Article

Multi-Criteria Vertical Handover Comparison between Wimax and Wifi

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Abstract: In next generation wireless networks, the most tempting feature is the ability of the user to move smoothly over different access networks regardless of the network access technology. In this paper we study the benefit of Multiple Attribute Decision Making (MADM) strategies for network selection. We compare three of these methods naming Simple Additive Weighting (SAW), Multiplicative Exponential Weighting (MEW) and Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) in a realtime ns-3 simulation. Analytic Hierarchy Process (AHP) provides the weights of attributes which allow the comparison in different types of applications. Therefore, we propose a performance evaluation model with a reconfiguration of AHP parameters used in the literature. Simulation results show that the proposed parameters provide an improvement of Delay and offer allowable Packet loss in different types of applications.

1. Introduction and Motivation

The most auspicious Next Generation Networks (NGN) are the heterogeneous networks. They are based on the coexistence and interoperability of different types of Radio Access Technologies (RAT), including the current and the forthcoming networks, intended to fit the requirements for various applications in the future. 4G came with the features "Always Best Connected (ABC)", "Anytime Anywhere" and "seamless communications". In [1], the authors assert that a terminal supports the ABC feature means that it is not only always connected, but also connected through the best available network and access technology at all times. The ABC concept includes virtually all types of access technologies; ABC achieve a win-win partnership because it considers user's and operator's benefits. In the mean time, 4G provides a larger coverage area, faster data transfer, low latency and low data transfer cost. The main issue for the 4G heterogeneous networks is Network Selection, *i.e.*, a flawless and proficient handover scheme that allows the roaming of mobile devices from one wireless system to another. Therefore, with ABC functionalities, terminals are able to select the best access network to fit various Quality of Service (QoS) requirements; terminals escape a network with high traffic load to avoid congestion and reduce costs by using network selection, this is known as Vertical handover, and vertical handover decision strategies are dressed specifically for this purpose. In generic terms for all wireless standards [2] proposed a handover decision scheme based on multi-criteria decision-making modeling providing a continuous connection in heterogeneous wireless networks, unlike traditional approaches which are mainly concerned with specific scenarios.

Being the key for resource management in a wireless heterogeneous network, dynamic network selection algorithms intend to provide users with the adequate QoS in terms of attributes and user's preferences. Both are aforethought during the process of network selection (see Figure 1). Hence, this technology is a hot research topic in the field of wireless communication. Network selection can be programmed by terminal or can depend on measurements of link quality of the network when multiple alternatives are available at the same time. The terminals are equipped more and more by new technologies; every terminal has no less than two network interfaces, such as WLAN, GPRS, HSPA, WIMAX or LIFI [3]. In the optimal cases, the user can move from one wireless network to a different wireless network seamlessly with no deterioration of the connection.
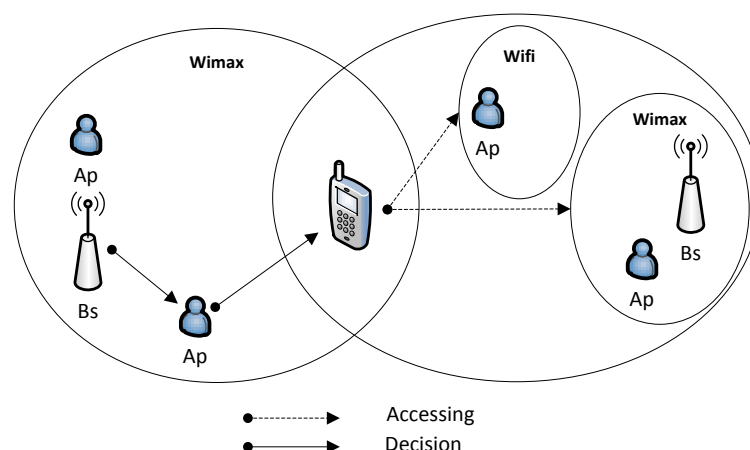
Figure 1. Network Selection Process.

