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Use of Fuzzy Logic for Networks Selection in Heterogeneous Wireless Environment

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Abstract— **Two proposals are presented in this study in an attempt to solve the problem of network selection, which are based on fuzzy logic techniques and methods of decision making. The first proposal uses a combination of the fuzzy method with two MADM (Multiple Attribute Decision Making) methods, the AHP (Analytic Hierarchy Process) and the GRA (Grey Relational Analysis), whereas the latter uses only the fuzzy logic technique. The two are compared with each other and with a third proposal, which uses a combination of AHP method along with a cost function. The results show that the two proposals presented in this paper are more efficient to sort and select the best access network compared to the third one.**

Keywords— Network selection, MADM, AHP, GRA, Fuzzy logic

I. INTRODUCTION

The existence of multiple wireless access networks of different technologies bring along distinct Internet access characteristics (cost, network parameters, security, etc.), which influence directly the quality of service of these networks.

Thus, in these types of environment it is important that the computer can always select the best access point in order to obtain the required flow for the application in use. For this, the use of network selection techniques to classify and select the best access point available in the environment becomes a crucial point so that the handover is executed in a concise way, avoiding some problems such as the ping-pong effect.

With the evolution of the mobile terminals (laptop, netbook, mobile phones, etc.) with multiple network interfaces (Wi-Fi, WiMAX, UMTS, etc.) and with the development of IP-based applications, they have become able to connect to different wireless networks hoping to get the best of real-time services (voice and video) and non-real time (SMS, MMS) [14], i.e., connection anywhere and anytime with the best access network available (ABC - Always Best Connected) [2].

So, the management of the handover becomes an essential part of this scenario (NGWN - Next Generation Wireless Networks), being composed of three phases [3]:

- Phase 1 - checking the available networks in the environment where the device is;
- Phase 2 - sorting and selecting the best access network;
- Phase 3 - executing the handover.

As it may be noted above, the handover takes place between wireless networks with different technologies, known as vertical handover. Instead, the horizontal handover happens between wireless networks with the same technology [4].

The network selection process is within this context whose function is to classify and select the best access network among those available in the environment, and it is divided into three distinct logic blocks, which are [1]: data collection, processing of data and classification of access networks. In general, strategies and network parameters directly impact the selection of network and they can be divided into the following categories [1]:

- Category 1: includes parameters that are not related to quality of service, since they do not change frequently, such as monetary cost, encryption, etc.;
- Category 2: includes widely used quality of service parameters, dynamic or not, provided the network, such as jitter, delay, packet loss, throughput, etc.

Therefore, this study aims to present two proposals supported by the use of Fuzzy Logic technology, demonstrating which one is the most effective in assisting the handover in the proposed scenario, comparing their results with a proposal that does not use such technology.

The remainder of this paper is organized as it follows: the work related to the techniques used is presented in section II; the characterization of experiments is shown in section III; in section IV, the proposals of network selection are described; in section V, the results showing the best proposal are presented; and, finally, the conclusion and future work are presented in section VI.

II. RELATED WORK

The authors in [5] make a comparison among the MADM, SAW, MEW and TOPSIS methods, whose goal is to classify access networks in three different scenarios. In the first scenario, TOPSIS and SAW methods proved similar in classification of networks, while the MEW method showed a slight variation in its classification. In the second scenario, where two networks are removed from the classification, the SAW and MEW methods proved similar, while the TOPSIS method obtained a change in its classification for suffering from the problem of abnormality ranking. Finally, a distinction between the classifications obtained in the previous scenarios is presented in the third scenario, where the TOPSIS method proves to be more consistent in the variations, while the SAW and MEW methods are constant with little variability in the classification of networks.

The network selection made by the authors in [6] is based on a fuzzy multiple criteria decision-making, where all the selected criteria are normalized by a normalization function and the result is fuzzified, generating a degree of membership between 0 and 1, which will be used to give weights to these criteria. Finally, the selection of the best access network is made by a cost function.

