Improvement on the handover technique for 5G network using fuzzy logic algorithm

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ABSTRACT

Beyond 5G (B5G) networks require advanced handover algorithms to guarantee seamless connectivity and optimum quality of service. Traditional handover methods are not sufficient to meet the stringent latency and reliability requirements of next-generation networks. To meet these challenges, the integration of fuzzy logic into handover algorithms offers a viable solution. The proposed approach utilizes parameters such as reference signal received power (RSRP), reference signal received quality (RSRQ), signal-to-interference plus noise ratio (SINR), and user equipment (UE) speed as inputs, while dynamically adjusting the time-to-trigger (TTT) and handover margin (HOM) as outputs. To assess the effectiveness of this algorithm, handover latency (HOL) and handover interruption time (HIT) are evaluated and compared with existing algorithms in the literature. The results show better and more efficient performance in both terms of latency and interruption time.

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1. INTRODUCTION

Mobility is the capacity of users or connected devices (such as smartphones, vehicles, or IoT sensors) to move around while maintaining a continuous and stable connection to the network. Handover management is an essential aspect of mobile networks [1]. A handover transfers an active cell connection from one cell (source) to another (target) without interrupting service [2].

To ensure seamless connectivity in the 5G network, high reliability, low latency, and an uninterrupted connection are essential [3]. To achieve this, the handover algorithm needs to be assured. Evaluation of handover performance is based on several criteria, such as latency, success rate, interruption time, and other indicators [4]. These parameters enable us to measure the efficiency and reliability of the process while identifying the improvements needed to meet the growing demands of modern networks and real-time applications.

In 5G networks, different types of handovers are employed, each designed to address specific needs and optimize network performance in diverse scenarios [5]. Although traditional methods remain effective for certain 5G applications and environments, they are insufficient for handling the complexity and demands of more advanced use cases. As a result, integrating advanced techniques, such as artificial intelligence and dynamic algorithms, becomes crucial [6].

Fuzzy logic is key in improving the handover process, particularly in advanced networks such as 5G networks. In contrast to conventional approaches based on fixed thresholds, fuzzy logic represents a dynamic and adaptive way of making complex decisions in uncertain and dynamic environments [7].

Several researchers have developed fuzzy logic-based handover algorithms [8]-[10], with handover control parameters (HCPs) playing an essential role in the handover process. These parameters influence the decision, timing, and quality of the handover, directly impacting network performance and the UX. The following points outline the main accomplishments of this paper:

- A proposed fuzzy logic-based algorithm has been developed that automatically adjusts handover margin (HOM) [11] and time-to-trigger (TTT) at the same time by utilizing the benefits of the fuzzy logic system. The suggested method adjusts TTT and HOM based on system outcomes by taking advantage of user equipment (UE) information, including reference signal received power (RSRP), reference signal received quality (RSRQ), signal-to-interference plus noise ratio (SINR), and speed.
- System performance is assessed using different mobility speed scenarios in terms of handover latency (HOL) probability and handover interruption time (HIT). Enhancing handover performance in a 5G mobile system is the goal of our proposal.
- After a performance analysis and comparison of our idea with many methods from the literature, including robust handover optimization technique with fuzzy logic controller (RHOT-FLC) [10] and the fuzzy logic controller (FLC) algorithm [12].

The rest of the article is structured as follows: section 2 presents related work. The new algorithm is proposed and presented in section 3. Performance analyses are then discussed in section 4, describing the simulation environment and performance measures. The article concludes in section 5.

2. RELATED WORK

In this section, we propose a comprehensive review of recent work on handover algorithms in 5G, highlighting their methodologies, strengths, limitations, and relevance in different deployment scenarios.

In 2021, Chen *et al.* [8] proposed a handover algorithm for a UE in 5G networks based on fuzzy logic. The parameters used are SINR and ΔSINR as input and HOM as output. Changing the SINR in UE improves 5G handover performance. The proposed algorithm has been compared with several handover algorithms in terms of radio link failure (RLF) rate and ping-pong rate.

