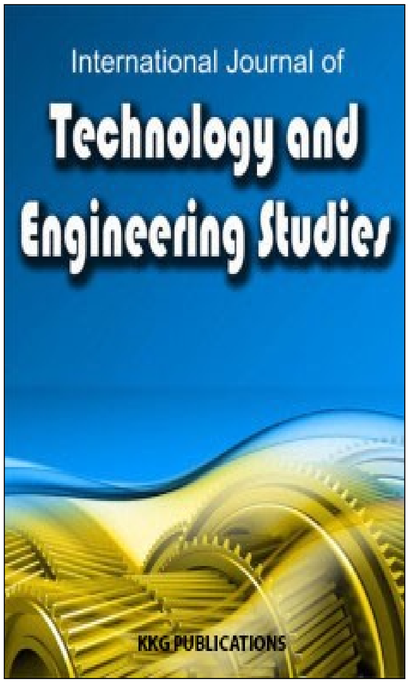

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MULTI-CRITERIA FUZZY-BASED HANDOVER DECISION SYSTEM FOR HETEROGENEOUS WIRELESS NETWORKS

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Abstract. In this paper, a fuzzy logic-based Handover Decision System design is proposed that allows for quick, intelligent, and comprehensive decisions during the handover procedure. Many researchers have developed numerous Handover Decision Systems (HDSs) to ensure seamless mobility between different Radio Access Technologies (RATs). However, by increasing the input parameters in available Handover Decision Systems, the algorithm execution time also increases. On the other hand, some algorithms consider mobility parameters a handover decision criterion but lack QoS-related parameters. The proposed design uses a minimum number of fuzzy rules to select the best network for handover and reduce execution time. In addition, a total of eight decision parameters are chosen as the handover decision-making criterion, including QoS, mobility, and efficiency-related parameters. These parameters enhance the intelligence of the decision algorithm and enable a comprehensive decision for performing handover. Simulation results for the current handover decision algorithm in terms of network selection performance show that it is superior to the Simple Additive Weighting, a non-fuzzy logic-based handover decision algorithm.

INTRODUCTION

Mobile users are the witnesses of rapid advancement in wireless technologies. The presence of Wireless Local Area Networks (WLAN), Worldwide Interoperability Microwave Access (WiMAX), and Universal Mobile Telecommunication System (UMTS) are the consequences of rapid progress in this field. Each technology has its 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 of different wireless technologies, as shown in Figure 1. Heterogeneous wireless network provides universal and seamless connectivity to users of all types of services. 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 [1]. On the other hand, to perform vertical handover, other parameters such as QoS, service cost, and data rate [2] have to be considered, and the system is more complicated than the horizontal handover. Significantly intelligent HDSs are required to select the best network for handover. Fuzzy logic is used to boost the intelligence of decision systems in many areas such as stock trading [3] and wireless sensor networks [4]. Many fuzzy logic-based handover decision systems have been introduced in the literature [5], [6]. However, the available fuzzy engines have a monolithic structure, and their rules are not sufficient for many applications. In a previous work [7], dedicated Fuzzy Membership Functions (FMFs) and various fuzzy rules were chosen for each type of traffic or service, to select the best network for handover. 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 [8] during the decision procedure to reduce the number of unnecessary handovers. However, the approach suffers a lack of QoS parameters. In [9], [10], and [11], QoS parameters are involved in the decision procedure, but there is a lack of mobility parameters.

