A Multi-criteria Handover Decision System for Heterogeneous Wireless Networks Based on Fuzzy Logic

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- Lastly, I would like to express my gratitude to all my friends for being by my side and encouraging me during my studies.

Abstract

Seamless mobility is one of the most important issues considered in wireless mobile communications. Many researchers have developed numerous handover decision systems (HDSs) to ensure seamless mobility between different Radio Access Technologies (RATs). By the appearance of real-time services in heterogeneous networks, numerous quality of service (QoS) parameters have to be included in the handover decision making process. However, by increasing the number of input parameters in available HDSs, the algorithm execution time is also increasing. To decrease the algorithm execution time, one can reduce the number of input parameters, which can degrade the decision accuracy. At the same time, most of the available handover decision algorithms comprised the QoS related parameters, but the mobility and efficiency parameters are non-existent. On the other hand, in some of the algorithms where the mobility parameters are considered as handover decision criterion, the absence of QoS related parameters are counted as its deficiency. In the current thesis, a fuzzy-logic based Handover Decision System design is proposed to make quick, intelligent, and comprehensive decisions during the handover procedure. In the proposed solution, the minimum number of fuzzy rules with eight-decision parameters, where four QoS, two mobility, and two efficiency related parameters are chosen as handover decision-making criterion, is considered to reduce the algorithm execution time, enhance the intelligence of the decision algorithm, and to make a comprehensive decision for performing handover. The simulation result of the current handover decision algorithm in terms of network selection performance shows that it is superior to the previous non-fuzzy logic based handover decision algorithm (Simple Additive Weighting).

Keywords Handover Decision System, Heterogeneous networks, Fully Logic, Fuzzy Membership Function

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List of Abbreviations

1G: First Generation

2G: Second Generation

3G: Third Generation

4G: Fourth Generation

TACS: Total Access Communication System

NMT: Nordic Mobile Telephone

GSM: Global System for Mobile Communication

GPRS: General Packet Radio Services

EDGE: Enhanced Data rate for GSM Evaluation

WCDMA: Wideband Code Division Multiple Access

UMTS: Universal Telecommunication System

QoS: Quality of Service

LTE: Long Term Evolution

WLAN: Wireless Local Area Networks

WiMAX: Worldwide Interoperability Microwave Access

RAT: Radio Access Technology

RSS: Received Signal Strength

HDS: Handover Decision System

FMF: Fuzzy Membership Function

FIS: Fuzzy Inference System

SAW: Simple Additive Weighting

AHP: Analytical Hierarchy process

ATM: Asynchronous Transfer Mode

CoG: Center of Gravity

AQ: Aggregated Quality of Service

NQ: Network Quality of Service

ME: Mobility Engine

EF: Efficiency Engine

DS: Degree of Satisfaction

LA: Latency

PL: Packet Loss

DR: Data Rate

VE: Velocity

CO: Coverage

SC: Service Cost

BL: Battery Life

GUI: Graphical User Interface

SD: Standard Definition

HD: High Definition

PS: percentage success

CHAPTER 1

INTRODUCTION

Chapter 1

Introduction

1.1 Introduction

Mobile users are the witnesses of rapid advancement in wireless communication technologies. This causes an exponential increase in the number of mobile users. To manage the rising demand for the mobile services, prompt development in wireless communication technologies are essential. The presence of numerous communication standards are the consequences of rapid progress in this field, which are categorized as different generations.

Each of the wireless communication technology is related to a particular generation. The first generation (1G) of mobile communication technology has appeared in 1970, which was Total Access Communication System (TACS) and Nordic Mobile Telephone (NMT) [1] and [2]. The 1G technologies were able to provide voice services with large mobile terminals. The mobile users were experiencing periodically call drops with low mobility [3].

The Global System for Mobile Communication (GSM) was introduced in the mobile wireless industry by 1990 as second generation (2G) of mobile technology standard. Unlike the 1G, 2G was based on digital technologies and supporting data services as well. To improve the data rate in order to support a new range of services, the General Packet Radio Services (GPRS) and the Enhanced Data rate for GSM Evaluation (EDGE), 2.5G and 2.75G respectively, are emerged.

By increasing the number of mobile applications and services, the demand for higher data rates and data services are also increased, which leads the mobile communication industry to introduce the third generation (3G) of mobile communication technologies to the market. As a result, the Wideband Code Division Multiple Access (WCDMA) and Universal Telecommunication System (UMTS) come into view. The mentioned technologies can provide width range of data services with high Quality of Service (QoS) and mobility.

As the time passes, the Long Term Evolution (LTE) appears as fourth generation (4G) of the mobile communication standard, which is superior to 3G technologies concerning data rate and service range. The 3G and 4G technologies were able to deliver mobile broadband internet services to the users [4].

Beside cellular networks, at the same time other wireless access technologies are also introduced, in order to provide mobile broadband internet services to the users. Due to that, many wireless communication technologies are present, like Wireless Local Area Networks (WLAN), Worldwide Interoperability Microwave Access (WiMAX), and so on. Each of the technologies as mentioned earlier has their own unique characteristics in terms of bandwidth, latency, cell size, and service cost. For instance, the connection speed of WLAN is very high, but its cell size is smaller compared to WiMAX and UMTS. Heterogeneous wireless networks comprise different wireless access technologies.

1.2 Heterogeneous Wireless Networks

Whenever a new mobile communication standard appears in the wireless communication industry, besides the new applications, it is suggested to support the existing applications as well. The heterogeneous wireless networks are the collections of different Radio Access Technologies (RATs) from 2.75G to 4G [5] and it will comprise beyond 4G in the future. The Heterogeneous wireless networks are able to provide universal and seamless connectivity to users for all types of services [1].

As shown in figure 1.1, the heterogeneous wireless networks are not just the collection of mobile cellular networks (GSM, UMTS, and so on), but it can comport with other standards like WLAN, WiMAX and so forth. When a mobile user moves across a heterogeneous environment surrounded by different radio access technologies, the network may perform horizontal or vertical handover to maintain the connection. The mobile user initiates horizontal handover when the received signal strength (RSS) declines and crosses a predefined threshold [6]. On the other hand, to perform vertical handover, other parameters such as QoS, service cost, and data rate [7] have to be considered, and the system is more complicated than the horizontal handover.

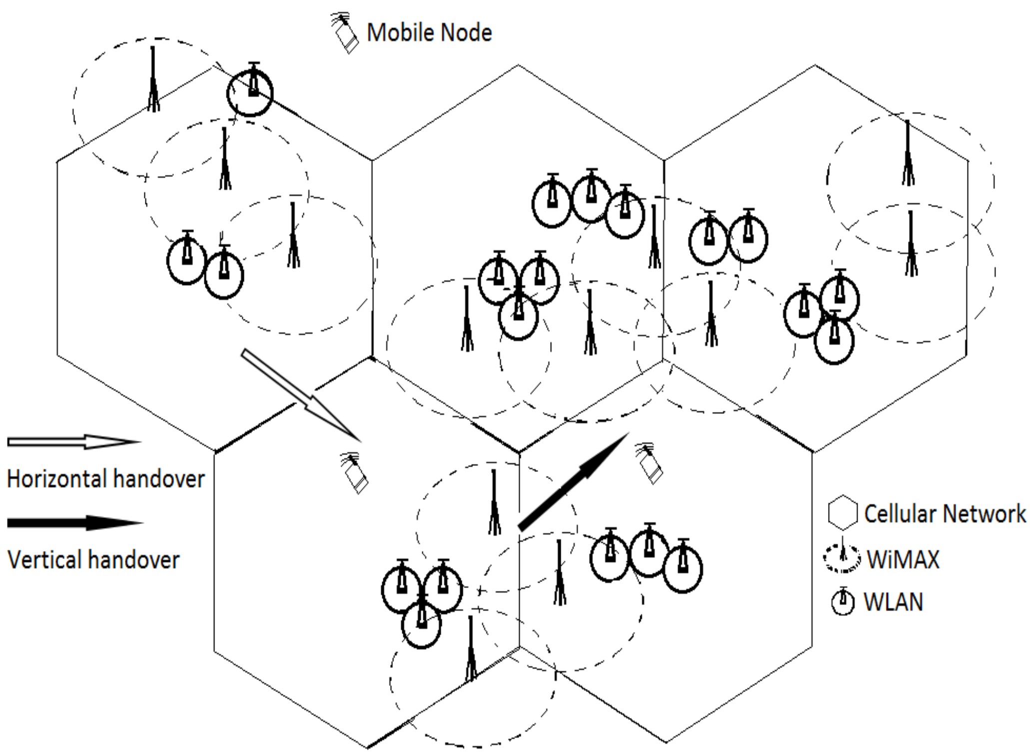

Figure 1.1. An example of heterogeneous wireless networks

1.3 Motivation

Providing universal and seamless connectivity to the mobile terminals while moving across a heterogeneous wireless environment is one of the biggest issues for researchers since many years. However, the main focus of this work is making a proper and intelligent decision for handover in a heterogeneous wireless network.

When a mobile terminal moves across a heterogeneous wireless network during an active session, it needs to perform the horizontal or vertical handover in order to maintain its connection. Significantly intelligent handover decision systems (HDSs) are required to select the best network for handover. In [8], [9] the Fuzzy logic is utilized for the sake of enhancing the capabilities of HDSs for stock trading and wireless sensor networks, respectively. Many fuzzy logic based HDS Algorithms are introduced in the previous works [10] and [11]. However, the available fuzzy engines have a monolithic structure, and their rules are not sufficient for many applications. In a previous work [12], dedicated fuzzy membership functions (FMFs) and various fuzzy rules were chosen for each type of traffic or service, to choose the best network for further process. This makes the HDS design very complicated for the high number of traffic types or different services. The moving speed of the mobile user is one of the important factors which is considered in [13] during the decision procedure to reduce the number of unnecessary handovers. However, the approach suffers a lack of QoS parameters. In [14], [15] and [16], QoS parameters are involved in the decision procedure, but there is lack of mobility parameters.

