Hybrid Network Selection Strategy by Using M-AHP/E-TOPSIS for Heterogeneous Networks

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***Abstract*—The most challenging problem in the heterogeneous wireless networks is ensuring seamless network selection. For that reason, a large variety of algorithms based on multi attribute decision making (MADM) have been proposed to deal with this issue. The analytic hierarchy process (AHP) and the technique for order preference by similarity to an ideal solution (TOPSIS) represent two MADM methods which are exhaustively used in the literature to cope with the network selection problem. However both of these methods still suffer from the ranking abnormality and the number of handoffs.**
Thus, we aim to propose a hybrid network selection strategy based multiple analytic hierarchy process (M-AHP) and the enhanced technique for order preference by similarity to an ideal solution (E-TOPSIS). The M-AHP method represents an extension of AHP which is used to weigh each criterion. While the E-TOPSIS method represents an extension of TOPSIS which is used to rank the alternatives. Simulation results demonstrate that our hybrid strategy for network selection can dealing with the limitations of MADM methods.

***Index Terms*—Heterogeneous Networks, Network Selection, Multi Attribute Decision Making, M-AHP, E-TOPSIS.**

I. Introduction

With the diversity of the services the users need to connect to internet anywhere and anytime with the best quality of service (QoS) and the minimum of the cost. Moreover, the fourth generation (4G) of wireless technologies such as IEEE 802.11, IEEE 802.16 and LTE are designed to support this diversity of the services. In addition, the mobile devices are equipped with multi-mode architecture which allow the users to have the opportunity to use a wealth of services across this heterogeneous networks. However, the important issue is how to provide ubiquitous access for the users under the principle “Always Best Connected” (ABC) [1]. To achieve this issue, the network selection decision [2] is intended to maintain the convergence between heterogeneous networks.

The MADM approach is very important solution for network selection problem. For that reason, several works based on MADM have been proposed and developed to tackle this issue. The MADM includes many methods such as analytic hierarchy process (AHP), analytic network process (ANP), simple additive weighting (SAW), multiplicative exponential weighting (MEW), grey relational analysis (GRA), and technique for order preference by similarity to ideal solution (TOPSIS).

In [3], [4] and [5] the network selection algorithm is based on AHP and GRA. The AHP method is used to get weight of each criterion. While GRA method is applied to rank the alternatives. In [6] and [7] the network selection decision is modeled using AHP and SAW. The AHP is used to provide a weight for each criterion involved in the network selection. While SAW algorithm is applied to provide the ranking of all alternatives.

In [8], [9] and [10] the network selection algorithm combines AHP and TOPSIS. The relative importance of different criteria are calculated by AHP method. While TOPSIS is used to rank the alternatives. In [11] the authors have proposed an intelligent selection algorithm which based on ANP method and TOPSIS algorithm. The first one is used to weigh different criteria and the second one is used to rank available networks. Although, AHP method has been widely used in the network selection process, it can provide imprecise weight concerning each criterion. This issue is due to the decision markers, AHP method is based only on the experience of one expert to build the matrix decision which can not reflect the real user's preferences. To deal with this limitation, the authors [12] have proposed multiple analytic hierarchy process (M-AHP) method. The M-AHP takes into account the experiences of multiple experts to build the matrix decision and to determine the weight for each criterion.

Moreover, TOPSIS method is often used to rank the available networks. However this method still presents two weaknesses ranking abnormality and the unnecessary handoffs. The ranking abnormality means that the ranking order of candidate networks changes when one alternative is added or removed from the candidate list. This phenomenon can make the network selection decision inefficient. The unnecessary handoffs means that mobile can perform unnecessary handoff which can leads to increase processing overheads. In order to improve the limits of the TOPSIS algorithm, the authors [13] have presented new algorithm based on ANP and enhanced TOPSIS (E-TOPSIS). The ANP method is used to weigh each criterion. While E-TOPSIS is used to rank available networks.

