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Integrated Fuzzy Solution for Network Selection using MIH in Heterogeneous Environment

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***Abstract*—Seamless handover between networks in heterogeneous environment is essential to guarantee end-to-end QoS for mobile users. A key requirement is the ability to select seamlessly the next best network. Currently, the implementation of the selection algorithm of the IEEE 802.21 standard by National Institute of Standards and Technology considers only the signal strength as a parameter to select the best destination network. In this paper, we improve the implementation of the existing selection algorithm by proposing an integrated solution to select the best destination network. Our proposed solution consists of proposing a Multi Criteria Selection Algorithm that modifies the current implemented algorithm by including additional parameters such as available bandwidth, mobile node speed and type of network. This first solution is complemented with a fuzzy logic model, which includes a new controller entity where parameters such as signal strength, signal quality and available bandwidth of the destination networks are considered as inputs. The inference rules for the controller entity are derived from a detailed analysis made on a large number of data retrieved from the servers of Alfa mobile telecommunications company. The results, initially obtained using Network Simulator, show that there is a need for a new framework taking into account additional parameters to guide network selection process during handover in order to provide mobile users with better QoS. They were then complemented with a model that qualified each candidate network in the vicinity of the mobile based on a scale of 0 (the least advisable network) and 1 (the most recommended network). This will lead to the mobile node choosing the network that has the maximum likelihood estimation between a set of recommended networks.**

Keywords-seamless vertical handover; QoS parameters; IEEE 802.21 MIH; fuzzy logic modeling

I. INTRODUCTION

Communicating from anywhere at any time is becoming a requirement of great importance for mobile users. However, the rapid expansion of wireless network technologies creates a heterogeneous environment. Nowadays, mobile users would like to acquire, directly from the device, different kinds of services like internet, audio and video conferencing, which sometimes require switching between different operators or network types. Moreover, user preferences are different. Some are interested in service costs only; others will be satisfied with broadband networks that cover large geographic areas, etc. Consequently, to satisfy the above requirements, user mobility should be covered by a set of different overlapping networks forming a heterogeneous environment. A mobile device should be able to choose, from all available networks in its environment, the one that meets its needs and ensures accordingly the transition from one cell to another in the same technology (horizontal handover) or between different types of technologies (vertical handover). During this handover period, the challenge is to conserve the QoS parameters guarantee. QoS is the capability of operators to provide satisfactory services for a given user in terms of data rates, call blocking, delay and throughput.

The remainder of this paper is organized as follows: Section II describes the background. Section III describes the main components of IEEE 802.21 standard and its implementation using NS2 simulator. Section IV provides an overview of wireless protocols used in our simulation environment. Section V describes the simulation scenarios and results. The fuzzy logic system is described in Section VI. Section VII discusses the fuzzy logic handover decision algorithm and we conclude in Section VIII.

II. BACKGROUND

In this section, we will present the MIH and Fuzzy Logic related works to select the destination network during handover. Our contributions to improve the selection of the destination network during handover are summarized at the end of this section.

A. MIH Related Work

The IEEE 802.21 [1][2] is an emerging standard, also known as Media Independent Handover (MIH) that supports management of seamless handover between different networks in a heterogeneous environment. The current implementation of the IEEE 802.21 standard for the network simulator (NS-2) by National Institute of Standards and Technology (NIST) based on draft 3 [3][4] considers only the Radio Signal Strength Indicator (RSSI) as a unique parameter to determine the best network [5]. We argue in this paper that this parameter alone is not sufficient to satisfy users' needs. Indeed, signal strength, available bandwidth (ABW), traffic on the serving network and packet loss ratio are among the other parameters that have an impact on the mobile user in terms of QoS. For example, a bad QoS, when using a real time application in a handover process, may be due to a lack of ABW because of high load in the host network while the signal strength is good.

Several attempts have been made to improve the handover within the MIH framework. Chandavarkar et al. [6] proposed an algorithm for network selection based on the strength of the battery, the speed of the mobile, and the coverage radius of the network in order to avoid power loss during handover and to improve the efficiency of seamless handover. Siddiqui et al. [7] proposed a new algorithm named TAILOR that uses different QoS parameters based on user preferences to select the destination network. Also, this algorithm optimizes the power consumption.

Jiadi et al. and Ying et al. [8][9], modified the MIH where handover is performed in three steps: initiation, selection and execution. The proposed process aims to improve the handover delay by adding new events to the initiation step that can be generated from the application layer instead of lower layer upon the user's satisfaction. Moreover, they added a new algorithm at the selection step based on price, delay, jitter, signal noise ratio (SNR) and available data rate within the MADM (Multi Attribute Decision Making) function to improve the QoS during the selection process.

The research work initiated in [10][11] proposed a selection algorithm based on the willingness of users to pay for a given service, while Cicconetti et al. [12] provided an algorithm based on three parameters: connectivity graph, connectivity table between nodes and the current geographical position of the serving network. The proposed algorithm reduces the handover time and the energy consumption of mobile node (MN) due to scanning.

The Media Independent Information Server (MIIS) component (see Section III) of MIH is not fully implemented by NIST. Arraez et al. [13] implement this service and install it on each access point (AP) allowing users to save the energy of the battery by just activating a single interface. According to the IEEE 802.21 standard, an MIH user communicates, through the link layer, with its MIHF, which sends a query to MIIS to retrieve the list of all networks in the vicinity. Alternatively, the authors of [14][15] developed a new method to communicate with the MIIS through the upper layers using Web Services.

Moreover, 802.11 protocols [16] define 11 channels for communication and force the MN during the handover to scan all channels looking for the active one. Khan et al. [17] proposed a new algorithm based on MIIS, to provide user with a list of only active channels to be scanned in order to save time during handover.

An et al. [18] added two new parameters to MIH that allow FMIPV6 to save the steps of proxy router solicitation and advertisement (RtSolPr/PrRtAdv). This resulted in a decrease of handover latency and improvement of packet loss ratio.

B. Fuzzy Logic Related Work

A fuzzy logic model has been also used for handover solution in heterogeneous environments. Unnecessary handovers, when oscillating between two networks, are commonly known in the literature as the Ping-Pong effect. Kwong et al. [19] show that the handover decision based only on RSSI may exhibit a drawback such as the Ping-Pong effect. P. Dhand [20] and Pragati et al. [21] proposed respectively a Fuzzy Controller for Handoff Optimization (FCHO) and a fuzzy algorithm based on multiple parameters to minimize the unnecessary handover and eliminate the Ping-Pong effect.