Liu *et al.* [13] have developed an algorithm based on fuzzy-technique for order preference by similarity to ideal solution (TOPSIS) that minimizes the ping-pong effect and the number of unnecessary handovers. The proposal integrates the advantages of fuzzy logic and TOPSIS. Received signal strength intensity (RSSI) and signal-to-noise ratio (SNR) are allocation criteria in this approach. The proposal is compared with the conventional RSSI based on the handover approach and the classical handover multi attribute decision making (MADM) method, simple additive weighting (SAW), and TOPSIS.

Deep learning is a widely used technique for delivering highly accurate results in classification tasks. In the context of 5G networks, this approach incorporates changes in the SINR of a UE to reframe the handover issue as a classification problem. By employing a deep neural network (DNN), the classification problem is effectively addressed. The algorithm performs better in reducing the RLF rate and ping-pong rate compared to existing state-of-the-art methods [14].

Liu *et al.* [15] decided to solve handover problems in advanced 5G networks and overcome the limitations of the current handover approach. The algorithm developed is fuzzy-TOPSIS, considering more than one attribute as a criterion for initiating the handover process and selecting the best neighboring base stations as handover targets. The proposed method combines the advantages of these two algorithms by combining fuzzy and TOPSIS. It intelligently determines the optimal fuzzy membership function from historical data of different criteria. The proposed handover scheme outperforms traditional approaches and can significantly minimize the number of handovers and ping-pong handovers while maintaining a relatively high quality of service.

The rapid growth of mobile users is expected to drive substantial densification of small cells within 5G mobile networks, which will operate alongside 4G networks. This densification will lead to a notable increase in mobility scenarios and handover rates. Ensuring stable and reliable connections for UE will pose a significant challenge for next-generation mobile networks. This challenge is further exacerbated by suboptimal HCPs, whether configured manually or automatically. Simulation results indicate that the proposed algorithm significantly reduces average ping-pong handover probability (PPHP) and outage probability (OP) rates with fixed HOM values, outperforming fixed TTT intervals [16].

Silva *et al.* [17] presents a fuzzy logic-based approach that combines user speed and radio channel quality to adjust the hysteresis margin for handover decisions. The proposed algorithm aims to minimize redundant handovers and handover failure rates, enabling users to take full advantage of dense small-cell deployment. Simulation results demonstrate that the algorithm effectively mitigates the ping-pong effect, maintaining it at an insignificant level (below 1%) across all evaluated scenarios. Furthermore, it significantly reduces the handover failure rate and the total number of handovers, outperforming existing algorithms, particularly in environments with a high density of small cells.

Existing work still has several limitations, including dependence on a limited number of parameters, low adaptability to rapid network variations, high complexity in some approaches, the use of fixed values for transfer parameters, and high dependence on precise mobility measurements. For these reasons, we considered improving the transfer algorithm.

The authors propose a robust transfer optimization technique with a fuzzy logic controller (RHOT-FLC). This proposal aims to provide automatic HCP configuration using RSRP, RSRQ, and UE speed information as input parameters to the proposed technique. This technique uses both HOM and TTT parameters, unlike other algorithms. RHOT-FLC has considerably improved its performance compared with previous methods. The RHOT-FLC technique achieves up to 95% reduction for HOP, 95.8% for HOF, 97% for HOPP, 94.7% for HOL, and 95% for HIT [10].

3. PROPOSED SYSTEM

Fuzzy logic is an artificial intelligence technique that emulates human reasoning to make decisions in uncertain or imprecise conditions. Unlike conventional systems that rely on binary rules (true or false), fuzzy logic operates with degrees of truth, expressed as values ranging between 0 and 1 [18]. This concept is rooted in fuzzy sets, where state boundaries are gradual rather than sharply defined. Fuzzy logic systems can model complex behaviors and deliver adaptive, flexible solutions by employing linguistic variables (e.g., low, medium, and high) and conditional rules derived from expert knowledge [19].

