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Comparative Analysis of Multi Attribute Decision Making in Vehicular Ad-Hoc Networks

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ABSTRACT

Multi Attribute Decision Making (MADM) is one of the most popular decision making method. MADM refers to making decisions over finite number of alternatives. In MADM models, each alternative has a performance rating for each attribute, and performance ratings for different attributes are usually measured by different units. In the next generation heterogeneous wireless networks, will support the vertical handover mechanism in which users can maintain the connections from different service providers using various technologies. In vehicular network, vehicles have highly dynamic topology related to the high velocity of the vehicle. Due to this inherent characteristic of vehicular networks, handover is necessary. Various approaches have been proposed to solve the handover decision problem, but the choice of decision method appears to be arbitrary and some of the methods even give disputable results. There are a number of vertical handover decision algorithms have been proposed in the literature recently, even though there is a lack of performance comparisons between different handover schemes. In this paper, the performance between different multiple attribute decision making methods are compared and analyzed.

Key words: Heterogeneous networks, vertical handover, MADM, Vehicular Network.

I. INTRODUCTION

The Multi Attribute Decision Making (MADM) is the most important tools for analyzing complex real problems. Due to their inherent ability to convert the diverse measurement units on various criteria for possible selection of the best/suitable alternative(s). MADM refers to making preference decisions over finite number of alternatives. Multi Attribute Decision Making (MADM) analysis has some unique characteristics such as each alternative has a performance rating for each attribute, and performance ratings for different attributes are usually measured by different units. Numerous normalization procedures are available to eliminate computation problems caused by different measurement units. Normalization procedures are used in MADM to convert the different measurement units of the performance ratings into a comparable unit. It is an attempt to review the various MADM methods and need further advanced methods for validation and testing of the various available approaches. The main objective of the paper is the comparative analysis of four candidate multiple attribute decision making algorithms that could be adopted for making appropriate network selection decision for heterogeneous networks in vehicular ad-hoc network. The main involvement of this paper is the cross-analysis among the four candidate multiple attribute decision making algorithms. The four algorithms are compared and analyzed in terms of sensitivity to the attribute. These attributes include bandwidth, delay, jitter, error rate, and cost of the network.

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The rest of the paper is structured as follows. In section II related works are discussed. Section III describes the four candidate multi attribute decision making algorithms, and Section IV presents some numerical results for comparing the four algorithms. Section V presents conclusion.

II. RELATED WORKS

A number of algorithms have been proposed for making network selection decision in vehicular ad-hoc networks. These algorithms have been primarily designed for making network selection decision for a homogeneous network. In [1], Stevens-Navarro and Wong have compared the performance of four multi attribute decision schemes for making Network selection decisions in a HWN. The algorithms considered are MEW, SAW, TOPSIS and GRA. However, Network selection decisions for multiple sessions have not been considered in the scheme. In [2] a comparison done among Simple Additive Weighting(SAW), Technique for Order Preference by Similarity to Ideal Solution(TOPSIS), Grey Relational Analysis (GRA) and Multiplicative Exponent Weighting (MEW) for handoff decision in HWN. In [3], Tran and Boukhatem have proposed a multi-attribute decision making (MADM) scheme namely DIA to solve Network selection problem in HWNs. The DIA scheme selects the alternative Network that has the closet Euclidean distance to the positive ideal alternative. Nevertheless, Network selection decisions for multiple sessions have not been considered in the paper. In [4], Martinez and Rico et al. have compared the performance of seven MADM algorithms for making Network selection decisions for a single session. The MADM methods considered are SAW, MEW, VIKOR, GRA, WMC, ELECTRE, and TOPSIS. The performance of the different schemes have been evaluated and compared but Network selection decisions for multiple sessions have not been considered in the scheme. In [6] the author compared the three handoff schemes Centralized Vertical handoff decision (C-VHD), Distributed Vertical handoff decision (D-VHD) and Trusted - Distributed Vertical handoff decision (TDVHD). These three schemes give seamless vertical handoff. The simulation result shows a comparison between three scheme performance in terms of handoff processing delay, end-end delay and throughput.

While adopting any decision making technique, the three steps are involved in numerical analysis of alternatives:

- Formative the relevant attribute and alternatives
- Add the numerical measures to the relative significance of the attribute and the impact of the alternatives on these attributes
- Process the numerical values to make a decision of a ranking of each alternative.

