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Performance Comparison between MADM Algorithms for Vertical Handoff in 4G networks

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***Abstract*—In a fourth generation (4G) wireless environment, the need for an user to be always best connected (ABC) anywhere at anytime leads to execute a vertical handoff decision for guaranteeing service continuity and quality of service (QoS). Several strategies have been proposed in the literature for addressing this problem, being multiple attribute decision making (MADM) one of the most promising methods. A comparative analysis of these methods including SAW, MEW, TOPSIS, ELECTRE, VIKOR, GRA, and WMC is illustrated with a numerical simulation, showing their performance for different applications such as: voice and data connections, in a 4G wireless system.**

***Index Terms*—Vertical handoff decision, 4G wireless networks, MADM.**

I. Introduction

The fourth generation (4G) of wireless communications is expected to integrate multiple networks over a common IP (Internet Protocol) platform. Thus, such 4G system may integrate wireless local area networks (WLAN/WiFi), 3G Universal Mobile Telecommunications System (UMTS), wireless metropolitan area networks (WMAN/WiMAX) among other networks. The expected 4G system is shown in Figure 1. Here, users expect the best connectivity to applications anywhere at anytime, which is the most important issue in such environment also known as the Always Best Connected (ABC) concept [1]. The ABC requirement must be performed based on decision factors such as received signal strength (RSS), available bandwidth, service type, monetary cost, network conditions, and user preferences. The existing homogeneous networks are unable to provide such ubiquitous service availability. Hence it is desirable to interoperate between heterogeneous and complementary wireless technologies (i.e., 3G, WLAN,WMAN), that is, mobile users will switch connections between different access technologies to satisfy the ABC requirement. This process is known as *vertical handoff* [2].

A vertical handoff is the process of changing the mobile connection between access points supporting different wireless technologies. Meanwhile, in an horizontal handoff the connection just move from one base station to another within the same access network. The vertical handoff consist mainly in three phases: network discovery, handoff decision and handoff execution. In the first step, the mobile terminal (MT) discovers its available neighboring networks. In the decision phase, the MT determines whether it has to redirect its connection based on comparing the decision factors offered by the available networks and required by the mobile user, that is, information gathered in the first phase. The last phase, is responsible for the establishments and release of the connections according to the vertical handoff decision.

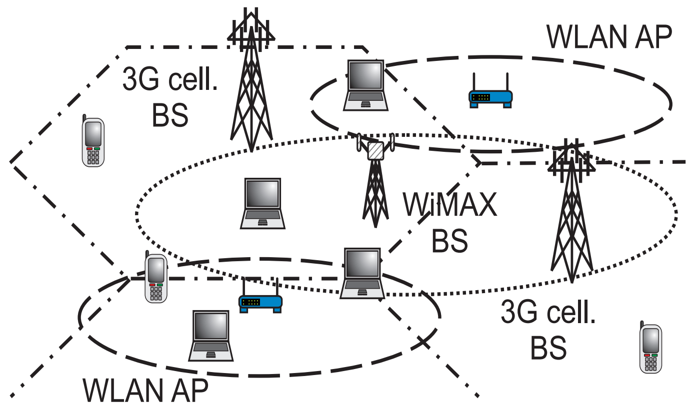

Fig. 1. Selected networks for each vertical handoff decision method.

Various Multiple Attribute Decision Making (MADM) [2] methods have been proposed in the literature for vertical handoff, methods such as SAW (simple additive weighting) [3], TOPSIS (technique for order preference by similarity to ideal solution) [3], MEW (multiplicative exponent weighting) [4] , Grey relational analysis (GRA) [5], ELECTRE (elimination and choice translating priority) [6], WMC (weighted Markov chain) [7], and VIKOR [8]. Considerable amount of research on develop MADM methods for vertical handoff have been conducted, and it is necessary to evaluate their performance under different scenarios in order to provide the best solution for a particular application. In [4], [9], and [10] brief simulation studies are addressed for this purpose, but only including SAW, MEW, TOPSIS, and GRA algorithms.

In this paper, we present a comparative study of seven MADM algorithms proposed in the literature, by mean of simulations and performance analysis for an heterogeneous wireless network, integrated by WLAN, UMTS and WiMAX networks, when the user conducts various applications.

The rest of the paper is organized as follows. In Section II, the studied MADM methods for vertical handoff decision are described. In Section III, simulation results are presented and some observations are discussed. Finally, in Section IV conclusions are given.