A fuzzy logic system operates through three primary phases: fuzzification, inference, and defuzzification. During the fuzzification phase, numerical input variables are transformed into fuzzy sets using membership functions. The inference phase follows, where the fuzzy rule expressed as an "IF-THEN" conditional statement is applied to process the fuzzy inputs and generate fuzzy outputs [20]. Finally, in the defuzzification phase, the fuzzy outputs are translated into a precise numerical value to provide a crisp production [21].

We introduce a fuzzy logic-based 5G handover method designed to minimize HIT and maximize HOL in 5G networks. The suggested fuzzy system uses four input parameters: velocity, SINR, RSRQ, and RSRP. Out of 53 defined fuzzy rules, it produces two output parameters: HOM and TTT. The values of the RSRP and RSRQ are adjusted according to 3GPP, Release 16 definition [22]. Figure 1 illustrates the fuzzy logic system diagram for our suggested approach.

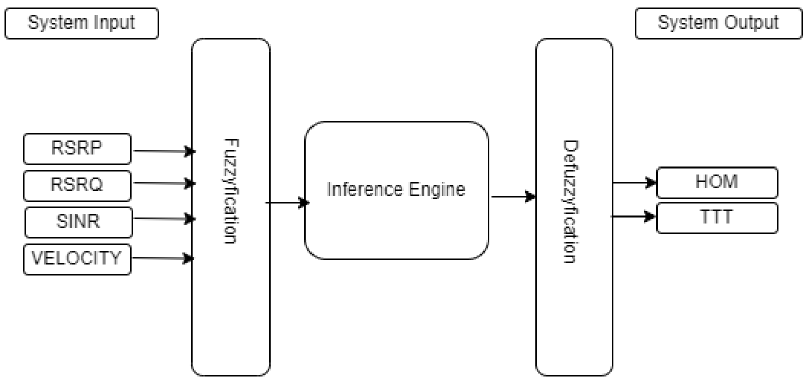

Figure 1. Fuzzy logic system for the proposed handover algorithm

The degree to which an element belongs to a fuzzy set is indicated by its membership value. Fuzzy sets allow partial membership with values ranging from 0 to 1, in contrast to standard sets where an element either completely belongs (membership value of 1) or does not belong at all (membership value of 0). The membership degrees for the input and output parameters are shown in Tables 1 and 2, respectively. The proposed handover algorithm follows a structured approach, as depicted in the flowchart in Figure 2 (see in Appendix):

a. RSRP comparison: the RSRP values of all gNBs are sorted and compared with the target gNB. A handover decision is taken only if the condition RSRPtarget > RSRPserving + HOM is satisfied.
b. Parameter update: system inputs, including UE speed, SINR, RSRQ, and RSRP values, are gathered for further processing.

c. Conversion to fuzzy sets: input parameters are transformed into fuzzy sets using the definitions in Tables 1 and 2, with membership degrees calculated for each function.
d. Application of fuzzy rules: fuzzy rules corresponding to the membership functions are applied to analyze the fuzzy input data.
e. Updating output parameters: the system dynamically adjusts the TTT and HOM values by analyzing the four input parameters.
f. Handover decision: the final handover decision is determined by combining the updated system parameters and selecting the most suitable target cell.