The network selection algorithm of the authors in [7] gives first preference to the UMTS network, in case the wi-fi is not available, since the former has a greater geographic coverage, not allowing the mobile device to run out of connection. Therefore, the mobile device only initializes the data collection of QoS criteria in order to select the best access network, when there is at least a wi-fi available, the maximum signal is greater than the established limit and it possibly remains a period of time in this environment, thus avoiding the ping-pong effect. After confirming the availability of wi-fi networks in the environment, the mobile device starts data collection, together with the calculation of the weights for each of the criteria for QoS by AHP method. The final decision to select the network will be taken by a cost function.

The authors' article in [8] divides the process of network selection in four stages, which are:

- Checking the need for handover;
- Selecting the appropriate network to continue the application traffic;
- Classifying networks and selecting the best;
- Running the handover.

Thus, in the first stage, is checked whether there is a need for handover, by monitoring the received signal strength and quality of service of networks. If so, the second stage starts, which selects the appropriate networks to continue the user's applications, and, finally, there is the classification of networks according to the user's preferences like cost and network parameters like received signal strength (RSS) in the third stage. In all three stages fuzzy logic is used in three different environments, in this case, applications that use download, voice applications and the user's preference. In download environment the WIMAX network was selected 80% of the time, in voice application environment the cellular network was selected 80% of the time and, finally, in the user's preference environment the WLAN network was selected 80% of the time.

III. METHODOLOGY

To assess the impacts of network parameters (QoS), jitter, delay and packet loss, in addition to the monetary cost parameter in the network selection process, a scenario with two computers and two access points was set up, which are structured as shown in Figure 1 and taking the following function:

- Computer 1: Client;
- Computer 2: Router;
- Wi-fi access point 1: 802.11b model;
- Wi-fi access point 2: 802.11g model;
- 3G base station 1: UMTS;
- 3G base station 2: UMTS.

The client computer has two USB (Universal Serial Bus) network interfaces and two USB 3G network interfaces, each previously connected to its respective access point. Therefore, the wi-fi interfaces are connected to access points 1 and 2, while the 3G interfaces are connected to different mobile operators, called base stations 1 and 2.

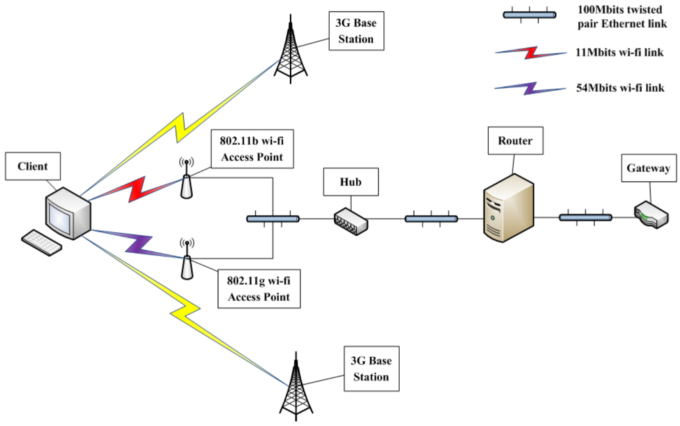

Figure 1. Representation of the structure of the test scenario

All computers used in the assembly of this scenario have the same configuration: Intel Atom Dual Core, 2GB RAM and 500GB hard drive. Table 1 shows the list of hardware and software installed and used in computers.

TABLE 1. LIST OF HARDWARE AND SOFTWARE USED IN SCENARIO FOR EXPERIMENTS

Computador	Software	Hardware
1	- Linux Ubuntu version 4.11 Natty Narwhal Operating System; - gcc version 4.5.2.	- Two wi-fi network cards: * Tenda 802.11N pattern. - Two 3G network cards: * ONDA MAS190UP model; * HUAWEI E173 model.
2	- FreeBSD version 8.2 operating system. - ipfw dummynet version 4.	- Three network cards: * 100Mbits Ethernet.

Thus, the experiments consisted of 35 iterations, each iteration consisting of two rounds and each round consisting of 10 ICMP (Internet Control Message Protocol) requirements of the client bound to its outgoing gateway, collecting the values of jitter, delay and packet loss generated in these two shifts, during a whole week, in the morning, afternoon and night shifts, totaling 420 iterations on a single day. It is important to mention that the best access network is selected in each iteration (60 seconds). Then, the averaged values of these parameters were forwarded to the processing and classifying techniques which selected the best network access.

