An Optimized Vertical Handover Approach Based on M-ANP and TOPSIS in Heterogeneous Wireless Networks

Mohamed Lahby, Abdelbaki Attioui and Abderrahim Sekkaki

Abstract Due to a deployment of different networks technologies such as 3G (UMTS, IEEE 802.11), 4G (LTE, IEEE 802.16) and 5G, the users have the opportunity to be connected to Internet at any time and any where. This ability to be quickly and easily connected is ensured by using the intelligent mobile terminal multi-modes such as mobile phones, smart-phones, IPAD, etc. These equipments mobiles have enabled users also to handle simultaneously various applications by using different access networks. The most issue in this heterogeneous wireless network is enabling for users to continuously choose the most appropriate access network during their communication. To deal with this task, we propose a new approach for network selection based on two multi attribute decision making (MADM) methods namely multiple analytic network process (M-ANP) and technique for order preference by similarity to ideal solution (TOPSIS) method. The M-ANP is used to weigh each criterion and TOPSIS is applied to rank the alternatives. The simulation results illustrate the effectiveness of our optimized approach in terms of reducing of the reversal phenomenon and the ping-pong phenomenon.

Keywords Heterogeneous wireless networks · IEEE 802.21 · Vertical handover · Multi Attribute Decision Making · M-ANP · TOPSIS

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1 Introduction

Nowadays, several wireless technologies such as 3G (UTMS, IEEE 802.11a, IEEE 802.11b, etc.), and 4G (IEEE 802.16, LTE, LTE-A) have already deployed by different telecommunication operator's. Moreover, this heterogeneous environment, can ensure diversity for multimedia applications and provide to mobile user the ability to be connected by using the mobile Internet. In addition theses application, taking advantage of the advanced features of the mobile devices which are equipped with several wireless interfaces. These diversity of interfaces allow the users not only to be connected at any access network, but also he can benefit simultaneously from variety of services delivered by these technologies.

The most important issue concerning this heterogeneous networks, is to ensure ubiquitous access for the end users, under the principle "Always Best Connected" (ABC) [1]. For that, the IEEE 802.21 standard [2] is intended to determine whether a vertical handoff should be initiated, and to choose the most suitable network in terms of quality of service (QoS) for mobile users.

The standard IEEE 802.21 defines three parts in order to manage the vertical handover process [3]. These parts are:

- Handover initiation: in this step, the terminal discovers available networks.
- Handover decision: it's namely also network selection decision. In this step the mobile terminal evaluates the reachable wireless networks to make a decision according some criteria such as battery, velocity, QoS level, security level, users preferences, perceived QoS, etc.
- Handover execution: it consists on establishing the target access network by using mobile IP protocol.

However, the network selection algorithm is not specified in IEEE 802.21 which is important role in the vertical handover process. To cope with this issue, our objective in this paper is to optimize this step by proposing a new approach for network selection decision which allows to the user to choose the most suitable network in terms of QoS.

During recent years, different algorithms were proposed in order to solve and to optimize the network selection problem. According to [3], we can categorize the network selection algorithms into four kinds such handover based RSS, handover based bandwidth, cost function and combination algorithms. The last category includes handover algorithms that use fuzzy logic, neural networks, genetic algorithms and MADM methods. Based on the literature review, the MADM methods represent a promising solution to choose dynamically the optimal access network, which can satisfying the QoS from the available networks.

This paper is organized as follows. Section 2 describes Multi Attribute Decision Making methods (MADM). Section 3 presents our access network selection algorithm based on M-ANP and TOPSIS two MADM methods. Section 4 includes the simulations and results. Section 5 concludes this paper.

2 MADM-based Network Selection

2.1 Related Work and Problem Statement

Several network selection algorithms based on MADM methods have been proposed and developed exhaustively in the literature in the last decade. In [4] the authors have evaluated the performance of eight MADM methods namely SAW, MEW, TOPSIS, GRA, VIKOR, DIA, E-TOPSIS and FADM. This comparison study allows to identify a suitable MADM algorithm which can be used in the context of vertical handover decision. In [5, 6] the network selection algorithm is based on Analytic Hierarchy Process (AHP) and Gray Relation Analysis (GRA) two MADM methods. The AHP method is used to determine weights for each criterion and GRA method is applied to rank the alternatives. In [7, 8] the network selection algorithm combines two MADM methods AHP and TOPSIS. The AHP method is used to get weights of the criteria and TOPSIS method is applied to determine the ranking of access network.