Several works have been done to select the best destination network by combining different types of parameters as input to a fuzzy model. Ling et al. [22] make use the RSSI and the distance between the MN and the base station. Yan et al. [23] use the velocity of MN and the ABW. Alternatively, Vasu et al. [24] use QoS parameter within a multi-criteria algorithm through a fuzzy logic controller (FLCs) rules. Sadiq et al. [25] propose a fuzzy logic based handover decision based on the RSSI of the AP and relative direction of the MN toward the APs. It also showed that using this schema, the handover latency at L2 level is improved. Authors of [26] use multiple parameters like bandwidth, SNR, traffic load and battery power to propose a fuzzy based vertical handover algorithm NG-VDA between LTE and WLAN. The research initiated in [27] proposed a modular fuzzy-based design for Handover Decision System (HDS) to deal with the large number of fuzzy inference rule base. Authors of [28] use the user preference and network parameters as input to the fuzzy system. Also it introduces fuzzy logic rules at different phases of the handover process. While authors of [29] proposed a fuzzy Q-Learning algorithm to find the optimal set of fuzzy rules in a Fuzzy Logic Controller (FLC) for traffic balancing in GSM-EDGE Radio Access Network (GERAN). To optimize the fuzzy logic algorithm without requiring an expert knowledge, Foong et al. [30] proposed a newer approach using Adaptive Network Fuzzy Inference System (ANFIS) where the training element is incorporated into the existing fuzzy handover algorithm. This training element helps in optimizing and modeling the membership function and the inference rules base.

C. Contributions

Different research work aimed to improve the standard itself or the NIST implementation of the standard. In this paper, we present two algorithms to improve the NIST implementation of the MIH standard.

The first contribution demonstrates, through simulation, that there is a need for additional input parameters with the RSSI to better select a destination network. This research work is complemented by a new fuzzy logic algorithm to better select the most appropriate destination network.

Within our first contribution we investigate, by experiment, the effect of the inclusion of three parameters with the RSSI into the selection mechanism during handover. These parameters are: ABW, type of network and mobile speed. As far as we know, these parameters have not been investigated at the same time before. As it will be detailed in Section V, our first experiment will show that by including the ABW, the packet loss ratio will be improved. The second experiment will show that based on the type (WIFI, WIMAX) of the current and destination network, we can save on packet loss. The third experiment will show that it is worthily significant to consider the velocity of the MN while selecting a new destination network. As a result, there is a need for a new model based on more than one input parameter to select the best destination network.

Concerning our second contribution, we propose a new model based on a fuzzy logic system that takes three parameters as an input to select the best destination network. This solution has been explored earlier in the literature. But the twist here lies in the fact that an accurate choice of the best destination network depends also on the accuracy of the membership function and the inference rules base used in the fuzzy logic model. Our added value for this contribution is that we construct our inference rules base after a detailed observation on more than 9500 records retrieved from the real server of an existing Lebanese mobile telecommunication company (Alfa). Among these 9500 records, we have 100 cases of vertical handover between GPRS network (2.5G) and UMTS (3G) network. Unfortunately, the LTE installation is still in progress for the all Lebanese Companies. After analysis of the QoS parameters value during handover, we conclude that the 100 cases of handover follow a set of 18 rules. These 18 rules constitute our inference rule. Also the membership function used is based on the exact values and threshold determined by Alfa. The findings are anticipated to be mirrored and extended to WIFI-WIMAX handovers, something that was not possible due to the lack of available data in such networks.

III. IEEE 802.21 STANDARD

The IEEE 802.21 standard, also known as Media Independent Handover (MIH), provides mobility management at layer 2.5 by being inserted between layer 2 and layer 3. As depicted in Figure 1, the Media Independent Handover Function (MIHF) is the main entity of the standard that allows communication in both directions between lower and upper layers through three services: event (MIES), command (MICS) and information (MIES) [4][31].

A. *Media Independent Event Services, MIES*

This service detects changes in the lower layers (physical and link) to determine if it needs to perform handover. Two types of events can occur: "MIH Event" sent by the MIHF to the upper layers (3 +), and "Link Event" that spreads from the lower layers to the MIHF.

B. *Media Independent Command Services, MICS*

This service uses two types of events. The "MIH Commands" transmitted by the user towards the MIHF and "Link Commands" sent by MIHF to lower layers.

C. *Media Independent Information Services, MIIS*

The MIIS let the mobile user discover and collect information about features and services offered by neighboring networks such as network type, operator ID, network ID, cost, network QoS, and much more. This information helps in making a more efficient handover decision across heterogeneous networks.

IV. WIFI, WIMAX, GPRS AND UMTS STANDARDS

In this section, we describe an overview of the emerging wireless technologies that we have used within the handover scenarios to validate our contributions.

A. *IEEE 802.11, WIFI*

IEEE 802.11, Wireless Fidelity (WIFI) [32], is a wireless local network technology designed for a private LAN with a small coverage area (hundreds of meters typically). Different versions of 802.11 communicate on different frequency bands with different bit rates. In all simulations that we performed during our research work, we use IEEE 802.11b version. Mobility support in conventional IEEE 802.11 standard is not a prior consideration and horizontal handover procedure does not meet the needs of real time traffic [33]. WIFI's QoS is limited in supporting multimedia or Voice over Internet Protocol (VoIP) traffic and several research activities have been carried out in an attempt to overcome this limitation [34].

B. *IEEE 802.16, WIMAX*

IEEE 802.16, WIMAX (Worldwide Interoperability for Microwave Access), technology is for metropolitan area network (MAN) covering a wide area at very high speed. QoS in WIFI is relative to packet flow and similar to fixed Ethernet while WIMAX define a packet classification and a scheduling mechanism with four classes to guarantee QoS for each flow: Unsolicited Grant Service (UGS), Real-Time Polling Service (RTPS), non-real-Time Polling Services (nrtPS) and Best Effort (BE). WIMAX mobile (802.16e) adds a fifth one called extended real-time Polling System (ertPS) [35]. WIMAX supports three handover methods: Hard Handover (HHO), Fast Base Station Switching (FBSS) and Macro-Diversity Handover (MDHO). The HO process [36] is composed of several phases: network topology advertisement, MS scanning, cell reselection, HO decision and initiation and network re-entry [37][38].