Table 1. The membership values for input

Input	Degree	Range
RSRP	Weak	[-160 80]
	Moderate	[-70 -50]
	Strong	[-40 -20]
RSRQ	Poor	[-60 -20]
	Moderate	[-20 10]
	Excellent	[10 20]
SINR	Poor	[-10 0]
	Moderate	[1 10]
	Excellent	[11 30]
Velocity	Slow	[0 20 40 60]
	Fast	[50 70 90 160]

Table 2. The membership values for output

Output	Degree	Range
HOM	Short	[0 0,5]
	Average	[0,4 0,8]
	High	[0,7 1]
TTT	Short	[0 220]
	Average	[220 520]
	Large	[520 640]

4. PERFORMANCE MODELING AND SIMULATION EVALUATION

4.1. Work environment

The simulation conducted using MATLAB 2020b [23] models a Beyond 5G (B5G) network in an urban environment. The simulated area spans 1000×1000 meters, utilizing a carrier frequency of 28 GHz and a system bandwidth of 500 MHz to support high-capacity and low-latency applications. Each cell, with a radius of 150 meters, is optimized for dense urban deployments and served by gNBs operating at a transmission power of 35 dBm, while UEs transmit at 23 dBm.

The network features 30 gNBs and 10 UEs, with each cell supporting a maximum of 10 users to prevent congestion and maintain optimal quality of service. The handover process is controlled by a TTT parameter, adjustable between 0 and 640 ms, and a HOM ranging from 0 to 1 dB, ensuring smooth and efficient cell transitions.

4.2. Simulation parameters

To assess the performance of the proposed handover algorithm in an environment representative of 5G and B5G networks, a series of simulations has been carried out based on a set of realistic parameters inspired by 3GPP recommendations and recent work in literature. The simulation scenario takes into account an urban environment with small cells deployed at high carrier frequency (28 GHz) and using high bandwidth (500 MHz), conditions typical of millimeter-wave networks. The parameters selected, summarized in the Table 3, cover physical aspects (area, frequency, cell radius, and transmit power), mobility conditions (UE speeds), and handover decision thresholds (TTT and HOM).

4.3. Results and discussions

This section provides the simulation study results for a new proposition compared with algorithms: FLC [12] and RHOT-FLC [10]. The proposed technique is evaluated using two important handover performance metrics (HOL, HIT) and assessed in five mobile speed scenarios (20, 40, 60, 80, and 120) km/h, as explained in the previous section. In addition, the algorithms are validated by using a simulation with B5G networks [24]. The performance metrics used for the 5G handover algorithm include:

HOL is a key performance metric in telecommunications networks. According to the 3GPP standards, HOL represents when the UE receives the handover order from the serving gNB and when the handover to the target gNB is completed. In other words, the HOL covers all the time required for the handover. In B5G networks, where many applications require extreme responsiveness, latency must be reduced to a maximum of 1 ms [25].

HIT: refers to the time during which the transmission of user data from the source cell to the target cell is interrupted during handover. This time, therefore, represents the minimum amount of time that the service is interrupted during a handover. 3GPP is working to reduce this time to minimize the impact on the UX during handover [26].

Table 3. The simulation parameters of our proposed algorithm

Parameters	Value	Parameters	Value
Simulation area (m)	(1000×1000)	Maximum number of UE per cell	10
Carrier frequency (GHz)	28	gNB	30
System bandwidth	500 MHz	UE	10
Cell radius (m)	150	TTT (ms)	0-640
Transmission power (dBm)	35	HOM (dB)	0-1
UE power (dBm)	23	Speed scenarios (km/h)	20, 40, 60, 80, 120

4.3.1. Handover latency

Figure 3 displays the HOL data, highlighting the system's performance under different mobility conditions. For 20 km/h, 40 km/h, 60 km/h, 80 km/h, and 120 km/h, the measured HOL values are 0.7 ms, 0.93 ms, 1.3 ms, 1.19 ms, and 0.6 ms, respectively. Based on these findings, the suggested algorithm's average transfer latency is 0.944 ms. The latency significantly increases to 0.93 ms at 40 km/h. Although there are more handovers at this intermediate speed, the system can still efficiently coordinate amongst gNBs (basic cells). With a value of 0.6 ms, the lowest of all tested speeds, a notable decrease in latency is seen at 120 km/h. This performance could result from the predictive or optimization techniques tailored to high mobility situations, like sophisticated triggering parameter adjustment or anticipatory handovers.