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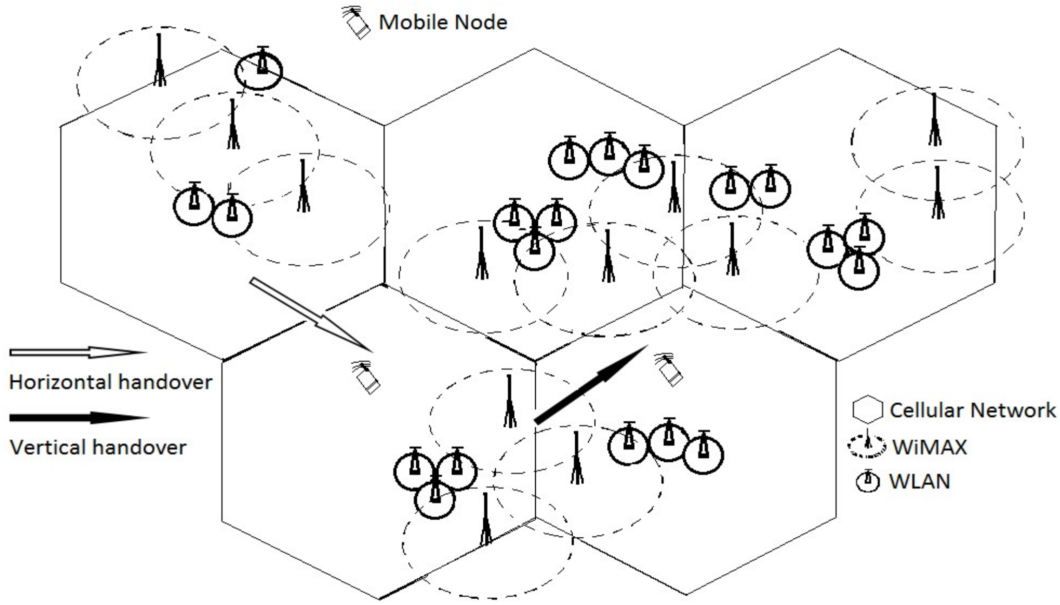

Fig. 1. An example of heterogeneous wireless networks

In this paper, a multi-criteria fuzzy-based handover decision system design is proposed. Our system has five fuzzy engines that deal with a set of eight decision parameters. The proposed model is compared with a Simple Additive Weighting (SAW), which is a non-fuzzy logic-based HDS algorithm. The results show that our proposed algorithm gives a significant improvement in terms of network selection performance. The rest of this paper is organized as follows: In Section II, we present related work. In Section III, the multi-criteria fuzzy-based HDS design is explained. In Section IV, the simulation results are discussed. Finally, we make our conclusions in Section V.

RELATED FUZZY-BASED HANDOVER DECISION SYSTEMS

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 enhance the intelligence of decision-making mechanisms in different areas including business forecasting [12], health care [13], and power management [14]. 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 has been employed in SAW [15] and Analytical Hierarchy process (AHP) [16] to determine the weight values of each decision parameter.

Since the demand for real-time applications is rapidly increasing, many attempts have been made to ensure the QoS [17] and [18]. However, the design structure of most of the fuzzy logic-based handover decision algorithms is monolithic, and the 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.

For dealing with the issues that are mentioned above, multiple engines have to be used in handover decision algorithms. There are two fuzzy engines used in [19] dealing with two different sets of decision parameters, and final decision value is obtained through application of a mathematical function to the output score of fuzzy engines. In the other works [7], [9], and [10], the authors are presenting multiple fuzzy engines' designs to select the best network for handover. However, the decision parameters are associated with the QoS and lack of mobility parameters. In [8], inverse attempt is made where the absence of QoS parameters is questioned.

MULTI-CRITERIA FUZZY-BASED HANDOVER DECISION SYSTEM DESIGN

In this section, our multi-criteria fuzzy-based handover decision system design is presented. The general architecture of the proposed HDS is shown in Figure 2 which comprises of five fuzzy engines, namely an Aggregated QoS (AQ) engine, a

Network QoS (NQ) engine, a Mobility Engine (ME), Efficiency Engine (EF), and a Degree of Satisfaction (DS) engine. In the proposed design, eight decision parameters are used to make an intelligent and comprehensive decision during the handover procedure: RSS, Latency (LA), Packet Loss (PL), Data Rate (DR), Velocity (VE), Coverage (CO), Service Cost (SC), and Battery Life (BL),. Each of the fuzzy engines deals with a particular group of decision parameters.

