An Optimum Vertical Handoff Decision Algorithm for UMTS-WiMAX

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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 mobile users to seamlessly switch network access and experience uninterrupted service continuity anywhere and anytime. 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 metropolitan area networks (WMANs) 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, called beyond third generation (B3G) or fourth generation (4G), 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, IEEE 802.16 or WiMAX (World-wide Interoperability for Microwave Access) can be used as a complementary access technology to third-generation (3G) cellular WWAN such as Universal Mobile Telecommunications System (UMTS) where users are always connected to access dynamic and powerful applications such as the Internet, voice and video. While 3G systems are designed primarily for mobile voice and data users, WiMAX systems are optimized to provide high-rate wireless connectivity for services and applications that require quality of service (QoS) guarantees. In addition, a mobile WiMAX overlay to a 3G wireless system can provide mobile operators with low cost additional capacity in spectrum and infrastructure limited regions, new real-time high speed data services, a proven and available path to an all-IP future and a seamless end user experience across services. Similarly, WiMAX and IEEE 802.11*x* wireless local area network (WLAN)/Wireless Fidelity (WiFi) are complementary and are expected to be incorporated in dual-mode chipsets in mobile devices, as WiMAX provides wider coverage, low latency and advanced security while WiFi is better suited for high-throughput, indoor LAN applications. The integration and interoperation of these heterogeneous networks requires the design of intelligent vertical handoff decision algorithms (VHDAs) to enable seamless 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.

A number of 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 uses a cost function as a measurement of the benefit obtained by handing off to a particular network. 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.

The third category of handoff decision algorithm uses multiple criteria (attributes and/or objectives) for handover decision. An integrated network selection algorithm using two multiple attribute decision making (MADM) methods, Analytic Hierarchy Process (AHP) and Grey Relational Analysis (GRA), is presented in [4] with a number of parameters.

Another 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 VHDA 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 describe vertical handoff in the evolving next generation wireless system. We provide the components of the vertical handoff decision algorithm in section 3. Then the fuzzy logic handoff initiation algorithm is presented in section 4. We explain the network selection scheme using a wireless network selection function in section 5. The use of Genetic Algorithm (GA) as an optimizer of the network selection function is explored in section 6. A performance evaluation of the VHDA using the GA optimization is given in section 7. Finally, we conclude the article.

2. VERTICAL HANDOFFS IN 4G NETWORKS

The next generation of cellular/wireless communications (B3G or 4G) is expected to be purely IP-based and consist of heterogeneous access networks and a converged packet-based core network. The evolving 4G network will seamlessly integrate various types of wireless access networks including the following:

- Wireless personal area networks (WPANs), such as ultra wideband and Bluetooth, that provide range-limited ad hoc wireless service to users;
- Wireless local area networks (WLANs), such as IEEE 802.11x (Wi-Fi), that provide high-throughput connections for stationary/quasi-stationary wireless users without the costly infrastructure of 3G;
- Wireless metropolitan area networks (WMANs), such as IEEE 802.16 (WiMAX), that provide wireless services requiring high-rate transmission and strict quality of service requirements in both indoor and outdoor environments;
- Wireless wide area networks (WWANs), such as Universal Mobile Telecommunications System (UMTS), that provide long-range cellular voice and limited-throughput data services to users with high mobility; and
- Regional/global area networks (e.g., radio and television broadcasting, satellite communications).

These heterogeneous wireless access networks typically differ in terms of signal strength, coverage, data rate, latency, and loss rate. Therefore, each of them is practically designed to support a different set of specific services and devices. However, these networks will coexist and use a common IP core to offer services ranging from low-data-rate non-real-time applications to high-speed real-time multimedia applications to end users since the networks have characteristics that complement each other. The limitations of these complementary wireless access networks can be overcome through the integration of the different technologies into a single unified platform (that is, a 4G system) that will empower mobile users to be connected to the 4G system using the best available access network that suits their needs. For example, given the complementary characteristics of WiMAX (faster data rate, low latency and low cost spectrum) and UMTS (slower data rate and long-range access), it is compelling to combine them to provide ubiquitous broadband wireless access for users equipped with multimode terminals. Users can then access services including real-time network storage services, mobile video and audio streaming, videoconferencing, gaming, broadcasting and multicasting, and a range of vertical applications such as inventory tracking, public safety, surveillance, fleet management, and educational services. Different services have different requirements: some services demand high bandwidths, some demand low latency, and others demand high processing power in the terminal. This means that these services can only be provided by using a converged next generation multi-access network.

