Survey and comparison of MADM methods for network selection access in heterogeneous networks

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***Abstract*—One of the key features of the the next generation of networks is the coexistence of multiple radio access technologies such as WIFI, WIMAX and LTE. This heterogeneous environment provides to the mobile users the possibility to use different services at any time and any where. Various multiple attribute decision making (MADM) algorithms have been proposed to manage the terminal mobility while ensuring the best continuity of services. Among the most MADM methods which are widely used for solving the network selection problem in the research literature are SAW, MEW, TOPSIS, GRA, VIKOR, DIA, E-TOPSIS and FADM. This paper evaluates the performance of eight MADM methods, that aim to ensure the seamless network selection under the principle always best connected.**

***Index Terms*—Heterogeneous wireless networks, Network selection, Multi attribute decision making.**

I. Introduction

The mobile terminals are becoming multiple interfaces and widely used nowadays. This, combined with availability of multitude radio access technologies supporting variety of services, opens the opportunities for the user to connect on the internet mobile at any time and any where. A major issue in heterogeneous networks is to ensure the seamless network selection under the principle Always Best Connected (ABC) [1]. This means that, the mobile terminal should be able to switch from one network access to another and keeping session continuity. However, keeping session continuity is not sufficient, the terminal mobile should be able to choose dynamically and in the real time the best suitable network in terms of quality of service (QoS).

One of the most challenging problems for coordination is vertical handover (VHO) or handoff, which is the decision for a mobile node to hand over between different types of networks (e.g. from IEEE802.11b to UMTS Networks and vice-versa). The process of vertical handoff consists of three main phases [2], namely i) system discovery, ii) handoff decision and iii) handoff execution. During the system discovery, a mobile terminal equipped with multiple interfaces has to determine the networks that can be used and what services are available in each network. During the handoff decision phase, the mobile terminal determines which the optimal access network should be used by the terminal mobile. To deal with this issue, a number of parameters must be considered. These parameters can be divided into four categories:

- Terminal information: battery, velocity, etc.
- Service information: QoS level, security level, etc.
- Network information: providers profile, current QoS parameters, etc.
- User information: users preferences, perceived QoS, etc.

Finally, during the handoff execution phase, connections are needed to be re-routed from the current network to the selected network in a seamless manner [3]. In this paper, this decision phase has been taken up with number of attributes offered by various networks. There are several schemes and decision algorithms proposed by researchers to deal with network selection problem such as Fuzzy logic [4,5], Genetic algorithms [6,7], Utility functions [8,9] and Multiple attribute decision making (MADM) methods [10]. 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.

The rest of the paper is organized as follows. Section 2 provides the contribution of various researchers to deal with the problem of vertical handoff using multi attribute decision making methods (MADM). Section 3 describes the enhanced evaluation model which used in simulation. Section 4 provides the simulation set-up and performance evaluation of various MADM methods for vertical handoff decision. Section 5 concludes the work with final remarks.

II. An overview of MADM-based network selection in heterogeneous wireless networks

Due to multi criteria nature of network selection problem, Multiple Attributes Decision Making (MADM) algorithms represent a promising solution to select the most suitable network in terms of quality of service (QoS) for mobile users. A large number of MADM algorithms have been proposed and used by researchers to deal with network selection problem which includes SAW, TOPSIS, MEW, GRA, VIKOR etc. Some algorithms are used for ranking the best network in terms of quality of service offered while some algorithms such as AHP and ANP are used to assign weights to various attributes. Ranking algorithms are used along with weighting algorithms to select the best network. But no algorithm has

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been proved best among others in terms of number of handoffs and ranking abnormality.

Table I provides statistics on the existing work in the literature and their percentage of use in context of handover. It can be concluded from table I that two ranking algorithms TOPSIS and GRA are popular among researchers as 35.71% of the references used TOPSIS and 17.14% used GRA algorithms. Although VIKOR algorithm has been used less in the references i.e. 8.57% but it is getting popular day by day. The table also shows that AHP method is the most used method for weight assignment in combination of TOPSIS and GRA i.e. 65.71% proposals. ANP is next to AHP in terms of popularity as 17.15% references used ANP for weight assignment with ranking algorithms.