The goal of this paper is providing an optimal network selection algorithm, which can deal with the weaknesses of MADM methods. For that, we propose hybrid strategy which combines M-AHP and E-TOPSIS. The M-AHP is applied to determine the suitable weights for different criteria. While the E-TOPSIS method is used to rank the alternatives.

This paper is organized as follows. Section II describes some MADM methods. Section III presents our hybrid strategy based on M-AHP and E-TOPSIS. Section IV includes the simulations and results. Section V concludes this paper.

II. Multi attribute decision making

A. AHP

The AHP is one of the extensive multi-attribute decision making developed by Saaty [14]. This approach has been widely used in network selection process to assign weights for different criteria. The AHP approach is based on five steps:

1) Building the structuring hierarchy: A problem is decomposed into a hierarchy, this one contains three levels: the overall objective is placed at the topmost level of the hierarchy, the subsequent level presents the decision factors and the alternative solution are located at the bottom level.
2) Building the pairwise comparisons: To establish a decision, AHP builds the pairwise matrix comparison such as

$$A = \begin{pmatrix} x_{11} & x_{12} & \dots & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & \dots & x_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \dots & \dots & x_{nn} \end{pmatrix} \quad where, \begin{cases} x_{ii} = 1 \\ x_{ji} = \dfrac{1}{x_{ij}} \end{cases} \tag{1}$$

Elements x_{ij} are obtained from the table I.

TABLE I
SAATY'S SCALE FOR PAIRWISE COMPARISON

Saaty's scale	**The relative importance of the two sub-elements**
1	Equally important
3	Moderately important with one over another
5	Strongly important
7	Very strongly important
9	Extremely important

3) Building the normalized decision matrix: A_{norm} is the normalized matrix of A(1), where $A(x_{ij})$ is given by, $A_{norm}(a_{ij})$ such:

$$a_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}} \tag{2}$$

4) Calculating the weights of criterion: The weights of the decision factor i can be calculated by

$$W_i = \frac{\sum_{j=1}^{n} a_{ij}}{n} \quad and \quad \sum_{j=1}^{n} W_i = 1 \tag{3}$$

With n is the number of the compared elements.
5) Calculating the coherence ratio (CR): To test consistency of a pairwise comparison, a consistency ratio (CR) can be introduced with consistency index (CI) and random index (RI).
Let define consistency index CI

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{4}$$

The λ_{max} is calculated by the following formula:

$$\lambda_{max} = \frac{\sum_{i=1}^{n} b_i}{n} \quad such \quad b_i = \frac{\sum_{j=1}^{n} W_i * a_{ij}}{W_i} \tag{5}$$

The coherence ratio CR is calculated by the following formula:

$$CR = \frac{CI}{RI} \tag{6}$$

If the CR is less than 0.1, the pairwise comparison is considered acceptable. The various values of RI are shown in table II.

TABLE II
VALUE OF RANDOM CONSISTENCY INDEX RI

criteria	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
RI	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

B. TOPSIS

The TOPSIS method has been developed in 1981 [15]. The basic principle of the TOPSIS is that the chosen alternative should have the "shortest distance" from the positive ideal solution and the "farthest distance" from the negative ideal solution. The procedure can be categorized in seven steps.

1) Construct of the decision matrix: the decision matrix is expressed as

$$D = \begin{pmatrix} d_{11} & d_{12} & \dots & \dots & d_{1m} \\ d_{21} & d_{22} & \dots & \dots & d_{2m} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ d_{n1} & d_{n2} & \dots & \dots & d_{nm} \end{pmatrix} \tag{7}$$

Where d_{ij} is the rating of the alternative A_i with respect to the criterion C_j
2) Building the normalized decision matrix: each element r_{ij} is obtained by the euclidean normalization:

$$r_{ij} = \frac{d_{ij}}{\sqrt{\sum_{i=1}^{m} {d_{ij}}^2}} \quad , i = 1, ..., m, j = 1, ..., n. \tag{8}$$