Cells of the heterogeneous access networks are overlaid within each other to form larger wireless overlay networks (WONs). A WON has a hierarchical structure with different levels [7]. Higher levels in the hierarchy cover a large area but provide lower bandwidth whilst lower levels are comprised of high bandwidth wireless cells that provide a smaller coverage area. WONs solve the problem of providing network connectivity to a large number of mobile users in an efficient and scalable way. The integration and internetworking of the heterogeneous access networks in the 4G system requires the design of intelligent handoff management schemes to enable mobile users to switch network access and experience uninterrupted service continuity anywhere and anytime.

Handoffs can be classified using the network type involved into horizontal (intra-system) and vertical (inter-system) cases as an MT moves within or between different overlays of a WON. *Vertical handoff* or *inter-system handoff* is a handoff that occurs between the different points of attachment belonging to different network technologies.

The vertical handoff process may be divided into three phases [8]: network discovery, handoff decision, and handoff execution. Handoff decision is the ability to decide when to perform the vertical handoff and determine the best handoff candidate access network.

Handoff metrics are used to indicate whether or not a handoff is needed. In traditional horizontal handoffs, only the RSS and channel availability are considered for handoff decisions. However, the RSS alone cannot be used for vertical handoff decisions because of the overlay nature of heterogeneous wireless networks and the different characteristics of the networks involved. In order to perform intelligent handoff decisions in the next generation heterogeneous wireless environment and provide seamless vertical handoff, the following metrics are suggested [3, 8, 9]:

(a) *Network conditions*. Network-related parameters such as traffic, available bandwidth, network latency, and congestion (packet loss) may need to be considered for effective network usage.

(b) *System performance*. To guarantee the system performance, a variety of parameters can be employed in the handoff decision, such as the RSS, channel propagation characteristics, path loss, interchannel interference, signal-to-noise ratio (SNR), and the bit error rate (BER).

(c) *Application types*. Different types of services such as voice, data and multimedia applications require different levels of data rate, network latency, reliability, and security.

(d) *Mobile terminal conditions*. Mobile terminal conditions include the screen size, portability/weight, performance (processing power, memory, and storage space), bandwidth requirements, networks supported, and dynamic factors such as velocity, moving pattern, and location information.

(e) *Security*. The ability of a network to resist attack from software virus, intruders and hackers, and to protect network infrastructure, services and confidentiality and integrity of customers data is a major issue and could sometimes be a decisive factor in the choice of a network. The most significant source of risks in wireless networks is that the technology's underlying communications medium, the airwave, is open to intruders. A network with high encryption is preferred when the information exchanged is confidential.

(f) *User preferences*. User preferences (such as preferred network operator, preferred technology type, preferred maximum cost) can be used to cater special requests for one type of network over another. For instance, if the target network to which a mobile node performs a handoff does not offer high security, the user may still decide to use the current network. Depending upon coverage, a user may wish to use a secure and expensive access network (such as UMTS) for his official e-mail traffic but may still opt for a cheaper network (for example, WiMAX) to access Web information.

(g) *Cost of Service*. The cost of services offered is a major consideration to users since different network operators and service providers may employ different billing plans and strategies that may affect the user's choice of access network and consequently handoff decision.

The work presented in this paper proposes the design of a VHDA that uses several of these metrics.

3. OVERVIEW OF THE VERTICAL HANDOFF DECISION ALGORITHM (VHDA)

A vertical handoff decision in a next generation wireless network environment (including WWAN, WLAN, WMAN, 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 [10]:

(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 blocks [11]:

- a *fuzzifier* which transforms the crisp inputs into degrees of match with linguistic values;
- a *fuzzy rule base* which contains a number of fuzzy IF-THEN rules;
- a *database* which defines the membership functions of the fuzzy sets used in the fuzzy rules;
- a *fuzzy inference engine* which performs the inference operations on the fuzzy rules; and

- a *defuzzifier* which transforms the fuzzy results of the inference into a crisp output.

