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Vertical Handoffs in Fourth Generation Wireless Networks

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Abstract:- This book chapter presents a tutorial on vertical handoff methods in the evolving 4G wireless communication networks. Integration architectures for various wireless access networks are described. Then handoff classification, desirable handoff features, the handoff process, and multimode mobile terminals are discussed. A section is devoted to some recently proposed vertical handoff techniques. We propose a vertical handoff decision algorithm that determines whether a vertical handoff should be initiated and dynamically selects the optimum network connection from the available access network technologies to continue with an existing service or begin another service.

Index Terms - Heterogeneous Wireless Access Networks, Vertical Handoffs in 4G Wireless Networks, Recently Proposed Vertical Handoff Techniques and Performance Evaluation of Network Selection.

I. INTRODUCTION

The next generation of mobile/wireless communication systems, called beyond third generation (B3G) or fourth generation (4G), is expected to include heterogeneous wireless networks that will coexist 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. The evolution of 4G networks will increase the growth in development of a diverse range of high-speed multimedia services, such as location-based services, mobile entertainment services, e-commerce, and digital multimedia broadcasting. The design and development of 4G wireless networks will allow seamless intersystem roaming across heterogeneous wireless access networks and packet-switched wireless communications. A major challenge of the 4G wireless networks is seamless vertical handoff or inter-system handoff across the multi-service heterogeneous wireless access networks as vertical handoff is the basis for providing continuous wireless services to mobile users roaming across the heterogeneous wireless networks. Multimode mobile terminals will have to seamlessly roam among the various access networks to maintain network connectivity since no single network can provide ubiquitous coverage and high quality-of-service (QoS) provisioning of applications. Users will increasingly expect all their services to be accessible anywhere and from any device.

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A key issue that aids in providing seamless vertical handoff is handoff decision, that is, the ability to correctly decide at any given time whether or not to carry out vertical handoff and determine the best handoff candidate access network. A vertical handoff decision algorithm must be able to decide on the need to timely and reliably initiate a handoff, and determine and select the appropriate access network(s) when a user can be reached through several access networks. In order to take an intelligent and better decision as to when to reliably initiate a handoff and which wireless access network should be chosen in a heterogeneous wireless system and make it possible to deliver each service via the network that is the most suitable for it, the following metrics have been proposed for use in

addition to the received signal strength indication (RSSI) measurements: service type, network conditions (such as data rate and network access delay), system performance, mobile node capabilities, user preferences, and cost of service.

II. HETEROGENEOUS WIRELESS ACESS NETWORKS

The next generation of cellular/wireless communications (B3G or 4G) is expected to be purely IP-based and consist of access networks and a converged 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 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 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 WLAN (faster data rate and short-distance access) and UMTS (slower data rate and long-range access), it is compelling to combine them to provide ubiquitous broadband wireless access.

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 [1]. 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 wireless access networks in the 4G system requires the design of intelligent handoff and location management schemes to enable mobile users to switch network access and experience uninterrupted service continuity anywhere and anytime.

Several approaches have been proposed for interworking between wireless broadband networks such as WLAN and 3G cellular networks such as UMTS. There are two candidate integration architectures for interworking between WLAN and 3G: tightly coupled and loosely coupled interworking [2]. In the tightly coupled approach, the WLAN is connected to the UMTS core network in the same manner as any other radio access network (RAN) such as UMTS terrestrial RAN. With loose coupling the WLAN is deployed as an access network complementary to the UMTS network by connecting the two networks through the Internet. The mobility management for the tight coupling scheme uses the existing mobility management solutions for cellular networks, whilst the mobility management for the loose coupling scheme is based on mobile IP (MIP).

