Using a New Fuzzy MADM Method to Improve the Number of Vertical Handovers in the Case of Wireless Technology Selection for VANETs

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Abstract: VANET is a promising project in the transportation field, and more precisely, in the intelligent transportation (ITS) area. Its heterogeneous architecture has led researchers to use vertical handover to allow vehicles to switch from one wireless technology to another (such as 5G, DSRC…) at any time and in any situation without losing connection. For this purpose, several methods have been developed, among them the Multi-attribute decision-making (MADM) methods, which allow the enhancement of decision-making in the vertical handover process. This paper proposes a new approach for wireless technology selection based on an improved TOPSIS method applied to order the alternatives. Simulation experiments have been conducted to evaluate our approach, and the results show that our TOPSIS* method is more efficient than the classical Fuzzy TOPSIS.

1 INTRODUCTION

Nowadays, the increasing number of accidents and traffic jams on our roads have motivated the automotive industry to increase the autonomy of vehicles, make the vehicle's path as safe as possible, and protect human life. For this reason, researchers in the automotive field have turned to intelligent transport systems (ITS). VANET (vehicular ad-hoc network) network is a specific case of MANET (Mobile Ad-hoc Networks) networks, which researchers consider a promising project in the ITS field. The idea is to interconnect vehicles and share resources and information between them to explore their surroundings better and cope with the different threats and issues that may arise on the way. In a VANET environment, vehicles communicate with each other via V2V(vehicle-to-vehicle) mode and with the infrastructure via V2I (vehicle-to-infrastructure) mode, which enables them to exchange with RSUs (Road-Side-Unit) and base stations to take advantage of several services such as internet access [1]. However, despite the multitude of technologies available (5G, 6G, DSRC ...), VANET faces several challenges; one of the most critical is the connection loss [2], caused by the high speed of the vehicles and the dynamic topology of the network. In order to overcome this issue, researchers have been interested in the vertical handover, allowing to pass from one technology (support) to another without loss of connection. This operation is focused on the selection of the best technology in a heterogeneous system such as VANET. For this purpose, we opt-in this article for the MADM (Multi-attribute decision-making) algorithms which have proven their efficiency in several fields. MADM is applied to select the best possible choice during the vertical handover phase by considering various decision criteria. In the MADM approach, there are several algorithms such as DIA (Distance to Ideal Alternative), ANP, and AHP/FAHP (Fuzzy Analytic Hierarchy Process) for measuring the criteria weight, and other algorithms for ranking the alternatives (networks and technologies) such as VIKOR, TOPSIS, and GRA. In this paper, we propose an improvement of the TOPSIS algorithm (TOPSIS*) to classify the available technologies to reduce the number of vertical handovers and improve the quality of service (QoS).

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2 RELATED WORK

Technology (support) selection is a fundamental step that requires a dynamic selection of the best support at a given time depending on the situation in which a vehicle is confronted because mobility in a VANET context directly impacts the topology and performance of the used protocols [3]. MADM has been presented as the most promising method to solve the alternative selection problem. It is easy to implement using simple mathematic methods and does not require any specific physical resources.

In addition, MADM methods are widely used for decision-making in the context of VHO; the most important methods are SAW, TOPSIS, and VIKOR [2] [4]. The main principle is to rank the alternatives according to the score of the measured weights. Some authors, such as [5], proposed arbitrary weights to identify the importance of each attribute (criterion) by QoS class. Others [6] were able to use the AHP to calculate the weight of the criterion vectors and apply the TOPSIS method to rank the alternatives (LTE, 4G, 5G ....). The results showed that the weight of the criterion vectors is important in the decision-making process.

Nevertheless, intelligent computing algorithms are still the most efficient since they use intelligent implementation techniques such as Fuzzy Logic and neural networks. Fuzzy logic is useful for VH decision-making because it can deal with radio signal inaccuracy, user preferences, and QoS parameters. Several authors [7] [8] have studied the Fuzzy AHP and Fuzzy TOPSIS combination to measure the relative weights of the evaluation criteria and classify the alternatives as an improved solution to a problem of inter-vehicle communications. This is why we have chosen the fuzzy approach in our technology selection model.

3 SYSTEM MODEL

In this study, we attempted to overcome the weaknesses of the FTOPSIS method for application fields characterized by high mobility, as is the case of VANET. One of the major concerns this method faces is the reversal phenomenon, which occurs at the preference order level due to the addition or removal of an alternative from the original decision problem. The authors have made several attempts [9] to improve the TOPSIS method, but no effective solution is implemented yet.

The method we propose (TOPSIS*) is improving the fuzzy TOPSIS method based on the vertical handover decision by combining it with the Fuzzy AHP to generate the criteria weights.

