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Intelligent Traffic Engineering in Software-Defined Vehicular Networking Based on Multi-Path Routing

AHED ABUGABAH[1], AHMAD ALI ALZUBI[2], OSAMA ALFARRAJ[2], MOHAMMED AL-MAITAH[2], AND WALEED S. ALNUMAY[2]

[1]College of Technological Innovation, Zayed University, Dubai, United Arab Emirates
[2]Computer Science Department, King Saud University, Riyadh 11473, Saudi Arabia

Corresponding author: Ahmad Ali AlZubi (aalzubi@ksu.edu.sa)

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ABSTRACT This paper addresses traffic engineering (TE) issues in software-defined vehicular networking (SDVN). A brief analysis of the features of SDVN, which improves the efficiency of TE in SDVN, is presented. The feasibility of using multi-path routing with TE is substantiated. A procedure and an example of the formation of multiple routes based on a modified wave routing algorithm are given. Considering the features of the SDVN technology, a modified TE method is proposed, which reduces both the time complexity of forming multiple paths and the path reconfiguration time. The dynamic path reconfiguration algorithm is presented.

INDEX TERMS Intelligent transportation system (ITS), multi-path routing, software-defined network, traffic engineering (TE).

I. INTRODUCTION

The ever-growing number of vehicles on the roads makes the vehicular ad-hoc network (VANET) an important research topic in the field of automotive and wireless technologies. VANETs are considered as a subclass of classic mobile ad hoc networks (MANETs) [1]–[3]. Where vehicles play the role of mobile nodes of the VANETs. That have embedded advanced equipment on-board, traveling on restricted routes (i.e., roads, streets and lanes), and communicating with each other for information exchange using vehicle-to-vehicle (V2V) communication protocols, and also between vehicles and road-side units (RSU) installed on the side of the roads (i.e., wireless and cellular network infrastructure), to form a link between a Vehicle-to-Infrastructure (V2I). Compared to static or low-speed moving nodes in a traditional wireless network, vehicles move faster and more unpredictably, resulting in frequent changes to VANET network settings [4]–[7]. This places higher demands on routing protocols in VANET networks. Most well-known routing methods are not effective for VANET networks [8]–[11]. In this regard, the urgent task is to develop routing and traffic design methods that consider the features of VANET networks. One of the promising approaches to solving this problem is the integration of VANET networks with software-defined networks (SDNs) within the framework of software-defined vehicular networking (SDVN) [12]–[15]. Fig. 1 shows the structure of SDN, which consists of three levels architecture:

- Infrastructure level, providing a set of network devices (switches and data transmission channels);
- A management level, that includes a network operating system that provides applications with network services and a software interface for managing network itself and network devices;
- Network application layer for flexible and efficient network management.

A distinctive feature of SDN is that the organization and management of the network is carried out at the software level using virtual switches and a central SDN controller. Fig. (1).

This allows the organization of both centralized and decentralized control of network devices, expanding the functionality of traffic construction and load balancing in the network. With the centralized paths formation, the SDN controller has complete information about the structure of the network and

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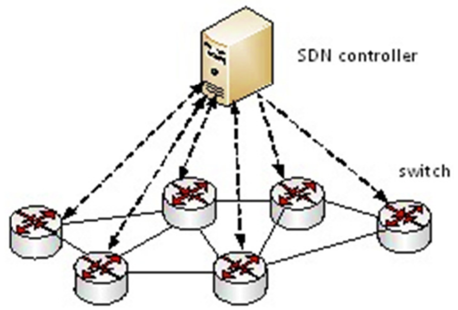

FIGURE 1. SDN structure.

its components, which allows them to be optimized according to specified metrics in the process of forming paths. The SDN controller updates the routing information of the SDN switches by updating their routing tables in order to select the optimal route in terms of minimizing power consumption and channel congestion [16]–[18].

The convergence of SDNs with VANET is seen as an important area that can solve most current VANET problems, such as dynamic path reconfiguration and traffic balancing [19]–[21].

Section 2 provides a brief overview of existing routing methods in VANET. Their advantages and disadvantages are determined. The feasibility of using multi-path routing methods in SDVN is substantiated.

Section 3 presents a modified method for constructing traffic in SDVN networks. The methods and algorithms for the formation and reconfiguration of routes are given.

In this work, we propose a method for constructing traffic, which, due to the peculiarities of SDN organization, and particularly, due to the presence of a central controller in the network, reduces the time it takes to form multiple routes and simplify the traffic construction procedure.

Moreover, we proposed a justified criterion for choosing a path from the set of available paths, which allows more uniform load of information transmission channels for specific parameters of quality service.

And also a modified algorithm for the formation of routing information is proposed, which allows simultaneous formation of the set of shortest paths between the start and end nodes, as well as between intermediate nodes of these paths. This algorithm is based on a modified channel state wave routing algorithm. The time complexity of this algorithm is less than that of the well-known multi-path routing algorithms. The presence of the shortest paths between the intermediate and final nodes eliminates the procedure for recalculating routes in the transmission process. This reduces the likelihood of transmission delays and congestion on transport paths.

