A Complementary Approach to Centralized Task Offloading Algorithms in Vehicular Ad-hoc Networks (VANETs)

Jian Gao[1], Yuxuan Qi[2], Wenkai Pan[2], Yuchen Ma[3], Xinyi Gong[3],
[1]Undergraduate Student in Electrical and Computer Engineering, University of British Columbia, Vancouver, Canada
[2]Undergraduate Student in Electrical Engineering, State University of Pennsylvania, University Park, USA
[2]Undergraduate Student in Electrical Engineering, Taiwan Yuan Ze University, Taiwan
[3]Undergraduate Student in International Business, Jinan University, Guangzhou, China
[3]High School Student, Bryn Mawr School, Baltimore, USA

Autonomous driving and other advanced applications in our current transportation system have significantly added to the demand of computational power on the road. As industrial research suggested, cloud computing will play an important role in solving the tasks that are generated but unable to be solved by modern vehicles. However, in an urban area, cellular base stations may fail to deliver crucial information due to the existing congestion in wireless channels caused by the large amount of LTE/5G-enabled devices. Therefore, in order to keep a reliable connection between the task generator and the computing server, a scheme of edge computing is introduced to Intelligent Transportation Systems (ITS) in which further optimizations can be made. For example, in the centralized approach of vehicular edge computing, the load of tasks can be balanced among a number of nearby Road Sign Units (RSUs) the Approximate Load Balancing Task Offloading Algorithm (ALBTOA) which is essentially based on game theory. Similarly, we aim to developping a foolproof algorithm to balance the loads effectively from a distributive perspective when data collected is not as much and every vehicle has to decide which server to offload to.

***Index Terms*—VANETs, VANET Security, Edge Computing, Intelligent Transportation System, Autonomous Driving.**

I. Introduction

INSPIRED by the unbounded imagination of ever-evolving cloud computing technologies, we saw that edge computing showed up a few years ago as a complementary form to conventional cloud computing. Adding to that, another super intriguing concept-Vehicular Network can be investigated in parallel since studies have shown that VANETs seem to be independent to future cellular technologies due to the fact that civil-use cellular network is now stymied by a bottleneck which is the lack of available bands left in the frequency spectrum. Moving to a higher frequency from what we had in place will lead to even smaller cluster sizes and greater costs correspondingly. Thus, instead of only applying cellular innovations to VANETs for system improvement, we should not ignore the great potential lying in the combination of vehicular networks and edge computing which could bring us various benefits. The most apparent can be the reduction in communication delay as this will be further explained when we compare the anticipated latency of the approach of MEC server and cloud computing server [1]. However, the V2I-only communication scheme for VANETs edge computing doesn't appear to be completely reliable for all latency-constrained ITS applications due to two major factors:

1) Limited Bandwidth

The bandwidth of a certain RSU wired to a MEC server is fixed according to 802.11p which is the most favourable protocol for all VANETs. Therefore, no more than a certain number of vehicles can be connected to the RSU at the same time.

2) Constrained Computational Power

The computational power of a MEC server is limited by its own hardware specifications. Once the server is fully loaded, topping up its work stack would be an inefficient task offloading decision even if there is no wireless congestion yet as discussed in (1).

To conclude, a large number of cars are most likely to cause problems in such a scenario. Thus, the offloading decisions are necessary to be regulated in a way that tasks in an area are distributed more evenly to more MEC servers through their RSUs. This is when the concept of fog computing kicks in and a combined method of V2V and V2I communication has now become a necessity as a part of our ultimate solution.

II. Related Work

Before digging into the proposed problem, it is worth bringing up some useful concepts for the sake of clarification later in this paper, after which related work will be evaluated as either the knowledge base we can work on or the potential problems that we shall try to avoid.

A. For Wireless Communication

1) Data Transmission Delay

Data transmission delay is the time between receiving the first and last bits of the packet during the transmission process. However, the delay is unrelated to the length of the packet, and it has a strong influence on the performance of network algorithms and causes problems such as reduced reliability of the network and low efficiency. The overall data transmission delay depends on following factors: Medium Access Control (MAC), capacity of the link, channel types [2].

2) DSRC

DSRC is a one-way or two-way short-range to medium-range wireless communication channel specifically designed for automotive applications and a corresponding set of protocols and standards. DSRC mainly has two types: vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I), both of which require low latency and good weather conditions to ensure the stability of the wireless interface. Therefore, the communication performance of DSRC is the key foundation for ensuring the reliability of V2X security application functions.

