Design of a Fuzzy-based Handover Function for Mobile Terminals with Real-time Traffic over Heterogeneous Wireless Networks.

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***Abstract*—The design of a fast and efficient media independent handover function (MIHF) for a 4G mobile supporting heterogeneous networks is the goal of this paper. This will be carried out for two classes of traffic with different quality of service requirements. Due to the imprecision and fast variability of the measured or estimated input parameters, the corresponding decision engines to be used in the MIHF, were based on fuzzy logic design. Three parameters are to be considered: the signal strength, the available bandwidth, and the connection cost. The two designed funtions showed a clear adaptability to the requirements of the two considered classes of traffic.**

I. INTRODUCTION

The connectivity enhancements brought by the new 4G wireless networks have contributed dramatically in bringing cloud computing to the wireless world [1]. Indeed the co-existence of a variety of wireless networks with different coverage areas, transmission speeds, mobility supports, and QoS provisions, have allowed mobile users to seamlessly stay hooked to the cloud while roaming. The challenges posed, however, in integrating these networks to provide both a better quality service and seamless coverage to their customers, are formidable [2] [3]. The design goals focus on exploiting the differences in the various network technologies, which may be incidentaly complementary, in providing better services to the users [4], including continuous network connectivity, high QoS, and at a reasonable price [5] [6]. Fuzzy-based designs have been found very attaractive and most suitable for systems with complex functions such as these [7], [8] [9], and[10].

The rest of the paper is organized as follows. In the next section a short introduction to handover mechanisms will be given. Afterwards, a detailed description of the network models, the parameters used in the decision functions, and the rules for obtaining the decision will be presented. Then, the performance analysis of a five networks environment will be carried for the two classes of traffic. Finally, conclusions will be presented.

II. HANDOVER MECHANISMS

Traditional handover algorithms for homogeneous networks focused mainly in their handoff criteria on link quality conditions. The common cost function for these techniques is to minimize the unnecessary handoffs while maintaining throughput and latency constraints [11]. In the case of heterogeneous networks, new context-based algorithms have been proposed. The objective in such algorithms has shifted to providing the user with the best available QoS at any time, which led to considering higher level context information. Under such circumstances, each candidate network is associated with a cost function, and the decision resides in selecting the network which has the lowest cost value. The cost function depends on a number of criteria, including the bandwidth, delay and power requirement [12] and [13].

Decision algorithms based on the *Fuzzy* concept have found a special interrest in such environment where the measurements are taken over a wireless medium, and are usually prone to imprecisions, and are continuously changing, especially in the case of high mobilty terminals. In the case of horizontal handovers over cellular networks, various aspects of fuzzy-based systems have been investigated, such as avoiding the ping-pong effect in [14], integrating call admission with handover [15], and load balancing in [16]. The case of vertical handover involving heterogeneous wireless networks has also been tackled by many researchers, but only at the foundation level [17], [18], [19], [20], and [21].

In our study, three network technologies are considered. The proposed Fuzzy Vertical Handover Decision Function (FVHDF) is based on Mamdani fuzzy inference system, and centroid defuzzifying method. It uses as inputs three parameters drawn from different categories. The simulation model is built using actual parameters of the wireless networks. Terminals following a random path will be considered. In addition to the models set for computing the FVHDF parameters, the most innovative part of our work resides in the design of the rules, as in [19], that mitigate the network varying conditions and optimize the QoS requirements of two classes of traffic taking into account the user preferences.

III. MODEL AND DECISION FUNCTIONS

The FVHDF will use parameters related to the wireless network, the mobile user preferences, and the type of traffic being carried. In this study, we will be considering three types of network technologies that are representative of different categories. We will be also considering two major traffic classes that have challenging QoS requirements.

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A. Model

The system to be considered is composed of five networks representing three different technologies: two wireless LANs (IEEE 802.11g), two wireless MANs (IEEE802.16e), and one UMTS (Release 99) cell. Table I shows some relevant characteristics of each network type [22][1]. Note that both WiMAX networks are assumed within the UMTS cell (which is common), and each WLAN is within a WiMAX network. It is assumed also, that all the networks are serving (with different QoS levels) two traffic classes with different QoS requirements: conversational and streaming.

TABLE I
RELEVANT NETWORK CHARACTERISTICS.