The horizontal handover is relying on Received Signal Strength (RSS) only and is easy to perform. However, vertical handover is more complicated because other parameters like latency, packet loss, data rate, jitter, service cost, velocity of the mobile terminal and so on are involved during handover decision-making process. To enhance the intelligence of HDS one can increase the count of inputs, this reduces the fuzzy rules count and raise the algorithm execution time. However, to reduce the algorithm execution time, one can decrease the number of decision parameters which reduces the accuracy of network selection for handover.

1.4 Objective

Every mobile user wants to have access to a variety and extensive communication services with high QoS while moving. Thus, the mobile terminals are intended to be able to serve all types of services in various situations for its users. The most significant issue is seamless mobility which can affect other services.

Considering the various types of services used in deferent areas (security, health, business, education, and so forth), especially the time-sensitive or real-time services, super-fast HDSs are required. The quickness of the HDSs are not the only subject, the other main topics involved are the QoS and moving speed of the mobile terminals, which needs to be observed carefully. Several attempts have been made in this regard. However, there are not sufficient decision parameters considered in the previously introduced HDSs.

The objectives of the current thesis are as follows:

1. A massive investigation to the previously proposed HDS algorithms has been carried out.
2. A new multi-criteria fuzzy based HDS has been designed to make intelligent, prompt, and comprehensive decisions for handover and ensuring the QoS for moving mobile terminals.
3. Evaluate the performance of proposed HDS in a heterogeneous wireless network.

1.5 Contributions

In this thesis, a multi-criteria fuzzy based handover decision system design is proposed. In the designed HDS, the handover decision is made by considering eight decision parameters (RSS, latency, packet loss, data rate, velocity of the mobile terminal, cell size, service cost and battery life of mobile terminal). Fuzzy logic is used to make more intelligent, quick, and comprehensive decisions in order to select the best network for handover. To enhance the accuracy of HDS, we have used the maximum count of inputs and a minimum count of fuzzy rules to decrease the total execution time of our algorithm.

In this work, the primary focus was to improve the QoS while the mobile terminal moves across the heterogeneous wireless environments with varying speeds. In addition, the proposed HDS intends to select the network for handover which is cost effective for the mobile users.

1.6 Organization of thesis

The thesis is organized as follows:

Chapter 1

In this chapter, the development of various mobile communication standards is described. Besides, the architecture of heterogeneous wireless networks is briefly discussed.

Chapter 2

In this chapter, an overview of handover and various HDS algorithms and their characteristics are presented. At the end of this chapter fuzzy logic is illustrated in a nutshell.

Chapter 3

The proposed multi-criteria fuzzy based HDS is extensively explained in this chapter. The overall architecture and its operation method are described at first. Then the design steps of each fuzzy engine is broadly demonstrated.

Chapter 4

In this chapter the simulation model, procedure, results and discussion are depicted. For the purpose of evaluating our HDS, a heterogeneous wireless network is created on the MATLAB platform. Then the simulation results of our HDS is compared with a non-fuzzy logic based HDS algorithm.

Chapter 5

Finally, the conclusion of the current thesis is presented in this chapter.

CHAPTER 2

Literature Review

Chapter 2

Literature Review

2.1 Introduction

At the beginning of this chapter, the handover and different types of handover are discussed. Subsequently, various types of HDS algorithms are presented, and their characteristics are described. At the end of this chapter, the fuzzy logic and its related components (the fuzzification process, the FIS, the fuzzy rules and the defuzzification) are illustrated.

2.2 Handover

When a mobile terminal crosses the boundary of a cell during an active session, to maintain its connection, it needs to perform handover. When the mobile terminal disconnects from a serving base station and connects to a new one without affecting the ongoing communication session, this process is called handover. As shown in figure 2.1, if the next RAT is same as the current, then the mobile terminal will perform horizontal and if the next cell has a different RAT, then the mobile terminal will perform vertical handover. Handover can be classified into different categories.

2.2.1 Horizontal handover and vertical handover

The mobile terminal while moving across a heterogeneous wireless environment, it will perform handover (horizontal or vertical) [17]. The traditional handover type was horizontal, where the mobile terminal executes the handover within the same network. Such handover decision was made considering the RSS. When the RSS drops and crosses the predefined threshold, the mobile terminal begins the horizontal handover. However, the mobile terminal may perform vertical handover it the new RAT is different from the serving RAT. In this case, the handover decision will be made considering other parameters besides RSS.

2.2.2 Hard handover and soft handover

When the connection of mobile terminal breaks from the serving base station before connecting to the new base station, such case is called hard handover (break before make). Although, the mobile terminal performs soft handover if it connects to the new base station before losing its connection with the previously serving base station (make before break).

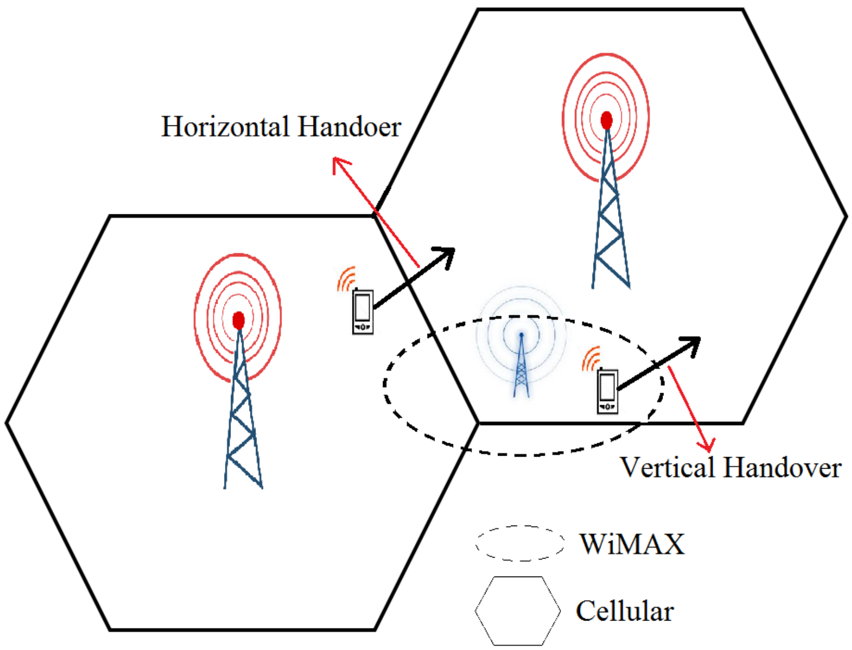

Figure 2.1. Horizontal and Vertical Handover

2.3 Related Vertical Handover Algorithms

The heterogeneous wireless networks encompass various types of radio access technologies with different bandwidths, latencies, cell sizes, service cost, and so on, to keep the users always connected. Therefore, significantly intelligent handover decision systems are needed to make quick, intelligent and comprehensive decisions during the handover procedure.

Fuzzy logic is extensively used as a tool to improve the intelligence of HDSs in various sectors including business forecasting [18], health care [19], and power management [20]. Recently, many researchers are utilizing fuzzy logic to design more intelligent handover decision systems. As a result, various algorithms with varying design complexity and intelligence levels have been introduced in this regard. Specifically, in handover decision systems, fuzzy logic have been employed in Simple Additive Weighting (SAW) [21] and Analytical Hierarchy process (AHP) [22] to determine the weight values of each decision parameters.

Since the demand for real-time applications are rapidly increasing, many attempts have been made to ensure the QoS [23] and [24]. However, the design structure of most of the fuzzy logic based handover decision algorithms are monolithic, and the fuzzy membership functions (FMFs) are fixed. There are two disadvantages for such designs: by increasing the number of input parameters, the algorithm execution time is also increasing, and with different types of traffic or services, the network selection performance diminishes.

To deal with the issues that are mentioned above, multiple engines have to be used in handover decision algorithms. There are two fuzzy engines used in [25] dealing with two different set of decision parameters and final decision value is obtained through the application of a mathematical function to the output score of fuzzy engines. In the other works [12], [14] and [15] the authors are presenting multiple fuzzy engines designs to create an optimal HDS for handover. However, the decision parameters are associated to the QoS and lack of mobility parameters. In [13] inverse attempt is made where the absence of QoS parameters are questioned.

2.4 Fuzzy Logic

In 1965, Dr. Lotfi Zadeh invented Fuzzy Logic at the University of California. In fuzzy logic, we are using the linguistic terms like “cold”, “cheap” or “heavy” instead of the numerical values such as “-1 degree”, “1 USD” or “100 Kg”. Fuzzy logic can be used in different fields where decision making is essential. Some of the applications of fuzzy logic are shown in figure 2.2 [26].

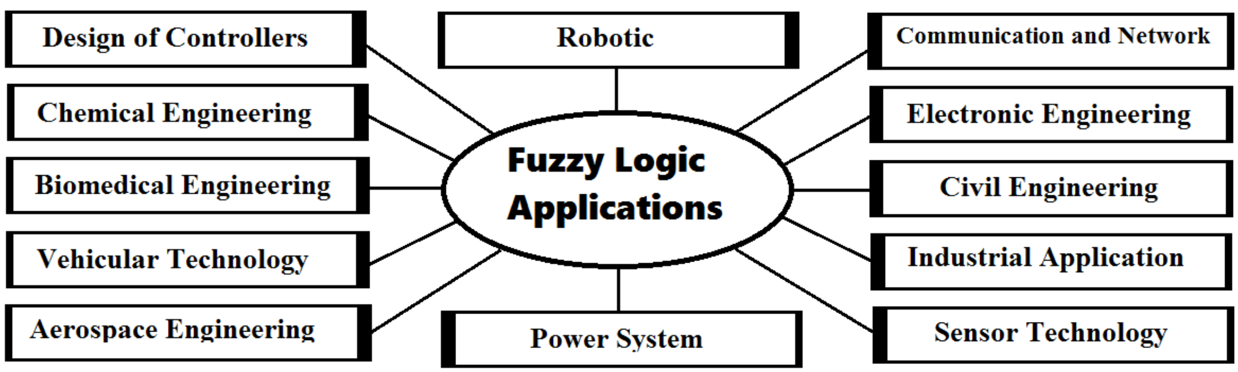

Figure 2.2. The Application of Fuzzy Logic

The application area of fuzzy logic is increasing day by day. Nowadays, its implementation is more apparent in different branches of engineering, where making intelligent and prompt decisions are vital. It also can be used in other fields such as stock trading [8] and wireless sensor networks [9] to boost the intelligence of decision-making systems. In the field of communications, it is used for telecommunication ranking, rate control, network admission control, management, and for modeling the Asynchronous Transfer Mode (ATM) network traffic. Also, the fuzzy logic has been utilized in many areas related to wireless communication systems.