II. AN OVERVIEW OF ROUTING METHODS IN TRANSPORT NETWORKS

In connection with the rapid growth of automotive communications, there are many studies, mainly routing methods, aimed at ensuring good performance and adaptability to changes in VANET network parameters. The dynamic nature of traffic necessitates the recalculation of metrics and rerouting. The quality of service on a VANET network primarily depends on routing protocols. A number of routing protocols and algorithms have been proposed for VANET [22]. The pros and cons of modern VANET routing protocols are discussed in [23]. There are different approaches for obtaining the optimal protocol in accordance with various parameters of quality of service (QoS) [24], such as security, low collision, and interference [25]. A review of routing protocols based on several metrics is presented in [26].

Currently, VANET networks most often use the ad hoc on-demand distance vector (AODV) [27]. Like all distance vector routing protocols, the AODV protocol is characterized by a relatively long rerouting time. This can lead to traffic congestion.

The use of multi-path routing allows you to quickly reroute [28] and increase network performance by 10 -15% by reducing the volume of service packets [29]. The use of multipath routing in VANET networks minimizes delays in data transmission due to channel failure, increases transmission reliability, and helps to balance the load [30], [31]. The main disadvantage of the well-known multi-path routing methods is their relatively great time complexity. This is due to the fact that the many paths are formed sequentially.

The wave routing algorithm proposed in [32] makes it possible to simultaneously form several paths from all intermediate nodes to the final node. This reduces the time complexity of the formation of multiple paths in comparison with the known methods of sequential formation of multiple paths. The wave algorithm refers to the algorithms according to the state of the channels and is most effective when there is a central network control device. These technologies include SDN technology [33]. Some research [34] presents studies on the integration of SDN and VANET. The advantages of SDVN networks are considered. The structure of the SDVN network is shown in Fig. 2.

The controller is the most important and fundamental part of the SDN architecture [36]–[38]. In SDN networks, control is carried out centrally in the controller [39], [40]. Centralized management using the SDN controller greatly simplifies network management by making efficient use of resources using global network information [33].

Compared to the traditional network, the main advantage of SDN networks is that traffic construction is carried out centrally in the SDN controller [41]. This allows for a more efficient process of traffic rerouting. Compared to the distributed methods of traffic construction and its balancing, the centralized method eliminates the need for the exchange of service information between network switches. This allows you to reduce the delay by about 5-10%, and the number of control packets in the network is reduced by 60-70% [42].

The centralized formation of routing information in the SDN controller also allows you to optimize the routing

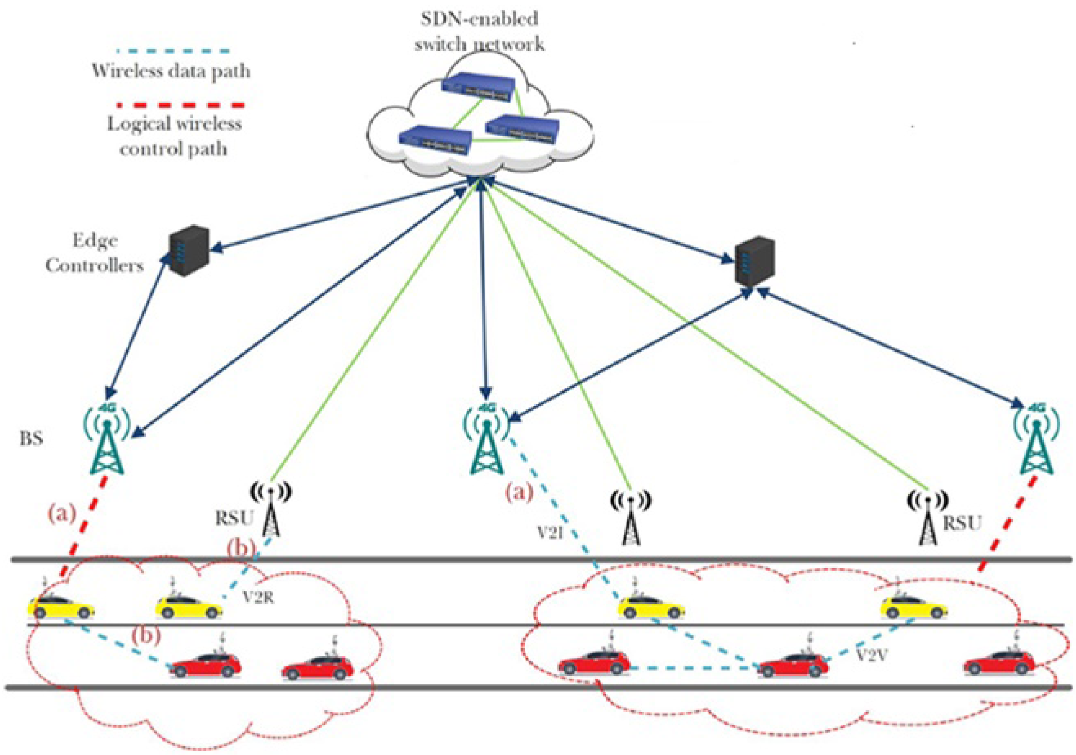

FIGURE 2. SDVN network structure [35].

procedure by eliminating the reformation of routes between intermediate sections of an already formed path [43].

III. DESIGNING TRAFFIC IN SOFTWARE-CONFIGURED TRANSPORT NETWORKS

A. TRAFFIC BALANCING

The main disadvantage of the known traffic control methods is that many large flows, called elephant flows, are redirected to the same path, which leads to load imbalance and loss of bandwidth [44]. In this regard, when designing traffic and balancing it, it is necessary to take into account the size and nature of a load of channels. This is especially true for transport networks in which a large load of channels leads to traffic jams.