Parameter	802.16e	802.11g	UMTS (R99)
BS TX power (dBm)	43	17	21
Min RX Power (dBm)	-99	-84	-117
MT max power (dBm)	23		
BS antenna height (m)	32	5	15
MT antenna height (m)		1.5	
BS Antenna gain (dBi)	15		
MT Antenna gain (dBi)	-1		
Operating freq (GHz)	2.5	2.4	2.2
Channel bandwidth (MHz)	5	5	5
FFT size	512	64	N/A
Frame (msec)	5	variable	10
No. of Symbols per frame	48		
Subcarrier spacing (kHz)	10.94	312.5	
Symbol duration (μs)	91.4		
Max data rate (Mbps)	5	12	0.384
Coverage area (km)	5	0.1	2
Min BS-MT distance (m)	36		
Vehicle speed (km/h)		20	

The handover decision will be based on three input criteria. As in conventional systems (i.e., horizontal handover), the signal strength is the first parameter to be used. The two other criteria are the cost for using the network, and the available bandwidth.

B. Membership Fuction Parameters

The calculation of the membership functions parameters for the three networks, to be considered in this model, will include the user preferences, the application QoS requirements, and the type of network. The three network parameters will be computed using the following methodology.

1) Received Signal Strength (RSS): The first parameter to be considered relates to the signal strength $P_i(x)$ perceived by the MT situated at a distance x from the BS of the i^{th} network. For each network, it is assumed that a value of 1 is given to 0 m distance (corresponding to $P_i^{(max)}$, which is equal to the transmission power of the BS), and a 0 to the maximum distance (equal to the network coverage range that corresponds to $P_i^{(Th)}$, which is equal to the minimum required power by the MT). To compute $P_i(x)$ as the distance x varies, the attenuation model proposed in [23] for WiMax networks is to be used for WiFi networks[2] [24]. The model is known by the modified COST 231 Hata path loss, given by:

$$\begin{aligned} Loss(x)_{dB} = \; & (44.9 - 6.55log_{10}(h_{BS}))\, log_{10}(\tfrac{x}{1000}) + \\ & +45.5 + (35.46 - 1.1h_{MS})\, log_{10}(f) - \\ & -13.82log_{10}(h_{BS}) + 0.7h_{MS} + C \end{aligned} \quad (1)$$

where x, h_{MS}, and h_{BS} are expressed in meters, and f in MHz, $C = 3$ dB for urban macro and 0 dB for suburban.

So, if we take $P_i^{(max)}$ as a reference, and $x = 0$ for the maximum power, then we get:

$$P_i(x)_{dBm} = P_i^{(max)}{}_{dBm} - Loss(x)_{dB} \quad (2)$$

In the case of the Cellular network, assumed to be UMTS Release 99, power control is used to increase the transmitted power so as to achieve a certain required QoS.

2) Available Bandwidth (ABW): The second parameter to be considered is related to the available bandwidth denoted by $B_i(s)$, which is assumed here a function of the SNR. However, there is a relation between the magnitude of the SNR and the distance x from the i^{th} BS (assuming a slowly variying noise). So, the ABW will be related to x, as shown in Table II [25]. Only WiMAX and WiFi networks were included since they are the only ones using OFDMA technology which allows multirate coding. In the case of UMTS (Release 99) which uses WCDMA, the data rate is kept constant through the variability of the transmitted power (to overcome in particular the "near-far" effect).

TABLE II
DATA RATES AND DISTANCE RELATION.

Network	**802.16**					
Distance (km)	0.36	0.4	0.5	0.72	0.8	1.0
Rate (Mbps)	11.34	10.08	7.56	5.04	3.87	2.52
Network	**802.11g**					
Distance (m)	15	30	45	61	76	91
Rate (Mbps)	11.8	10.6	8	4.1	1.6	0.9

A piecewise approximation of the relation between the ABW and the distance will be assumed. Thus, for a distance between 360 m and 400 m the ABW will be assumed to be equal to 11.34 Mbps for WiMax; and for a distance between 15 and 30 m the ABW will be assumed equal to 11.8 Mbps.

