Vertical Handoff Decision Algorithm Based on Fuzzy Logic and Genetic Algorithm

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Abstract — The integration of diverse but complementary cellular and wireless technologies in the next generation of wireless communication systems requires the design of intelligent vertical handoff decision algorithms to enable seamless terminal, personal and network mobility, and to provide for continuity and transfer of existing sessions. This paper provides an adaptive multiple attribute vertical handoff decision algorithm that enables wireless access network selection at a mobile terminal using fuzzy logic concepts and a genetic algorithm. A performance study using the integration of wireless wide area networks (WWANs) and wireless local area networks (WLANs) as an example shows that our proposed vertical handoff decision algorithm is able to determine when a handoff is required, and selects the best access network that is optimized to network conditions, quality of service requirements, mobile terminal conditions, user preferences, and service cost.

1. INTRODUCTION

The next generation of wireless communication systems will involve the integration of diverse but complementary cellular and wireless technologies, all of which will coexist in a heterogeneous wireless access environment and use a common IP core to offer a diverse range of high data rate multimedia services to end users since the networks have characteristics that complement each other. For example, given the complementary characteristics of 802.11x WLAN (faster, high-bandwidth, lower-cost, short-distance access) and third-generation (3G) cellular WWAN such as Universal Mobile Telecommunications System (UMTS) (slower, higher-cost, long-range always connected access), it is compelling to combine them to provide ubiquitous wireless access for users with contemporary mobile devices that are equipped with multiple network interfaces. The integration and interoperation of these heterogeneous networks requires the design of intelligent vertical handoff decision algorithms (VHDAs) to enable seamless terminal, personal and network mobility, and to provide for continuity and transfer of existing sessions.

A decision for vertical handoff may depend on several issues relating to the current network that the mobile node is already connected to and to the network that it is going to handoff. Vertical handoff decision involves a tradeoff among many handoff metrics including quality of service (QoS) requirements (such as network conditions and system performance), mobile terminal conditions, power requirements, application types, user preferences, and a price model. Using these metrics involves the optimization of key parameters (attributes), including signal strength, network coverage area, data rate, reliability, security, battery power, network latency, mobile velocity, and service cost. These parameters may be of different levels of importance to the vertical handoff decision.

Three main categories of vertical handoff decision algorithm are proposed in the research literature. The first category is based on the traditional strategy of using the RSS combined with other parameters. In [1], Ylianttila *et al*. show that the optimal value for the dwelling timer is dependent on the difference between the available data rates in both networks. The second category combines several metrics such as bandwidth and service cost for handoff decision. In [2], the authors propose a policy-enabled handoff across a heterogeneous network environment using a cost function defined by different parameters such as available bandwidth, power consumption, and cost. The cost function is estimated for the available access networks and then used in the handoff decision of the mobile terminal (MT). Using a similar approach as in [2], a cost function-based vertical handoff decision algorithm for multi-services handoff was presented in [3]. The available network with lowest cost function value becomes the handoff target. However, only the available bandwidth and the RSS of the available networks were considered in the handoff decision performance comparisons. A tutorial on the different aspects of handoffs is presented in [4], but there was no optimization of the vertical handoff decision function.

The third category of handoff decision algorithm uses artificial intelligence techniques. In [5], Pahlavan *et al.* present a neural networks-based approach to detect signal decay and making handoff decision. In [6], Chan *et al.* propose a mobility management in a packet-oriented multi-segment using Mobile IP and fuzzy logic concepts. Fuzzy logic is applied to the handover initiation phase, and fuzzy logic and multiple objective decision making concepts are applied during the decision phase to select an optimum network. However, the handover management is for vertical handoff between different wide area networks.

