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An Optimum Vertical Handoff Decision Algorithm Based on Adaptive Fuzzy Logic and Genetic Algorithm

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Abstract Handoff decision making is one of the most important topics in wireless heterogeneous networks architecture as there are many parameters which have to be considered when triggering handoff and selecting suitable access point. More intelligent approaches which reckon user profiles, application requirements, and network conditions must be improved so that desired performance results for both user and network could be provided. In this paper we introduce a new adaptive vertical handoff decision making algorithm in which fuzzy membership functions are optimized by means of genetic algorithm. Genetic algorithm is an adaptive search technique based on natural selection and genetic rules. In addition to that, it takes places in various scientific applications and can be used to adjust the membership functions in fuzzy systems. The purpose of the study is to adjust the shape of fuzzy membership functions, properly, using genetic algorithm in order to achieve optimum handoff performance. The results show that, compared to the several different algorithms performance of the proposed approach with genetic algorithm is significantly improved for both user and network in terms of number of handoff while the other requirements are still satisfied.

Keywords Vertical Handoff · Cognitive radio · Heterogeneous networks · Genetic algorithms · Fuzzy logic

1 Introduction

The various wireless technologies are compelling today's wireless networks to become heterogeneous and making available a wide range of new applications. That is the reason why the development of mobile terminal designs continues to grow and changes our living standards [1]. Furthermore, in recent years, there is a sharp rise in number of users in cellular

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environment. As a result of which there is a growing demand for some of the services, such as streaming video, audio, and video conference.

Wireless network technologies are different from each other usually in terms of bandwidths, frequencies, latencies, and etc. Currently, no single technology simultaneously provides a low latency, high bandwidth, and cost-effective services to all mobile users. So as to enable seamless communications in wireless environment, providing support for well-organized handoff between the various technologies will play a crucial role [2].

Handoff is described as a process of transferring an ongoing call or data session from one access point to another in wireless networks. More clearly, handoff is the process of changing the communication channel (frequency, modulation scheme, data rate, spreading code, or combination of them) associated with the current connection while a call is in progress.

Traditional handoff process, called horizontal handoff, takes place to provide a seamless service when a user moves between two adjacent cells. Generally, horizontal handoff is based on only single parameter such as RSS (Received Signal Strength), SNR (Signal-to-Noise Ratio), and etc., and initializes when received signal strength indicator (RSSI) or SNR drops below a specified handoff threshold. It is also performed between two access points each of which has same network technology. On the other hand, vertical handoff process takes place between different technologies. Because the next generation wireless systems involve a mixture of various technologies, it is obvious that, traditional handoff mechanisms will not be sufficient. Using only one metric for vertical handoff decision making is not efficient since existing networks overlap with each other. Considering more performance metrics, such as; data rate, monetary cost, user's speed, and etc., as well as RSS more realistic performance results can be achieved for these heterogeneous structures.

Consequently, in heterogeneous wireless networks, it is critical to design an efficient vertical handoff algorithm for providing seamless connection. Artificial intelligent algorithms based on fuzzy logic, neural networks or neuro-fuzzy systems are familiar approaches to solve vertical handoff problems.

In this study, a Smart Mobile Terminal (SMT) is proposed that scans the environment for available Radio Access Technologies (RATs). It evaluates the working conditions of RATs using its newly developed hybrid fuzzy-genetic algorithm based vertical handoff algorithm (HFGA-VHA), triggers handoff process if necessary, and chooses the best Access Point (AP) to camp on. The proposed SMT is modeled and simulated using OPNET Modeler Software for performance evaluation. Besides, the handoff algorithms incorporated in SMT is implemented in MATLAB Software. The contributions of this study can be summarized as follows:

- A new GA based adaptive fuzzy logic vertical handoff algorithm is designed for five different applications and five different wireless technologies include Wi-Fi (Wireless Fidelity), GSM (Global System for Mobile Communications), GPRS (General Packet Radio Service), UMTS (Universal Mobile Telecommunications System), and WiMAX (Worldwide Interoperability for Microwave Access) properly.
- Performance of the proposed HFGA-VHA is compared with that of others in the literature, i.e. simple additive weighting (SAW) based, pure fuzzy based, neuro-fuzzy based and an existing fuzzy-genetic based vertical handoff algorithms.
- HFGA-VHA and aforementioned handoff decision algorithms are modeled using MATLAB and the network side of the scenario is implemented in OPNET Modeler simulation software. During the simulation, both parts work together for more realistic estimation and substantiation.

- A new cognitive smart mobile terminal, which senses the environment for all possible AP technologies and changes its working parameters such as bandwidth, data rate and so on in an effort to connect available AP, is developed.
- A new multi-criteria handoff decision system, which has the ability to adapt its structure according to the application requirements and network conditions, is proposed.
- To the best knowledge of authors, using GA for handoff decision making in order to optimize fuzzy logic membership functions is the first in literature.

2 Related Works

Although the vertical handoff concept is relatively new, several studies can still be found in the literature. In [3], the authors discuss different factors and metrics which are considered when triggering handoff. In addition to that, they describe a vertical handoff decision function which enables devices to assign weights to different network factors such as monetary cost, QoS (Quality of Service), power requirements, personal preference, and so on. A novel fuzzy logic-based handoff decision algorithm for the mobile subsystem of tactical communications systems is introduced in [4].

In Ref. [5], a fuzzy based vertical handoff decision algorithm is aimed between GSM, GPRS and WLAN (Wireless Local Area Network) networks with bandwidth, coverage area, power consumption and sojourn time parameters. Another fuzzy based vertical handoff decision algorithm with Elman neural network is proposed between WLAN and UMTS [6]. Bandwidth, mobile speed and number of user values are taken as input parameters in the study. Ref. [7] provides a multi-criteria decision making algorithm based on fuzzy logic and artificial neural networks. It considers SIR (Signal to Interference Ratio), BER (Bit Error Rate) and transmission rate for handoff possibility. In [8], fuzzy logic and genetic algorithm based vertical handoff decision algorithm was explored with RSS and cost parameters on UMTS-WiMAX networks.

Combined fuzzy logic and genetic algorithms have been used to give proposed scheme the required scalability, flexibility, and simplicity in Ref. [9]. Genetic algorithm has been used to help the users or networks operator to find suitable values for the weights in the offline mode.