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II. Review of MADM Methods for Vertical Handoff

The most known and used MADM algorithms for vertical handoff are Simple Additive Weighting (SAW) [3], Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) [3], and Multiplicative Exponent Weighting (MEW) [4] between others. These algorithms have to evaluate and compare the decision factors for each wireless network, in order to detect and trigger a vertical handover. The factors can be classified as benefical, i.e., the larger, the better, or cost, i.e., the lower, the better. In the following these algorithms are described.

A. SAW and MEW

The decision problem can be expressed in a $M \times N$ decision matrix, where the j-th attribute of the i-th network is represented as x_{ij}. **SAW** [3] is the best known and most widely used scoring method, the score of each candidate network i is obtained by adding the contributions from each attribute r_{ij} multiplied by the weight factors w_j. Then, the selected network A^*_{SAW} is:

$$A^*_{SAW} = \arg\max_{i \in M} \sum_{j \in N} w_j r_{ij},$$

where $r_{ij} = x_{ij}/x_j^+$ for benefit parameters, and $r_{ij} = x_j^-/x_{ij}$ for cost parameters, moreover, $x_j^+ = \max_{i \in M} x_{ij}$ and $x_j^- = \min_{i \in M} x_{ij}$, and the weight vector must satisfy $\sum_{j=1}^{N} w_j = 1$.

MEW [4] is another scoring method, for which the scores of the networks are determined by the weighted product of the attributes. The selected network A^*_{MEW} is:

$$A^*_{MEW} = \arg\max_{i \in M} \prod_{j \in N} r_{ij}^{w_j}.$$

B. TOPSIS

In Technique for Order Preference by Similarity to Ideal Solution Algorithm (**TOPSIS**) [3] with M alternatives that are evaluated by N decision criteria is viewed as a geometric system with M points in the N dimensional space. Here, the chosen candidate network is the one which have the shortest distance to the ideal solution and the longest distance to the worst case solution. To compute the network ranking-list, TOPSIS requires the following steps:

Step 1: Construct the normalized decision matrix, which allows comparison across the attributes, this matrix is given by:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}.$$

Step 2: Construct the weighted normalized decision matrix as $v_{ij} = w_j * r_{ij}$.

Step 3: Determine ideal and negative-ideal solutions by:

$$A^+ = \{(\max_{i \in M} v_{ij} | j \in J), (\min_{i \in M} v_{ij} | j \in J')\},$$

and

$$A^- = \{(\min_{i \in M} v_{ij} | j \in J), (\max_{i \in M} v_{ij} | j \in J')\},$$

where J is the set of benefit parameters, and J' is the set of cost parameters. **Step 4:** Calculate the separation measure between the networks and the positive and negative ideal networks by:

$$s_i^+ = \sqrt{\sum_{j \in N} (v_{ij} - v_j^+)^2}, \quad s_i^- = \sqrt{\sum_{j \in N} (v_{ij} - v_j^-)^2}.$$

Step 5: Calculate the relative closeness to the ideal solution.

$$c_i^* = \frac{s_i^-}{(s_i^+ + s_i^-)}.$$

A set of alternatives can now be preference ranked according to the descending order of c_i^*. Then the selected network A^*_{TOP} is:

$$A^*_{TOP} = \arg\max_{i \in M} c_i^*.$$

C. ELECTRE

In Elimination and Choice Translating Priority (**ELECTRE**) algorithm [6], a reference attribute vector is used to adjust the raw attribute values for the alternative networks before they are compared. The value of each of the attributes in the decision matrix is compared with a corresponding reference attribute value x_j^{ref}. An absolute difference between the two values is taken to calculate a new matrix as follows.

$$r_{ij} = |x_{ij} - x_j^{ref}| \tag{1}$$

Now in this matrix all attribute values can be considered to have a monotonically decreasing utility. Since a lower value for an adjusted attribute in (1) is considered an indication of a better network in the selection process, each attribute in (1) can be normalized as follows,

$$\hat{r}_{ij} = \frac{\max_{i \in M}\{r_{ij}\} - r_{ij}}{\max_{i \in M}\{r_{ij}\} - \min_{i \in M}\{r_{ij}\}}$$

