Vertical Handoff Decision Algorithms Using Fuzzy Logic

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Abstract

This paper reports on the design and implementation of multi-criteria vertical handoff decision algorithms in a heterogeneous wireless wide area network (WWAN) and a wireless local area network (WLAN) environment. An "IP-centric Field Workforce Automation" project aims to ensure free movement of field workers between networks while always connected in an IP mode, and to allow a user to use one device across many types of networks. This requires the integration and interoperation of heterogeneous networks, and the provision of seamless vertical handoff. We use a fuzzy logic inference system to process a multi-criteria vertical handoff decision metrics.

Keywords – Vertical handoff, mobility management, fuzzy logic handoff decision algorithm, WWAN, WLAN

1. INTRODUCTION

The key objective of most "IP-centric Field Workforce Automation" research projects is to ensure global access and mobility between heterogeneous wireless networks, and to allow a user to use one device across many types of networks. This objective requires the integration and interoperation of heterogeneous networks, such as WWAN and WLAN.

Given the complementary characteristics of WLAN (faster, high-bandwidth, lower-cost, short-distance access) and WWAN (slower, higher-cost, long-range always connected access), it is compelling to combine them to provide ubiquitous wireless access for users with contemporary mobile devices that are equipped with multiple network interfaces. The natural trend is to use high-bandwidth WLANs in hotspots and switch to WWANs when the coverage of the WLAN is not available or the network condition in the WLAN is not good enough. *Vertical handoff* between WWAN and WLAN enables seamless terminal, personal and network mobility. It provides for continuity and transfer of existing sessions. Vertical handoff can be separated into three phases: network discovery, handoff decision, and handoff execution.

A mobile node (MN) searches for reachable wireless networks during the network discovery process. A multimode (equipped with multiple access network interfaces) MN 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 MN. It is critical to avoid keeping idle interfaces always on in order to avoid excessive consumption of battery power. The system discovery time should be low so that the MN can benefit from the new wireless network.

Handoff decision is the ability to decide when to perform the vertical handoff. Handoff metrics are the qualities that are measured to indicate whether or not a handoff is needed. 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 order to take an intelligent and better decision as to which wireless network should be chosen 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 RSSI measurements: service type, network conditions (such as available bandwidth and network access delay), system performance, mobile node capabilities, user preferences, and monetary cost. A fuzzy logic based algorithm that adopts the RSS threshold and hysteresis values as input parameters was proposed in [1]. A proposal for mobility management in a packet-oriented multi-segment using Mobile IP and fuzzy logic concepts was proposed in [2]. However, no results on the handoff decision algorithm were provided.

Once the vertical handoff decision has been made, the remaining key issue is handoff execution which requires the actual transfer of data packets to a new wireless link in order to reroute the connection path of a mobile user to the new point of attachment. Many proposals have been made for performing vertical handoffs between heterogeneous wireless networks. The first one handles mobility at the network layer by using Mobile IP (MIP) [3]. The second approach considers mobility at the application layer by using the Session Initiation Protocol (SIP) [4]. Both MIP- and SIP-based approaches involve overhead and inefficiency. Another approach is to consider mobility at the transport layer using the Stream Control Transmission Protocol (SCTP) [5]. The multi-homing feature of SCTP and the dynamic address reconfiguration (DAR) extension for SCTP, referred to as mobile SCTP (mSCTP) [6], allow endpoints to add, delete, or change IP addresses. Simulation results on vertical handoff using mSCTP have appeared in the literature [7, 8, 9]. The mSCTP is targeted for the client-server model, where a mobile node (MN) initiates an SCTP session with a fixed correspondent node (CN). For supporting vertical handoff where the fixed CN initiates an SCTP session with the MN, the mSCTP must be used with a location management scheme such as SIP. A major drawback of using SCTP is that almost all of the current Linux kernel implementations of SCTP do not provide the DAR extension features of SCTP and almost all open source

SIP servers and user agents do not support SCTP. We have installed and tested the SCTP throughput performance of the OpenSS7 Linux kernel SCTP implementation [10] on two Pentium 4 machines in our network laboratory as part of a scheme to implement vertical handoff using mSCTP and SIP.
In this article we focus on a fuzzy logic-based handoff decision algorithm. The remainder of the article is organised as follows. In the next section we introduce the concepts of fuzzy inference systems. The fuzzy logic handoff decision algorithms are then presented. Finally, we conclude the article.