In this paper, we present the design of a fuzzy logic based vertical handoff initiation scheme involving some key parameters, and the solution of the wireless network selection problem using a fuzzy multiple attribute decision making (FMADM) algorithm. In particular, an optimum access network is selected using a wireless network selection function defined on multiple attributes and optimized with a genetic algorithm. The remainder of the article is organised as follows. In the next section we provide the components of the vertical handoff decision algorithm. Then the fuzzy logic handoff initiation algorithm is presented in section 3. We explain the network selection scheme using a wireless network selection function in section 4. We explore the use of Genetic Algorithm (GA) as an optimizer of the network selection function in section 5. A performance evaluation of the vertical handoff decision scheme using the GA optimization is given in section 6. Finally, we conclude the article.

2. Overview of the Vertical Handoff Decision Algorithm (VHDA)

A vertical handoff decision in a next generation wireless network environment (including WWAN, WLAN, WiMAX and Digital Video Broadcasting) must solve the following problem: given a mobile user equipped with a contemporary multi-interfaced mobile device connected to an access network, determine whether a vertical handoff should be initiated and dynamically select the optimum network connection from the available access network technologies to continue with an existing service or begin another service. Hence, our proposed VHDA consists of two parts [7]:

(a) A Fuzzy Logic Handoff Initiation Algorithm which uses a fuzzy logic inference system (FIS) to process a multi-criteria vertical handoff initiation metrics, and

(b) An Access Network Selection Algorithm which applies a unique fuzzy multiple attribute decision making (FMADM) access network selection function to select a suitable wireless access network.

The vertical handoff decision function is triggered when any of the following events occur: (a) when the availability of a new attachment point or the unavailability of an old one is detected, and (b) when the user changes his/her profile, and thus altering the weights associated with the network selection attributes. Then the two-part algorithm is executed for the purpose of finding the optimum access network for the possible handoff of the already running services to the optimum target network.

We use a Mamdani FIS that is composed of the functional blocks [8]: a *fuzzifier,* a *fuzzy rule base,* a *database,* a *fuzzy inference engine,* and a *defuzzifier.*

The access network selection scheme involves decision making – a process of choosing among alternative courses of action for the purpose of attaining a goal or goals – in a fuzzy environment. It can be solved using FMADM which deals with the problem of choosing an alternative from a set of alternatives based on the classification of their imprecise attributes. The multiple attribute defined access network selection function selects the best access network that is optimized to the user's location, device conditions, service and application requirements, cost of service and throughput.

The block diagram shown in Figure 1 describes the vertical handoff decision algorithm.

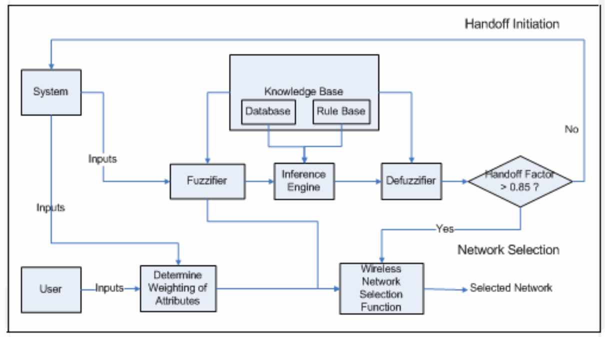

Figure 1. *Block diagram for Vertical Handoff Decision*

3. Handoff Initiation Algorithm

Vertical handoff is more complex because an MT can maintain connectivity to many overlaying networks that each offer varying QoS. Computing and choosing the correct time to initiate vertical handoff reduces subsequent handoffs, improves QoS, and limits the data signaling and rerouting that is inherent in the handoff process. To process vertical-related parameters, we use fuzzy logic, which uses approximate modes of reasoning to tolerate vague and imprecise data. Fuzzy logic inference systems express mapping rules in terms of linguistic language. A Mamdani FIS can be used for computing accurately the handoff factor which determines whether a handoff initiation is necessary between an UMTS and WLAN. We consider two handoff scenarios: handoff from UMTS to WLAN, and handoff from WLAN to UMTS.