The 3G Partnership Project (3GPP) has defined WLAN/3G interworking in a series of 6 scenarios. These scenarios describe an increasing level of integration between the two systems: (1) Common Billing and Customer Care, with the goal of providing a single bill and customer care to the subscriber; (2) 3G-based Access Control and Charging, where the 3G provides the authentication, authorization, and accounting (AAA) procedures to WLAN users with an equal security level; (3) Access to 3G Packet-Switched (PS) Services, to allow an operator to extend these services to subscribers in a WLAN environment; (4) Access to 3G PS Services with Service Continuity, with the goal that the services of scenario 3 would survive a change of access across the 3G and WLAN systems; (5) Access to 3G PS-Services with Seamless Service Continuity, to provide seamless service continuity between the 3G and WLAN access networks; Access to 3G Circuit-Switched (CS) Services with Seamless Mobility, to allow access to 3G CS services from the WLAN system with seamless mobility

III. VERTICAL HANDOFFS IN 4G WIRELESS NETWORKS

Handoff Classification

Mobility management is a main challenge in the evolving multi-service 4G heterogeneous network. It consists of two components: location management and handoff management. Location management tracks and locates the mobile terminal (MT) for successful information delivery. Handoff management maintains the active connections for roaming MTs as they change their point of attachment to the network.

Handoff is the mechanism by which an ongoing connection between an MT and a correspondent terminal is transferred from one point of attachment to the network to another. That is, handoff is the mechanism by which an MT keeps its connection active when it migrates from the coverage area of one network attachment point to another. In cellular voice telephony and cellular data networks, such a point of attachment is called an access point (AP), and in wireless local area networks, it is called a base station (BS).

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.

Horizontal handoff or intra-system handoff is a handoff that occurs between the APs or BSs of the same network technology. In other words, a horizontal handoff occurs between the homogeneous cells of a wireless access system. For example, the changeover of signal transmission of an MT from an IEEE 802.11g AP to a geographically neighbouring IEEE 802.11g AP is a horizontal handoff process. The network automatically exchanges the coverage responsibility from one point of attachment to another every time an MT crosses from one cell into a neighbouring cell supporting the same network technology. Horizontal handoffs are mandatory since the MT cannot continue its communication without performing it.

Vertical handoff or inter-system handoff is a handoff that occurs between the different points of attachment belonging to different network technologies. For example, the changeover of signal transmission from an IEEE 802.11g AP to the BS of an overlaid cellular network is a vertical handoff process. Thus, vertical handoffs are implemented across heterogeneous cells of wireless access systems, which differ in several aspects such as received signal strength (RSS) bandwidth, data rate, coverage area, and frequency of operation. The implementation of vertical handoffs is more challenging as compared to horizontal handoffs because of the different characteristics of the networks involved.

In general, there are two types of vertical handoff: upward and downward. An upward vertical handoff is a handoff to a wireless overlay with a larger cell size and lower bandwidth. A downward vertical handoff is a handoff to a wireless overlay with a smaller cell size and larger bandwidth. Thus, a mobile device performing an upward vertical handoff disconnects from a network providing smaller coverage area and higher access speed (for example, WLAN) to a new one providing broader coverage but lower access speed (for example, WWAN), while a mobile device performing a downward vertical handoff disconnects from a network providing broader coverage area and lower access speed to a new one providing limited coverage but higher access speed.

Handoffs can also be classified using the number of connections involved as soft or hard.

A handoff is hard if the MT can be associated with only one point of attachment at a time. In other words, an MT may set up a new connection at the target point of attachment after the old connection has been torn down.

A soft handoff or a make before break handoff occurs if the MT can communicate with more than one point of attachment during handoff. In this case, the MT's connection may be created at the target point of attachment before the old point of attachment connection is released. For example, an MT equipped with multiple network interfaces can simultaneously connect to multiple points of attachment in different networks during soft handoff.

DESIRABLE HANDOFF FEATURES

An efficient handoff algorithm can achieve many desirable features by trading off different operating characteristics. Some of the major desirable features of a handoff algorithm are described below:

Fast: A handoff algorithm should be fast so that the mobile device does not experience service degradation or interruption. Service degradation may be due to a continuous reduction in signal strength or an increase in co-channel interference (CCI). Service interruption may be due to a "break before make" approach of handoff.

Reliable: A handoff algorithm should be reliable. This means that the service should have good quality after handoff. Many factors help in determining the potential service quality of a candidate BS or AP. Some of these factors include received signal strength (RSS), signal-to-interference ratio (SIR), signal-to-noise ratio (SNR), and bit error rate (BER).

