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New Multi Access Selection Method Based on Mahalanobis Distance

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Abstract

In next generation wireless communications, the evolution of the mobile terminal towards a multimode architecture, will allow the mobile users to benefit simultaneously from various radio access technologies (RAT's). The most important issue is how to choose the most appropriate time to start a redirection of traffic flow, and how to choose the most suitable network in terms of quality of service (QoS) for mobile's user.
This paper proposes a novel method based on mahalanobis distance which takes into consideration the correlation with different criteria and also aims to choose the optimal network while ensuring no ranking abnormality and reducing the number of handoffs. Simulation results are presented to illustrate the effectiveness of our novel method based on mahalanobis distance.

Keywords: Heterogeneous Multi-Access, Network Selection, Multi Attribute Decision Making, Mahalanobis Distance

1 Introduction

In the next generation of heterogeneous multi-access environments, the evolution of the mobile terminals towards a multimode architecture, will allow the mobile users to benefit simultaneously from various radio access technologies (RAT's), such as wireless technologies (802.11a, 802.11b, 802.15, 802.16, etc.) and cellular networks (GPRS, UMTS, HSDPA, LTE, etc.).
The most important issue in next generation wireless communications is to maintain a seamless service continuity under the principle "Always Best Connected" (ABC) [1], to achieve this issue a vertical handover decision [2] is intended to choose the most appropriate time to perform handover and to

choose the most suitable network in terms of quality of service (QoS) for mobile users.
The vertical handover process can be divided into three parts namely: handover initiation, network selection and handover execution. The present work concentrate on the second step of the vertical handover. For that, we propose a new approach for network selection decision which allows to the user to choose the most suitable network in terms of QoS.
However, no single wireless network technology is considered to be more favorable than other technologies in terms of QoS. In other words, each network access in RAT's seems to be specifically characterized by the bandwidth offered, the coverage ensured by the network as well as the cost to deliver the service. Moreover, there is some kind of complementarity between these various networks, for example, 801.11a offers a higher bandwidth with a cover limited, while UMTS ensures a large cover with lower bandwidth.
The network selection algorithm depends on multiple criteria which are:

- From terminal side: battery, velocity, etc.
- From service side: QoS level, security level, etc.
- From network side: provider's profile, current QoS parameters, etc.
- From user side: users preferences, perceived QoS, etc.

Several schemes and decision algorithms have been proposed and developed exhaustively in the literature to solve the network selection problem, we can categorize them into four kinds such as genetic algorithms [3], fuzzy logic [4], utility functions [5] and multi attribute decision making (MADM) methods [6,7,8,9,10,11,12]. In [3] the genetic algorithm is applied to optimize the access network function with the goal of selecting the optimal access network. In [4] the authors have proposed an intelligent approach for vertical handover based on fuzzy logic. In [5] the authors proposed a network selection scheme based on utility function which takes more key factors for multimedia communication in the future urban road wireless networks. These factors include data rate, bit error rate, latency, power consumption, monetary cost, load balance, individual's preference and handoff stability.
Due to great number of criteria and algorithms which can be used in network selection, the most challenging problems focus in selecting the appropriate criteria and definition of a strategy which can exploit these criteria. According to nature of network selection problem MADM algorithms, represent a promising solution to select the most suitable network in terms of QoS for mobile users. However the major limitations of MADM methods are the ranking abnormality and the ping-pong effect. The ranking abnormality means that the ranking of candidate networks change when low ranking alternatives are removed from

the candidate list, which can make the selection problem inefficient. The ping pong effect occurs when the terminal mobile performs excessive handoffs for a given time which causing the higher number of handoffs. This phenomenon can led to increasing in power consumption and the decreasing in throughput. In this paper we propose a new approach for network selection decision in order to deal with the ranking abnormality and reducing the number of handoffs. Our solution is based on mahalanobis distance which can take into account the correlation between different criteria and also aims to make the best decision about the selection of the target network to connect to.
The rest of this paper is organized as follows. Section 2 presents review of related work concerning network selection decision based on MADM methods. Section 3 presents five MADM methods namely AHP, SAW, MEW, TOPSIS and DIA. Section 4 describes our novel method based on mahalanobis distance for the network selection. Section 5 includes the simulations and results. The conclusion is given in section 6.