All traffic generated in wi-fi networks was done by the router through the ipfw (ipfirewall) command, since we have no control over the 3G networks because operators do not allow access to their infrastructure. Therefore, as there was no way of knowing how much traffic was being transmitted over 3G networks, our own traffic needed to be created in wi-fi access points, simulating a lot of traffic. Graphs based on these experiments will be designed to visually demonstrate at what point the best network was selected for each proposal, and the classification given by them as well.

It is relevant to mention that the experiments took place in a fixed terminal, i.e., with no movements in it.

IV. Proposals

A. *Network selection using fuzzy logic, AHP and GRA*

Our first proposal for network selection is aimed at using two strategies already quite widespread in the literature, except combining them in order to rank and select the best available network access in the environment the most efficiently possible. The strategies are: fuzzy logic and two MADM, AHP and GRA methods.

The choice of fuzzy logic was motivated by the accurate output supplied from the raw data input, while the choice of AHP was motivated due to its efficient method to generate weights for objective data and, finally, the choice of GRA was motivated because it is a very efficient method of classifying alternatives to meet a certain goal, in this case the choice of the best access network.

Our system is divided into three functional blocks: the collector, processor and decision maker. The collector aims to collect data concerning the delay, jitter and packet loss, provided by the ICMP, as it can be seen in Figure 2.

The monetary cost parameter is fixed, with no need to be collected. It just needs to be informed by the mobile operator with the value of wi-fi networks, 0 and the network values of base station 1 and base station 2, 89.9 and 79.9 reais respectively, since only the terminal access to the access point is being considered.

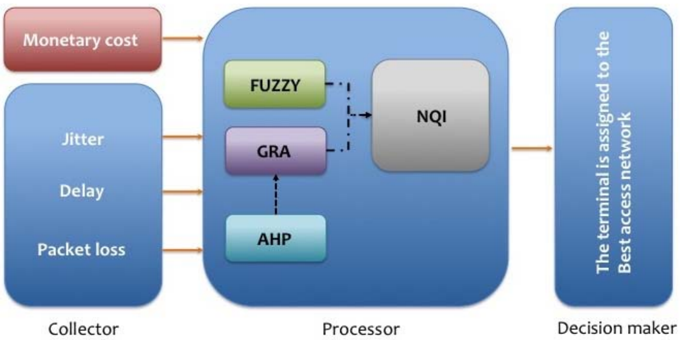

Figure 2. Architecture of the fuzzy logic, AHP and GRA proposal

This collection takes place through two rounds of 10 ICMP, based on the user's terminal to the access point, where at every turn the collected values are stored in a file, in this case, the medium RTT (Round Trip Time), because we are dealing with the sum of all the end-to-end delay [9].

Once stored, these data are then processed by the processor whose module consists of the fuzzy logic technique and the AHP and GRA methods in order to classify access networks in the environment where the terminal is.

Among the known types of traffic, there are the data, the audio and video, considering that the audio and video produce a large amount of network traffic. As there are no known video thresholds, we chose to use the thresholds audio in the fuzzy system, since they are already known and documented, stating that in a transmission of audio (VoIP - Voice over Internet Protocol), the delay cannot be greater than 300 ms, the jitter cannot be greater than 150ms and packet loss cannot exceed more than 3% [11] - [13], leaving the sound ineligible for the human ear, in these cases.

Under this assumption, in the fuzzy system, each linguistic variable jitter, delay, packet loss and monetary cost have three linguistic terms, which are: low, medium and high, where the universe of discourse of each of them is within the audio traffic thresholds. Each of these terms was fuzzified with triangle membership function with the inference of the Mamdani method over the generated result, as it can be can be seen in Figure 3.