2. FUZZY LOGIC

Fuzzy logic can be viewed as a theory for dealing with uncertainty about complex systems, and as an approximation theory. This perspective shows that fuzzy logic has two objectives: a) to develop computational methods that can perform reasoning and problem solving tasks that require human intelligence, and b) to explore an effective trade-off between precision and the cost in developing an approximate model of a complex system [11, 12].

2.1. FUZZY INFERENCE SYSTEM

Inference is known as the process that draws conclusions from a set of facts using a collection of rules. The fuzzy inference system is a computing framework based on the concepts of fuzzy set theory, fuzzy if-then rules, and fuzzy reasoning. Two types of fuzzy inference systems that can be implemented are the Mamdani-type and the Sugeno-type [13]. The differences between these fuzzy inference systems lie in the consequents of their fuzzy rules, and therefore their aggregation and defuzzification processes differ accordingly. A Mamdani fuzzy inference system is composed of the functional blocks:

- *Fuzzifier* – The fuzzifier transforms the crisp inputs into degrees of match with linguistic values. The fuzzifier maps a crisp point, $\underline{x} = [x_1, x_2, x_3, \dots, x_n]^T \in U$, into a fuzzy set $A = \{(x_1, \mu_A(x_1)), (x_2, \mu_A(x_2)), \dots, (x_n, \mu_A(x_n))\}$ in U, where $\mu_A : U \rightarrow [0, 1]$ is the membership function of the fuzzy set A and $\mu_A(x_i)$ is the membership degree of x_i in A.

- *Fuzzy rule base* – It contains a number of fuzzy IF-THEN rules. If a fuzzy system has n inputs and a single output, its fuzzy rule R_j is of the general form:

  IF x_1 is A_{1j} and x_2 is A_{2j} and … and x_n is A_{nj}, THEN y is B_j.

  A_{ij} and B_j are fuzzy sets in $U_i \subset R$ and $V \subset R$, respectively. The variables $\underline{x} = [x_1, x_2, x_3, \dots, x_n]^T \in U_1 \times U_2 \times \dots \times U_n$ and $y \in V$ are called the input and the output linguistic variables, respectively;

- *Fuzzy inference engine* – The fuzzy inference engine performs the inference operations on the fuzzy rules. Fuzzy logic principles are used to combine fuzzy IF-THEN rules in the rule base, and fuzzy sets in $U = U_1 \times U_2 \times \dots \times U_n$ are mapped into fuzzy sets in V. Let $A \in U$ be the input to the fuzzy inference engine, and let the fuzzy rule be represented as the fuzzy implication $R = R_{1j} \times R_{2j} \times R_{3j} \times \dots \times R_{nj} \rightarrow Gj = C$ in $U \times V$. Then, each fuzzy IF-THEN rule determines a fuzzy set $D = B_j \in V$ using the composition:

$$\mu_D(u, w) = sup_{\underline{x} \in U} [\mu_{R \rightarrow C}(\underline{x}, y) \Delta \mu_A(\underline{x})]$$

- *Defuzzifier* – A defuzzifier transforms the fuzzy results of the inference into a crisp output. It maps fuzzy sets in V into a crisp output $y \in V$. A popular defuzzification method is the centroid calculation which returns the centre of area under the curve given by

$$y = \Sigma \underline{y}(\mu_B(\underline{y})) / \Sigma(\mu_B(\underline{y})),$$

where $\underline{y}$ is the centre of the fuzzy set C. The bisector, middle of maximum, largest of maximum, and smallest of maximum are other defuzzification methods.

A fuzzy inference system is shown in Figure 1, where the input and output of the fuzzy system are $\underline{x} \in R^N$ and $y \in R$, respectively.