III. MULTI-ATTRIBUTE DECISION MAKING METHODS

The Multi attribute decision making problem considered in this paper involves a set of alternatives Network (N1,N2,N3,and N4), which are evaluated based on a set of attributes (i.e. bandwidth, delay, jitter, error rate, network cost)[10]. A set of users specified weight (W), where $W=(W_{ij})$, i={1,2,…n} for j={1,2,…m} denotes weight value that represents the relative importance of each attribute to each service. To make easier to assess the relative importance of the attribute, network traffic type is divided into four types as illustrated in Table 1.

Table 1
Traffic Types

Traffic type	*Network Application type*
Conventional Service	Low latency for delay – High bit error rate
Streaming Service	Average Delay – Average bit error rate
Best Effort Service	High delay - Low bit error rate
Background Service	Slightly Higher than Best Effort Service

To set application priority levels, network application is classified into levels from 1 to 7 as illustrated in Table 2.

Table 2
Application priority

Priority Level	*Network Application Type*
Level -1 (Lowest level)	Best effort
Level -2	Background
Level -3	Medium load
Level -4	Excellent load
Level -5	Controlled load
Level -6	Voice and Video
Level -7 (Highest level)	Network controlled traffic

Table 3 shows the assignment of weights by a user to each of the network selection attribute. The weights assigned to attribute are on the standard scales from (1-7). The weight value indicates the relative importance of the attribute. The priority level-1 represents the lowest level i.e. least important that can be assigned to an attribute. The priority level-7 represents the highest level i.e. high important that can be assigned to an attribute.

Table 3
Assigning Weight values of Attributes

Traffic Type	*Bandwidth*	*Delay*	*Jitter*	*Error rate*	*Cost*
Conventional Service	3	6	5	2	6
Streaming Service	5	6	6	3	3
Best Effort Service	3	1	1	7	1
Background Service	2	1	1	1	1

The three Multi Attribute Decision Making algorithms investigated in this paper are discussed in the following subsection.

Simple Additive Weighting

The following steps are required when using SAW algorithm for group decision making in heterogeneous networks.

Step-1: Specify the user weight W for a set of services, for which network is to be selected

$$W = (W_{ij}) \ \ i = \{1, 2,..., m\} \ j = \{1, 2,..., n\} \tag{1}$$

Then calculate the weight ratio (i.e. Normalized weighted value)

$$W = \frac{W_{ij}}{\sum_{i=1}^{m} W_{ij}} \quad j = \{1, 2, \ldots, n\}$$

Step-2: Aggregate the normalized weighting W_{ij} for each attribute for different traffic types using the following equations.

$$G_{ij} = \frac{1}{n}\Sigma W_{ij} \;\; i = \{1, 2, ..., m\} \; j = \{1, 2, ..., n\} \tag{3}$$

Then the collective attribute for the group aggregated Wa is obtained by

$$W_t = \{W_{a1}, W_{a2}, ..., W_{an}\} \tag{4}$$

Step-3: Construct a decision matrix D for network and Attribute

$$\begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{bmatrix} d_{11} & d_{12} & \cdots & d_{1n} \\ d_{21} & d_{22} & \cdots & d_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ d_{m1} & d_{m2} & \cdots & d_{mn} \end{bmatrix} \end{array}$$

Step-4: Build the normalized decision matrix using benefit criteria and cost criteria for each and every element.

For benefit criteria

$$DM = \frac{X_{ij}}{Max(X_{ij})} \tag{5}$$

For cost criteria

$$DM = \frac{Min(X_{ij})}{X_{ij}} \tag{6}$$

Step-5: To obtain the weighted normalized decision matrix, aggregate the normalized decision matrix and the group weighting vector

$$V_{ij} = G_{ij} * DM_{ij} \;\; i = \{1, 2,...., m\} \; j = \{1, 2,..., n\} \tag{7}$$

Step-6: Calculate the Score of each alternative

$$S_i = \Sigma\, V_{ij} \;\; i = \{1, 2, ..., m\} \; j = \{1, 2, ..., n\} \tag{8}$$

Step-7: The alternative with the highest score value is then selected as the most suitable network.

$$\text{SAW} = \text{Max}\ (\text{S}_\text{i}) \tag{9}$$

SAW (Simple Additive Weighting): The overall score of a candidate network is determined by the weighted sum of all the attribute values.