In [10], Fuzzy inference system which uses Adaptive Neuro-Fuzzy Inference system of MATLAB in which triangular membership function and fuzzy based inference engine is used along with neural network for the weight adjustment was discussed. Several techniques used in the traditional handoff decision process along with ANFIS (Adaptive Network Fuzzy Inference System) are explained in [11], followed by comparisons.

The differences of our study can be summarized as; (1) to the best knowledge of authors, using GA for handoff decision making in order to optimize fuzzy logic membership functions is the first in literature, (2) a cognitive radio that senses GSM/GPRS/Wi-Fi/UMTS/WiMAX technologies has been designed, (3) performance results of the proposed method have been compared with aforementioned methods, and (4) for more realistic performance evaluation, OPNET and MATLAB tools have been cooperated.

3 Pure Fuzzy Logic Based Vertical Handoff System

Applications of fuzzy logic are found in many research and application fields, including artificial intelligence, engineering, computer science, pattern recognition, and etc. Nowadays,

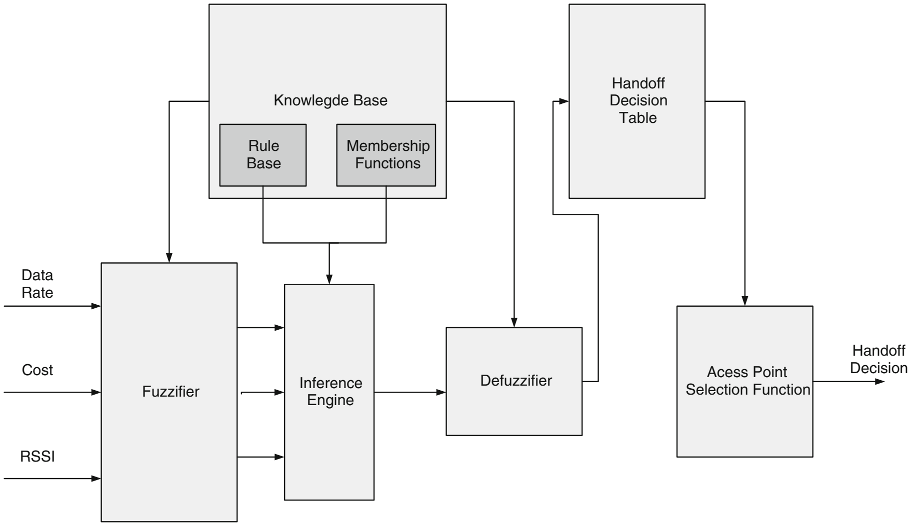


Fig. 1 Block diagram of the proposed fuzzy logic based handoff decision system

fuzzy logic is being integrated with artificial intelligence based systems and teamed with other advanced techniques, such as neural networks and genetic algorithms, to produce enhanced results with less effort.

In general, vertical handoff includes three steps; handoff initiation, handoff decision, and finally handoff execution. Firstly, handoff initiation contains some preparation for a handoff process such as the measurement of RSS, SNR, battery level, mobile speed, and etc. In the second step, handoff decision algorithm checks the current network connection, determines whether a handoff is necessary or not, and selects the suitable access point to handoff. Finally, handoff execution establishes the connection with the new access point.

The smart terminal proposed in this study is in complete charge of managing the handoff process as well as its other functions through the capability of cognitive radio structure. SMT senses the medium by scanning the frequency spectrum to get the available APs parameters such as data rate, cost, and RSSI periodically. These parameters obtained from the handoff broadcast packets are utilized in SAW based algorithm, pure fuzzy logic based handoff decision algorithm, neuro-fuzzy based algorithm, an existing fuzzy-genetic based algorithm and HFGA-VHA.

Fuzzy logic based handoff algorithm is preferred in the SMT since fuzzy logic is capable of dealing with imprecise data and modeling nonlinear functions. Figure 1 illustrates the essential components of the fuzzy logic based vertical handoff decision system which is similar to one given in Ref. [13] for comparative performance evaluation. During the handoff initiation process, three widely used parameters are considered; received signal strength (RSS), data rate (DR) and monetary cost (C).

The first step of the handoff system is to feed the considered context parameters into a fuzzifier as can be shown in Fig. 1. The role of the fuzzifier here is transforming the real-time measurements into fuzzy sets. For example, if RSS is considered in crisp set, in the corresponding fuzzy set, the signal can be represented as quite weak, medium or strong. A few examples of developed fuzzy rules are given below:

IF (DataRate is low) and (Cost is low) and (RSSI is weak) then (APCV is 1)
IF (DataRate is medium) and (Cost is low) and (RSSI is medium) then (APCV is 4)
IF (DataRate is high) and (Cost is low) and (RSSI is medium) then (APCV is 9)
IF (DataRate is high) and (Cost is high) and (RSSI is medium) then (APCV is 5)
IF (DataRate is high) and (Cost is high) and (RSSI is strong) then (APCV is 6)

The membership values are obtained by mapping the values for particular parameter into a membership function. After that, we need to perform fuzzy conversion by using a reverse engine commonly named defuzzifier to generate Access Point Candidate Values (APCVs) which describe the candidacy level of APs. APCV is generally defined by a real number in order to quantify the strength of the candidacy level of the AP found. For instance, APCV can be designed to vary between zero and ten where zero denotes the weakest, whereas ten represents the strongest candidacy level of quantification. Accordingly, if an Access Point is able to support a data rate of 50 Kbps, has a cost of 0.1 unit and RSS of −63 dBm then the APCV of this hot spot is calculated as 9.2484. As a last step, the calculated APCV is utilized for deciding handoff initialization and choosing the best candidate AP.

Membership functions of the fuzzy system inputs are given in Figs. 2, 3, and 4, respectively. Trim and trapezoid are chosen as the fuzzy membership functions due to their capability of achieving better performance for especially real time applications [12,13].

