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A QoS Based Algorithm for the Vertical Handover between WLAN IEEE 802.11e and WiMAX IEEE 802.16e

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Abstract: Various wireless technologies have been proposed to fulfill the high data rate requirements for real time applications, such as video streaming and other real time applications, in the new wireless 4G and 5G eras. However, due to the complementary characteristics of some of these technologies, such as high coverage area with low date rate, or small coverage area with high date rate, solutions involving the integration between two types of these technologies have been suggested. Since among the user's requirements in 4G wireless networks is to have access to the network resources anytime anywhere, IEEE 802.16e and IEEE 802.11e have been integrated to provide the users with seamless connectivity to network resources by supporting handover between them. This paper presents a vertical handover algorithm between IEEE 802.11e and IEEE 802.16e that satisfies the QoS requirements of the carried traffic. The optimal decision is obtained by taking into account the RSS received signal strength, user preferences, monetary cost, Mobile Node (MN) velocity and QoS such as data rate, delay, and BER. The proposed algorithm is based on the Analytic Hierarchy Process (AHP) within an IEEE 802.21 framework. Four traffic-based profiles were proposed for best effort, conversational, streaming, and interactive applications. A simulation model was built to evaluate the proposed algorithm in terms of MN connectivity during vertical handover, average delay, throughput, blocking probability, and dropping probability. The results confirm that the proposed algorithm satisfied the QoS for the different types of traffic during vertical handover.

Keywords: Vertical Handover, IEEE802.11e, IEEE802.16e,QoS, AHP, MIH, Decision making

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1. INTRODUCTION

Next-generation wireless networks are being developed as Internet Protocol (IP) based infrastructures, with the integration of various wireless access technologies, such as WLAN IEEE 802.11e, and WiMAX IEEE 802.16e. Due to the complementary capabilities of these technologies, it is possible to provide, through their integration, the users with seamless mobility and required quality of service (QoS) such as high data rate, low delay and low BER.

Early versions of IEEE 802.11 WLAN standard have been designed to provide best effort services at low cost and without any QoS support. The IEEE 802.11e amendment proposed QoS support at the MAC layer through some priority mechanisms known by Enhanced Distributed Channel Access (EDCA) and HCF (Hybrid Coordination Function) Controlled Channel Access (HCCA).

The IEEE 802.16 standard defines five service flows. To achieve the classification of a frame, a connection identifier (CID) is included in the frame header, and five QoS parameters for traffic flow resource reservation are used.

The IEEE 802.21 standard proposes a framework to integrate various types of network technology. It works as an intermediate layer and provides a general interface between the lower layers and higher layers of different network technology. This is achieved by providing information about the link layer technologies to the higher layers to provide session continuity without dealing with the specifics of each technology.

Due to the availability of WLAN and WiMAX it is possible to equip a MN with dual network connectivity, allowing the MN to roam transparently from one network technology to another. The question is when and to which available network the MN will be triggered to make handover.

Many algorithms related to vertical handover decision making have been proposed in the literature, among which AHP (Analytic Hierarchy Process) is to be considered here. AHP is a mathematical-based process, which has been used extensively in general decision-making applications. Here, it will be used to select the best

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available network, and then make handover decisions between WLAN and WiMAX. Five criteria will be used in this process: Received Signal Strength RSS, User preference, monetary cost, Mobile Node velocity and QoS such as data rate, delay, and Bit-Error-Rate.

The rest of the paper is organized as follows. The related work is presented in section 2. Section 3 presents decision-making using AHP. The contribution parameter functions is presented in section 4. In section 5, the proposed algorithm is described. The Network topology to be used is presented in section 6. In section 7, the Simulation configuration is presented. Finally, the results and conclusion are presented in section 8.

2. RELATED WORK

Although many studies have been conducted in developing algorithms for the vertical handover decision, only few considered the QoS as decision parameter. This section presents some studies related to our work.

Studies in [1-4] tackle the integration issue of Wi-Fi and WiMAX in a heterogeneous network environment. They have addressed the lower layer technical issues, such as packet formatting, modulation, and coding, but ignored the performance issues for real time traffic flows.

A Vertical Handover Decision (VHD) algorithm based on the prediction of traveling distance is proposed in [5]. The objective is to minimize the probability of handover failures and unnecessary handovers from cellular networks to WLANs. The handover is triggered from cellular network to WLAN only if the expected time to be spent by the MN inside the WLAN is larger than a threshold value.

In [6], an adaptive lifetime-based VHO algorithm is proposed. It takes into account the wireless signal strength, handoff latency, application's QoS and delay tolerance. It has also introduced application-based signal strength threshold (ASST) that provides this algorithm with the ability to fulfill the system handoff signaling and different application requirements. However, this algorithm has a disadvantage in increasing packet delay as the lifetime increases.

In [7], a QoS based VHD algorithm, taking into account the RSS, residual bandwidth, state of the MN, and the type of application running on the MN is presented. Its advantage is in providing high system throughput and low latency for real time data transmission. However, it fails to determine the available bandwidth, and to prevent the ping-pong effect.

Another VHD algorithm between WLAN and WiMAX based on QoS has been proposed in [8]. It introduces a good method for estimating the available bandwidth as a criterion for taking a handover decision, and it has a low complexity since the parameters required for bandwidth are easy to obtain in real networks. However, it does not include details about handover delay, which is a very important parameter in a handover operation for most systems like RTS.

The authors in [9] propose an efficient QoS based vertical handover decision between IEEE 802.11 and IEEE 802.16. The objective was to solve the problems of high cost convergence network and handover delay. The challenges were in the dynamically self-organized, self-configured mesh network, and the ping-pong effect.