3.1. *Handoff from UMTS to WLAN*

Suppose that a MT that is connected to a UMTS network detects a new WLAN. An FIS calculates the handoff factor which determines whether the MT should handoff to the WLAN. We use as input parameters the RSSI, data rate, network coverage area, and perceived QoS of the target WLAN network. The crisp values of the input parameters are fed into a fuzzifier in a Mamdani FIS, which transforms them into fuzzy sets by determining the degree to which they belong to each of the appropriate fuzzy sets via membership functions (MFs). Next, the fuzzy sets are fed into a fuzzy inference engine where a set of fuzzy IF-THEN rules is applied to obtain fuzzy decision sets. The output fuzzy decision sets are aggregated into a single fuzzy set and passed to the defuzzifier to be converted into a precise quantity, the handoff factor, which determines whether a handoff is necessary.

Each of the input parameters is assigned to one of three fuzzy sets; for example, the fuzzy set values for the RSSI consist of the linguistic terms: Strong, Medium, and Weak. These sets are mapped to corresponding Gaussian MFs. The universe of discourse for the fuzzy variable RSSI is defined from -78 dBm to -66 dBm. The fuzzy set “Strong” is defined from -72 dBm to -66 dBm with the maximum membership at -66 dBm. Similarly, the fuzzy set “Medium” for the RSSI is defined from -78 dBm to -66 dBm with the maximum membership at -72 dBm, and the fuzzy set “Weak” for the RSSI is defined from -78 dBm to -72 dBm with the maximum membership at -78 dBm. The universe of discourse for the variable Data Rate is defined from 0 Mbps to 56 Mbps, the universe of discourse for the variable Network Coverage is defined from 0 m to 300 m, and the universe of discourse for the variable Perceived QoS is defined from 0 to 10. The fuzzy set values for the output decision variable Handoff Factor are Higher, High, Medium, Low, and Lower. The universe of discourse for the variable Handoff Factor is defined from 0 to 1, with the maximum membership of the sets “Lower” and “Higher” at 0 and 1, respectively. The MF for the input fuzzy variable RSSI is shown in Figure 2.

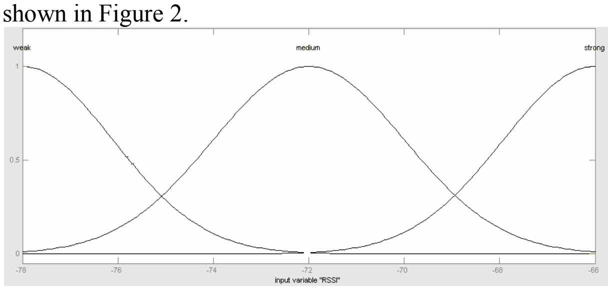

Figure 2. *Membership Function for RSSI*

Since there are four fuzzy input variables and three fuzzy sets for each fuzzy variable, the maximum possible number of rules in our rule base is $3^4 = 81$. The fuzzy rule base contains IF-THEN rules such as:

- IF RSSI is weak, and data rate is low, and network coverage area is bad, and perceived QoS is undesirable, THEN handoff factor is lower.
- IF RSSI is weak, and data rate is low, and network coverage area is medium, and perceived QoS is acceptable, THEN handoff factor is low.
- IF RSSI is strong, and data rate is high, and network coverage area is good, and perceived QoS is desirable, THEN handoff factor is higher.
- IF RSSI is strong, and data rate is medium, and network coverage area is medium, and perceived QoS is acceptable, THEN handoff factor is high.

The crisp handoff factor computed after defuzzification is used to determine when a handoff is required as follows:

if *handoff factor* > 0.85, then initiate handoff;
otherwise do nothing.

3.2. *Handoff from WLAN to UMTS*

Since the WLAN has a smaller coverage range, when the mobile user is moving out of a WLAN area, we need to have an accurate and timely handoff decision to maintain the connectivity before the loss of WLAN access to an AP that the MT is connected. The parameters that we are using in this directional handoff include the RSSI, data rate, network coverage area, and perceived QoS of the current WLAN network.