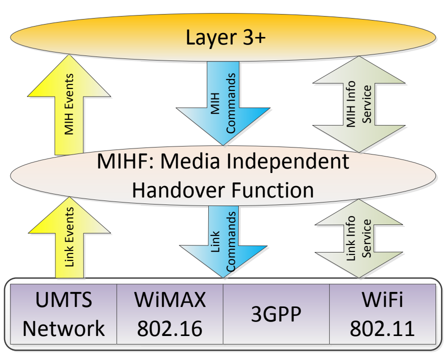

Figure 1. MIH Architecture

C. General Packet Radio Service, GPRS 2.5G

The General Packet Radio Service (GPRS) is an improved version of Global System for Mobile Telecommunications (GSM). GPRS was originally standardized by European Telecommunications Standards Institute (ETSI) and now maintained by the 3rd Generation Partnership Project (3GPP) [39][40]. GPRS Introduces two new elements [41] to the existing GSM architecture: the serving GPRS Support Node (SGSN) to control the communications and mobility management between the mobile stations (MS) and the GPRS network; and the Gateway GPRS Support Node (GGSN) that acts as an interface between the GPRS network and external packet switching networks such as Internet, or GPRS networks of different operators [42].

GPRS has several enhancements vs. GSM. (1) It introduces services based on packet-switching technique instead of the circuit-switching network. (2) It eliminates the monopolization of the GSM channel, reducing by that the communication cost and improving the transmission speed [43].GPRS assign a static IP address for the user reducing by that the time of session establishment and access to the service comparatively to GSM. GPRS enables billing by volume [44] (the number of exchanged packets) or based on the content (e.g., by image sent). Finally, GPRS introduces more sophisticated security mechanism than GSM [45].

D. Universal Mobile Telecommunications System, UMTS

UMTS is the third generation evolution of the GSM/GPRS systems; standardization work is done at a worldwide level within the 3GPP. UMTS, by integrating packet and circuit data transmission [46], allows the interoperability with GSM and its evolution. With the use of the Wideband Code Division Multiple Access protocol (W-CDMA), UMTS provide high transmission rate that can reach 2 Mbit/s allowing a better use of e-commerce, multimedia and Visio conference application from anywhere at any time. UTRAN is the great innovation of UMTS and is in charge of control and radio resource management. It enables the exchange of information between the mobile terminal and the core network. UTRAN consists of two main entities: (1) the RNS that contains one or more base station (Node B) and the Radio Network Controller (RNC), (2) the Serving GPRS Support Node SRNC controlling the mobility management. UMTS manage seamlessly two types of handover: soft and hard handover [47].

V. MIH PERFORMANCE EVALUATION

In this section, we will present three scenarios to assess the impact of the ABW, type of network, and user velocity on selecting a destination network during handover. For the three scenarios, the decision for handover is totally taken by MIH.

A. Simulation Environment

To show the limits of using one parameter to select an access network and to motivate the need of advanced selection methods that combine several constraints, we present several simulation scenarios using NS2, v2.29, which support the MIH module implemented by NIST.

The covered scenarios focus on criteria other than RSSI when evaluating network in the vicinity for handover. The first scenario investigates and assesses the impact of the selected network available bandwidth. The second one deals with the type of destination network. While the third scenario addresses the speed effect of the MN on QoS during handover.

Various simulation parameters are summarized in Table I. The traffic used has a constant bit rate (CBR), which allows for calculating the number of packet loss. It also could be used to simulate voice traffic. Packet size is always constant to 1500 bytes and the throughput is determined by varying the interval of sending packet during simulation.

B. Scenario I: NIST Selection Weakness

1) Topology Description: The topology of this scenario, shown in Figure 2, consists of two WIFI Access Points AP1 and AP2 (802.11b) located inside an 802.16 base station (BS) coverage area and one MN equipped with multiple interfaces. It is important to note that other streams of traffic source are connected to AP2 consuming its bandwidth. By doing that, I would simulate the connection of more than one mobile. Initially, the MN connected to AP1, starts moving to the center of the BS coverage area and on its way detect AP2. According to the NIST handover algorithm, that selects a new network based on the RSSI only, AP2 is considered as better network than WIMAX and the MN will make a handover from AP1 to AP2. Once the MN reaches the limit coverage area of AP2, the handover to WIMAX base station occurs.

2) Scenario I Results: By increasing the throughput of traffic generated by the CBR application on the MN, we observe an overall greater number of packet losses. Figure 3 shows the packet loss during HO. When a MN loses the signal on AP1 it needs to make a HO to another network, it has 2 choices: handover to AP2 or to WIMAX. According to NIST algorithm, which selects a new network based on the signal strength only, AP2 is selected and Figure 3 shows the number of Packet Loss (PL) during handover AP1-AP2. When the MN reaches the limit coverage area of AP2 and makes the handover to WIMAX. At this point, we observe another value of PL during HO AP2-WIMAX.

3) Critics of the NIST algorithm: The main issue with this algorithm lies in the fact that it selects a destination network based on the signal strength received by the MN, which is unsatisfactory. Indeed, a MN, near to an overloaded base station, receives a strong signal. According to NIST algorithm, the MN handover to this base station will occur and will result in a high packet loss ratio due to a lack of ABW.

C. Multi Criteria Selection Algorithm

In this section, a new selection algorithm named Multi Criteria Selection Algorithm (MCSA) will be proposed. It is a modified version of the algorithm proposed by NIST to select a destination network based on two criteria: RSSI and ABW of the destination network. We assume that the user preference is mainly composed of selecting a network with the largest ABW whatever the cost is within a predefined maximum limit. Then, we compare the number of packet loss during HO between MCSA and NIST algorithm.

1) Strategy of our MCSA algorithm: A MN that is connected to a serving network receives beacons and Router Advertisement (RA) from WIFI and WIMAX networks in the vicinity. According to our proposed algorithm, MN will select the network that has the biggest ABW. In order to get the value of ABW to the MN, we added to the structure of the beacons and RA in NS2 a new field that holds the value of ABW.

2) MCSA results: in order to compare MCSA and NIST results, we use the same topology of simulation cited in Figure 2. By using our proposed MCSA algorithm, which aims to find among the visible list of networks, the one that have the largest ABW, WIMAX is selected instead of AP2 and the total number of handovers decreases resulting in improving the total number of PL and the Quality of Service is thus preserved during the mobility of the MN.