2 Related Work

In order to choose the best network, various approaches based on MAMD methods have been proposed. The MADM includes many methods such as analytic hierarchy process (AHP), simple additive weighting (SAW), multiplicative exponential weighting (MEW), grey relational analysis (GRA), technique for order preference by similarity to ideal solution (TOPSIS) and the distance to the ideal alternative (DIA). In [6] four vertical handover decision algorithms namely, SAW, MEW, TOPSIS and GRA are studied and compared for all four traffic classes namely, conversational, streaming, interactive and background. In [7] and [8], the network selection algorithm is based on AHP and GRA, the AHP method is used to weigh each criterion and GRA method is applied to rank the alternatives. In [9], [10] and [11] the network selection algorithm combines the AHP method and the TOPSIS method, the AHP method is used to get weights of the criteria and TOPSIS method is applied to determine the ranking of access network.
Among MADM methods mentioned above, TOPSIS method has been extensively used to solve the network selection problem. However, TOPSIS still suffers from ranking abnormality. In order to improve the limit of the TOPSIS algorithm, in [11], the author has proposed an iterative approach for application of TOPSIS for network selection problem. The disadvantage of this method lies in the computation time, for example, if we have n available access networks we must repeat iterative TOPSIS n-1 until the best interface network is reached. Reference [12] presents the distance to ideal alternative (DIA) algorithm. DIA selects the alternative that is the shortest euclidean distance to positive ideal alternative (PIA). One of the main disadvantages

of PIA method is doesn't take into consideration the normalization type, in other words, when the low ranking alternative is removed from the candidate list, the normalized attribute values of all alternatives will be changed and the ranking order of the alternative will be changed as well. Another disadvantage of this method is that, the euclidean distance used by DIA doesn't take into account the correlation between different criteria, all the components of the vectors will be treated in the same way. In [13] the authors proposed the ranking algorithm based on finding the median of each column in the normalized weighted decision matrix. The disadvantage of this method is that, the ranking algorithm consists on summing each value of the row elements. By doing so, all the values of the vectors are treated in the same way, and the different criteria are not correlated as well. In addition TOPSIS method still suffer from the ping-pong effect.
To cope with these issues, this paper proposes a novel method based on Mahalanobis distance which can take into account the correlation between different criteria and also aims to make the best decision about the selection of the target network to connect to.

3 MULTI ATTRIBUTE DECISION MAKING

3.1 AHP

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

1. Construct of 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. Construct of the pairwise comparisons: to establish a decision, AHP builds the pairwise matrix comparison such as:

$$A = \begin{pmatrix} x_{11} & x_{12} & \dots & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & \dots & x_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \dots & \dots & x_{nn} \end{pmatrix} where\ x_{ji} = \begin{cases} 1 & \text{if } i = j; \\ \frac{1}{x_{ij}} & \text{if } i \# j. \end{cases} \quad (1)$$

   Elements x_{ij} are obtained from the table 1, it contains the preference scales.

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

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:

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

$$A = \begin{pmatrix} a_{11} & a_{12} & \dots & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & \dots & a_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \dots & \dots & a_{nn} \end{pmatrix} \tag{3}$$

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

$$W_i = \frac{\sum_{j=1}^{n} a_{ij}}{n} \quad and \quad \sum_{j=1}^{n} W_i = 1 \tag{4}$$

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

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{5}$$

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

$$\lambda_{max} = \frac{\sum_{i=1}^{n} b_i}{n} \quad such \quad b_i = \frac{\sum_{j=1}^{n} W_i * a_{ij}}{W_i} \tag{6}$$

- We calculate the coherence ratio CR by the following formula:

$$CR = \frac{CI}{RI} \tag{7}$$

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

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

3.2 SAW

Simple Additive Weighting (SAW) [15] is the best known and simplest multi attribute decision making method for evaluating a number of alternatives in terms of a number of decision criteria. The SAW method consists of the following steps:

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

$$D = \begin{pmatrix} d_{11} & d_{12} & \dots & \dots & d_{1n} \\ d_{21} & d_{22} & \dots & \dots & d_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ d_{n1} & d_{n2} & \dots & \dots & d_{nn} \end{pmatrix} \tag{8}$$

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

2. Construct the normalized decision matrix: each element r_{ij} is obtained by Max method normalization [16].

   - For benefit attribute, the normalized value of r_{ij} is computed as:

$$r_{ij} = \frac{d_{ij}}{d_j^{max}} \tag{9}$$

   - For cost attribute, the normalized value of r_{ij} is computed as:

$$r_{ij} = 1 - \frac{d_{ij}}{d_j^{max}} \tag{10}$$

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

$$v_{ij} = W_i * r_{ij} \quad where \ \sum_{i=1}^{m} W_i = 1 \tag{11}$$

4. Calculate the score of each alternative A_i

$$S_i = \sum_{j=1}^{m} v_{ij} \quad where \ i = 1, ..., n \tag{12}$$

5. The selected alternative is computed by:

$$SAW^* = \max_{i=1}^{n} S_i \tag{13}$$

3.3 MEW

Multiplicative Exponent Weighting (MEW)[15], also as known as the weighted product method. The MEW method consists of the following steps:

1. Construct of the decision matrix: can be calculated as equation 8.

2. Construct the normalized decision matrix: can be calculated as equations 9 and 10.

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

$$v_{ij} = r_{ij}^{W_j} \quad where \ \sum_{i=1}^{m} W_i = 1 \tag{14}$$

4. Calculate the score of each alternative A_i

$$P_i = \prod_{j=1}^{m} v_{ij} \quad where \ i = 1, ..., n \tag{15}$$

5. The selected alternative is computed by:

$$MEW^* = \max_{i=1}^{n} P_i \tag{16}$$

3.4 TOPSIS

Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS), known as a classical multiple attribute decision-making (MADM) method, has been developed in 1981 [17]. 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: can be calculated as equation 8.

2. Construct the normalized decision matrix: each element r_{ij} is obtained by the euclidean normalization [18].

$$r_{ij} = \frac{d_{ij}}{\sqrt{\sum_{i=1}^{m} {d_{ij}}^2}} \quad , i = 1, ..., m, j = 1, ..., n. \tag{17}$$

3. Construct the weighted normalized decision matrix: can be calculated as equation 11.

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

$$A^* = [V_1^*, ..., V_m^*] \;\; and \;\; A^- = [V_1^-, ..., V_m^-], \tag{18}$$

   - For desirable criteria:

$$V_i^* = max\{v_{ij}, j = 1, ..., n\} \tag{19}$$

$$V_i^- = min\{v_{ij}, j = 1, ..., n\} \tag{20}$$

   - For undesirable criteria:

$$V_i^* = min\{v_{ij}, j = 1, ..., n\} \tag{21}$$

$$V_i^- = max\{v_{ij}, j = 1, ..., n\} \tag{22}$$

5. Calculation of the similarity distance:

$$S_j^* = \sqrt{\sum_{i=1}^{m} (V_i^* - v_{ji})^2}, j = 1, ..., n \tag{23}$$

   and

$$S_j^- = \sqrt{\sum_{i=1}^{m} (v_{ji} - V_i^-)^2}, j = 1, ..., n \tag{24}$$

6. Ranking:

$$C_j^* = \frac{S_j^-}{S_j^* + S_j^-} \quad , j = 1, ..., n. \tag{25}$$

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

3.5 DIA

The distance to the Ideal Alternative (DIA), algorithm belonging to the MADM category, that we developed [12] to select dynamically the best network interface. The DIA method consists of the following steps:

1. Construct of the decision matrix: can be calculated as equation 8.
2. Construct the normalized decision matrix: can be calculated as equation 17.
3. Construct the weighted normalized decision matrix: can be calculated as equation 11.
4. Determination of the ideal solution A^* and the anti-ideal solution A^-(see equations 18, 19, 20, 21, 22).
5. Calculate the Manhattan distance to the positive and negative attribute:

$$D_j^* = \sum_{i=1}^{m} |V_i^* - V_{ji}|, j = 1, ..., n \tag{26}$$

and

$$D_j^- = \sum_{i=1}^{m} |V_{ji} - V_i^-|, j = 1, ..., n \tag{27}$$

6. Determine the "positive ideal alternative" (PIA) which has minimum D^*, and maximum D^-.

$$PIA = \{min(D_j^*), max(D_j^-)\} \ , j = 1, ..., n. \tag{28}$$

7. Calculate the distance of an alternative to the PIA:

$$R_j = \sqrt{(D_j^* - min(D_j^*))^2 + (D_j^- - max(D_j^-))^2} \tag{29}$$

A set of alternatives is ranked according to the increasing order of R_j.

4 NETWORK SELECTION BASED ON MAHALANOBIS DISTANCE ALGORITHM

4.1 Mahalanobis distance

Mahalanobis distance is a metric, introduced by P.C. Mahalanobis in 1936 [19], it has played a fundamental and important role in statistic, and data analysis, with multiple measurements. Mahalanobis distance is based on correlation

between variables by which different patterns can be identified and analyzed, it differs from euclidean distance in that takes into account the correlation of all attributes values.
The mahalanobis distance between an individual x and a population's multivariate mean u is computed by:

$$D_M(x) = (x-u)^T * S^{-1} * (x-u) \tag{30}$$

Where S^{-1} is the inverse covariance matrix.