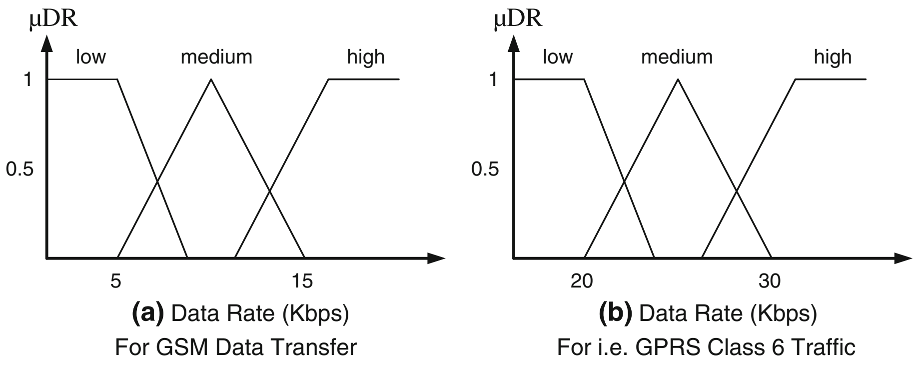
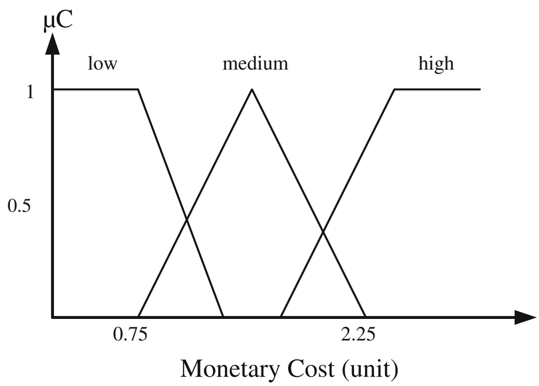


Fig. 2 Fuzzy membership functions for data rate (DR)

Fig. 3 Fuzzy membership functions for monetary cost (C)



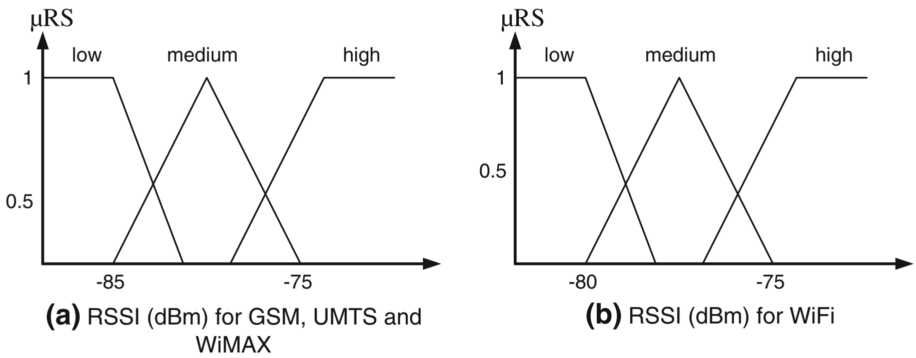


Fig. 4 Fuzzy membership functions for RSSI (RS)

The Data Rate (DR) input can dynamically change its structure according to the application requirements. For instance, if the data rate requirement of an application is 9.6 Kbps (GSM data transfer) then the membership function (μDR) is similar to the one given in Fig. 2a. On the other hand, when the application needs more bandwidth, e.g., 25 Kbps (GPRS Class 6 traffic), then it dynamically changes its structure to adapt the new working condition as seen from Fig. 2b.

The cost parameters from APs are obtained from handoff packets and sent to the SMT to be considered in handoff decision process. In our simulation scenario, we assume that networks have specific unit price information which is known by AP and sent to the SMT in the handoff broadcast packet. Its membership function (μC) can be seen in Fig. 3.

The RSSI input of the fuzzy system has also the ability to change its structure according to the network requirements as data rate. The RSSI membership function (μRS) for GSM, UMTS and WiMAX is shown in Fig. 4a, and for Wi-Fi network is shown Fig. 4b, respectively.

The output of the fuzzifier is aggregated into a single fuzzy variable, using inference engine that has a knowledge base determined by the experiences, and passed to the defuzzifier to be converted into a precise quantity referred as APCV. Finally, handoff process is decided using the output of the fuzzy inference system, i.e., APCV.

The analytic model of the fuzzy inference system is as follows [4,5]. Three dimensional pattern vectors (input of the fuzzifier) for candidate access points are (PV_c):

$$PV_c = [DR_c; C_c; RS_c] \tag{1}$$

where DR is data rate, C is monetary cost, and RS is RSSI value of available AP. Three dimensional fuzzy pattern vectors (PV_F, output of fuzzifier and input of inference engine) for candidate access points is:

$$PV_F = [PF_1; PF_2; PF_3] \tag{2}$$

Since product inference rule is utilized in the fuzzy inference engine, then, for a new pattern vector, contribution of each rule in the fuzzy rule base (C_r) is computed by:

$$C_r = \prod_{i=1}^{3} \mu_{F_i}(P_i) \tag{3}$$

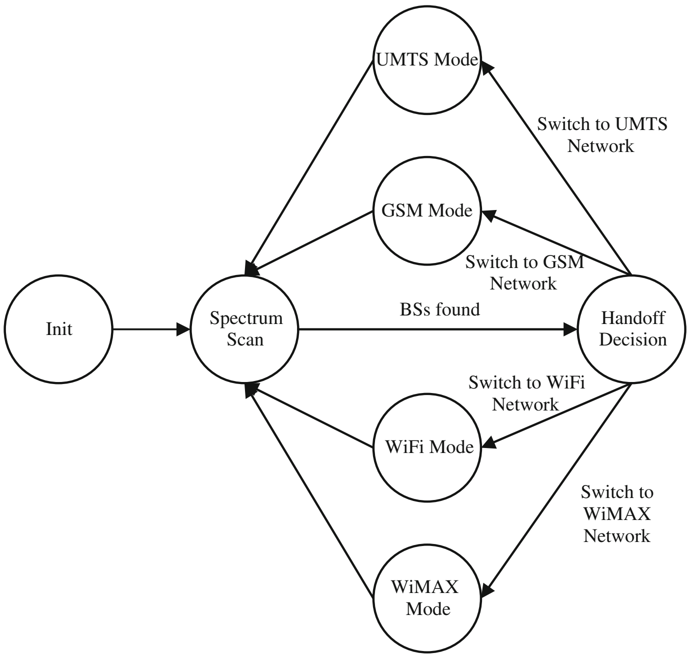


Fig. 5 The SMT cross-layer process model

Since we have 27 rules and a center average defuzzifier is utilized, the output of the defuzzifier (APCV) is:

$$M_a = \frac{\sum_{l=1}^{27} y^l \left(\prod_{i=1}^{3} \mu_{F_i}(P_i)\right)}{\sum_{l=1}^{27} \left(\prod_{i=1}^{3} \mu_{F_i}(P_i)\right)} \tag{4}$$

where, y^l is the output of the rule l.