TABLE I. SIMULATION PARAMETERS

WIFI Access Point AP1 and AP2 Parameters	
Transmission Power (Pt_)	0.027 W
Receiving Threshold (RXThresh)	1.17557e-10 W
Carrier Sending Threshold (CXTresh)	1.058.13 e-10 W
Coverage Radius	150 meters
Radio Propagation Model	Two-RayGround
Frequency (Freq)	2.4 GHz
Sensitivity to link degradation (lgd_factor_)	1.2
Physical Data Rate	11 Mbps
WIMAX Parameters	
Transmission Power (Pt_)	30 W
Receiving Threshold (RXThresh)	3e-11 W
Carrier Sending Threshold (CXTresh)	2.4 e-11 W
Coverage Radius	1500 meters
Radio Propagation Model	Two-RayGround
Frequency (Freq)	3.5 GHz
Sensitivity to link degradation (lgd_factor_)	1.2
Antenna Type	Omni Antenna
Modulation	OFDM
Physical Data Rate	30 Mbps

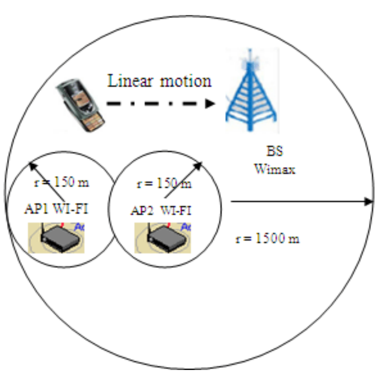

Figure 2. Scenario I topology

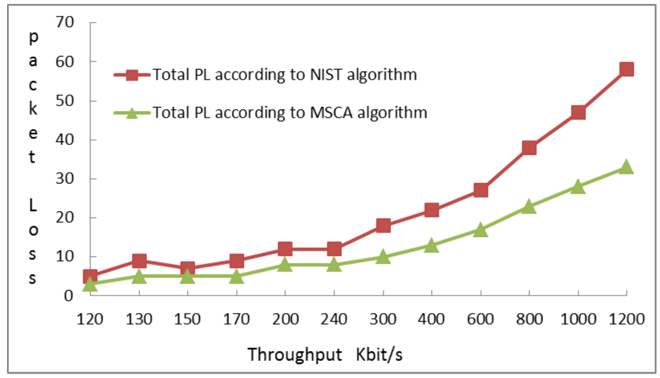

Figure 3. Packet loss according to NIST and MCSA algorithm.

For a user who gives more importance to the number of Packet Loss rather than type of network (WIFI or WIMAX), it is better to follow the strategy of our proposed MCSA algorithm that improves the packet loss ratio by 33% with respect to the NIST. Table II shows the improvement concerning the number of HO and the PL with MSCA for a given throughput.

We can conclude that selecting a destination network using only RSS as indicator does not meet the needs of all users. A more accurate choice of the destination network during handover would consider the ABW of the considered network. A new framework is needed to consider the values of different criteria while taking a decision in order to make a better choice concerning the destination network during handover.

In order to better understand the sequence of events that an MN and a network perform during a successful HO, we provide a short description of messages sequence chart in Figure 4. The dashed and non-dashed blocs represent the flow of handover messages according to NIST and MCSA algorithm. By using our MCSA algorithm, we can save all messages in the dashed bloc, which enables less signaling over the network and improves packet loss.

A detailed description of the events sequence according to the implementation of the IEEE 802.21 standard by NIST, corresponding to our simulation scenario and taking into account our MCSA algorithm or not, is summarized as follows:

1) MIH user on the MN sends MIH Capability Discovery Request to discover the link capability supported (events and commands) for each MAC on each node.
2) MIH user on the MN sends MIH Register Request to register to the local and remote MIHF.
3) MIH User on the MN sends MIH Get Status requesting the available network interface; it discovers the presence of two interfaces (WIFI and WIMAX) supporting events and commands services of MIHF.
4) MIH user on the MN sends MIH Event Subscribe request to subscribe to the events on the given links for local and remote MIHF. This latter sends MIH Event Subscribe response to the MIH User of the MN.

TABLE II. COMPARISON OF HO NUMBER AND PL WITH EACH ALGORITHM

According to NIST algorithm		According to MCSA algorithm	
Number of HO	***Total PL***	***Number of HO***	***Total PL loss***
2 (AP1 to AP2 and AP2 to WIMAX)	20 AP1 to AP2:9 and AP2 to WIMAX:11	1 (AP1 to WIMAX)	10 AP1 to WIMAX:10

5) Once the BS decides the reservation of bandwidth, it informs the MN of the frame structure in the uplink and downlink. It sends the DL-MAP/UL-MAP to the WIMAX interface of the MN. The WIMAX base station is detected and generates a Link Up event toward the MIHF of MN.
   MIHF of the MN order the WIMAX interface of MN to connect to the BS.
6) In this case, a router solicitation is sent from the MIPV6 module of MN to the neighbor discovery module of the BS.
7) Neighbor discovery module of the BS replies by sending RA to the MIPV6 module of MN with the network prefix of WIMAX base station = 3.0.0; router-life time= 1800s.
8) MN's WIFI interface receives a beacon message with a power above the threshold value and triggers a Link Detect event; the ABW of AP1 is largely available (not consumed by any other traffic), according to both algorithm MCSA and NIST, AP1 is considered as a better network.
9) MIHF of MN sends a Link Connect message to the WIFI interface of MN; exchanges of association Request/Response between MN and AP1.
10) The WIFI interface of the MN, in its sends a Link Up message to the MIHF and MIH user of MN.
11) Exchanging of RA and router solicitation between the MIPV6 of MN and the neighbor discovery module of AP1 (first WIFI access point).
12) Starting of traffic flow between the WIFI interface of the MN and the correspondent node through the AP1 access point.
13) Once MN reaches the limit coverage of the AP1, it starts receiving the beacon message coming from AP2. Detect the presence of a beacon power above the defined threshold.
14) WIFI interface of the MN sends a Link Going Down and Link Down to the MIH user of MN.
15) MIH user of MN sends a Link Scan request to the MIHF of MN.
16) The WIFI interface of MN sends a probe request and starts scanning the 11 channels of WIFI interface looking for an active one.
17) This message received by AP2, which reply by sending a probe response to the MIH user of MN through its MIHF. MIH user of MN detects the presence of AP2.

According to NIST algorithm, that considers this AP as a better network, decides to handover to it (and continues with step 19). But according to MCSA algorithm, which evaluates the ABW of AP2 before handover to it, find its ABW, consumed by other traffic, very small comparatively to WIMAX, ignore this network and handover to WIMAX directly (jump to step number 20).