TABLE I
SURVEY ON HANDOVER ALGORITHMS BASED ON MADM METHODS

	AHP	**ANP**	**FAHP**	**FANP**	**%ranking algorithms**
SAW	[10] [11] [12] [13] [14] [15] [32] [33]	[41]			12.86
MEW	[10] [14] [15] [16] [32] [33]	[41]			10.00
TOPSIS	[10] [14] [15] [17] [18] [19] [20] [21] [32] [33] [34] [42]	[21] [22] [23] [35] [41] [42]	[21] [24] [25] [37] [42]	[21] [42]	35.71
GRA	[10] [14] [15] [26] [27] [28] [29] [30] [32] [43]		[25] [37]		17.14
DIA	[34] [36]		[37]		4.28
VIKOR	[33] [38] [39]	[38] [39] [40]			8.57
ELECTRE	[14] [15] [33]		[31]		5.71
E-TOPSIS		[41]			1.43
FADM	[4] [5]		[37]		4.28
%weighting algorithms	65.71	17.15	14.28	2.68	

Despite the amount of research done in the area of network selection especially on the performance evaluation of the MADM methods, not much focus has been placed on the impact of the MADM methods on the energy efficiency. However, there is no study that examines the validity of MADM methods which led to inefficient network selection due to inconsistent ranking outcomes.

III. PERFORMANCE ANALYSIS OF MADM METHODS FOR NETWORK SELECTION ACCESS

The selecting of the most suitable MADM algorithm to rank different the available networks is one of the main problems for network selection. To deal with this issue, the performance analysis of MADM-based network selection less networks techniques for network selection is intended necessary for each network selection algorithm. Several evaluation models for network selection have proposed in the literature to evaluate the performance for network selection algorithm. In [44] the authors compare the performance of five VHA, namely SAW, MEW, TOPSIS, GRA, and UA (Abique's Algorithm). For each network selection algorithm, the fuzzy logic is applied to build the evaluation scale and compare different handover metrics.

In [15], the author compare the performance of seven VHA based on MADM methods which are SAW, MEW, TOPSIS, ELECTRE, VIKOR, GRA and WMC (weighted Markov chain). The performance evaluation is focused on four parameters of QoS namely packet delay, packet jitter, the available bandwidth and the total bandwidth. Two different applications were considered: voice and data connections. Each traffic application was associated with six attributes: available bandwidth, total bandwidth, packet delay, packet jitter, packet loss and cost per byte.

In [33] the authors have proposed a new evaluation model for network selection algorithms based on multi criteria evaluation and criticality analysis. However, the proposed model suffers from the lack of a weighting algorithm which can be applied to weigh each handover metric. To deal with this problem, in [22] the authors have proposed an enhanced evaluation model based [33]. The major advantage of this new enhanced model is to weigh each handover metric.

For our performance analysis we use the enhanced evaluation model [3] because this one takes into account a weighting algorithm which can be used to weigh each handover metric. In addition, this model allows to identify the appropriate MADM algorithm which should be used to select the best access network for heterogeneous networks. In this section, we present an enhancement of the evaluation model [3] which combines the multi criteria evaluation and criticality analysis. This model allows to to determine the suitable MADM algorithm which can be used for network selection according to all traffic classes. The procedure can be categorized in seven steps:

1) Identification of the evaluation parameters;
2) Construct the evaluation matrix EM:
$$EM = (v_{ij}) \tag{1}$$
Where v_{ij} is the measured value of the vertical handover algorithm Alg_i with respect the parameter P_j.
3) Construct the normalized evaluation matrix $Norm\_EM$:
$$Norm\_EM = (d_{ij}) \tag{2}$$
Where d_{ij} is the normalized value of the v_{ij}.
4) Construct the criticality matrix: according to valuation scale defined in table II, we analyze the evaluation matrix obtained in second step. the criticality matrix c_{ij} is computed as:
$$c_{ij} = k \tag{3}$$
5) Construct the weighted criticality matrix by applying the ANP method;

6) Calculation of the criticality index of each network selection;

$$CI_i = 100 * (\sum_{j=1}^{m} t_{ij})/n \quad where \ i = 1, ..., n \tag{4}$$

n is the maximum valuation level of all parameters.