Now, is necessary take into consideration the relative importance of each of the attributes involved in the decision about network selection. For the j-th attribute is assigned a weight w_j, such that $\sum_{j=1}^{N} w_j = 1$. Using the weights, an updated matrix is calculated by,

$$\tilde{r}_{ij} = w_j \hat{r}_{ij} \tag{2}$$

In order to compare the network alternatives, the concept of concordance and discordance has been introduced in ELECTRE, which are measures of satisfaction and dissatisfaction of the decision maker when one alternative is compared with another. It firstly uses pair-wise comparisons of networks to obtain the concordance set $CSet(k, l)$ indicating the attribute of network k is better than network l and the discordance set $DSet(k, l)$ indicating the attribute of network k is worse than network l. The concordance and discordance sets are formed as follows,

$$CSet_{kl} = \{j | \tilde{r}_{kj} >= \tilde{r}_{lj}\}$$
$$DSet_{kl} = \{j | \tilde{r}_{kj} < \tilde{r}_{lj}\}$$

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Using the concordance and discordance sets, corresponding matrices are constructed. The elements of the concordance matrix C can be represented as,

$$C_{kl} = \sum_{j \in CSet_{kl}} w_j$$

The entries for the concordance matrix are not defined for the diagonal. ELECTRE defines the elements of discordance matrix as follows,

$$d_{kl} = \frac{\sum_{j \in DSet_{kl}} |\tilde{r}_{kj} - \tilde{r}_{lj}|}{\sum_{j \in N} |\tilde{r}_{kj} - \tilde{r}_{lj}|}$$

Similarly, the entries for the discordance matrix are also not defined for the diagonal. A new parameter $\tilde{C}_i$, called the net concordance index is calculated. $\tilde{C}_i$ is a measure of dominance of an alternative i over other alternatives. It can be calculated as follows,

$$\tilde{C}_i = \sum_{j \in N,\ j \neq i} C_{ij} - \sum_{j \in N,\ j \neq i} C_{ji}$$

Similarly, the term net discordance index D_i, is defined as a measure of relative weakness of alternative i over other alternatives, and can be calculated as

$$\tilde{D}_i = \sum_{j \in N,\ j \neq i} D_{ij} - \sum_{j \in N,\ j \neq i} D_{ji}$$

An alternative with the highest value of net concordance index $\tilde{C}$ and the lowest value of net discordance index $\tilde{D}$ would be preferred. However, if it is not the case, the alternatives are ranked based on the concordance and discordance indices and each alternative is ranked by taking the average of these two rankings. The alternative with the highest average ranking is considered to be the best alternative. Alternatives with the same average ranking would be considered equally suited.

D. VIKOR

For **VIKOR** [8] method the following steps are required:

Step 1: For each parameter $j = 1, 2, 3, ..., N$, determine the best and the worst values given by:

$$F_j^+ = \{(\max_{i \in M} x_{ij} | j \in N_b), (\min_{i \in M} x_{ij} | j \in N_c)\},$$

and

$$F_j^- = \{(\min_{i \in M} x_{ij} | j \in N_b), (\max_{i \in M} x_{ij} | j \in N_c)\},$$

where $N_b \subset N$ is the set of benefit parameters, and $N_c \subset N$ is the set of cost parameters.

Step 2: Compute the values of S_i and R_i for $i = 1, 2, 3, ..., M$ given by:

$$S_i = \sum_{j \in N} w_j \frac{(F_j^+ - x_{ij})}{(F_j^+ - F_j^-)},$$

and

$$R_i = \max_{j \in N} \left[w_j \frac{(F_j^+ - x_{ij})}{(F_j^+ - F_j^-)} \right],$$

where w_j is the importance weight of parameter j.

Step 3: Compute the values of Q_i for $i = 1, 2, 3, ..., M$ given by:

$$Q_i = \gamma \left(\frac{S_i - S^+}{S^- - S^+} \right) + (1 - \gamma) \left(\frac{R_i - R^+}{R^- - R^+} \right),$$

where

$$S^+ = \min_{i \in M} S_i, \quad S^- = \max_{i \in M} S_i,$$
$$R^+ = \min_{i \in M} R_i, \quad R^- = \max_{i \in M} R_i,$$

and parameter γ with $0 \leq \gamma \leq 1$ is the weight of the strategy and represents the *majority of criteria*.

Step 4: Given the values for the Q, R and S for all $i \in M$, rank the candidate networks in an increasing order.

The selected network A^*_{VIK} is:

$$A^*_{VIK} = \arg \min_{i \in M} Q_i^*.$$

E. GRA

In Grey Relational Analysis (**GRA**) [5] algorithm, grey relational coefficient (GRC) is used as the coefficient to describe the similarity between each candidate network and the best reference network (an ideal network formed by choosing the best value of each attribute). GRA is usually implemented following three steps: normalization data, defining the ideal sequence, and computing GRC.