In addition, there are several methods used to assign weights for the criteria such as analytic hierarchy process (AHP), fuzzy analytic hierarchy process (FAHP), analytic network process (ANP), fuzzy analytic network process (FANP) and random weighting. Determining the most suitable weights for different criteria for each traffic classes is one of the main problems in the network selection decision. The work in [9] studied and compared five weighting algorithms namely AHP, FAHP, ANP, FANP and RW for all four traffic classes namely, conversational, streaming, interactive and background. According to reference [9], the ANP method is the appropriate algorithm which should be used to weigh the criteria. In this context, the work in [10] proposed intelligent network selection strategy which combines two MADM algorithms the ANP method to the TOPSIS technique. The ANP method is used to find the differentiate weights of available networks by considering each criterion and the TOPSIS method is applied to rank the alternatives.

However, one of the major limitations of the ANP method is that in the majority of situations necessitate to re-establish the pairwise comparison matrix in cases, where the judgment matrix is inconsistent. This weakness is due to the decision markers, ANP 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 these weakness we propose Multiple Analytic Network Process (M-ANP) method, this one takes into account the experiences of multiple experts to build the matrix decision and to determine the weights of criteria. On the other hand TOPSIS method suffers from ranking abnormality [11].

The goal of this paper, is providing an optimal network selection algorithm, which can deal with the ranking abnormality of TOPSIS method. For that, we propose a new approach which combines two MADM methods, the multiple analytic network process (M-ANP) and TOPSIS method. The M-ANP is applied to determine the suitable weights for different criteria and TOPSIS method is used to rank the alternatives.

2.2 The ANP Method

The ANP method is proposed by Saaty [12], in order to extend the AHP approach to problems with dependence and feed beck within clusters (inner dependence) and between clusters (outer dependence). The ANP method is based on six steps:

1. Model construction: A problem is decomposed into a network in which nodes corresponds to components. The elements in a component can interact with some or all of the elements of another component. Also, relationships among elements in the same component can exist. These relationships are represented by arcs with directions.
2. Construct of the pairwise comparisons: To establish a decision, ANP builds the pairwise matrix comparison such as

$$A = (x_{ij})\ where\ x_{ji} = \begin{cases} 1 & \text{si } i = j; \\ \frac{1}{x_{ij}} & \text{si } i\#j. \end{cases} \tag{1}$$

   Elements x_{ij} are obtained from the Table 1, it contains 1–9 preference scales.
3. Construct 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

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

   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).

Table 1 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
2, 4, 6, 8	Intermediate values

Table 2 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

Let us define consistency index CI

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

Also, we need to calculate the λ_{max} by the following formula:

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

We calculate the coherence ratio CR by the following formula:

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

The various values of RI are shown in Table 2. If the CR is less than 0.1, the pairwise comparison is considered acceptable.

6. Construct the super-matrix formation: the local priority vectors are entered into the appropriate columns of a super-matrix, which is a partitioned matrix where each segment represents a relationship between two components.

2.3 The TOPSIS Technique

The TOPSIS technique is known as a classical MADM method, has been developed in 1981 [13]. 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 six steps:

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

$$D = (d_{ij}) \tag{7}$$

where d_{ij} is the rating of the alternative A_i with respect to the criterion C_j

2. Construct 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. Construct the weighted normalized decision matrix: The weighted normalized decision matrix v_{ij} is computed as:

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

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

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

- For desirable criteria:

$$V_i^* = max\{v_{ij}, j = 1, ..., n\} \ and \ V_i^- = min\{v_{ij}, j = 1, ..., n\} \tag{11}$$

- For undesirable criteria:

$$V_i^* = min\{v_{ij}, j = 1, ..., n\} \ and \ V_i^- = max\{v_{ij}, j = 1, ..., n\} \tag{12}$$

5. Calculation of the similarity distance:

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

and

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

6. Ranking:

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

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

3 Our Optimized Vertical Handover Algorithm

In order to provide an optimal network selection algorithm, we propose a new approach which combines two MADM methods such as M-ANP and TOPSIS. The M-ANP method, takes into consideration the experiences of multiple experts to build the matrix decision and to weigh each criterion. In this work, M-ANP method is based on the experience of three experts. The basic principle of M-ANP as follows:

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

$$W_{ANPi} = [a_{i1}, a_{i2}, ...a_{im}] \ \ where \ \sum_{j=1}^{m} a_{ij} = 1 \ \ and \ \ i = 1, ..., 3 \tag{16}$$

The weight vector $W_{M\text{-}ANP}$, can be calculated by using geometric mean:

$$W_{M\text{-}ANP} = [c_1, c_2, ...c_m], \ \ c_j = \sqrt[3]{\prod_{i=1}^{3} a_{ij}} \ \ where\, j = 1, ..., m \tag{17}$$

In addition, the algorithm assumes wireless overlay networks which entails three heterogeneous networks such as UMTS, IEEE 802.11 and IEEE 802.16. The six attributes associated in this heterogeneous environment are: Cost per Byte (CB), Available Bandwidth (AB), Security (S), Packet Delay (D), Packet Jitter (J) and Packet Loss (L).

