A Fuzzy Logical RAT Selection Scheme in SDN-Enabled 5G HetNets

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Abstract. Mobile communication systems are witnessing an ongoing-increase in connected devices and new types of services. This considerable increase has led to an exponential augmentation in mobile data traffic volume. The dense deployment of small base stations and mobile nodes in traffic hotspots is considered one of the potential solutions aimed at satisfying the emerging requirements in 5G/Beyond 5G wireless networks. However, the ultra-densification poses challenges for the mobility management, including frequent, unnecessary and ping-pong handovers, with additional problems related to increased delay and total failure of the handover process. In this paper, we propose a new handover management approach using the Software Defined Networking (SDN) paradigm to overcome performance limitations linked to handover taking place at dense femtocell environments. With the exploitation of SDN, data plane and control plane are separated thus the HO decision can be made at the SDN controller. In addition, in order to reduce the complexity and delay of handover process, a Fuzzy logic system is used to decide whether a target candidate is suitable for handover. Simulation results validate the efficiency of our proposal.

Keywords: 5G · Macrocell · Femtocell · SDN · MIH · Handover · RAT Selection · Fuzzy logic

1 Introduction

Nowadays, there is an exponential deployment of radio networks characterized by an increasing number of users and panoply of services. Next Generation Wireless Networks (NGWNs) will combine existing and new technologies such as GPRS, UMTS, LTE, WiMAX and other backbone internet to provide high throughput anytime, anywhere for multimedia services. Mobile users will be able to communicate through different radio access technologies (RAT) and roam from one RAT to another by using multimode user equipement. This new mobile broadband technology is characterized by networks having different coverage ranges such as macro-cell, small-cell and atto-cell [1, 2], and diverse technologies interacting with varied types of entities. Although this new technology will bring several advantages in many areas, issues regarding mobility management are still a big challenge that needs to be solved in the future B5G/6G mobile networks. The outstanding issues include the challenges related to mobility routing, handover decisions,

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handover authentication and control parameters settings, and more other mobility issues. So, to manage such a network and overcome these drawbacks, flexibility will be the key feature of this mobile generation. This architectural flexibility will be released by implementing the Software Defined Network (SDN) in the 5G mobile network [3]. SDN is based on the separation between the control plane, and the data plane allowing the handling of the traffic by means of software [4]. This separation helps improve scalability, flexibility, reliability, and simplification of network management [4, 5]. SDN architecture transforms network devices (e.g. switches) into dummy devices with no intelligence functions such as routing, major processing, and mobility management [6]. On the other hand, the IEEE 802.21 standard proposes a media independent handover (MIH) [7] specification for achieving seamless handover for mobile users in the same or in different networks. The main functionality offered by MIH is a seamless connection to different RATs. The control messages are relayed by the Function (MIHF) located in the protocol stack between the layer 2 wireless technologies and IP at layer 3. The MIH Information Service (MIIS) offers a variety of criteria and services that can be used to avoid network scanning. But sometimes scanning avoidance leads to inconsistent handover, that is, increased handover failure rates.

While there are many open challenges in 5G HetNets, our focus here is on identifying a solution to the problem of handover management. Understandably, handover procedures for existing networks are needed to support the macrocell/femtocell integrated network. Understandably, this situation may result in a large accumulation of unnecessary and frequent handovers, and also increase the risk of handover failure. In this paper, we propose a solution to optimize the handover in5G HetNets. In order to avoid unnecessary handoff and reduce the excessive interference, we present a handover strategy between Femtocell and Macrocell base on QoS level under SDN/MIH based 5G network. Our solution resides in creating a novel multi-criteria network selection mechanism. RSSI of Base Station, mobile user's movement direction, and base station available capacity are factors used in this work to improve handover decision while sustaining perceived network performance.

The main contributions of this work are as follows: i) Proposal of an interworking architecture that integrates MIH and SDN paradigms and enhances the handover procedure. The optimized architecture involves new components for the management of the handover. (ii) Proposal of an optimized network selection process divided into two stages, which are pre-selection and network selection. The pre-selection eliminates the non-potential candidate networks dependent on the mobility profile of the mobile node. The network selection process is based on multiple parameters using fuzzy logical model. (iii) The feasibility of the proposed RAT selection scheme in handover management is verified by extensive numerical simulations. The HO performances are evaluated in terms of average throughput of UE, average ping-pong HO rate, average handover failure HOF rate, and average HO delay. Compared with the performance of other existing HO strategies, our algorithms are more significant. The rest of the paper is organized as follows. Section 2 provides a background on the related research topic. Section 3 presents the system model. In Sect. 3.1, the MIH/SDN optimized handover scheme is described in detail. Section 4 presents simulation settings and provides the results and discussion. Finally, Sect. 5 concludes our study.