In fuzzy logic, by the contrast of modeling the system mathematically, the rule-base "IF A AND B THEN C" is used to make a proper decision [27]. As shown in figure 2.3, there are four steps for making a decision by fuzzy logic. Each of the four stages is illustrated as follows:

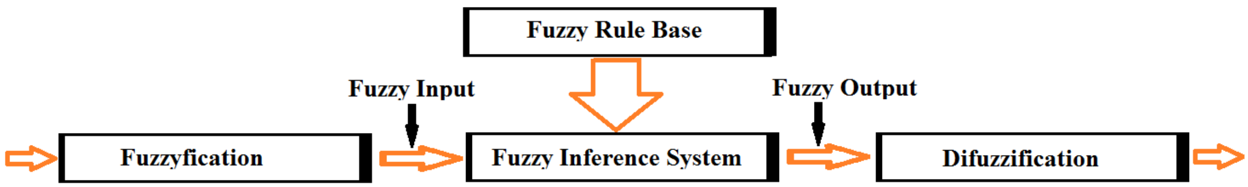

Figure 2.3. Fuzzy Logic

2.4.1 The Fuzzification Process

In this process, the crisp values of input parameters are transforming into the linguistic terms or the Fuzzy Membership Functions (FMSs) of fuzzy sets. Each of the input parameters forms a fuzzy set and the FMFs, or members of each fuzzy set are then showed in linguistic terms **[28]**.

In figure 2.4 and 2.5 two type of FMFs (Triangular and Trapezoidal, respectively) are shown. There are other types of FMFs as well, as example Gaussian and so on, but the two above mentioned are used in the present work.

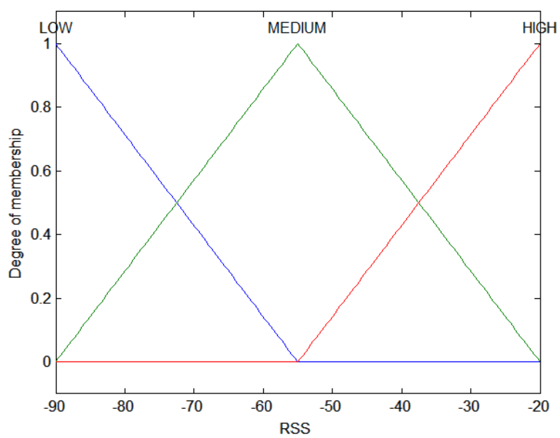

Figure 2.4. Triangular FMFs

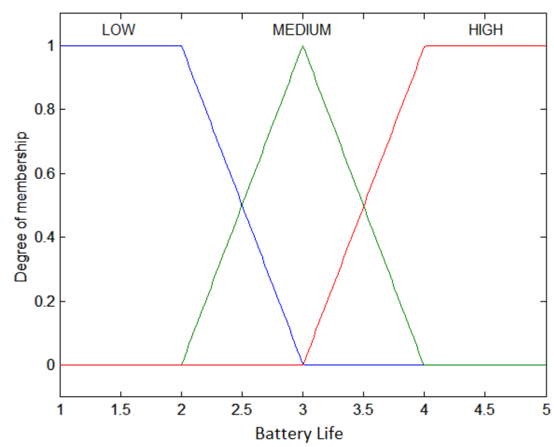

Figure 2.5. Trapezoidal FMFS

2.4.2 The Fuzzy Inference System (FIS)

The process of mapping the input parameters provided to the input of a fuzzy engine into an output value based on a fuzzy rule (IF-THEN rule) is called the fuzzy inference. This is performed by the fuzzy inference system. There are two types of FISs, Sugeno-type, and Mamdani-type of FIS **[29]**.

The different types of fuzzy rules used in the fuzzy engine make the Sugeno-type and Mamdani-type of FIS. Hence, the fuzzification and defuzzification processes are also different. In this thesis, the Mamdani-type of FIS is used to design the related fuzzy engines.

2.4.3 The Fuzzy Rules

This step defines the behavior of the fuzzy engines. Using the IF-THEN rules, according to the values of input parameters or input FMFs, the fuzzy engine will decide the output FMFs. The number of input parameters is directly proportional to the number of fuzzy rules. It means, by increasing the number of parameters at the input of fuzzy engines, the number of fuzzy rules are also increasing, and vice versa. Also, the overall execution time of the system and the system complexity is increasing [14].

Table 2.1. Fuzzy Rules example

No	LA	PL	DR	Output
1	L	L	L	M
2	L	L	M	M-H
3	L	L	H	H
...				
27	H	H	H	M

As can be seen in Table 2.1, IF the value of the FMF of latency, packet loss and data rate are Low THEN the output value or FMF is Medium. IF the value of latency and packet loss is Low and the value of data rate is High at the input of the fuzzy engine THEN the output FMF is High.

2.4.4 The Defuzzification Process

After applying the mentioned steps, a single FMF in linguistic form will be obtained at the output of the fuzzy engine. The defuzzification process will convert this linguistic value into a crisp value. Since it is not possible to use the output values or output FMFs in a linguistic term for further processes, it needs to be converted into a numerical format.

In general, several methods can be used to convert the FMFs from a linguistic term to a numerical or crisp value, which are:

a. Center of Gravity
b. Mean of Maximum
c. Universe of Discourse
d. Smallest of Maximum
e. Largest of Maximum
f. Weighted Average
g. Bisector of Area

The most common method is the Center of Gravity (CoG), which is used in this thesis. It finds where a vertical line slices the aggregate set into equal masses.

2.5 Summary

In this chapter the handover procedure and different types of handover are demonstrated. Moreover, it covers various types of HDS algorithms and their characteristics. At the end of this chapter, fuzzy logic and its components (the fuzzification process, the FIS, the fuzzy rules, and the defuzzification process) are elaborated. In the next chapter, the architecture and design method of proposed multi-criteria fuzzy based HDS algorithm is presented.

CHAPTER 3

Multi-criteria Fuzzy based Handover decision System Design

Chapter 3

Multi-criteria Fuzzy based Handover decision System Design

3.1 Introduction

This chapter describes the design of proposed multi-criteria fuzzy based handover decision system algorithm. The general architecture of proposed HDS design is shown in figure 3.1. Our model comprises five fuzzy engines, namely the Aggregated Quality of Service (AQ) engine, the Network Quality of Service (NQ) engine, the Mobility Engine (ME), the Efficiency Engine (EF), and the Degree of Satisfaction (DS) engine. In the proposed design, eight variables or decision parameters are used, which are received signal strength (RSS), latency (LA), packet loss (PL), data rate (DR), velocity (VE), coverage (CO), service cost (SC), and battery life (BL), to make an intelligent and comprehensive decision during handover procedure.

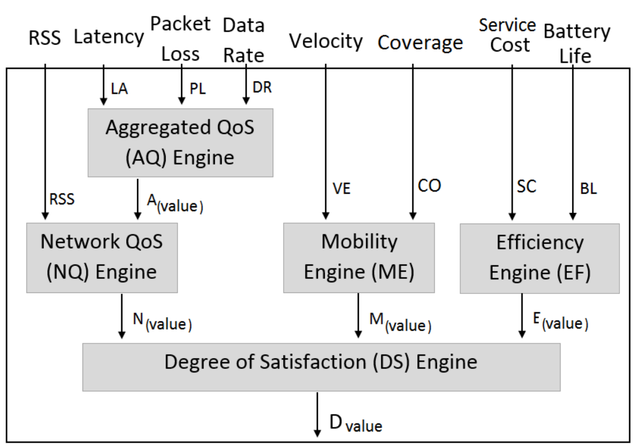

Figure 3.1. Fuzzy Based HDS Algorithm Design

The proposed algorithm is designed using the graphical user interface (GUI) of Fuzzy Logic Toolbox provided by MATLAB simulator. Fuzzy Logic Toolbox in MATLAB platform provides five interfaces or GUI tools (the FIS Editor, the Membership Function Editor, the Rule Editor, the Rule

Viewer, and the Surface Viewer) to build, observe, and edit fuzzy inference systems, which are shown in figure 3.2. All of the five interfaces are linked to each other, and if any changes are made in one interface, the remaining four interfaces are changing accordingly.

The number of input and output variables and their names can be specified using the FIS Editor. There is no limitation on the number of inputs in the Fuzzy Logic Toolbox. However, by increasing the number of inputs the complexity of the fuzzy engine and the number of fuzzy rules and also increasing. The shapes and names of all input and output variables are defined using the Membership Function Editor. By using the Rule Editor, we set, edit or delete the fuzzy rules to specify the behavior of the system in various situations. The remaining two GUIs (the Rule Viewer and the Surface Viewer) are read-only tools, where we can observe the operation of the system in different conditions.