Multiplicative Exponent Weighting: The following steps describes group decision making approach for MEW

Step-1: Specify the user weight and determine the normalized weight value using the formula

$$W = (W_{ij}) \quad i = \{1, 2,..., m\} \; j = \{1, 2,..., n\} \tag{10}$$

$$G_{ij} = \frac{1}{n}\Sigma W_{ij} \;\; i = \{1, 2, ..., m\} \; j = \{1, 2, ..., n\} \tag{11}$$

Step-2: Determine the group aggregated weighting vector for each of the attribute using the formula

$$G_{ij} = \frac{1}{n} \Sigma W_{ij} \quad i = \{1, 2, ...m\} \; j = \{1, 2, ..., n\} \tag{12}$$

Step-3: Construct a decision matrix D for network and attribute

$$\begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{bmatrix} d_{11} & d_{12} & \cdots & d_{1n} \\ d_{21} & d_{22} & \cdots & d_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ d_{m1} & d_{m2} & \cdots & d_{mn} \end{bmatrix} \end{array}$$

Step-4: Build the normalized decision matrix using the formula

$$DM = \frac{X_{ij}}{Max(X_{ij})} \tag{13}$$

$$DM = \frac{Min(X_{ij})}{X_{ij}} \tag{14}$$

Step-5: Build the weighted normalized matrix (i.e. the aggregated weighted vector for each of the attribute and exponent the normalized matrix) such that

$$V_{ij} = (DM_{ij})^{G_{ij}} \, i = \{1, 2, ..., m\} \; j = \{1, 2, ..., n\} \tag{15}$$

Step-6: Compute the score of each alternative using the formula

$$P_i = \Pi \; V_{ij} \; i = \{1, 2, ..., m\} \; j = \{1, 2, ..., n\} \tag{16}$$

Step-7: The highest score of the alternative network is then selected as the most suitable alternative for handover.

$$MEW = Max(P_i) \tag{17}$$

Technique for Order Preference by Similarity to Ideal Solution

TOPSIS is used to select the most suitable alternative Network using multi attribute decision making in heterogeneous networks and the steps are discussed as follows

Step-1: Specify the user weight and determine the normalized weight value using the formula

$$W_1 = X_1 \Big/ \sum_{i=1}^{n} X_i \quad i = 1, ..., 5 \tag{18}$$

Step-2: Construct a decision matrix

$$\begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{bmatrix} d_{11} & d_{12} & \cdots & d_{1n} \\ d_{21} & d_{22} & \cdots & d_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ d_{m1} & d_{m2} & \cdots & d_{mn} \end{bmatrix} \end{array}$$

Step-3: Construct the normalized decision matrix as follows

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \qquad \underset{\text{The number of alternatives}}{\underset{\swarrow}{i = 1, 2, ..., m;}} \qquad \underset{\text{The number of attributes}}{\underset{\swarrow}{j = 1, 2, ..., n}} \tag{19}$$

Step-4: Build the weighted normalized decision matrix using the equation

$$v_{ij} = (w_j)(r_{ij}) \quad i = 1, 2, ..., m; \; j = 1, 2, ..., n \tag{20}$$

Step-5: Compute the Positive ideal solution and the Negative ideal solution to represent benefit and cost criteria. For Benefit criteria and Cost criteria is given as

$$\begin{aligned} A^+ &= \left\{ \left(\max_i v_{ij} \mid j \in J \right), \left(\min_i v_{ij} \mid j \in J' \right), i = 1, 2, ..., m \right\} = \left\{ v_1^+, v_2^+, ..., v_n^+ \right\} \\ A^- &= \left\{ \left(\min_i v_{ij} \mid j \in J \right), \left(\max_i v_{ij} \mid j \in J' \right), i = 1, 2, ..., m \right\} = \left\{ v_1^-, v_2^-, ..., v_n^- \right\} \end{aligned} \tag{21}$$

Step-6: Determine the separation of each alternative from positive and negative ideal solutions

$$S_i^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^+)^2} \quad i = 1, 2, ..., m \tag{22}$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2} \quad i = 1, 2, ..., m \tag{23}$$

Step-7: Compute the closeness coefficient of each alternative

$$C_i = \frac{S_i^-}{S_i^+ + S_i^-} \quad i = 1, 2, ..., m; \; 0 \le C_i \le 1 \tag{24}$$

Step-8: The highest closeness coefficient value of the alternative network is then selected as the most suitable network for handover.

$$\text{TOPSIS} = \text{Max}\,(C_i) \tag{25}$$

TOPSIS (Technique for Order Preference by Similarity to Ideal Solution): the selected candidate network is the one which is the closest to ideal solution and the farthest from the worst case solution.