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 (ANSF) selects the best access network that is optimized to the user's location, device conditions, service and application requirements, cost of service and throughput. This paper proposes to use a GA to optimize the ANSF with the goal of selecting the optimal access network.

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

4. 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 handoff-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 WiMAX. We consider two handoff scenarios: handoff from UMTS to WiMAX, and handoff from WiMAX to UMTS.

4.1. *Handoff from UMTS to WiMAX*

Suppose that an MT that is connected to a UMTS network detects a new WiMAX. An FIS calculates the handoff factor which determines whether the MT should handoff to the WiMAX. We use as input parameters the RSSI, data rate, network coverage area, and perceived QoS of the target WiMAX 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 60 Mbps, the universe of discourse for the variable Network Coverage is defined from 0 m to 50 Km, 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.

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:

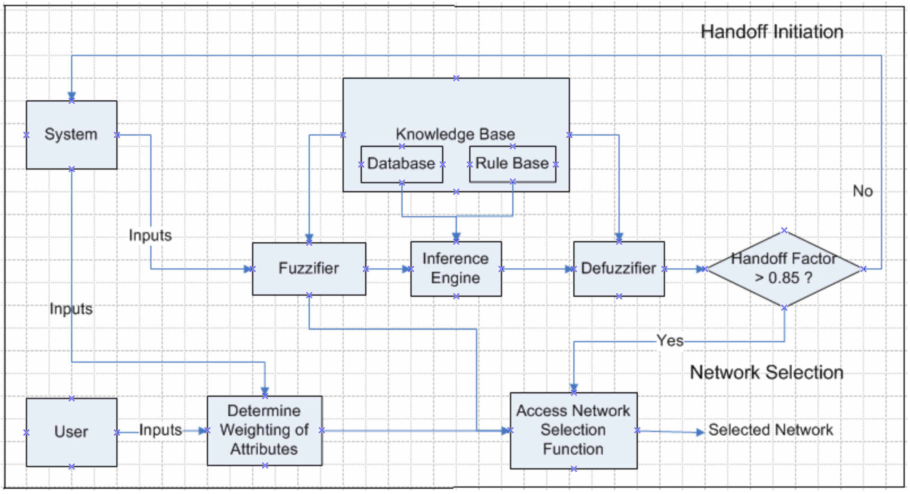

Figure 1. *Block diagram for Vertical Handoff Decision*

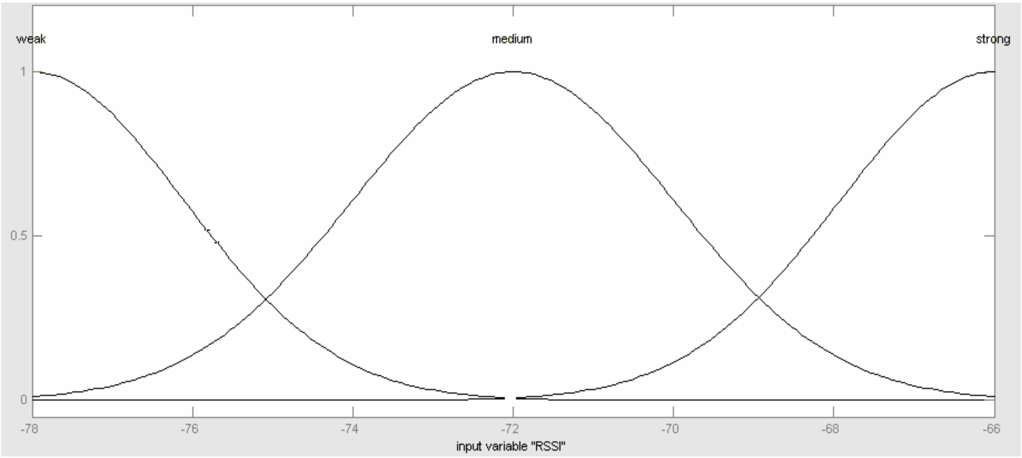

Figure 2. *Membership Function for RSSI*

- 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.

4.2. *Handoff from WiMAX to UMTS*

The parameters that we are using in this directional handoff include the RSSI, data rate, network coverage area, and perceived QoS of the current WiMAX 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-WiMAX 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.