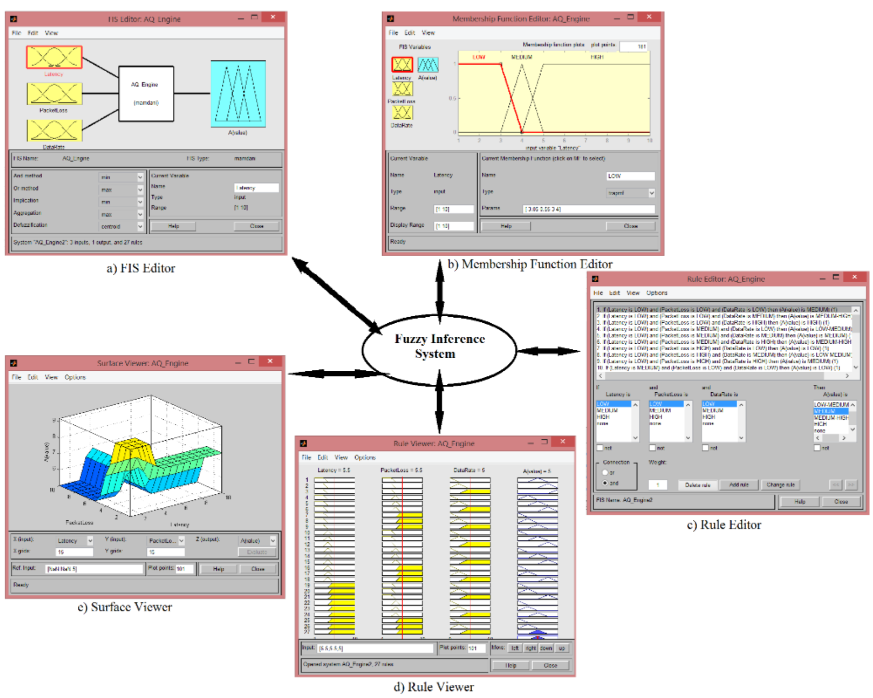

Figure 3.2. Fuzzy Logic Toolbox GUI Tools

3.2 Fuzzy Based Engines Design

In this thesis, eight decision parameters received signal strength (RSS), latency (LA), packet loss (PL), data rate (DR), velocity (VE), coverage (CO), service cost (SC), and battery life (BL) are considered as input variables. The values of LA, PL, and DR are fed into the AQ engine to evaluate the QoS for each wireless network and gives us the $A_{(value)}$ as its output. The values of VE and CO are fed into ME fuzzy engine which returns $M_{(value)}$ at the output. The values of SC and BL are entered into EF fuzzy engine to generate the $E_{(value)}$. The values of RSS and QoS of each wireless networks ($A_{(value)}$) are applied to the input of NQ fuzzy engine which gives the $Q_{(value)}$. The output of NQ, ME, and EF fuzzy engines ($Q_{(value)}$, $M_{(value)}$, and $E_{(value)}$) are used as inputs of DS fuzzy engine to calculate the final score for each of the candidate wireless network.

The design procedure of all fuzzy engines are described as follows:

3.2.1 AQ Fuzzy Engine Design

We have used Mamdani type of FIS to design the AQ fuzzy engine. Using the FIS Editor, three variables (Latency, Packed Loss, and Data Rate) are assigned as its input and $A_{(value)}$ is the output of this fuzzy engine, as can be seen in figure 3.3. Figure 3.4 shows the Membership Function Editor interface where the fuzzy membership functions of input and output variables are defined within the range of 0 to 10. Three fuzzy membership functions (LOW, MEDIUM, and HIGH) with trapezoidal shapes are used to indicate each of the input variables. While, in the case of output variable ($A_{(value)}$), five fuzzy membership functions (L, L-M, M, M-H, and H) with triangular shape.

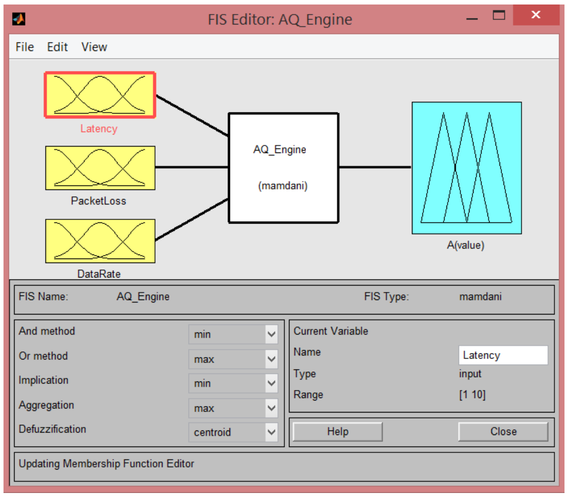

Figure 3.3. The FIS Editor of AQ Fuzzy Engine

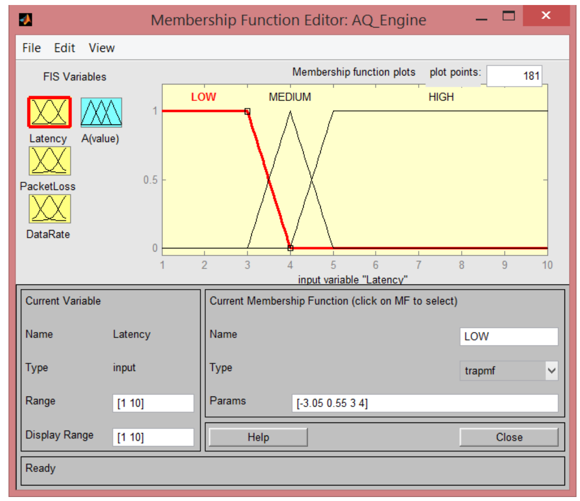

Figure 3.4. The Membership Function Editor of AQ Fuzzy Engine

The fuzzy sets corresponding to each of the input variables (LA, PL, and DR) are defined as $\widetilde{LA}$, $\widetilde{PL}$, $\widetilde{DR}$. Since, there are three variables or three fuzzy sets at the input of AQ fuzzy engine and each of them has three FMFs (L, M, and H), as per equations 1 of [30] we need 27 fuzzy rules to define the behavior of mentioned fuzzy engine. The Rule Editor interface is used to define the fuzzy rules for the AQ fuzzy engine, which is shown in figure 3.5. The list of applied rules for this particular fuzzy engine is described in Table 3.1, where we can observe the changes of output fuzzy membership functions ($A_{(value)}$) with different values of input fuzzy membership functions. The changes in $A_{(value)}$ is more obvious in the Rule Viewer of AQ fuzzy engine which is shown in figure 3.6.

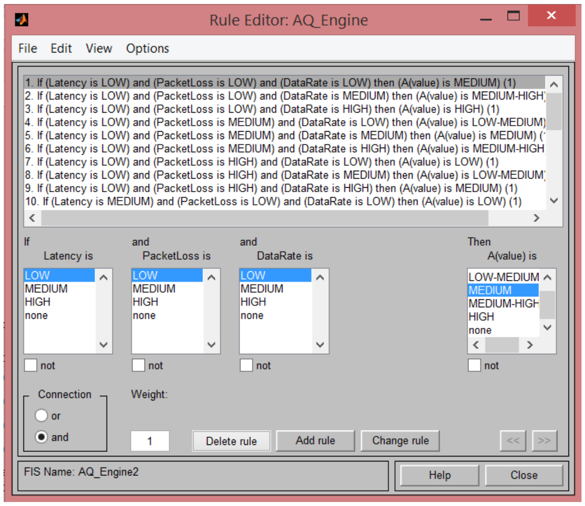

Figure 3.5. The Rule Editor of AQ Fuzzy Engine

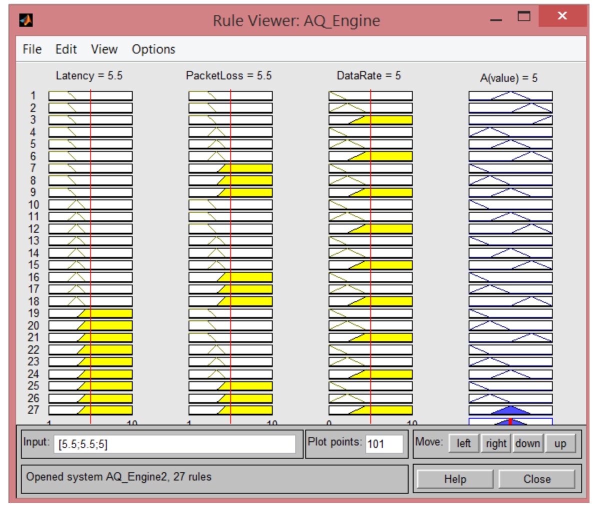

Figure 3.6. The Rule Viewer of AQ Fuzzy Engine

Each of the decision output is dependent on a fuzzy rule, which is defined by the Rule Editor interface. This process gives us the output value of AQ fuzzy engine ($\widetilde{AQ}$), with five FMFs (L, LOW-M, M, M-H, and H). The crisp values of each variable are fuzzified and entered into the FIS. Equation 1 describes the aggregated fuzzified data of AQ fuzzy engine which is $\mu\widetilde{AQ}$ [30].

Table 3.1. Fuzzy Rules for AQ Fuzzy Engine

No	LA	PL	DR	$A_{(value)}$
1	L	K	L	M
2	L	K	M	M-H
3	L	K	H	H
4	L	M	L	L-M
5	L	M	M	M
6	L	M	H	M-H
7	L	H	L	L
8	L	H	M	L-M
9	L	H	H	M
10	M	L	L	L
11	M	L	M	M
12	M	L	H	M-H
13	M	M	L	L
14	M	M	M	M
15	M	M	H	M-H
16	M	H	L	L

17	M	H	M	L-M
18	M	H	H	M-H
19	H	L	L	L
20	H	L	M	L-M
21	H	L	H	M-H
22	H	M	L	L
23	H	M	M	L-M
24	H	M	H	M
25	H	H	L	L
26	H	H	M	L-M
27	H	H	H	M

$$\mu\widetilde{AQ}(y) = \max_k[\min[\mu\widetilde{LA}^k(\text{Latency}),\ \mu\widetilde{PL}^k(\text{PacketLoss}),\ \mu\widetilde{DR}^k(\text{DataRate})]] \quad \text{for } k = 1, 2, 3, \ldots, 27 \qquad (1)$$

Then the FIS is performing the defuzzification process to convert the aggregated fuzzified data back into crisp value. By applying centroid method, the $A_{(value)}$ is obtained by using the equation 2 [30].

$$A_{(value)} = \frac{\int \mu\widetilde{AQ}(y).y dy}{\int \mu\widetilde{AQ}(y) dy} \qquad (2)$$

3.2.2 NQ Fuzzy Engine Design

Mamdani type of FIS is used to design the NQ fuzzy engine. Two input variables (RSS and $A_{(value)}$) are assigned as its inputs and $Q_{(value)}$ as its output using the FIS Editor which is shown in figure 3.7. In figure 3.8 the Membership Function Editor interface of NQ fuzzy engine is shown, where the membership functions of input and output variables are defined. The RSS is set within the range of -90 to -20 dBm, where the range of $A_{(value)}$ and $Q_{(value)}$ is from 0 to 10. Three membership functions (LOW, MEDIUM, and HIGH) are used for each of the input and output variables, but, five fuzzy membership functions (LOW, LOW-MEDIUM, MEDIUM, MEDIUM-HIGH, and HIGH) are specified at the output of this fuzzy engine. The shapes of all input and output variables of this fuzzy engine are triangular shapes.