The remainder of this paper is organized as follows. Related works about vertical handover decision (VHD) strategies are summarized in Section 2. In Section 3, the authors introduce the performance evaluation model and the new configuration of AHP weights and the handover algorithms are compared. Section 4 presents the simulations and the results discussion. Finally, Section 5 concludes the work and gives some perspectives.

2. Related Works

Vertical Handover is an important step to acomplish the best QoS in an heterogeneous environment that needs a dynamic selection of the best convenient network, and the decision phase is the most crucial in this case. It is about assembling the performances of each candidate network, and ranking them in purpose to select the best network. It is leading a revolution in the internet by carrying an improved Quality of Experience (QoE) for users of wireless services.

In the literature, different approaches have been proposed to handle the vertical handover decision problem: good network performance, user satisfaction, flexibility, efficiency, and multi-criteria solution. In the same context of heterogeneous environment, authors of [4] compared classical handover decision strategies (RSSbased), and came to the conclusion that they are not sufficient to make a vertical handover decision. They do not consider the current context or user preferences. Indeed, vertical handover decision strategy involves complex considerations and compromises. It needs to be flexible and efficient considering the useful criteria and reasonable policies or rules applicable to both the user's professional and personal communications. In this context, [5] conclude that the mobility management of heterogeneous networks not only depends on network parameters, but also on terminal's velocity, battery power, location information, user's preferences, service's capabilities and QoS requirements. [4,6] presented a panorama of vertical Handover Decisions. Using cost or utility functions; utility/cost refers to the satisfaction that a good or service provides to the decision maker. In the same context, [6] specified that other studies on the network selection issue could also evaluate networks based on utility/cost functions which combine multiple attributes. Furthermore, authors of [7], as well, proposed an algorithm for network selection based on averaged received signal strength, outage probability and distance.

In [8], an intelligent handover decision mechanism has been proposed based on the context-aware strategy and Media Independent Handover in order to reduce the latency, to enable seamless vertical handover and always guarantee the best connected concept. However, some studies focus also on other mathematical models such as fuzzy logic methods which can be used in VHD. The authors of [9] proposed an utility-based Radio Access Technology (RAT) selection optimization in heterogeneous wireless networks, they introduced three utility-based optimization functions based on the type of application that users request. They formulated the terminal assignment problem as an optimization problem, which is recognized as NP-hard.

The goal in vertical handover process is that a terminal should join the best Access Point to address the needs of the users. Interface selection turns into a "decision making" problem with multiple options -*Alternative networks* - and attributes -*QoS Parameters*- user preferences and application requirements. Among several approaches that have been proposed for decision making and network selection, MADM is one of the most promising methods.

In [10], MADM refers to making preference decision over the available alternatives that are characterized by multiple attributes. MADM problems have several common characteristics such as *Alternatives*, *Multiple attributes*, *Decision matrix*, *Attribute weights* and *Normalization*. Most MADM algorithms that have been studied in [11–15] for the network selection problem are compensatory algorithms which means they combine multiple attributes to find the best alternatives, *versus* non compensatory algorithms used to find acceptable alternatives that satisfy the minimum cutoff.

The most popular classical MADM methods according to [4] are SAW, MEW and TOPSIS which are compensatory algorithms. The mathematical modeling of these methods is given in the next section. The authors of [15] proposed giving weights to know the relative importance of each metric or attribute in the conseidered QoS Class. They used AHP to calculate the vectors of weight. Their results showed the importance of those weights in the decision.

Therefore, in this paper we focus on investigating in how to generate the importance weight according to new access technologies.