5. 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 access network selection function (ANSF) defined on a set of attributes. The ANSF 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 ANSF 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 ANSF 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 ANSF 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:

- *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 is not error prone and so 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 access 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:

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

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

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

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 [12], and assigns 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:

$$B \cdot V = \lambda_{max} \cdot V \tag{3}$$

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

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

where $\boldsymbol{x}$ is the vector of membership function values.
The optimum wireless network is given by the combinatorial optimization problem involving the vector of membership function values of the corresponding input parameters:

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

such that

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

and

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

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 ANSF f_i for the current network and target networks. Vertical handoff takes place if the target network receives a higher f_i.

6. GA OPTIMIZATION OF THE ANSF

This section explores the use of GAs for solving the optimization problem of maximizing the ANSF in equation (5). Mathematical optimization (e.g., the MATLAB Optimization toolbox) is not suitable for solving the access network selection problem because it always selects the upper bounds of a solution vector $\boldsymbol{x}$ for calculating the optimum value of an objective function. Instead, a metaheuristic (such as the GA, simulated annealing, evolutionary computation, tabu search, ant colony optimization) would be suitable. The GA is a search method for solving optimization problems that is based on natural selection [13]. 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, and many selection procedures have been proposed to accomplish this including roulette-wheel selection, ranking selection, stochastic universal selection, and tournament selection.
c) *Elitism.* Some of the individuals in the current population that have the best fitness are chosen as *elite* individuals and are passed to the next population as children. Elitism allows the solutions to improve over time.
d) *Crossover (Recombination).* 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]. That is, a uniform random number, r, is generated and if $r \le p_c$, the two randomly selected parents undergo recombination. 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 ANSF in equation (5) 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:

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

7. PERFORMANCE EVALUATION OF NETWORK SELECTION

We test the performance of the VHDA in a scenario that simulates a working day in the life of a scientist, Dr. Blay, who commutes from his suburban home to his office in the metropolitan area of the city. Dr. Blay’s house is in the coverage area of three cellular networks (GPRS_1, UMTS_1, and UMTS_2), while the metro area is served by three cellular networks (GPRS_1, UMTS_1, and UMTS_2), and three WMAN networks (WiMAX_1 (IEEE 802.16d), WiMAX_2 (IEEE 802.16e), and WiMAX_3 (IEEE 802.16e)).

Use Cases:

Case 1: Before leaving home for work, Dr. Blay decides to check his official e-mail for any important messages using his 4G MT. The user profile indicates that security is of absolute importance (9) than the other attributes whilst reliability is of demonstrated importance (7) over all attributes except the security, data rate is strongly important (5) than all other attributes except security and reliability, and the network coverage is weakly important (3) than all other attributes except security, reliability and data rate.

Case 2: As Dr. Blay drives along the highway, he decides to download a large file containing a scientific report using the UMTS_2 network. After encountering traffic jam in the metro, he changes his user profile to complete downloading and start reading the report. 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 mobile terminal velocity is weakly important (3) than the remaining attributes.

Evaluation:

Case 1: This case involves only an access network selection as the ANSF is triggered by a new service request. The matrix ***B*** and weighting matrix ***W*** are indicated below:

$$\boldsymbol{B}=\begin{array}{c|ccccccccc|} & C_1 & C_2 & C_3 & C_4 & C_5 & C_6 & C_7 & C_8 & C_9 \\ \hline C_1 & 1 & 1/5 & 1/3 & 1 & 1/7 & 1/9 & 1 & 1 & 1 \\ C_2 & 5 & 1 & 5 & 5 & 1/7 & 1/9 & 5 & 5 & 5 \\ C_3 & 3 & 1/5 & 1 & 3 & 1/7 & 1/9 & 3 & 3 & 3 \\ C_4 & 1 & 1/5 & 1/3 & 1 & 1/7 & 1/9 & 1 & 1 & 1 \\ C_5 & 7 & 7 & 7 & 7 & 1 & 1/9 & 7 & 7 & 7 \\ C_6 & 9 & 9 & 9 & 9 & 9 & 1 & 9 & 9 & 9 \\ C_7 & 1 & 1/5 & 1/3 & 1 & 1/7 & 1/9 & 1 & 1 & 1 \\ C_8 & 1 & 1/5 & 1/3 & 1 & 1/7 & 1/9 & 1 & 1 & 1 \\ C_9 & 1 & 1/5 & 1/3 & 1 & 1/7 & 1/9 & 1 & 1 & 1 \end{array} \Rightarrow \boldsymbol{V}=\begin{pmatrix} 0.0439 \\ 0.1889 \\ 0.0935 \\ 0.0439 \\ 0.3967 \\ 0.8880 \\ 0.0439 \\ 0.0439 \\ 0.0439 \end{pmatrix} \Rightarrow \boldsymbol{W}=\begin{pmatrix} 0.0246 \\ 0.1057 \\ 0.0523 \\ 0.0246 \\ 0.2220 \\ 0.4970 \\ 0.0246 \\ 0.0246 \\ 0.0246 \end{pmatrix} \quad (9)$$