3) Building the weighted normalized decision matrix: The weighted normalized decision matrix v_{ij} is computed as:

$$v_{ij} = W_i * r_{ij} \quad where \sum_{i=1}^{m} W_i = 1 \tag{9}$$

4) Determination of the ideal solution A^* and the anti-ideal solution A^-:

$$A^+ = [V_1^+, ..., V_m^+] \quad and \quad A^- = [V_1^-, ..., V_m^-], \tag{10}$$

- For desirable criteria:

$$V_i^+ = max\{v_{ij}\} \quad and \quad V_i^- = min\{v_{ij}\} \tag{11}$$

- For undesirable criteria:

$$V_i^+ = min\{v_{ij}\} \quad and \quad V_i^- = max\{v_{ij}\} \tag{12}$$

5) Calculation of the similarity distance:

$$S_j^+ = \sqrt{\sum_{j=1}^{m} (V_i^+ - v_{ij})^2}, j = 1, ..., n \tag{13}$$

and

$$S_j^- = \sqrt{\sum_{j=1}^{m}(v_{ij} - V_i^-)^2}, j = 1, ..., n \quad (14)$$

6) Calculation of relative closeness to the ideal solution: This step involves calculating the relative closeness to the ideal solution, which is defined as:

$$C_j^* = \frac{S_j^-}{S_j^+ + S_j^-} \ , j = 1, ..., n. \quad (15)$$

7) Ranking: A set of alternatives can be ranked according to the decreasing order of C_j^*.

C. E-TOPSIS

The E-TOPSIS approach is belonging to the MADM category [13] which extends the TOPSIS algorithm to select dynamically the best network interface. The E-TOPSIS approach consists of the following steps:

1) Building the decision matrix: can be calculated as equation 7.
2) Building the normalized decision matrix: can be calculated as equation 8.
3) Building the weighted normalized decision matrix: can be calculated as equation 9.
4) Determination of the ideal solution A^* and the anti-ideal solution A^-(see equations 10, 11, 12, 13, 14).
5) Calculation of the similarity distance: can be calculated as equation 15.
6) Calculation of relative closeness to the ideal solution: we introduce the relative importance λ_1 of ideal solution and λ_2 of anti ideal solution in order to calculate the new value of the similarity C_j^* (Eq. (15)) namely $C_j^{*^{New}}$. The expression of $C_j^{*^{New}}$ is given by the following formula:

$$C_j^{*^{New}} = 1 - \frac{\lambda_1 * S_j^+ + \lambda_2 * S_j^-}{S_j^+ + S_j^-} \ , j = 1, ..., n. \quad (16)$$

7) Ranking: A set of alternatives can be ranked according to the decreasing order of $C_j^{*^{New}}$.

III. Hybrid strategy for network selection

In this section we propose our hybrid strategy for network selection decision. The proposed strategy combines M-AHP and E-TOPSIS . The M-AHP method is used to weigh the criteria and E-TOPSIS is applied to rank each access network. The M-AHP method takes into account the experiences of multiple experts to build the matrix decision and to determine the weights of criteria. In this work, M-AHP method based on the experience of five experts.

Let define the weight vector W_{AHP_i}, obtained by AHP based only on the experience of one expert i:

$$W_{AHPi} = [a_{i1}, a_{i2}, ...a_{im}] \ where \ \sum_{j=1}^{m} a_{ij} = 1 \ and \ i = 1, ..., 5 \quad (17)$$

The weight vector W_{M-AHP}, can be calculated by using geometric mean:

$$W_{M-AHP} = [c_1, c_2, ...c_m], \ c_j = \sqrt[5]{\prod_{i=1}^{5} a_{ij}} \ where \, j = 1, ..., m \quad (18)$$

In addition, in order to overcome the ranking abnormality of TOPSIS algorithm we itroduce E-TOPSIS [13]. This one takes in the account the relative importance λ_1 of ideal solution and λ_2 of anti ideal solution to calculate the new value of relative closeness to the ideal solution of $C_j^{*^{New}}$. This value is used to rank each access network and to reduce the ranking abnormality phenomenon.