In [10], a QoS negotiation-based vertical handoff decision scheme was developed in order to balance the user satisfaction and network efficiency. A merit function was adopted to find the best possible network by combining QoS factors with their corresponding weights.

In [11], a mechanism for the vertical handover between Wi-Fi and WiMAX that supports QoS and QoE requirements of end users, as well as guaranteeing load balancing is proposed, but failed to include important criteria, such as user preferences and BER.

The authors in [12] present a review of vertical handover decision algorithms and give a comparison between them. The decision algorithms were classified into four categories depending on the criteria used in the algorithm. These classes are: RSS based algorithm, cost function based algorithm, bandwidth based algorithm, and Combination algorithms.

A very similar scenario to ours was studied in [13]. It considered a three technologies heterogeneous networks, namely Wi-Fi, WiMAX and UMTS. Although the objective was to provide QoS to MNs, the approach was simplistic and considered only the Signal to Interference and Noise Ratio (SINR).

3. DECISION MAKING USING AHP

AHP is one of the famous methods used in decision making in many fields such as Routing in VANETs [14] and Cloud computing [15]. It has been developed by Thomas Saaty [16], and is, mathematically, a well proven in identifying the most suitable choice among multiple alternatives based on some predefined objectives. It will be used in our study to select the most suitable network from alternative available networks (WLAN IEEE 802.11e and WiMAX IEEE 802.16e) according to predefined QoS applications profiles.

AHP constructs a decision-making problem with different hierarchy levels; ordering the goal, criteria, sub-criteria, and decision alternatives from the top to bottom in the hierarchy tree. The AHP process performs pairwise comparisons to measure the relative importance of elements at each level of the hierarchy and evaluates alternatives at the lowest level of the hierarchy in order to make the best decision.

In our work, six criteria have been selected to compare between WLAN and WiMAX, namely: user preference, monetary cost, MN velocity, data rate, bit error rate, and delay. The last three criteria are referred to as QoS parameters.

First, the Hierarchy tree is constructed as is shown in Figure 1. Second, the criteria used to compare between WLAN and WiMAX are determined and distributed in two level. Then the criteria at each level have to be compared to each other to get the corresponding local priority. After that, the criteria in the second level have to be compared to get the priority of each sub-criterion. The second level of criteria includes data rate, BER, and delay. Each priority of sub-Criteria has to multiply to the priority of QoS to get the global priority. The global priority means how the weight of each criterion is contributing in making the decision of vertical handover.

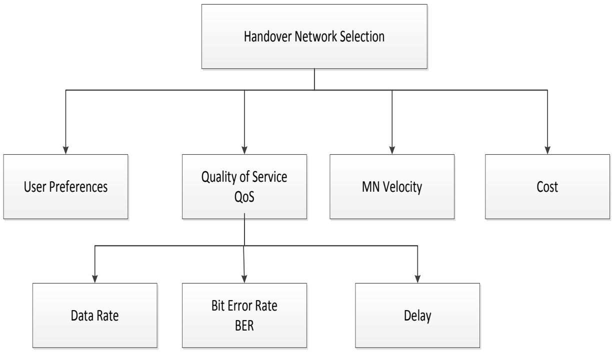

Figure 1. Hierarchical tree to select the best Network.

A. *Profile Defined in AHP*

We have designed four profiles related to the criteria used in VHD algorithm execution. The first profile is a user-preference based, the second is QoS based, the third is cost based, and the fourth profile is mobility based. Furthermore, we assumed that in each profile there are four applications: best effort, conversional, streaming, and interactive. The user has to take these assumptions in consideration during assigning the weights for each criterion while making pairwise comparison.

As best effort applications do not need any QoS guarantees, it needs low data rate and medium delay, but it needs high reliability. Streaming applications need high to medium data rate, are not delay sensitive, but need high reliability. Conversational applications need high data rate, tolerate medium to high reliability, and medium to low delay.

Table 1 shows the requirements for each type of these applications [17]. All these characteristics have to be taken in consideration by the user during the assignment of the weights for the criteria in the pairwise comparison.

After that, the weight for each criterion has to be assigned according to the profile and to the application used. Table 2 to Table 5 show the assignments of weights for the criteria used to make pairwise comparison.

TABLE 1. REQUIREMENTS FOR EACH TYPE OF APPLICATION [17].

Requirements **Application**	**Data Rate (kbps)**	**Delay (msec)**	**BER (%)**
Best Effort	1-24	0-600	zero
Streaming	5-700	300-400	zero
Interactive video	28.2 - 500	0-200	0-0.001
Conversational	64-1920	0-100	0.01

TABLE 2. WEIGHTS FOR THE FIRST LEVEL CRITERIA FOR PROFILE 1.

	User Preference	**Cost**	**QoS**	**MN Velocity**	**Priority**
User Preference	1	7	5	3	**0.6023**
Cost	1/7	1	1	5	**0.1728**
QoS	1/5	1	1	3	**0.1463**
MN Velocity	1/3	1/5	1/3	1	**0.0786**

TABLE 3. WEIGHTS FOR THE FIRST LEVEL CRITERIA FOR PROFILE 2.

	User Preference	**Cost**	**QoS**	**MN Velocity**	**Priority**
User Preference	1	1/3	5	7	**0.3108**
Cost	3	1	5	7	**0.5438**
QoS	1/5	1/5	1	3	**0.0975**
MN Velocity	1/7	1/7	1/3	1	**0.0479**

TABLE 4. WEIGHTS FOR THE FIRST LEVEL CRITERIA FOR PROFILE 3.

	User Preference	**Cost**	**QoS**	**MN Velocity**	**Priority**
User Preference	1	2	1/5	3	**0.1642**
Cost	1/2	1	1/7	2	**0.0978**
QoS	5	7	1	9	**0.6775**
MN Velocity	1/3	1/2	1/9	1	**0.0605**

TABLE 5. WEIGHTS FOR THE FIRST LEVEL CRITERIA FOR PROFILE 4.