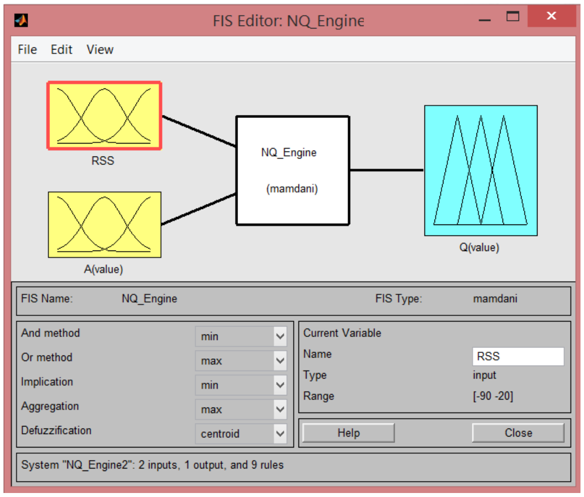

Figure 3.7. The FIS Editor of NQ Fuzzy Engine

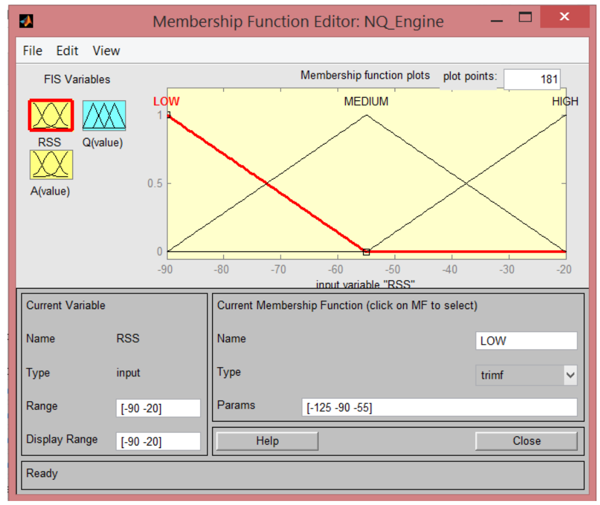

Figure 3.8. The Membership Function Editor of NQ Fuzzy Engine

The fuzzy sets corresponding to each of the input variables (RSS and $A_{(value)}$) are defined as $\widetilde{RS}$ and $\widetilde{AQ}$. Since, there are two variables or two fuzzy sets at the input of NQ fuzzy engine, and each of them has three fuzzy membership functions (LOW, MEDIUM, and HIGH), according to equation 1 of [30], we need 9 fuzzy rules to specify the behavior of the mentioned fuzzy engine. The Rule Editor interface, shown in figure 3.9, is used to define the fuzzy rules for the NQ fuzzy engine. The applied rules in this fuzzy engine is listed in Table 3.2, where we can observe the changes of $Q_{(value)}$ or output fuzzy membership functions with different values of input fuzzy membership functions. The changes of $Q_{(value)}$ is more apparent in the Rule Viewer as shown in figure 3.10.

Each of the decision output of this engine is dependent on a fuzzy rule, which is defined by the Rule Editor interface. This process gives us the output value of NQ fuzzy engine ($\widetilde{NQ}$), with five fuzzy membership functions (LOW, LOW-MEDIUM, MEDIUM, MEDIUM-HIGH, and HIGH).

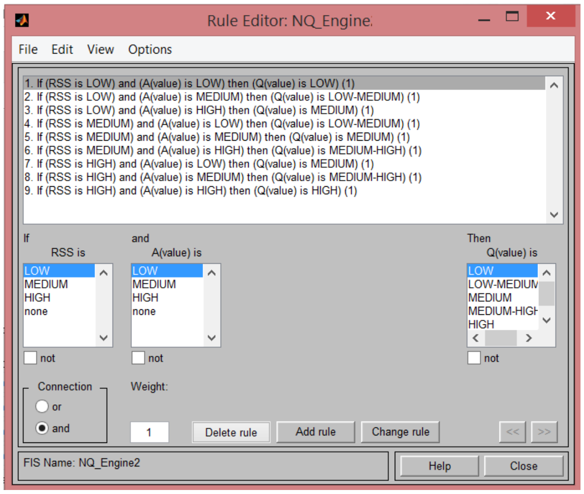

Figure 3.9. The Rule Editor of NQ Fuzzy Engine

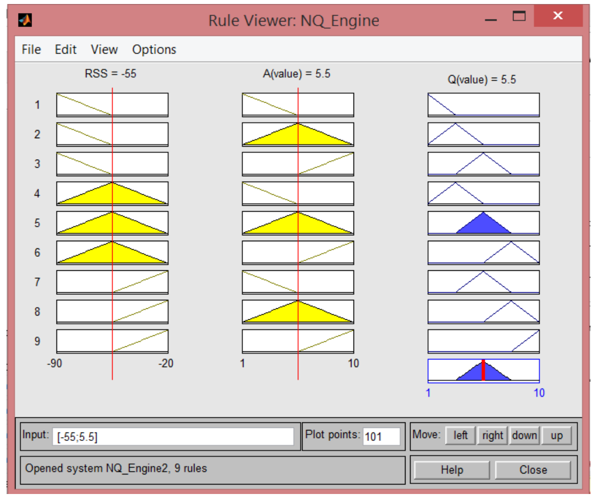

Figure 3.10. The Rule Viewer of NQ Fuzzy Engine

Table 3.2. Fuzzy Rules for NQ Fuzzy Engine

No	RSS	$A_{(value)}$	$Q_{(value)}$
1	L	L	L
2	L	M	L-M
3	L	H	M
4	M	L	L-M
5	M	M	M
6	M	H	M-H
7	H	L	M
8	H	M	M-H
9	H	H	H

The crisp values of each variable are fuzzified and entered into FIS. By using equations 3 [30] the aggregated fuzzified data of NQ fuzzy engine ($\mu\widetilde{NQ}$) is obtained.

$$\mu\widetilde{NQ}(y) = \max_k[\min[\mu\widetilde{RS}^k(\text{RSS}), \mu\widetilde{AQ}^k(A_{(value)})]] \quad \text{for } k = 1, 2, 3, \ldots, 9 \tag{3}$$

Then the FIS is performing the defuzzification process to convert the aggregated fuzzified data back into crisp value. By applying centroid method, the $Q_{(value)}$ is obtained by using the equation 4 [30].

$$Q_{(value)} = \frac{\int \mu\widetilde{NQ}(y).y dy}{\int \mu\widetilde{NQ}(y) dy} \quad (4)$$

3.2.3 ME Fuzzy Engine Design

We have used Mamdani type of FIS to design the NQ fuzzy engine. Two input variables (Velocity and Coverage) are assigned as its inputs and $M_{(value)}$ as its output using the FIS Editor which is shown in figure 3.11. In figure 3.12 the Membership Function Editor interface of ME fuzzy engine is shown, where the membership functions of input and output variables are defined. The VE is defined within the range of 0 to 200 Km/H, where the range of CO is defined from 0 to 2000 m and $M_{(value)}$ is from 0 to 10. Three membership functions (LOW, MEDIUM, and HIGH) with triangular shapes are used for VE and three membership functions (LOW, MEDIUM, and HIGH) with trapezoidal shapes are used for CO, but five fuzzy membership functions (LOW, L-M, M, M-H, and H) with triangular shapes specified at the output of this fuzzy engine.

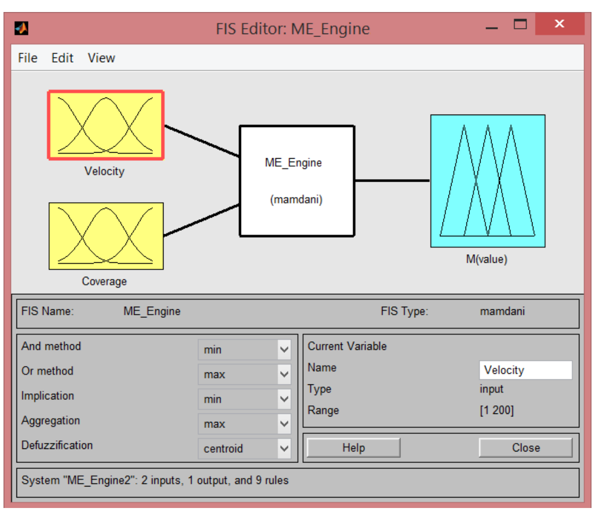

Figure 3.11. The FIS Editor of ME Fuzzy Engine

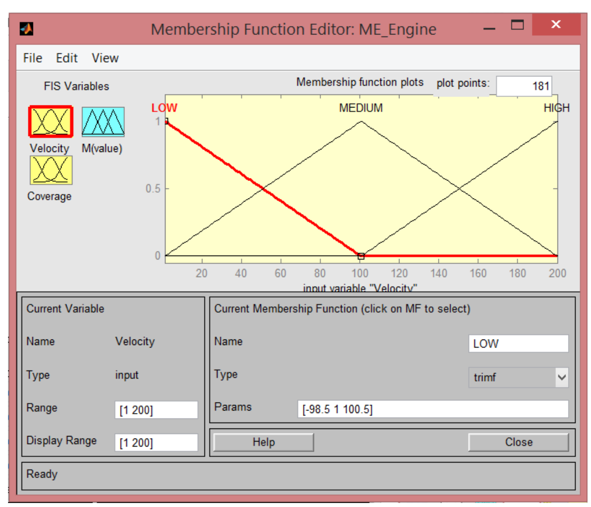

Figure 3.12. The Membership Function Editor of ME Fuzzy Engine

The fuzzy sets corresponding to each of the input variables (VE and CO) are defined as $\widetilde{VE}$ and $\widetilde{CO}$. Since, there are two variables or two fuzzy sets at the input of ME fuzzy engine, and each of them has three FMFs (L, M, and H), according to equation 1 of [30], we need 9 fuzzy rules to specify the behavior of the mentioned fuzzy engine. The Rule Editor interface, shown in figure 3.13, is used to define the fuzzy rules for the ME fuzzy engine. The applied rules in this fuzzy engine are listed in Table 3.3, where we can observe the changes of $M_{(value)}$ or output fuzzy membership functions with different values of input fuzzy membership functions. The changes of $M_{(value)}$ is more obvious in the Rule Viewer as shown in figure 3.14.