At the same time, the speed of vehicles and, accordingly, the travel time, depends on the density of vehicles. Different densities along sections of the track also lead to a decrease in the average speed and throughput of the transport network. The safe distance between vehicles depends on the square of their speed. Accordingly, with an increase in the density of vehicles, the throughput of roads sharply decreases. With this in mind, the shortest path can be chosen as optimal only if it consists of sections of road with a density of vehicles of 25-80% [45]. In this regard, it is necessary to choose tracks with a minimum average load and a minimum mean square deviation of the track load from the average value. For this purpose, in this paper, it is proposed to use the criterion of uniformity of loading of path channels:

$$Di = (d_i^0 + \sum\nolimits_{j=1}^{n} \frac{l_j \left(d_j - d_i^0\right)^2}{L_i}), \tag{1}$$

where n is the number of plots (channels) for the way □i between the starting point of the path (vertex vs) final destination (vertex ve);

d_i^0 – average path channel load Pi;
d_j – *channel loading* $p_j \in P_i$;
Li – path length Pi;
lj – channel length p_j.

$$d_i^0 = \frac{1}{n} \sum\nolimits_{j=1}^{n} \frac{l_j \times d_j}{L}. \tag{2}$$

Value d_i^0 defines a less loaded path.

The standard deviation of the load path channels $(\left(\boldsymbol{d_j} - \boldsymbol{d_i^0}\right)^2)$ characterizes the degree of uniformity of load path channels.

The choice of the path, taking into account this criterion, contributes to the uniform loading of the channels of the transport network. Thus, the coefficient Di allows for the optimization of vehicle traffic.

IV. THE METHOD OF FORMING MULTI- PATHS

Routing information is generated in SDVN in a centralized way in the SDN controller. The transport network is represented as a loaded graph G(V,E,W), where

V = {vi | i = 1, 2, .., n}—many vertices of the graph; E = {ei, j | j = 1, 2, .., k—set of edges of the graph; W = {wj | j = 1, 2, .., m}—the set of weights of the edges of the graph. The vertices of the graph correspond to the intersections of roads. The edges of the graph correspond to sections of the path between adjacent intersections. The edge weight of the graph characterizes the metric of this section of the path. In this case, the weight wi,j ribs ei,j—this is the vehicle's transit time Li,j for the way Pz. Accordingly, the metric of the entire path is equal to the sum of the weights of all sections of this path.

For each road junction, a virtual switch is created in the SDN controller (Si). A virtual route table specifies destination (vd), adjacent vertex vj in direction to destination, metric (Mi), and loading path (Di). Knots vd and vi determine the path vector Rj (vd, vi) of vj в vd, in the direction vi.

If there are several disjoint paths in the routing table, the corresponding number of lines is formed. For example, if there are two shortest paths between the switches Sj and Sd, the routing table will be as follows:

TABLE 1. Switch route table *Si*.

Destination	Adjacent vertex	Path Metrics	Path Load
vd	vj	M1	D1
vd	vr	M2	D2

With a modified wave routing algorithm, the formation of routing information is carried out in the opposite direction from the destination (vertex vd) to the beginning of the path (vertex vs). The formation of routing information in the reverse order allows the simultaneous generation of many disjoint paths. At the same time, paths are formed between the final and all intermediate switches, which eliminates, if necessary, the re-formation of paths from intermediate switches to the final node.

Paths are formed sequentially between adjacent sets of vertices Vi + 1 н Vi. By an adjacent set of vertices, we mean sets of vertices Vi = {vi | i = 1, 2, .., n} н Vi + 1 = {vj | j = 1, 2, .., n} with a common set of edges Ec = {e, Where: v j ∈ Vi + 1 and v k ∈ Vi}. Path formation begins at the vertex of the graph. vd, appropriate destination Sd at i = 1. In this case, many V1 = {vd}, and many V2 = {vj} represent many vertices adjacent to a vertex vd. Then, for each switch Sj, corresponding vertex v j ∈ V2, adjacent to the vertex vd, is entered in this route table. On the second wave of routing, the formation of routes from the peaks continues v j ∈ Vi + 1 to the heights v k ∈ Vi. As a result, route tables of switches Sj for vertices are formed v j ∈ Vi + 1. The process continues until all paths between the peaks are formed vs and vd.

As an example, consider the formation of routing information when transmitting information from the switch S1 (vertex v1) to the switch S16 (vertex v16) transport network, the graph of which is presented in Fig. 2. As a metric, we will consider travel time.

At the initial stage of creating switch routing tables i = 1. Lots of V1 = {v16} and many adjacent peaks V2 = {v13, v14, v15}. The formation of the routing tables of the switches of the set V2.

Then, routing information is exchanged between switches at the same level. As a result, additional paths are added to the route tables.

Then, in a similar way, the formation of the route tables of the switches of the set V3 = {v9, v10, v11, v12}.