3) IEEE 802.11p

IEEE 802.11p (also known as WAVE, wireless access in-vehicle environment) is a communication protocol extended from the IEEE 802.11 [3]. Mainly used in the wireless communication of automotive electronics, its application framework includes the data exchange between high-speed vehicles and also between vehicles and standard ITS roadside infrastructure at 5.9 GHz (5.85-5.925 GHz). IEEE 802.11p helps us to achieve advanced handoff scheme, mobile operation, enhanced security, identification, peer-to-peer network authentication.

4) Related Work

Usually, the cellular phone channel is used to estimate V2V communication. To overcome the problem of the multipath fading channel, two technologies are implemented: Orthogonal Frequency Division Multiplexing (OFDM) technology and Multiple Input Multiple Output (MIMO) diversity technology. Simulation results have shown that OFDM technology overcomes the problem of multipath fading under high transmit power [4].

B. For Offloading Strategies

1) Multi-criteria Ranking

First introduced in 1981, Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) is an algorithm widely used in the data science when dealing with multi-attribute decision-making problems (MADC). Thus, this method can come to great help in terms of evaluating all possible alternative computational resources upon which the best will be chosen in the view of a car. More details will be revealed in section V.

2) Entropy-weighting Method

Entropy-weight Method (EWM) essentially illustrates the idea that more dispersion will lead to more information stored in a set of data [5]. Commonly implemented in solving MADC, EWM is a valued method to compensate for the distortion in information caused by the normalization and additional operations of data.

3) Multi-hop Connection

There is no doubt that a multihop data system will greatly benefit safety applications and traffic efficiency applications of VANETs since it offers the task generator a number of alternatives of whether the designated server or the optimal path to it. However, data inconsistency and redundancy still exist in current multihop data dissemination protocols. [11] defines three metrics that would characterize communication redundancy for vehicular networks–redundant paths, critical nodes, and distribution of information.

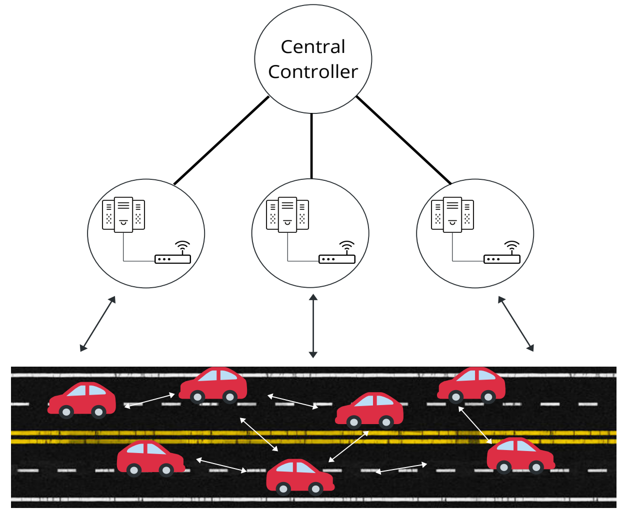

Fig. 1. A typical centralized scheme of edge computing for VANETs

4) Related Work

[6] proposed a hierarchical architecture of vehicular networks for ITS where three technical layers are present–application layer, data aggregation layer, and access network layer. Regarding the task generation and distribution problems that we currently investigate, there are generally two categories. One is the centralized approach with the other being the distributed approach. In the former, a central controller in the data aggregation layer acts as an interface between physical network routers and network operators. Thus, various upsides are expected from this approach since the task offloading decisions are mostly made on a higher level in the network instead of the vehicles themselves. As mentioned in [1], all the physical properties of the cars can be gathered at the same time for comparison to find the best path to the RSU through V2V connections. Furthermore, the control data from each vehicle connected can be easily collected for foreseeable optimizations in task distributing algorithms and marketing research. However, the drawbacks of the centralization are obvious, and one of them would be security issues, such as DoS, identity spoofing, modification repudiation, repudiation, Sybil attack, and information disclosure [7]. While research regarding VANETs' security is being conducted, it is the best for us to propose a backup solution that can solely perform without the offloading commands coming down from the central controller which is also known as the software-defined networking (SDN) controller.