Communication quality: The communication quality should be maximized through minimizing the number of handoffs. Excessive handoffs lead to heavy handoff processing loads and poor communication quality. The more attempts at handoff, the more chances that a call will be denied access to a channel, resulting in a higher handoff call dropping probability.

Traffic balancing: The handoff procedure should balance traffic in adjacent cells, thus eliminating the need for channel borrowing, simplifying cell planning and operation, and reducing the probability of new call blocking.

Interference prevention: A handoff algorithm should minimise global interference. Transmission of bare minimum power and maintenance of planned cellular borders can help achieve this goal.

Context-awareness: A handoff algorithm should be context-aware. The algorithm should adapt to its surroundings and acquire and utilise user, mobile terminal, and network information to improve QoS, connectivity and maintain a high level of user satisfaction.

Vertical Handoff Process

The vertical handoff process may be divided into three phases: network discovery, handoff decision, and handoff execution.

A. Network discovery

A mobile terminal (MT) searches for reachable wireless networks during the network discovery process. A multimode (equipped with multiple access network interfaces) MT must activate the interfaces to receive service advertisements broadcasted by different wireless technologies. A wireless network is reachable if its service advertisements can be heard by the MT. The simplest way to discover reachable wireless networks is to always keep all interfaces on. It is critical to avoid keeping the idle interface always on since keeping the interface active all the time consumes the battery power even without receiving or sending any packets.

B. Handoff decision

Handoff decision is the ability to decide when to perform the vertical handoff and determine the best handoff candidate access network. Horizontal handoff decisions mainly depend on the quality of the channel reflected by the RSS and resources available in the target cell. A handoff is made if the RSS from a neighbouring BS exceeds the RSS from the current BS by a predetermined threshold value.

In vertical handoffs, many network characteristics have an effect on whether or not a handoff should take place. Traditional handoff decision metrics based on the received signal strength indication (RSSI) and other physical layer parameters used for horizontal handoff in cellular systems are insufficient for the challenges of the next generation heterogeneous wireless systems. In vertical handoff, the RSSs are incomparable because two different networks with different characteristics are involved.

Handoff decision mechanism

The handoff decision mechanism or handoff control may be centralized (that is, the handoff decision may be located in the MT itself (as in mobile data and WLANs) or in a network entity (as in cellular voice)). These cases are called mobile-controlled handoff (MCHO) and network-controlled handoff (NCHO), respectively.

In NCHO the network makes a handoff decision based on measurements of the RSSs of the MT at a number of BSs. Information about the signal quality for all users is available at a single point in the network that facilitates appropriate resource allocation.

In MCHO the MT is completely in control of the handoff process. This type of handoff has a short reaction time (on the order of 0.1 sec). The MT itself first discovers all the available networks. It then measures the signal strengths from surrounding BSs and interference levels on all channels, and makes the evaluations for the handoff decision. A handoff can be initiated if the SS of the serving BS is lower than that of another BS by a certain threshold.

In network-assisted handoff (NAHO), the network assists the MT in the decision process by performing data collection and analysis. The MT can also provide its location and any other information that could be considered by the network in the analysis. The network only assists the MT in the decision process and the final decision is done by the MT.

Handoff metrics in heterogeneous networks

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:

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.

System performance: To guarantee the system performance, a variety of parameters can be employed in the handoff decision, such as the RSS, channel propagation

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characteristics, path loss, interchannel interference, signal-to-noise ratio (SNR), and the bit error rate (BER).

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

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. The velocity attribute has a necessary effect and larger weight on vertical handoff decision than in horizontal handoff. 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.

Battery power: Battery power may be a significant factor for handoff in some cases since wireless devices operate on limited battery power. For example, when the battery level decreases, handing off to a network with lower power requirements would be a better decision.

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.

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, WLAN) to access web information.

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.