18) MIH user sends to MIHF an MIH Link ConFig. This generates a Link Connect to the WIFI interface of MN (connection to AP2).
19) MIH user sends to the MIHF a MIH Link Disconnect, which disconnects the connection between the WIFI interface of MN and AP1. According to NIST algorithm, we continue with step 21 and according to MCSA we jump to step 28 saving by that all steps between 21 and 27. Thus, the signaling overhead decreases.
20) The WIFI interface of MN sends a Link Handover Imminent message to the MIHF of MN.
21) MIH user of MN sends Link Handover Complete to the MHIF of MN.
22) WIFI interface of MN sends Link Up indication event to the MIH user of MN through his MIHF announcing the detection of AP2 (second WIFI access point).
23) MIPV6 module of MN sends router solicitation to the WIFI interface of AP2, which answer by a RA with the new prefix (2.0.1).
24) Starting of traffic between the WIFI interface of MN and correspondent node (CN) through AP2.
25) MIH user sends the MIH Capability Discovery Request and response to the MAC layer of AP2 testing if the Events and Commands events list is supported.
26) The MN reaches the limit coverage of AP2, starts a Link Going Down event, the WIFI interface of MN sends a Link Scan event looking for others network (delaying the connection to WIMAX) do not find anyone else WIMAX.
27) MN connects to WIMAX and a Link Disconnect event with WIFI is triggered and the traffic continues to the end of the simulation through WIMAX.

D. *Scenario II: Type of Network Impact*

In this scenario, we use the NIST algorithm without extension to show that it needs to be improved by considering other parameters with the signal strength.

1) Topology Description: Figure 5 illustrates the topology of scenario II. During this simulation, we compare the delay taken by MN when it makes a HO from WIFI to WIMAX (Figure 5a) versus handover from WIMAX to WIFI (Figure 5b). Measurements are done according to the handover algorithm of NIST only.

During the simulation, the MN moves from WIFI (AP1) toward the center of BS. Once it reaches the limit coverage of AP1, a "Link Going Down" trigger is fired announcing the need for handover. Since the only available network is 802.16 (WIMAX), the handover is made to this network. We also study the same simulation when the mobile moves from WIMAX to WIFI.

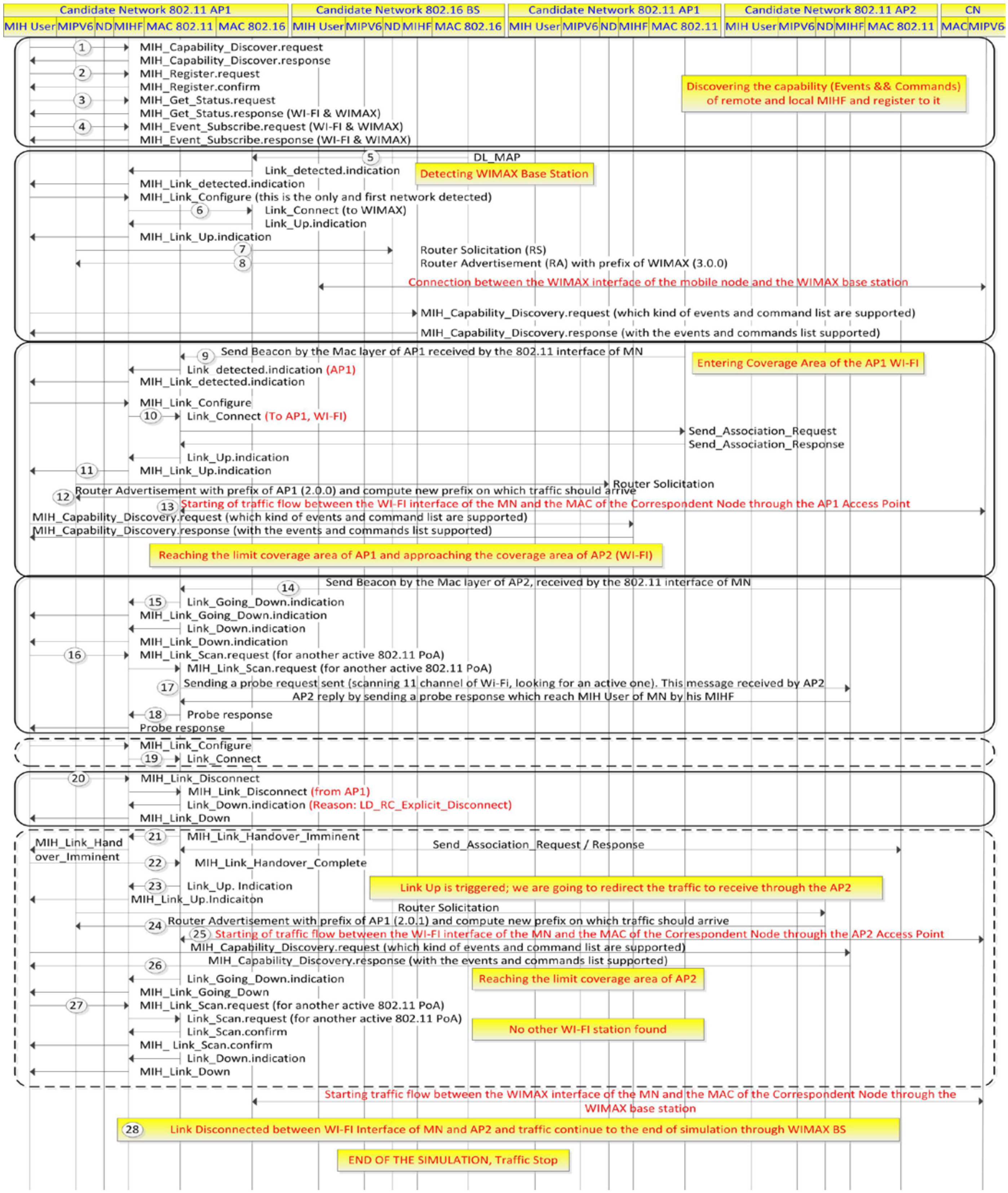

Figure 4. Handover Flow Chart Messages according to NIST and our MCSA algorithm

2) Scenario II Results: Figure 6 shows a decreasing curve of the handover delay as a function of the traffic throughput generated by the MN application. Handover delay is the time difference between the first packet received on the destination network and the last packet received on the current served network. When we increase the throughput, the time between two consecutive packets is smaller and packets reach the destination network earlier, which explains the appearance of the downward curves of handover delay in Figure 6. It shows also that for the same application throughput, the handover delay depends on the type of destination Network (WIFI or WIMAX).