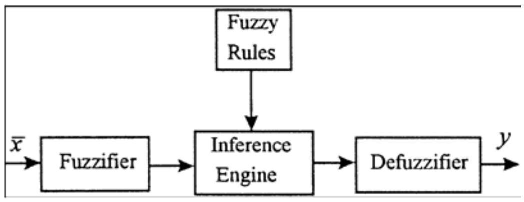


Figure 1. *Fuzzy Inference System*

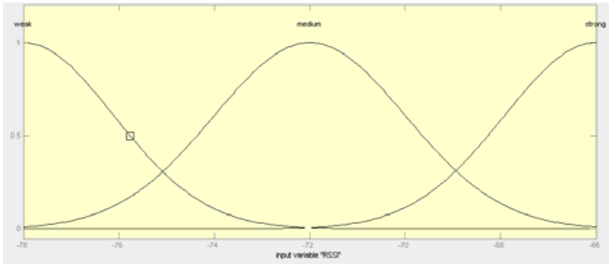
3. FUZZY LOGIC HANDOFF DECISION ALGORITHM

A handoff algorithm must be capable of making a decision based on incomplete information and in a region of uncertainty. We are designing an adaptive multi-criteria handoff decision algorithm that incorporates fuzzy logic because of the inherent strength of fuzzy logic in solving problems exhibiting imprecision and the fact that many of the terms used for describing radio signals are fuzzy in nature [2, 14]. The algorithm gives users the option to influence the handoff result by specifying user preferences such as the preferred user wireless network and the QoS required. Fuzzy logic can be exploited to develop approximate solutions that are both cost-effective and highly useful.
We consider two handoff scenarios: handoff from WWAN to WLAN, and handoff from WLAN to WWAN.

3.1. HANDOFF FROM WWAN TO WLAN

Since the WWAN could be always on and the WLAN is optional, the objective of the handoff from the WWAN to WLAN is to improve the QoS. A user connected to a WWAN system would like to move into a WLAN area and change the connection to WLAN to obtain a higher bandwidth service at a lesser cost. The multimode MN associated with the WWAN monitors at repeated intervals and measures the RSSI of nearby WLANs to see whether or not a better high data rate WLAN service is available. Input data from both the user and the system are required for the handoff decision algorithm, whose main purpose is to select an optimum wireless network for a particular service that can satisfy the following objectives: preferred user wireless network, good signal strength, good network coverage, optimum bandwidth, low cost, high reliability, and low network latency. The priority order of the preferred user wireless network could be office WLAN, residential WLAN, and then public WLAN, where the priority order is based on security, throughput, cost, and routing performance. The RSSI of the target network must be larger than the RSSI threshold (say, -76 dBm) which enables quality WLAN communication service for a period of time. Fuzzy logic algorithms can be implemented in the MN as a Handoff Decision Engine to provide rules for decision making. The input parameters (preferred user wireless network, RSSI, available bandwidth, and network coverage area of the target WLAN network) are fed into a fuzzifier, which transforms them into fuzzy sets by determining the degree to which they belong to each of the appropriate fuzzy sets via membership functions. 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 during the final stage of the handoff decision.

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 (S), Medium (M), and Weak (W). These sets are mapped to corresponding Gaussian membership functions. 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 Available Bandwidth 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 Preferred User Wireless Network is defined from 0 to 10. The fuzzy set values for the output decision variable Handoff are {Yes (Y), Probably Yes (PY), Uncertain (U), Probably No (PN), and No (N)}. The universe of discourse for the variable Handoff is defined from 0 to 4, with the maximum membership of the sets “No” and “Yes” at 0 and 4, respectively. The MFs for the input and output fuzzy variables are shown in Figure 2.



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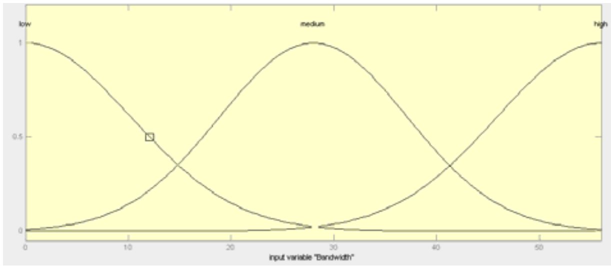

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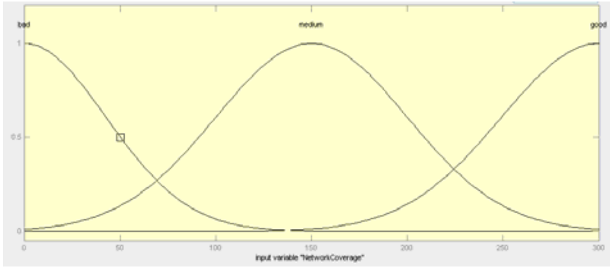