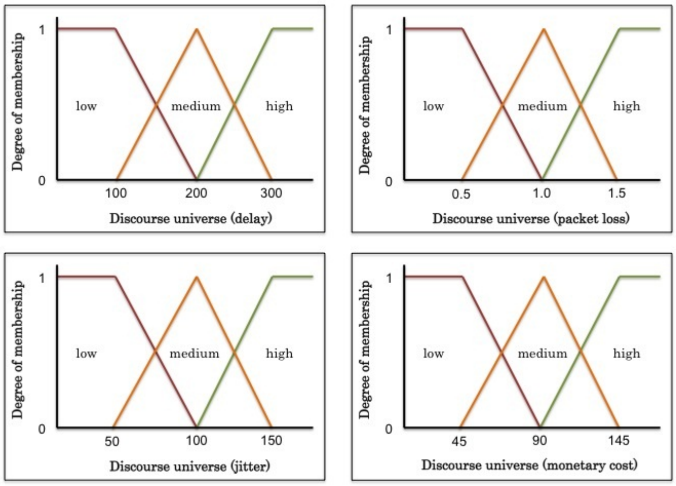

Figure 3. Fuzzification

Here are some examples of the rules of fuzzification used in this proposal.

- if delay is low and jitter is low and packet loss is low and monetary cost is low, then MOS is great;
- if delay is low and jitter is low and packet loss is low and monetary cost is medium, then MOS is great;
- if delay is low and jitter is low and packet loss is low and monetary cost is high, then MOS is great;
- if delay is low and jitter is low and packet loss is medium and monetary cost is low, then MOS is great;

- if delay is low and jitter is low and packet loss is average and monetary cost is medium, then MOS is close to great;
- if delay is low and jitter is low and packet loss is average and monetary cost is average, then MOS is good;

Finally, the defuzzification has the linguistic variable called "mos", which has five linguistic terms, which are: bad, close to good, good, close to great and great, as it can be seen in Figure 4. The final result is calculated by the maximum center method.

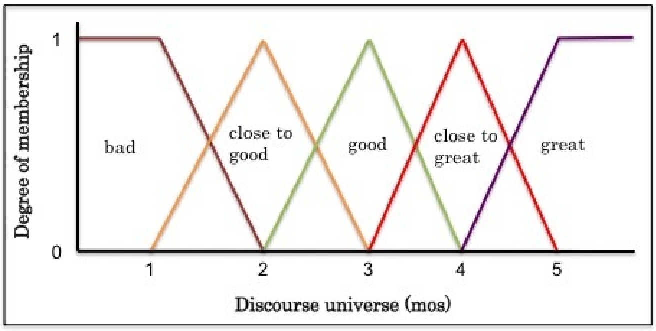

Figure 4. Deffuzification

So as it can be seen, our fuzzy system has four inputs and one output, the latter informs how much quality the network has. Besides, there is the GRA method, which will also receive the same values collected from jitter, delay, packet loss and monetary cost, resulting in the classification (score) of each network. This classification is made possible because of the weights provided by the AHP method for each criterion. The weights obtained by AHP for the criteria mentioned above are 0.18, 0.25, 0.05 and 0.52 respectively.

These weight values were based on the importance of each network QoS criterion concerning the audio transmission, i.e., jitter has a slightly larger importance than the delay for voice traffic and they have a much greater importance than the packet loss [13], while the monetary cost has a much greater importance than the criteria mentioned above, since we assume that the user will always opt for the cheaper access network.

Finally, there is the decision maker module, whose function is to select the best access network among those available in the environment where the user is, through the biggest value of the NQI (Network Quality index) variable resulting from the processor module, whose final value is an arithmetic average of the results generated by fuzzy logic and the result generated by the AHP and GRA methods.

B. *Network selection using fuzzy logic*

Our second proposal of network selection has all the characteristics of the first one, except for the AHP and GRA methods, i.e., only the technique of fuzzy logic is used, as it can be seen in Figure 5.