Algorithm 1 Generation of Routing Information in Network Switches

Notations:
vd : destination vertex
vs : vertex of the road
Vi + 1 = {vj}: multiple vertices adjacent to multiple vertices Vi = {vj}
Rj (vd, vi): vector path from the vertex vj to the vertex vd towards the vertex vi
Pj (vd, vi): the way from the vertex vj to the vertex vd
li,j : the link between the peaks vi and vj
Mi : path metric Pj
mi,j : path link metric
Di : uniform load criterion Pi.
TSj : switch routing table Sj

begin
i = 1;
Vi = {vd};
form Vi + 1 = {vj | i = 1, .., k};
For everyone vj ∈ Vi + 1 **identify** Rj (vd, vi);
Rj(vd, vi) → TSj /* **bring in** Rj (vd, vi) **in** TSj */;
Pj (vd, vi) = Pi (vd, vm + li, j;
Calculate Mi;
Mi → TSj /* **bring in** Mi в TSj */;;
Calculate Di;
Di → TSj /* **bring in** Di в TSj */;
if vs ∈ Vi + 1 **then go to** 15;
Vi := Vi + 1;
go to 4
End

TABLE 2. Switch route table S13.

Destination	Adjacent vertex	Path Metrics	Path Load
V16	V16	0.3	D1

TABLE 3. Switch route table S14.

Destination	Adjacent vertex	Path Metrics	Path Load
V16	V16	0.4	D1

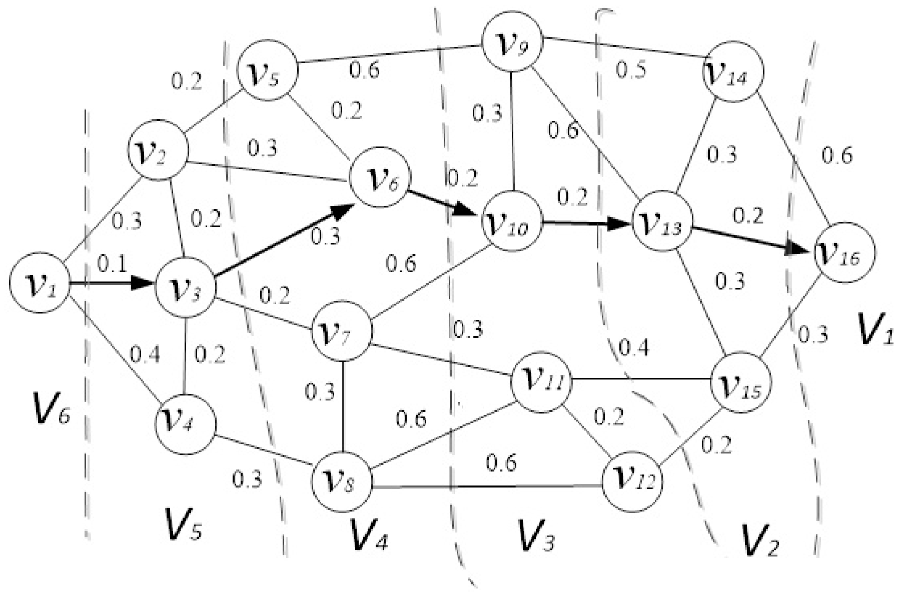

FIGURE 3. Transport network graph.

TABLE 4. Route table switch S15.

Destination	Adjacent vertex	Path Metrics	Path Load
V16	V16	0.3	D1

TABLE 5. Switch route table S13.

Destination	Adjacent vertex	Path Metrics	Path Load
V16	V16	0.2	D1
V16	V15	0.6	D2
V16	V14	0.9	D3

TABLE 6. Switch route table S14.

Destination	Adjacent vertex	Path Metrics	Path Load
V16	V16	0.6	D1
V16	V13	0.5	D2

TABLE 7. Switch route table S15.

Destination	Adjacent vertex	Path Metrics	Path Load
V16	V16	0.3	D1
V16	V13	0.6	D2

Then, in a similar way, the formation of the route tables of the switches of the set V4 = {v5, v6, v7, v8}.

Then, in a similar way, the formation of the route tables of the switches of the set V4 = {v2, v3, v4, v8}.

TABLE 8. Switch route table S9.

Destination	Adjacent vertex	Path Metrics	Path Load
V16	V13	0.8	D1
V16	V14	1.0	D1
V16	V10	0.7	D1

TABLE 9. Switch route table S10.

Destination	Adjacent vertex	Path Metrics	Path Load
V16	V13	0.4	D1
V16	V9	1.1	D1

TABLE 10. Switch route table S11.

Destination	Adjacent vertex	Path Metrics	Path Load
V16	V15	0.8	D1
V16	V12	0.7	D1

TABLE 11. Switch route table S12.

Destination	Adjacent vertex	Path Metrics	Path Load
V16	V15	0.5	D1
V16	V11	1.0	D1

Then, in the same way, the switch routing table is formed S1.

A. TRAFFIC CONSTRUCTION

Based on the switch routing table S1, the path is formed in the forward direction from the vertex V1 to the vertex V16.

TABLE 12. Switch route table S5.

Destination	Adjacent vertex	Path Metrics	Path Load
V16	V9	1. 2	D1
V16	V6	0.8	D2

TABLE 13. Switch route table S6.

Destination	Adjacent vertex	Path Metrics	Path Load
V16	V5	1.4	D1
V16	V10	0.6	D2

TABLE 14. Switch route table S7.

Destination	Adjacent vertex	Path Metrics	Path Load
V16	V10	1.0	D1
V16	V11	1.0	D1
V16	V8	1.4	D1

TABLE 15. Switch route table S8.