	User Preference	**Cost**	**QoS**	**MN Velocity**	**Priority**
User Preference	1	2	3	1/3	**0.2244**
Cost	1/2	1	1/2	1/7	**0.0810**
QoS	1/3	2	1	1/5	**0.1134**
MN Velocity	3	7	5	1	**0.5812**

After that, the AHP will be applied using these values of weights for each criterion to evaluate the corresponding priority of each criterion (as shown in the right most column of each table).

The same procedure is followed at the second level of criteria, containing data rate, delay, and BER. Tables 6-9 show the weights for each criterion in the second level of hierarchy tree. These weights have been assigned taking into account the requirements for each application, as shown in Table 1. In other word, the data rate for example will get high weight in conversational application profile, but it gets low weight in best effort application profile.

Then the global priority has to be obtained by multiplying the weight of each criterion in the second level with their corresponding parents in the upper level. This means that the priorities of data rate, delay, and BER have to be multiplied by the priority of QoS in the first level to get the global priority of them.

The global priority, shown in Table 10, depicts the criterion contribution in making the VH decision. The availability alternative networks should be compared with respect to each criterion. After that, all priorities for each alternative network should be summated to get its total priority. The alternative which gets the highest value will be selected as the best network. Note that the summation of the priorities of all alternatives must equal to one.

TABLE 6. WEIGHTS FOR THE SECOND LEVEL CRITERIA FOR BEST EFFORT APPLICATION.

	Data Rate	**Delay**	**BER**	Priority
Data Rate	1	5	1/9	0.1513
Delay	1/5	1	1/9	0.0519
BER	9	9	1	0.7968

TABLE 7. WEIGHTS FOR THE SECOND LEVEL CRITERIA FOR CONVERSATIONAL APPLICATION.

	Data Rate	**Delay**	**BER**	**Priority**
Data Rate	1	1/9	1	**0.0909**
Delay	9	1	9	**0.8182**
BER	1	1/9	1	**0.0909**

TABLE 8. WEIGHTS FOR THE SECOND LEVEL CRITERIA FOR STREAMING APPLICATION.

	Data Rate	**Delay**	**BER**	**Priority**
Data Rate	1	5	9	**0.7352**
Delay	1/5	1	5	**0.2067**
BER	1/9	1/5	1	**0.0582**

TABLE 9. WEIGHTS FOR THE SECOND LEVEL CRITERIA FOR INTERACTIVE APPLICATION

	Data Rate	**Delay**	**BER**	**Priority**
Data Rate	1	1	1/5	**0.1429**
Delay	1	1	1/5	**0.1429**
BER	5	5	1	**0.7143**

TABLE 10. GLOBAL PRIORITY OF CRITERIA FOR PROFILE 1 FOR CONVERSATIONAL APPLICATION.

Criteria	User pref.	Cost	Rate	Delay	BER	velocity
Global priority	0.602	0.173	0.013	0.120	0.013	0.079

B. *Score of the alternative Networks*

After computing the global priority, the alternative network (WLAN, WiMAX) has to be compared to each other with respect to each criterion taking into consideration both the respective profile and application, with a total of 16 scenarios.

The comparison between WLAN and WiMAX needs the scores for each network corresponding to each criteria depending on the real value measured by the MN or by the network. It is assumed that there is a context sharing between MN and networks, or that the information in the network is advertised. Here we need to differentiate between static scores, such as cost and user preference, which are determined by the user, and dynamic scores, which is assigned depending on the measured value during the communication between MN and a specific Network.

Dynamic scores can be computed using (1) or (2), as it has been used in [18]. Eq. (1) is used for dynamic scores like mean data rate, where the target value is preferred to be as high as possible. On the contrary, Eq. (2) is used for getting dynamic scores like delay, and BER, where the target value is preferred to be as low as possible. If there is any missing parameter, i.e. not advertised by a particular network, its default value is used.

$$S_i = \begin{cases} \left(1 - \frac{\mathrm{Cr_i} - \mathrm{L_i}}{\mathrm{U_i} - \mathrm{L_i}}\right) \times 10\ ; & \mathrm{L_i} < Cr_i < \mathrm{U_i} \\ 1\ \ ; & \mathrm{Cr_i} \geq \mathrm{U_i} \\ 9\ ; & \mathrm{Cr_i} \leq \mathrm{L_i} \end{cases} \qquad (1)$$

$$\mathrm{S_i} = \begin{cases} \left(\frac{\mathrm{Cr_i} - \mathrm{L_i}}{\mathrm{U_i} - \mathrm{L_i}}\right) \times 10\ ; & \mathrm{L_i} < Cr_i < \mathrm{U_i} \\ 9\ \ ; & \mathrm{Cr_i} \geq \mathrm{U_i} \\ 1\ ; & \mathrm{Cr_i} \leq \mathrm{L_i} \end{cases} \qquad (2)$$

where $\mathrm{S_i}$ is the score for network corresponding to a criterion *i*; $\mathrm{Cr_i}$ is the current value offered by the specific network; $\mathrm{U_i}$ is the upper limit of the application requirment such as in Data rate, Delay, BER, and the upper MN velocity acceptable during its mobility within the coverage area of specific Network; and $\mathrm{L_i}$ is lower limit requirement for each application. The lower and upper limits requirements for each application are as listed in Table 1.