The proposed SMT process model is developed using OPNET Modeler software and its cross layer design is outlined in Fig. 5. It includes physical, MAC, and some upper layer functions. It is composed of a CSMA/CA MAC module for the Wi-Fi capability, a GSM module in order to handle GSM operations, a UMTS module for 3G capability, a WiMAX module including its functions and the proposed GA based adaptive fuzzy logic smart handoff unit which is in charge of managing all of the handoff operations.

During the spectrum sensing period, SMT listens to wireless medium for APs handoff broadcast packets for every 100 ms. Each of APs periodically sends its own handoff broadcast packets which include the parameters required, i.e., data rate, monetary cost, RSSI. Along with the listening period, the SMT changes its working parameters such as frequency, modulation, data rate, and bandwidth to adapt any possible AP and to receive its handoff broadcast packets. When any AP is found in the vicinity, SMT gets the handoff broadcast packet and extracts related parameters in order to use as inputs of the proposed vertical handoff algorithm. With those parameters, SMT calculates the APCV using its fuzzy inference system, and stores all of the pieces of information required in the handoff decision table (HDT).

As soon as the scan process is completed, APCV of each available AP is compared with that of current APs. If the difference between the compared values is equal to or greater than the handoff resolution [1](HR) the new AP is chosen as a serving node.

4 The Proposed Hybrid Fuzzy-Genetic Algorithm Based Vertical Handoff Algorithm

Genetic algorithm (GA) is a search algorithm that uses operations found in natural genetics to guide the walk through a search space. GA is proven to be robust search in complex spaces, offering a valid approach to problems requiring efficient and effective search [14]. GA starts with a population of randomly generated solutions named chromosomes and advances toward better solutions by applying genetic operators. The detailed information about genetic algorithms can be found in [15].

In this study, GA based optimization of membership functions used in pure fuzzy based algorithm is proposed in order to get better performance results, i.e., achieving reduced number of handoff. In other words, it is aimed to perform more realistic handoff decision making by means of being adjusted membership functions that belong to data rate, monetary cost, and RSS information with some constraints and fitness function. Optimized fuzzy membership functions are obtained in offline mode with genetic algorithms and embedded to pure fuzzy logic based handoff algorithm. So, in online mode, the complexity of the system is not influenced by the genetic algorithm.

The membership functions considered are trapezoid and triangular functions which are defined by four and three parameters, respectively. The Eq. 5 shows a trapezoidal function (μ) formally described by

$$\mu(x,a,b,c,d) = \left\{ \begin{array}{ll} 0, & x \le a \\ \frac{x-a}{b-a}, & a \le x \le b \\ 1, & b \le x \le c \\ \frac{d-x}{d-c}, & c \le x \le d \\ 0, & d \le x \end{array} \right\} \quad (5)$$

which shapes for the case (b = c) into a triangular membership function. Figure 6 shows the fields of a, b, c, and d variables.

In the population of our GA, a candidate solution is C_k, k = 1,…, K (K, number of chromosomes), and rules are defined as,

"If DR_1 is A_{i1} and $Cost_1$ is A_{i2} and RSS_1 is A_{i3} then output is B_i''.

The rule is presented by a piece of chromosome $C_{ki,}$ i = 1,…, m (m, number of variables in a chromosome). So,

$$C_{ki} = \{C_{k1} C_{k2} \ldots C_{km}\}. \quad (6)$$

As can be shown in Fig. 6, a membership function can be defined with four variables and represented with 4-tuple A_{ij} will be shown (a_{ij}, b_{ij}, c_{ij}, d_{ij}). Then, vector of C_{ki} is presented:

$$C_{ki} = \left(a_{i1}, b_{i1}, c_{i1}, d_{i1,\ldots,} a_{im}, b_{im}, c_{im}, d_{im}\right) \quad \text{with} \quad a < b < c < d \quad (7)$$

[1] Handoff resolution value is used to introduce a hysteresis to the pure fuzzy logic based vertical handoff algorithm and HFGA-VHA. Mobile terminal takes into account the HR value in order to decide whether any handoff process is required or not. If the APCV is greater an amount of specified HR value than the one current AP has, then the handoff process is initialized.

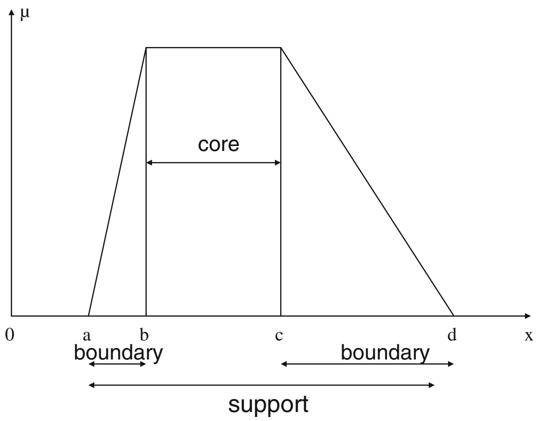


Fig. 6 Trapezoidal membership function

At the stage of creating population, there are thirty five variables (m = 35) totally in each chromosome. Twelve chromosomes (K = 12) are formed in the population.

Finally, we present initial population such as:

$$C = (C_1, C_2, \ldots, C_{12}) \tag{8}$$

A gene is an element of chromosome that is formed with binary codes, each gene consists of six bits and then all genes are converted to real values in appropriate ranges such as $[c_t^l, c_t^r]$ ([left boundary, right boundary]). The size of population is 35*12*6 = 2520 bits.

In the meanwhile, we use real-valued coding, where chromosomes are represented as floating point numbers. The second step after initialization of population is to calculate the fitness values of chromosomes by the fitness function with F_{APCV}, G_{APCV} and HR values obtained from the block diagrams as shown in Fig. 7. The fitness function measures the goodness of a solution in a given population. The primary objective of genetic algorithm is to optimize a fitness function. Consequently, the fitness function should be carefully set by considering all factors that play important role in optimizing the problem under investigation [16].