3. Evaluation Approach

3.1. System Model

As in [16], our contribution consists of a handover decision phase; decision makers must choose the best network from available networks. The goal of this contribution is to analyze the weights given to the metrics, so that, as reported in the Algorithm block diagram shown in Figure 2, simulation provides the system with the metrics in realtime and a pairwise comparison is applied according to each QoS class: Conversational, Streaming, Interactive and Background. Then a weighting method (AHP in this work) is used to calculate the weight vectors in order to obtain the relative importance of each metric or attribute. Consequently, SAW, TOPSIS and MEW are applied to the weighted matrices to obtain the final decision for each method. The handover decisions are made in real-time and repeatedly, in our case the process is repeated every 5 s.
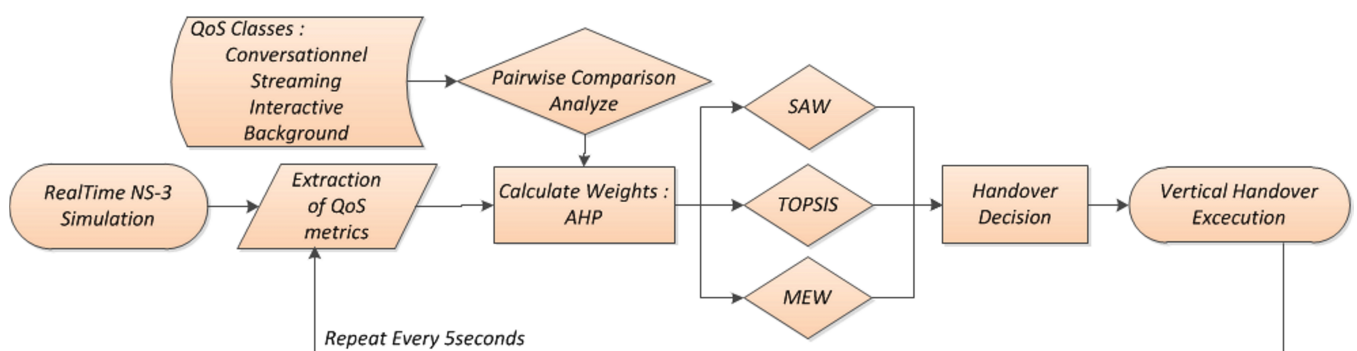
Figure 2. Algorithm Block.

In [17], authors explain that a determined set of weights produces certain quality or merit degree for each network; these merit values change if we consider another set of weights. The goal is to obtain the best merit value, which will correspond to the selected network for the VH decision phase. Accordingly, the more combinations of weights, the more possibilities to get better merit values we will

have. In this work, and to compare SAW, TOPSIS and MEW algorithms, we have been concentrated on the weighting phase with AHP, we have reconfigured the weights done previously in the literature, considering Throughput, Delay, Jitter and Bit Error Rate (Ber) of the participating access networks to make the handover decisions. The vertical handoff decision problem can be formulated as a matrix form Q, where each row i corresponds to the candidate network and each column j corresponds to an attribute. The matrix of alternative networks is settled conforming to the attributes.

$$
Q_{N,M} = \begin{matrix} Network_1 \\ Network_2 \\ \vdots \\ Network_N \end{matrix}
\begin{matrix} Attribute_1 & Attribute_2 & \ldots & Attribute_M \end{matrix}
\begin{pmatrix} q_{11} & q_{12} & \cdots & q_{1M} \\ q_{21} & q_{22} & \cdots & q_{2M} \\ \vdots & \vdots & \ddots & \vdots \\ q_{N1} & q_{N2} & \cdots & q_{NM} \end{pmatrix}
$$

As all three methods grant the evaluated criteria to be expressed in different measurement units, it is necessary to convert them into normalized values.

$$
n_{ij} = \frac{q_{ij}}{\sqrt{\sum_{i=1}^{i=N} q_{ij}^2}}, j = 1, ..., M \tag{1}
$$

In addition, weight factor is assigned conveniently to each criterion to report its importance which is determined by (AHP).

3.2. Analytic Hierarchy Process : AHP

The concept of weight involved in each method, is solved by the use of the AHP method. The authors of [18] proposed this process for decision-making in multi-criteria problems, they introduced AHP as a method of measurement with ratio scales, AHP allows comparison and a choice of preset options. It is based on the comparison of pairs of options and criteria.

In our approach, AHP is used to calculate the weight vector w, which represents the importance of each metric with respect to different QoS classes for use in SAW, MEW and TOPSIS methods. AHP provide as results $w_j > 0$, which represents the weight or importance of the jth attribute, given that $\sum_{j=1}^{j=M} w_j = 1$.