C. Network Priorities

When the criterion score for each network is obtained, the corresponding priority is computed as follows:

1) The ratio between the score of WLAN network to the scores of WiMAX network for the same criterion are calculated using Eqs. (3).

$$RS_{ab} = \begin{cases} \left(\left(1-\frac{S_a}{S_b}\right)\times 10\right)^{-1} & ; S_a > S_b \\ \left(1-\frac{S_a}{S_b}\right)\times 10 & ; S_a < S_b \\ 1 & ; S_a = S_b \end{cases} \qquad (3)$$

where RS_{ab} is the relative score between score S_a and score S_b; where S_a and S_b scores of WLAN and WiMAX networks for the same criterion [18].

2) Create 2×2 matrix to compare WLAN and WiMAX based on their scores for each criterion using (4).

$$\begin{array}{c} WLAN \\ WiMAX \end{array} \begin{bmatrix} 1 & RS_{ab} \\ 1/RS_{ab} & 1 \end{bmatrix} \qquad (4)$$

3) The total Priority for each network is obtained using (5).

$$Pr = \sum_1^j C_j(P_j) \qquad (5)$$

Where Pr is the priority for a specific network; C_j is the priority of the *jth* criterion (with respect to other criteria, as computed in tables 2-10); and P_j is the network priority for the *jth* criterion.

The network that gets the highest priority is the best choice, and will be selected as the next target network for the MN.

4. THE CONTRIBUTION PARAMETERS FUNCTIONS

1. RSS Received Signal Strength

During the mobility of MN, it can go across many coverage areas of wireless networks. Depending on the strength of the signal received by MN, it will be able to communicate with the network. The connection between the MN and the network may be lost, if the RSS becomes less than a predefined threshold value RSS_{th}.

Eq. (6) has been proposed in [19] and it can be used to calculate the RSS.

$$RSS = \frac{P_t\, G_r\, G_t \lambda^2}{(4\pi)^2 d^2\, L} \qquad (6)$$

where P_t is the transmitted power, and G_r, G_t are the gains of the receiver and the transmitter, respectively; λ is the wave length of the transmitted signal, and L is path loss factor.

2. Signal to noise Ratio:

The SNR (signal to noise ratio) has direct relation effect on the Bit Error Rate. It is given by (7) [20].

$$\text{SNR [dB]} = \text{Pr [dBm]} - N_0 \text{ [dBm]} \qquad (7)$$

Where N_0 is the thermal noise in dB, and Pr is the received power.

The SNR may be related to the ratio of the energy per chip to the power spectral density of the noise Eb/N0 through (8).

$$\frac{E_b}{N_0} = 10\log10(V/M) + \text{SNR[dB]} \qquad (8)$$

3. Bit Error Rate (BER):

The BER is one of the most important parameters that affect the selection of the best network that supports the requirements of some applications. The SNR and BER are related through Eq. (9), along with the modulation type, modulation rate, and the distance between the MN and the network access point.

$$\text{BER} = \text{berawgn}\left(\frac{E_b}{N_0}, \text{Modtype}, \text{M}\right) \qquad (9)$$

4. MN Velocity

The velocity of the MN is one of the criteria that affect to the choice of the best available network. It affects the vertical handover, since it may cross the whole network coverage area within few seconds, while the time needed to achieve vertical handover is larger than that. In our proposed algorithm, preference is given to networks with large coverage area when the MN is very fast.

5. Delay Analysis

1) For WLAN

To estimate the expected delay of packet transmission through WLAN, the concept of backoff method can be applied. The author in [21] presented an analytic model for multiple prioritized classes of traffic under high traffic condition. Then he computed the expected delay as in (10), (11) and (12):

$$E[D_i] = E[X_i].E[V] \qquad (10)$$

$$E[X_i] = \sum_{j=0}^{\text{retry } i}\left[\frac{p_i^j - p_i^{\text{retry}_i+1}}{1-p_i^{\text{retry}_i+1}}\ \frac{W_{j,i}+1}{2}\right] \qquad (11)$$

$$E[V] = (1-P_b)\delta + P_b\, P_s\, T_S + P_b(1-P_S) \qquad (12)$$

where $E[D_i]$ is the expected delay of the packet transmission for the priority (i); $E[X_i]$ is the total number of idle slots that the frame encounters during backoff stages; P_s represents the probability that a successful transmission occurs in a slot time; P_b is the probability that the channel is busy; *j* stands for the backoff stage taking values from (0, 1, . . . , Li, *retry*); *retry* represents the retransmission retry limit; *i* is the index of class priority; δ represents the duration of an empty slot time; $T_{E(L)}$ is the time to transmit the average payload; T_s is the average time that the channel is sensed busy because of a successful transmission; and T_C is the average time that the channel has a collision.

2) For WiMAX:

IEEE 802.16 networks are regulated by a request-grants mechanism in the process of bandwidth request and for resource grants that are pre-negotiated in the case of higher priority traffic. So, the analysis of traffic delay is divided into two components: delay of bandwidth request phase (collision resolution) and delay of data transmission phase. The first can be modeled by implementing backoff algorithm as in WLAN. Assuming a fixed number of stations *N* contending to transmit a bandwidth request message to the base station, and saturation conditions, i.e. each station has a packet to transmit after the completion of each successful transmission, an following the steps in [22], the average delay of bandwidth request message $\mathrm{E[D_r]}$ will be given by (13).

$$\mathrm{E[D_r] = E[N_c](E[\delta] + T_C) + (E[\delta] + T_S)} \qquad (13)$$

where $\mathrm{E[N_c]}$ is the expected number of collision experienced by request messages, given by (14); $\mathrm{E[\delta]}$is the average time delay of the backoff counter specified by a station before accessing the channel under busy conditions, given by (15); $\mathrm{T_S}$ is the time duration of successful transmission; and $\mathrm{T_C}$ is the time duration of collision of transmission.

$$\mathrm{E[N_c]} = \frac{1}{\mathrm{P_S}} - 1 \qquad (14)$$

$$\mathrm{E[\delta] = E[\beta] + E[\emptyset]} \qquad (15)$$

where $\mathrm{E[\beta]}$ is the average time interval of *k* slots required for the counter to reach state $\mathrm{b_{i,0}}$ (counter reach to zero), and $\mathrm{E[\emptyset]}$ is the time that the station's counter remains frozen.