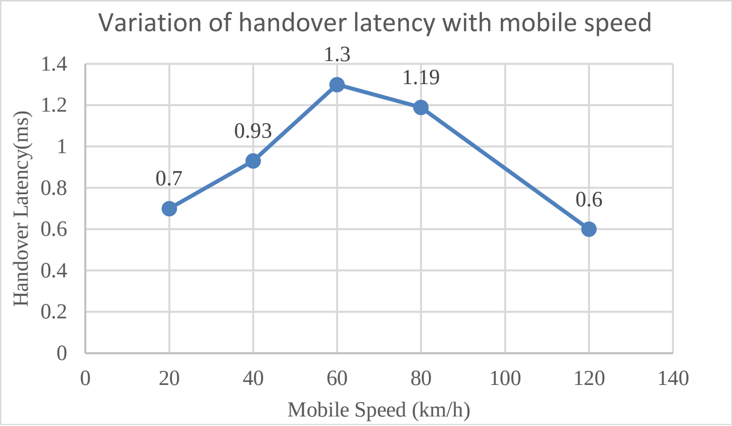

Figure 3. HOL for different mobile speeds

4.3.2. Handover interruption time

Figure 4 shows the variations in HIT values as a function of different mobile speeds, highlighting the system's performance in various mobility scenarios. The minimum HIT value, measured at 0.62 ms for a speed of 80 km/h, reflects optimal handover management at this intermediate speed. This result suggests that the algorithm maintains a balance between signal stability and the speed of handover procedures, thanks to effective dynamic adjustments to parameters such as TTT and hysteresis (HOM).

In contrast, the maximum HIT value, recorded at 1.8 ms for a speed of 20 km/h, reveals challenges specific to low-mobility scenarios. At this speed, the slower movements of UE can generate local signal fluctuations, increasing the likelihood of premature triggers or unnecessary handovers, such as ping-pong handovers. These situations lead to delays in the finalization of transfers, thus increasing downtime.

4.3.3. Comparison of results

Figure 5 highlights the performance of the different algorithms in terms of average latency (HOL). The proposed algorithm stands out by achieving an average latency of just 0.944 ms, demonstrating its effectiveness in managing inter-cell handovers in 5G networks. This outstanding performance is the result of integrating advanced approaches based on dynamic adjustments to handover parameters, such as TTT and hysteresis (HOM), combined with robust predictive techniques. These adjustments minimize interruptions while adapting efficiently to various mobility and network density scenarios.