IV. Simulations and results

In order to validate our hybrid strategy for network selection which based on M-AHP to weigh different criteria and E-TOPSIS to rank available networks, we present the performance comparison between three algorithms:

- TOPSIS: this algorithm is based on two MADM methods AHP and TOPSIS. The AHP method is used to weigh different criteria. While The TOPSIS is applied to get the ranking of available networks.
- E-TOPSIS: this algorithm is based on AHP and E-TOPSIS. The AHP method is applied to get the weights of different criteria. While the E-TOPSIS is used to rank the available networks.
- ME-TOPSIS: this algorithm is our proposed hybrid strategy for network selection. It combines M-AHP and E-TOPSIS. Firstly the M-AHP is used to calculate the weights for each criterion. While the E-TOPSIS is applied to rank the networks.

We perform four simulations according to four traffic classes [16] namely interactive, conversational, background, and streaming. For each simulation, we provided the values for average of ranking abnormality and the number of handoffs. The three algorithms were run in 50 vertical handoff decision points by using MATLAB simulator.

Three wireless access networks are used: UMTS, WLAN and WIMAX. The six criteria associated in this heterogeneous environment are: Available Bandwidth (AB), Security (S), Cost per Byte (CB), Packet Jitter (J), Packet Delay (D), and Packet Loss (L). During the simulation, the measures of every criterion for candidate networks are randomly varied according to the ranges shown in table III. We use AHP method to weigh λ_1 and λ_2. The vector weights of λ_1 and λ_2 concerning each traffic class are displayed in table IV.

A. The simulation 1

In this simulation, the traffic analyzed is background traffic. The weight vector of TOPSIS (E-TOPSIS) and ME-TOPSIS are displayed in figure 1.

TABLE III
HANDOFF METRICS OF THE CANDIDATE NETWORKS

criteria **network**	**CB** (%)	**S** (%)	**AB** ($mbps$)	**D** (ms)	**J** (ms)	**L** ($per10^6$)
UMTS	60	50	0.1-2	20-50	5-15	20-80
WLAN	15	60	1-10	100-140	10-20	20-80
WIMAX	50	60	1-60	60-100	3-10	20-80

TABLE IV
THE RELATIVE IMPORTANCE OF λ_1 AND λ_2 FOR EACH TRAFFIC CLASS

Traffic class	λ_1	λ_2
Background	**0.677**	**0.333**
Conversational	**0.800**	**0.200**
Interactive	**0.857**	**0.143**
Streaming	**0.889**	**0.111**

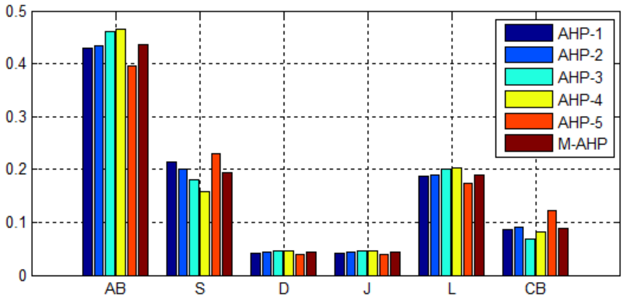

Fig. 1. Weights associated with the criteria for background traffic

1) Ranking abnormality: Figure 2 shows that the TOPSIS method reduces the risk to have an abnormality problem with a value of 45%, and E-TOPSIS method reduces the risk with a value of 42%. While our ME-TOPSIS method reduces the risk with a value of 36%. For background traffic, our mechanism ME-TOPSIS can reduce the ranking abnormality problem better than TOPSIS and E-TOPSIS. In addition the E-TOPSIS reduces the ranking abnormality better than TOPSIS.