The design of the fuzzy inference system for this handoff scenario is similar to the design of the fuzzy inference system for the UMTS-to-WLAN handoff.
The fuzzy rule base contains IF-THEN rules such as:

- IF RSSI is weak, and data rate is low, and network coverage area is bad, and perceived QoS is undesirable, THEN handoff factor is higher.
- IF RSSI is strong, and data rate is high, and network coverage area is good, and perceived QoS is desirable, THEN handoff factor is lower.

4. Network Selection Algorithm

A suitable access network has to be selected once the handoff initiation algorithm indicates the need to handoff from the current access network to a target network. We formulate the network selection decision process as a MADM problem that deals with the evaluation of a set of alternative access networks using a multiple attribute wireless network selection function (WNSF) defined on a set of attributes. The WNSF is an objective function that measures the efficiency in utilising radio resources and the improvement in quality of service to mobile users gained by handing off to a particular network. It is defined for all alternative target access networks that cover the service area of a user. The network that provides the highest WNSF value is selected as the best network to handoff from the current access network according to the mobile terminal conditions, network conditions, service and application requirements, cost of service, and user preferences.

The WNSF is triggered when any of the following events occur: (a) a new service request is made; (b) a user changes his/her preferences; (c) the MT detects the availability of a new network; (d) there is severe signal degradation or complete signal loss of the current radio link. Parameters (attributes) used for the WNSF include the signal strength (S), network coverage area (A), data rate (D), service cost (C), reliability (R), security (E), battery power (P), mobile terminal velocity (V), and network latency (L). Input data from both the user and the system are required for the network selection algorithm, whose main purpose is to determine and select an optimum cellular/wireless access network for a particular high-quality service that can satisfy the following objectives [4, 9]:

- *Good signal strength*: Signal strength is used to indicate the availability of a network, and an available network can be detected if its signal strength is good.
- *Good network coverage*: Frequent handoffs incur delay and loss of packets. A network that provides a large coverage area enables mobile users to avoid frequent handoffs as they roam about.
- *Optimum data rate*: A network that can transfer signals at a high rate is preferred since a maximum data rate reduces service-delivery time for non-real-time services and enhances QoS for adaptive real-time services.
- *Low service cost*: The cost of services offered is a major consideration to users and may affect the user’s choice of access network and consequently handoff decision. A user may prefer to be

connected through the cheapest available access network in order to reduce service cost incurred.

- *High reliability*: A reliable network can be trusted to deliver a high level of performance.
- *Strong security*: As strong security enhances information integrity, a network with high encryption is preferred when the information exchanged is confidential.
- *Good mobile velocity*: Handing off to an embedded network in an overlaid architecture of heterogeneous networks is discouraged when traveling at a high speed since a handoff back to the original network will occur very shortly afterward when the mobile terminal leaves the smaller embedded network. High mobile users are connected to the upper layers and benefit from a greater coverage area.
- *Low battery power requirements*: Power consumption should be minimized since mobile devices have limited power capabilities. When the battery level decreases, handing off to a network with lower power requirements would be a better decision, and
- *Low network latency*: High network latency degrades applications and the transfer of information. A handoff algorithm should be fast so that the mobile device does not experience service degradation or interruption.