Next Generation Multimode Terminals

The evolution toward 4G networks will necessitate a user-centric approach where users can access different access networks and services using a single device equipped with multiple radio interfaces. Terminals and devices capable of supporting different types of access technologies are being designed. The next generation of mobile terminals includes devices capable of supporting multiple access systems by incorporating several interface cards and appropriate software for switching between multiple interface technologies. An intelligent multimode terminal should be able to decide autonomously the active interface that is best for an application session and to select the appropriate radio interface as the user moves in and out of the vicinity of a particular access technology. The decision regarding the switching of the interface and the handoff of the active sessions to the new active interface may be decided based on network conditions, QoS requirements of the running applications, and user preferences.

Requirements that need to be fulfilled in order to design intelligent multimode terminals include:

- The terminal should operate with minimum inputs from the user. From the perspective of a user experience, it is preferable to carry out these decisions in an automated manner rather than querying the user every time a new interface becomes available or an old interface disappears.
- Radio access interfaces should be selected based on network conditions, QoS requirements of applications, and user preferences.
- The requirements of applications should be determined and then a decision made whether an application could benefit from changing interfaces.

Traffic should be balanced while changing the active interface in a way that is transparent to the user, that is, as seamlessly as possible.

The multimode terminal must be capable of:

- Detecting the availability of access networks;
- Finding, receiving and processing measurements regarding the characteristics of available access networks;
- Accessing, modifying and storing the user profile;
- Allowing the user to dynamically redefine his/her preferences; and
- Supporting the applications in seamlessly handing off the existing connections from one access network to another.

IV. RECENTLY PROPOSED VERTCAL HANDOFF TECHNIQUES

Vertical handoff decision has recently received much attention. 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 [11], 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 [12], the authors propose a policy-enabled handoff across a heterogeneous network environment using different parameters such as available bandwidth Bn, power consumption Pn, and cost Cn. The cost function fn of the network n is given by

$$f_n = w_b \cdot \ln(1/B_n) + w_p \cdot \ln(P_n) + w_c \cdot \ln(C_n) \ \left(\sum w_i = 1\right),$$

where w_b, w_p, and w_c are the weights of the parameters. The cost function is estimated for the available access networks and then used in the handoff decision of the MT.

Using a similar approach as in [12], a cost function-based vertical handoff decision algorithm for multi-services handoff was presented in [9]. The selection of the optimal network, *n_opt*, is based on

$$n\_opt = argmin(f^n) \ \forall \ n,$$

where f^n is the handoff cost function for network *n*, and is calculated as

$$f^n = \sum_s \left(\prod_i E^n_{s;i}\right) \sum_j f_{s;j}\,(w_{s;j})\, N(Q^n_{s;j}),$$

where N(Qns;j) is the normalized QoS parameter, Qns;j, representing the cost in the jth parameter to carry out service s on network n, fs;j (ws;j) is the jth weighting function for service s and Ens;i is the ith network elimination factor of service s. 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 multimode terminal is in a better position to make handoff decisions since it has access to information relating to its capabilities, and knowledge of surrounding access networks and user profiles. This calls for the development of a terminal management system (TMS) responsible for detecting available access networks and for making optimal network selection based on all gathered information. Optimal operation of the 4G network system can be achieved through the joint contributions of the management systems possessed by both the network and the MT. A network management system (NMS) will be responsible for joint management of the heterogeneous network resources and the provision of QoS to users.

A TMS possessed by the MT will be responsible for the intelligent monitoring of the MT's status, for detecting available access networks in the vicinity of the MT, for making optimal access network selection, and for interaction with the NMS. In [13], Koutsorodi et al. present a mobile terminal architecture for devices operating in heterogeneous environments, which incorporates intelligence for supporting mobility and roaming across access networks. They compute the function:

$$OF(p, q) = w_q \times \text{Quality}(p, q) + w_o \times \text{Operator}(p) + w_t \times \text{Technology}(p) - w_c \times \text{Cost}(p, q), \quad (4)$$

for all $p \in P = \{p_1, p_2, \dots, p_n\}$, $n \in Z$, and $q \in Q(p) = \{q_1, q_2, \dots, q_m\}$, $m \in Z$; P is the set of attachment points that the terminal perceives, $Q(p)$ is the set of quality levels at which attachment point p can offer the service under consideration. The optimal attachment point and quality level for each of the requested/running services is the determination of: $\max \forall_{p \in P}\{\max \forall_{q \in Q(p)}\{OF(p, q)\}$.