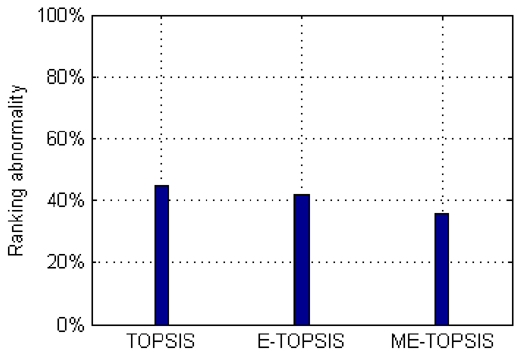

Fig. 2. Average of ranking abnormality for background traffic

2) Number of handoffs: Figure 3 shows that the TOPSIS method diminishes the number of handoffs with a value of 45%, and the E-TOPSIS provides a value of 36%. While the ME-TOPSIS method provides a value of 30%. We deduce that for background traffic, ME-TOPSIS method provides better performances concerning the number of handoffs than TOPSIS and E-TOPSIS. In addition the E-TOPSIS reduces the number of handoffs better than TOPSIS.

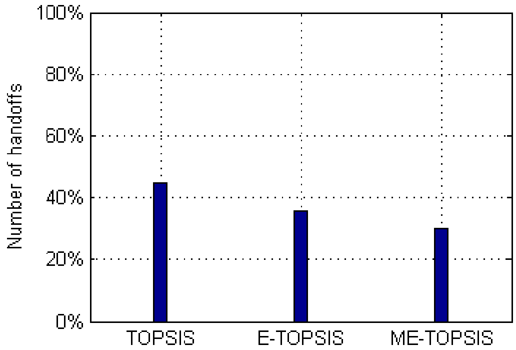

Fig. 3. Average of number of handoffs for background traffic

B. The simulation 2

In this simulation, the traffic analyzed is conversational traffic. The weight vector of TOPSIS (E-TOPSIS) and ME-TOPSIS are displayed in figure 4.

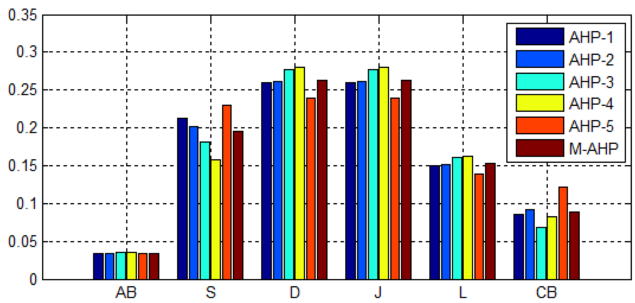

Fig. 4. Weights associated with the criteria for conversational traffic

1) Ranking abnormality: Figure 5 shows that the TOPSIS method reduces the risk to have an abnormality problem with a value of 27%, and E-TOPSIS method reduces the risk with a value of 20%. While our ME-TOPSIS method reduces the risk with a value of 18%. For conversational traffic, our mechanism ME-TOPSIS can reduce the ranking abnormality problem better than TOPSIS and E-TOPSIS. In addition the E-TOPSIS reduces the ranking abnormality better than TOPSIS.

2) Number of handoffs: Figure 6 shows that the TOPSIS method diminishes the number of handoffs with a value of 55%, and the E-TOPSIS provides a value of 50%. While the ME-TOPSIS method provides a value of 45%. We deduce that for conversational traffic, ME-TOPSIS method provides better performances concerning the number of handoffs than TOPSIS and E-TOPSIS. In addition the E-TOPSIS diminishes the number of handoffs better than TOPSIS.