IV. NUMERICAL ANALYSIS

The above section outlines the three Multi Attribute decision making algorithms, SAW, MEW and TOPSIS which is used for the network selection in this paper. For instance, suppose a moving vehicle is currently connected to a WiFi network and has to make decision among four candidate networks N1, N2, N3, N4. Network selection criteria considered here are bandwidth, delay, jitter, Error rate and cost which denoted as C1, C2, C3,C4, C5 respectively. The decision matrix D is as follows

Table 4
Network Parameters

Network	*BandwidthC1*	*DelayC2*	*JitterC3*	*ErrorC4*	*CostC5*
N1	30	50	10	0.01	10
N2	40	80	10	0.008	20
N3	80	90	15	0.009	30
N4	40	30	20	0.012	8

SAW Method

Saw method requires a comparable scale for all elements in the decision matrix, the comparable scale is obtained by using the equation (5) and (6).

Table 5
Decision Matrix

Network	*Bandwidth*	*Delay*	*Jitter*	*Error*	*Cost*
N1	0.375	0.556	0.5	0.833	0.333
N2	0.5	0.889	0.5	0.667	0.667
N3	1	1	0.75	0.75	1
N4	0.5	0.333	1	1	0.267

The preference on network criteria is modeled as weights assigned by the user on the criteria. The aggregation of the normalized decision matrix is calculated by using the equation (7).

$$W_i = 0.229 \quad 0.194 \quad 0.183 \quad 0.232 \quad 0.162$$

By applying the weight factor, the weighted average values for the alternatives are calculated. The final score for the alternative are shown below

$$S_i = \begin{matrix} 0.532369 \\ 0.641111 \\ 0.896362 \\ 0.637166 \end{matrix}$$

The highest score S_i value is then selected as the most suitable alternative network. The results show that the ranking order of the alternative for SAW is N3, N2, N4, and N1.

MEW Method

Using MEW method, the first step is to construct normalized decision matrix, and the aggregated weighted vector for each of the attribute and exponent the normalized matrix is given below

Table 6
Decision Matrix (MEW)

Network	*Bandwidth*	*Delay*	*Jitter*	*Error*	*Cost*
N1	0.798	0.892	0.881	0.959	0.837
N2	0.853	0.977	0.881	0.911	0.937
N3	1	1	0.949	0.936	1
N4	0.853	0.808	1	1	0.808

The weighted average values for the alternatives are calculated using the equation (15) and the final score of alternatives are shown below.

$$P_i = \begin{matrix} 0.503621 \\ 0.626123 \\ 0.887578 \\ 0.556426 \end{matrix}$$

The highest score P_i value is then selected as the most suitable alternative network. The results show that the ranking order of the alternative for MEW is N3, N2, N4, and N1.

TOPSIS Method

Using TOPSIS method, first construct a decision matrix, and normalize the decision matrix using equation (19).

Table 7
Normalized Decision Matrix

Traffic code	*Bandwidth*	*Delay*	*Jitter*	*Error rate*	*Cost*
T1	0.136	0.273	0.227	0.091	0.273
T2	0.217	0.261	0.261	0.130	0.131
T3	0.231	0.077	0.077	0.538	0.077
T4	0.333	0.167	0.167	0.167	0.167

Then construct weighted normalize decision matrix using the equation (23). The following Table 8 presents the weighted normalized decision matrix.

Table 8
Weighted Normalize Decision Matrix

Network	*Bandwidth*	*Delay*	*Jitter*	*Error rate*	*Cost*
N1	0.040	0.102	0.079	0.046	0.071
N2	0.085	0.156	0.091	0.053	0.068
N3	0.181	0.052	0.041	0.246	0.060
N4	0.131	0.037	0.116	0.101	0.035

Find out the positive ideal Solution A^+ and negative ideal solution A^- is as follows

$$A^+ = \{0.180 \quad 0.156 \quad 0.116 \quad 0.246 \quad 0.071\}$$

$$A^- = \{0.040 \quad 0.037 \quad 0.040 \quad 0.046 \quad 0.035\}$$

Then determine the distance between each alternative.