The optimum wireless network must satisfy:

$$\underset{\boldsymbol{u}}{\text{maximize}}\ f_i(\boldsymbol{u})$$

where $f_i(\boldsymbol{u})$ is the objective or fitness function evaluated for the network i and $\boldsymbol{u}$ is the vector of input parameters. The function f_i can be expressed as:

$$f_i(\boldsymbol{u}) = f(S_i, A_i, D_i, 1/C_i, R_i, E_i, V_i, 1/P_i, 1/L_i) = \sum_{i=1}^{6} w_X \cdot N_f(X_i) + \sum_{i=1}^{3} w_Y \cdot N_f(1/Y_i), \quad (1)$$

where $N_f(X)$ is the normalized function of the parameter X and w_X is the weight which indicates the importance of the parameter X, with $X_i = S_i, A_i, D_i, R_i, E_i, V_i$, and $Y_i = C_i, P_i, L_i$. Normalization is needed to ensure that the sum of the values in different units is meaningful. A simple way to obtain $N_f(X)$ is normalization with respect to the maximum or minimum values of the real-valued parameters. Therefore, we have

$$f_i(\boldsymbol{x}) = \sum_{i=1}^{6} w_X \cdot (X_i / X_{max}) + \sum_{i=1}^{3} w_Y \cdot (Y_{min} / Y_i) \quad (2)$$

A suitable normalized function of the parameter X is the fuzzy membership function μ_X. In order to develop this function, data from the system are fed into a fuzzifier to be converted into fuzzy sets. The values of the parameters are normalized between 0 and 1. Then a single membership function is defined such that $\mu_{Cj}(0) = 0$ and $\mu_{Cj}(1) = 1$ if the goal is to select a network with a high parameter X value; and such that $\mu_{Cj}(0) = 1$ and $\mu_{Cj}(1) = 0$ if the goal is to select a network with a low parameter X value.

Determination of Attribute Weights: Data from the system are fed into a fuzzifier to be converted into fuzzy sets. Suppose that $A = \{A_1, A_2, \dots, A_m\}$ is a set of m alternatives and $C = \{C_1, C_2, \dots, C_n\}$ is a set of n handoff decision criteria (attributes) that can be expressed as fuzzy sets in the space of alternatives. The criteria are rated on a scale of 0 to 1. The degree of membership of alternative A_j in the criterion C_i, denoted $\mu_{Ci}(A_j)$, is the degree to which alternative A_j satisfies this criterion. A decision maker judges the criteria in pairwise comparisons [10], and assigns the values $a_{ij} = 1/a_{ji}$ using the values $a_{ij} = 1/a_{ji}$ using the judgment scale proposed by Saaty: 1 – equally important; 3 – weakly more important; 5 – strongly more important; 7 – demonstrably more important; 9 – absolutely more important. The values in between {2, 4, 6, 8} represent compromise judgments. An n x n matrix B is constructed so that:

(1) $b_{ii} = 1$; (2) $b_{ij} = a_{ij}$, $i \neq j$; (3) $b_{ji} = 1/ b_{ij}$.

Using this matrix, the unit eigenvector, V, corresponding to the maximum eigenvalue, λ_{max}, of B is then determined by solving the equation:

$$B \cdot V = \lambda_{max} \cdot V \quad (3)$$

The values of V are scaled for use as factors in weighting the membership values of each attribute by a scalar division of V by the sum of values of V to obtain a weighting matrix W.

In general, the fitness value for the network i is thus given by

$$f_i(\boldsymbol{x}) = \sum_{j=1}^{n} w_j \cdot \mu_{Cj}(A_i), \quad (4)$$

where $\boldsymbol{x}$ is the vector of membership values.

The optimum wireless network is given by the optimization problem:

$$\max f_i(\boldsymbol{x}) = \max\{ \sum_{j=1}^{n} w_j \cdot \mu_{Cj}(A_i)\} \quad (5)$$

such that

$$0 \leq w_j \leq 1, \text{ and } \sum_{j=1}^{n} w_j = 1. \quad (6)$$

and

$$\{\mu_{Cj}(A_i)\}_{\min} \leq \mu_{Cj}(A_i) \leq \{\mu_{Cj}(A_i)\}_{\max} \quad (7)$$

The MT calculates the handoff initiation factor in the handoff initiation algorithm when the MT detects a new network or the user changes his/her preferences or the current radio link is about to drop. If the handoff initiation algorithm indicates the need for a handoff of the already running services from the current network to a target network, the mobile terminal then calculates the WNSF f_i for the current network and target networks. Vertical handoff takes place if the target network receives a higher f_i.