The decision about access network selection in a heterogeneous wireless environment can be solved using specific multiple attribute decision making (MADM) algorithms such as Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Weighted Product Model (WPM), Weighted Sum Model (WSM), Analytic Hierarchy Process (AHP), and Grey Relational Analysis (GRA). An integrated AHP and GRA algorithm for network selection is presented in [14] with a number of parameters.

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 [15], Chan et al. propose a mobility management in a packet-oriented multi-segment using Mobile IP and fuzzy logic concepts. Handover is separated into initiation, decision and execution phases. MIP is used in the execution phase, fuzzy logic is applied to the 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.

Many proposals have been made for performing handoffs while roaming across heterogeneous wireless networks. These approaches operate at different layers of the Internet protocol stack.

When designing a new architecture for implementing vertical handoff, it is important to limit the modifications required to existing wireless systems, and to minimise the amount of network traffic needed. In [16], Eddy addresses the issue of which layer in the IP protocol stack mobility belongs to. He discusses the various strengths and weaknesses of implementing mobility at three different layers of the protocol stack. He concludes that the transport layer is the most likely place for a mobility protocol, but the best approach may be a cross-layer approach where interlayer communication is used.

Network layer solutions provide mobility-related features at the IP layer. In [17], Floroiu et al. provide a quantitative analysis of a Mobile IPv4-based WLAN-GPRS (General Packet Radio Service) handover prototype, and identify a number of side effects related to the link layer and routing mechanisms. Mobile IP (MIP) is a mobility management protocol proposed to solve the problem of node mobility by redirecting packets to the mobile node's current location. MIP provides IP layer mobility by enabling a mobile node (MN) that originates from its home network to be addressable by the same home IP address across different foreign networks the MN is visiting. This is realized by maintaining a binding between the MN's home IP address and the care-of-address (CoA), which is the IP address allocated to the MN in the currently visited foreign network. A number of other functional entities (mobility agents) involved in the management of bindings are a home agent (HA) located in the home network and a number of foreign agents (FAs) located in visited foreign networks. The binding is created as a result of the MN registering its new CoA with its HA as soon as it detects that its location has changed. Data traffic originated from and addressed to the MN is redirected between the HA and the FAs by means of IP-in-IP encapsulation. There are certain routing inefficiencies in MIP including triangle routing, triangle registration, encapsulation and need for home addresses. MIPv6 eliminates triangular routing and enables the correspondent node to reroute packets on a direct path to the MT.

The transport layer approach requires a means to detect and reconfigure mobile hosts as they move from one network type to another. This includes the detection of new networks and the allocation of new IP addresses. These tasks are often handled by Dynamic Host Configuration Protocol (DHCP) or Router/Neighbor Discovery methods. Recent transport-level management protocols that have been proposed include the Stream Control Transmission Protocol (SCTP) and the Datagram Congestion Control Protocol (DCCP). SCTP [18] is an IP-based transport protocol tailored for the transport of signaling data over IP networks. An SCTP connection, called an association, provides novel services such as multi-homing, which allows the end points of a single association to have multiple IP addresses, and multi-streaming, which allows for independent delivery among data streams. The proposed dynamic address reconfiguration (DAR) extension for SCTP enables each end point to add or delete an IP address to or from an existing association, and to change the primary IP address for an active SCTP association using address configuration (ASCONF) messages. Due to the multi-homing feature of mobile SCTP (mSCTP) that is, an SCTP implementation with its DAR extension, an end point's network interface can be added into the current association if it is possible for the interface to establish a connection to the Internet via an IP address. The capabilities of mSCTP to add, to change, and to delete the IP addresses dynamically during an active SCTP association provides an end-to-end vertical handoff solution between two IP access networks such as UMTS and WLAN [19]. Both the MT, or mobile client, and a fixed correspondent node, or fixed server, are assumed to implement mSCTP as shown in Figure 1. The multimode MT supports both UMTS and WLAN at the physical and data link layers. The handoff execution procedure has three basic steps: Add IP address, Vertical handoff triggering, and Delete IP address.