The second component of the delay is modeled as an M/G/1 priority queue, where the real-time traffic has a preemptive priority over non-real-time traffic, as in [22]. Taking into consideration the following assumptions:

- Real-time virtual requests RTVR have predetermined and known bandwidth for the BS.
- Arrivals for RTVR and NRTR follow independent Poisson process with arrival rates λ_1 and λ_2 , respectively.
- Service times for RTVR and NRTR are assumed independent and identically distributed with a general distribution, with mean service times μ_1 and μ_2, respectively.
- Service policy for both traffic is FIFO.
- μ reservation slots are assumed allocated by the BS in each UL-MAP.

The average delay for real-time traffic will be given by (16), the delay for non-real-time by (17) and its average by (18):

$$E[D_1] = \frac{\lambda_1 E[v_1^2]}{2(1-\lambda_1 . E[v_1])} \qquad (16)$$

$$D_2 = (t_2 - t_1) + \sum_{i=1}^{L} S_i + \sum_{j=1}^{g} V_j \qquad (17)$$

where $(t_2\text{-}t_1)$ is the time duration between the NRTR arrival to the BS and its start of service; $\sum_{\mathrm{i=1}}^{\mathrm{L}} \mathrm{S_i}$ is the average time for serving the NRTR traffic; $\sum_{\mathrm{j=1}}^{\mathrm{g}} \mathrm{V_j}$ is the mean time to serve the RTVR, which interrupted the NRTR; and g is the mean Number of RTVR.

$$E[D_2] = E[T_{MAP}] - E[t'] + E[L]E[S] + E[g].E[v1] \qquad (18)$$

where $[S]$ is the average service time for NRTR; $E[v1]$ is the average service time of RTVR; $E[t']$ is the average arrival time of a NRTR within $[t_1, t_2]$; $E[g]$ is the average number of RTVR arrivals that arrived before the i^{th} NRTR is served; and $E[l]$ is the average number of NRTR arrivals from t_1 to $E[t']$ [22].

5. THE PROPOSED ALGORITHM

The main objectives of the proposed algorithm are to increase the system throughput, and decrease both the handover failures and the unnecessary handovers. Its operation may be summarized in the following steps:

1. The MN scans for signals of neighboring networks; if a signal is sensed, then the RSS is measured for each network;
2. All networks with RSS less than the minimum threshold are discarded. If a network exceeds the threshold value, then the corresponding resources and the delay have to be checked if they satisfy the application requirements. If more than one network satisfies these tests, then the AHP function is called to determine the priority of each network;
3. According to the results of AHP function, the MN will be connected to the network that has the highest priority. If the priorities of the two networks are equal, the MN stays connected to the current network;

It worth mentioning that the checking of availability of network resources before taking handover decision is very important to avoid handover failure or ping-pong effect, which will worsen the performance of the network.

6. NETWORK TOPOLOGY

Two topologies will be used to evaluate our proposed algorithm. Figure 2 displays the first network topology used to evaluate the vertical handover decision algorithm proposed in this paper. For simplicity, it consists of only one BS for WiMAX and one AP for WLAN. Both AP and BS are connected to the same gateway, so that WiMAX and WLAN get the same IP address. A random number of MN's provided with dual interface capabilities are distributed randomly across the coverage area of both networks.

Figure 3 displays the second network topology. It consists of only one BS for WiMAX and six APs for WLAN. Like the first topology, both BS and APs are connected to the same gateway. Each MN takes a position in the coverage area of WLAN or WiMAX randomly and moves in a random fashion. MNs arrive to the coverage area of WLAN or WiMAX at random times according to a Poisson distribution.

7. SIMULATION CONFIGURATION

The proposed algorithm has been simulated using Matlab R2008a. The following specific characteristics were chosen for our networks:

- The coverage area of the system considered in the study is 4000 meters.
- In the first case, the WLAN AP was located at (1000, 0), and the second, the six AP's were located at (500, 0), (1000, 0), (1500, 0), (2500, 0), (3000, 0), and (3500, 0), respectively.
- BS of WiMAX was located at (2000, 0) in both topologies.

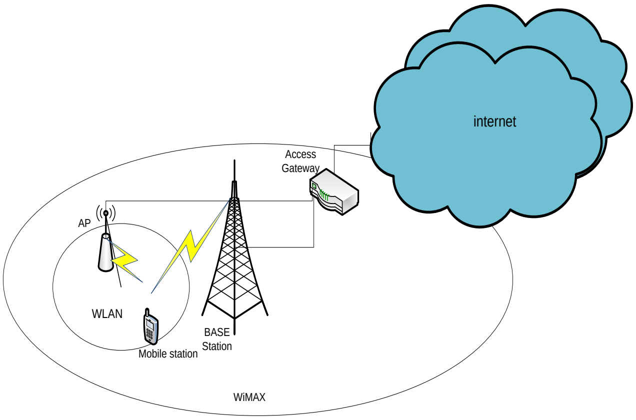

Figure 2. Network topology 1.