In comparison to the centralized approach mentioned above, the distributed method is more like an object-oriented programming language which allows each task generator to send its packets to the most optimal designated server.

III. System Model

In this section, we will clarify prerequisites for the system model with a quick simulation made to compare SISO OFDM and MIMO OFDM where the latter can be seen as the better implementation. Then we introduce the channel models for V2V/V2I communications and propose the ultimate problem.

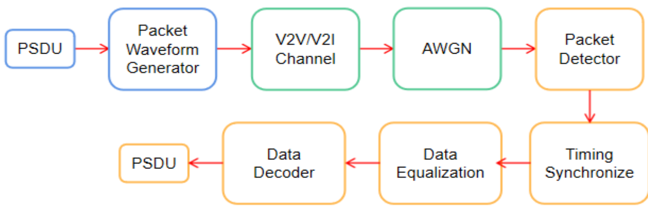

Fig. 2. Block diagram for the communication model

A. Prerequisites

In our real life, because vehicles are going relatively fast on the highway, Doppler Effect will become notable. For simplification, we build our simulation scene in an urban aera where vehicles are passing at an intermediate speed in one direction. In addition, we analyse the power measurement data received in line-of-sight scenarios.

B. Block Diagram

With this simple block diagram, we can get a general idea of the whole transmission process [12]. In our example, an end-to-end simulation is utilized to decide the packet error rate (PER) for 802.11p with a fading channel at a choice of SNR points with channel tracking. For each SNR point, multi-packets are transmitted by a V2V channel, demodulated and the PSDU is recovered. The PSDU is transmitted to determine the number of packet errors. For each packet, packet detection, timing synchronization, carrier frequency offset correction and phase tracking are performed at the receiver. For channel tracking, decision directed channel estimation is used to compensate for the high Doppler spread.

C. Communication Model

Although, in OFDM, the peak-to-average power ratio (PAPR) is large, resulting in the low power efficiency of the RF amplifier [4]. Compared with a single carrier system, since the OFDM signal is formed by adding multiple independent modulated subcarrier signals, such a composite signal may generate a relatively large peak power, which will also cause a large peak-to-average power ratio, also referred as peak-to-average ratio. We can consider the vehicle as a device with considerable power due to the fact that it has a solid battery and a reliable engine.

Multiple feasibility studies have shown that OFDM and MIMO can achieve higher data rates and fewer bit error rates in a highly dynamic V2V environment [4]. In addition, simulation results indicate that combining Alamouti space-time codes with OFDM and MIMO (2x2) can effectively reduce bit error rate (BER) in multi-fading channel problems. Meanwhile, as [4] graphically illustrates, when the BER is 0.01, the signal-to-noise ratio of MIMO OFDM is only 17db, while the SNR of SISO OFDM reaches 20db with QPSK modulation. When BER increases, the gap between two SNRs gets larger. The same goes for 16 QAM and 64 QAM. So we conclude that the implementation of MIMO OFDM will achieve higher transmission speeds and lower SNRs.

Moreover, [10] has proposed an accurate path loss model of vehicular environments which is crucial for the vehicular communication system design and for our decision-making in offloading. Therefore, we are supposed to compute the value of Path Loss for our model in MATLAB by using a simplified formula which is

$$L = \frac{P_r}{P_t G_t G_r} = \frac{A_e}{4\pi G_r d^2} = \left(\frac{\lambda}{4\pi d}\right)^2 \tag{1}$$

where λ is signal wavelength, $\mathbf{P_r}$ and $\mathbf{P_t}$ are received power and transmitted power, and then $\mathbf{G_r}$ and $\mathbf{G_t}$ are received gain and transmitted gain respectively with $\mathbf{G_r}$ being the physical distance between the receiver and transmitter.

Received power can be derived as

$$P_r = \frac{EIRP}{4\pi d^2} A_e = \frac{P_t G_t G_r \lambda^2}{(4\pi d)^2} \tag{2}$$

D. V2V/V2I Specifications

With vehicles moving on the road, the transmission of data occurs in both V2V communication and V2I communication. Thus, we need to think about what factors we should consider when calculating the transmission rates for the respective scenarios. According to [1], a set of formulas is shown below.