The AQ fuzzy engine is provided with three inputs; LA, PL, and DR, which are used to measure the QoS of all wireless networks and provide the A(value). The values of A(value) and RSS are given to the NQ fuzzy engine, the values of VE and CO are given to the ME fuzzy engine, and the values of SC and BL are given to the EF fuzzy engine, with the values of Q(value) and E(value) generated as output values. The output of the NQ, ME, and EF fuzzy engines are connected to the DS fuzzy engine, which evaluates the final value, D(value), for all candidate wireless networks.

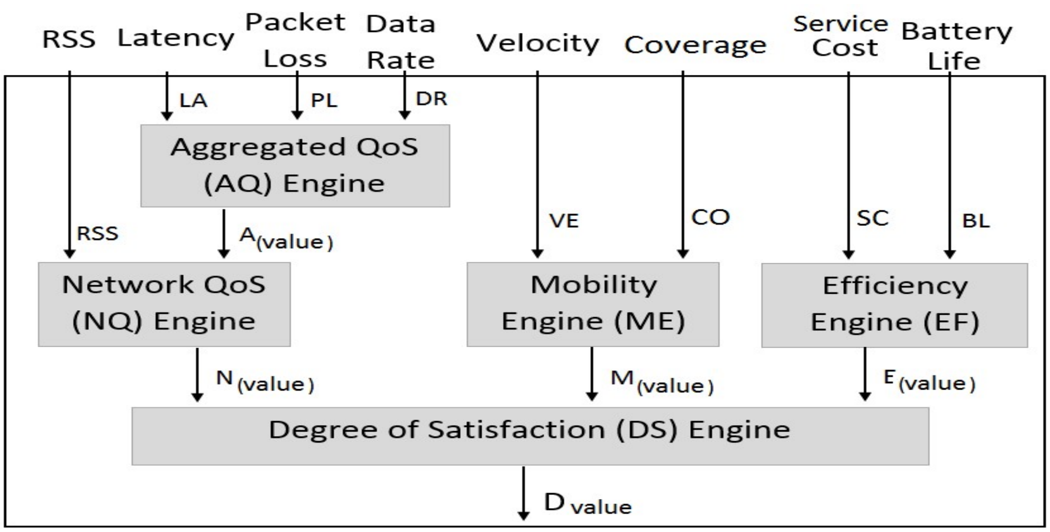

Fig. 2. Fuzzy-based HDS design

Fuzzy-Based Engines' Design

Eight decision parameters (RS, LA, PL, DR, VE, CO, SC, and BL) are considered. The values of LA, PL, and DR are fed into the AQ engine to evaluate the QoS for each wireless network, and the values of VE and CO, and SC and BL are fed to ME and EF fuzzy engines respectively. The values of RSS and QoS ($\mathrm{A}_{(\mathrm{value})}$) are applied to the input of NQ engine. The three fuzzy engines NQ, ME, and EF generate $\mathrm{Q}_{(\mathrm{value})}$, $\mathrm{M}_{(\mathrm{value})}$, and $\mathrm{E}_{(\mathrm{value})}$ which are used as inputs of the DS fuzzy engine to calculate the final score for each of the candidate wireless networks.

The fuzzy sets corresponding to each decision parameter are defined as $\widetilde{RS}$, $\widetilde{LA}$, $\widetilde{PL}$, $\widetilde{DR}$, $\widetilde{VE}$, $\widetilde{CO}$, $\widetilde{SC}$, and $\widetilde{BL}$. Three fuzzy memberships (Low, Medium, and High) are assigned to all the fuzzy sets at the input. A total of 81 fuzzy rules are used in this design (27, 9, 9, 9, and 27 rules required for AQ, NQ, MO, EF, and DS fuzzy engines respectively), as per equation 1 of [20].

Each decision output depends on a fuzzy rule, which is predefined in a rule base. This process gives the output of all fuzzy sets $\widetilde{AQ}$, $\widetilde{NQ}$, $\widetilde{ME}$, $\widetilde{EF}$, and $\widetilde{DS}$, each with five fuzzy memberships (Low, Low-Medium, Medium, Medium-High, and High). Triangular and trapezoidal functions are used for fuzzy memberships at the inputs of the fuzzy sets of AQ, NQ, MO, EF, and the DS fuzzy engine.