In our GA based method, the fitness function (Eq. 9) is expressed as an error minimizing problem. The fitness function calculates fitness of chromosomes in range $[c_t^l, c_t^r]$ using the fitness criterion. At the evaluation of fitness, the results that are obtained from pure fuzzy based algorithm (F_{APCV}, APCV values from pure fuzzy based algorithm) and handoff resolution that is needed for making handoff are regarded in error minimizing problem. Therefore, fitness function finds an optimum minimized error that provides desired results. G_{APCV} is the value from tuned fuzzy membership functions with GA, and HR is the threshold value (chosen as 2 after several trials for getting better results) that is used for handoff resolution. Figure 7 shows the process steps of our GA based method.

$$\text{Fitness} = \frac{1}{F_{APCV} + HR - G_{APCV}} \tag{9}$$

More explicit expression of the fitness function:

$$\text{Fitness} = 1 \Bigg/ \left(\frac{\sum_{l=1}^{27} y^l \left(\prod_{i=1}^{3} \mu_{F_i}(P_i) \right)}{\sum_{l=1}^{27} \left(\prod_{i=1}^{3} \mu_{F_i}(P_i) \right)} + HR - \frac{\sum_{l=1}^{27} y^l \left(\prod_{i=1}^{3} \mu_{G_i}(P_i) \right)}{\sum_{l=1}^{27} \left(\prod_{i=1}^{3} \mu_{G_i}(P_i) \right)} \right) \tag{10}$$

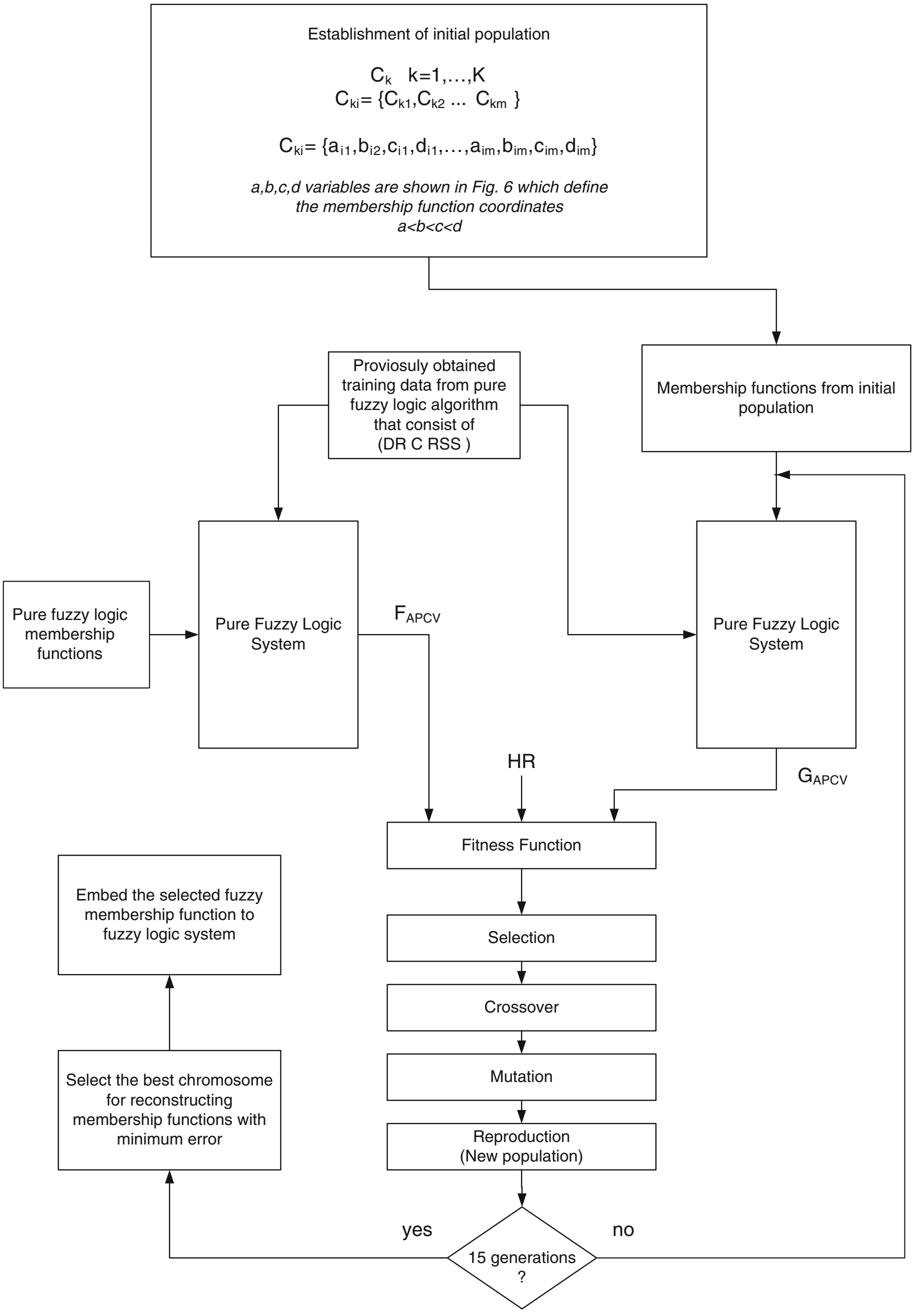


Fig. 7 GA based algorithm schema

In pure fuzzy logic system, contribution of each rule in the fuzzy rule base is given by $\prod_{i=1}^{3} \mu_{F_i}(P_i)$ and in developed HFGA-VHA based system, contribution of each rule in the fuzzy rule base is given by $\prod_{i=1}^{3} \mu_{G_i}(P_i)$ as shown in Fig. 7.

Membership function tuning process usually affects some of rules and all rules may affect each fuzzy operation. Consequently, the main problem is to solve tuning processes to provide the closest match for realistic applications. So, previously obtained training data from pure fuzzy logic algorithm that consist of DR, C and RSS values are used to get F_{APCV} and G_{APCV} outputs.

Selection process is to prefer better solutions and we have been used roulette-wheel method for selecting operation. During each generation, chromosomes that satisfy the selection criteria can survive while others with lower fitness values are destroyed.