For V2I communications, the data transmitting rate between vehicle-i and vehicle-k can be computed as

$$r_{i,j}^{v2i} = \omega_{i,j} \log_2 \left(1 + \frac{p_{i,j} \cdot g_{i,j}^{v2i}}{\sigma^2 + I_{i,j}}\right) \tag{3}$$

For V2V communications, the data transmitting rate between vehicle-i and vehicle-k can be computed as

$$r_{i,k}^{v2v} = \omega_{i,k} \log_2 \left(1 + \frac{p_{i,k} \cdot g_{i,k}^{v2v}}{\sigma^2 + A_0 \left(L_{i,j}\right)^{-2}}\right) \tag{4}$$

Bandwidth, transmission power, noise power, and antenna gain of the transmitter and receiver all appear in both formulas. However, the difference remains that V2V communication is more concerned with the distance between vehicles, while V2I communication is closely related to interference.

E. Problem Formulation

The ultimate problem we came up with is formulated as following: how do we properly allocate the excessive computational power of MEC servers to the vehicles on the road dealing with pending tasks that their CPUs are incapable to solve. The guidance from [1] can be quite clear when the whole hierarchy (Fig. 1) operates normally. However, in the extreme cases of cyber attacks or blackouts, our approach to offloading decisions tends to be ambiguous. Thus, we now propose a solution to offloading tasks in a distributed manner as the backup option as mentioned in previous section. Our approach to the problem can essentially be divided into two sections–a realistic communication model which is already covered in section III and a reasonable algorithm for making offloading decisions in section IV. To prove the practicability of our proposal, a simulation will be carried out in section V with all relevant parameters given in the table.

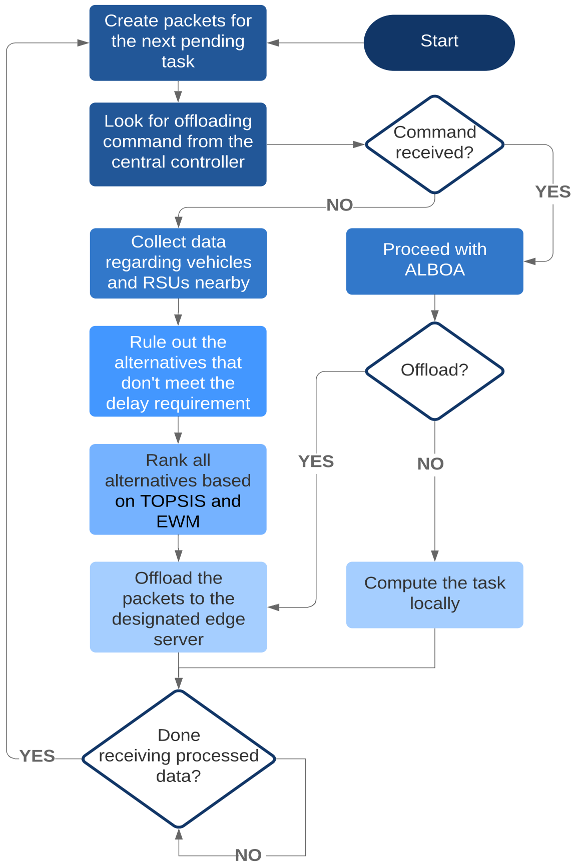

Fig. 3. Flow chart for the proposed solution

IV. Offloading Decisions

Assuming the service of the central controller is interrupted, the tactics of GTNOA, PGTOA, and ALBOA from [1] are no longer practically possible. We will have no choice but to let the cars determine where the pending tasks should go on their own, as previously mentioned.

The flow chart (Fig. 3) gives a first intuition of our main idea. To be clear, the left branch represents the distributed edge computing strategy while the right branch takes commands from the central controller when they are available again.

To further explain the shown mechanism, after ruling out the communication paths that don't meet the basic time requirement which may cause navigation failures and even safety issues, the options remaining get ranked by the proposed method combining TOPSIS and EWM in the following paragraphs.

In TOPSIS, there are four kinds of metrics–benefit index, cost index, intermediate index, and interval index as shown in Table I. For simplification regarding our proposed problem, we will consider only the communication delay, PER, and edge server CPU performance with the first two being cost indexes which are better to be of low values for the final ranking process. Here we assume the performance of CPUs is not constrained by other hardware factors.