7) Ranking the network selection algorithms according to the decreasing order of CI_i^*.

TABLE II
CRITICALITY MATRIX FOR EVALUATING MADM ALGORITHMS

Very low k=1	**Low k=3**	**Medium k=5**	**High k=7**	**Very hight k=9**
$d_{ij} > 80\%$ **of the max value**	$d_{ij} > 60\%$ **of the max value**	$d_{ij} > 40\%$ **of the max value**	$d_{ij} > 20\%$ **of the max value**	$d_{ij} <= 20\%$ **of the max value**

IV. NUMERICAL RESULTS AND DISCUSSION

In this section, we propose the simulation results, in order to determine the suitable MADM algorithm which can be used for network selection. For that, we make four simulations for four traffic classes namely background, conversational, interactive and streaming. For each simulation, eight algorithms namely FADM, E-TOPSIS, VIKOR, TOPSIS, GRA, DIA, SAW and MEW are tested in order to provide the values for average of two performance evaluation namely ranking abnormality (P1) and number of handoffs (P2). In the second step, we use the enhancement of the evaluation model to analyze the results of the performance of these algorithms in order to select the best of theme.

For each simulation, the measures of every criterion for candidate networks are randomly varied according to the ranges shown in table III. In addition, we notice that the ANP method is applied to weigh each criterion. Finally, the all algorithms were run in 100 network selection decision points by using MATLAB simulator.

TABLE III
ATTRIBUTE VALUE 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

A. The simulation 1

The traffic analyzed in this simulation is background traffic, table IV shows the values for average of two performance evaluation ranking abnormality and number of handoffs concerning the eight methods namely FADM, E-TOPSIS, VIKOR, TOPSIS, GRA, DIA, SAW and MEW.

Based on the table II, we analyze the evaluation matrix obtained in the table IV. The results of the analysis between the table II and the table IV are shown in the table V.

Before evaluating the performance parameters of each algorithm in order to choose the best vertical handover algorithm between themes, we use the ANP method to calculate the weights of ranking abnormality and number of handoffs.

Table VI presents the associated weights of each performance parameters for background traffic.

TABLE IV
PERFORMANCE EVALUATION FOR BACKGROUND TRAFFIC

MADM algorithms	**P1**(%)	**P2**(%)
TOPSIS	50.00	70.00
GRA	20.00	80.00
DIA	30.00	60.00
SAW	50.00	70.00
MEW	60.00	60.00
E-TOPSIS	18.00	35.00
FADM	6.50	28.00
VIKOR	20.00	38.00

TABLE V
COMPARISON MATRIX FOR BACKGROUND TRAFFIC

MADM algorithms	**P1(%)**	**P2(%)**
TOPSIS	1	1
GRA	7	1
DIA	5	3
SAW	1	1
MEW	1	3
E-TOPSIS	7	5
FADM	9	7
VIKOR	7	5

TABLE VI
WEIGHTING VECTOR OF BACKGROUND TRAFFIC

Evaluation parameters	**P1**	**P2**	**Weights**
P1	1	1	0.5
P2	1	1	0.5

Table VII shows a comparison of various MADM algorithms for network selection according to the scores and the criticality index for background traffic. We notice that FADM method has the highest score, which means that this algorithms has the best performance than E-TOPSIS, VIKOR, TOPSIS, GRA, DIA, SAW and MEW. Moreover, VIKOR and E-TOPSIS methods are qualified as the second favorable solution in the context of the handover decision. Finally, we observe that the small value of the index of criticality is provided by two methods TOPSIS and SAW.