During the reproduction phase of GA, two classical genetic operators named crossover and mutation are used. Crossover refers to some part of individuals exchange between them in order to produce new individuals and single-point crossover is performed with 0.5 crossover probability.

The principle of mutation in GAs is preserving and introducing diversity. Mutation should permit the algorithm to keep away from local minima by preventing the population of chromosomes from becoming too similar to each other. Mutation rate is selected as 0.01 in our genetic algorithm. Mutation changes a gene's position in the binary string with mutation probability equal to the mutation rate. Obviously, this process consists of changing 0–1 or vice versa.

Until one of the stopping criteria is reached (GA will be terminated at the end of 15 generations that is determined after several trials[2]), the steps of algorithm are repeated. After all, new and optimized membership functions are spontaneously obtained. We choose the membership functions that produce more reliable and consistent results considered current applications. In our simulation model, there are five types of application, five types of access point, and three types of membership function that belong to three levels (low, medium, high). Therefore, we have been obtained 225 optimized membership functions totally. Some of them have been given in Figs. 8 and 9).

After tuned fuzzy membership functions (for each AP and each application) are obtained in offline mode, they are embedded to the pure fuzzy logic system. In Sect. 5, this newly created system (HFGA-VHA based) has been deployed for all application scenarios for making handoff decision in the online mode.

5 Simulation Scenario

In proposed simulation scenario that is modeled using OPNET Modeler and illustrated in Fig. 10, a heterogeneous network is designed that consists of four wireless networks; GSM, Wi-Fi, UMTS and WiMAX access points, each has specific working parameters. The developed SMT explained in some part of sections is also modeled in OPNET. The implementation of hybrid fuzzy-genetic algorithm based vertical handoff algorithm (HFGA-VHA) strategy which is incorporated into the SMT is completed with MATLAB. Rayleigh fading channel is adopted for emulating the multipath propagation channel [17].

As mentioned before, SMT performs five different applications, in turn, SMT is capable of generating time sensitive voice traffic (13 Kb/s), GSM data traffic (9.6 Kb/s), Class 6 GPRS data traffic (25 Kb/s), and image traffics (50 and 100 Kb/s). It moves along with the trajectory shown in Fig. 10 with a pedestrian speed during the simulation run time, senses the environment periodically for possible AP, has the aforementioned fuzzy logic based

[2] 15 generations produced the optimum results. We had approximately the same outcomes for the attempts after fifteenth generation. So, 15 generations has been chosen in the genetic algorithm.

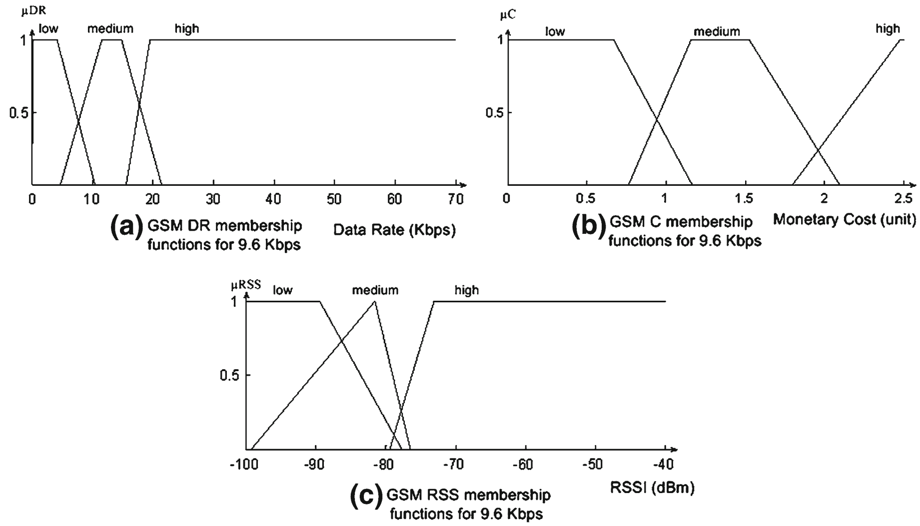


Fig. 8 Optimized GSM membership functions for 9.6 Kbps data transfer

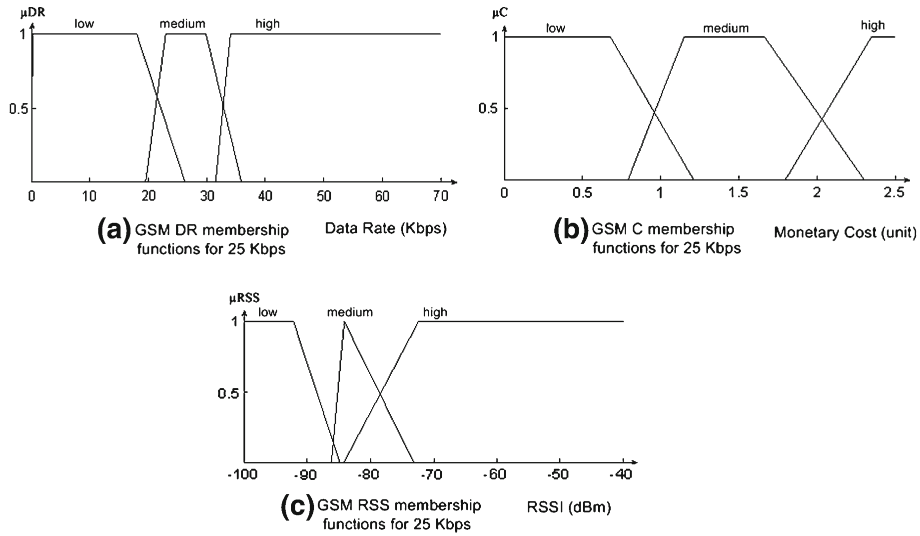


Fig. 9 Optimized GSM membership functions for 25 Kbps data transfer

handoff decision system, and has the capability of performing GSM, GPRS, Wi-Fi, UMTS and WiMAX functionalities. The GSM base station, in our scenario, supports 9.6 Kb/s data transfer and voice transfer application, whereas UMTS has more bandwidth, i.e. adequate for multimedia applications, and can achieve 25 Kb/s data transfer with GPRS serving. WiMAX, on the other hand, supports faster mobile users, provides much more bandwidth with, has a higher monetary cost and deployed commonly in rural areas. The simulation parameters are tabulated in Table 1.