Type of index	Factors we currently consider
Benefit index	CPU performance
Cost index	PER, Delay
Intermediate index	
Interval index	

TABLE I
TOPSIS Evaluation Criteria

Before we proceed, all data collected needs to be normalized by using following mathematical functions [13].

$$\overline{x_l} = \frac{1}{x_i} \tag{5}$$

$$\overline{x_l} = \max(X) - x_i \tag{6}$$

$$\overline{x_l} = 1 - \frac{|x_i - x_{best}|}{\max\left(|X - x_{best}|\right)} \tag{7}$$

$$\bar{x}_l = \begin{cases} 1 - \frac{a - x_i}{M}, x_i > a \\ 1, \quad a < x_i < b \\ 1 - \frac{x_i - b}{M}, \quad x_i > b \end{cases} \tag{8}$$

It is noted that (5), (6), and (7) are for benefit index, cost index, and intermediate index respectively. (8) is for the calculation regarding interval index where $\mathbf{M} = \max\{\mathbf{a} - \min(\mathbf{X}), \max(\mathbf{X}) - \mathbf{b}\}$ and $\mathbf{a}, \mathbf{b}$ are the upper and lower boundaries of the interval.

Generally, the standardization and grading of data is done as

$$z_i = \frac{x_i}{\sqrt{\sum_{i=1}^{n} x_i^2}} \tag{9}$$

$$C = \frac{D^-}{D^+ + D^-} \tag{10}$$

The standardized element is derived as $\mathbf{z_i}$. In terms of grading, $\mathbf{C}$ represents the final grade. $\mathbf{D^+}$ and $\mathbf{D^-}$ represent the distances to the best value and the worst.

However, a proper way to assigning weights to each of the criteria becomes necessary as the scales of indexes are different. As discussed in section II, this is where Entropy-weighing method (EWM) can come to help.

$$e = -\frac{1}{\ln(n)} \times \sum_{i=1}^{n} p_i \times \ln(p_i) \tag{11}$$

where $\mathbf{p_i}$ is the selected value divided by the sum of the values in series, and $\mathbf{n}$ is the number of values.

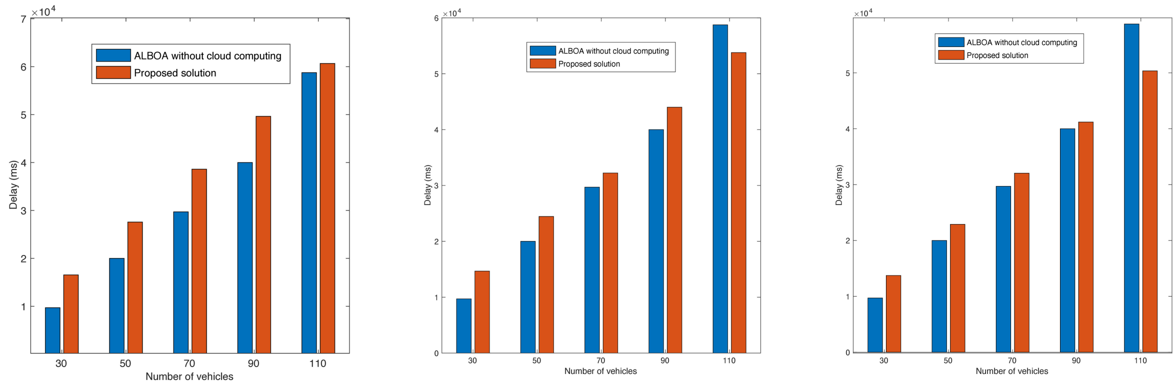

Fig. 4. Simulation results

Number of Vehicles (N)	30-110
Channel Bandwidth (W)	20 MHz
Gain (G)	1
Noise power	-100 dBm
Transmit power	100 mW
Data size	1000 KB
CPU frequency (vehicles)	1-2 GHz
CPU frequency (MEC servers)	4-8 GHz

TABLE II
SIMULATION PARAMETERS

V. Performance Analysis

To finally validate our algorithm from the distributed perspective, the parameters for the realistic simulation are provided in Table II in a manner similar to the validation of An Approximate Load Balancing Task Offloading Algorithm (ALBOA) in [1].

A. Simulation Setup

All key parameters for the simulation are given in Table II. Since we define the SNR is uniformly 20dB on the road, PER is calculated to be a fixed value of 0.029851 according to our system model. Thus, we mostly just consider CPU availability and transmission delay for our quick simulation.

In addition, several assumptions are made. The link between the RSU and the connected MEC server is seen infinitely fast. The cloud computing component of ALBOA is not taken into consideration since we want the comparison to be reasonably fair. Also the threshold of the maximum permissible delay is not set.