Weight computing needs answering to a sequence of comparisons between a pair metrics. The common way to ask a question is to consider two elements, and find out which one satisfies the criterion more. The answers are given by using the fundamental 1-9 AHP scale [18,19]. The values in the answers correspond to the scale in Table 1 below.

Table 1. The scale of importance [18].

Importance	Definition	Explanation
1	*Equal importance*	Two parameters contribute equally
3	*Moderate importance of one over another*	Experience favored 3 times one than another
5	*Strong importance*	Experience favored 5 times one than another
7	*Very Strong importance*	A parameters is favored and dominant in practice
9	*Extreme importance*	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	*Intermediate values*	When Compromise is needed

Table 2 presents the answers of the questions asked about the relative importance between each pair, for example, in Conversational Class, the first comparison is (Ber, Jitter), the question is : How much more is Ber preferred over Jitter in conversational Class? Indeed, Jitter is 7 times more important than Ber, so the value in matrix is $1/7$, and accordingly 7 is put in the opposite side (symmetrical to the diagonal). The other values can be obtained from Table 1.

Table 2. Analytic Hierarchy Process (AHP) Matrices for Each Traffic Class.

Conversational	Ber	Jitter	Delay	Throughput	**Interactive**	Ber	Jitter	Delay	Throughput
Ber	1	1/7	1/7	3	Ber	1	3	7	3
Jitter	7	1	3	7	Jitter	1/3	1	5	3
Delay	7	1/3	1	7	Delay	1/7	1/5	1	1/7
Throughput	1/3	1/7	1/7	1	Throughput	1/3	1/3	7	1
Streaming	Ber	Jitter	Delay	Throughput	**Background**	Ber	Jitter	Delay	Throughput
Ber	1	1/3	1/7	1/7	Ber	1	7	7	9
Jitter	3	1	1/3	1/3	Jitter	1/7	1	3	5
Delay	7	3	1	1/3	Delay	1/7	1/3	1	5
Throughput	7	3	3	1	Throughput	1/9	1/5	1/5	1

In [15] the authors explain that if C is defined as an AHP comparison matrix as in Table 1, then by solving the system : $U.w = n_{max}$ (where n_{max} is the largest eigenvalue of U), the priority or importance vector w can be obtained. Thus, the weights rely on the QoS prerequisite of the traffic classes. We use the eigenvector method used by the AHP to figure out the weights prensented in Table 3.

Table 3. Importance Weights Per Class.

Traffic Class	Ber	Jitter	Delay	Throughput
Conversational	0.07968	0.55464	0.31956	0.04610
Streaming	0.05104	0.13444	0.29493	0.51957
Interactive	0.50385	0.27509	0.04608	0.17496
Background	0.68037	0.17644	0.10390	0.03926

3.3. Vertical Handover Decisions

In this section we present the mathematical models of the methods SAW, TOPSIS and MEW. To calculate the score of the available networks given by the methods in the four QoS classes, the problem is also expressed as:

$$
Q_{N,M} = \begin{array}{c} \\ Network_1 \\ Network_2 \\ \vdots \\ Network_N \end{array}
\begin{array}{cccc}
Attribute_1 & Attribute_2 & \ldots & Attribute_M \\
\left(\begin{array}{cccc}
w_1 & w_2 & \ldots & w_M \\
n_{11} & n_{12} & \ldots & n_{1M} \\
n_{21} & n_{22} & \ldots & n_{2M} \\
\vdots & \vdots & \ddots & \vdots \\
n_{N1} & n_{N2} & \ldots & n_{NM}
\end{array} \right)
\end{array}
$$

3.3.1. SAW

The overall score of each candidate network is determined by the weighted sum of all attribute values. The score S_{SAW} of each candidate network C_i is obtained by summing the contributions of each n_{ij} normalized metric multiplied by the assigned importance weight w_j. The selected network is:

$$
S_{SAW} = \max_i \sum_{j=1}^{M} w_j \cdot n_{ij} \tag{2}
$$

Such that, w_j is the weight vector taken from Table 3. n_{ij} is the value of normalized attribute j of network i. N and M are respectively the number of candidates and the number of network attributes considered.