The M-ANP algorithm based network selection contain three level in order to weigh the criteria. The first level includes three criteria QoS, security and cost, the second level includes four QoS parameters such as AB, D, J and L and the level 3 includes three available networks UMTS, IEEE 802.11 and IEEE 802.16.

Our new approach for network selection based on M-ANP and TOPSIS consists of the four following steps:

1. Assign weights to level-1: the M-ANP method is used to get a weight of the decision criteria of level 1.
2. Assign weights to level-2: the M-ANP method is used to get a weight of the decision criteria of level 2.
3. Assign weights to level-3: the weight vector of each available network is calculated by multiplication of the weight vector obtained in level 1 with the weight vector obtained in level 2.
4. Select the best access network: the method TOPSIS is applied to rank the available networks and select the access network that has the highest value of C_j^* (see the steps of TOPSIS method).

4 Simulation and Results

In order to validate our optimized vertical handover approach which based on M-ANP to weigh different criteria and TOPSIS to rank available networks, we present the performance comparison between four algorithms:

Table 3 Attribute values for the candidate networks

Nework/criteria	CB (%)	S (%)	AB (mbps)	D (ms)	J (ms)	L ($per10^6$)
UMTS	60	70	0.1–2	25–50	5–10	20–80
IEEE 802.11	10	50	1–11	100–150	10–20	20–80
IEEE 802.16	50	60	1–60	60–100	3–10	20–80

- TOPSIS-ANP 1: this algorithm is applied by the first expert, it's based on the ANP method which used to get the weights of criteria and TOPSIS algorithm which applied to rank each access network.
- TOPSIS-ANP 2: this algorithm is applied by the second expert, it's based on the ANP method to weigh criteria and TOPSIS algorithm.
- TOPSIS-ANP 3: this algorithm is applied by the third expert, it's based on the ANP method and TOPSIS algorithm.
- TOPSIS-M-ANP: this algorithm represents our optimized strategy for network selection. Firstly the M-ANP is used to weigh each criterion. While the TOPSIS is applied to get the ranking of different networks.

We perform four simulations according to four traffic classes [14] namely background, conversational, interactive, and streaming. For each simulation, we provided the values for average of ranking abnormality and the number of handoffs.

We execute these algorithms in 1000 decision points by using MATLAB simulator. During the simulation, the measures of each criterion for candidate networks are randomly varied according to the ranges shown in Table 3.

4.1 Simulation 1

In this simulation, the traffic analyzed is background traffic. The set of importance weights of the criteria based on each algorithm are displayed in Fig. 1.

4.1.1 Ranking Abnormality

Figure 2 shows that TOPSIS-ANP 1, TOPSIS-ANP 2, TOPSIS-ANP 3 and TOPSIS-M-ANP reduce the risk to have an abnormality problem with the values of 33, 35, 32.5 and 25.42 % respectively. For background traffic, our strategy TOPSIS- M-ANP can reduce the ranking abnormality problem better than TOPSIS based on one decision maker.