The SMT camps on the Wi-Fi hotspot because of having higher RSSI, sufficient bandwidth and extremely low cost at the beginning of scenario. After 300 ms, data rate of Wi-Fi

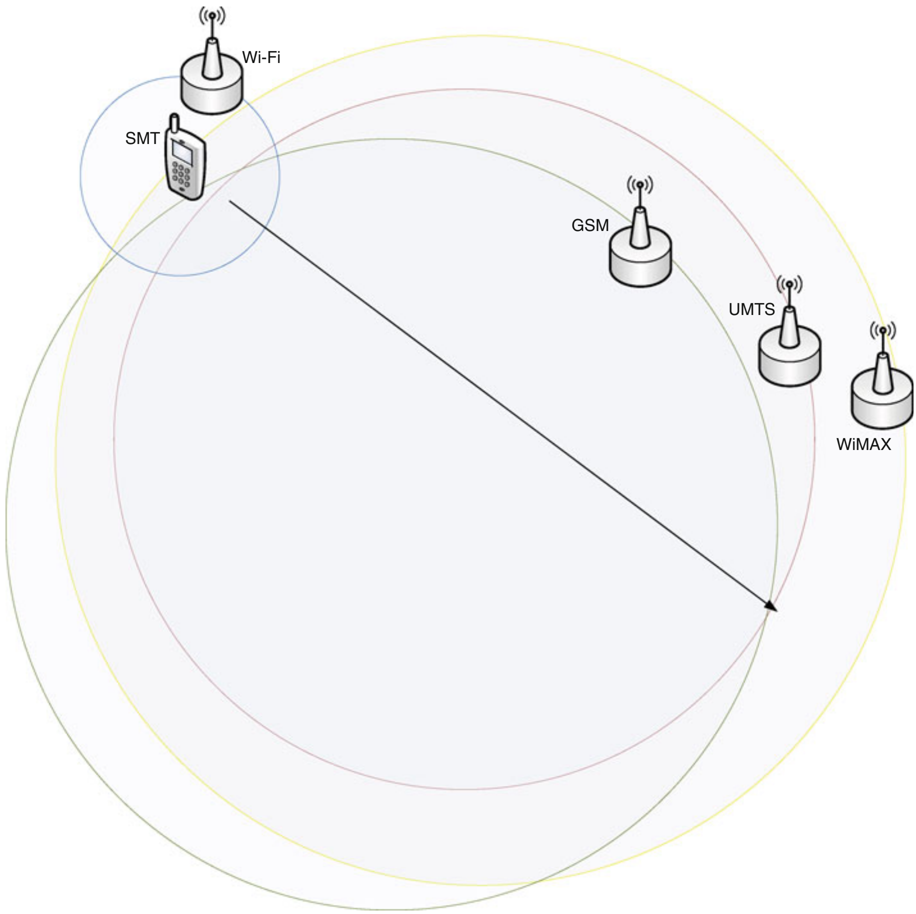


Fig. 10 Example vertical Handoff scenario

Table 1 Simulation parameters

Parameter	Value
Message size	13* Kb/s, 25* Kb/s, 9.6* Kb/s, 50* Kb/s, 100* Kb/s
Data rate	Wi-Fi = 1 Mb/s, GSM = 270,833 b/s, UMTS = 3840000 b/s, WiMAX = 4104000 b/s
Frequency band	Wi-Fi = 2400 MHz, GSM = 890–935 MHz, UMTS = 2110–1920 MHz, WiMAX = 3300–3400 MHz
Handoff resolution	2
Transmitter power	Wi-Fi = 100 mW, GSM =1.5 W, UMTS=20 mW, WiMAX = 100 mW
Speed of mobile	2.5 Km/s
Area size	4 × 4 Km
Scan period	100 ms
Monetary cost	Wi-Fi = 0.1 GSM = 1.8 UMTS = 2.0 WiMAX = 3.5
Channel model	Rayleigh fading channel

*Generated using exponential distribution function Exp (Mean) decreases dramatically. SMT decides to change the AP considering the applications requirements although the Wi-Fi has appropriate RSSI and cost parameters. As can be seen from Fig. 10 there are three alternative APs other than the serving Wi-Fi.

For data transfer with 9.6 Kb/s and voice transfer with 13 Kb/s, this dramatic decrease in bandwidth consequently reduces the APCV of the Wi-Fi as shown in Fig. 11, since the data rate is one of three inputs for the fuzzy based algorithm developed. The GSM base station, similar to the others except Wi-Fi, is able to provide appropriate bandwidth for the applications referred. When compared with the other ones, the GSM base station has lower cost and higher RSS parameters. Therefore, it has a better APCV, which implies it is the best candidate base station, as illustrated in Fig. 11.

For the same scenario except introduced traffic, i.e. 25 Kb/s data transfer, the GSM base station is not appropriate in spite of its low cost and high data rate. So, there exist two alternatives; UMTS and WiMAX. Since the monetary cost of the UMTS is comparatively lower (at least it has chosen lower than WiMAX in our scenario), then it is chosen as the new serving base station as can be seen from Fig. 12.

As in the data transfer application with 25 Kb/s, the GSM again is not appropriate in terms of bandwidth for the image transfer application with 50 Kb/s. Moreover, the UMTS base

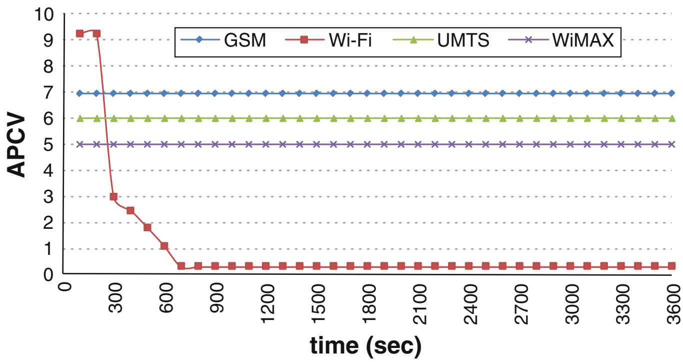


Fig. 11 APCV output of the HFGA-VHA based algorithm for data and voice transfer application (9.6 and 13 Kbps)

