathit{SINR})$ (or $\mu_N(\mathit{\Delta SINR})$, $\mu_F(\mathit{\Delta SINR})$, and $\mu_P(\mathit{\Delta SINR})$) for fuzzy sets GOOD, MODEST, and BAD (or $\mathit{NONFALL}$, FALL, and PLUNGE), respectively, are developed and shown in Fig. 4a (or Fig. 4b). Take a UE with $\mathit{SINR} = -3.6$ dB and $\mathit{\Delta SINR} = -3.9$ dB/200ms, for an example. Then, $\mu_B(-3.6) = \frac{-3-(-3.6)}{-3-(-4)} = 0.6$, $\mu_M(-3.6) = \frac{-3.6-(-4)}{-3-(-4)} = 0.4$, and $\mu_G(-3.6) = 0$. Similarly, $\mu_P(-3.9) = \frac{-3.5-(-3.9)}{-3.5-(-4)} = 0.8$, $\mu_F(-3.9) = \frac{-3.9-(-4)}{-3.5-(-4)} = 0.2$, and $\mu_N(-3.9) = 0$.

TABLE I: The Rule Base.

Rule Number	SINR	$\mathit{\Delta SINR}$	HOM
1	*GOOD*	*NONFALL*	*HIGH*
2	*GOOD*	*FALL*	*HIGH*
3	*GOOD*	*PLUNGE*	*HIGH*
4	*MODEST*	*NONFALL*	*HIGH*
5	*MODEST*	*FALL*	*HIGH*
6	*MODEST*	*PLUNGE*	*LOW*
7	*BAD*	*NONFALL*	*HIGH*
8	*BAD*	*FALL*	*LOW*
9	*BAD*	*PLUNGE*	*LOW*

The rule base part comprises all possible relationships (called rules) between the fuzzy sets for inputs SINR and $\mathit{\Delta SINR}$ and two fuzzy sets HIGH and LOW for the output HOM, as shown in Table I, where rule 9 states that if SINR is BAD AND $\mathit{\Delta SINR}$ is PLUNGE, then HOM is LOW.

The inference engine part calculates the activated degrees of fuzzy sets HIGH and LOW in two steps. In step 1, for each rule i with the membership degree $\mu_i(\mathit{SINR})$ (or $\mu_i(\mathit{\Delta SINR})$) of the fuzzy set for the input SINR (or $\mathit{\Delta SINR}$), the activated degree α_i of rule i is calculated as $\min\{\mu_i(\mathit{SINR}), \mu_i(\mathit{\Delta SINR})\}$ since in rule i, the Boolean operator "AND" is used to connect the membership degrees of the fuzzy sets respectively for the inputs SINR and $\mathit{\Delta SINR}$. For example, the activated degree α_9 of rule 9 for a UE with $\mathit{SINR} = -3.6$ dB and $\mathit{\Delta SINR} = -3.9$ dB/200ms

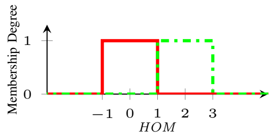


Fig. 5: The membership functions $\mu_H(x)$ and $\mu_L(x)$ for the output HOM, where $\mu_L(x)$ and $\mu_H(x)$ are shown in red solid and green dashdotted lines, respectively.

