Novel Network Selection Algorithm Based on Fuzzy Inference

Doru Todinca
Department of Computers
University Politehnica of Timisoara
Email: doru.todinca@cs.upt.ro

Cosmin Cernăzanu-Glăvan
Department of Computers
University Politehnica of Timisoara
Email: cosmin.cernazanu@cs.upt.ro

***Abstract*—In the heterogeneous mobile networks of the future, the mobile users, equipped with multi-mode terminals, will be able to select the radio network that suits best the needs of the mobile user and of the applications running on the mobile terminal.**

In this work we propose a novel network selection algorithm based on fuzzy inference. Our algorithm permits a prioritization of the users by using different fuzzy rules for each class of users. We investigate by simulation the efficiency of our algorithm and compare its results with an existing network selection algorithm, called consumer surplus.

I. Introduction

The process when a mobile user disconnects from its current radio access network (RAN) and selects a different RAN, is called vertical handover (VHO), or vertical handoff. The new RAN can either belong to the same network operator as the old RAN, but using a different radio access technology (RAT), or it can belong to a different network operator. Horizontal handover is the process, very common in cellular networks, when a user, due to its mobility, disconnects from the base station that serves its current cell and connects to a base station that serves another cell, both cells belonging to the same RAT and to the same operator.

While the horizontal handover is triggered by technical factors, mainly by the received signal strength (RSS), being also influenced by the speed of the user and the availability of resources in each cell, the vertical handover is a more complex process, depending on numerous factors related to radio access networks, to mobile users and their applications. Such factors are: technical characteristics (RSS, error rate, etc), cost, geographical area coverage, battery state, requirements of the applications running on the user's terminal, and even subjective factors like user's preference for a certain network or a certain network operator.

Vertical handover process has three phases: network discovery, network selection decision, and handover execution [1]. In this work we discuss only the network selection decision.

The algorithms used for network selection decision can be based on multi-attribute decision making (MADM) techniques, on fuzzy logic, on neural networks (NN), etc. Surveys on network selection decision algorithms are given in [1], [2], [3], [4], [5].

Wenhui Zhang explained in [6] that fuzzy logic is very useful for the VHO algorithms because the factors considered by the VHO algorithms are not only technical and precise (like received signal strength, used for horizontal handover), but there can be also subjective factors, like the preference for a certain RAT, or the perceived QoS. Also, it is possible for some parameters involved in the VHO process to be expressed in an imprecise, qualitative rather than quantitative way: high network load, or low battery state. All these situations can be treated in an unified way using fuzzy logic, as demonstrated in [6] or [7].

Fuzzy logic has been used for VHO in combination with multi-attribute decision making (MADM) in [6], [7], [8], [9], or in combination with neural networks in [10]. The analysis performed by Zhag in [6] showed that the combination of fuzzy and MADM can bring to contradictory results, while the approach from [10], with fuzzy and neural networks, is too computationally intensive in our opinion.

In consequence, in this work we propose an algorithm for network selection that uses fuzzy logic, but instead of fuzzy MADM or fuzzy NN, we are using fuzzy inference, because fuzzy inference has proved its flexibility and robustness in many technical areas.

Fuzzy inference was used for VHO between WLANs and mobile networks in [11], [12], [13].

The paper [11] uses fuzzy inference to adapt the hysteresis value used for VHO as a function of user's speed. The authors compare their fuzzy algorithm with a conventional VHO algorithm, that cannot deal efficiently with different users' speed. This comparison is not fair, in our opinion, because real algorithms used for handover, even for horizontal HO, can deal with fast moving users by using a dwell time ([14]).

In [13], the authors use fuzzy inference for handover between UMTS and WLAN as a function of the bandwidth and the predicted received signal strength. The authors also use a prediction algorithm in order to predict the future RSS value. This predicted value is used to trigger the VHO process and the prediction algorithm aims to void sudden fluctuations of the RSS. However, existing algorithms used for HO ([14]) use a sliding window algorithm for computing a weighted average from the past and current values of RSS. This average value is used for triggering the handover. This averaging process eliminates the sudden fluctuations of the RSS, and hence the complex algorithm used in [13] is not necessary in practice.