The crisp values of each decision parameter are fuzzified and entered into a Fuzzy Inference System (FIS). In this design, we have used Mamdani FIS. Equations 1, 2, 3, and 4 describe the aggregated fuzzified data $\mu\widetilde{AQ}$, $\mu\widetilde{NQ}$, $\mu\widetilde{ME}$, and $\mu\widetilde{EF}$ related to AQ, NQ, ME, and EF fuzzy engines (equation 4 of [20]):

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

for k = 1, 2, 3,...., 27

$$\mu\widetilde{NQ}(y) = maxk[min[\mu\widetilde{RS}^k(\text{RSS}), \mu\widetilde{AQ}^k(\text{A(value)})]] \quad (2)$$

for k = 1, 2, 3,...., 9

$$\mu\widetilde{ME}(y) = maxk[min[\mu\widetilde{VE}^{k}(\text{Velocity}), \mu\widetilde{CO}^{k}(\text{Coverage})]] \quad (3)$$

for k = 1, 2, 3,...., 9

$$\mu\widetilde{EF}(y) = max_k[min[\mu\widetilde{SC}^{k}(\text{ServiceCost}),\mu\widetilde{BL}^{k}(\text{BatteryLife})]] \quad (4)$$

for k = 1, 2, 3,...., 9

Defuzzification is performed to convert the aggregated fuzzified data into a crisp value. By applying the centroid method, the $A_{(value)}$, $Q_{(value)}$, $M_{(value)}$, and $E_{(value)}$ are obtained using the equations 5, 6, 7, and 8 (Equation 5 from [20]):

$$A_{(value)} = \frac{\int \mu\widetilde{AQ}(y).ydy}{\int \mu\widetilde{AQ}(y)ydy} \quad (5)$$

$$Q_{(value)} = \frac{\int \mu\widetilde{NQ}(y).ydy}{\int \mu\widetilde{NQ}(y)ydy} \quad (6)$$

$$M_{(value)} = \frac{\int \mu\widetilde{ME}(y).ydy}{\int \mu\widetilde{ME}(y)ydy} \quad (7)$$

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

We apply a similar method to the DS fuzzy engine. Accordingly, we obtain the aggregated fuzzified data, $\mu\widetilde{DS}$ and the crisp output value, $D_{(value)}$ of DS fuzzy engine from equation 9 and 10 respectively.

$$\mu\widetilde{DS}(y) = max_k[min[\mu\widetilde{DQ}^{k}(Q_{(value)}), \mu\widetilde{DM}^{k}(M_{(value)}), \mu\widetilde{DE}^{k}(E_{(value)})]] \quad (9)$$

for k = 1, 2, 3,...., 27

$$D_{(value)} = \frac{\int \mu\widetilde{DS}(y).ydy}{\int \mu\widetilde{DS}(y)ydy} \quad (10)$$

The input FMFs of AQ, NQ, ME, and EF, are shown in Figures 3, 4, 5, and 6 respectively. The output FMFs for all fuzzy engines are given in Figures 7. The fuzzy rules of each fuzzy engine are provided in Tables 1, 2, 3, 4, and 5.