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

We performed the GA optimization experiments by using 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, and settled on the options: population size p_s = 20, elite count = 2, single-point crossover with p_c = 0.8, and mutation probability p_m = 0.01.

The solutions obtained using the MATLAB GA toolbox are summarized in Table 2.

It is best to select the UMTS_2 to check the e-mail since the UMTS_2 provides the optimal positive ANSF value.

Case 2: 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 (Km), and Perceived QoS as {-67.2, 56.1, 36.7, 5.63}, {-67.3, 48.8, 47.9, 6.5} and {-67.01, 48.6, 47.6, 6.8} for WiMAX_1, WiMAX_2, and WiMAX_3 respectively. These set of values are fed into the FIS and we obtain the Handoff Factor values 0.874, 0.875 and 0.876, thus indicating the need to hand off to any of the WMANs for the requested service.

Table 1. *Parameters for Performance Evaluation*

Criteria		w_j	Membership Values (*lb*, *ub*)		
			GPRS_1	UMTS_1	UMTS_2
RSSI	C_1	0.0246	0.5, 0.9	0.5, 0.9	0.5, 0.9
Data Rate	C_2	0.1057	0.03, 0.05	0.05, 0.1	0.05, 0.1
Network Coverage	C_3	0.0523	0.3, 0.9	0.1, 0.5	0.1, 0.6
Network Latency	C_4	0.0246	0.3, 0.5	0.4, 0.6	0.4, 0.6
Reliability	C_5	0.2220	0.7, 0.85	0.7, 0.9	0.7, 0.9
Security	C_6	0.4970	0.75, 0.85	0.8, 0.9	0.8, 0.9
Power Requirement	C_7	0.0246	0.6, 0.7	0.7, 0.8	0.7, 0.8
Mobile Velocity	C_8	0.0246	0.01, 0.8	0.01, 0.9	0.01, 0.85
Service Cost	C_9	0.0246	0.5, 0.7	0.5, 0.6	0.5, 0.65

Table 2. *Optimization Values for Case 1*

Criteria		w_j	Optimal Membership Values		
			GPRS_1	UMTS_1	UMTS_2
RSSI	C_1	0.0246	0.9000	0.8819	0.9000
Data Rate	C_2	0.1057	0.0456	0.0964	0.0941
Network Coverage	C_3	0.0523	0.9000	0.5000	0.5957
Network Latency	C_4	0.0246	0.3964	0.5975	0.5581
Reliability	C_5	0.2220	0.8494	0.9000	0.9000
Security	C_6	0.4970	0.8500	0.9000	0.9000
Power Requirement	C_7	0.0246	0.7000	0.7675	0.7532
Mobile Velocity	C_8	0.0246	0.8000	0.9000	0.8500
Service Cost	C_9	0.0246	0.6140	0.5843	0.6500
Optimum ANSF Value			-0.7468	-0,7752	-0.7795

The second stage of the VHDA is to compute the ANSF for all the available networks. The mobile terminal proceeds to gather data on all required parameters. After calculating the matrix ***B*** and weighting matrix ***W***, we summarise the attribute weights and the membership values (lower bound, upper bound) of the three available networks for the attributes in Table 3.

The solutions obtained using MATLAB and the GA toolbox are summarized in Table 4. Also shown in Table 5 for comparison are solutions obtained using the MATLAB Optimization toolbox.