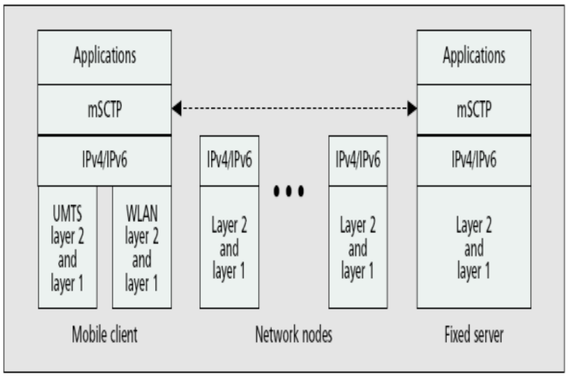

Figure 1. Protocol architecture using Msctp

The Session Initiation Protocol (SIP)-based handoff [20] approach is an application-layer solution that provides personal and terminal mobility management in heterogeneous networks. SIP is an application-layer control protocol for establishing, modifying, and terminating multimedia sessions in IP-based networks between two or more participants. The main entities in SIP are user agents, proxy servers, and redirect servers. Terminal mobility requires SIP to establish a connection either during the start of a new session (pre-call mobility), when the MT has already moved to a different location, or in the middle of a session (mid-call mobility). For mid-call mobility, the MT sends another INVITE message about the MT's new IP address and updated session parameters to the correspondent host (CH). Performing a vertical handoff during an ongoing session is similar to mid-call mobility. An MT performs two key functions to initiate a WLAN-to-UMTS handoff [21]: data connection setup, and a SIP message exchange that re-establishes the connection. For a UMTS-to-WLAN vertical handoff, the MT goes through the following steps to update its location with the CH: DHCP registration procedure, and SIP message exchange. A major limitation of SIP-based handoff is unacceptable handoff delay.

In [22], Zhang et al. propose a mobility management system for vertical handoff between WWAN and WLAN that integrates a connection manager to detect network condition changes and the availability of multiple networks, and a virtual connectivity manager that uses an end-to-end principle to maintain a connection without additional network infrastructure support. For handoff from WWAN to WLAN, the authors propose a MAC layer sensing scheme to estimate network conditions., and for handoff from WLAN to WWAN, they propose a signal decay detection approach by using the Fast Fourier Transform (FFT) property: the fundamental term of the FFT of a statistically decreasing sequence x(n) with length N always has a negative imaginary part. That is,

$$E\,[\,X(1) = \sum_{n=0}^{N-1} x(n)\,\sin(-2\pi n / N)\,] < 0.$$

V. A VERTICAL HANDOFF DECISION ALGORITHM

In this section, we describe our proposed vertical handoff decision algorithm that possesses many desirable features, and prove the viability and implementation of our proposal by a performance evaluation.

Overview of the Vertical Handoff Decision Algorithm

Vertical handoff decision in a heterogeneous wireless environment depends on several factors. A 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. Consequently, our proposed vertical handoff scheme consists of two parts:

(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 [23]:

- 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;
- 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 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 2 describes the vertical handoff decision algorithm.

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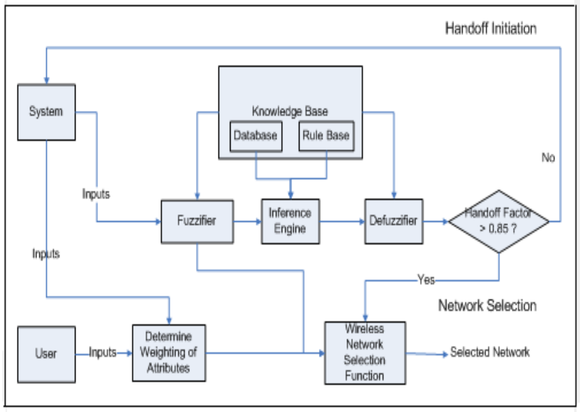

Figure 2. Block diagram for Vertical Handoff Decision

Handoff Initiation Algorithm

Vertical handoff is more complex because an MT can maintain connectivity to many overlaying networks that each offer varying QoS. Therefore, the optimal time to initiate vertical handoff requires the handoff algorithm to process a range of parameters. Computing and choosing the correct time 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 mimics the human mind and 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.