Handover delay from WIMAX to WIFI is smaller than the handover delay from WIFI to WIMAX. When the MN connected to AP1 moves to the center of BS (Figure 5a), it reaches the limit coverage area of AP1 and generates a "Link Going Down" trigger. In this case, a scan process starts looking for a new network delaying the connection to BS (Figure 6). While for handover from WIMAX to WIFI network (Figure 5b), the MN does not trigger this event because it is still in the coverage area of WIMAX (no loss of WIMAX signal) and that's why we have less handover time (Figure 6).

As a conclusion of this experiment, we can say that based on the type of destination network, we can have different values of handover delay and consequently different value of PL.

As shown in Figure 6, we can note that by varying the throughput values between 120Kbit/s and 170Kbit/s, the handover time (WIFI / WIMAX) varies between 275ms and 200ms hence exceeding the maximum acceptable value of the QoS end-to-end delay parameter (150ms) [48] for real time application. This criterion is worthy of consideration when selecting a new network during HO.

E. Scenario III: Speed Impact

1) Topology Description: In this scenario, shown in Figure 7, we study the effect of MN speed on the packet loss during HO. At the beginning, the MN connected to WIMAX, moves to the center of the BS, resulting on a handover to AP1 and AP2 according to NIST algorithm. Once the MN reaches the limit coverage of AP2, it returns to WIMAX network.

2) Scenario III Results: For the three different experimented speeds, the packet loss on WIMAX is null because 802.16e WIMAX is designed to support high speed mobile user [48][49]. Once an MN starts moving toward the center of the BS, it detects the presence of AP1. According to the NIST algorithm, it makes a HO to AP1. Some PL occurs during this HO and the value of this PL increases with mobile node speed (Figure 8) because WIFI, unlike WIMAX, is limited in high-speed transport communications environment [50]; and does not support high speed mobility. Indeed, for a speed of 20m/s we can see a great impact of Doppler Effect on the system performance [51], which is a source of quality of service deterioration.

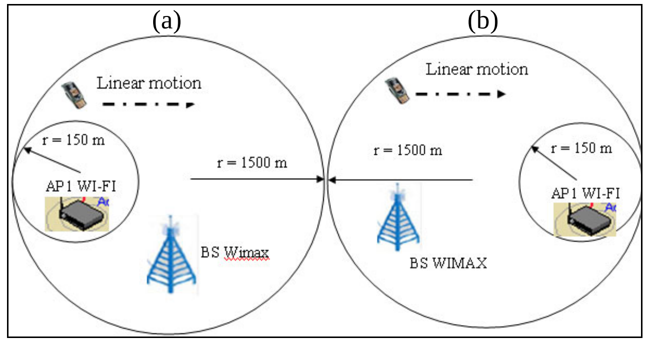

Figure 5. (a) Handover WIFI-WIMAX, and (b) Handover WIMAX-WIFI

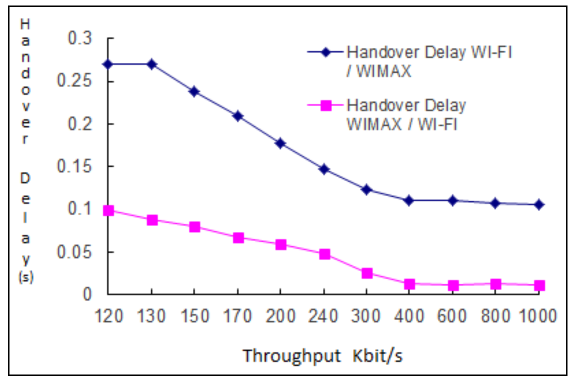

Figure 6. Handover Delay Curves

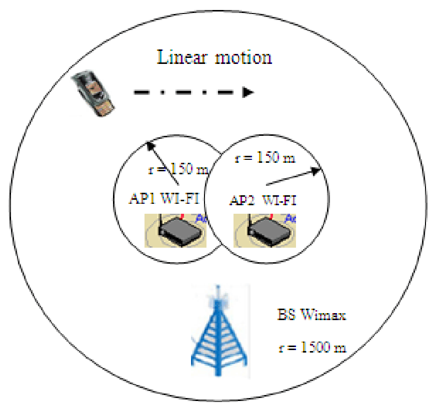

Figure 7. Scenario III topology

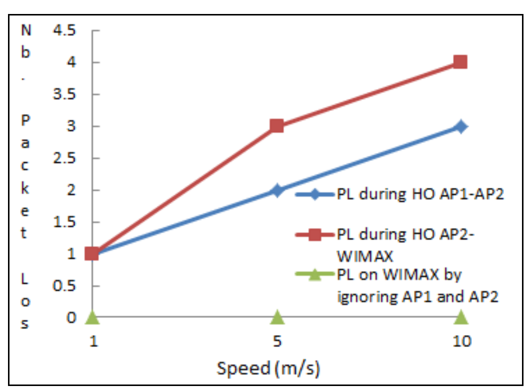

Figure 8. Packet loss as a function of mobile speed

The same process happens during handover from AP1 to AP2 as we experienced other number of packet loss that increases with mobile speed. Moreover, when the MN handover from AP2 to WIMAX some packet loss occur whose number increase with mobile speed. Accordingly, we conclude that users who give importance to the number of packet loss and MN speed would prefer to stay on WIMAX and never stream through AP1 or AP2. Hence, we conclude that NIST fails to meet the requirement of mobile user moving at a speed higher than the pedestrian speed (1m/s). Thus, we argue that there is a need for a new framework that takes into account the user speed.

As a conclusion of the above three experiments, we can say that selection algorithm provided by NIST must be improved by introducing more QoS parameters during selection. As such, a fuzzy logic system complementing the proposed algorithm will be introduced in the subsequent sections.