Other fuzzy inference algorithm used for HO between

WLAN and UMTS are given in [12] and [15]. While [12] presents only a suggested solution, without simulation results, but with many fuzzy rules, in [15] the fuzzy inference is used only for handoff initiation, while for network selection is used a fuzzy MADM algorithm.

Wilson et al present in [16] a fuzzy inference algorithm used for VHO, but it is only an initial development of their work. The fuzzy if-then rules used are not given by the authors.

An interesting example of fuzzy inference applied in VHO decision algorithms is given in [17], where the authors make a distinction between the admission control (AC) for network access, and inter-system handover. The AC is used only once per session, for first selection of the network, and then, a fuzzy inference algorithm is used for inter-system handover (i.e. VHO). The inputs of the VHO fuzzy algorithm are the frame drop rate, the number of handovers already performed in the session and the time QoS was above a given threshold, while the output of the fuzzy inference is the decision to handover or not.

Our approach, presented in this work, is somehow similar with that from [17], but we use the fuzzy inference for the first selection of the network, at the beginning of a session. After the initial network selection we consider that the mobile user can use the existing HO algorithms when it moves from one cell to another.

Of course, it is possible to ‘call’ the fuzzy selection algorithm in certain circumstances, for example if, for some reasons, the initial selection was not optimal (the user did not received the desired RAN), or if new RANs become available.

We believe that our approach has several advantages:

1) In this way, the network operators will preserve their existing algorithms for horizontal and even for vertical HO, and use the new fuzzy algorithm only for initial network selection. Network operators already use VHO algorithms between UMTS and GSM/EGPRS networks. See, for example, [18], section 9.3.2 “Inter-system Handovers between WCDMA and GSM”, for a discussion about VHO between UMTS and GSM. This kind of VHO can be determined by load balancing between existing technologies, or by ending of the geographic coverage of one network.
2) We make a separation between the complex, flexible and subjective criteria used for initial selection of a radio access network from a series of such RANs (problem for which fuzzy logic can be very useful) and the technical criteria used for horizontal HO, for which well established algorithms can be applied.
3) The fuzzy inference algorithm, which needs a relatively high computing power, is not used very often.

The rest of the paper is organized as follows: next section presents our simulation model, section III describes our fuzzy inference based network selection algorithm, and section IV contains the simulation results that validate our algorithm. The paper ends with a section of conclusions and future work.

II. The simulation model

We have used OMNeT++ [19] in order to implement our simulation model. OMNeT++ is a discrete event network simulator where a simulation model consists of several interconnected modules. Simple modules, described in C++, are at the base of any structural description, no matter how complex it is. Communication between modules is realized in OMNeT++ using *messages*.

Our OMNeT++ model of a VHO system is shown in figure 1.

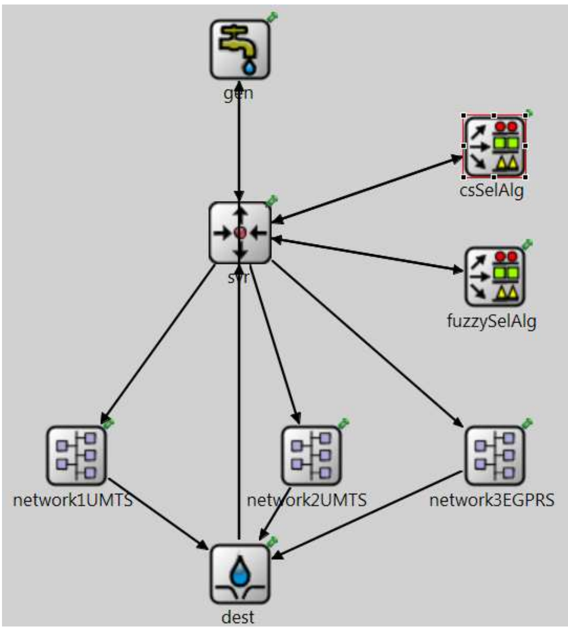

Fig. 1. The OMNET++ model of the VHO system

The generator module (*gen* in figure 1) creates OMNeT++ messages that correspond to real-life IP packets, or to real files, or web pages, depending on the type of traffic that is modeled.