5. GA Optimization of the WNSF

This section explores the use of GAs for solving the optimization problem of maximizing the WNSF in equation (5). We do not use mathematical optimization (e.g., the MATLAB Optimization toolbox) because it always selects the upper bounds of a solution vector $\boldsymbol{x}$ for calculating the

optimum value of an objective function. The GA is a search method for solving both constrained and unconstrained optimization problems that is based on natural selection, the process that drives biological evolution [11]. Each solution is associated with a fitness measure that reflects how good it is, compared with other solutions in the population. The measure could be an objective function that is a mathematical model or a computer simulation. In the following, we assume a function minimization problem. Hence, a good solution is one that has low relative fitness.
We can use a GA to evolve solutions to a problem by the following steps:

Step 1: *Initialization*. The algorithm begins by creating a random initial population.
Step 2: The algorithm then creates a sequence of new populations. At each step, the algorithm uses the individuals in the current generation to create the next population. To create the new population, the algorithm iteratively performs the following steps:

a) *Evaluation*. The fitness values of the candidate solutions in the current population are evaluated.
b) *Selection*. The algorithm selects members, called parents, based on their fitness. The main idea of selection is to prefer better solutions to worse ones.
c) *Elitism*. Some of the individuals in the current population that have lower fitness are chosen as *elite* individuals and are passed to the next population as children.
d) *Crossover*. Crossover combines the vector entries or genes of two parents to form potentially better solutions (offspring) for the next generation. The crossover is controlled by the crossover probability p_c which is typically in the range [0.7 – 0.95]. Common crossover operators are *k-point crossover* and *uniform crossover*.
e) *Mutation*. Mutation applies random changes to one or more genes of an individual parent to form children. Mutation adds to the diversity of a population. It is performed with a low probability p_m typically in the range [0.01 – 0.2].
f) *Replacement*. The current population is replaced with the children created by selection, crossover, and mutation to form the next generation.

Step 3: The algorithm stops when one of the stopping criteria is met.

To tackle the optimization problem of maximizing the WNSF in equation (5) under the weights w_j by using a GA, we assume a function minimization problem. Hence, a good solution is one that has low relative fitness. Since our GA algorithm performs minimization of an objective function $f(\boldsymbol{x})$, maximization of the objective function in equation (5) is achieved by supplying the routine with minus $f_i(\boldsymbol{x})$ because the point at which the minimum of $-f_i(\boldsymbol{x})$ occurs is the same as the point at which the maximum of $f_i(\boldsymbol{x})$ occurs.
Therefore, we define the equivalent minimization problem:

$$\min(-f_i(\boldsymbol{x})) = \min\{-\sum_{j=1}^{n} w_j \cdot \mu_{Cj}(A_i)\} \tag{5'}$$

such that

$$0 \le w_j \le 1, \text{ and } \sum_{j=1}^{n} w_j = 1. \tag{6}$$

and

$$\{\mu_{Cj}(A_i)\}_{\min} \le \mu_{Cj}(A_i) \le \{\mu_{Cj}(A_i)\}_{\max} \tag{7}$$

We add the linear constraint:

$$\sum_{i=1}^{9} \mu_{Cj}(A_i) \le 9 \tag{8}$$

We use the stochastic universal selection rule that lays out a line in which each parent corresponds to a section of the line of length proportional to its scaled value. We use the options: population size $p_s = 20$, single-point crossover with $p_c = 0.8$, and mutation probability $p_m = 0.01$.