Destination	Adjacent vertex	Path Metrics	Path Load
V16	V12	1.1	D1
V16	V11	1.4	D1
V16	V7	1.3	D1

TABLE 16. Switch route table S2.

Destination	Adjacent vertex	Path Metrics	Path Load
V16	V15	0.8	D1
V16	V12	0.7	D1

TABLE 17. Switch route table S3.

Destination	Adjacent vertex	Path Metrics	Path Load
V16	V7	1.1	D1
V16	V6	0.9	D1
V16	V4	1.6	D1
V16	V2	1.1	D1

TABLE 18. Switch route table S4.

Destination	Adjacent vertex	Path Metrics	Path Load
V16	V8	1.4	D1
V16	V11	1.0	D1

In each intermediate node, an available transmission direction with a minimum metric is selected.

In this case, in the first step, based on the route table of the switch S1, the direction of transmission is selected towards

TABLE 19. Switch route table S1.

Destination	Adjacent vertex	Path Metrics	Path Load
V16	V2	1. 2	D1
V16	V3	1.0	D1
V16	V4	1.4	D1

Algorithm 2 Shortest Path Formation

begin ;
i = 1;
if {Pj (vd, vi)} $\neq \emptyset$ **go to** 5;
Formed {Rj (vd, vi)}q;
Select Rj (vd, vi) /∗ **vector path direction with minimal metric** */;
Pj (vd, vi) = ls, j;
if MPj (vd, vi) **constant go to** 9;
for j := 1 **step** 1 **to** k **do**
  begin
    switch table update Sj
  end;
Choose Rj (vd, vk) /* **track direction with minimal metrics** */;
Pj (vd, vk) = Pj (vd, vi) + li, k; /* **extension of the path towards the vertex** vd */;
if i = n **go to** 12 **else**
  begin
  i = i + 1;
  go to 7;
  end;
end.

the node V3. As a result, a path is formed: P1 (V1, V16) with minimum metric M1 = 1. This path goes through the following peaks: {V1, V3, V6, V10, V13, V16}.

The presence of alternative transmission directions in all intermediate nodes allows the creation of many disjoint paths between the starting and ending nodes of the network with relatively minimal metrics. The maximum number of disjoint paths is equal to the minimum degree of the start or end vertex of the path graph. For transport networks, this value is usually equal to three. In this case, in addition to the path P1 (V1, V16) there are no intersecting paths P2 (V1, V16) and P3 (V1, V16).

Way P2 (V1, V16) runs through the peaks: {V1, V2, V5, V9, V14, V16}. The metric of a given path M2 = 2.2. Way P3 (V1, V16) runs through the peaks: {V1, V4, V8, V12, V15, V16}. The metric of a given path M2 = 2.2.

B. DYNAMIC PATH RECONFIGURATION

The centralized method of generating routing information allows us to exclude the procedure for creating new paths when changing the network topology or overloading its channels.

TABLE 20. Switch route table S13.

Destination	Adjacent vertex	Path Metrics	Path Load
V16	V16	0.7	D1
V16	V15	0.6	D2
V16	V14	0.9	D3

TABLE 21. Switch route table S10.

Destination	Adjacent vertex	Path Metrics	Path Load
V16	V13	0.8	D1
V16	V9	1.1	D1

TABLE 22. Switch route table S6.

Destination	Adjacent vertex	Path Metrics	Path Load
V16	V5	1.4	D1
V16	V10	1.0	D2

TABLE 23. Switch route table S3.

Destination	Adjacent vertex	Path Metrics	Path Load
V16	V7	1.1	D1
V16	V6	1.4	D1
V16	V4	1.6	D1
V16	V2	1.5	D1

In this case, only the metrics of the paths through which the path with the changed metric passes are recalculated. This procedure is performed centrally in the SDN controller. This allows one to quickly and dynamically update the routing tables of switches and, without additional delays, to reconfigure the paths in the process of transmitting the information.

Changing the metrics of individual channels can lead to an increase in the overall path metric. Moreover, the farther the vehicle is from the critical section of the track, the more options are available to bypass the congested section of the network. In this case, the metric may increase slightly. For example, when increasing the metric of a path section l13,15 to 0.7, the corresponding correction of the switching tables of many vertices will be made {V1, V3, V6, V10, V13,} the way P1 (V1, V16).

In this case, the shortest path from the vertex V13 to the vertex V16 will go through the vertex V15. When the vehicle is at the vertex V13 peak transmission delay, V15 will be on 0.4 more than before increasing the metric of the track l13,16. The path metric for vertices will increase accordingly: V6 and V10.

Switch Routing Tables S3 and S1 will also be adjusted.

Resulting from the vertex V3, a path through the peaks will be formed {V7, V11, V15, V16}. Compared with the initial metric it will be only 0.1 more.

V. CONCLUSION

This article proposes a combined method of traffic construction in a transport network based on SDN. Routing information is generated centrally in the SDN controller based on a modified channel state wave routing algorithm. Centralized updating of routing information in the SDN controller, in comparison with distributed routing algorithms, can significantly reduce the time needed to update routing information and simplify the process of traffic construction. Despite the fact that VANET routing pays more attention to the wireless community, there are still many problems that have not yet been thoroughly investigated. As a further direction in the development of VANET routing protocols, it is necessary to predict the loading of a transport network channel based on artificial intelligence systems [46].