TABLE VII
THE CRITICALITY INDEX OF ALGRITHMS FOR BACKGROUND TRAFFIC

MADM Algorithms	**Criticality index**	**Rank**
TOPSIS	11.11	7
GRA	44.44	4
DIA	44.44	5
SAW	11.11	8
MEW	22.22	6
E-TOPSIS	66.67	3
FADM	88.89	1
VIKOR	66.67	2

B. The simulation 2

This simulation consists in analyzing conversational traffic, in order to determine the suitable MADM algorithm. The table

VIII shows the measures for ranking abnormality and number of handoffs concerning the all methods.

TABLE VIII
PERFORMANCE EVALUATION FOR CONVERSATIONAL TRAFFIC

MADM algorithms	P1(%)	P2(%)
TOPSIS	36.00	80.00
GRA	18.00	60.00
DIA	27.00	60.00
SAW	42.00	80.00
MEW	60.00	65.00
E-TOPSIS	16.50	42.00
FADM	5.50	25.00
VIKOR	18.00	26.00

Based on the table II, we analyze the evaluation matrix obtained in the table VIII. The results of the analysis are shown in the table IX.

TABLE IX
COMPARISON MATRIX FOR CONVERSATIONAL TRAFFIC

MADM algorithms	P1(%)	P2(%)
TOPSIS	5	1
GRA	7	3
DIA	5	3
SAW	3	1
MEW	1	1
E-TOPSIS	7	5
FADM	9	7
VIKOR	7	7

Then, we use the ANP method to weigh the ranking abnormality and number of handoffs. The values of the weight granted to these parameters according to the conversational service are illustrated in table X.

TABLE X
WEIGHTING VECTOR OF CONVERSATIONAL TRAFFIC

Evaluation parameters	P1	P2	Weights
P1	1	1/3	0.250
P2	3	1	0.750

Table XI shows the scores of the criticality index of the all algorithms analyzed for conversational traffic. We notice that FADM method has the highest score, which means that this algorithms has the best performance than E-TOPSIS, VIKOR, TOPSIS, GRA, DIA, SAW and MEW. Moreover, VIKOR algorithm is qualified as the second favorable solution in the context of the handover decision. Finally, we observe that the small value of the index of criticality is provided by MEW algorithm.

C. The simulation 3

In this third simulation, we also calculate criticality index of various algorithms in order to determine the best solution than we must use in context of the selection of the network for interactive traffic.

The table XII shows the values for average of two performance evaluation ranking abnormality and number of handoffs concerning the all MADM methods.

TABLE XI
THE CRITICALITY INDEX OF ALGRITHMS FOR CONVERSATIONAL TRAFFIC

MADM Algorithms	Criticality index	Rank
TOPSIS	22.22	6
GRA	44.44	4
DIA	38.89	5
SAW	16.67	7
MEW	11.11	8
E-TOPSIS	61.11	3
FADM	83.33	1
VIKOR	77.78	2

TABLE XII
PERFORMANCE EVALUATION FOR INTERACTIVE TRAFFIC

MADM algorithms	P1(%)	P2(%)
TOPSIS	42.00	70.00
GRA	25.00	60.00
DIA	33.00	80.00
SAW	55.00	75.00
MEW	42.00	70.00
E-TOPSIS	25.00	40.00
FADM	12.00	36.00
VIKOR	22.00	28.00

Based on the table II, we analyze the evaluation matrix obtained in the table XII. The results of the analysis between the table II and the table XII are shown in the table XIII.

TABLE XIII
COMPARISON MATRIX FOR INTERACTIVE TRAFFIC

MADM algorithms	P1(%)	P2(%)
TOPSIS	3	1
GRA	5	3
DIA	5	1
SAW	1	1
MEW	3	1
E-TOPSIS	5	5
FADM	7	5
VIKOR	7	7

The values of the weight granted to these parameters according to the interactive service are illustrated in table XIV.

TABLE XIV
WEIGHTING VECTOR OF INTERACTIVE TRAFFIC

Evaluation parameters	P1	P2	Weights
P1	1	1/5	0.167
P2	5	1	0.833

Table XV shows a comparison of various MADM algorithms for network selection according to the scores and the criticality index for interactive traffic. According to this table, we notice that the greatest value of the index of criticality is given by the VIKOR algorithm (99,99%). That implies that VIKOR algorithm is most adapted to be implemented in the context of the selection network than FADM, E-TOPSIS, TOPSIS, GRA, DIA, SAW and MEW.