6. Performance Evaluation of Network Selection

The performance of the vertical handoff decision algorithm is tested within the framework of a scenario that simulates a typical day in the life of a mobile services technician, Mr. Alex. Mr. Alex commutes from his home to carry out service requests in the residences of several clients of his company. Three cellular networks (GPRS_1, UMTS_1, and UMTS_2) cover the whole simulation area. Two WLAN systems (WLAN_P_1 and WLAN_P_2) partly overlay the service area, and another one, WLAN_O, is in the Office of Mr. Alex. During the lunch break, Mr. Alex who has just started to download some multimedia files using the UMTS_1 network moves into the coverage areas of UMTS_1 and two public WLANs, and wishes to use a cheaper high data-rate wireless access network to complete downloading the files. In this case, the data rate attribute is of absolute importance (9) over all the other attributes; service cost is of demonstrated importance (7) over all attributes except the data rate; network latency is of very strong importance (6) than all attributes except the data rate and service cost; reliability is of strong importance (5) than all attributes except the data rate, service cost and network latency; and power requirement is weakly important (3) than the remaining attributes.

Evaluation: We first check to see whether a handoff should be initiated by calculating the handoff initiation factor. Suppose that the MT records the data values of RSSI (dBm), Data Rate (Mbps), Network Coverage Area (m), and Perceived QoS as {-67.2, 34.08, 249.7, 5.63} and {-67.01, 48.6, 180.6, 6.8} for WLAN_P_1 and WLAN_P_2 respectively. These set of values are fed into the FIS and we obtain the Handoff Factor values 0.874 and 0.875, thus indicating the need to hand off to any of the WLANs for the requested service.
The second stage of the VHDA is to compute the WNSF for all the available networks. The mobile terminal proceeds to gather data on all required parameters. The matrix $\boldsymbol{B}$ and weighting matrix $\boldsymbol{W}$ are indicated below:

$$\mathbf{B} = \begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \\ C_6 \\ C_7 \\ C_8 \\ C_9 \end{array} \begin{array}{c} \begin{array}{ccccccccc} C_1 & C_2 & C_3 & C_4 & C_5 & C_6 & C_7 & C_8 & C_9 \end{array} \\ \begin{pmatrix} 1 & 1/9 & 1 & 1/6 & 1/5 & 1 & 1/3 & 1 & 1/7 \\ 9 & 1 & 9 & 9 & 9 & 9 & 9 & 9 & 9 \\ 1 & 1/9 & 1 & 1/6 & 1/5 & 1 & 1/3 & 1 & 1/7 \\ 6 & 1/9 & 6 & 1 & 6 & 6 & 6 & 6 & 1/7 \\ 5 & 1/9 & 5 & 1/6 & 1 & 5 & 5 & 5 & 1/7 \\ 1 & 1/9 & 1 & 1/6 & 1/5 & 1 & 1/3 & 1 & 1/7 \\ 3 & 1/9 & 3 & 1/6 & 1/5 & 3 & 1 & 3 & 1/7 \\ 1 & 1/9 & 1 & 1/6 & 1/5 & 1 & 1/3 & 1 & 1/7 \\ 7 & 1/9 & 7 & 7 & 7 & 7 & 7 & 7 & 1 \end{pmatrix} \end{array} \Rightarrow \mathbf{V} = \begin{pmatrix} -0.0351 \\ -0.8750 \\ -0.0351 \\ -0.2183 \\ -0.1246 \\ -0.0351 \\ -0.0651 \\ -0.0351 \\ -0.4024 \end{pmatrix} \Rightarrow \mathbf{W} = \begin{pmatrix} 0.0192 \\ 0.4793 \\ 0.0192 \\ 0.1196 \\ 0.0682 \\ 0.0192 \\ 0.0357 \\ 0.0192 \\ 0.2204 \end{pmatrix} \quad (9)$$

The attribute weights and the membership values (lower bound, upper bound) of the three available networks for the attributes are summarized Table 1 below.