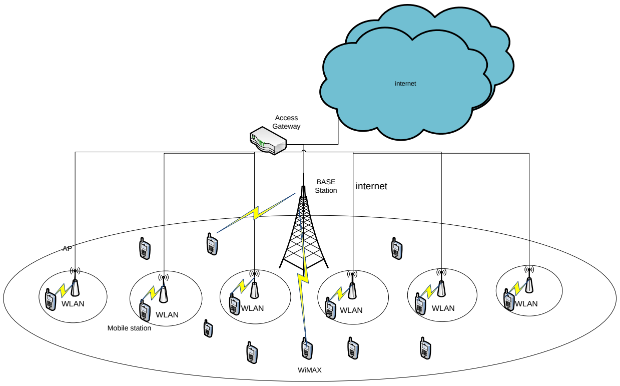

Figure 3. Network topology 2.

- The velocity of MN is random.
- The MNs move from left to right in straight line, when the MN exceeds the coverage area of WiMAX, i.e. the MN reaches position (4000, 0), it returns to position (0, 0).
- Each MN has a random service time.
- The RSS changes according to the variance of the distance between the MN and BS or AP only.
- Traffic is classified into four different classes 0-3, depending on their requirements, as was shown in Table 1.
- MN gets a random location within the coverage area of WiMAX or WLAN.
- Inter-arrival of MNs to the system is assumed exponentially distributed.
- WLAN configuration is as shown in Table 11.

TABLE 11. WLAN CONFIGURATION.

AC_i	CW_{min}	CW_{max}	r_i	$AIFS_i$
0	32	1024	7	SIFS+3 slots
1	16	256	7	SIFS+3 slots
2	16	256	7	SIFS+2 slots
3	8	128	7	SIFS+2 slots

Common parameters	**values**
AP Tx power	20 dB
RSS_{th}	-83 dB
AP hight	1.5 meters
Payload	8192 bits
MAC Header	272 bits
PHY header length (Tp)	192 µs
Data rate DR	54 Mbps
Control rate RC	I Mbps
Data length	8464 bits/DR + Tp
RTS length	160 bits/ RC + Tp
CTS length	112 bits/RC + Tp
ACK length	112 bits/RC + Tp
SIFS	10 µs
Slot time	20 µs
DIFS	50 µs

- WiMAX configuration is as follows:
  - The height of BS is 30 meters;
  - two types of traffic classes: real-time traffic and non-real-time;
  - BS transmitter power = 43 dB; $\text{WiMAX}_{\text{RSS}_{\text{th}}} = -78\ dB$;
  - Real-time traffic has priority over the non-real -time traffic.
  - Bandwidth scheduling is based on reservation polling method, and during the bandwidth request all MNs contend to get a bandwidth from the BS in the same priority and this

phase is modeled as WLAN using backoff algorithm.

- FCFS method is used for the traffic with same priority.

8. RESULTS AND CONCLUSION

The simulation was run using four profiles, as was described in Tables 2-5. In profile 1, the user preferences has higher priority; in profile 2, the cost has higher priority; in profile 3, the QoS has higher priority; and in profile 4, the MN velocity has higher priority.

Each MN has only one type of traffic. We have chosen four MNs to follow and study their behavior and Vertical handover. We have assumed that each MN has different type of traffics.

The performance metrics that have been studied in different profiles are RSS, connectivity, throughput, delay, blocking probability and dropping probability.

A. *First topology*

1) *Profile 1*

The simulation time was 600 seconds, the average inter-arrival for MNs was 3 seconds, the average connection time of MNs was 60 seconds, and the velocity speed of MNs was uniformly distributed over the interval [1:6] m/sec.

a) *Handover*

Figure 4 displays the connectivity of MN#4, which carries interactive video traffic. It was assumed that the MN has preference of WLAN over WiMAX. The connectivity of MN to WiMAX was denoted by the value y=1, and the connectivity of MN to WLAN by y= -1.

At the beginning, the MN is connected to WiMAX since it is within the coverage area of WiMAX only, and it has not entered the coverage area of WLAN yet. At time 150, the RSS of WLAN-AP becomes available and enough to make connection between MN and WLAN AP. Then the MN makes handover to WLAN, while the MN goes across the WLAN coverage area it is still connected to it. After that, at time 220 the MN leaves the coverage area of WLAN and then makes handover to WiMAX.

b) *Throughput*

Figure 5 shows the average throughput for each MN over 10 simulation runs, along with the corresponding confidence intervals. Best effort traffic has the lowest throughput, while video conference traffic has the highest throughput.

As may be noticed, traffic differentiation has been achieved according to the four types preassigned priorities, i.e. the highest priority traffic achieved the highest throughput.

c) *Delay*

Figure 6 shows the average delay for each MN within the system over 10 simulation runs, along with the corresponding confidence intervals. Here also the traffic with the highest priority gets the lowest delay, and the traffic with the lowest priority gets the highest delay. The Traffic differentiation, according to the traffic's priorities, is achieved here as well.

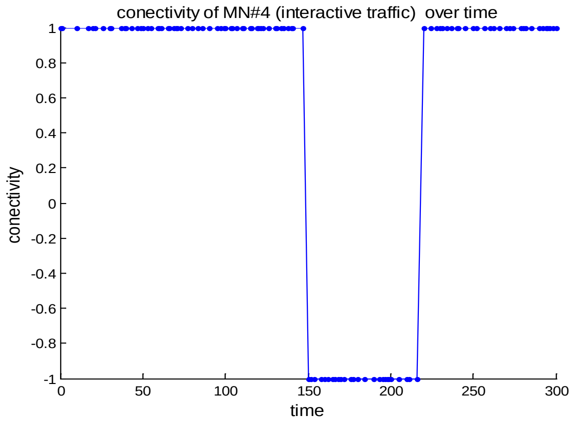

Figure 4. Connectivity of MN#4 in profile#1.