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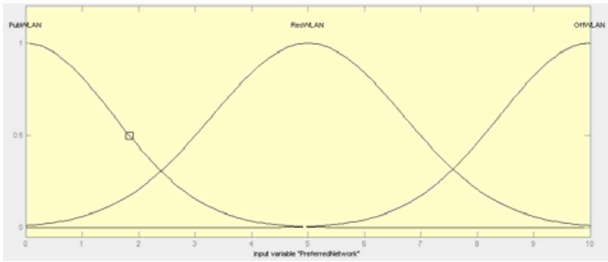

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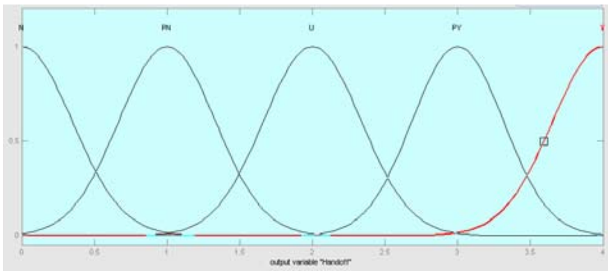


(e)

Figure 2. *Membership Functions for Fuzzy Variables (a) RSSI, (b) Bandwidth, (c) Network Coverage, (d) Preferred Network, and (e) Handoff*

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 available bandwidth is low, and network coverage area is bad, and preferred user wireless network is public WLAN, THEN handoff is N.
- IF RSSI is weak, and available bandwidth is low, and network coverage area is medium, and preferred user wireless network is residential WLAN, THEN handoff is PN.
- IF RSSI is strong, and available bandwidth is high, and network coverage area is good, and preferred user wireless network is office WLAN, THEN handoff is Y.
- IF RSSI is strong, and available bandwidth is medium, and network coverage area is medium, and preferred user wireless network is residential WLAN, THEN handoff is PY.
- IF RSSI is medium, and available bandwidth is high, and network coverage area is good, and preferred user wireless network is office WLAN, THEN handoff is Y.
- IF RSSI is medium, and available bandwidth is low, and network coverage area is medium, and preferred user wireless network is public WLAN, THEN handoff is U.

Figure 3 shows a MATLAB-based Mamdani fuzzy logic inference display of the combined six IF-THEN rules indicated above.

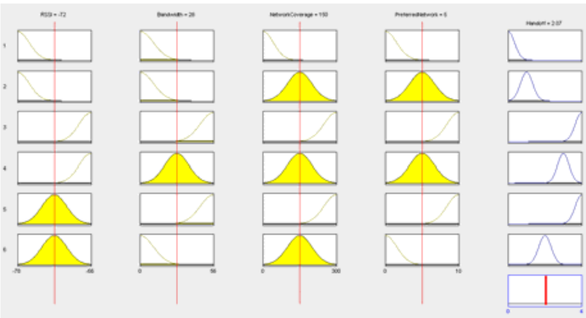


Figure 3. *Fuzzy Inference Display of IF-THEN rules*

3.2. HANDOFF FROM WLAN TO WWAN

Since 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. The parameters that we are using in this directional handoff include RSSI, available bandwidth, 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 WWAN-to-WLAN handoff. We are using three fuzzy sets for each of the input variables (preferred user wireless network, RSSI, network coverage, and available bandwidth) and five fuzzy sets for the output variable. The fuzzy sets are mapped to corresponding Gaussian membership functions. The fuzzy set values for the output decision variable Handoff are {Yes (Y), Probably Yes (PY), Uncertain (U), Probably No (PN), and No (N)}.

The fuzzy rule base contains IF-THEN rules such as:

- IF RSSI is weak, and available bandwidth is low, and network coverage area is bad, and perceived QoS is undesirable, THEN handoff is Y.
- IF RSSI is weak, and available bandwidth is low, and network coverage area is medium, and perceived QoS is undesirable, THEN handoff is PY.
- IF RSSI is strong, and available bandwidth is high, and network coverage area is good, and perceived QoS is desirable, THEN handoff is N.
- IF RSSI is strong, and available bandwidth is medium, and network coverage area is medium, and perceived QoS is undesirable, THEN handoff is PN.

Figure 4 shows a MATLAB based fuzzy logic inference displays of the combined four IF-THEN rules indicated above. Figure 5 shows the Surface Viewer for the system composed of these four rules in three specific cases.