Handoff from UMTS to WLAN

A fuzzy logic inference system can be implemented in the MT as a Handoff Initiation Engine to provide rules for decision making. Suppose that a MT that is connected to a UMTS network detects a new WLAN. It 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 RSSI and data rate indicate the availability of the target 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 3.

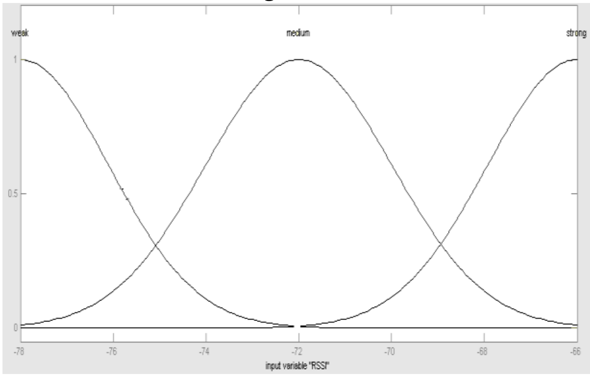

Figure 3. Membership Function for RSSI

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.

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

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desirable, THEN handoff factor is lower.

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 or fitness 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.

Network selection in a heterogeneous all-IP wireless network environment depends on several factors. 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 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*: 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.
- *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.
- *High reliability*: A reliable network can be trusted to deliver a high level of performance.
- *Strong security*: 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

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

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

$$f_i(\boldsymbol{x}) = f\,(S_i, A_i, D_i, 1/C_i, R_i, E_i, V_i, 1/P_i, 1/L_i)$$

$$= \sum_{i=1}^{6} w_X \cdot N_f\,(X_i) + \sum_{i=1}^{3} w_Y \cdot N_f\,(1/Y_i),$$

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

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

A suitable normalized function of the parameter X is the fuzzy membership function µX. 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 µCj(0) = 0 and µCj(1) = 1 if the goal is to select a network with a high parameter X value; and such that µCj(0) = 1 and µCj(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 = {A1, A2, … , Am} is a set of m alternatives and C = {C1, C2, … , Cn} 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 Aj in the criterion Ci, denoted µCi(Aj), is the degree to which alternative Aj satisfies this criterion. A decision maker judges the criteria in pairwise comparisons [24], and assigns the values aij = 1/aji using the values aij = 1/aji 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:

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

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

$$B \cdot v = \lambda_{max} \cdot v$$

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

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

The optimum wireless network is given by the optimization problem:

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

such that

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

and

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

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

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.

(a) 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.

(b) He also decides to continue participating in an afternoon company meeting through a video call. Here, data rate is of strong importance (7) than all other attributes, service cost is of strong importance (5), and network latency is of weak importance (3) than the remaining attributes.

Evaluation

(a) 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 vertical handoff decision algorithm is to compute the WNSF for all the available networks. The mobile terminal proceeds to gather data on all required parameters. The matrix B and weighting matrix W are indicated below:

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

The attribute weights and the membership values of the three available networks for the attributes are summarized in the table below.

Table 1. Parameters for Case (a)

Criteria		w_j	Membership Values $\mu_{Cj}(A_i)$		
			UMTS_1	WLAN_1	WLAN_2
RSSI	C_1	0.0192	0.9	0.9	0.9
Data Rate	C_2	0.4793	0.1	0.7	0.9
Network Coverage	C_3	0.0192	0.6	0.2	0.1
Network Latency	C_4	0.1196	0.6	0.8	0.85
Reliability	C_5	0.0682	0.9	0.8	0.8
Security	C_6	0.0192	0.9	0.65	0.6
Power Requirement	C_7	0.0357	0.8	0.6	0.6
Mobile Velocity	C_8	0.0192	0.9	0.01	0.01
Service Cost	C_9	0.2204	0.6	0.9	0.9

We define the WNSF as

$$f_i(\mathbf{x}) = \sum_{j=1}^{9} w_j \cdot \mu_{Cj}(A_i)$$

Evaluating the function using the weights w_j the membership values $\mu_{Cj}(A_i)$ for the available networks yields:

$f_{\text{UMTS-1}}(\mathbf{x}) = 0.4052$, $f_{\text{WLAN-P-1}}(\mathbf{x}) = 0.7393$, and $f_{\text{WLAN-P-2}}(\mathbf{x}) = 0.8383$.