For the background (e-mail, FTP) or interactive (WWW) traffic, the generator will create the next file or web page only after the previous one has arrived at the destination. The destination module *dest* informs the generator when the file has been completely sent. For the streaming traffic, the generator will generate data packets at certain time intervals, without any feedback from the destination module, and the server (*svr*) will have to store the packets waiting to be sent.

The destination module performs also statistics collection and deletes the OMNeT++ messages that model the files that arrive at destination.

The network selection algorithm is represented in the current implementation by two OMNeT++ modules, the *fuzzySelAlg*, that implements our fuzzy inference based VHO algorithm, and the *csSelAlg*, that contains the consumer surplus (CS) algorithm ([20]).

In the model we have two UMTS and one EGPRS networks: *network1UMTS*, *network2UMTS*, *network3EGPRS*. The user can chose one of them in order to send its files.

Each radio access network consists of a general part, common to all types of radio access technologies, and a part that is specific to each radio technology. The common part is a high level representation, that models data transfer at IP level, considering that the transfer rate of a user remains constant during the transfer of an IP packet. The transfer rate depends on the radio conditions (i.e., the quality of the radio link between the user and the base station) and on the network load.

More details about our model are given in [21].

III. The fuzzy inference network selection algorithms

In this section we describe a novel fuzzy logic based network selection algorithm that uses fuzzy inference in order to select a radio access network.

In the current stage of our work, the algorithm can select between two networks, one being considered to be better. More precisely, the fuzzy rules are formulated in order to determine if the better network is selected or not. If the better network is not selected, then the other network will be the selected one.

Fuzzy inference is based on fuzzy IF THEN rules, that can be expressed in the form IF premises THEN conclusion. In our case, the rules are in the form:

IF *user's preference* for the better network is Very High AND *network load* is Low THEN *selection decision* of the better network is Strong Select.

The inputs of the algorithm are the linguistic variables *user's preference* and *network load*, while *selection decision* is the linguistic variable from the conclusions of the fuzzy if-then rules. Linguistic variables are variables that have as values terms in a natural or artificial language. In our case, the linguistic variable *user's preference* has the values *very high (VH)*, *high (H)*, *medium (M)* and *low (L)*, while the linguistic variable *network load* (UMTS cell load) has the terms *low (L), medium (M), high (H)* and *very high (VH)*.

The terms of a linguistic variable are fuzzy sets. A fuzzy set is a set where each of its elements is characterized by a membership function (or degree of membership) with values in the real number intervals [0,1]. This means that, for a fuzzy set, an element belongs to that set in a certain degree (in a classic, or crisp set, an element either belongs or it does not belong to that set). The degree of membership is usually denoted with μ. More details about fuzzy logic can be found for example in [22].

Figure 2 presents the internal representation of the linguistic variables *user's preference* and *network load*. In our implementation, based on the implementation from [23], the domains of values of the linguistic variables are represented on a number of bits n, in this case on 64 bits. If necessary, we use linear function for scaling the real domain of values to the domain of internal representation. For example, for the linguistic variable *network load*, the real domain is between 0 and 100%, domain that is scaled to integer interval [0, 63].

In our implementation, the membership functions are represented on integer values in the interval $[0, 2^m - 1]$, instead of real numbers in the interval [0,1], in order to increase the processing speed. In the current simulations $m = 4$.

The fuzzy linguistic variable selection decision is represented in figure 3. Its terms are: *Strong Reject (SR), Weak Reject (WR), Weak Select (WS)* and *Strong Select (SS)*.