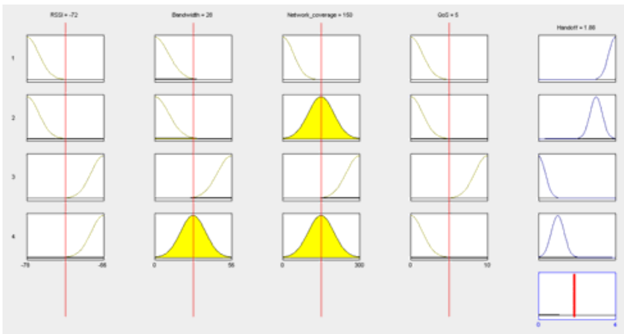
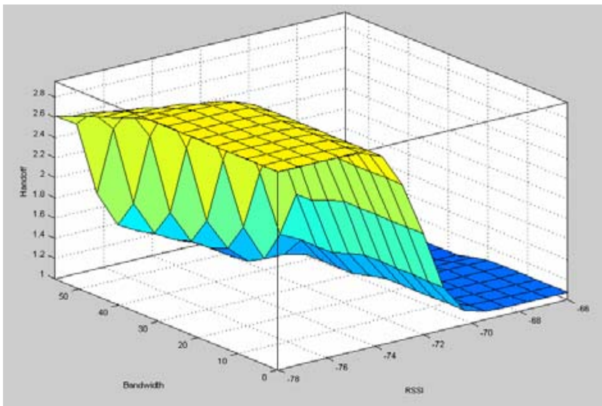


Figure 4. *Fuzzy Inference Display of IF-THEN rules*



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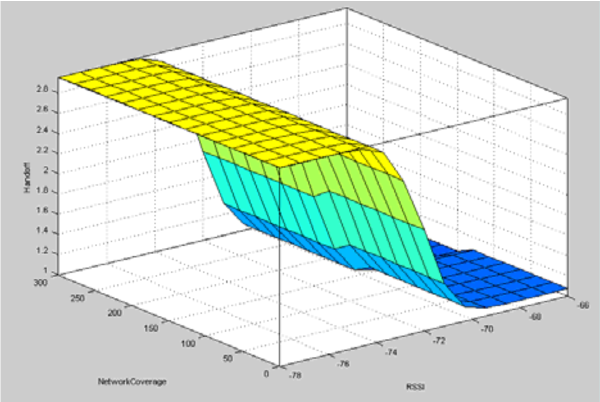

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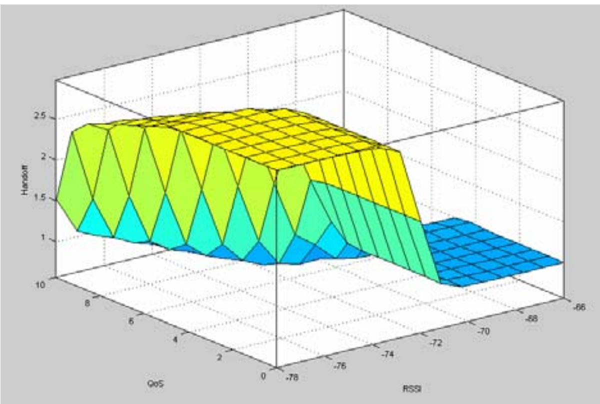

(c)

Figure 5. *(a) Surface Viewer for the fuzzy handoff in the case of constant network coverage and QoS, (b) Surface Viewer for the fuzzy handoff in the case of constant bandwidth and QoS, and (c) Surface Viewer for the fuzzy handoff in the case of constant bandwidth and network coverage.*

The Fuzzy Logic Toolbox of MATLAB is being used to design appropriate fuzzy inference systems that will be simulated with Simulink.

4. CONCLUSION AND FUTURE WORK

This paper has presented the use of fuzzy logic concepts to design an adaptive multi-criteria vertical handoff decision algorithm that is both cost-effective and highly useful. We demonstrated how the use of fuzzy logic concepts can be used to combine multiple metrics from the network and the user to obtain useful handoff decisions. Simulink will be used to simulate all completed fuzzy inference systems that shall be designed in order to help us evaluate the performance of the algorithms.

5. ACKNOWLEDGMENT

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