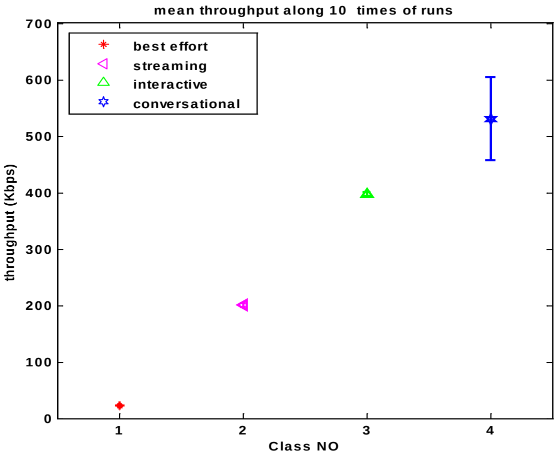

Figure 5. Avg. throughput over 10 simulation runs.

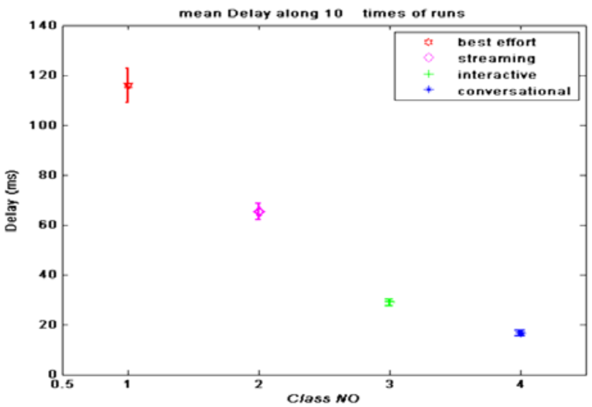

Figure 6. Avg. delay for the traffic types in profile#1.

d) *Blocking and Dropping Probability*

Figure 7 and Figure 8 display the dropping probability and the blocking probability, respectively. Both the blocking probability and dropping probability increase as the traffic intensity increases. We may notice that the blocking probability is higher than the dropping probability. This is because the system guarantees the data rate for existing MNs already connected to the network: the new arrivals that come when there is no residual capacity are blocked.

The dropping may happen in two cases: when the MN goes far away from the BS or AP, to the point where the data rate becomes lower than the minimum requirement for the application, or when the MN tries to make a vertical handover to a new network and there are not enough resources in the target network.

2) *Profile 3*

In profile 3, the QoS takes priority over the remaining criteria. In other words, QoS gets higher weight in making vertical handover decision. The obtained results are presented for the various measures.

a) *Delay*

Figure 9 shows the average delay for each MN and for each class. It may be noted that the delay of class 3 (conversational traffic) has the lowest delay, while class 0 (Best Effort traffic) has the highest delay. These results are in agreement with the class requirements of low delay for conversational traffic and tolerable delay for best effort.

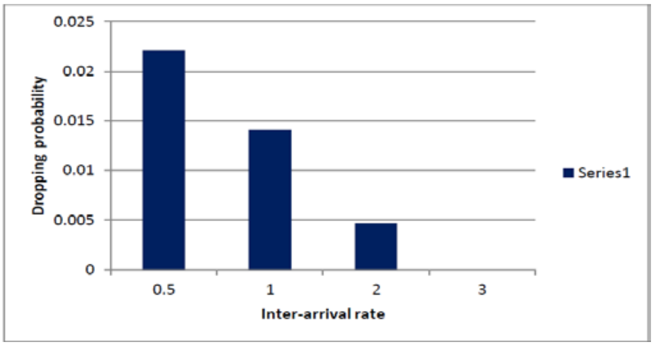

Figure 7. Dropping probability in profile#1.

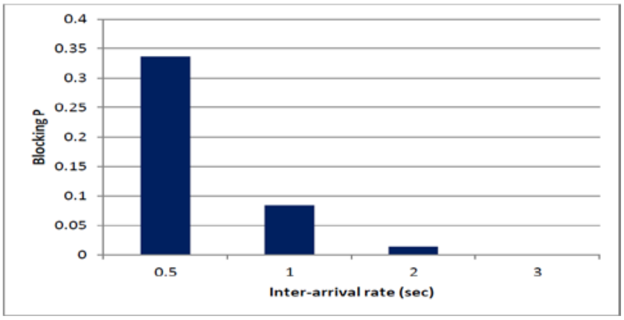

Figure 8. Blocking probability in profile#1.

b) *Throughput*

Figure 10 shows the average throughput for each MN within each class. It may be noticed that class 0, best effort traffic, has the lowest throughput, while class 2, interactive traffic, has the highest throughput.

It was expected that the conversational traffic will get the highest value of throughput, but the result was in contrast of that. This is because the conversation traffic requires also low delay, and the weight of delay score in AHP is very high. This means that the MNs with conversational traffic prefer WiMAX, which assures lower delay and low throughput, to WLAN.

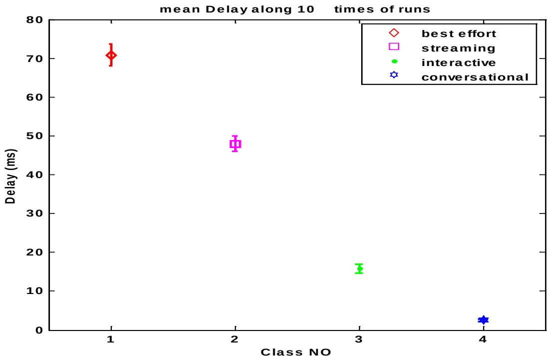

Figure 9. Avg. Delay for each MN within each class in profile 3.