is $\min\{\mu_B(-3.6), \mu_P(-3.9)\} = \min\{0.6, 0.8\} = 0.6$. Similarly, $\alpha_1 = \min\{\mu_G(-3.6), \mu_N(-3.9)\} = 0$, $\alpha_2 = \min\{\mu_G(-3.6), \mu_F(-3.9)\} = 0$, $\alpha_3 = \min\{\mu_G(-3.6), \mu_P(-3.9)\} = 0$, $\alpha_4 = \min\{\mu_M(-3.6), \mu_N(-3.9)\} = 0$, $\alpha_5 = \min\{\mu_M(-3.6), \mu_F(-3.9)\} = 0.2$, $\alpha_6 = \min\{\mu_M(-3.6), \mu_P(-3.9)\} = 0.4$, $\alpha_7 = \min\{\mu_B(-3.6), \mu_N(-3.9)\} = 0$, and $\alpha_8 = \min\{\mu_B(-3.6), \mu_F(-3.9)\} = 0.2$.
In step 2, the activated degree α_H (or α_L) of fuzzy set $HIGH$ (or LOW) is calculated as the maximum of the activated degree of each rule with fuzzy set $HIGH$ (or LOW) for the output HOM since in the rule base, the Boolean operator "OR" is used to connect all rules with the same fuzzy set $HIGH$ (or LOW) for the output HOM. For example, the activated degree α_L of fuzzy set LOW for a UE with $SINR = -3.6$ dB and $\Delta SINR = -3.9$ dB/200ms is $\max\{\alpha_6, \alpha_8, \alpha_9\} = 0.6$. Similarly, $\alpha_H = \max\{\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5, \alpha_7\} = 0.2$.

Given the activated degrees α_H and α_L and the developed membership functions $\mu_H(x)$ and $\mu_L(x)$ of fuzzy sets $HIGH$ and LOW (shown in Fig. 5), respectively, the defuzzyfication part evaluates the output HOM by $\frac{\alpha_H}{\alpha_H+\alpha_L} \times 2$, which is the gravity center at HOM of effective $\mu_L(x)$ (with height $\mu_L(x)$) and $\mu_H(x)$ (with height $\mu_H(x)$). For example, the output HOM of a UE is $\frac{0.2}{0.2+0.6} \times 2 = 0.5$ if the UE has $SINR = -3.6$ dB and $\Delta SINR = -3.9$ dB/200ms.

B. The analysis

As we know, it is challenging to design a perfect fuzzy logic by studying massive data. Yet, we discover two principles to help the design of a well-performed fuzzy logic: p1) avoid a handover as the SINR of a UE is non-falling (i.e. $\Delta SINR \geq 0$), and p2) trigger a handover as the future SINR of a UE will fall below the out-of-synchronization threshold. To carry out principle p2, it suffices to ensure a handover is triggered once $SINR + \Delta SINR \leq -8$. Theorems 1 and 2 show the proposed algorithm carries out principles p1 and p2, respectively, in the dense urban scenario depicted in the 3GPP technical report [16] and demonstrated in section II-A. In the following results, the settings of the dense urban scenario are used.

Theorem 1. For any UE, if $\Delta SINR \geq 0$, then $HOM = 2$.

Proof. Due to $HOM = \frac{\alpha_H}{\alpha_H+\alpha_L} \times 2$, it suffices to show $\alpha_L = 0$ as $\Delta SINR \geq 0$. When $\Delta SINR \geq 0$, $\mu_P(\Delta SINR) = \mu_F(\Delta SINR) = 0$, implying $\alpha_6 = \alpha_8 = \alpha_9 = 0$, and thus $\alpha_L = \max\{\alpha_6, \alpha_8, \alpha_9\} = 0$. This completes the proof. □

Lemma 1. For any UE, if $SINR \geq 5$, then $SINR + \Delta SINR > -8$, given that the inter site distance of small (or macro) base stations is greater than 40 (or 150) m.

Proof. First note that a UE served by a small (or macro) base station does not receive the interference from macro (or small) base stations since the small base station and the macro base station are operated at different carrier frequencies. Due to the page limit, the proof of this lemma for a UE served by a macro base station is omitted due to its similarity with that for a UE served by a small base station. We need to show for a UE served by a (small) base station, $-8 - SINR$ is the lower bound of $\Delta SINR$. We consider a UE directly moving toward the nearest non-serving (small) base station since the UE has the maximum decrease on $SINR$ in such case.