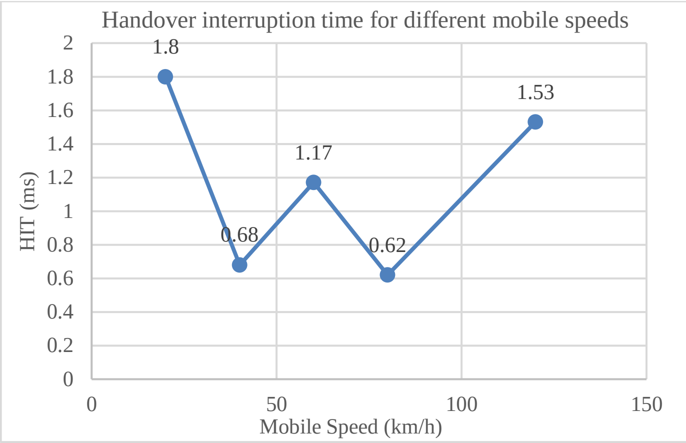

Figure 4. HIT for different mobile speeds

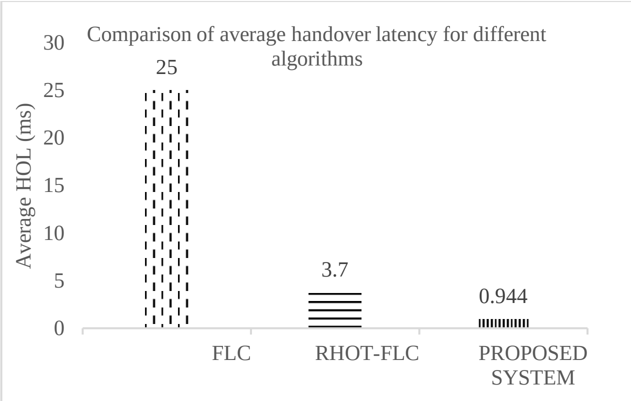

Figure 5. Average HOL for different algorithms

In comparison, the FLC algorithm achieves a significantly higher average latency of 25 ms. Although fuzzy logic is effective in adjusting certain parameters to dynamic network conditions, its lack of predictive mechanisms limits its ability to handle complex scenarios, especially those involving rapid changes in signal conditions. The RHOT-FLC algorithm, which combines predictive mechanisms (RHOT) with fuzzy logic, offers a significant improvement with an average latency reduced to 3.7 ms. This combination improves decision-making and reduces delays but is still disappointing in terms of the efficiency of the proposed algorithm.

Figure 6 shows the average HIT for the different algorithms studied, highlighting their effectiveness in handling transfer interruptions. The proposed algorithm achieves a remarkably low average latency of 1.16 ms, demonstrating a significant reduction compared to other approaches. This result reflects the effectiveness of this algorithm in optimizing handover procedures, thanks in particular to the integration of advanced mechanisms for predicting and dynamically adapting trigger parameters, such as TTT and HOM.

In contrast, the FLC algorithm, which is entirely based on fuzzy logic, has a significantly greater average latency of 12.8 ms. This method lacks the predictive capabilities required to handle complicated scenarios or high-mobility environments, despite allowing for modifications based on network conditions. With an average latency of 1.8 ms, the RHOT-FLC algorithm provides better performance by fusing the benefits of fuzzy logic with predictive mechanisms (RHOT). Despite its effectiveness, the suggested approach, which includes extra improvements to reduce interruption time, still outperforms it by a small margin.

These results underline the superiority of the proposed algorithm, which manages to meet the requirements of 5G networks by achieving a HIT well below the critical threshold of 2 ms. Its ability to minimize interruptions, even in complex environments and high mobility scenarios, makes it particularly suitable for mission-critical applications such as augmented reality, autonomous vehicles, and ultra-reliable low-latency communications (URLLC). By integrating advanced mechanisms and optimizing performance, this algorithm meets the challenges of next-generation networks, guaranteeing smooth, reliable transfers for a variety of demanding use cases.

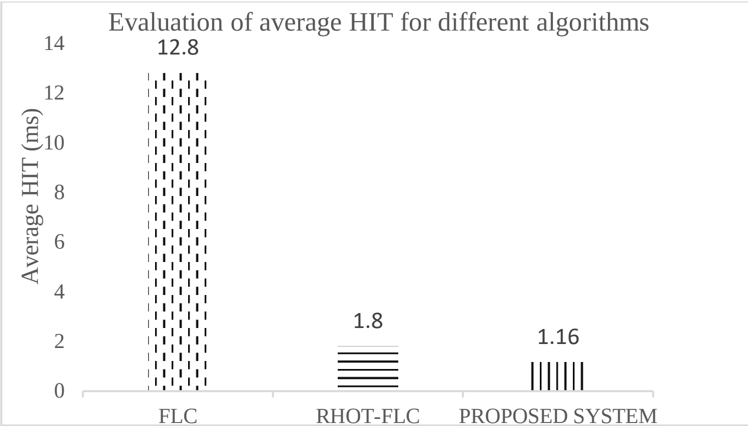

Figure 6. Average HIT for different algorithms

In conclusion, analysis of the results presented in the Figures 5 and 6 shows a clear improvement in the performance of the proposed system compared with existing approaches (FLC and RHOT-FLC). In terms of average HOL, the proposed system registers a significantly lower value than those obtained by FLC and RHOT-FLC, reflecting an enhanced ability to perform cell-to-cell handover with minimal delay. Similarly, for the average HIT, the proposed system shows optimized performance, significantly reducing the time during which the user's connection is suspended. These results demonstrate the effectiveness of the algorithm developed, which not only improves the responsiveness of the handover process but also enhances users' quality of experience (QoE) in the context of 5G networks.