VI. Fuzzy Logic System

Fuzzy logic is the theory to deal with the multivalued sets and the uncertainty principle [52]. As Figure 12 shows, the fuzzy logic system is composed of three processing units: fuzzification, fuzzy inference rules base engine and a defuzzification unit [53]. A membership function gives the image of the value for a fuzzy set in the range 0 to 1. This value is called Membership Degree. During the fuzzification process, the crisp value of each input parameter is mapped into the appropriate fuzzy set using the corresponding membership function. The input parameters for our proposed model are: Received Signal Code Power measured in UMTS (RSCP), the signal strength on GPRS (RXLEVEL), the ratio of the received energy per chip measured on UMTS (Ec/Io), the signal quality received on GPRS (RXQUAL) and the ABW. A membership function can take different forms: triangular, trapezoidal, Gaussian and sigmoidal [54]. The membership functions of the input parameters in our system are shown in Figure 9, Figure 10 and Figure 11, respectively. For (Ec/Io) and RSCP the input values are transformed into one of the four fuzzy sets (Bad, Acceptable, Good and Very good) while the ABW is mapped into one of the three fuzzy set (Low, Medium and High). Due to their simplicity and computational efficiency, the triangular form combined with the trapezoid one is used for the membership functions. Moreover, this form of membership function has been widely used in real time applications [55]. The universe of discourse of each input parameter is depicted in Table IV.

Two schemas exist for the fuzzy inference rules base namely Sugeno [56] and Mamdani [57]. The former schema is ideal for linear technique and gives a crisp value as a result while the latter is a good pattern for an expert knowledge system in the form of IF-THEN [58] but gives a symbolic value as a result. The fuzzy rule base, in our case, is a collection of IF-THEN rules that help to choose the best network in the context of QoS guarantee for a given user. Our fuzzy rules base is extracted from the observation done on more than 9500 voice data records. This data was retrieved from the server of an operating mobile telecommunications company (Alfa) after a long drive test. Among the 632 cases of handovers we received, 100 cases were for vertical handover. As the scope of our research is for vertical handover, we consider only these 100 cases between GPRS and UMTS networks.

After analysis, we find that these 100 cases of handover follow a set of rules that will constitute our fuzzy rules base (see Table III). Moreover, these rules were completed thanks to experts from the Alfa telecom company in order to cover all remaining handover scenarios. The fuzzy inference engine will be applied on the fuzzy rules base to help choosing the best network during handover.

The role of the deffuzifier is to compile the output of the fuzzy inference engine and convert it from natural language to a crisp value using the centroid method. This method computes the gravity center of the membership function for a given fuzzy value. The final crisp output corresponds to a scoring value for each candidate network between 0 (the worst network) and 1 (the best network).

For the sake of simplicity, the following abbreviations are used for the fuzzy sets: H for High, M for Medium, L for Low, B for Bad, A for Acceptable, G for Good and VG for Very Good.

VII. Fuzzy Logic Handover Decision Algorithm

We consider the scenario given by Figure 13. The MN connected to Network 1, reaches its limit coverage area and needs to select the best network among the available ones in its vicinity. Our proposed algorithm will use the three parameters Ec/Io or RXQUAL, RSCP or RXLEVEL and ABW of the destination networks as input, see Figure 12. Values of the input parameters for each candidate network are given by Table V. The fuzzification process maps, for each candidate network, the three input parameters values to their name(s) of membership function(s) and memberships degree(s) in the function(s). For example, Figure 11 shows the memberships degree of the Ec/Io input parameter for Net. #2 (-11 dB) with the membership functions Good (G, 0.25) and Acceptable (A, 0.75). Table VI shows the (Membership-FN, Membership-Degree) for each candidate network. Each triplet (EC/Io, RSCP and ABW) of input parameters can fire one or more rules in our base with different strength α_i. Before calculating the crisp output value by defuzzification, we must calculate the firing strength of each rule as the minimum of the triplet input values (see Table VII). For each value of a handover output (Ho output), a numerical value between 0 and 1 is assigned. (Highly Recommended (HR) = 1, Recommended (R) = 0.5, Lowly Recommended (LR) = 0.25 and Not Recommended (NR) = 0). Networks with bad (B) or low (L) value for any input parameters are considered as not recommended. Our inference base looks only for recommended networks. Finally, the crisp value that represents the score for each candidate network (between 0 and 1) is given by the following formula [59]:

$$z_0 = \sum_{i=1}^{n} \alpha_i z_i \Big/ \sum_{i=1}^{n} \alpha_i \quad (1)$$

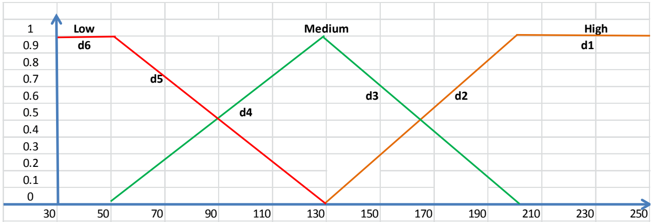

Figure 9. Membership Function for ABW

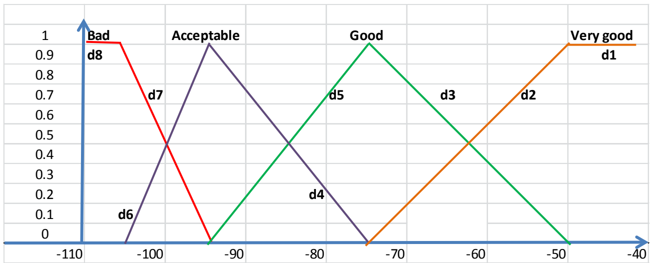

Figure 10. Membership Function for RSCP

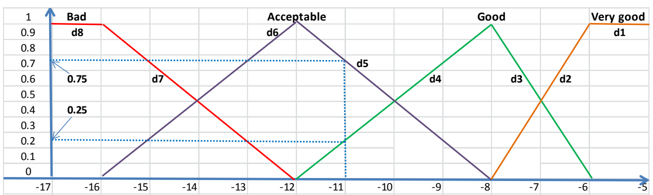

Figure 11. Membership Function for EC/Io

TABLE III. INFERENCE RULES BASE

Rule No.	ABW	Ec/Io	RSCP	Ho output
1	L	A	M	LR
2	L	A	H	R
3	L	G	M	R
4	L	G	H	R
5	L	VG	M	R
6	L	VG	H	R
7	M	A	M	R
8	M	A	H	R
9	M	G	M	R
10	M	G	H	HR
11	M	VG	M	HR
12	M	VG	H	HR
13	H	A	M	R
14	H	A	H	R
15	H	G	M	HR
16	H	G	H	HR
17	H	VG	M	HR
18	H	VG	H	HR