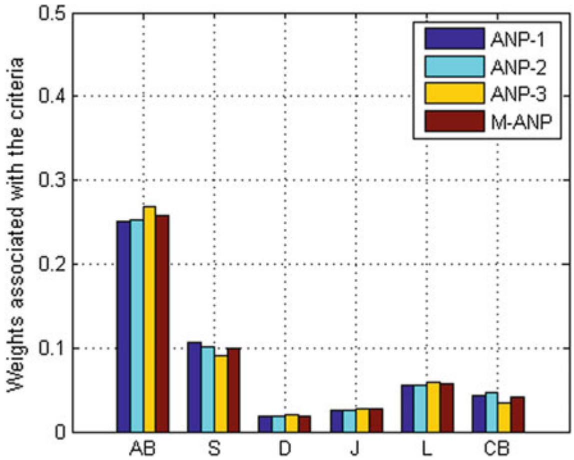

Fig. 1 Weights associated with the criteria for background traffic

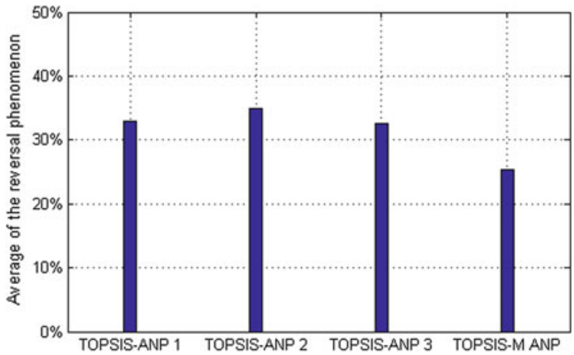

Fig. 2 Average of Ranking abnormality for background traffic

4.1.2 Number of Handoffs

Figure 3 shows that TOPSIS-ANP 1, TOPSIS-ANP 2, TOPSIS-ANP 3 algorithms diminish the number of handoffs with the values of 42, 46 and 42.50 % respectively. While the TOPSIS-M-ANP method provides a value of 33.35 %. We deduce that for background traffic, TOPSIS-M-ANP method provides better performances concerning the number of handoffs than all TOPSIS based on one expert to weigh the criterion.

4.2 Simulation 2

In this simulation, the traffic analyzed is conversational traffic. The weights of the criteria based on each algorithm are displayed in Fig. 4.

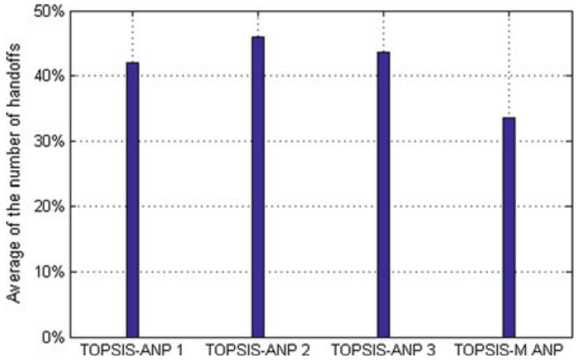

Fig. 3 Average of number of handoffs for background traffic

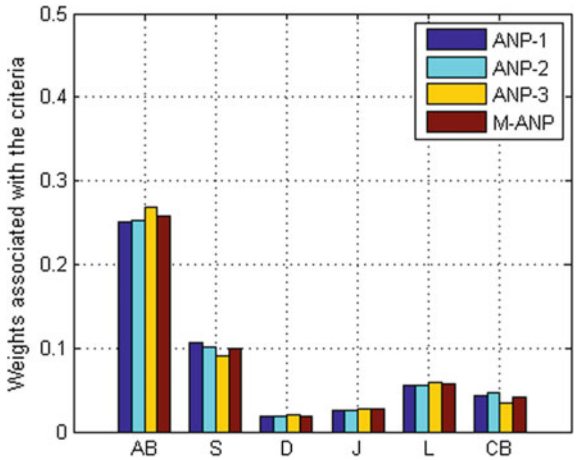

Fig. 4 Weights associated with the criteria for conversational traffic

4.2.1 Ranking Abnormality

Figure 5 shows that the three methods TOPSIS-ANP 1, TOPSIS-ANP 2, TOPSIS-ANP 3 reduces the risk of the abnormality phenomenon with the values of 25.5, 23.33 and 26.66 % respectively. While our TOPSIS based on M-ANP reduces the risk with a value of 20.5 %. For conversational traffic, our approach TOPSIS-M-ANP can reduce the ranking abnormality problem better than all algorithms which based on TOPSIS and one expert using ANP method.

4.2.2 Number of Handoffs

Figure 6 shows that the TOPSIS-ANP 1 method diminishes the number of handoffs with a value of 37.5 %, the TOPSIS-ANP 2 provides a value of 36 % and the TOPSIS-ANP 3 provides a value of 38.66 %. While the TOPSIS-M-ANP method