REFERENCES

[1] X. Ge, Z. Li, and S. Li, "5G software defined vehicular networks," *IEEE Commun. Mag.*, vol. 55, no. 7, pp. 87–93, 2017.
[2] O. AlFarraj, A. Tolba, S. Alkhalaf, and A. AlZubi, "Neighbor predictive adaptive handoff algorithm for improving mobility management in VANETs," *Comput. Netw.*, vol. 151, pp. 224–231, Mar. 2019.
[3] Z. Ning, Y. Li, P. Dong, X. Wang, M. S. Obaidat, X. Hu, L. Guo, Y. Guo, J. Huang, and B. Hu, "When deep reinforcement learning meets 5G-enabled vehicular networks: A distributed offloading framework for traffic big data," *IEEE Trans. Ind. Informat.*, vol. 16, no. 2, pp. 1352–1361, Feb. 2020, doi: 10.1109/TII.2019.2937079.
[4] C. Chen, Y. Ding, X. Xie, S. Zhang, Z. Wang, and L. Feng, "TrajCompressor: An online Map-matching-based trajectory compression framework leveraging vehicle heading direction and change," *IEEE Trans. Intell. Transp. Syst.*, early access, Apr. 23, 2019, doi: 10.1109/TITS.2019.2910591.
[5] A. Tolba and A. Altameem, "A three-tier architecture for securing IoV communications using vehicular dependencies," *IEEE Access*, vol. 7, pp. 61331–61341, 2019.
[6] J. Wang, X. Kong, A. Rahim, F. Xia, A. Tolba, and Z. Al-Makhadmeh, "IS2Fun: Identification of subway station functions using massive urban data," *IEEE Access*, vol. 5, pp. 27103–27113, 2017.
[7] Z. Ning, Y. Feng, M. Collotta, X. Kong, X. Wang, L. Guo, X. Hu, and B. Hu, "Deep learning in edge of vehicles: Exploring trirelationship for data transmission," *IEEE Trans. Ind. Informat.*, vol. 15, no. 10, pp. 5737–5746, Oct. 2019.
[8] C. Chen, D. Zhang, X. Ma, B. Guo, L. Wang, Y. Wang, and E. Sha, "Crowddeliver: Planning city-wide package delivery paths leveraging the crowd of taxis," *IEEE Trans. Intell. Transp. Syst.*, vol. 18, no. 6, pp. 1478–1496, Jun. 2017.
[9] B. Jedari, F. Xia, H. Chen, S. K. Das, A. Tolba, and Z. AL-Makhadmeh, "A social-based watchdog system to detect selfish nodes in opportunistic mobile networks," *Future Gener. Comput. Syst.*, vol. 92, pp. 777–788, Mar. 2019.
[10] Z. Ning, P. Dong, X. Wang, J. Rodrigues, and F. Xia, "Deep reinforcement learning for vehicular edge computing: An intelligent offloading system," *ACM Trans. Intell. Syst. Technol.*, vol. 10, no. 6, p. 60, 2019.
[11] C. Chen, S. Jiao, S. Zhang, W. Liu, L. Feng, and Y. Wang, "TripImputor: Real-time imputing taxi trip purpose leveraging multi-sourced urban data," *IEEE Trans. Intell. Transp. Syst.*, vol. 19, no. 10, pp. 3292–3304, Oct. 2018.
[12] A. Rahim, K. Ma, W. Zhao, A. Tolba, Z. Al-Makhadmeh, and F. Xia, "Cooperative data forwarding based on crowdsourcing in vehicular social networks," *Pervas. Mobile Comput.*, vol. 51, pp. 43–55, Dec. 2018.
[13] Z. Ning, J. Huang, X. Wang, J. J. P. C. Rodrigues, and L. Guo, "Mobile edge computing-enabled Internet of vehicles: Toward energy-efficient scheduling," *IEEE Netw.*, vol. 33, no. 5, pp. 198–205, Sep. 2019.

[14] J. Li, Z. Ning, B. Jedari, F. Xia, I. Lee, and A. Tolba, ''Geo-social distance-based data dissemination for socially aware networking,'' *IEEE Access*, vol. 4, pp. 1444–1453, 2016.

[15] A. Tolba, ''Content accessibility preference approach for improving service optimality in Internet of vehicles,'' *Comput. Netw.*, vol. 152, pp. 78–86, Apr. 2019.

[16] X. Wang, Z. Ning, X. Hu, L. Wang, L. Guo, B. Hu, and X. Wu, ''Future communications and energy management in the Internet of vehicles: Toward intelligent energy-harvesting,'' *IEEE Wireless Commun.*, vol. 26, no. 6, pp. 87–93, Dec. 2019.

[17] A. Tolba and E. Elashkar, ''Soft computing approaches based bookmark selection and clustering techniques for social tagging systems,'' *Cluster Comput.*, vol. 22, no. 2, pp. 3183–3189, Mar. 2019.

[18] H. Liu, X. Bai, Z. Yang, A. Tolba, and F. Xia, ''Trust-aware recommendation for improving aggregate diversity,'' *New Rev. Hypermedia Multimedia*, vol. 21, nos. 3–4, pp. 242–258, Oct. 2015.

[19] O. AlFarraj, A. AlZubi, and A. Tolba, ''Trust-based neighbor selection using activation function for secure routing in wireless sensor networks,'' *J. Ambient Intell. Hum. Comput.*, vol. 2018, Jun. 2018, doi: 10.1007/12652-018-0885-1.