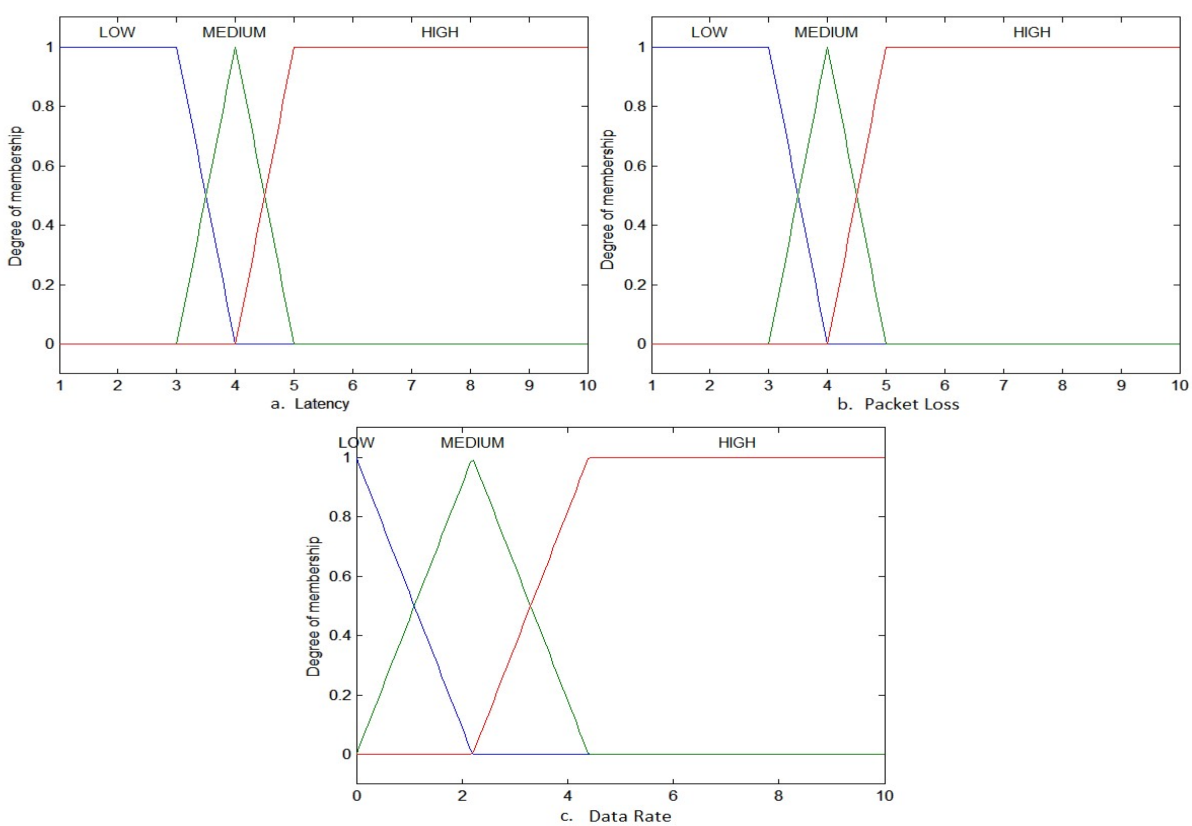

Fig. 3. Input FMFs of AQ engine

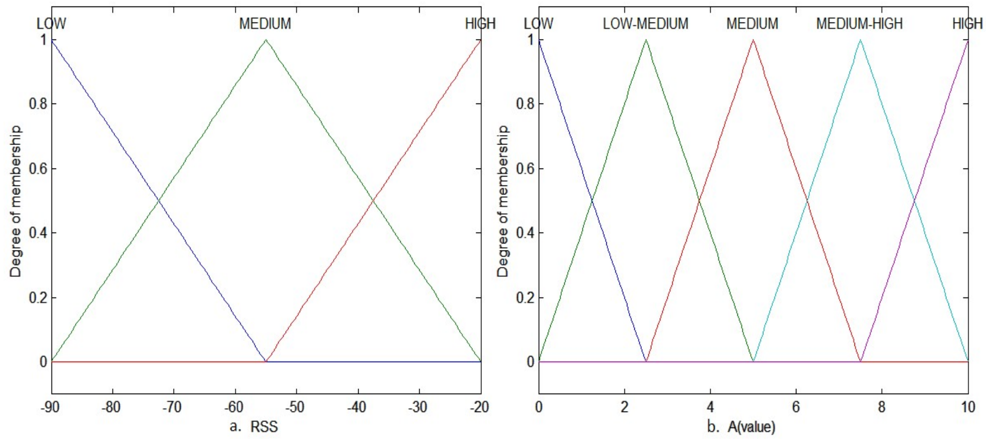

Fig. 4. Input FMFs of NQ engine

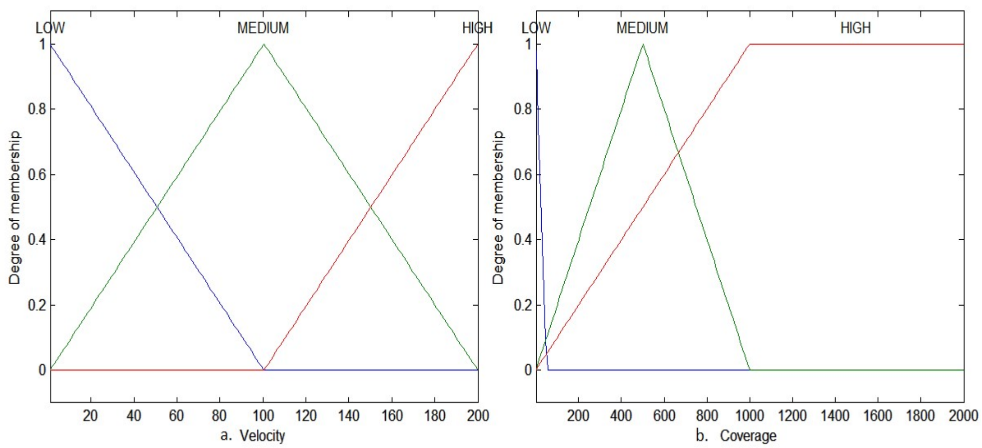

Fig. 5. Input FMFs of ME engine

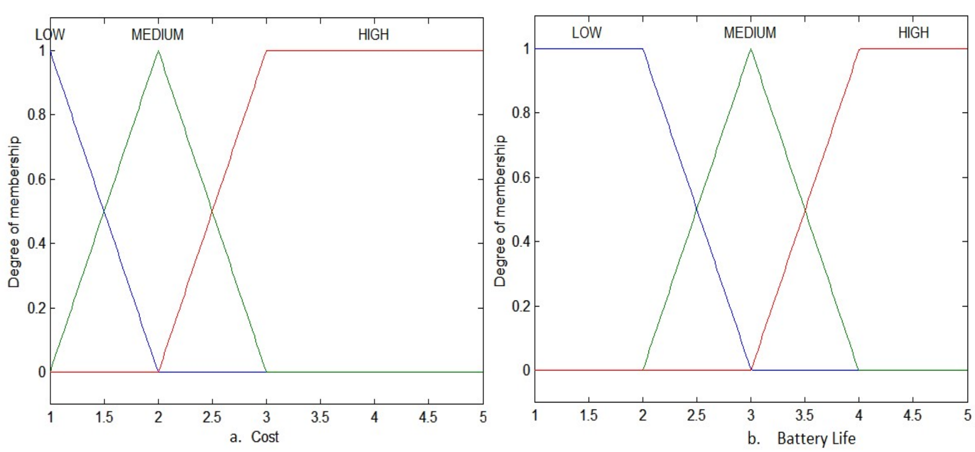

Fig. 6. Input FMFs of EF engine

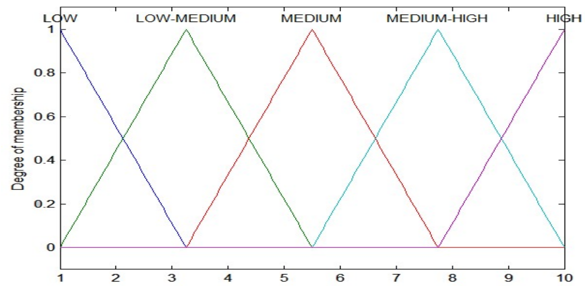

Fig. 7. Output FMFs of all fuzzy engines

TABLE 1
FUZZY RULES FOR AQ ENGINE

No	Latency Packet	Loss	Data Rate	Output
1	Low	Low	Low	Medium
2	Low	Low	Medium	Medium-High
3	Low	Low	High	High
		...		
27	High	High	High	Medium