The results in Table 5 show that mathematical optimization always selects the upper bounds of a solution vector ***x*** for calculating the optimum value of an objective function, while the results in Table 4 show that a GA provides a list of the optimum ANSF values and the optimum membership function values. Consequently, the GA (or another suitable metaheuristic) is better suited for solving the access network selection problem.

Therefore, based on the results of the optimum values of the ANSF for the access networks in Table 4, the WiMAX_2 provides the optimal positive result and it will be suitable to handoff from the UMTS_2 to the WiMAX_2 to complete

Table 3. *Parameters for Performance Evaluation (Case 2)*

Criteria		w_j	Membership Values (lb, ub)			
			UMTS_2	WiMAX_1	WiMAX_2	WiMAX_3
RSSI	C_1	0.0192	0.5, 0.9	0.5, 0.9	0.5, 0.9	0.5, 0.9
Data Rate	C_2	0.4793	0.05, 0.1	0.2, 0.95	0.2, 0.9	0.2, 0.9
Network Coverage	C_3	0.0192	0.1, 0.45	0.2, 0.85	0.2, 0.92	0.2, 0.95
Network Latency	C_4	0.1196	0.4, 0.6	0.5, 0.9	0.5, 0.9	0.5, 0.9
Reliability	C_5	0.0682	0.7, 0.9	0.7, 0.9	0.7, 0.9	0.7, 0.9
Security	C_6	0.0192	0.8, 0.9	0.8, 0.9	0.8, 0.9	0.8, 0.9
Power Requirement	C_7	0.0192	0.7, 0.8	0.6, 0.75	0.6, 0.75	0.6, 0.75
Mobile Velocity	C_8	0.0357	0.01, 0.9	0.005, 0.1	0.01, 0.5	0.01, 0.5
Service Cost	C_9	0.2204	0.5, 0.6	0.6, 0.8	0.6, 0.83	0.6, 0.85

Table 4. *Optimization Values for Case 2*

Criteria		w_j	Optimal Membership Values			
			UMTS_2	WiMAX_1	WiMAX_2	WiMAX_3
RSSI	C_1	0.0192	0.8815	0.8750	0.8487	0.9000
Data Rate	C_2	0.4793	0.1000	0.9500	0.9000	0.8892
Network Coverage	C_3	0.0192	0.4500	0.8047	0.9148	0.9344
Network Latency	C_4	0.1196	0.6000	0.8925	0.8962	0.9000
Reliability	C_5	0.0682	0.9000	0.8915	0.8945	0.9000
Security	C_6	0.0192	0.8996	0.8664	0.8812	0.9000
Power Requirement	C_7	0.0192	0.7752	0.7500	0.7484	0.7432
Mobile Velocity	C_8	0.0357	0.7566	0.0675	0.5000	0.4965
Service Cost	C_9	0.2204	0.6000	0.7980	0.8300	0.8084
Optimal ANSF Value			-0.3980	-0.8644	-0.8655	-0.8579

Table 5. *Optimization Values for Case 2 using Mathematical Optimization*

Criteria		w_j	Optimal Membership Values			
			UMTS_2	WiMAX_1	WiMAX_2	WiMAX_3
RSSI	C_1	0.0192	0.9000	0.9000	0.9000	0.9000
Data Rate	C_2	0.4793	0.1000	0.9500	0.9000	0.9000
Network Coverage	C_3	0.0192	0.4500	0.8500	0.9200	0.9500
Network Latency	C_4	0.1196	0.6000	0.9000	0.9000	0.9000
Reliability	C_5	0.0682	0.9000	0.9000	0.9000	0.9000
Security	C_6	0.0192	0.9000	0.9000	0.9000	0.9000
Power Requirement	C_7	0.0192	0.8000	0.7500	0.7500	0.7500
Mobile Velocity	C_8	0.0357	0.9000	0.1000	0.5000	0.5000
Service Cost	C_9	0.2204	0.6000	0.8000	0.8300	0.8500
Optimal ANSF Value			-0.4040	-0.8695	-0.8678	-0.8728

downloading the multimedia file.

8. CONCLUSION

A main challenge for seamless mobility in the evolving multi-access next generation wireless communication system is the design of intelligent handoff management schemes. 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. We are doing further work to compare the genetic algorithm optimizations with simulated annealing optimizations.

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