4.2 Access network selection algorithm

In order to provide an optimal network selection algorithm, we propose a new approach which combines the AHP method and Mahalanobis distance. The AHP method is applied to find the weights of different criteria and the Mahalanobis distance is applied to determine the ranking of each access network. the utilization of mahalanobis distance allows to measure the distance between each alternative A_i and the weighted normalized decision matrix. The best alternative is the smallest mahalanobis distance.
The algorithm assumes wireless overlay networks which entails three heterogeneous networks such as UMTS, WLAN and WIMAX. 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).
Fig. 1 exhibits the three level AHP hierarchy for network selection problem. The level 1 includes three criteria QoS, security and cost, the level 2 includes four QoS parameters such as AB, D, J and L and the level 3 includes three available networks UTMS, WIFI and WIMAX.
Our new approach for network selection based on mahalanobis distance consists of the nine following steps:

1. Assign weights to level-1-criteria: the AHP method is used to get a weight of the decision criteria of level 1.

2. Assign weights to level-2-criteria: the AHP method is used to get a weight of the decision criteria of level 2.

3. Assign weights to level-3-alternatives: 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. Construct of the decision matrix: can be calculated as equation 8.

5. Construct the normalized decision matrix: in our simulation, we used two types of normalization, first one, can be calculated as equations 9, 8 and second one can be calculated as equation 17.

6. Construct the weighted normalized decision matrix: can be calculated as equation 11.

7. Calculate the mahalanobis distance of each A_i: can be calculated as equation 30, the result as expressed by:

$$D_M(A_i) = [D_{i1}, ..., D_{im}] \tag{31}$$

8. Calculate the mean of the attributes vector obtained as equation 31.

$$C_i = \frac{\sum_{j=1}^{m} D_{ij}}{m} \tag{32}$$

9. Select the best access network: A set of alternative can now ranked according the increasing order of C_i.

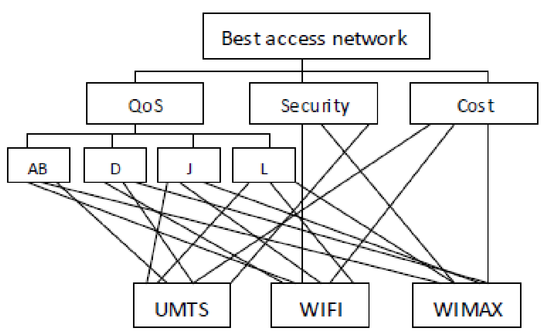

Figure 1: The three level AHP hierarchy for network selection problem

5 RESULTS AND SIMULATION

In order to illustrate the effectiveness of our algorithm based on Mahalanobis Distance we present performance comparison between five algorithms namely: SAW, MEW, TOPSIS, DIA and NMMD (Novel Method based on Mahalanobis Distance). The traffic analyzed is background traffic, in each simulation the all algorithms were run in 100 vertical handoff decision points. The performance evaluation is focused on two aspects, which are: ranking abnormality and number of handoffs.

We perform two simulations, in the first one, we present the performance of TOPSIS, DIA and NMMD; the attribute values of all algorithms are normalized by the euclidean normalization; and in the second simulation, we present

Table 3: ATTRIBUTE VALUES FOR THE CANDIDATE NETWORKS

criteria **network**	**CB** (%)	**S** (%)	**AB** ($mbps$)	**D** (ms)	**J** (ms)	**L** ($per 10^6$)
UMTS	60	70	0.1-2	25-50	5-10	20-80
WLAN	10	50	1-11	100-150	10-20	20-80
WIMAX	50	60	1-60	60-100	3-10	20-80

the performance of SAW, MEW and NMMD; the attribute values of all algorithms are normalized by linear scale transformation max normalization.
During the simulation, the measures of every criterion for candidate networks are randomly varied according to the ranges shown in table 3.
The weight vector of the background traffic according to the QoS requirements which calculated by using AHP method is depicted in figure 2.

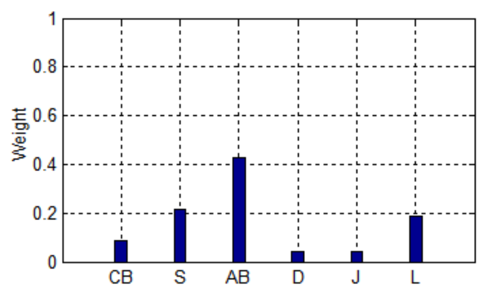

Figure 2: The associated weights for background traffic

5.1 The simulation 1

In this simulation, we present the performance comparison between three vertical handoff decision algorithms TOPSIS, DIA and NMMD.