[20] Z. Al-Makhadmeh and A. Tolba, ''An intelligence-based recurrent learning scheme for optimal channel allocation and selection in device-to-device communications,'' *Circuits, Syst., Signal Process.*, vol. 39, no. 2, pp. 997–1018, Feb. 2020.

[21] X. Bai, I. N. Z. Lee, A. Tolba, and F. Xia, ''The role of positive and negative citations in scientific evaluation,'' *IEEE Access*, vol. 5, pp. 17607–17617, 2017.

[22] J. Kakarla, S. Siva Sathya, B. Govinda Laxmi, and R. Babu B, ''A survey on routing protocols and its issues in VANET,'' *Int. J. Comput. Appl.*, vol. 28, no. 4, pp. 38–44, 2011.

[23] I. Wahid, A. A. Ikram, M. Ahmad, S. Ali, and A. Ali, ''State of the art routing protocols in VANETs: A review,'' *Procedia Comput. Sci.*, vol. 130, pp. 689–694, 2018, doi: 10.1016/j.procs.2018.04.121.

[24] A. M. Mezher and M. A. Igartua, ''Multimedia multimetric map-aware routing protocol to send video-reporting messages over VANETs in smart cities,'' *IEEE Trans. Veh. Technol.*, vol. 66, no. 12, pp. 10611–10625, Dec. 2017, doi: 10.1109/TVT.2017.2715719.

[25] C. Sottile, A. F. Santamaria, and S. Marano, ''A reactive routing protocol for VANETs based on composite metric concept,'' in *Proc. Int. Symp. Perform. Eval. Comput. Telecommun. Syst. (SPECTS)*, Monterey, CA, USA, Jul. 2014, pp. 642–646, doi: 10.1109/SPECTS.2014.6880005.

[26] C. Tripp-Barba, A. Zaldívar-Colado, L. Urquiza-Aguiar, and J. A. Aguilar-Calderón, ''Survey on routing protocols for vehicular ad hoc networks based on multimetrics,'' *Electronics*, vol. 8, no. 10, p. 1177, Oct. 2019, doi: 10.3390/electronics8101177.

[27] A. Yasser, M. Zorkany, and N. Abdel Kader, ''VANET routing protocol for V2 V implementation: A suitable solution for developing countries,'' *Cogent Eng.*, vol. 4, no. 1, Aug. 2017, doi: 10.1080/23311916.2017.1362802.

[28] M. Moza and S. Kumar, ''Analyzing multiple routing configuration,'' *Int. J. Comput. Netw. Inf. Secur.*, vol. 8, no. 5, pp. 48–54, May 2016, doi: 10.5815/ijcnis.2016.05.07.

[29] K. Rajasekaran and K. Balasubramanian, ''Energy conscious based multipath routing algorithm in WSN,'' *Int. J. Comput. Netw. Inf. Secur.*, vol. 8, no. 1, pp. 27–34, Jan. 2016, doi: 10.5815/ijcnis.2016.01.04.

[30] A. D. Devangavi and R. Gupta, ''Adaptive congestion controlled multipath routing in VANET: A multiagent based approach,'' *Int. J. Agent Technol. Syst.*, vol. 9, no. 1, pp. 43–68, Jan. 2017, doi: 10.4018/IJATS.2017010103.

[31] M. Bani Younes and A. Boukerche, ''Intelligent traffic light controlling algorithms using vehicular networks,'' *IEEE Trans. Veh. Technol.*, vol. 65, no. 8, pp. 5887–5899, Aug. 2016.

[32] Y. Kulakov and A. Kogan, ''The method of plurality generation of disjoint paths using horizontal exclusive scheduling,'' *Adv. Sci. J.*, vol. 2014, no. 9, pp. 16–18, Jul. 2014, doi: 10.15550/asj.2014.09.016.

[33] W. Xia, Y. Wen, C. H. Foh, D. Niyato, and H. Xie, ''A survey on software-defined networking,'' *IEEE Commun. Surveys Tuts.*, vol. 17, no. 1, pp. 27–51, 4th Quart., 2015. [Online]. Available: https://www.ntu.edu.sg/home/ygwen/Paper/XWF-CST-15.pdf

[34] L. Nkenyereye, L. Nkenyereye, S. M. R. Islam, Y.-H. Choi, M. Bilal, and J.-W. Jang, ''Software-defined network-based vehicular networks: A position paper on their modeling and implementation,'' *Sensors*, vol. 19, no. 17, p. 3788, Aug. 2019, doi: 10.3390/s19173788.

[35] M. T. Abbas, A. Muhammad, and W. C. Song, ''SD-IoV: SDN enabled routing for Internet of vehicles in road-aware approach,'' *J. Ambient Intell. Hum. Comput.*, vol. 10, no. 5, pp. 1265–1280, May 2019, doi: 10.1007/s12652-019-01319-w.

[36] M. Z. Abdullah, I. Al-Mustansiriyah, N. A. Al-Awad, and F. W. Hussein, ''Evaluating and comparing the performance of using multiple controllers in software defined networks,'' *Int. J. Modern Edu. Comput. Sci.*, vol. 11, no. 8, pp. 27–34, Aug. 2019, doi: 10.5815/ijmecs.2019.08.03.