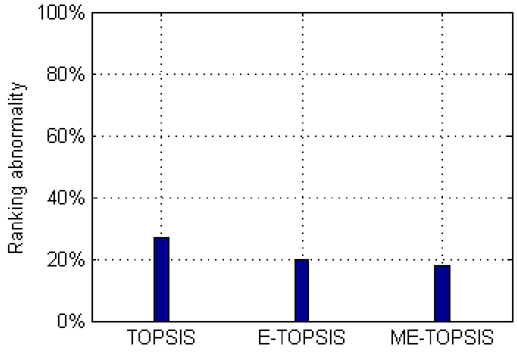

Fig. 5. Average of ranking abnormality for conversational traffic

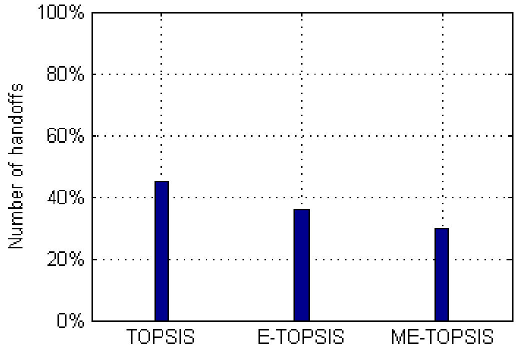

Fig. 6. Average of number of handoffs for conversational traffic

C. The simulation 3

In this simulation, the traffic analyzed is interactive traffic. The weight vector of TOPSIS (E-TOPSIS) and ME-TOPSIS are displayed in figure 7.

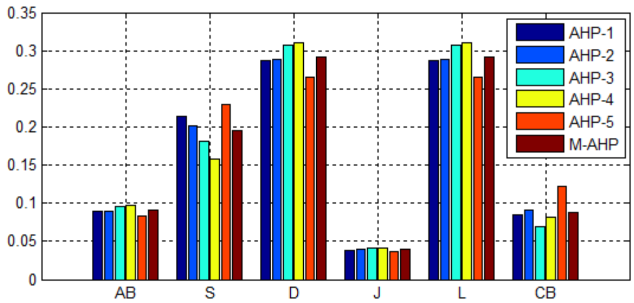

Fig. 7. Weights associated with the criteria for interactive traffic

1) Ranking abnormality: Figure 8 shows that the TOPSIS method reduces the risk to have an abnormality problem with a value of 45%, and E-TOPSIS method reduces the risk with a value of 36%. While our ME-TOPSIS method reduces the risk with a value of 30%. For interactive traffic, our mechanism ME-TOPSIS can reduce the ranking abnormality problem better than TOPSIS and E-TOPSIS. In addition the E-TOPSIS reduces the ranking abnormality better than TOPSIS.

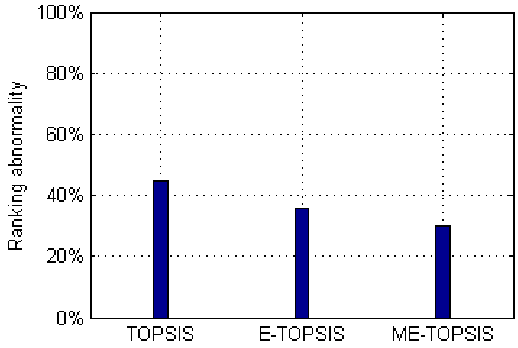

Fig. 8. Average of ranking abnormality for interactive traffic

2) Number of handoffs: Figure 9 shows that the TOPSIS method diminishes the number of handoffs with a value of 36%, and the E-TOPSIS provides a value of 30%. While the ME-TOPSIS method provides a value of 30%. We deduce that for conversational traffic, ME-TOPSIS method provides better performances concerning the number of handoffs than TOPSIS and E-TOPSIS. In addition the E-TOPSIS reduces the number of handoffs better than TOPSIS.

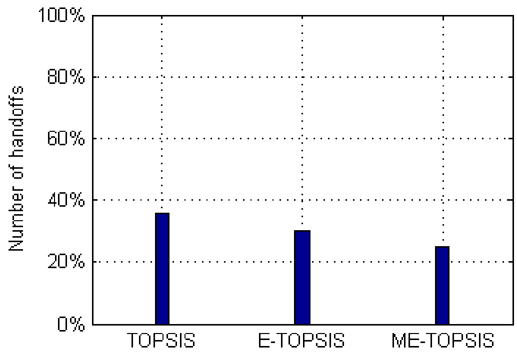

Fig. 9. Average of number of handoffs for interactive traffic

D. The simulation 4

In this simulation, the traffic analyzed is streaming traffic. The weight vector of TOPSIS (E-TOPSIS) and ME-TOPSIS are displayed in figure 10.