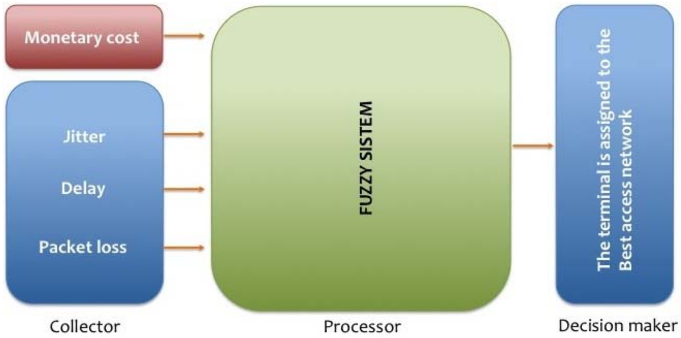

Figure 5. Architecture of the proposed fuzzy logic

Fuzzy logic is a mathematical technique that works with the theory of sets, i.e., each of the linguistic terms used in both the fuzzification and defuzzification are subsets as bad, good, great, etc. If all values collected from access networks meet, for example, within the range belonging to the bad subset, even with different values from each other, they will have the same score, a fact that constrains the application of this technology to the data sets that may not have this feature. Therefore, we present an alternative to the use of fuzzy logic on data with these characteristics, the use of the GRA technique.

V. RESULTS

The results obtained with each of the proposals is featured in the graphics below, which were produced based on the total average of the parameters of jitter, delay and packet loss collected from the access networks that were selected in each iteration.

The proposal using the combination of fuzzy logic with the AHP and GRA methods proved very efficient in selecting network, with the final result of 99.76% correct choice on the access networks available in the environment, as shown in Figure 6.

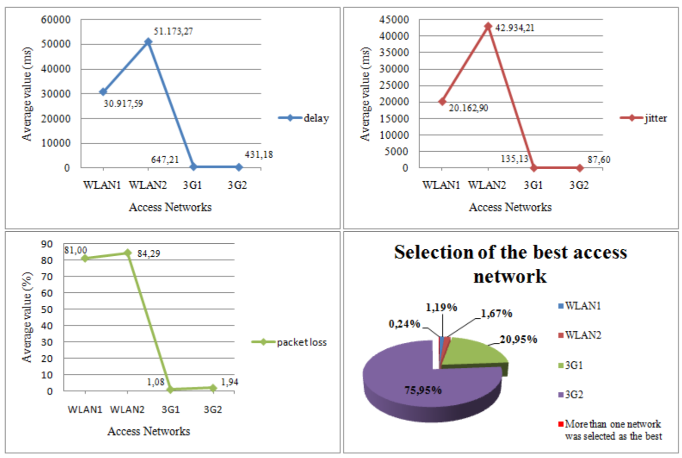

Figure 6. Network selection using fuzzy logic, AHP and GRA

By looking at the average values of each criterion, ranging from the tens or hundreds of one network to another, it is possible to notice that they are in the same fuzzy subset, i.e., the WLAN1 and WLAN2 access networks, though with high values in their criteria, would have the same classification as the other networks in some iterations, and the classification by the given weights to each criterion prevailed when combined with the AHP and GRA methods. Thus, 1.19% of WLAN1 choice and 0.24% of WLAN2 choice occurred in an iteration where all criteria were judged by the fuzzy system getting the same punctuation and the same happened with the GRA method, since in this sense, the monetary cost criterion stood out at the time of choice.

The proposal using only fuzzy logic proved slightly less efficient in the network selection, with the final result of 97.86% correct choice on the access networks available in the environment, as shown in Figure 7.