3) Cost: The third parameter is related to the cost $C_i(x)$ of transmitting over the i^{th} BS when the MT is situated at a distance x. The cost here depends on both the network type and the service received (given a network, it is usually related to the bit-rate being provided). So, the cost will vary from network to network, and also will vary depending on the service priority, bandwidth guarantee, or dropping policy being given to a certain MT. In the UMTS case, an extra cost should be added to cover for the higher power to be used. Thus, as the distance between the MT and the BS increases, the cost will also increase. We propose the relative costs of 1 for WLAN, 2 for WiMax, and 4 for UMTS [26] [27]:

[1]The WLAN throughput was assumed using TCP in a mixed environment with RTS/CTS, while the UMTS throughput was assumed in a high mobility environment.

[2]The WLAN is assumed to be used in an outdoor setting.

C. Rules for the Fuzzy Handover Decision (F_i)

After computing the three parameters for each one of the five networks, the corresponding decision function values $F_i,\ i = 1,\ 2,\ \cdots, 5$, will be computed. The decision functions to be used are based on fuzzy rules that are traffic dependent, i.e. only the QoS requirements for the two types of traffic are considered. The mobile terminal will then execute a handover to the network k which verifies: $F_k = Max\,\{F_i : i = 1, 2, \cdots 5\}$.

1) Conversational traffic: The related rules are depicted in Table III. This type of traffic requires high bandwidth and strong signal strength, but should pay lesser importance to cost. Thus, the *Handover* decision has to be initiated if the signal strength RSS is below a certain level, and this is true for any type of traffic. If the available bandwidth ABW is *small*, with this type of traffic a *Handover* has to be initiated, since otherwise the communication will become unintelligible. If, however, both the RSS is *not weak*, and the ABW is *large*, then for this type of traffic the *Stay* connected to the same network option is selected. In the second case where the *Stay* option was opted while the ABW was *medium*, stricter conditions were imposed with a *strong* RSS and *not expensive* cost. In all remaining cases, represented by the fourth and fifth rules, the decision is left *Neutral*. The final decision will then depend on the results from the other networks.

TABLE III
RULES FOR A *Conversational* APPLICATION.

op	RSS	op	ABW	op	Cost	Decision
IF	*weak*	**OR**	*small*	x	x	Handover
IF	*not weak*	**AND**	*large*	x	x	Stay
IF	*strong*	**AND**	*medium*	**AND**	*not expensive*	Stay
IF	*medium*	**AND**	*medium*	x	x	Neutral
IF	*strong*	**AND**	*medium*	**AND**	*expensive*	Neutral

2) Streaming traffic: The related rules are depicted in Table IV. This type of traffic has preference for high bandwidth, but accepts also lower bandwidth if provided at a reasonable cost. Thus, here also if the RSS is *weak* irrespective of the other parameters, a *Handover* request is initiated. If the RSS is *not weak* while the ABW is *small* and the Cost is *expensive*, then a *Handover* request is also requested, since the user is not willing to pay a lot for a low bandwidth. However, if the SNR is *not weak* and the ABW is *large*, then irrespective of the cost, the user is willing to *Stay* in the current network. While if the ABW is *medium*, he is willing to *Stay* only if both the RSS is *not weak* and the cost is *not expensive*. The third case of *Stay* decision is when the ABW is *small*, but it requires an RSS *not weak* and a *cheap* cost. In all remaining cases, represented by the sixth and seventh rules, *Neutral* is selected and the decision is left to the results obtained from the other networks.

IV. Performance Evaluation

To be able to test our proposed handover engine, a realistic heterogeneous network composed of seven sub-networks is considered (the previous one with the addition of another WiFi

TABLE IV
RULES FOR A *Streaming* APPLICATION.

op	RSS	op	ABW	op	Cost	Decision
IF	*weak*	x	x	x	x	Handover
IF	*not weak*	**AND**	*small*	**AND**	*expensive*	Handover
IF	*not weak*	**AND**	*large*	x	x	Stay
IF	*not weak*	**AND**	*medium*	**AND**	*not expensive*	Stay
IF	*not weak*	**AND**	*small*	**AND**	*cheap*	Stay
IF	*not weak*	**AND**	*small*	**AND**	*medium*	Neutral
IF	*not weak*	**AND**	*medium*	**AND**	*expensive*	Neutral

network within each WiMAX sub-network), as shown in Fig. 1. A random path is asumed in this case with a constant speed of 10 m/sec, and at each measurement point a new direction of the MT is generated randomly.