Since WLAN_P_2 yields the highest value for the WNSF, it is best to handoff from UMTS_1 to the WLAN_P_2 in order to complete downloading the multimedia files.

(b) The matrix ***B*** and weighting matrix ***W*** are indicated below:

$$\mathbf{B} = \begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \\ C_6 \\ C_7 \\ C_8 \\ C_9 \end{array} \begin{array}{c} \begin{array}{ccccccccc} C_1 & C_2 & C_3 & C_4 & C_5 & C_6 & C_7 & C_8 & C_9 \end{array} \\ \begin{pmatrix} 1 & 1/7 & 1 & 1/3 & 1 & 1 & 1 & 1 & 1/5 \\ 7 & 1 & 7 & 7 & 7 & 7 & 7 & 7 & 7 \\ 1 & 1/7 & 1 & 1/3 & 1 & 1 & 1 & 1 & 1/5 \\ 3 & 1/7 & 3 & 1 & 3 & 3 & 3 & 3 & 1/5 \\ 1 & 1/7 & 1 & 1/3 & 1 & 1 & 1 & 1 & 1/5 \\ 1 & 1/7 & 1 & 1/3 & 1 & 1 & 1 & 1 & 1/5 \\ 1 & 1/7 & 1 & 1/3 & 1 & 1 & 1 & 1 & 1/5 \\ 1 & 1/7 & 1 & 1/3 & 1 & 1 & 1 & 1 & 1/5 \\ 5 & 1/7 & 5 & 5 & 5 & 5 & 5 & 5 & 1 \end{pmatrix} \end{array}$$

$$\Rightarrow \mathbf{V} = \begin{pmatrix} 0.0777 \\ 0.8753 \\ 0.0777 \\ 0.1895 \\ 0.0777 \\ 0.0777 \\ 0.0777 \\ 0.0777 \\ 0.4022 \end{pmatrix} \Rightarrow \mathbf{W} = \begin{pmatrix} 0.0402 \\ 0.4528 \\ 0.0402 \\ 0.0981 \\ 0.0402 \\ 0.0402 \\ 0.0402 \\ 0.0402 \\ 0.2081 \end{pmatrix}$$

Evaluating the WNSF in (14) using the weights w_j in (15) and membership values for the available networks from Table 1 yields:

$f_{UMTS-1}(\boldsymbol{x}) = 0.4300$, $f_{WLAN-P-1}(\boldsymbol{x}) = 0.7098$, and $f_{WLAN-P-2}(\boldsymbol{x}) = 0.7992$.

In this case too, WLAN_P_2 yields the highest value for the WNSF, and therefore it is best to handoff to WLAN_P_2 in order to make the video call.

The scenarios indicate that multiple services can be received on a multimode device in a next generation access network.

6. CONCLUSION

The fourth generation of wireless networks is expected to include heterogeneous wireless networks that will coexist 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. A major challenge of the evolving 4G wireless networks is seamless vertical handoff across the multi-service heterogeneous wireless access networks. A key issue that aids in providing seamless vertical handoff is handoff decision. This chapter presents a tutorial on the different aspects of vertical handoff a 4G multi-network environment. Integration architectures for various wireless access networks, handoff classification, desirable handoff features, multimode mobile terminals, and the complete handoff decision process are described. Some recently proposed vertical handoff techniques are presented.

Finally, we propose a vertical handoff decision algorithm that determines whether a vertical handoff should be initiated and dynamically selects the optimum network connection from the available access network technologies to continue with an existing service or begin another service. We prove the viability of our proposal by a performance evaluation.

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