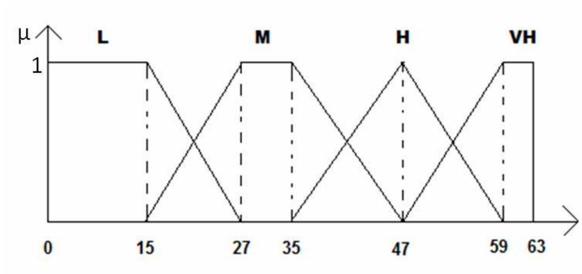

Fig. 2. The internal representation of linguistic variables *user's preference* and *network load* [23]

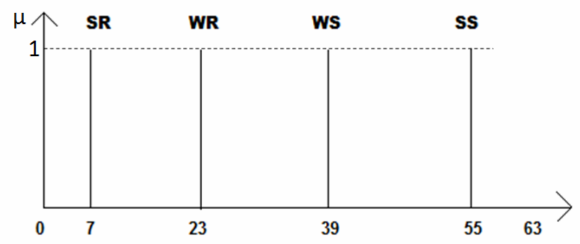

Fig. 3. The internal representation of linguistic variable *selection decision*

In order to ensure a prioritization between users, we consider three classes of users: *high precedence* (HP) users, *medium precedence* (MP) users and *low precedence* (LP) users. A certain user can belong to only one category of users (e.g. HP).

The complete set of fuzzy rules is represented in table I for high precedence users, in table II for medium precedence user, and in table III for low precedence users. The precedence is based for example on users' subscription, so that high precedence users have priority over medium or low precedence users for selecting the better network.

		User's preference			
		L	**M**	**H**	**VH**
Network load	**L**	WR	WS	SS	SS
	M	WR	WS	SS	SS
	H	WR	WS	WS	SS
	VH	SR	WR	WS	SS

TABLE I
THE SET OF FUZZY RULES FOR HP USERS

The better network is selected if, after applying the fuzzy inference, the resulted value of the selection decision is bigger

		User's preference			
		L	**M**	**H**	**VH**
Network load	**L**	SR	WR	WS	SS
	M	SR	WR	WS	SS
	H	SR	SR	WR	WS
	VH	SR	SR	SR	WR

TABLE II
THE SET OF FUZZY RULES FOR MP USERS

		User's preference			
		L	**M**	**H**	**VH**
Network load	**L**	SR	WR	WS	WS
	M	SR	WR	WR	WS
	H	SR	SR	SR	SR
	VH	SR	SR	SR	SR

TABLE III
THE SET OF FUZZY RULES FOR LP USERS

than 31 (the middle of the [0, 63] interval used for the internal representation of the linguistic variable selection decision).

IV. SIMULATION RESULTS

In this section we present the simulation results obtained with our fuzzy inference-based network selection algorithm. We compare our algorithm with the consumer surplus algorithm from [20]. For a better comparison, we use a simulation scenario similar to that from [20]:

- the modeled traffic type is FTP
- we use the network selection algorithm after the transfer of each file
- the file lengths are the same as in Table 1 from [20].
- we consider the length of an IP packet to be 1000 bytes.

A. The simulation setup

For our simulations, we realized two configurations, one with two UMTS networks, and one with one UMTS and one EGPRS networks. When we use two UMTS networks, one of them has better radio conditions and smaller network load, and we call it the 'good' UMTS network (cell), the other being the 'bad' cell. In the configuration with one EGPRS network, the UMTS network is the 'bad' UMTS network.

The cell load for the two UMTS networks is modified with a value given by a normal distribution with zero mean value and standard deviation of 150 in the case of the good network, and of 200 for the bad network. This happens at intervals of 0.6 s for the 'good' UMTS network, and at 0.3 s for the 'bad' UMTS network. Because the mean value of the distributions is zero, for both UMTS networks the network load will fluctuate around the initial load, without having an increasing or decreasing trend. The initial load of the good network is 256 kbps, while for the bad network it is 512 kbps.

The radio conditions are modeled also by normal distributions. For the good UMTS network the maximum transfer rate supported by the radio link is given by a normal distribution with a mean value of 256 and a deviation of 100, while for the bad UMTS network, the mean value is 80 and the deviation is 70. It means that for the good UMTS network, the radio link will ensure a transfer rate in the interval $[256 - 100, 256 + 100]$ kbps, most values being 256 kbps. For the other network the values of the transfer rate will be in the interval $[80 - 70, 80 + 70]$ kbps, with a maximum number of values around 80 kbps. The actual transfer rate will be the minimum between the value given by the quality of the radio link, and the available cell capacity.