As shown in Figure 1, we collect the evaluation criteria and the alternatives chosen for this study; then, we build the decision matrix using the information recovered from the first step. Once this is done, the pairwise comparison process is initiated for each QoS class. In this study, we considered the following evaluation criteria: data rate, latency, throughput, and coverage which will be processed as weight vectors by the Fuzzy AHP method, and finally, we apply our TOPSIS* method on the fuzzy matrices that have been measured to order our alternatives. Regarding the alternatives selected for this study, 5G/6G and DSRC/WAVE wireless mediums have been selected as the most used means of communication in a VANET network by the vehicles moving within it.

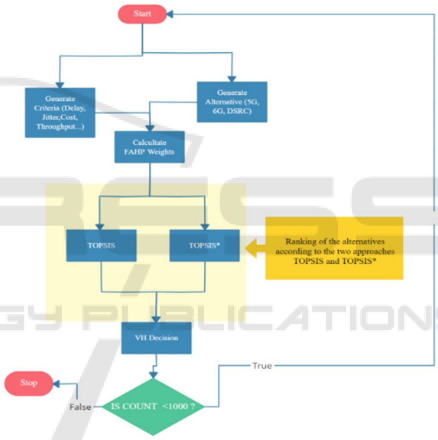

Figure 1 : System Model

4 METHODS USED IN OUR STUDY

4.1 Fuzzy Set Theory

Zadeh [10] introduced the fuzzy set theory to reflect the uncertainty of human decisions and thoughts. its ability to represent vague data is a very important contribution in the field of mathematics, especially the one related to abstract, vague object classes. A fuzzy set is represented by a function called membership function *F (1)* which associates for any point X a real number in the interval [0,1]

$$F_{A(x)} = \begin{cases} \dfrac{x-l}{m-l}, & l < x < m \\ \dfrac{h-x}{h-m}, & m < x < h \\ 0 & , Otherwise \end{cases} \tag{1}$$

In the pairwise comparison, the TFN defined by the three real numbers (l,m,h) in order to express a fuzzy event.

4.2 Method Fuzzy AHP

AHP technique is used to process and analyze complex decisions, although this technique has weaknesses in its interpretation and adaptability to heterogeneous systems. Fuzzy AHP has emerged as a contouring solution combining AHP with fuzzy logic. The importance of this method is in the phase of generating for each pair of factors fuzzy relative importance. the fuzzy evaluation matrix is thus obtained:

$$\tilde{P} = (p_{ij})_{n*m} = \begin{pmatrix} (1,1,1) & \cdots & \tilde{p}_{1m} \\ \vdots & \ddots & \vdots \\ \tilde{p}_{n1} & \cdots & (1,1,1) \end{pmatrix} \tag{2}$$

Such us:

$$p_{ij} = (l_{ij}, m_{ij}, u_{ij})$$

Knowing that there are several implementations of the weighting process via FAHP, we chose the one proposed by Bucklet [11]. This one uses the geometric mean approach to calculate the resultant vector in the pairwise comparison matrix:

$$\tilde{S}_i^{P/G} = \left(\tilde{S}_i^{P/C_1} \otimes \tilde{S}_1^{C/G}\right) \oplus \square \cdots \oplus \left(\tilde{S}_i^{P/C_m} \otimes \tilde{S}_m^{C/G}\right) \tag{3}$$

with:

$$\tilde{S}_i = (\tilde{p}_{i1} \otimes \cdots \otimes \tilde{p}_{im})^{1/m} \otimes ((\tilde{p}_{11} \otimes \cdots \otimes \tilde{p}_{1m})^{1/m} \oplus \cdots \oplus (\tilde{p}_{m1} \otimes \cdots \otimes \tilde{p}_{mm})^{1/m})^{-1}$$

Lastly, we apply the Fuzzy AHP method to each QoS class, and the associated weight vectors are generated for each of the criteria.

4.3 Fuzzy TOPSIS

The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) was designed in the 1980s. It is a ranking method that is easy to implement and apply. It aims at selecting the best alternative that has the shortest distance to the positive ideal solution and the farthest distance to the negative solution simultaneously.

The distances separating each alternative X from the ideal positive and anti-ideal solutions are given as follows:

$$ds_i^+ = \sqrt{\textstyle\sum_{j=1}^{M} |\max_i(v_{ij}) - v_{ij}|}$$

$$ds_i^- = \sqrt{\textstyle\sum_{j=1}^{M} |\min_i(v_{ij}) - v_{ij}|} \tag{4}$$

We calculate just after the relative proximity to the ideal solution with the following formula:

$$Rp_i = \frac{ds_i^+}{ds_i^+ + ds_i^-} \tag{5}$$

4.4 Proposed TOPSIS*

The procedure we followed considers the mobile feature of the vehicles not taken into account by the classical FTOPSIS method. For this reason, we started by modifying the previous equation, introducing two new parameters (b,w) expressing the relative importance towards the anti-ideal and ideal solution calculated by applying FAHP for each of the QoS classes.