Suppose that the inter site distance of small base stations is at least d m, and $x - 2$ and x m is the distance between the UE and the serving base station before and after the UE moves toward the nearest non-serving base station, respectively, where 2 m is the moving distance of the UE in 200 ms at the speed 30 km/h. We first evaluate the lower bound of $\Delta SINR$ of the UE. To this end, we have the following two claims: c1) the $SINR$ of the UE with the distance $x - 2$ m from the serving base station, denoted by $s(x-2)$, is no greater than $-29.6\log_{10}(\frac{x-2}{d-x+2})$ dB and c2) the $SINR$ of the UE with the distance x m from the serving base station, denoted by $s(x)$, is no less than $-43.54 - 29.6\log_{10}(\frac{x}{d-x}) + 20\log_{10}(d)$, as shown in Appendix A. By c1 and c2, the lower bound of $\Delta SINR$ of the UE with the distance x m from the serving base station, denoted by $ds(x)$, is $-43.5 - 29.6\log_{10}(\frac{(x)(d-x+2)}{(d-x)(x-2)}) + 20\log_{10}(d)$.

Next, we claim that c3) the distance between a UE and the serving base station is at least y when the UE with the $SINR$ equal to $z = -43.54 - 29.6\log_{10}(\frac{y}{d-y}) + 20\log_{10}(d)$. The proof of c3 is given in Appendix A. Note that the $\Delta SINR$ of a UE decreases as the UE is closer to the serving base station. Thus, for a UE with the $SINR$ equal to z, the $\Delta SINR$ of the UE is at least $ds(y) = -43.5 - 29.6\log_{10}(\frac{(y)(d-y+2)}{(d-y)(y-2)}) + 20\log_{10}(d)$. Therefore, for a UE, $SINR + \Delta SINR \geq z - 43.5 - 29.6\log_{10}(\frac{(y)(d-y+2)}{(d-y)(y-2)}) + 20\log_{10}(d)$. For each of $SINR = z = 5, 7, 9, 11$, the lower bound of $SINR + \Delta SINR$ (which is $z - 43.5 - 29.6\log_{10}(\frac{(y)(d-y+2)}{(d-y)(y-2)}) + 20\log_{10}(d)$) is evaluated for variable inter site distances of small base stations d, as shown in Fig. 6. As can be seen, to have $SINR + \Delta SINR > -8$, when $SINR$ increases, the minimum inter site distance of small base stations decreases. And, when $SINR = 5$, $SINR + \Delta SINR > -8$ if the inter site distance is greater than 40 m. This completes the proof. □

Theorem 2. For any UE, if $\Delta SINR < 0$ and $SINR + \Delta SINR \leq -8$, then $HOM = 0$, given that the inter site distance of small (or macro) base stations is greater than 40 (or 150) m.

Proof. By Lemma 1, $SINR + \Delta SINR \leq -8$ only if $SINR < 5$. Due to $HOM = \frac{\alpha_H}{\alpha_H+\alpha_L} \times 2$, it suffices to show $\alpha_H = 0$

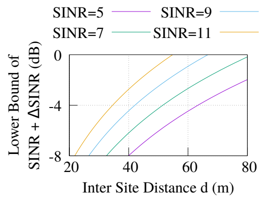


Fig. 6: The impact of the inter site distance of small base stations on $SINR + \Delta SINR$ for $SINR = 5, 7, 9, 11$.

if $SINR < 5$ and $SINR + \Delta SINR \leq -8$. There are two cases: c1) $SINR < -4$ and c2) $-4 \leq SINR < 5$. For c1, $\mu_G(SINR) = \mu_M(SINR) = 0$. Since $\Delta SINR < 0$, $\mu_N(\Delta SINR) = 0$. Hence, $\alpha_H = 0$. For c2, $\mu_G(SINR) = 0$. Since $\Delta SINR \leq -8 - SINR \leq -4$, $\mu_F(\Delta SINR) = \mu_N(\Delta SINR) = 0$. Hence, $\alpha_H = 0$. $\square$

In the following, we consider the special case that small (or macro) base stations are placed on a triangular grid since this placement achieves the maximum base station density in the transmission range of a base station, which incurs the maximum interference of a UE from the non-serving small (or macro) base stations. Theorem 3 shows the proposed algorithm carries out principle p2 in such case. Due to the page limit, the proof of Theorem 3 is omitted. Please refer to the technical report [21].