It means that the average load of each cell will remain close to the initial value. The difference between the good and the bad cell is given by the radio conditions. For the good cell, the possible transfer rate is given by a normal distribution with an average value of 256 and a deviation of 100, while for the bad network the possible transfer rate is given by a normal distribution with an average of 80 and a deviation of 70. The radio conditions are modified at intervals of 0.4 s for the good UMTS network, and 0.2 s for bad UMTS network.

For the EGPRS network, the radio conditions are represented by nine modulations and coding scheme (MCSs), each MCS providing a certain transfer rate for the end user. The 9 MCSs are given by a uniform distribution. The cell load is modified by a number of time slots in the interval $[-4, 4]$ generated by an uniform distribution. If the generated number is positive, it means that a new user comes into the cell, and the cell capacity decreases with the generated value, while if the generated number is negative, then a mobile user leaves the cell, and the cell capacity increases. The mobile modeled user receives maximum 4 time slots, if there are available. Based on the cell load, we compute the number of mobile stations (MSs) that share a time slot, and divide the capacity of the time slot (given by its MCS) to the number of MSs that share it [21].

We consider that in case of congestion, or in case of bad radio conditions, the modeled user still receives radio resources, but with a minimum transfer rate. For the results presented here, the minimum transfer rate is considered to be 8.0 kbps for all networks.

All simulations were run for 100000 seconds, simulation time.

B. Results

The average file delays are represented in figure 4, in function of the file lengths, for files from 10 kB to 200 kB. The file lengths are expressed in bits, including the headers, as in the table 1 from [20]. The difference between the good and the bad UMTS cells can be better seen for the longer files.

For the configuration with one UMTS and one EGPRS cell, the results obtained for the EGPRS cell are very close to those obtained for the UMTS cell and hence we did not represent them.

Figure 5 shows the percentage of late files for MP users and for two UMTS networks. Here we consider that a file is a late file if its delay is bigger than 10 seconds. Unlike [20], we have considered that late files are still accepted by the user, and we count these files. Again, the results obtained for the EGPRS

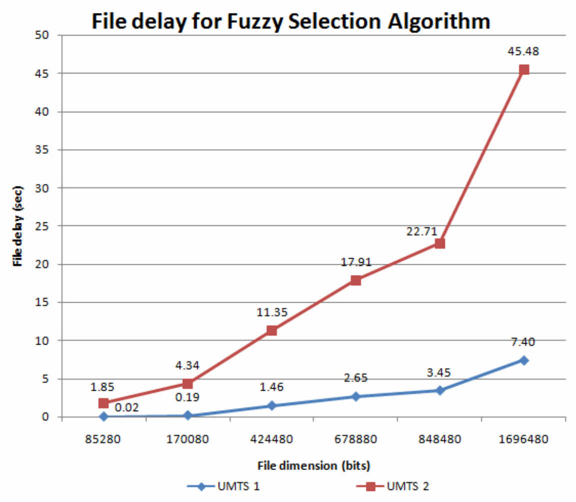

Fig. 4. File mean delay for different file lengths with fuzzy inference algorithm and two UMTS networks

cell are very close to those obtained for the bad UMTS cell and are not shown here.

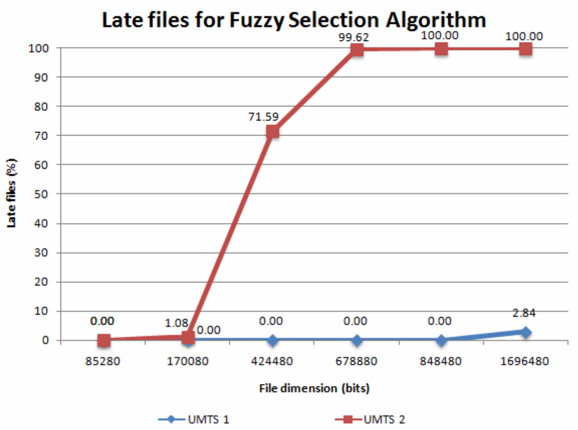

Fig. 5. The percentage of late files with fuzzy inference algorithm and two UMTS networks

The results from figures 4 and 5 are for MP users and for two UMTS networks, because for HP users all files will be sent on the better network, while for LP users, all files will be sent on the worse network.