TABLE 2
FUZZY RULES FOR ME ENGINE

No	RSS	$A_{(value)}$	Output
1	Low	Low	Low
2	Low	Medium	Low-Medium
3	Low	High	Medium
		...	
9	High	High	High

TABLE 3
FUZZY RULES FUZZY RULES FOR AQ ENGINE FOR ME ENGINE

No	VE	CO	Output
1	Low	Low	Medium
2	Low	Medium	Medium-High
3	Low	High	High
		...	
9	High	High	Medium

TABLE 4
FUZZY RULES FOR EF ENGINE

No	SC	BL	Output
1	Low	Low	Medium
2	Low	Medium	Medium-High
3	Low	High	High
		...	
9	High	High	Medium

TABLE 5
FUZZY RULES FOR DS ENGINE

No	$Q_{(value)}$	$M_{(value)}$	$E_{(value)}$	Output
1	Low	Low	Low	Low
2	Low	Low	Medium	Low-Medium
3	Low	Low	High	Medium
		...		
27	High	High	High	High

SIMULATION AND RESULTS

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 options 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 parameter are generated from the range shown in Table 6 for SD and full HD video streaming. The values for latency, packet loss, data rate, service cost, and battery life were generated as [7], the value of RSS is taken from [20], and the cell sizes of cellular, WiMAX, and WLAN are 2 Km, 1 Km, and 50 m respectively. The value of the velocity of mobile node is generated from 1 to 200 Km/h.

The multi-criteria fuzzy-based HDS is developed using fuzzy logic toolbox for 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 are uniform. The two algorithms are compared in terms of Percentage Success (PS), defined as how many times (expressed as a percentage) the HDS algorithm selects the best network for handover which fulfils all the QoS requirements. The following procedure has been taken to simulate both of the mentioned algorithms:

TABLE 6
DECISION PARAMETERS FOR SD AND FULL HD SERVICES

Network	UMTS	WiMAX	WLAN
RSS (dBm)		-90 to -20	
Latency (sec)		1 7 (rec. $\leq$ 5)	
Packet Loss (%)		1 7 (rec. $\leq$ 5%)	
Data Rate (Mbps)	1 5	1 6	1 8
Velocity (Km/h)		1 200	
Coverage (m)	1 - 2000	1 - 1000	1 50
Service Cost	3	2	1
Battery Life (Hours)	0.74*(2.5-5)v	0.55*(2.5-5)	2.5-5

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 is necessary and the average value of multiple trials is obtained. For each of the service options (SD and full HD video streaming) 10 trials, 1000 runs of simulations are carried out for each trial. Out of the 1000 outputs for each HDS, the number of times that both of the HDSs select the best network for handover (the Number of Success (Ns)) and the number of times that the HDSs select a network, which does not satisfy the data rate and QoS requirements (the Number of Failures (Nf)), are determined. Finally, for both HDSs, the PS is calculated by using equation 11 [20].

$$PS = \frac{NS}{NS + Nf} + 100 \tag{11}$$

The simulation reveals a comparison for network selection performance of fuzzy-based HDS with SAW. As mentioned before, there are various inputs for network selection using HDS design and SAW algorithm, where the robustness of algorithms with numbers of inputs is needed to be employed.

Accordingly, Figures 8 and 9, which illustrate the percentage of success with respect to the number of the trails, exhibit the performances' comparison of fuzzy-based HDS with SAW for video streaming in SD and full HD formats.

In Figure 8, the network selection performance for service in SD format of fuzzy-based HDS is 25.75% better than the SAW algorithm, which indicates the robustness of the algorithm. Similarly, for service in full HD format, the fuzzy-based HDS algorithm for network selection performance is 15.78% more than the SAW algorithm. Moreover, the algorithm execution time for both HDS designs has been compared through a 2.4 GHz Intel ® Core^{TM} 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.

In a nutshell, the results of this simulation show that the fuzzy-based HDS design has the capability to enhance the intelligence of HDS for wireless mobile networks and makes comprehensive decisions for handover.