Each of the decision output of this engine is dependent on a fuzzy rule, which is defined by the Rule Editor interface. This process gives us the output value of ME fuzzy engine ($\widetilde{ME}$), with five fuzzy membership functions (LOW, LOW-MEDIUM, MEDIUM, MEDIUM-HIGH, and HIGH). The crisp values of each variable are fuzzified and entered into FIS. By using equations 5 [30] the aggregated fuzzified data of ME fuzzy engine ($\mu\widetilde{ME}$) is obtained.

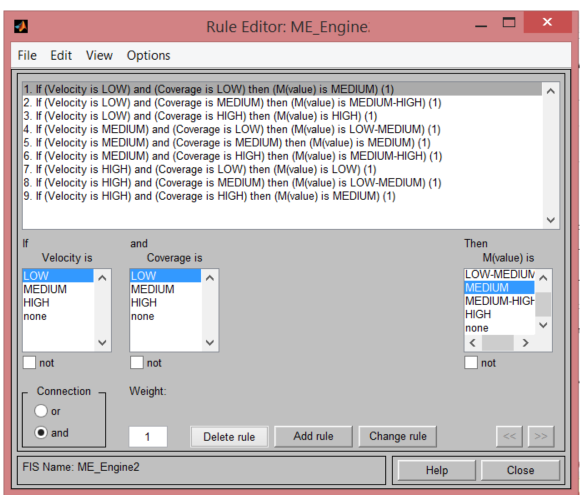

Figure 3.13. The Rule Editor of ME Fuzzy Engine

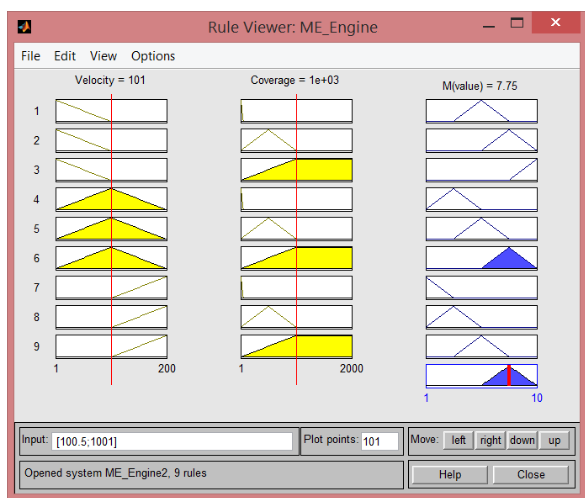

Figure 3.14. The Rule Viewer of ME Fuzzy Engine

Table 3.3. Fuzzy Rules for ME Fuzzy Engine

No	VE	CO	$M_{(value)}$
1	L	L	M
2	L	M	M-H
3	L	H	H
4	M	L	L-M
5	M	M	M
6	M	H	M-H
7	H	L	L
8	H	M	L-M
9	H	H	M

$$\mu\widetilde{ME}\ (y) = \max_k[\min[\mu\widetilde{VE}^k(\text{Velocity}),\ \mu\widetilde{CO}^k(\text{Coverage})]] \quad \text{for } k = 1, 2, 3, \ldots, 9 \tag{5}$$

Then the FIS is performing the defuzzification process to convert the aggregated fuzzified data back into crisp value. By applying centroid method, the $M_{(value)}$ is obtained by using the equation 6 [30].

$$M_{(value)} = \frac{\int \mu\widetilde{ME}(y).y dy}{\int \mu\widetilde{ME}(y) dy} \tag{6}$$

3.2.4 EF Fuzzy Engine Design

Mamdani type of FIS is selected to design the EF fuzzy engine. Two input variables (Service Cost and Battery Life) are assigned as its inputs and $E_{(value)}$ as its output using the FIS Editor which is shown in figure 3.15. In figure 3.16 the Membership Function Editor interface of EF fuzzy engine is shown, where the membership functions of input and output variables are defined. The input variables (SC and BL) are defined within the range of 1 to 5, where the output ($E_{(value)}$) range is from 0 to 10. Three membership functions (LOW, MEDIUM, and HIGH) with trapezoidal shapes are used for each of the input variables, but, five FMFs (L, L-M, M, M-H, and H) with triangular shapes.

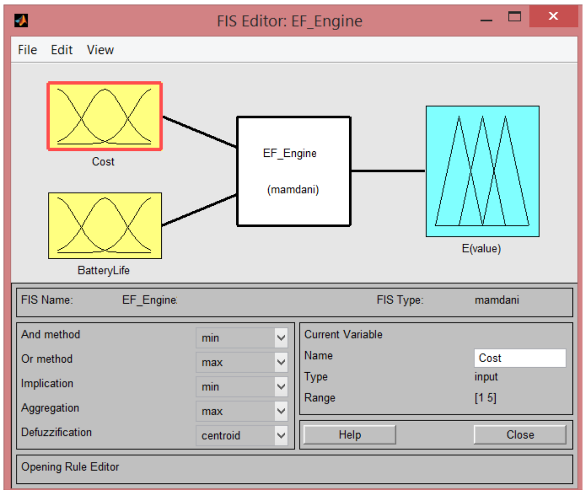

Figure 3.15. The FIS Editor of EF Fuzzy Engine

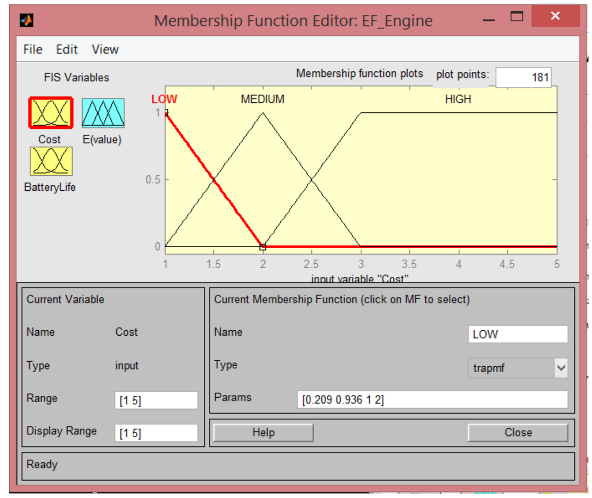

Figure 3.16. The Membership Function Editor of EF Fuzzy Engine

The fuzzy sets corresponding to each of the input variables (SC and BL) are defined as $\widetilde{SC}$ and $\widetilde{\text{BL}}$. Since, there are two variables or two fuzzy sets at the input of EF fuzzy engine, and each of them has three FMFs (L, M, and H), according to equation 1 of [30], we need 9 fuzzy rules to specify the behavior of the mentioned fuzzy engine. The Rule Editor interface, shown in figure 3.17, is used to define the fuzzy rules for the EF fuzzy engine. The applied rules in this fuzzy engine are listed in Table 3.4, where we can observe the changes of $E_{(value)}$ or output fuzzy membership functions with different values of input fuzzy membership functions. The changes of $E_{(value)}$ is more obvious in the Rule Viewer as shown in figure 3.18.

Each of the decision output of this engine is dependent on a fuzzy rule, which is defined by the Rule Editor interface. This process gives us the output value of EF fuzzy engine ($\widetilde{EF}$), with five fuzzy membership functions (LOW, LOW-MEDIUM, MEDIUM, MEDIUM-HIGH, and HIGH). The

(7)

crisp values of each variable are fuzzified and entered into FIS. By using equations 7 [30] the aggregated fuzzified data of EF fuzzy engine ($\mu\widetilde{EF}$) is obtained.

$$\mu\widetilde{EF}\,(y) = \max_k[\min[\mu\widetilde{SC}^k(\text{ServiceCost}),\ \mu\widetilde{BL}^k(\text{BatteryLife})]]$$
$$\text{for } k = 1, 2, 3, \ldots, 9$$