The consumer surplus (CS) network selection algorithm selects a network based on the predicted benefit (the consumer surplus) that a user will have for the transfer of its files. The benefit is the difference between a utility function representing the amount of money that a user would pay for a file, and the cost charged by the network for that file. If a file arrives to late for the user, then it worth nothing for him, otherwise it uses a linear utility function [20]. In our model, the CS algorithm is implemented by the OMNeT++ module *csSelAlg* from figure 1.

A comparison between the two network selection algorithms (fuzzy and CS), from the user's point of view, can be based on the total number of files transferred by the modeled user during the 100000 seconds of simulation time. Figure 6 presents the results for the CS algorithm, and for the fuzzy algorithm, for the three types of users: LP, MP and HP. Of course, the number of files depends on the file length. From figure 6 it can be seen that high precedence users transfer more files than the medium precedence users, while the LP users transfer the smallest number of files. When the CS algorithm is used, the number of files is almost the same as the number of files transferred by the MP users with the fuzzy selection algorithm (the curves denoted MP and CS in figure 6 almost overlap).

This means that the fuzzy algorithm applied for medium precedence users gives similar results with the CS algorithm. The high precedence users are advantaged by the selection algorithm in the sense that they can select the better (but more expensive network) whenever they want, while the low precedence users receive mostly the cheapest, but less efficient network.

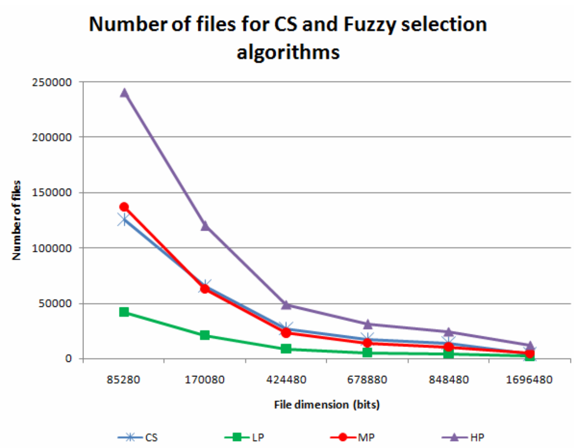

Fig. 6. The number of files sent by the modeled user with CS and fuzzy inference algorithm, for two UMTS networks

The fuzzy algorithm has the advantage, over the consumer surplus algorithm, that it can prioritize the users, but the cost is a more computational intensive algorithm.

The duration of simulations on a laptop equipped with Intel Core i7-2670QM CPU at 2.20 GHz, Windows 7 Enterprise 64bit is 921 seconds for the fuzzy algorithm, HP users, for all the six file lengths, two UMTS cells, and, in the same conditions, 750 seconds for the fuzzy inference algorithm, LP users, 738 seconds for MP users, and only 28 seconds for CS algorithm.

V. Conclusions and Future Work

This work presents a novel fuzzy logic based network selection algorithm and the simulation results that validate our algorithm. The fuzzy algorithm is compared with a consumer surplus algorithm proposed by Ormond et al in [20].

Our fuzzy logic based network selection algorithm is, to the best of our knowledge, the first fuzzy logic-based network selection algorithm that enables a prioritization of the users. Our algorithm is applied only at the initial selection of a network, during a data transfer session, which will allow network operators to maintain their existing algorithms used for handover.

The future work part will consists of the following tasks:

1) to adapt the set of our fuzzy rules in order to allow the modeled user to select between any number of existing radio access networks.
2) to compare the fuzzy inference based network selection algorithm with a fuzzy MADM algorithm.
3) to improve the fuzzy logic controller architecture that we are using in order to speed-up the simulations.
4) to perform a sensitivity analysis, in order to see how different parameters influence the efficiency of our VHO algorithm.

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