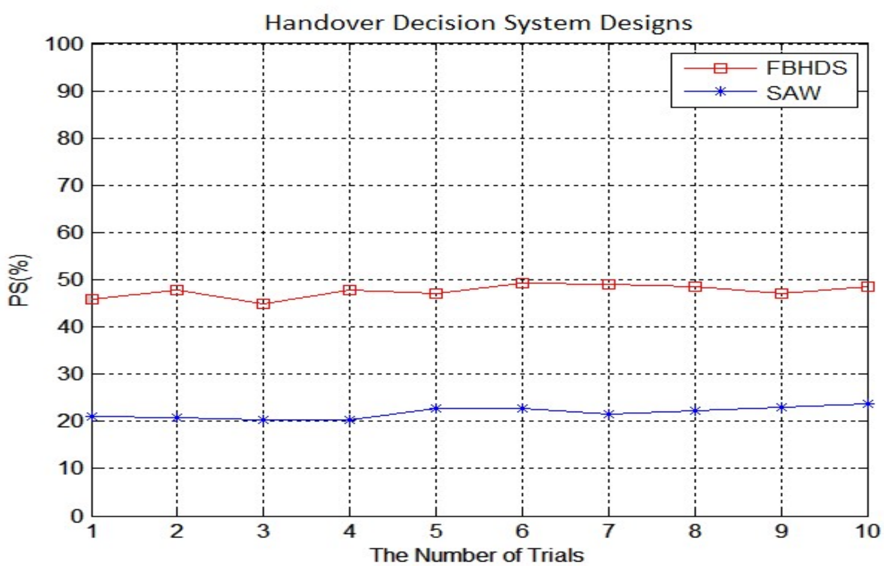

Fig. 8. Network selection performance for video streaming in SD format

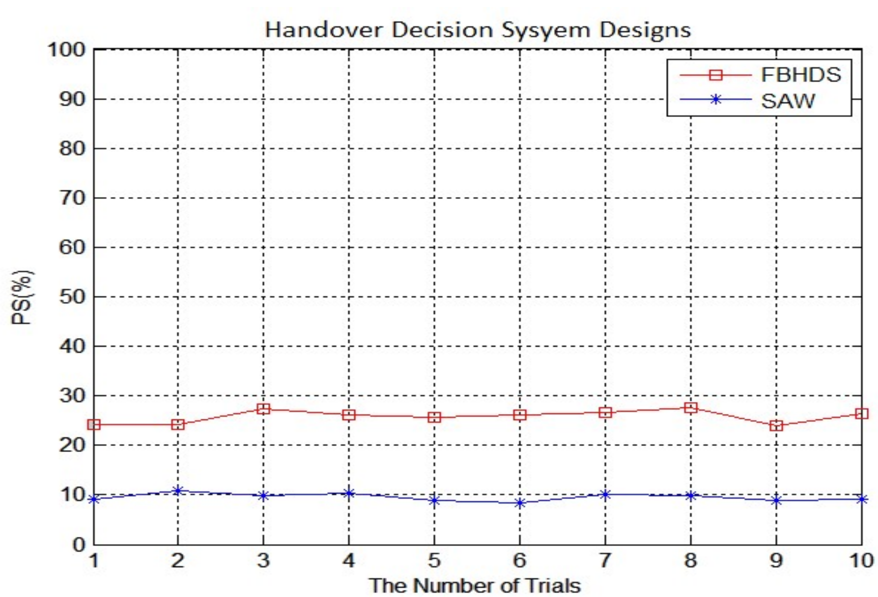

Fig. 9. Network selection performance for video streaming in HD format

CONCLUSION AND RECOMMENDATIONS

Our main focus is to enhance the intelligence of handover decision system 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 section III of this paper, a multi-criteria fuzzy-based handover decision system design has been presented to enhance the network selection performance and make prompt and comprehensive decisions for handover. The proposed design 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 are compared with a non-fuzzy-based HDS algorithm, SAW, which determines significant improvements in terms of network selection performance for SD and full HD video streaming formats, and reduction in algorithm execution time.

Declaration of Conflicting Interests

There are no identifiable conflicts of interest.

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