Theorem 3. For any UE, if $\Delta SINR < 0$ and $SINR + \Delta SINR \leq -8$, then $HOM = 0$, given that the small (or macro) base stations are placed on a triangular grid with the inter site distance greater than 15 m.

IV. Simulation

A. Simulation Settings

Scenario: The dense urban scenario depicted in the 3GPP technical report [16] and demonstrated in section II-A is used. All UEs are uniformly distributed in the area initially. Each indoor UE moves at the speed 3 km/h based on the random walk mobility model [22], where the UE randomly chooses a direction from the interval $[0, 2\pi)$ every 10 seconds. Each outdoor UE moves at the speed 30 km/h based on the Manhattan mobility model [23], where the area is composed of horizontal and vertical streets every 50 m, and the UE can turn left, right, or go straight at every crossroads with the probability 0.25, 0.25, and 0.5, respectively. If a UE reaches the boundary of the area, the UE bounces off the boundary with an angle determined by the incoming direction.

Performance Metrics: Two performance metrics, including radio link failure (RLF) rate and ping-pong rate, are used to evaluate the performance of our algorithm. According to [5], an RLF of a UE occurs when the timer T310 of the UE expires. The timer T310 is triggered to count down from 1 s once the SINR of the UE falls below the out-of-synchronization threshold $Q_{out} = -8$ dB, and keeps running until expiry if the SINR of the UE does not rise above the in-synchronization threshold $Q_{in} = -6$ dB [20]. A ping-pong occurs when a UE is handed over from base station A to base station B and then handed over back to base station A if the time of the UE staying at base station B is less than the minimum-time-of-stay $MTS = 1$ s. The RLF rate and ping-pong rate denotes the number of RLFs and ping-pongs per minute per UE in average, respectively.

Comparison Methods: Our algorithm (denoted by OURS) is compared with the following schemes, including:

1) Best Connection (BC) [24]: the HOM of a UE is set to 0 dB. Thus, each UE is always handed over to the base station with the greatest RSRP.
2) Constant HOM (CH) [24]: the HOM of a UE is set to 3 dB.
3) Self-tuning Handover Algorithm (SHA) [11]: the RSRP threshold of a UE is evaluated by the velocity, RSRP, and RSRQ of the UE based on the fuzzy logic, and a handover of a UE is triggered if the RSRP of the UE is lower than the RSRP threshold and the RSRP of some neighboring base station of the UE is HOM greater than that of the serving base station, where $HOM = 2$.
4) Adaptive Handover Algorithm (AHA) [12]: the HOM of a UE is determined by the velocity, RSRP, and RSRQ of the UE based on fuzzy logic.
5) Route-aware Handover Algorithm (RHA) [6]: given the future trajectory of a UE, a handover of a UE is triggered and the target base station is designated once the estimated SINR is lower than the out-of-synchronization threshold $Q_{out} = -8$ dB and does not rise above the in-synchronization threshold $Q_{in} = -6$ dB in 1 s. RHA is employed by the base station.

In BC, CH, SHA, AHA, and our algorithm, each of which is employed by the UE, once a handover of a UE is triggered, the base station with the greatest RSRP is designated as the target base station in the simulations.