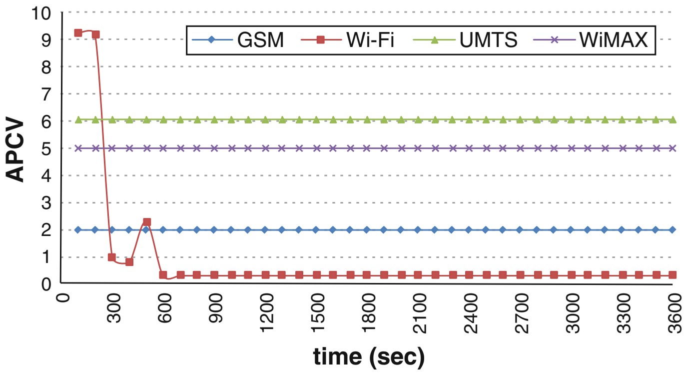


Fig. 12 APCV output of the HFGA-VHA based algorithm for data transfer application (25 Kbps)

station is able to satisfy the QoS requirements of the application traffic with low cost. So, the UMTS base station has a better APCV (Fig. 13) and this makes it the new hotspot.

As in the image transfer application with 50 Kb/s, the GSM again is not appropriate in terms of bandwidth for the image transfer application with 100 Kb/s. Moreover, the UMTS base station is even not capable to satisfy the QoS requirements of the application traffic due to its higher bandwidth requirement. The WiMAX base station, as can be seen from the Fig. 14, has a better APCV and consequently the SMT chooses it as the new serving base station.

Number of handoff is an important parameter when comparing the performance of handoff algorithm designs. It is desired to have minimum number of handoff while the requirements of user, application, and network are satisfied. In this study, the proposed GA based adaptive fuzzy based vertical handoff system is also compared with four algorithms; (1) based on pure fuzzy logic and (2) based on simple additive weighting (SAW) [18] method, (3) an existing fuzzy logic and genetic algorithm based method [8,9] and (4) a neuro-fuzzy based handoff method [19].

For the results shown in Fig. 15, another scenario that has the same simulation parameters and working conditions as in Fig. 10 except the trajectory which is randomly determined instead linear as shown in Fig. 10 is used for comparison of vertical handoff decision algorithms in terms of number of handoff.

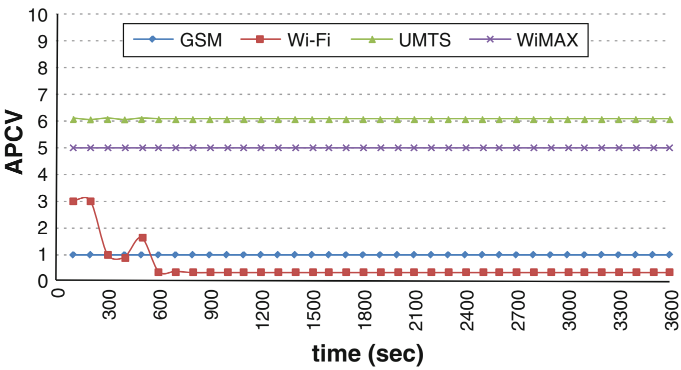


Fig. 13 APCV output of the HFGA-VHA based algorithm for image transfer application (50 Kbps)

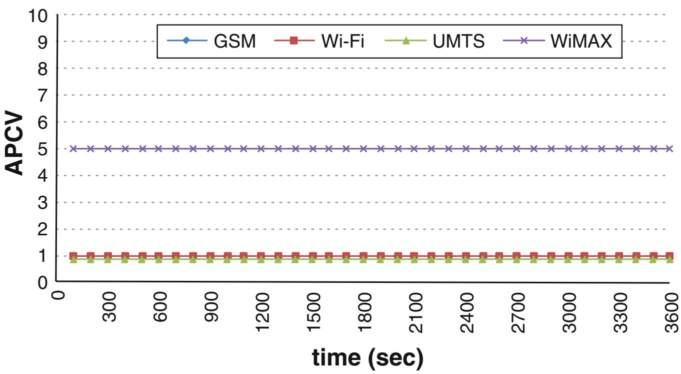


Fig. 14 APCV output of the HFGA-VHA based algorithm for image transfer application (100 Kbps)

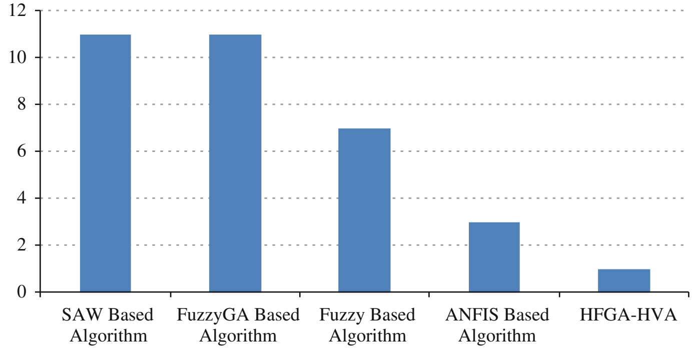


Fig. 15 Number of handoffs for each handoff decision algorithms

The results show that hybrid fuzzy-genetic algorithm based on vertical handoff algorithm (HFGA-VHA) dramatically reduces the number of handoffs, thanks to adjusted fuzzy membership functions, while the user and application requirements are still supported. As can be shown in Fig. 15, HFGA-VHA based algorithm decides handoff only one time that expected result while pure fuzzy-based system, SAW based method, neuro-fuzzy based method and an existing fuzzy-genetic based algorithm trigger handoff seven times, eleven times, three times and eleven times respectively.

6 Conclusions

A main problem for seamless mobility in the heterogeneous network is the design of intelligent handoff management schemes. This paper has presented to design of a hybrid fuzzy-genetic algorithm based vertical handoff algorithm (HFGA-VHA) that is both cost-effective and high useful. Besides, the use of GA may give a great potential to fuzzy logic based optimization approach for tuning fuzzy membership functions to perform different applications corresponded various wireless network technologies as a flexibility tool for optimization.

According to the results obtained, HFGA-VHA algorithm is able to determine whether a handoff is necessary or not, properly, and selects the best candidate access network considering the aforementioned parameters. Furthermore, HFGA-VHA algorithm noticeably reduces the number of handoffs compared to the other counterparts.

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