To calculate the new value of the relative proximity of the optimal solution, we propose the following equation:

$$Rp^*{}_i = \frac{\mathrm{b}*ds_i^+}{\mathrm{b}*ds_i^+ + w*ds_i^-}$$

5 SIMULATIONS AND RESULTS

5.1 Simulation

The simulation performed for both 5G and DSRC wireless technologies involved the four QoS class types (Streaming, Conversational, Interactive, and Background) that cover the different user-side requirements. The Generation of the values for each of the criteria was randomly produced based on the ranges specified in Table 1; the simulation was performed in 1000 vertical handover decision cases using a java program designed for this purpose.

Table 1 : QoS Criteria

Tech	Latency (ms)	Throughput (Mb/s)	Data rate (Mb/s)	Coverage (m)
DSRC	100-1000	0.01-20	100-500	150-500
5G/ 6G	10-100	0.1-100	1000-10^5	10-100

First, we constructed our pairwise comparison matrix using the linguistic variables[12] listed in Table 2, and then we apply the FAHP method to generate the weights per criteria (Latency, Throughput, Data Rate and Coverage). Next, we apply our AHP method again to determine the importance of b,w relative to the ideal solution and the anti-ideal solution, respectively (Table 3). Finally, we apply the enhanced TOPSIS method (TOPSIS*) to measure the new closeness to the ideal solution and rank our alternatives for the four classes of QoS.

Table 2 :Membership function of linguistic scale

Fuzzy Number	Linguistic Scales	TFN
$\tilde{1}$	Equally important (Eq)	(1,1,1)
$\tilde{3}$	Weakly important (Wk)	(2,3,4)
$\tilde{5}$	Essentially important (Es)	(4,5,6)
7	Very Strongly important (Vs)	(6,7,8)
9	Absolutely important (Ab)	(9,9,9)

Table 3 : Values of b and w for each QoS class

QoS Class	b	w
Streaming	0.720	0.300
Conversational	0.850	0.150
Background	0.750	0.180
Interactive	0.900	0.080

5.2 Results and Discussion

The comparison results presented in this paper show that the improved TOPSIS method is more efficient than the conventional TOPSIS method for wireless technology selection in a heterogeneous and topologically dynamic environment. In the first simulation, we evaluate the proposed approach compared to the classical method, the second simulation, comparing the average numbers of Vertical Handover by each methods.

It should be noted that the number of simulations carried out allowed us to go through the different situations that a vehicle using a vehicular ad-hoc network network may face, as well as having a database of different parameter values (latency, bandwidth, coverage...) that can give them an advantage to override or signal an urgent obstruction on the way.

The following figure shows that the applied method reduces considerably the number of Vertical Handover for the four QoS classes (Streaming, Conversational, Background, Interactive) allowing to overcome the deficiencies of the classical method. And to be a suitable solution for autonomous mobile vehicles evolving in a heterogeneous environment.

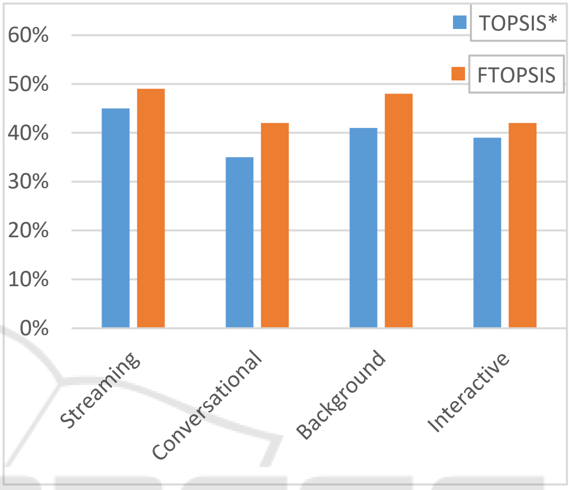

Figure 2 :Average of the number of Vertical Handover for all Qos Class

The new TOPSIS* approach allows, as explained, to reduce the number of handovers; for example, it reduces the number of handovers by 7% compared to the classical Fuzzy TOPSIS method. Below is a table of the different improvements that the new approach offers compared to the classical method for the four QoS classes.

Table 4 :Improvement of the VH of the new approach.

Traffic Class	TOPSIS*
Streaming	**4** ↓
Conversational	**7** ↓
Background	**7** ↓
Interactive	**3** ↓

6 CONCLUSION

This paper proposes a new approach to improve the selection of wireless technologies in the VANET network by improving the standard Fuzzy TOPSIS alternative selection method to fit the VANET context. Our approach uses the Fuzzy AHP method to measure the relative weight of the selection criteria. The simulation we performed shows that the proposed method significantly improves vertical handovers compared to the classical method.

In future work, we intend to improve our java program used in the simulation to include the routing protocol settings during inter-vehicle communication and include other parameters to fit better with the VANET context.

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