3.3.2. TOPSIS

The selected network is the one that is closest to the ideal solution and farthest from the worst case solution. These networks are defined as the network with the best and worst values for each metric. For a metric of performance, the best value is the largest. For a cost metric, the best value is the lowest. The steps of TOPSIS are cited in [20]:

Step 1: Calculate the weighted normalized decision matrix as follows:

$$v_{ij} = w_{ij} \cdot n_{ij} \tag{3}$$

Step 2: Determine the "positive ideal" and "negative ideal" alternatives. They are given by:

$$A^+ = \{v_1^+, v_2^+, ...\}, v_j^+ = \max_i(v_{ij}) \tag{4}$$

$$A^- = \{v_1^-, v_2^-, ...\}, v_j^- = \min_i(v_{ij})$$

Step 3: Calculate the distances. The separation of each alternative A^i from the ideal solution A^+ and the separation of each alternative A^i from the ant-ideal solution A^- are calculated as:

$$d_i^+ = \sqrt{\sum_{j=1}^{M} |v_i^+ - v_{ij}|} \tag{5}$$

$$d_i^- = \sqrt{\sum_{j=1}^{M} |v_i^- - v_{ij}|}$$

Step 4: Calculate the relative proximity to the ideal solution. The relative proximity of A_i with regards to A^+ and A^- is given by R_i and can be expressed as:

$$R_i = \frac{d_i^+}{d_i^+ + d_i^-} \tag{6}$$

where R_i is the best while it is most proximate to 0; $R_i \in [0, 1]$.

3.3.3. MEW

The score S_{MEW} of network i is determined by the weighted product of the attributes (or metrics):

$$S_{MEW} = \prod_{j=1}^{M} n_{ij}^{w_j} \tag{7}$$

Note that in this eq, w_j is a positive power for gain metrics $n_{ij}^{w_j}$, and a negative power for cost metrics $n_{ij}^{-w_j}$. Since the score of a network obtained by MEW does not have an upper limit, it is proper to compare each network with the score of the positive ideal network A^+ which is defined by the first part of Equation (4). The value ratio Ri between network i and the positive ideal is calculated by:

$$R_i = \frac{\prod_{j=1}^{M} n_{ij}^{w_j}}{\prod_{j=1}^{M} (n_{ij}^*)^{w_j}} \tag{8}$$

where $R_i \in [0, 1]$. Hence, the selected network is : $A_{MEW} = \max_i(R_i)$.

4. Performance Evaluation

4.1. Simulations

In this simulation, to explain Vertical Handover schemes we use the same scenario for different mathematical theories.

On the network side, we consider two available networks (WLAN and Wimax). Both are ideal partners for operators to deliver convenient and affordable services, they are open IEEE wireless standards built from scratch for IP-based applications. We used the same scenario as in [16]. On the user side, we consider four types of applications with different QoS requirements including Conversational, Streaming, Interactive and background. Each traffic class is combined with four different QoS parameters or attributes: Throughput, e2e Delay, Jitter, and Ber. The four traffic classes have different QoS requirements. Therefore, different weights have been assigned to the AHP method for the same attribute with different traffic classes. We use our own weights which are shown in Table 3. Although the simulation is maintained for 10 min, $100,000$ packets are supposed to be sent and the decision is made every 5 s in realtime.

In case of N different available networks, the terminal needs to apply the methods for the four QoS classes. For each method, the terminal perform 4 x N computations to select the optimal network, the total of $3 \times 4 \times N$ computations in the case of all decision schemes.

To calculate the time T the terminal will require selecting the optimal network, we translated the complexity of the algorithms $\mathcal{O}(n^2) = max(\mathcal{O}(SAW), \mathcal{O}(TOPSIS), \mathcal{O}(MEW))$. Typically, for high quality and seamless handover, the packet delay must not exceed 150 ms. Assuming the terminal performs one billion operations per second, the approximate running time of each algorithm where $n < 5$ is 250 ns. Accordingly, the time to find the rank of all the available network is ~ 1 ms for the four types of applications

The following section details the development of the network through the simulation.