B. Simulation Results

The result of each setting is obtained by running the simulation for 900 s. Figs. 7 and 8 show the impacts of the average number of small base stations per macro base station and the transmit power of the small base station on the RLF rate and the ping-pong rate, respectively. As can be seen, both the RLF rate and the ping-pong rate increase when the number of small base stations or the transmit power of the small base station increases. This is because when a UE in a small base station has more neighboring small base stations or higher transmit power of neighboring small base stations, the UE receives more interference from the other small base stations and thus experiences a worse SINR. Besides, since the RHA is aware of the future trajectory of a UE, the RHA can precisely estimate the SINR of a UE after a certain while, and thus, can achieve a near optimal RLF rate and a near optimal ping-pong rate as well. However, the RHA is not suitable for the current 5G network since the base station cannot be aware of the future location of the UE. In addition, using the BC, a UE always hands over to the base station with the greatest RSRP. Thus,

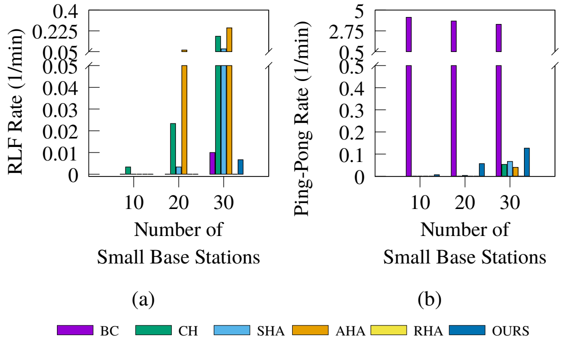


Fig. 7: Impact of the average number of small base stations per macro base station on the (a) RLF rate, and (b) ping-pong rate.

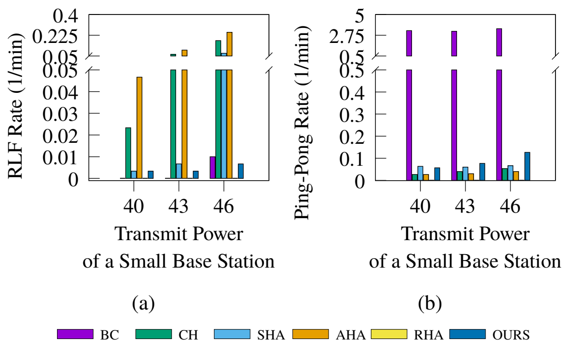


Fig. 8: Impact of the transmit power of the small base station on the (a) RLF rate, and (b) ping-pong rate when the average number of small base stations per macro base station is 30.

among all algorithms without the future trajectory of a UE, the BC has the lowest RLF rate except that 30 small base stations are in a macro base station or the small base station has the maximum transmit power 46 dBm, and has the highest ping-pong rate. As 30 small base stations are in a macro base station or the small base station has the maximum transmit power 46 dBm, the BC has a higher RLF rate than our algorithm. This is because the BC is more likely to hand over a UE from a macro base station with a good SINR to a small base station with the greatest RSRP but with a worse SINR due to the inteference introduced by the other small base stations while our algorithm can keep the UE staying in the macro base station if the $\Delta SINR \geq 0$ or $SINR + \Delta SINR > -8$. As anticipated, our algorithm outperforms CH, SHA, and AHA in terms of the RLF rate since our algorithm dynamically adjusts the HOM and takes the SINR change of a UE into account. Besides, our algorithm has a slightly higher ping-pong rate, as compared to CH, SHA, and AHA. The reason is that to prevent an RLF, our algorithm is unavoidable to perform some necessary handovers that result in ping-pong.

V. Conclusion

In this paper, we study the design of a UE-controlled fuzzy-logic-based handover algorithm for the 5G network. To address the issue of the irregular SINR change of a moving UE, the SINR change of a UE is taken into account in the proposed algorithm. Our algorithm ensures a handover is not triggered as the SINR of a UE is non-falling, and is triggered as the future SINR of a UE will lead to a disconnection with the serving base station.