The normalization of the sequence data is performed according to the three situations (larger-the-better, smaller-the-better, and nominal-the-best) as follows:

$$r_{ij} = \frac{x_{ij} - l_j}{u_j - l_j},$$

$$r_{ij} = \frac{u_j - x_{ij}}{u_j - l_j},$$

$$r_{ij} = 1 - \frac{|x_{ij} - m_j|}{\max u_j - m_j, m_j - l_j},$$

where $u_j = \max_{i \in M} x_{ij}$, $l_j = \min_{i \in M} x_{ij}$, and m_j is the largest value in the situation of nominal-the-best, for $j = 1, 2, 3, ..., N$. The ideal sequence x_0 is defined to contain the upper bound, lower bound, or moderate bound respectively in larger-the-better, smaller-the-better or nominal-the-better situations. The GRC can be then calculated as following:

$$GRC_i = \frac{1}{m} \sum_{j=1}^{m} \frac{\Delta_{\min} + \Delta_{\max}}{\Delta_i + \Delta_{\max}},$$

where

$$\Delta_i = |x_{0j} - r_{ij}|,$$

and

$$\Delta_{\max} = \max_{i \in M, j \in N} \Delta_i, \quad \Delta_{\min} = \min_{i \in M, j \in N} \Delta_i$$

The larger the GRC, the more preferable the network will be. The selected network A^*_{GRA} is:

$$A^*_{GRA} = \arg \max_{i \in M} GRC_i.$$

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TABLE I
RANGE OF VALUES OF THE NETWORKS' PARAMETERS.

Parameter	UMTS1	UMTS2	WLAN1	WLAN2	WiMAX1	WiMAX2
Available Bandwidth (Mbps)	0.1-2	0.1-2	1-11	1-54	1-60	1-60
Total Bandwidth (Mbps)	2	2	11	54	60	60
Packet Delay (ms)	25-50	25-50	100-150	100-150	60-100	60-100
Packet Jitter (ms)	5-10	5-10	10-20	10-20	3-10	3-10
Packet Loss (per 10^6)	20-80	20-80	20-80	20-80	20-80	20-80
Cost per byte (price)	0.6	0.8	0.1	0.05	0.5	0.4

F. WMC

The weighted Markov chain (**WMC**) [7] algorithm include the following steps:

Step 1: Construction of weighted Markov chain transition matrix MC. Initialize a $M \times M$ matrix $MC = \{mc_{ij}\}$ with all element values are equal to 0, in which mc_{ij} represent transition probability from alternative p_i to the network p_j.

Step 2: For each decision factor q, a ranking list is obtained as

$$\tau_q = [p_1 \geq p_2 \geq \cdots \geq p_M]$$

where "$\geq$" represents some ordering relation, and $\tau_q(p)$ denotes the ranking of alternative p with regard to factor q.

Step 3: For each mc_{ij} in MC, update

$$mc_{ij} = mc_{ij} + \frac{w_q}{\tau_q(p_i)}, \quad \text{if} \quad \tau_q(p_i) \geq \tau_q(p_j).$$

Step 4: Computation of stationary probabilities:

$$\pi_j = \sum_{i=0}^{M} \pi_i mc_{ij}, \quad \sum_{j=0}^{N} \pi_j = 1$$

The selected network A^*_{WMC} is:

$$A^*_{WMC} = \arg\max_{j \in M}(\pi_j)$$

III. SIMULATION RESULTS

In order to evaluate the performance of each MADM algorithm, we consider a network selection situation in a 4G environment integrated by three network types as WLAN, UMTS and WiMAX, and there are two networks of each type. In this work, six decision criteria have to be evaluated and compared in order to detect and to trigger a vertical handoff. Including available bandwidth (Mbps), total bandwidth (Mbps), packet delay (ms), packet jitter (ms), packet loss (per each 10^6 packets) and cost per byte (price). The range of values of the parameters or decision criteria are shown in Table I. The values of assigned weights for different services considered in this study are: case 1, all parameters have the same weight, this is the baseline case; case 2, delay and packet jitter have 70% of importance and the rest is equally distributed among the other parameters, this case is suitable for voice connections; and case 3, available and total bandwidth have 70% of importance, this case is suitable for data connections. In each vertical handoff decision point, the attribute values may be the same, increase or decrease within the range shown in Table I. In order to varying the values of the decision criteria, a Markov chain is used for each attribute, where the transition probabilities for an increment or decrement are 0.4, while the probability of being in the same value is 0.2. For each application, we consider 50 vertical handoff decisions points for a total of 150 points in the simulation study.