4.2. Results

In some point of the simulation, we give Wifi more importance with the weighting vectors, but in all of the following figures Wimax is selected, indeed the choise is based on multiple factors, bandwidth occupation for example. Therefore, to compare the performance of each decision we choose the number of lost packets and the end-to-end delay during the simulation. Those parameters vary within the change of performance of the methods and considering the time taken by each method to be excecuted and the packets dropped all along the vertical handover excecution.

The Figures 3 and 4 describe the end to end delay and the Packet Loss respectively of each traffic class for each handover decision algorithm, also, it presents the difference of the performance between the weights given in [15] and presented with our scenario in [16] and our weights with the same scenario.

In terms of delay, the weights offer a better performance for the four type of application against the packet loss, the new weight helped in increasing the number of lost packets, even though the number of lost packets is very low considering the number of packets that should be transmitted ($100,000$).

In Conversational Class, the results show that TOPSIS and SAW maintained the same performance in terms of delay and packet loss. In Streaming Class, SAW presented a slightly low delay as did TOPSIS for packet loss. On the Interactive Traffic, MEW showed the best performance in terms of delay and SAW provides the best performance in terms of packet loss. Finally, in the Background Class, MEW has better loss rate whereas both MEW and TOPSIS maintained the same performance.
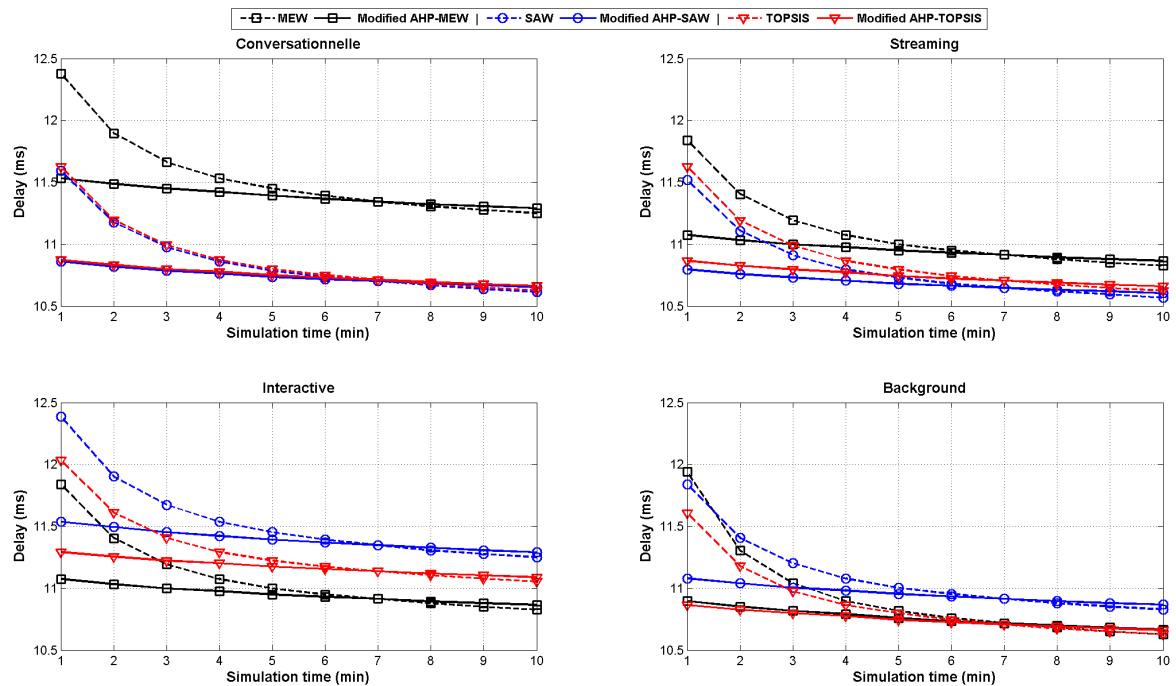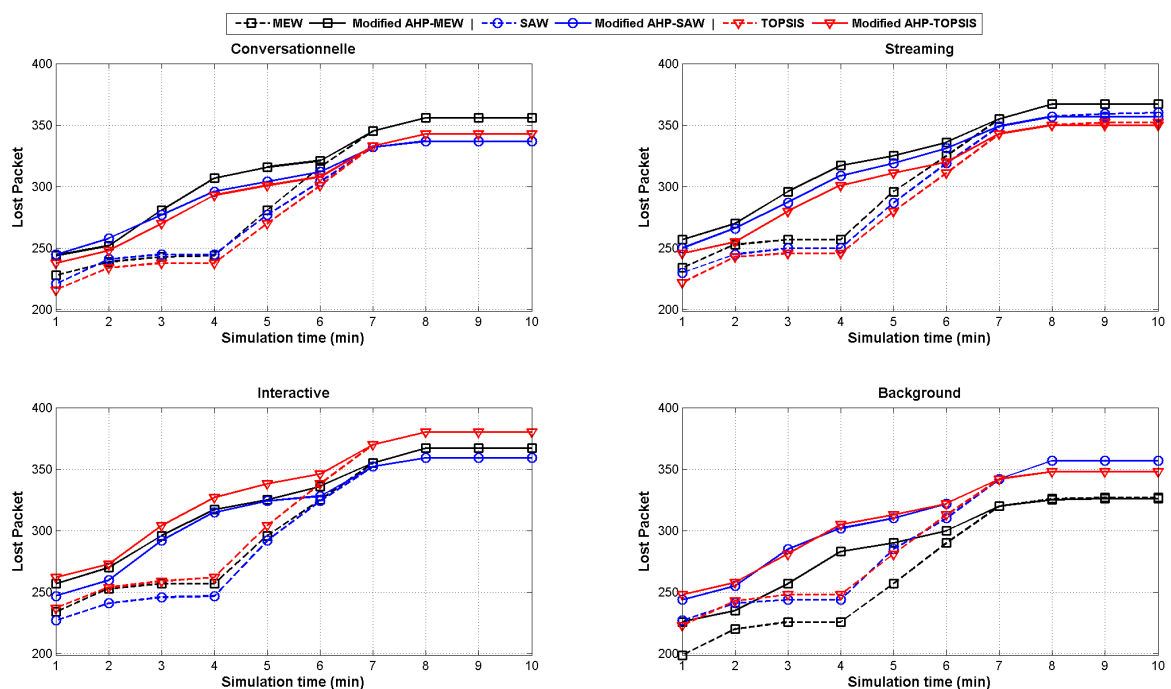