TABLE IV. UNIVERSE OF DISCOURSE

RSCP (dBm)	Bad < -105	Acceptable -95 to -105	Good -95 to -75	Very Good >-50
EC/Io (dB)	Bad < -16	Acceptable -16 to -12	Good -12 to -8	Very Good -8 to -6
ABW (Mbps)	Low < 50	Medium 50 to 130	High 130 to 250	

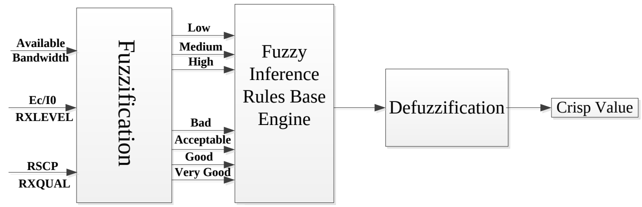

Figure 12. Fuzzy Logic Processing Units

Where α_i is the firing strength for a given rule and z_i is the numerical value assigned to the handover output value of each rule. The crisp scoring value for each network should be calculated. The network that has the nearest value to 1 is the most recommended one. For example, calculation of the crisp scoring value for Net. 2 are as follows: the input parameters of the second network fire rules number 1, 2, 3 and 4 of our base with different strength. The firing strength of each rule is calculated as the minimum of all input parameter's value for a given rule. Table VII shows only the fired rules with strength greater than zero. It would be pointless to show rules whose firing strength is null. Table VII shows the scoring value for each recommended network in the vicinity of the MN. These scores are calculated according to formula given in (1). For example, score of the Network #2 is calculated as follow:

$$\frac{[(0.4 \text{ x } 0.25)+(0.5\times 0.5)+(0.25\times 0.5)+(0.25\times 0.5)]}{(0.4+0.5+0.25+0.25)}=0.42$$

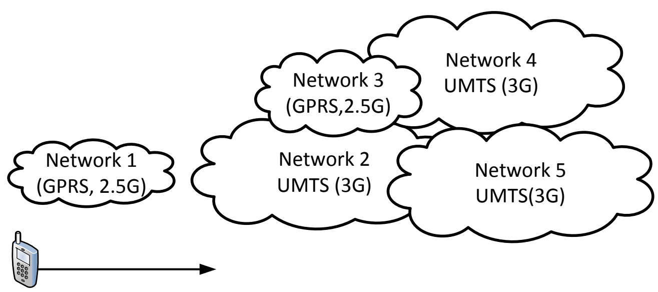

Figure 13. Studied scenario

TABLE V. PARAMETERS VALUES FOR CANDIDATE NETWORKS

	Net. 2	Net. 3	Net. 4	Net. 5
RSCP (dBm)	-100	-80	-90	-70
EC/Io (dB)	-11	-14	-7.5	-7.5
ABW (Mbps)	170	110	220	90

TABLE VI. (MEMBERSHIP-FN, MEMBERSHIP-DEGREE) FOR EACH CANDIDATE NETWORK

	Net. 2	Net. 3	Net. 4	Net. 5
RSCP (dBm)	(A, 0.5) (B, 0.5)	(A, 0.25) (G, 0.75)	(A, 0.75) (G, 0.25)	(VG, 0.2) (G, 0.8)
EC/Io (dB)	(G, 0.25) (A, 0.75)	(A, 0.5) (B, 0.5)	(VG, 0.25) (G, 0.75)	(VG, 0.25) (G, 0.25)
ABW (Mbps)	(H, 0.6) (M, 0.4)	(L, 0.25) (M, 0.75)	(H, 1)	(L, 0.5) (M, 0.5)

TABLE VII. FIRING STRENGTH OF EACH RULE AND NETWORK SCORING FOR DIFFERENT CANDIDATE NETWORKS

Net. #	Fired Rules #	Strength of the fired rules	Network scoring
2	1	Min (0.5, 0.75, 0.4) = 0.4	0.42
	2	Min (0.5, 0.75, 0.6) = 0.5	
	3	Min (0.5, 0.25,0.4) = 0.25	
	4	Min (0.5, 0.25, 0.6) = 0.25	
3	1	Min (0.25, 0.5, 0.75) = 0.25	0.41
	7	Min (0.75, 0.5,0.75) = 0.5	
4	4	Min (0.75, 0.75, 1) = 0.75	0.66
	6	Min (0.75, 0.25, 1) = 0.25	
	10	Min (0.25, 0.75, 1) = 0.25	
	12	Min (0.25, 0.25, 1) = 0.25	
5	9	Min (0.8, 0.75, 0.5) = 0.5	0.73
	11	Min (0.8, 0.25, 0.5) = 0.25	
	15	Min (0.2, 0.75, 0.5) = 0.2	

By a simple comparison of the network scoring column of Table VII, we found that Net. #5 is the most recommended one among all available networks in the vicinity of the MN.

VIII. CONCLUSION AND FUTURE WORK

In this paper, we have evaluated the effect of some parameters like Radio Signal Strength, available bandwidth, type of network (802.11 or 802.16) and mobile speed for choosing the best network in the vicinity. We conclude that choosing a network based on the Radio Signal Strength only is not always a good strategy. The experiments that we conducted using the NS2 showed that the inclusion of additional parameters significantly improves the packet loss ratio and so the QoS guarantee for mobile users. Even with the significant improvements that were introduced with MCSA algorithm, we investigated a model that is based on fuzzy logic to address the short-falls of our modified and enhanced algorithm. The new integrated system provides a better comprehensive solution. The limitation of the fuzzy logic work lies in the fact that the records were collected and experimented with cover 2G & 3G networks HO, so we have to extend these records to those of WIFI and WIMAX. However, our theoretical calculations prove that irrespective of networks type, the results should be similar to a great extent. It is worth mentioning that several attempts were made to obtain needed data from the USA, but without much success due to confidentiality and intellectual property concerns.

In future work, we will propose a framework with a generic model that takes into consideration different levels of constraints such as network parameters with users and operators preferences to improve the selection of the best candidate network and optimize QoS parameters in terms of packet loss ratio, delay and jitter for real time applications. In addition, attempts will be made to secure data regarding WIFI and WIMAX handover in order to validate the fuzzy logic model findings and prove the prescribed assumptions put forward in this research work. Furthermore, the proposed fuzzy logic algorithm will be implemented in NS2. At that point, a concrete comparison will be conducted among MCSA, the fuzzy logic algorithm and a customized model based on multiple linear regression strategy that is under investigation to better select a destination network.

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