The positive ideal solution is given below

$$S_i + = \begin{matrix} 0.252589399 \\ 0.216569393 \\ 0.129399387 \\ 0.196787804 \end{matrix}$$

Negative ideal solution is given below

$$S_i^- = \begin{matrix} 0.083734933 \\ 0.140754611 \\ 0.245703341 \\ 0.130202076 \end{matrix}$$

Finally the closeness (C_i) of the ideal solution is calculated using equation (24) and presented as follows

$$C_i = \begin{matrix} 0.24897 \\ 0.39391 \\ 0.655029 \\ 0.398184 \end{matrix}$$

From the closeness value, Network N3 is the best alternative network to connect the vehicle to maintain the service continuity by TOPSIS algorithm. The Ranking order of TOPSIS is N3, N4, N2, and N1.

V. RESULT AND DISCUSSION

This section discusses the results obtained from the numerical simulation of the four candidate multi attribute decision making algorithms. Different user specified weight levels are considered for each of the session criterion using the three network selection algorithms namely SAW, MEW, and TOPSIS. The simulation results of the four candidate MADM algorithms are analyzed. The analysis of the candidate MADM algorithms shows the sensitivities of the algorithms , as well as how the user preference to different weight levels contribute to network selection choice for a group of multiple sessions in Heterogeneous Vehicular Networks (HVN).

The HVN consists of four Networks out of which the most suitable Network is to be selected for each group of handoff sessions. In addition, we examine and analyze the sensitivity of each of the Network selection for the four candidate MADM algorithms with respects to each criterion. 100 groups of multiple handoff sessions are considered in the simulations, and each group consists of four classes of handover sessions namely; video streaming, file downloading, voice, and web browsing. Each of the classes of active session is assigned weight for each of the five network selection criteria.

For a particular group of sessions, the weight assigned to the criterion whose sensitivity is to be analyzed is varied from 1 to 7, whereas the weights assigned to the remaining criteria are kept constant for the group of handoff sessions. The aim of the scenario is to investigate how users' weights specified for a particular criterion affect network selection decisions. In HVNs, users can specify different weight for different criteria. The value of a particular criterion weight depends on the importance of the criterion to individual users for different classes of service. The results obtained from the sensitivity analysis of the candidate algorithms for each attribute are given in the following subsection.

Sensitivity Analysis of MADM

If one attribute weight value is changed will affects the weight of the other attributes[12]. The changed weight value is calculated by

$$W_p' = Wp + \Delta p$$

where Wp – weight of the attribute

Δp- increased weight

The weight value of the other attributes are calculated by

$$W_j' = \frac{1-Wp'}{1-Wp} * W_j$$

The sensitivity analysis paying attention on determining the most sensitive attribute in the model. This attribute is one that, the least change in its weight value relative to others, leads to change in ranking of alternatives. Also they found the value of changing the weight value of one attribute that leads to the change in ranking of alternatives. The ratio of new and old weights of all attribute except the value changed attribute will not change[12], that is

$$\frac{W_i'}{W_j'} = \frac{W_i}{W_j};\ i,\ j = 1, 2, 4;$$

Table 9 presents the ranking order of SAW, MEW and TOPSIS algorithms.

Table 9
The Ranking Order of SAW, MEW and TOPSIS

	N1	*N2*	*N3*	*N4*
SAW	0.53	0.64	0.90	0.64
MEW	0.50	0.63	0.89	0.56
TOPSIS	0.25	0.39	0.66	0.40

The results show that the ranking order of the alternatives is same for SAW and MEW algorithms (N3, N2, N4, and N1). The ranking order of TOPSIS is N3, N4, N2, and N1.

To analyze the sensitivity of an attribute, the weight of the attribute (jitter) is increased by 0.2. After changing the weight of the attribute, the new score of alternatives are calculated and present in table 10.

Table 10
The Ranking Order of SAW, MEW and TOPSIS (New weight)

	N1	*N2*	*N3*	*N4*
SAW	0.52	0.61	0.86	0.73
MEW	0.50	0.59	0.85	0.64
TOPSIS	0.44	0.50	0.49	0.41

The results show that the ranking order of the alternatives for SAW and MEW is (N3, N4, N2, and N1. The ranking order of TOPSIS is N2, N3, N1, and N4. It is clear that the ranking has changed from the old alternative to new alternative.

Figures 1-3 shows that the sensitivity of implemented algorithms on the attribute (jitter) among four available network.