B. Results

By running multiple iterations using different levels of CPU frequencies, the results are clearly indicated in Fig. 4 where they are compared to the method of ALBOA without cloud computing. High performance vehicular and server CPUs significantly reduce the total delay as expected. With the number of vehicles ranging from 30 to 110, in most cases, the total delay of proposed solution is really close to what we can get out of ALBOA, which qualifies the former to be the complementary approach.

C. Future Work

1) Other Criteria

As indicated in [14], more criteria can be taken into consideration when carrying out TOPSIS, such as computational complexity of the task, and priority of the task. The application of EWM remains the same as long as the delay of the chosen alternative meets the maximum permissible delay requirement.

2) Multihop Data System

It is obvious that a multi-hop system will introduce more communications paths from V2V connections. Thus, optimizations can undeniably be made to our current proposed solution. However, there are some major obstacles as mentioned in section II which add to the complexity of the whole problem.

VI. Conclusion

In conclusion, we firstly studied the pros and cons of many edge computing schemes for vehicular networks. Then we looked at the distributed style of approach in great details. Related work was evaluated from the perspectives of both communication models and offloading tactics, after which our own method of combining TOPSIS and EWM was introduced and validated by MATLAB simulation. Further optimizations were briefly discussed in section V.

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REFERENCES

[1] J. Zhang, H. Guo, J. Liu, and Y. Zhang, "Task Offloading in Vehicular Edge Computing Networks: A Load-Balancing Solution," *IEEE Transactions on Vehicular Technology,* vol. 69, no. 2, pp. 2092–2104, 2020.

[2] S. Khanvilkar et al, "Multimedia Networks and Communication," *The Electrical Engineering Handbook, Academic Press,* 2005.

[3] F. A. Teixeira et al, "Vehicular networks using the IEEE 802.11p standard: An experimental analysis," *Vehicular Communications,* vol. 1, (2), pp. 91-96, 2014.

[4] Ahmad Baheej Al-Khalil, B. Ahmad , Al-Sherbaz Ali, Turner Scott, "Enhancing the Physical Layer in V2V Communication Using OFDM – MIMO Techniques".

[5] H. Jati and D. D. Dominic, "A New Approach of Indonesian University Webometrics Ranking Using Entropy and PROMETHEE II," *Procedia Computer Science,* vol. 124, pp. 444-451, 2017.

[6] L. Xiao, W. Zhuang, S. Zhou, and C. Chen, "Learning-based VANET Communication and Security Techniques," *Wireless Networks,* 2019.

[7] M. Wahiduzzaman, M. Sookhak, A. Gani, and R. Buyya, "A survey on vehicular cloud computing," *Journal of Network and Computer Applications,* vol. 40, pp. 325–344, Apr. 2014.

[8] H. Bolcskei and E. Zurich, "MIMO-OFDM WIRELESS SYSTEMS: BASICS, PERSPECTIVES, AND CHALLENGES," *IEEE,* 2006.

[9] H. Zhou, H. Wang, X. Chen, X. Li and S. Xu, "Data Offloading Techniques Through Vehicular Ad Hoc Networks: A Survey," *IEEE Access,* vol. 6, pp. 65250-65259, 2018, DOI:10.1109/ACCESS.2018.2878552.

[10] S. Mansi, B. Gajana, "Path-loss Models Macro-cell Urban areas"

[11] S. Dietzel et al, "Graph-Based Metrics for Insider Attack Detection in VANET Multihop Data Dissemination Protocols," *IEEE Transactions on Vehicular Technology,* vol. 62, (4), pp. 1505-1518, 2013.

[12] J. Yin et al, "Performance evaluation of safety applications over DSRC vehicular ad hoc networks," 2004, DOI: 10.1145/1023875.1023877.

[13] Zavadskas, Edmundas Kazimieras; Mardani, Abbas, "Development of TOPSIS Method to Solve Complicated Decision-Making Problems - An Overview on Developments from 2000 to 2015", *International Journal of Information Technology and Decision Making,* 2016 v.15 no. 3, pp. 645–682

[14] Z. W. Lamb and D. P. Agrawal, "Analysis of Mobile Edge Computing for Vehicular Networks," *Sensors (Basel, Switzerland),* vol. 19, (6), pp. 1303, 2019.