1) Ranking abnormality: Figure 11 shows that the TOPSIS method reduces the risk to have an abnormality problem with a value of 45%, and E-TOPSIS method reduces the risk with a value of 35%. While our ME-TOPSIS method reduces the risk with a value of 30%. For streaming traffic, our mechanism ME-TOPSIS reduces this problem better than TOPSIS and E-TOPSIS. In addition the E-TOPSIS method reduces the ranking abnormality better than TOPSIS method.

2) Number of handoffs: Figure 12 shows that the TOPSIS method diminishes the number of handoffs with a value of 55%, and the E-TOPSIS provides a value of 52%. While the

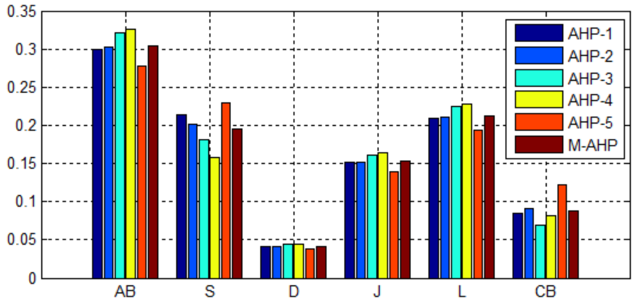

Fig. 10. Weights associated with the criteria for streaming traffic

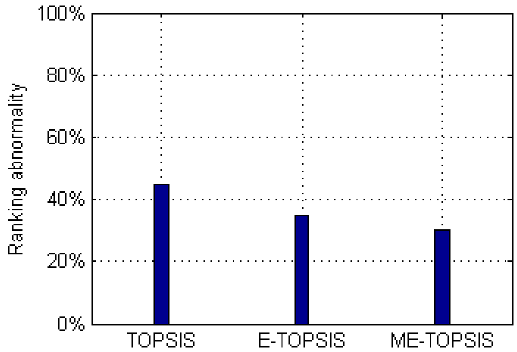

Fig. 11. Average of ranking abnormality for streaming traffic

ME-TOPSIS method provides a value of 50%. We deduce that for streaming traffic, ME-TOPSIS method provides better performances concerning the number of handoffs than TOPSIS and E-TOPSIS. In addition the E-TOPSIS method reduces the number of handoffs better than TOPSIS.

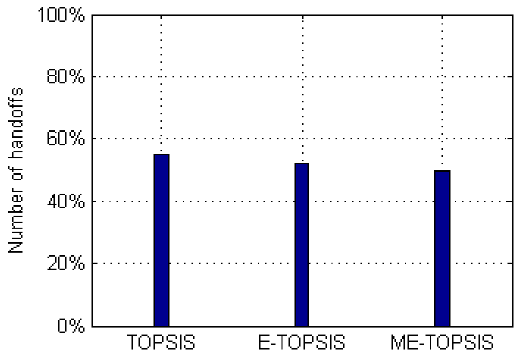

Fig. 12. Average of number of handoffs for streaming traffic

V. Conclusion

In this work we have proposed hybrid strategy ME-TOPSIS for network selection which based on M-AHP method and E-TOPSIS method. The M-AHP method is an extension of the classical AHP which is based on the experiences of multiple experts to assign a suitable weights of different criteria. While the E-TOPSIS is the enhanced of TOPSIS algorithm which is used to rank the available networks.

The simulation results show that, for each traffic classe, our mechanism ME-TOPSIS provides better performances concerning two evaluation parameters such as ranking abnormality and number of handoffs than the two algorithms such as TOPSIS and E-TOSPIS. Moreover the E-TOPSIS method reduces the ranking abnormality and the number of handoffs better than TOPSIS method for each traffic classe.

We conclude that by considering the relative importance λ_1 of ideal solution and λ_2 of anti ideal solution, the E-TOPSIS provides the better results than the TOPSIS. In addition by considering the experiences of multiple experts to weigh the different criteria our hybrid network selection strategy ME-TOPSIS provides the better results than the E-TOPSIS.

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