V. CONCLUSION

The performance comparison between SAW, MEW and TOPSIS (MADM) algorithms are presented in this paper. The results indicate that TOPSIS algorithms are more consistent across all the criteria considered when compared to the SAW and MEW algorithms in Heterogeneous Vehicular Networks. Therefore, TOPSIS algorithms are more suitable for making optimal network selection decisions for a group of multiple handoff

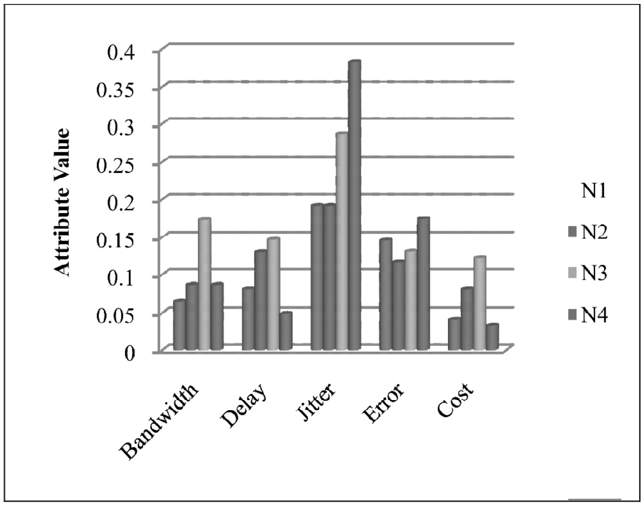

Figure 1: Sensitivity Analysis on attribute (jitter) Using SAW method

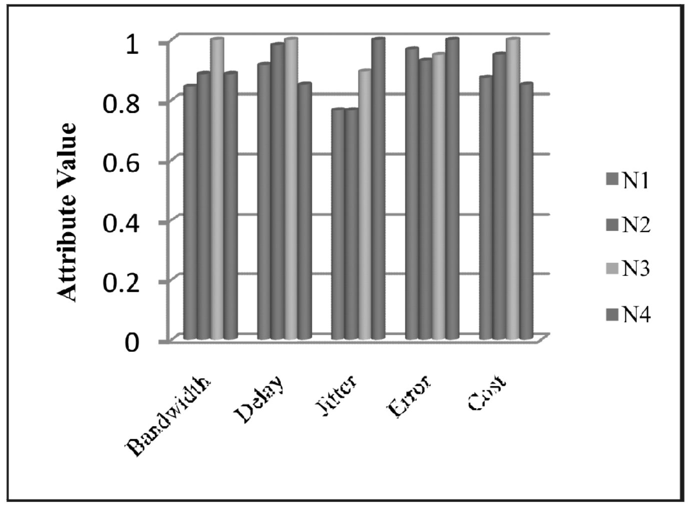

Figure 2: Sensitivity Analysis on attribute (jitter) Using MEW method

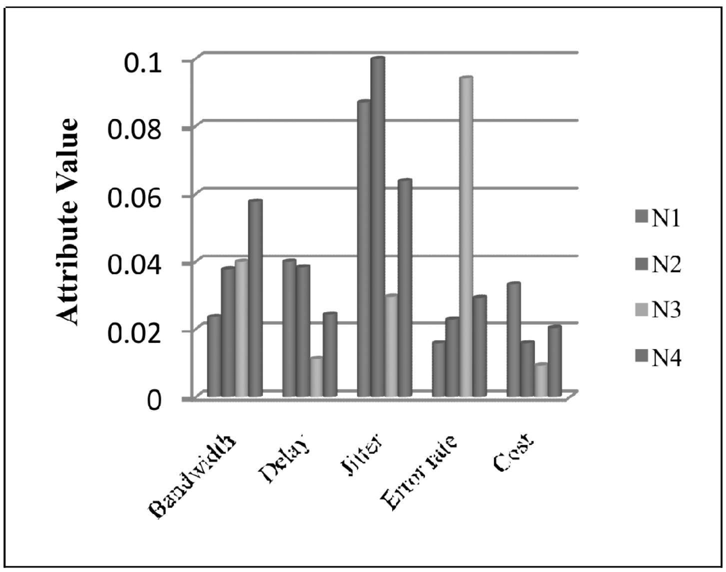

Figure 3: Sensitivity Analysis on attribute (jitter) Using TOPSIS method

sessions from a Heterogeneous Vehicular Network. Results also showed that all three algorithms depend on the importance weights assigned to the attributes.

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