Moreover, the FADM methods is qualified as the second desirable solution in the context of the handover decision than E-TOPSIS, TOPSIS, GRA, DIA, SAW and MEW. Finally, we observe that the small value of the index of criticality is provided by two methods TOPSIS and MEW. Consequently, these two algorithms are not favorable to be used for network selection access.

TABLE XV
THE CRITICALITY INDEX OF ALGRITHMS FOR INTERACTIVE TRAFFIC

MADM Algorithms	Criticality index	Rank
TOPSIS	19.04	6
GRA	47.61	4
DIA	23.80	5
SAW	14.28	8
MEW	19.04	7
E-TOPSIS	71.42	3
FADM	76.18	2
VIKOR	99.99	1

D. The simulation 4

The table XVI shows the measures of the evaluation parameters for streaming traffic concerning the eight methods namely FADM, E-TOPSIS, VIKOR, TOPSIS, GRA, DIA, SAW and MEW.

TABLE XVI
PERFORMANCE EVALUATION FOR STREAMING TRAFFIC

MADM algorithms	P1(%)	P2(%)
TOPSIS	50.00	70.00
GRA	20.00	80.00
DIA	30.00	60.00
SAW	50.00	70.00
MEW	60.00	60.00
E-TOPSIS	18.00	35.00
FADM	6.50	28.00
VIKOR	20.00	40.00

Based on the table II, we analyze the evaluation matrix obtained in the table XVI. The results of the analysis between the table II and the table XVI are shown in the table XVII.

TABLE XVII
COMPARISON MATRIX FOR STREAMING TRAFFIC

MADM algorithms	P1(%)	P2(%)
TOPSIS	1	1
GRA	7	1
DIA	5	3
SAW	1	1
MEW	1	3
E-TOPSIS	7	5
FADM	9	7
VIKOR	7	5

Before evaluating the performance parameters of each algorithm in order to choose the best MADM algorithm for network selection, we apply the ANP method to calculate the weights of ranking abnormality and number of handoffs. Table XVIII presents the associated weights of each performance parameters for streaming traffic.
Table XIX presents the comparison of the eight MADM methods for network selection according to the values of the criticality index for streaming traffic. We notice that FADM method has the highest score (88.89%), which means that this

TABLE XVIII
WEIGHTING VECTOR OF STREAMING TRAFFIC

Evaluation parameters	P1	P2	Weights
P1	1	1/7	0.125
P2	7	1	0.875

algorithm has the best performance than E-TOPSIS, VIKOR, TOPSIS, GRA, DIA, SAW and MEW.
Moreover,two methods VIKOR and E-TOPSIS methods are qualified as the second favorable solution in the context of the handover decision. Finally, we observe that the small value of the index of criticality is provided by two algorithms TOPSIS and SAW.

TABLE XIX
THE CRITICALITY INDEX OF ALGRITHMS FOR STREAMING TRAFFIC

MADM Algorithms	Criticality index	Rank
TOPSIS	11.11	7
GRA	44.44	4
DIA	44.44	5
SAW	11.11	8
MEW	22.22	6
E-TOPSIS	66.67	3
FADM	88.89	1
VIKOR	66.67	2

V. CONCLUSION

In this paper, the network selection access has been investigated and analyzed by using differents multiple attribute decision making methods. This comparison study allows to identify a suitable MADM algorithm which can be used in the context of vertical handover decision.
The simulation results leads us to conclude that for background, conversational, and streaming traffic, the FADM algorithm has the highest score the criticality index of the all algorithms. So, this algorithm, represents the most appropriate method for network selection, for these three traffic classes. In addition, the VIKOR algorithm is desirable than other methods to select the best access network which should be applied for interactive traffic.
Finally, according to the simulation results, we affirm that there is no MADM algorithm which represent the most appropriate methof for all traffic classes.

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