Figure 3. Behavior of Delay over Time.

Figure 4. Behavior of Packet Loss over Time.

5. Conclusions

In terms of resource management in the heterogeneous wireless network, dynamic network selection algorithms provide users with the appropriate QoS in terms of operator's and user's preferences.

Therefore, in this paper, we presented the mathematical models of three different vertical handoff decision algorithms, SAW, TOPSIS and MEW and the comparison between their performances in four types of applications: conversational, streaming, interactive and background. In addition, we investigated the weights provided to those methods in order to figure out how to establish, objectively, the vertical handover without decision makers mediation required by AHP. The realtime simulation includes Wifi and Wimax. The attributes considered are throughput, delay, jitter, and Ber. Results showed that the proposed parameters provide an improvement of Delay and offer allowable Packet loss in different types of application.

For the future, we intend to enhance AHP with fuzzy logic to achieve the objectivity needed in vertical handover. Also, we consider improving the simulation with sufficient performance comparison using realtime data acoording to each type of applications.

Author Contributions

Maroua Drissi: Main writing and also designing the total system, analyzing and improving the proposed system; Mohammed Oumsis: Total supervision of the paperwork, review, and comments, *etc*. Both authors have read and approved the final manuscript.

Conflicts of Interest

Authors declare no conflict of interest.

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