2 Related Works

In the conventional RSS-based solutions, HO is triggered when the user obtains a higher SINR from a nearby network while its current signal quality is degrading. In [8], the authors propose to use macro-assisted small cells based on the split of Control and User planes where small cells are considered as data only carriers. This solution improved the HO failure and energy consumption; however, it has a scalability problem at the macro cell level as this latter is expected to handle the control plane of a big number of femtocells. More intelligent techniques, such as Fuzzy rule-based algorithms, have been used in order to determine the best network, to reduce unnecessary HOs and improve throughput, taking into account bit error rate, delay, jitter and bandwidth as QoS parameters for HO decision [9]. However, the existing Fuzzy TOPSIS solutions deal with only QoS parameters and were not used in the case of HOD algorithms for HetNets with D2D communications. Other study has been carried out on the channel scanning method. In [10], the authors proposed an algorithm for vertical handover decision-making able to choose the best-optimized access network. This algorithm uses two major approaches namely the Bio-geographical Based Optimization (BBO) method and the Markov chain method. The proposed algorithm uses the IEEE 802.21 standard to acquire different handover decision information. It was proved via the simulation that this algorithm is able to select the best network candidate accurately based on the requirements of the connection in accordance with the requirements of the application and the preferences of the users.

Wang et al. [11] proposed an SDN-based architecture for future wireless networks. The proposed SDN controller is able to predict a user's movement path such that the relevant point of attachment is able to do handover in advance. Then, they proposed a novel self-healing approach to mitigate different failures occurring in backhaul to boost the robustness and reliability of future wireless networks. Experimental results verified that the proposed SDN-based architecture reduces handover latency compared to conventional scheme. However, in this paper, the authors don't provide details of their proposed handover scheme. Monira et al. in [12], proposed an SDN-based 5G handover solution to optimize handover delay by addressing the diversity of 5G networks with the help of SDN. In this work, the authors developed an authentication mechanism where a centralized authentication server establishes mutual trust among the domain controllers to ensure the credibility of the connected network components. However, this study did not deal the handover decision and network selection algorithms. Meanwhile, in [13–15], the researchers suggested various SDN-based HO algorithms for LTE-Advanced/5G HetNets. In [15], the authors proposed an SDN-based QoS VHD where the network with highest RSS and highest QoS score is selected for HO in dense HetNets. In this proposed solution, network context information such as RSS, Bandwidth, BLER, Jitter and Delay, user context information such as the user speed and service context information such as the application type are taken into consideration in the decision. Simulation results indicated that the proposed approach could reduce the signaling overhead, handover delay and handover dropping probability. However, additional decision parameters are required to ensure better QoS.

Hocine et al. in [16], dealt with the problem of energy saving during vertical handover in 5G communication systems. The proposed approach is based on MIH framework including modifications to make MIH more collaborative in energy saving. However, in this proposal the study of mobility management aspects is absent specially the handover decision and the best network selection. Khitem et al. in [17], proposed a new solution that involves resource allocation and vertical handover process based on MIH. In this solution, new elements are added in the core network to enhance the vertical handover procedure and to support the resource management process in next-generation wireless networks. Simulation results indicated that the proposed scheme could optimize the vertical handover process and improve the overall network performance, such as the fairness index, call blocking rate, etc. However, the handover decision strategy does not consider the users' preferences. Moreover, the execution of this scheme takes a lot of time, which causes long handover latency

3 Handover Approach in 5G HetNets

3.1 The Integrated 5G MIH-SDN Controller Architecture

In our approach, we focus on the adoption of the Logically Centralized Physically Distributed (LC-PD) [6] control plane architecture with MIH cooperation, as shown in Fig. 1, into the 5G mobile network. Our proposed framework incorporates an additional functional unit into SDN to assist in handover discovery, and the decision of candidate networks based on the networks' QoS parameters.