Table 3.4. Fuzzy Rules for EF Fuzzy Engine

No	SC	BL	$E_{(value)}$
1	L	L	M
2	L	M	M-H
3	L	H	H
4	M	L	L-M
5	M	M	M
6	M	H	H
7	H	L	L
8	H	M	L-M
9	H	H	M

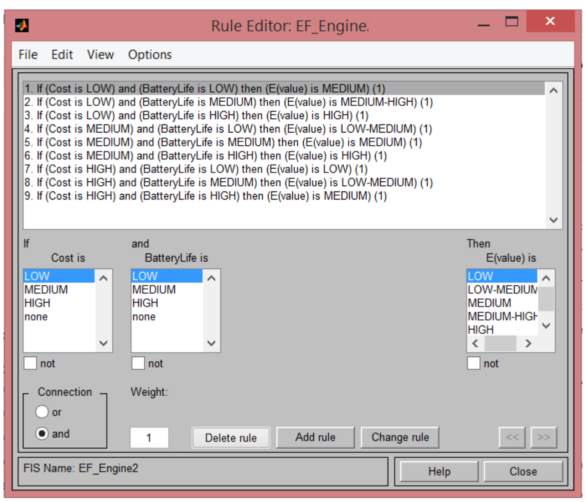

Figure 3.17. The Rule Editor of EF Fuzzy Engine

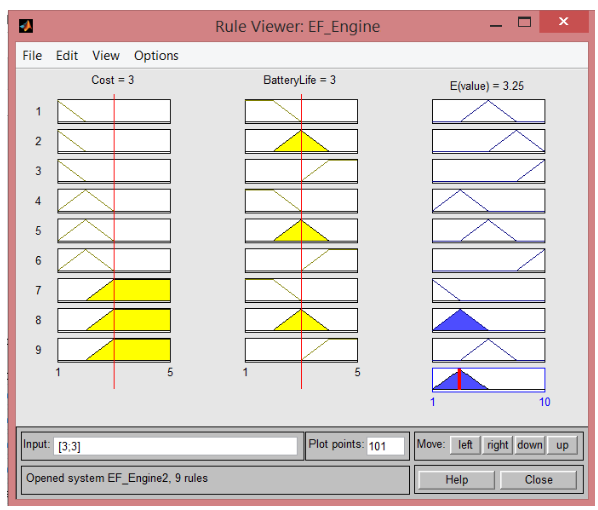

Figure 3.18. The Rule Viewer of EF Fuzzy Engine

Then the FIS is performing the defuzzification process to convert the aggregated fuzzified data back into crisp value. By applying centroid method, the $E_{(value)}$ is obtained by using the equation 8 [30].

$$E_{(value)} = \frac{\int \mu\widetilde{EF}(y).ydy}{\int \mu\widetilde{EF}(y)dy} \qquad (8)$$

3.2.5 DS Fuzzy Engine Design

We have used Mamdani type of FIS to design the DS fuzzy engine as well. Using the FIS Editor, three variables ($Q_{(value)}$, $M_{(value)}$, and $E_{(value)}$) are assigned as its input and $D_{(value)}$ is the output of this fuzzy engine, as can be seen in figure 3.19. Figure 3.20 shows the Membership Function Editor interface where the fuzzy membership functions of all input and output variables are defined within the range of 0 to 10. Three fuzzy membership functions (LOW, MEDIUM, and HIGH) with triangular shapes are used to indicate each of the input variables. While, in the case of output variable ($D_{(value)}$), five FMFs (L, L-M, M, M-H, and H) with triangular shapes.

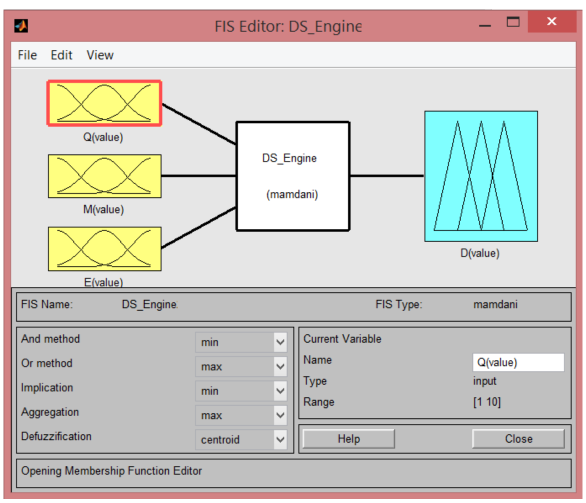

Figure 3.19. The FIS Editor of DS Fuzzy Engine

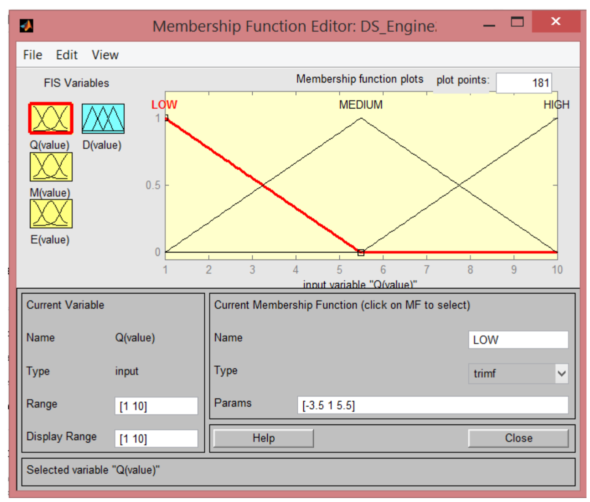

Figure 3.20. The Membership Function Editor of DS Fuzzy Engine

The fuzzy sets corresponding to each of the input variables ($Q_{(value)}$, $M_{(value)}$, and $E_{(value)}$) are defined as $\widetilde{DQ}$, $\widetilde{DM}$, $\widetilde{DE}$. Since, there are three variables or three fuzzy sets at the input of DS fuzzy engine and each of them has three FMFs (L, M, and H), as per equations 1 of [30] we need

27 fuzzy rules to define the behavior of mentioned fuzzy engine. The Rule Editor interface is used to define the fuzzy rules for the DS fuzzy engine, which is shown in figure 3.21. The list of applied rules for this particular fuzzy engine is described in Table 3.5, where we can observe the changes of output fuzzy membership functions ($D_{(value)}$) with different values of input fuzzy membership functions. The changes in $D_{(value)}$ is more obvious in the Rule Viewer of DS fuzzy engine which is shown in figure 3.22.

Each of the decision output is dependent on a fuzzy rule, which is defined by the Rule Editor interface. This process gives us the output value of DS fuzzy engine ($\widetilde{DS}$), with five fuzzy membership functions (LOW, LOW-MEDIUM, MEDIUM, MEDIUM-HIGH, and HIGH). The crisp values of each variable are fuzzified and entered into the FIS. Equation 9 describes the aggregated fuzzified data of DS fuzzy engine which is $\mu\widetilde{DS}$ [30].

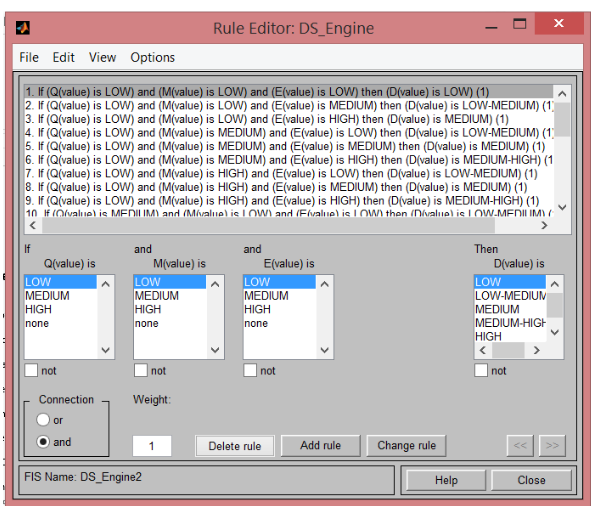

Figure 3.21. The Rule Editor of DS Fuzzy Engine

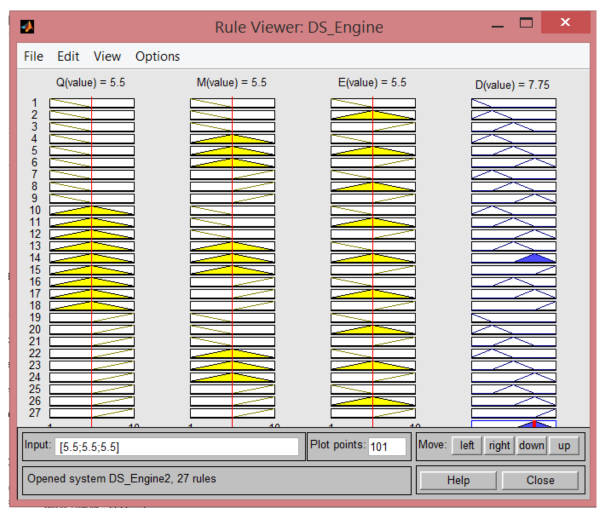

Figure 3.22. The Rule Viewer of DS Fuzzy Engine

Table 3.5. Fuzzy Rules for DS Fuzzy Engine

No	$Q_{(value)}$	$M_{(value)}$	$E_{(value)}$	$D_{(value)}$
1	L	L	L	L
2	L	L	M	L-M
3	L	L	H	M
4	L	M	L	L-M
5	L	M	M	M
6	L	M	H	M-H
7	L	H	L	L-M
8	L	H	M	M
9	L	H	H	M-H
10	M	L	L	L-M
11	M	L	M	M
12	M	L	H	M-H
13	M	M	L	M
14	M	M	M	MH
15	M	M	H	H
16	M	H	L	M
17	M	H	M	M-H
18	M	H	H	H
19	H	L	L	L
20	H	L	M	L-M
21	H	L	H	M
22	H	M	L	L-M
23	H	M	M	M
24	H	M	H	M-H
25	H	H	L	M
26	H	H	M	M-H
27	H	H	H	H

$$\mu\widetilde{DS}(y) = \max_k[\min[\mu\widetilde{DQ}^k(Q_{(value)}), \mu\widetilde{DM}^k(M_{(value)}), \mu\widetilde{DE}^k(E_{(value)})]] \quad \text{for } k = 1, 2, 3, \ldots, 27 \qquad (9)$$

Then the FIS is performing the defuzzification process to obtain the crisp value back from the fuzzified data. By applying centroid method, the $D_{(value)}$ is obtained through using the equation 10 [30].

(10)

$$D_{(value)} = \frac{\int \mu\widetilde{DS}(y).ydy}{\int \mu\widetilde{DS}(y)dy}$$

3.3 Summary

A comprehensive and detailed overview of designing the proposed multi-criteria fuzzy based HDS algorithm is presented. This chapter starts with the illustration of the general architecture of our proposed HDS algorithm, and the functions of each fuzzy engine are described. Furthermore, it presents the design method and behavior of each fuzzy engine. In the nest chapter, the performance evaluation of developed fuzzy logic based HDS algorithm is performed, and the results are compared with a non-fuzzy logic based HDS algorithm (SAW).