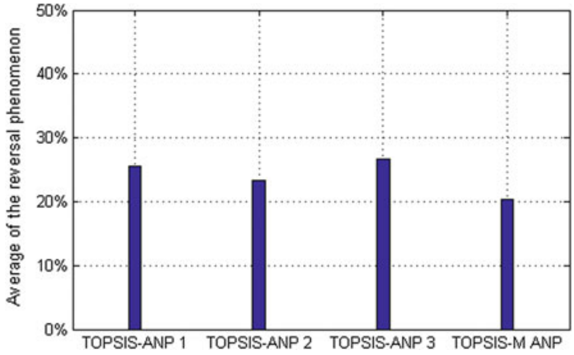

Fig. 5 Average of Ranking abnormality for conversational traffic

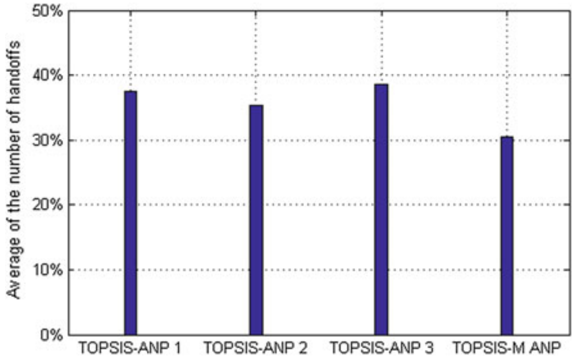

Fig. 6 Average of number of handoffs for conversational traffic

provides a value of 30.44 %. We deduce that for conversational traffic, TOPSIS based on M-ANP provides better performances concerning the number of handoffs than all algorithms.

4.3 Simulation 3

This simulation consists in analyzing interactive traffic, the weights of the criteria based on each algorithm are displayed in Fig. 7.

4.3.1 Ranking Abnormality

Figure 8 shows that the four algorithms TOPSIS-ANP 1, TOPSIS-ANP 2, TOPSIS-ANP 3 and TOPSIS-M-ANP reduce the risk of ranking abnormality with the values of 18.33, 19.67, 17.57 and 14.33 % respectively. For interactive traffic, our strategy TOPSIS-M-ANP can reduce the ranking abnormality problem better than TOPSIS based on one decision maker.

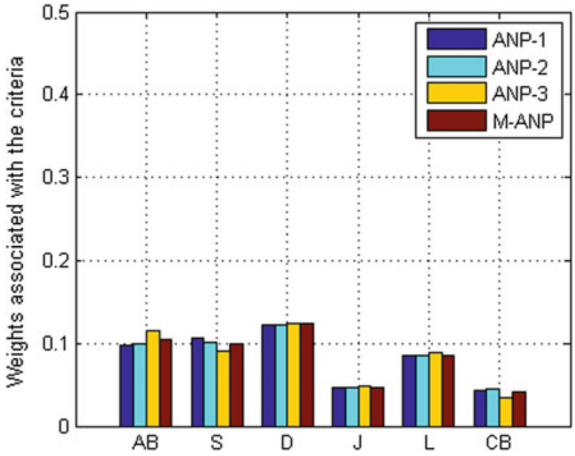

Fig. 7 Weights associated with the criteria for interactive traffic

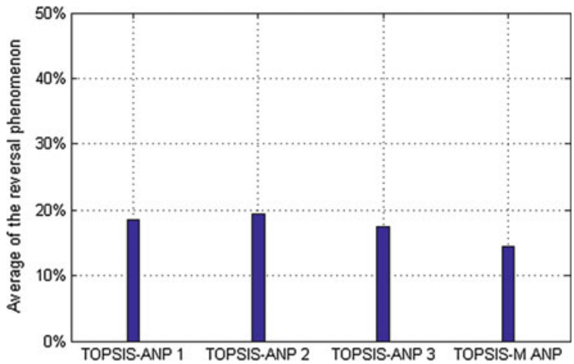

Fig. 8 Average of ranking abnormality for interactive traffic

4.3.2 Number of Handoffs

Figure 9 shows that TOPSIS-ANP 1, TOPSIS-ANP 2, TOPSIS-ANP 3 algorithms diminish the number of handoffs with the values of 25.5 %, 26.5 % and 24.66 % respectively. While the TOPSIS-M-ANP method provides a value of 18.33 %. We deduce that for interactive traffic, TOPSIS-M-ANP method provides better performances concerning the number of handoffs than all TOPSIS based on one expert to weigh the criterion.

4.4 Simulation 4

This simulation consists in analyzing streaming traffic, the weights of the criteria based on each algorithm are displayed in Fig. 10.