5. CONCLUSION

Fuzzy logic is proving to be a particularly relevant approach for optimizing handover processes in mobile networks, especially given the growing complexity and increased dynamics of the environments specific to B5G networks. Thanks to its ability to deal with uncertainty and contextual variations, it offers a flexible and adaptive decision-making framework, essential for guaranteeing high-quality service and ensuring continuity of connectivity.

In this study, a rigorous selection of input parameters such as RSRP, RSRQ, SINR, and UE speed enabled the construction of a high-performance fuzzy logic system. The integration of these parameters led to a significant improvement in network performance, reducing both communication interruptions and unnecessary handovers, while maintaining low latency and service stability.

The results obtained demonstrate that the fuzzy logic approach represents a robust, scalable, and efficient solution to meet the stringent requirements of next-generation mobile networks and provides a solid basis for the future development of intelligent mobility management algorithms.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

DATA AVAILABILITY

Data will be made available on request.

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APPENDIX

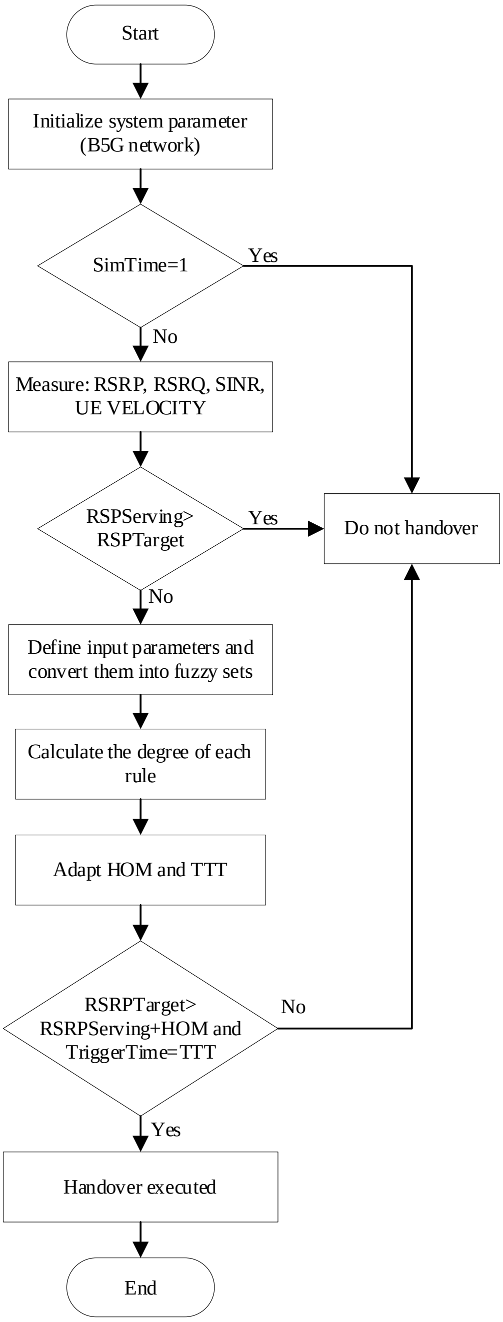

Figure 2. Block diagram of the proposed algorithm

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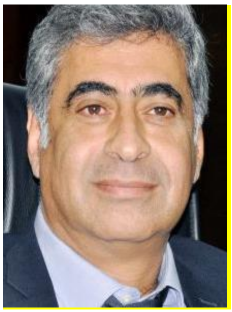

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