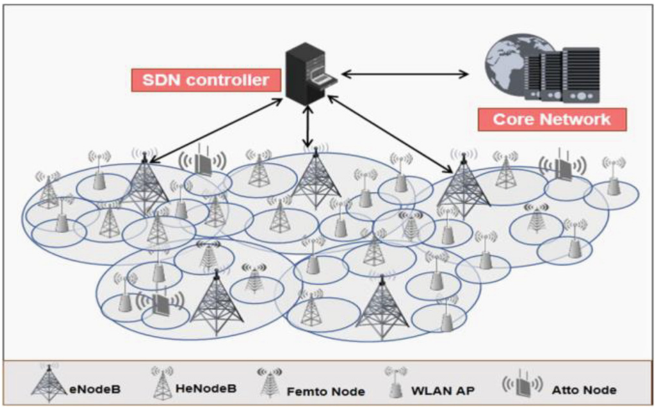

Fig. 1. SDN-based 5G Network Architecture

The proposed software-defined handover architecture is based on MIH and SDN to optimize handover in 5G networks. In addition, this architecture involves new component for the management of the handover. Figure 2 shows the proposed architecture, which consists of four units:

- MIH Enable Multi Interface Mobile Node MN: This logical device can use any of the available wireless networks supported by its interfaces. It consists of all functionalities necessary for an end user to access B5G network. The Negotiator Service

Monitor (NSM) define a mapping between the terminal context of the WiFi and LTE that enables the translation function to define values for WiFi context information-elements (resp., for LTE context information exchange) based on values related to a LTE association (resp., for WiFi association).

- SDN Controller with MIHF extension: We have introduced extension Handover Management Unit (HMU) for handover decision-making and network selection. HMU is introduced between the MIH layer and the upper layer in the protocol stack of the SDN controller. It can sense the MN's conditions in real time. Thus, it can use switch to collect the QoS information calculated by the network side before MN's computational capacity cannot support the services. Based on collected information, HMU determines in advance the need for the handover and chooses the best access network among heterogeneous networks, leading to the success of the handover process.
- Information Server (IS): providing static information about RATs like MAC address, location, and service provider's name.
- OpenFlow switches: associate diverse types of PoAs to the SDN controller. OpenFlow switches are responsible for the data forwarding. They consist of one or more flow tables. A flow entry consists of the source address, destination address, session id, port number, time, etc. [18]. An OpenFlow switch updates its flow tables based on instructions that are provided via an OpenFlow protocol from the SDN controller.

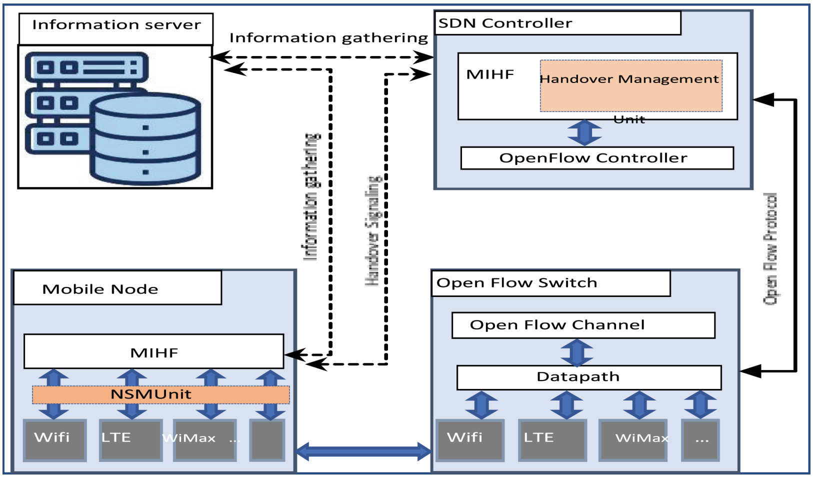

Fig. 2. Proposed Vertical Handover Framework

3.2 A Proposed Multi-criteria RAT Selection Scheme

The core idea behind the proposed architecture is based on mobility management to accommodate more calls while reducing the ping pong effect, handover delay and handover failure ratio and satisfying at the same time applications expectations. Thus, our proposed QoS management approach has been designed based on the following foundations:

Pre-selection Network: In this phase, the HMU performs the pre-selection process. The SDN controller first calculates the QoS score of the qualified networks. To judge whether the performance meets the user's requirement, QoS is quantitatively measured by some important parameters for user experience. Nonetheless, to define a cost function that takes into account MN's requirements, we involve another important metric which is the application type-based priority (P). Indeed, according to the temporal characteristics, the data in 5G can be divided into three categories [19]: Complex real-time data (CRT): whose time requirements are strict and have the highest priority, Soft real-time data (SRT)are more tolerant to changes in the timeout and Non-real-time data (NRT): non-real-time data is not time-sensitive and have the least priority. So, Q the denotation of QoS score can be computed as:

$$\begin{aligned} Q_{i,j} = w_{RSRP} * \ln RSRP_{i,j} + w_d * \ln \frac{1}{d_{i,j}} + w_B * \ln B_{i,j} \\ + w_p \ln P_{i,j} + w_{BER} * \ln BER_{i,j} + w_{jit} * \ln JIT_{i,j} \end{aligned} \tag{1}$$

With:

$$w_{RSRP} + w_d + w_B + w_P + w_{BER} + w_{JIT} = 1$$

where W_{RSRP}, W_d, W_B, W_P, W_{BER} and W_{JIT} are the weighting factors of reference signal received power (RSRP), delay, bandwidth, application type-based priority, block error rate (BLER) and jitter, respectively. In (1), specially, factors that have negative effects on QoS are expressed in the form of reciprocal in "ln" function to reduce the QoS value.

After QoS calculation, a RAT is considered to be a candidate if it has a QoS score greater than the QoS score of the current RAT.

Network Selection and Fuzzy Logic Controllers: The SDN controller needs to select only the potential candidate based on multi-criteria metrics. The considered criteria are as follow. On the one hand, the network conditions which refer the characteristics of each RAT such as RSS and load. The RSS for non-3GPP networks or RSRP for 3GPP networks of the available RATs: is a measurement used for evaluating the signal quality of the neighbor base stations. The traffic load of the network: the traffic load of the cellular base stations and/or Wi-Fi Access Points (APs) (in terms of available bandwidth). It is the ratio between the number of resources used in the network and the total number of resources in the network for a period of time t. On the other hand, the mobile node conditions which refer to the parameters of each MN such as velocity and the requested type of service (ToS). To identify the ToS, we consider the two principles variables, requested Tolerated delay and Data-Rate (bit rate). The speed of the vehicle is a crucial decision parameter. Fast moving vehicle may cross over WLAN coverage rapidly. Thus, handing it over from a cellular network to a WLAN could cause quick successive handovers which may result in high signaling overheads and delays.

To identify the best suitable radio access network, we adopt fuzzy logic algorithmin our proposed scheme. Fuzzy logic is an ideal tool for dealing with uncertainty cases, when the inputs are rough estimated values [12]. The fuzzy logic controller is composed of four elements. These are fuzzification, rule base, inference mechanism and defuzzification. The proposed block diagram of a fuzzy logic control system is shown in Fig. 3. The fuzzifier under takes the transformation (fuzzification) of the input values to the degree that these values belong to a specific state (e.g., low, medium, high, etc.) as shown in Table 1. After that, the inference mechanism correlates the inputs and the outputs using simple "IF…THEN…" rules. Then, the output degrees for all the rules of the inference phase are being aggregated. The output of the decision making process, comes from the defuzzification procedure.

In the proposed scheme, fuzzy logic controller is applied on the following criteria: speed, type of service and network load. We assume three types of networks such as LTE-A macro cell, LTE-A femtocell and Wi-Fi. Every time that the algorithm is triggered, all the available eNB, Home eNB (HeNB) and APs are evaluated.

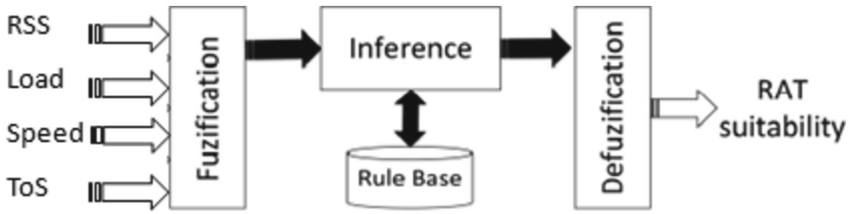

Fig. 3. Block diagram of fuzzy logic control system

For each output, there is a set of four triangular membership functions that represent the four following linguistic variables: "not acceptable NA", "probably not acceptable PNA", "probably acceptable PA" and "acceptable A". The fuzzy controller of the proposed scheme takes four inputs: (i) load factor, ld; (ii) Signal Strength factor, RSS; (iii) speed factor, SP; and (iv) data rate, DR; v) Tolerated delay, TD to identifying the type of service factor and output the selection decision, Sd. Below is the description of the structure of the proposed fuzzy logic controller.