[37] A. K. Singh, N. Kumar, and S. Srivastava, ''PSO and TLBO based reliable placement of controllers in SDN,'' *Int. J. Comput. Netw. Inf. Secur.*, vol. 11, no. 2, pp. 36–42, Feb. 2019, doi: 10.5815/ijcnis.2019.02.05.

[38] E. Gamess, D. Tovar, and A. Cavadia, ''Design and implementation of a benchmarking tool for openflow controllers,'' *Int. J. Inf. Technol. Comput. Sci.*, vol. 10, no. 11, pp. 1–13, 2018, doi: 10.5815/ijitcs.2018.11.01

[39] B. Isong, S. A. Mafikeng, T. Kgogo, and F. Lugayizi, ''Trust establishment in SDN: Controller and applications,'' *Int. J. Comput. Netw. Inf. Secur.*, vol. 9, no. 7, pp. 20–28, Jul. 2017, doi: 10.5815/ijcnis.2017.07.03.

[40] K. S. Sahoo, S. K. Mishra, S. Sahoo, and B. Sahoo, ''Software defined network: The next generation Internet technology,'' *Int. J. Wireless Microw. Technol.*, vol. 7, no. 2, pp. 13–24, 2017, doi: 10.5815/ijwmt.2017.02.02.

[41] A. M. Yasir, H. A. Chasib, and Q. M. Zainab, ''Analyzing methods and opportunities in software-defined (SDN) networks for data traffic optimizations,'' *Int. J. Recent Innov. Trends Comput. Commun.*, vol. 6, no. 1, pp. 75–82, 2018. [Online]. Available: http://www.ijritcc.org

[42] P. Kumar, R. Dutta, R. Dagdi, K. Sooda, and A. Naik, ''A programmable and managed software defined network,'' *Int. J. Comput. Netw. Inf. Secur.*, vol. 10, no. 12, p. 11, 2017.

[43] Y. Kulakov, A. Kohan, and S. Kopychko, ''Traffic orchestration in data center network based on software-defined networking technology,'' in *Proc. Int. Conf. Comput. Sci., Eng. Educ. Appl. (ICCSEEA)*, 2019, pp. 228–237.

[44] Z. Shu, J. Wan, J. Lin, S. Wang, D. Li, S. Rho, and C. Yang, ''Traffic engineering in software-defined networking: Measurement and management,'' *IEEE Access*, vol. 4, pp. 3246–3256, 2016.

[45] M. T. Abbas and W. C. Song, ''A path analysis of two-level hierarchical road. Aware routing in VANETs,'' in *Proc. 9th Int. Conf. Ubiquitous Future Netw. (ICUFN)*, Jul. 2017, pp. 940–945.

[46] W. Tong, A. Hussain, W. X. Bo, and S. Maharjan, ''Artificial intelligence for Vehicle-to-everything: A survey,'' *IEEE Access*, vol. 7, pp. 10823–10843, 2019.

AHED ABUGABAH received the degrees in information systems in Australia. He worked in the airline industry in the aircraft engineering and supply chain management. Before joining Zayed University in 2016, he was involved in administration as an Associate Dean and a University Council Member at American University, United Arab Emirates. He is currently an Assistant Professor with the College of Technological Innovation, Zayed University. His research interests include information systems, enterprise applications and development, healthcare information systems, and RFID in healthcare.

AHMAD ALI ALZUBI received the Ph.D. degree in computer networks engineering from the National Technical University of Ukraine (NTUU), in 1999. He is currently a Full Professor with King Saud University (KSU). His current research interests include computer networks, cloud computing, big data, and data extracting. He is a Certified Member of the Board of Assessors of Quality Management System at King Saud University (BOA-QMS). He also served for three years as a Consultant and a Member of the Saudi National Team for Measuring eGovernment in Saudi Arabia.

OSAMA ALFARRAJ received the master's and Ph.D. degrees in information and communication technology from Griffith University, in 2008 and 2013, respectively. His Ph.D. dissertation investigates the factors influencing the development of eGovernment in Saudi Arabia and it is a Qualitative Investigation of the Developers Perspectives. He is a Certified Member of the Board of Assessors of Quality Management System at King Saud University (BOA-QMS), Riyadh, Saudi Arabia. He is currently an Associate Professor of Information and Communication Technology (ICT) at King Saud University. He is a Faculty Member of the Computer Science Department, Community College, King Saud University.

MOHAMMED AL-MAITAH received the B.S. and M.S. degrees in computers, complexes, systems and networks from Badolia University, in 1995, and the Ph.D. degree in computer engineering from Vinnitsa State Technical University, in 1999. He is currently a Full Professor with the Department of Computer Science, Community College, King Saud University (KSU). His current research interests include neuro computing, control systems, and algorithms. In addition to teaching, he is a member of the KSU Assessors Board (Assessor for the KSU-Quality Management System).

WALEED S. ALNUMAY received the bachelor's degree in computer science from King Saud University, Riyadh, Saudi Arabia, in 1993, the master's degree in computer science from the University of Atlanta, Atlanta, GA, USA, in 1996, and the Ph.D. degree in computer science from Oklahoma University, Norman, OK, USA, in 2004. He is currently working as an Assistant Professor with the Mobile Networking in Computer Science Department, King Saud University. He has published research articles in reputed international conferences and journals. His main research interests include computer networks and distributed computing that includes but not limited to mobile ad-hoc and sensor networks, information-centric networking, and software-defined networking.