5.1.1 Ranking abnormality

Figure 3. shows the average value of the ranking abnormality problem in 100 vertical handoff decision points. We notice that, the TOPSIS method reduces the risk to have this problem with a value of 50%, the DIA method reduces the risk with a value of 40%, and NMMD method with a value of 30%.
So, our NMMD method reduces the ranking abnormality problem better than two algorithms such as TOPSIS and DIA according to the euclidean normalization.

5.1.2 Number of handoffs

Figure 4. shows the average value of the number of handoffs in 100 vertical handoff decision points. We notice that, the TOPSIS method reduces the number of handoffs with a value of 60%, the DIA method reduces the number of handoffs with a value of 50%, and NMMD method with a value of 40%.
So our NMMD method reduces the number of handoffs better than two algorithms such as TOPSIS and DIA according to the euclidean normalization.

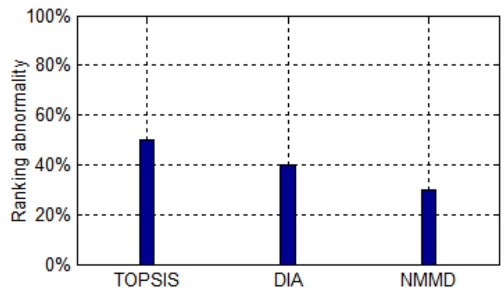

Figure 3: Average of ranking abnormality

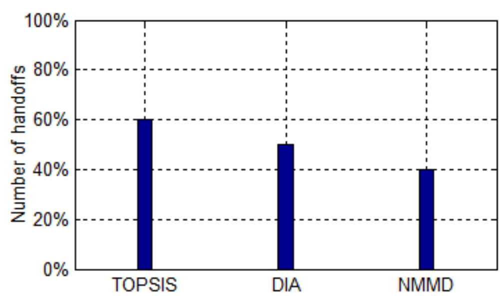

Figure 4: Average of handoffs' number

5.2 The simulation 2

In this simulation, we present the performance comparison between three vertical handoff decision algorithms SAW, MEW and NMMD.

5.2.1 Ranking abnormality

Figure 5. shows the average value of the ranking abnormality problem in 100 vertical handoff decision points. We notice that, the SAW method reduces the risk to have this problem with a value of 40%, the MEW method reduces the

risk with a value of 60%, and NMMD method with a value of 30%.
So, our NMMD method reduces the ranking abnormality problem better than two algorithms such as SAW and MEW according to the linear scale transformation max normalization.

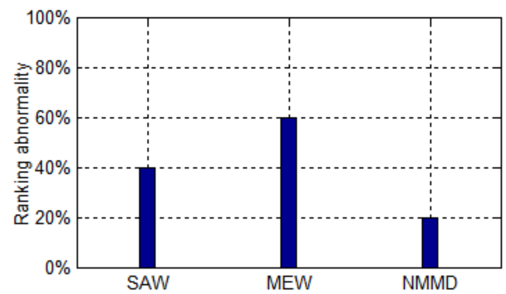

Figure 5: Average of ranking abnormality

5.2.2 Number of handoffs

Figure 6. shows the average value of the number of handoffs in 100 vertical handoff decision points. We notice that, the SAW method reduces the number of handoffs with a value of 60%, the MEW method reduces the number of handoffs with a value of 50%, and NMMD method with a value of 30%.
So, our NMMD method reduces the number of handoffs better than two algorithms such as SAW and MEW according to the linear scale transformation max normalization.

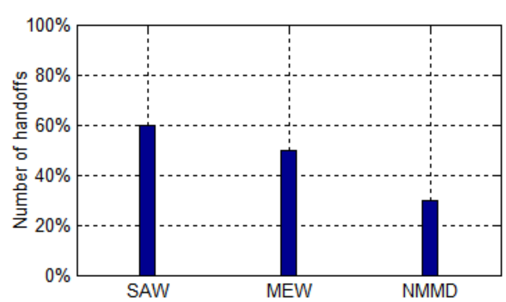

Figure 6: Average of handoffs' number

6 Conclusion

In this work, we have proposed a novel method NMMD based on two methods such as the AHP method and mahalanobis distance. The NMMD method takes

into consideration the correlation between different criteria and also aims to choose dynamically the best optimal network, which can satisfying the quality of service for background traffic.
The simulation results show that our method is able to deal with ranking abnormality problem better than all decision algorithms such as SAW, MEW, TOPSIS and DIA for two normalization type namely euclidean normalization and linear scale transformation max normalization. In addition we deduce that NMMD method provides best performance concerning the number of handoffs than the all algorithms.

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