Table 1. Values of decision variables.

Decision variables	Low	Medium	High
MN Speed (Km/h)	<40	From 40 to 60	From 80 to 140
RSS (dBm)	From −140 to −70	From −70 to −60	From −60 to −44
Load (%)	<30	From 30 to 70	From 70 to 100
Data rate (Mb/s)	<0,5	From 0,5 to 1,4	From 1,5 to 2
Tolerable delay (ms)	<150	From 150 to 30	From 300 to 500

Membership Functions: Trapezoidal and triangular membership functions are chosen for simplicity. The membership functions for input and output linguistic parameters are shown in Fig. 4. The values of the membership functions have been chosen based on commonly used values of membership functions in various literatures. For the fuzzy controller, the term sets for ld, SP, DR, TD, and Sd are defined as follows:

i) U(ld) = {Low, Medium, High}
ii) U(RSS) = {Low, Medium, High}
iii) U(SP) = {Low, Medium, High}
iv) U(DR) = {Low, Medium, High}
v) U(TD) = {Low, Medium, High}
vi) U(Sd) = {NA, PNA, PA, A}

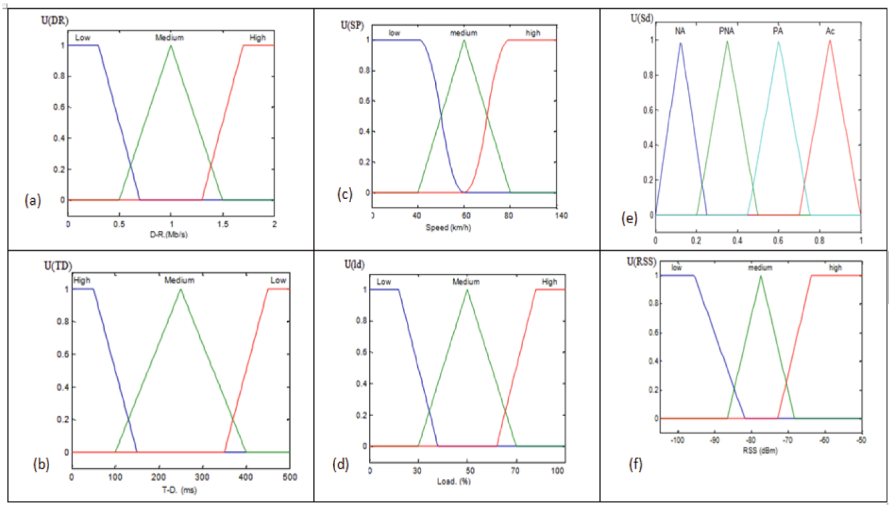

Fig. 4. Membership functions for (a) Data rate, DR (b) Tolerated delay, TD (c) Speed, SP (d) load factor, lc (e) selection decision (sd)

Examples of fuzzy inference system (FIS) rules:

(a) If D-R is low and T-D is medium then eNB is PA, HeNB is PA and AP is PA
(b) If D-R is high and T-D is high then eNB is A, HeNB is PA and AP is PNA
(c) If Speed is high then eNB is A, HeNB is PNA and AP is PNA

The strategy of the rules is the following. The RAT, which is characterized by high RSS and low load, is advantageous for the MN with high speed and QoS requirements choice. On the other hand, high mobility MN are preferably placed in larger cells and small cells are avoided to minimize the unnecessary handover. On the contrary, MN characterized by low or medium speed will be served by femtocells, in order to offload the traffic of the macro cells. Finally, the defuzzification process aggregates all the outcomes of all the rules and ends up to a certain degree of the output value, i.e., RAT suitability. The network with the highest RAT suitability will be selected. The suitability value ranges from 0 to 1 (0 to 100% respectively).