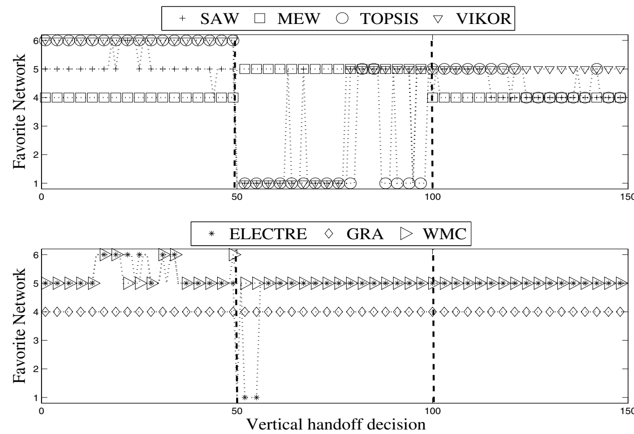

Fig. 2. Selected networks for each vertical handoff decision method.

A. Preferred Network

Figure 2 shows the selected alternatives for each MADM algorithm, in this figure are included the applications as follows: points 1-50 for case 1, 51-100 for case 2, and 101-150 for case 3. In Figure 2, according to Table I, network 1 corresponds to UMTS1, network 2 to UMTS 2, network 3 to WLAN1, network 4 to WLAN2, network 5 to WiMAX1, and network 6 to WiMAX2. For the baseline case, in almost all vertical handoff decisions five of the algorithms select networks WiMAX1 and WiMAX2 and only GRA and MEW select WLAN2. In fact, this behavior of GRA is the same in the other cases. For case 2 (voice connections), VIKOR, SAW, TOPSIS and ELECTRE execute vertical handoffs between WiMAX1 and UMTS1 since the 3G network is able to offer lower values of packet delay and jitter. For case 3 (data connections), SAW, MEW, TOPSIS and VIKOR execute vertical handoffs between WiMAX2 and WLAN2 since the WiFi network is able to offer higher values of available and total bandwidth. Note that in cases 2 and 3, WMC remains in the same network all the time.

B. Results case 1 (baseline) vs case 2 (voice)

For the voice connections case, note in Figure 2 that there are more vertical handoffs in order to achieve the best connectivity by reducing the packet delay, except for WMC and GRA methods. With MEW, a vertical handoff from WLAN2 to WiMAX1 is required. For this application, packet delay and packet jitter are the most important parameters. Figure 3 shows the packet delay achieved by the seven vertical handoff algorithms, decision points 1 to 50 corresponds to case 1 and decision points 51 to 100 to case 2. We can see that in case 2 VIKOR is able to obtain the lowest values of packet delay followed by SAW, TOPSIS and ELECTRE. Note that MEW is able to reduce its packet delay compared to case 1, while GRA and WMC remain with the same values as in case 1 since they decide not perform vertical handoffs. Figure 4 shows the packet jitter achieved by the seven vertical handoff algorithms, decision points 1 to 50 corresponds to case 1 and decision

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points 51 to 100 to case 2. We can see that in case 2 VIKOR, SAW, TOPSIS, ELECTRE and WMC are able to achieve slightly lower values of jitter compared to case 1. MEW is able to reduce its packet jitter to less than 50% compared to case 1, while GRA remains with the same values as in case 1.

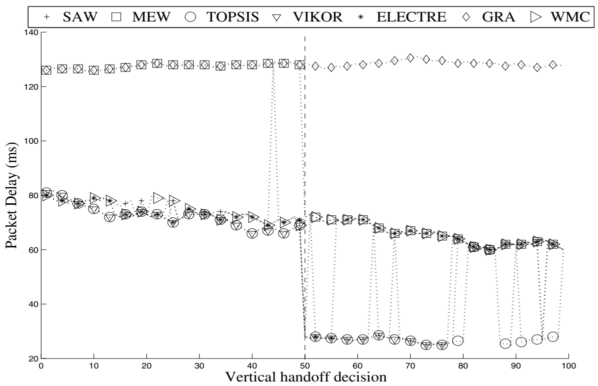

Fig. 3. Values of packet delay selected by the decision methods.