Table 1. *Parameters for Performance Evaluation*

Criteria		w_j	Membership Values (lb, ub)		
			UMTS_1	WLAN_1	WLAN_2
RSSI	C_1	0.0192	0.5, 0.9	0.5, 0.9	0.5, 0.9
Data Rate	C_2	0.4793	0.05, 0.1	0.2, 0.7	0.2, 0.9
Network Coverage	C_3	0.0192	0.1, 0.6	0.05, 0.2	0.05, 0.1
Network Latency	C_4	0.1196	0.4, 0.6	0.5, 0.8	0.5, 0.85
Reliability	C_5	0.0682	0.7, 0.9	0.7, 0.8	0.7, 0.8
Security	C_6	0.0192	0.8, 0.9	0.5, 0.65	0.5, 0.6
Power Requirement	C_7	0.0357	0.7, 0.8	0.5, 0.6	0.5, 0.6
Mobile Velocity	C_8	0.0192	0.01, 0.9	0.005, 0.01	0.005, 0.01
Service Cost	C_9	0.2204	0.5, 0.6	0.8, 0.9	0.8, 0.9

The solutions obtained using the MATLAB GA toolbox are summarized in Table 2. We also show in Table 3 solutions obtained using the MATLAB Optimization toolbox.

Table 2. *Optimization Values*

Criteria		w_j	Optimal Membership Values		
			UMTS_1	WLAN_1	WLAN_2
RSSI	C_1	0.0192	0.8875	0.9000	0.9000
Data Rate	C_2	0.4793	0.0978	0.7000	0.9000
Network Coverage	C_3	0.0192	0.5386	0.2000	0.1000
Network Latency	C_4	0.1196	0.5971	0.8000	0.8438
Reliability	C_5	0.0682	0.9000	0.8000	0.7897
Security	C_6	0.0192	0.8890	0.6476	0.6000
Power Requirement	C_7	0.0357	0.7997	0.5938	0.5991
Mobile Velocity	C_8	0.0192	0.8873	0.0100	0.0100
Service Cost	C_9	0.2204	0.5916	0.8859	0.9000
Optimum WNSF Value			-0.4001	-0.7360	-0.8368

Table 3. *Optimization Values using Mathematical Optimization*

Criteria		w_j	Optimal Membership Values		
			UMTS_1	WLAN_1	WLAN_2
RSSI	C_1	0.0192	0.9000	0.9000	0.9000
Data Rate	C_2	0.4793	0.1000	0.7000	0.9000
Network Coverage	C_3	0.0192	0.6000	0.2000	0.1000
Network Latency	C_4	0.1196	0.6000	0.8000	0.8500
Reliability	C_5	0.0682	0.9000	0.8000	0.8000
Security	C_6	0.0192	0.9000	0.6500	0.6000
Power Requirement	C_7	0.0357	0.8000	0.6000	0.6000
Mobile Velocity	C_8	0.0192	0.9000	0.0100	0.0100
Service Cost	C_9	0.2204	0.6000	0.9000	0.9000
Optimum WNSF Value			-0.4052	-0.7393	-0.8383

The results in Table 3 confirms the statement we made at the beginning of section 5 that mathematical optimization always selects the upper bounds of a solution vector $\boldsymbol{x}$ for calculating the optimum value of an objective function. The GA provides a list of the optimum WNSF values and optimum membership function values. Therefore, in our opinion the GA is better suited for solving the wireless network selection problem.

Based on the optimum values of the WNSF for the three access networks in Table 2, the WLAN_P_2 provides the optimal positive result and it will be suitable to handoff from the UMTS_1 to the WLAN_P_2 to complete downloading the multimedia files.

7. CONCLUSION

This paper has presented the design of an adaptive multi-attribute vertical handoff decision algorithm that is both cost-effective and highly useful. We demonstrated the use of fuzzy logic concepts to combine multiple metrics from the network to obtain useful handoff initiation schemes and used a genetic algorithm to optimise the selection of suitable access networks with a fuzzy multiple attribute defined wireless network selection function.

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