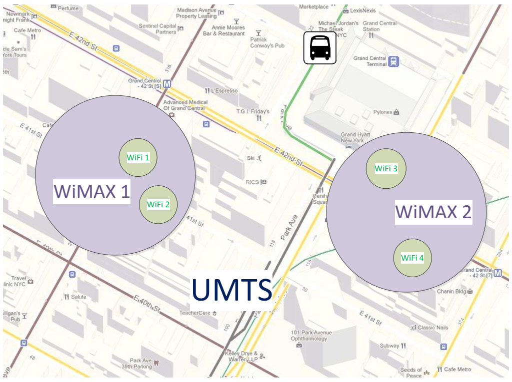

Fig. 1. Seven networks setup with random path.

The results obtained for the two applications are as shown in Fig. 2 for the conversational case and in Fig. 3 for the streaming case.

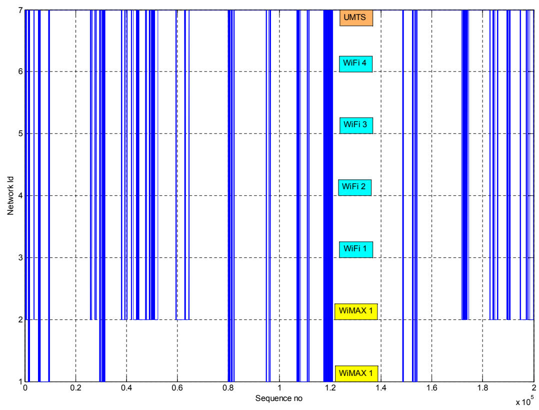

Fig. 2. Network connectivity for a conversational application.

The average results obtained in each case are as shown in Table V. In the first run, all 261 handovers in the conversational case occured also in the streaming case, with an extra 56 handovers occuring only in the streaming but not in the conversational. In the second and third runs, similar results were obtained with the same trend of 30 and 58 extra

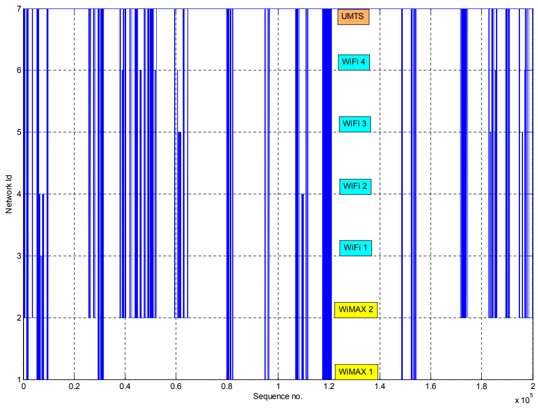

Fig. 3. Network connectivity for a streaming application.

handovers in both respective runs from the conversational case. These extra handovers were due to the fact that the streaming traffic has a stronger tendancy towards cheaper networks represented by WiFi and WiMax.

TABLE V
AVERAGE PERFORMANCE MEASURES FOR THE TWO APPLICATIONS.

run	No. of Handovers		average bandwidth		average cost	
	Conv	Str	Conv	Str	Conv	Str
R1	261	317	1.8574	1.8564	0.9328	0.9321
R2	241	271	1.7362	1.7357	0.9383	0.9380
R3	275	333	1.9945	1.9932	0.9265	0.9258
R4	473	539	1.6267	1.6261	0.9433	0.9429
R5	771	955	1.9148	1.9134	0.9301	0.9294

On the other hand, the conversational traffic achieved a slightly higher average throughput in all five runs, since it is more bandwidth hungry. Of course this has been achieved with a higher cost.

V. CONCLUSIONS

In this paper a model has been setup for the analysis of vertical handover between heterogeneous networks through the use a fuzzy logic based functions. The results show that the proposed functions can easily differentiate between applications with various QoS requirements. Furthermore, it uses the complementary characteristics of the available network technologies in a very efficient manner.

Through a careful design of the two functions tailored for the QoS needs of the two considered traffic clases, the objectives of these two applications were achieved successfully. Additionally, using these functions both an improved performance over a connection limited to the UTMS network, and a differentiation between the two applications have been achieved with a higher bandwith for the conversational and a lower cost for the streaming.

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