4 Performance Evaluation

In this section, the performance of the proposed handover management scheme is evaluated through a simulation analysis using MATLAB tool. This software is a suitable environment for our simulations because it has basic functions already present and necessary to evaluate the process of various traffic models. We adopt the conventional used hexagonal cells. The total number of macro cells is 24, and the radius of each is 1 Km. For the smaller cells, the total number equal to 500 APs distributed randomly in the network, and the radius of each varies from 50 to 200 m. Mobile Nodes are distributed randomly around AP, and they move randomly with a velocity varies from 5 km/h to 140 km/h. More details on the configuration parameters used in this simulation are given in Table 2. In order to make the simulation more accurate, we ran the simulation 10 times and averaged the results. To evaluate the performance of the proposed MIH/SDN-based vertical handover approach, we compare it by our previous handover mechanism based on utility function [17].

Table 2. Simulation Parameters.

Parameters	Values
Number of macrocells	24
Macrocell coverage	1000 m
Number of small cells	50–500
femtocell coverage	250
LTE BW/Data rate	20 MHz/100 Mbps
LTE range of RSRP	From −140 dBm to −44 dBm
Resource blocks (RBs)	100 RBs and 180 kHz per RB
802.11p BW/Data rate	10 MHz/6 Mbps
802.11p range of RSS	From −90 dBm to −30 dBm
Number of MN	125–1250
Vehicles speed (km/h)	20–140
Mobility model	Random walk model
Minimum association RSRP	−112 dBm

First, we measure the handover delay according to the increase of handover request arrival rate for the proposed and the existing solutions. Handover delay is the time it took from the disconnection of the MN from the ancient PoA until the MN correctly receives the first packet from the new PoA. Then, we measure the handover failure rate and ping-pong effect for all types of traffic classes.

Figure 5 presents the impact of the handover request arrival rate (request/second) and the delay occurred following the proposed and the existing handover approaches. We remark that our proposed handover algorithm gets significantly lower delay than the

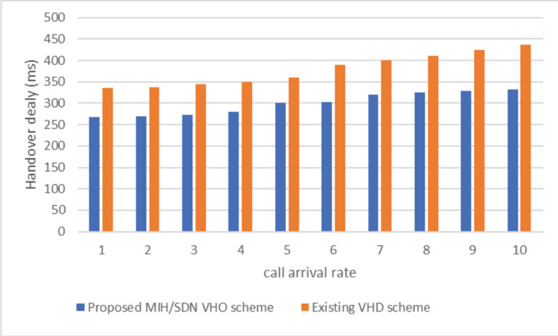

Fig. 5. Comparison of handover delay versus call arrival rate

other handover procedure. By analysing Fig. 5, we note that MIH/SDN-based vertical handover approach provides a 26% decrease in handover delay compared to the previous handover approach. This best result can be justified by the fact that the utilization of the SDN technology, when the density of networks is significantly important, reduces the complexity of the handover process.

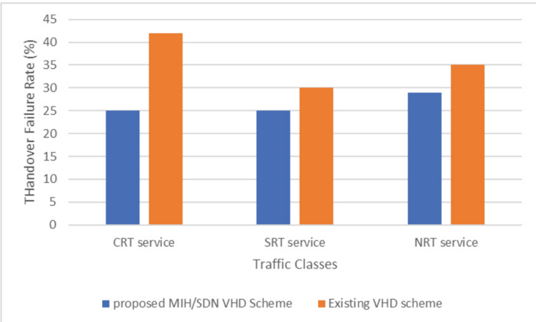

Fig. 6. Comparison of HO Failure Rate versus all Traffic Classes

Figure 6 depicts the handover failure ratios of the proposed and our previous handover mechanism. We observe from this figure, that the MIH/SDN-based vertical handover solution outperforms the previous approach by having less handover failure ratio. We show that the novel approach registers a decrease of 30% compared to the other solution.

5 Conclusion

In this work, we focus on proposing a solution to the problem of handover management in 5G HetNets. We have proposed a novel multi-criteria network selection mechanism. The objectives of the proposed approach are to decrease handover failure and delay and to distribute traffic load uniformly among available network to improve the average system resource utilization. The proposed algorithm is based on fuzzy logic scheme to support the decision making process. Simulation results demonstrate that, compared to existing works, the proposed approach significantly reduces the handover delay and failure.

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