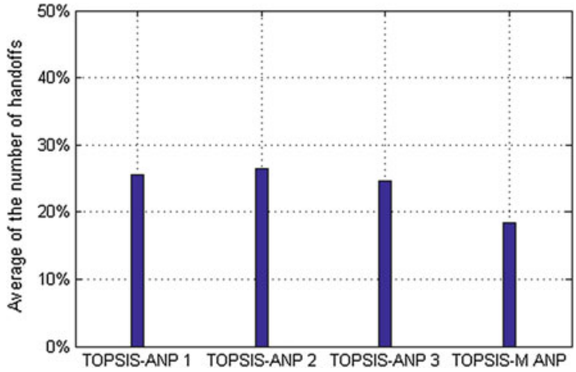

Fig. 9 Average of number of handoffs for interactive traffic

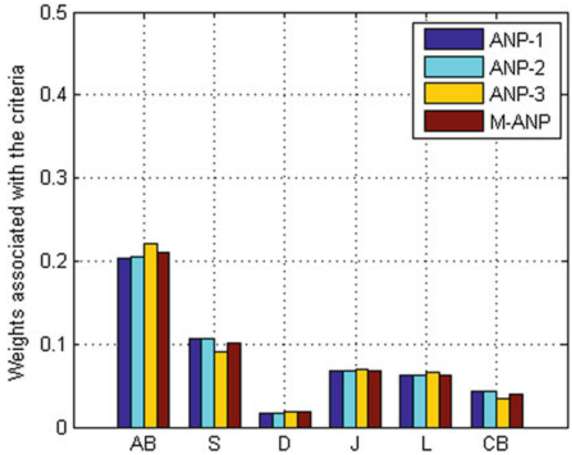

Fig. 10 Weights associated with the criteria for streaming traffic

4.4.1 Ranking Abnormality

Figure 11 shows that the three methods TOPSIS-ANP 1, TOPSIS-ANP 2, TOPSIS-ANP 3 reduces the risk of the abnormality phenomenon with the values of 35 %, 36.5 % and 35.66 % respectively. While our TOPSIS based on M-ANP reduces the risk with a value of 28.5 %. For streaming traffic, our approach TOPSIS-M-ANP can reduce the ranking abnormality problem better than all algorithms which based on TOPSIS and one expert using ANP method.

4.4.2 Number of Handoffs

Figure 12 shows that the TOPSIS-ANP 1 method diminishes the number of handoffs with a value of 45.5 %, the TOPSIS-ANP 2 provides a value of 46.33 % and the TOPSIS-ANP 3 provides a value of 45.44 %. While the TOPSIS-M-ANP method

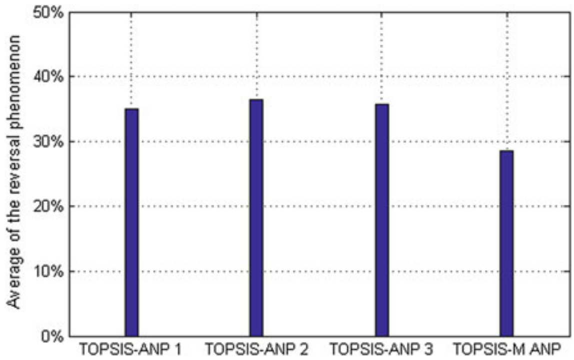

Fig. 11 Average of Ranking abnormality for streaming traffic

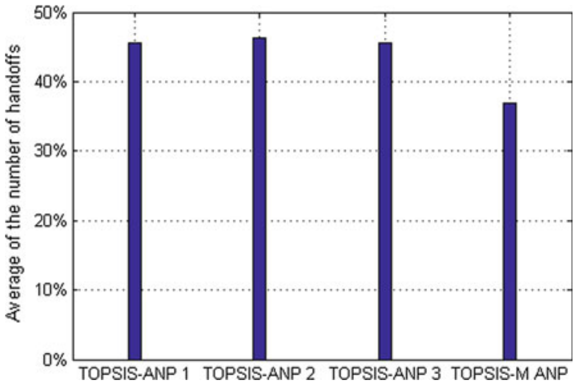

Fig. 12 Average of number of handoffs for streaming traffic

provides a value of 36 %. We deduce that for streaming traffic, TOPSIS based on M-ANP provides better performances concerning the number of handoffs than all algorithms.

5 Conclusion

In this work, we have proposed a new approach based on multiple analytic network process (M-ANP) method and TOPSIS method. The M-ANP method, allows to assign a suitable weights of different criteria better than ANP method.

The simulation shows that, for each traffic classes, our method based on M-ANP and TOPSIS can reduce the ranking abnormality problem better than ANP and TOPSIS method for all traffic classes.

In the other hand our optimized algorithm which combine M-ANP and TOPSIS two MADM methods provides best performance concerning the number of handoffs than the classical algorithm based on ANP and TOPSIS for each traffic.

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