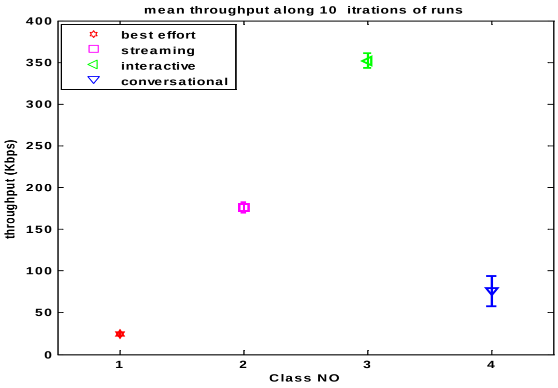

Figure 10. Avg. throughput for MNs in profile#3.

c) Connectivity

Figure 11 displays the connectivity of MN#1 with best effort traffic. The node makes handover to WLAN as soon as the network became available at t=120, and goes back to WiMAX when it became unavailable at t=170. The same behavior was recorded for the two other nodes, MN#2 and MN#3.

Figure 12 displays the connectivity of MN#4 carrying conversational traffic. In this case, it stayed connected to WiMAX during the whole period. This because the delay, the most important criteria for conversational traffic, in WiMAX is lower than that in WLAN.

B. Second topology

The proposed algorithm has been evaluated using the second topology, as shown in Figure 3. The simulation has been run and configured as in profile#1.

1) RSS

Figure 13 displays the RSS of a MN. The MN crosses six WLAN coverage areas. The RSS of WLAN increases as the MN gets closer to the AP, and decreases as it gets farther from it.

At the same time, the MN goes across the coverage area of the single WiMAX network. During the MN movement, it is expected that the MN applies the proposed AHP algorithm when it becomes within the double coverage area.

2) Connectivity

Figure 14 displays the connectivity of MN#2 with streaming traffic, where the connectivity to WiMAX is represented by the value y=1, and the connectivity to WLAN is represented by y= -1. Here also, the MN executes six handovers to the six WLANs as soon as they became available.

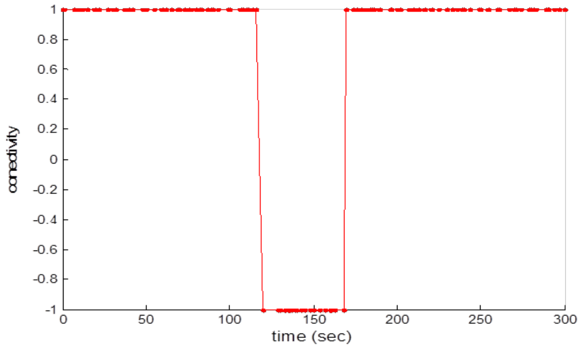

Figure 11. Connectivity of MN#1 with Best effort traffic in profile#3.

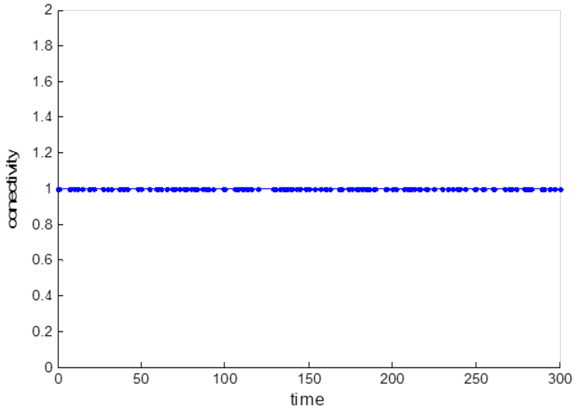

Figure 12. Connectivity of MN#4 with conversational traffic.

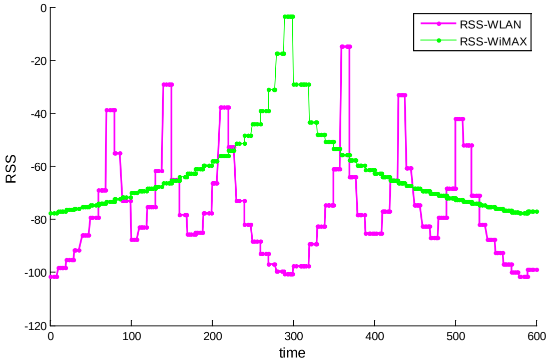

Figure 13. RSS by MN in topology#2.

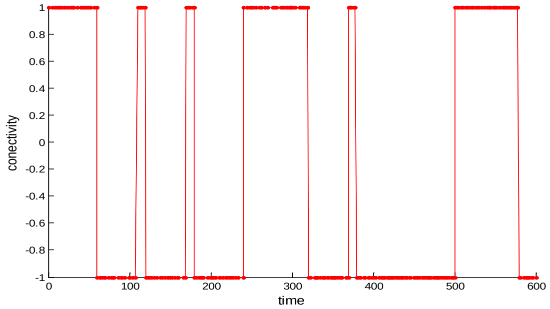

Figure 14. Connectivity of MN#2 in topology#2.

9. CONCLUSION

In this paper, an efficient QoS based algorithm for the vertical handover between WLAN and WiMAX has been proposed. It was based on the Analytic Hierarchy Process (AHP), which is used in decision making. In achieving this, four criteria have been considered, namely: User preferences, QoS including (Data rate, Delay, BER), Cost, and MN velocity.

Four profiles have been applied in the evaluation of this Algorithm; the priority for each Criteria is assigned according to an AHP scale. The QoS parameters were selected according to the application being used. Best Effort, streaming, interactive, and conversational traffic were considered in evaluating the proposed vertical handover algorithm.

The measures used in this evaluation were the connectivity during vertical handover, throughput, delay, and the effect of inter-arrival on the blocking probability and dropping probability.

The presented results showed that vertical handover decisions were achieved precisely to provide the MN with the best QoS. Furthermore, they satisfied the various traffic classes in terms of QoS.

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