CHAPTER 4

Simulation Results and Discussion

Chapter 4

Simulation Results and Discussion

4.1 Introduction

In this chapter the simulation scenario, the simulation results and discussion of the proposed multi-criteria fuzzy logic based HDS concerning network selection performance are presented. For this purpose, Five WLAN, two WiMAX, and one mobile cellular cell are created in MATLAB platform. Another widely used HDS, which is a non-fuzzy logic based algorithm (SAW) is also placed in the same scenario for comparison. The simulation results shows, based on eight decision parameters (RSS, latency, packet loss, data rate, velocity, cell size, service cost and battery life), the proposed fuzzy logic based HDS makes more intelligent, comprehensive and quick decisions to determine the admirable network than the non-fuzzy logic based HDS algorithm.

4.2 Simulation Scenario

To evaluate the proposed multi-criteria fuzzy based HDS algorithm in terms of network selection performance, we have created one cellular, two WiMAX and five WLAN networks in MATLAB platform. One type of traffic (video streaming) with two service option is generated:

1. Standard definition (SD) video streaming with 1 Mbps data rate and
2. Full high definition (HD) with 4.3 Mbps data rate.

The discrete uniform probability distribution values for each input decision parameters are generated from the range shown in Table 4.1 for SD and full HD video streaming. The values for latency, packet loss, data rate, service cost, and battery life were generated as [12], the value of RSS is taken from [30], and the cell size of cellular, WiMAX, and WLAN are 2 Km, 1 Km, and 50 m respectively. The value of the velocity of the mobile terminal is generated from 1 to 200 Km/h.

Table 4.1. Decision Parameters for SD and Full HD Services

Network	RSS (dBm)	Latency (sec)	Packet Loss (%)	Data Rate (Mbps)	Velocity (Km/h)	Cell size (m)	Cost	Battery Life (hours)
UMTS	-90 to -20	1 - 7 (rec. ≤ 5)	1 - 7 (rec. ≤ 5%)	1 – 5	1 - 200	1 - 2000	3	0.74*(2.5-5)
WiMAX				1 – 6		1 - 1000	2	0.55*(2.5-5)
WLAN				1 – 8		1 - 50	1	2.5-5

4.3 Results and Discussion

As described in chapter 3, the multi-criteria fuzzy based HDS is developed using the fuzzy logic toolbox of MATLAB simulator. For comparison, we have created a non-fuzzy logic based HDS (SAW) algorithm in the same platform, where the weights of each decision parameter for SAW is uniform. The two algorithms are compared in terms of percentage success (PS), explained just as how many times the HDS algorithm picks a suitable network, which fulfills all the QoS requirements. The following procedure has been taken to simulate both of the mentioned algorithms:

As the values of input parameters are randomly selected from the predefined range, the final score is also random; a high number of simulation runs are necessary, and the mean value of various trials are obtained. For both of the service options (SD and full HD video streaming) 10 trials, 1000 times the simulation runs are executed for each of the trial. from the 1000 outputs for each HDSs, the number of times that both of the HDSs selects the best network for handover (the number of success (Ns)) and the number of times that the HDSs selects a network, which does not satisfy the QoS requirements (the number of failures (Nf)), are determined. Finally, for both HDSs the PS is calculated through using equation 11 [30].

$$PS = \frac{Ns}{Ns + \mathrm{Nf}} \times 100 \tag{11}$$

The network selection performance of fuzzy based HDS is compared with SAW in figure 4.1 and 4.2 for video streaming in SD and full HD formats respectively. As figure 4.1 shows, the network selection performance for service in SD format (with 1 Mbps data rate) of fuzzy based HDS is 25.75 % better than SAW, and as indicated in figure 4.2 the difference is 15.78 % for service in full HD format (with 1 Mbps data rate). The results of this simulation show that the fuzzy based HDS design is capable of improving the intelligence of HDS for wireless mobile networks and makes comprehensive decisions for handover.

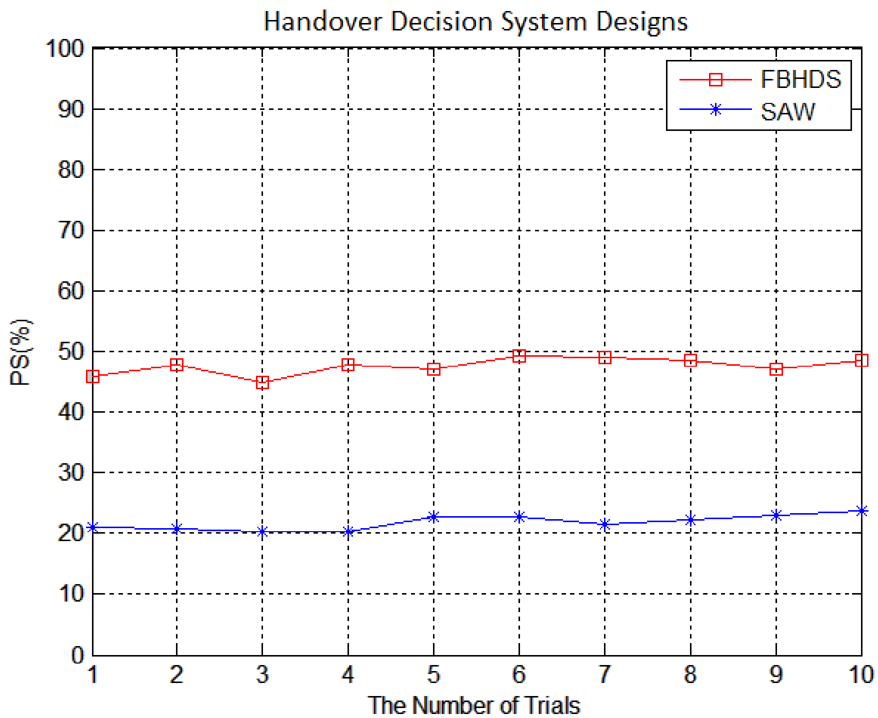

Figure 4.1. Network Selection Performance for Video Streaming in SD format

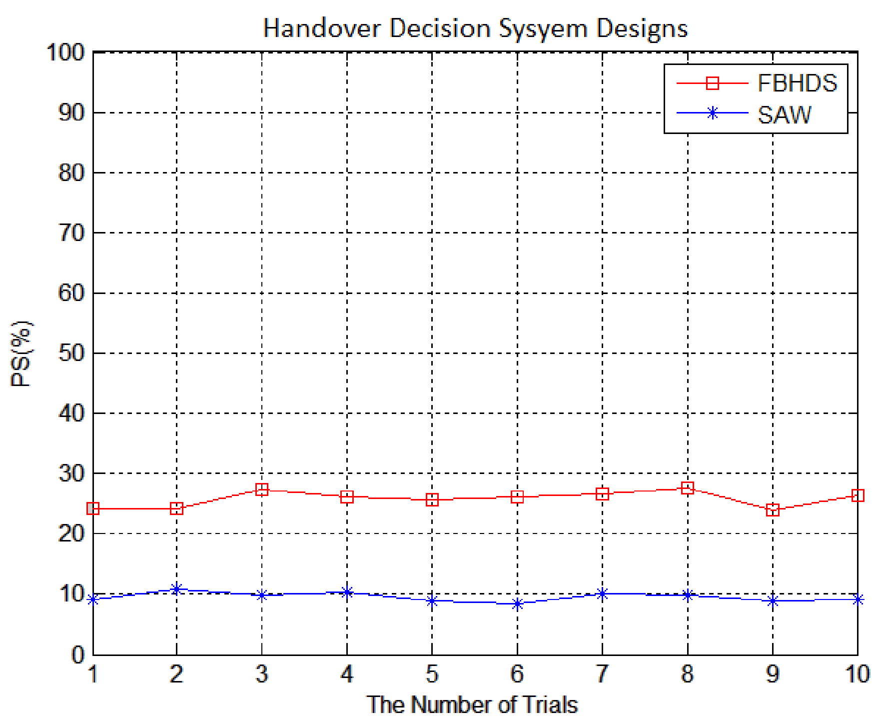

Figure 4.2. Network Selection Performance for Video Streaming in HD format

The algorithm execution time for both HDS designs has been compared through a 2.4 GHz Intel® Core™ i5 with 8 GB memory. The results show that the execution time of proposed HDS is 24.562 ms, and for SAW the algorithm execution time is 40.093 ms that means the proposed design is 15.531 ms faster.

4.4 Summary

This chapter gives an overview of our simulation model and the multi-criteria fuzzy based HDS, which was described in chapter 3, has been evaluated in the sense of network selection performance. The results coming from the proposed HDS is then compared with a non-fuzzy logic based HDS (SAW) algorithm.

We can conclude that the multi-criteria fuzzy based HDS is superior to SAW in the sense of network selection. Our proposed fuzzy-based HDS algorithm is able to select the best network for handover in a very short period of time.

CHAPTER 5

Conclusion

Chapter 5

Conclusion

Providing seamless mobility to fulfill the user's expectations in terms of universal connectivity is one of the most important issues in wireless communications. Many attempts have been made by numerous researchers to ensure seamless mobility between different types of radio access technologies, some of them are presented in chapter 2. There are an insufficient number of decision parameters in the previous schemes to make an intelligent and comprehensive decision for handover.

Our primary focus is improving the intelligence of HDS for heterogeneous wireless networks through using fuzzy logic and making comprehensive and quick decisions for handover based on multiple input parameters. It has been indicated that the proposed HDS design enhances the network selection performance and reduces the algorithm execution time. In the chapter of this thesis, a multi-criteria fuzzy based HDS design has been presented to improve the network selection performance and make prompt and comprehensive decisions for handover. The proposed model is simulated in a heterogeneous wireless environment by a video streaming traffic in two formats (SD and full HD). The simulation results of proposed fuzzy-based HDS is compared with a non-fuzzy based HDS algorithm (SAW), which determines significant enhances in the sense of network selection performance for SD and full HD video streaming formats, and reduction in algorithm execution time.

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