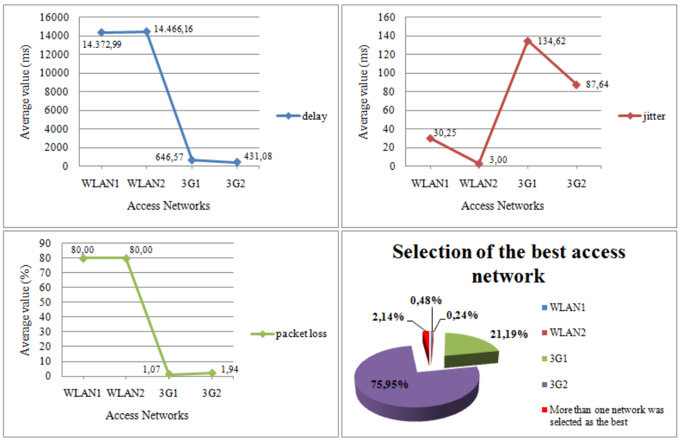

Figure 7. Network selection using fuzzy logic

By looking at the average values of each criterion, ranging from the tens or hundreds of one network to another, it is possible to notice that they are in the same subset, i.e., the access networks, though with high values in their criteria, would have the same classification as the other networks in some iterations. Thus, the 2.14% related to the selection of more than one access network is due to the fact that in more than one iteration the values of jitter, delay and packet loss are stored in the same fuzzy subset.

The proposal of network selection in [7], when used in our scenario, got a very poor performance in relation to the other two proposals, as shown in Figure 8. This is because of the cost function used by the authors, having a parameter value to 0, using equation (2), since all of our criteria are of cost, i.e., the lower the value of the collected data, the better the values of the operation, and even the final score of the access network will result in the value 0.

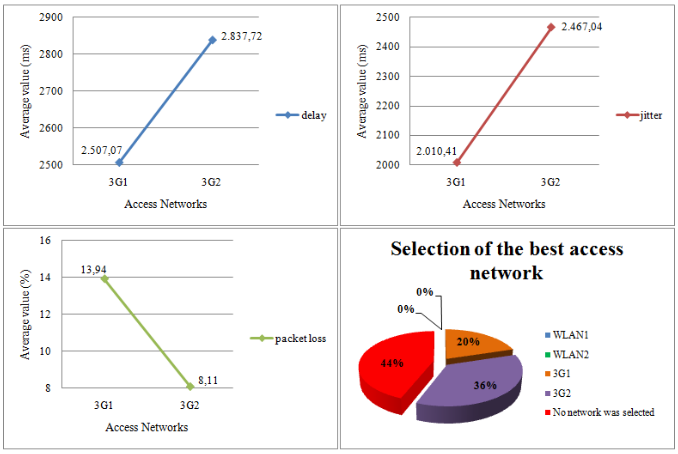

Figure 8. Network Selection using AHP and cost function

The weights given to jitter, delay, packet loss and monetary cost criteria through the AHP method were 0.323, 0.323, 0.198 and 0.154 respectively.

The authors standardized parameters using two assumptions:

The bigger, the better:

$$S(x_{ij}) = \frac{x_{ij}}{\max\{x_{ij} \mid i = 1,2,\ldots,m\}} \tag{1}$$

The smaller, the better:

$$S(x_{ij}) = \frac{\min\{x_{ij} \mid i = 1,2,\ldots,m\}}{x_{ij}} \tag{2}$$

The normalization of the parameters is:

$$N(x_{ij}) = \frac{S(x_{ij})}{\sum_{j=1}^{n} S(x_{ij})} \qquad i = 1,2,\ldots,m \tag{3}$$

Thus, the rate of decision making in the network i can be calculated as:

$$I_i = \sum_{j=1}^{n} w_j N(X_{ij}) \qquad i = 1,2,\ldots,m \tag{4}$$

Therefore, the proposal in [7] failed to select any access network in 44% of the experiments because the final score of WLAN1 and WLAN2 networks are equal to zero, making the solution ineffective for this type of scenario. By observing Figure 8, it is possible to verify that the 3G1 access network has a lower percentage of selection against 3G2 network, even with its monetary cost inferior to this network, it happens because some of the network parameters, delay, jitter and packet loss have values equal to zero in some iterations, thus influencing the choice of 3G2 network at certain times.

VI. Conclusion and Future Work

In this article we implemented two proposals, which had a very good performance in the proposed scenario, showing the effectiveness of the fuzzy logic technique that combined with classification methods as the GRA proved even more efficient.

Therefore, we can see that the decision-making methods are very useful in the classification of alternatives to achieve a goal and combined with an artificial intelligence technique makes the final result even more accurate.

As future work, these proposals are intended to be integrated with a handover software to a mobile device like a cell phone, enabling tests in motion, thus encompassing the whole process of mobility management.

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