Via simulations, our algorithm is compared with the state-of-the-art handover methods, including BC [24], CH [24], SHA [11], AHA [12], and RHA [6], in terms of the RLF rate and the ping-pong rate. Simulation results show RHA has the lowest RLF rate and the lowest ping-pong rate since RHA can precisely estimate the future SINR of a UE due to that RHA is aware of the future trajectory of the UE. In most cases, BC has the best (or worst) performance in terms of the RLF (or ping-pong) rate because BC always hands over a UE to the base station with the greatest RSRP. The performance of our algorithm is close to that of BC and better than that of CH, SHA, and AHA in terms of the RLF rate since we take the change of the SINR of a UE into account. On the other hand, our algorithm has a slightly higher ping-pong rate than CH, SHA, and AHA because our algorithm performs some necessary handovers resulting in ping-pong to prevent an RLF.

Future research includes the study of extending our algorithm to consider the dual connectivity operations in a 5G network. Another research direction is to consider the quality of experience (QoE) of a moving UE in a 5G network using the extension of our algorithm.

Appendix A
Proofs of Claims in Lemma 1

Proof of Claim c1: The received power of the UE from the serving base station, denoted by $p_s(x-2)$, is $p_t - l(x-2) = -43.54 - 29.6\log_{10}(x-2)$ dBm, where $p_t = 46$ dBm is the transmit power of a small base station and $l(x) = 89.54 + 29.6\log_{10}(x)$ is the path loss model. And, for the UE, the interference from the non-serving base stations, denoted by $p_i(x-2)$, is no less than the interference from the nearest non-serving base station, i.e., $p_t - l(d-x+2) = -43.54 - 29.6\log_{10}(d-x+2)$. Thus, for the UE with the distance $x-2$ m from the serving base station, the $SINR$, denoted by $s(x-2)$, is no greater than $p_s(x-2) - p_i(x-2) = -29.6\log_{10}(\frac{x-2}{d-x+2})$ dB.

Proof of Claim c2: The received power of the UE from the serving base station, denoted by $p_s(x)$, is $p_t - l(x) = -43.54 - 29.6\log_{10}(x)$ dBm, where $p_t = 46$ dBm is the transmit power of a small base station and $l(x) = 89.54 + 29.6\log_{10}(x)$ is the path loss model. Since the transmission range r of a small base station with the transmit power 46 dBm is 70 m, the UE experiences the interference from at most n non-serving base stations, where $n = \frac{2r}{d} \times \frac{2r}{\frac{\sqrt{3}}{2}d} = \frac{22362.13}{d^2}$. Thus, for the UE, the interference from the non-serving base station, denoted by $p_i(x)$, is no greater than the n-fold received power of the nearest non-serving base station in Watt (or the received power of the nearest non-serving base station plus $10\log_{10}(n)$ in dBm), i.e., $p_t - l(d-x) + 10\log_{10}(n) = -29.6\log_{10}(d-x) - 20\log_{10}(d)$ dBm. Therefore, for the UE with the distance

x m from the serving base station, the $SINR$, denoted by $s(x)$, is no less than $p_s(x) - p_i(x) = -43.54 - 29.6\log_{10}(\frac{x}{d-x}) + 20\log_{10}(d)$.

Proof of Claim c3: We claim that the distance between a UE and the serving base station is at least y when the UE with the $SINR$ equal to $z = -43.54 - 29.6\log_{10}(\frac{y}{d-y}) + 20\log_{10}(d)$. Suppose not. Since the $SINR$ of a UE increases as the UE is closer to the serving base station, the $SINR$ of the UE is greater than that of another UE with distance y from the serving base station which is $s(y)$. Namely, $z > s(y)$. However, by c2, $s(y) \geq -43.54 - 29.6\log_{10}(\frac{y}{d-y}) + 20\log_{10}(d)$, and by our claim, $z = -43.54 - 29.6\log_{10}(\frac{y}{d-y}) + 20\log_{10}(d)$. Then, $s(y) \geq z$, a contradiction.

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