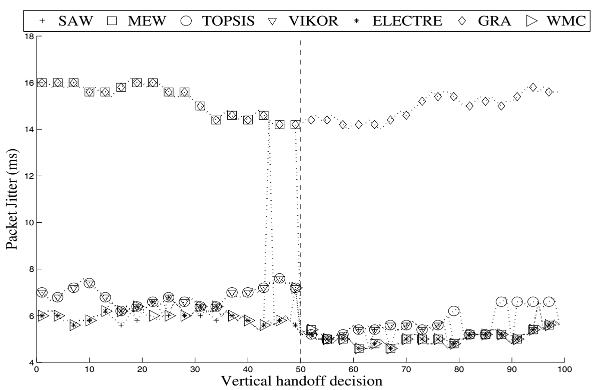

Fig. 4. Values of packet jitter selected by the decision methods.

C. *Results case 1 (baseline) vs case 3 (data)*

For data connections case, note in Figure 2, one of the most important criteria is the total bandwidth and corresponds to WiMAX1, methods as WMC, ELECTRE and VIKOR select this. On the other hand, the available bandwidth is necessary for data transmission, but in the simulation,WLAN2 provides a higher available bandwidth than the rest. This causes that methods as SAW, MEW and TOPSIS perform a vertical handoff to WLAN2 to achieve the best connectivity. On the other hand, GRA algorithm selects WLAN2 for all the vertical handoff decision points. Figure 5 shows the available bandwidth achieved by the seven vertical handoff algorithms, decision points 1 to 50 corresponds to case 1 and decision points 51 to 100 to case 3. We can see that in case 3, MEW and GRA are able to obtain the highest values of available bandwidth followed by SAW and TOPSIS. On the other hand, VIKOR, ELECTRE and WMC reduce their available bandwidth compared to case 1. Figure 6 shows the total bandwidth achieved by the seven vertical handoff algorithms, decision points 1 to 50 corresponds to case 1 and decision points 51 to 100 to case 3. We can see that VIKOR and WMC obtain the highest values followed by SAW, TOPSIS, MEW and GRA.

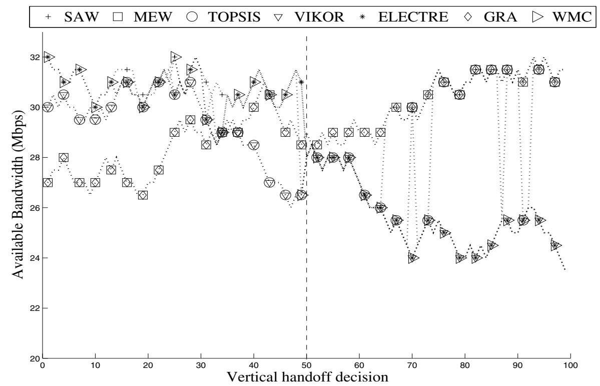

Fig. 5. Values of available bandwidth selected by the decision methods.

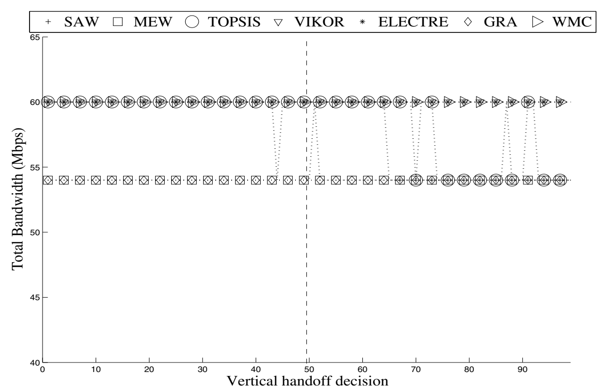

Fig. 6. Values of total bandwidth selected by the decision methods.

IV. Conclusions

In this paper, we provide a simulation study of several vertical handoff decision algorithms, with the aim of understand its performance for different user applications. We consider two different applications: voice and data connections. Methods as SAW, VIKOR and TOPSIS are suitable for voice connections, these algorithms provide a compromise for achieve the lower values of jitter and delay packet available in a 4G wireless network. In a data connection case, GRA and MEW algorithms provide the solution with highest available bandwidth necessary for this application.

As future work, we plan to consider other types of connections and study the impact of the importance weights assignment in the performance of the MADM algorithms.

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