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A reliable position-based routing scheme for controlling excessive data dissemination in vehicular ad-hoc networks

Zainab H. Ali [a,*], Noha A. Sakr [b], Nora El-Rashidy [c], Hesham A. Ali [d]

[a] Department of Embedded Network Systems and Technology, Faculty of Artificial Intelligence, Kafrelsheikh University, El-Geish st, Kafrelsheikh 33516, Egypt
[b] Department of Computer Engineering and Control Systems, Faculty of Engineering, Mansoura University, Eldakahlia, Mansoura 33511, Egypt
[c] Department of Machine Learning and Information Retrieval, Faculty of Artificial Intelligence, Kafrelsheikh University, El-Geish st, Kafrelsheikh 33516, Egypt
[d] Department of Computer Engineering and Control Systems, Faculty of Engineering, Mansoura University, Egypt- Faculty Artificial Intelligence, Delta University for Science and Technology, Gamasa 35712, Egypt

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ABSTRACT

In the past two decades, the automotive industry has undergone tremendous changes, as this field has become one of the fastest developing and growing fields, especially with the progress of global digitization and massive research related to networks. So, it comes as no surprise that self-driving vehicles are ubiquitous mainly relying on Vehicular ad-hoc networks (VANETs). This transformation ensures improved road navigation and traffic congestion avoidance by relying on Rapid Data Deployment (DD). On the other hand, although DD achieves high connection reliability, it may affect network bandwidth and performance. In addition, excessive DD causes frequent link outages resulting in reduced data delivery, massive packet loss, and premature end of network life. This paper presents an integrated architecture proposal for a vehicle dynamic assistance architecture, based on reliable methods to ensure steering accuracy while minimizing the energy expended for controlling the DD rate via VANETs. The proposed architecture integrates between Software-Defined Networks (SDN) and fog computing based on dealing with the mobility factors that exploit vehicle communication behaviors. Such integration will aid in improving network performance in terms of packet delivery and DD. The study also discusses how to take into consideration the Euclidean distance, geographical routing information, residual power ratio, and latency time to maximize network stability and avoid possible link disruption. The simulation results prove that there is a 62% to 70% enhancement of the whole power consumption and network throughput, depending on the implementation of the proposed position-based routing approach. Interestingly, the proposed routing protocol is a dual-phase routing protocol with a 90% of SDN data packet delivery ratio and an 82% of SDN data loss reduction. So, when the SDN fails to deliver packets, the proposed position-based routing handles them as a parallel mechanism of SDN.

1. Introduction

Smart Transportation (ST) is a promising technology, in developing countries with shallow road capacity, poor economic resources, imperfect motorization, and insufficient infrastructure. ST allows vehicles to increase dynamic real-time interaction through the propagation of road information among motorcars to assist drivers and enhance the quality of traffic journey [1]. Vehicular Ad-Hoc Network (VANET) is a foundation of ST, it allows the spread of information about road safety among vehicles via emergency message transmission to aid drivers in taking early preventive measures during hazardous troubles to avert accidents and enhance road protection [2,3]. Although VANET offers many automotive assistance services to meet the demands of passengers and the constraints of Quality of Service (QoS), it may not be able to provide a comprehensive view of the nodes' behavior due to the fast-frequently fragmentation of its topology. Additionally, vehicles' lack of transmission dependability has a negative impact on the rate of network lifetime and overall performance [4,5].

Excessive data transmission across VANET to deliver effective communication causes notable deterioration in lifetime and network performance [6]. The nodes in the communication process are commonly establishing a uniform-path connection through the sender and the receiver which causes the transmission journey to be difficult in VANETS because of the high dynamic moving of vehicles in VANET

* Corresponding author.
E-mail address: zainabhassan@ai.kfs.edu.eg (Z.H. Ali).

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therefore the determination of the optimal next-hop is not guaranteed for all situations [7,8]. A topology-based routing has generally innovated to supply the best route for data gathering taking into consideration power conservation [2,9,10]. Recently, research on routing can be classified into two categories. First, topology-based routing that works based on the information collected about link status and the packet forwarding method such as Source-Tree Adaptive Routing (STAR) protocol, Optimized Link-State Routing (OLSR), and Ad-hoc vehicle On-demand Distance Vector routing protocol (AODV). Second, position-based routing or geographical routing such as Fisheye State Routing (FSR) and the Temporally Ordered Routing Algorithm (TORA) which are concerned with geographical metrics like vehicle position and neighbor direction with no demand to carry on a static route or locating the best path between sender and receiver. It is considered to be suitable schema for obtaining an effective path based on the physical location information in realistic networks [11].

In VANET, the optimal route selection has typically acquired by the node broadcasting its location information with other neighbors in the network, which leads to easy routing management [12,13]. However, several challenges have been faced with this type of routing technique such as the optimum detection for the reliability of the route between sender and receiver which forces massive amounts of data to be broadcasted. This raises not only communication congestion probability but also low data packet delivery and high-power consumption [14]. Another important issue is continuous breaks in link connections due to the loss of neighbors causes poor communication quality and high delay time [15,16].

For reliable communication with sufficient network bandwidth, Software-Defined-Network (SDN) has been currently employed in realistic networks to offer accurate information about the traffic status and neighboring nodes across the networks that relying mainly on the free exchange of data among the VANET items. According to [6,17,18], the data transmission process consumes more than two-thirds of the total energy of sensor batteries; this affects not only network lifetime but also packet delivery and delay time. One solution is alleviating the influence of high data transmission to select the optimal next-hop. Hence, delivering complete network overviews has become necessary. An SDN is. It has successfully forged cooperation between various data management units to furnish a local network overview [19,20].

By reducing processing power and data transfer volume, an SDN enhances the performance of the VANET as a whole [21] with permitting the network operations to decouple data exchanges generated by the vehicular units. Such partition affects network performance and holds the process of the data transmission inline. By resource provisioning, expediting internal decision-making, and streamlining VANET governance procedures, an SDN supports the QoS requirements. The SDN-controller significantly supports OpenFlow by maintaining the flow tables that contain a list of flow entries throughout the VANET. In order to optimize the flow of traffic and provide a reliable method of tracing the present status of the VANET traffic, it also introduces a comprehensive view of status and topology [22].

Fog computing expands local cloud services at the edge of the end-user. It promotes realistic networks to extract sophisticated data locally without the demand to transmit this extraordinary data volume to the cloud server. This property not only reduces network bandwidth usage and power consumption but also boosts network lifetime and stability [23]. Moreover, fog computing accelerates location awareness, and rapid response to unpredictable traffic events [24].

In this study, a dynamic vehicular-assisted architecture allowing the cooperation of SDN and fog technology to improve VANET performance is introduced. The novelty of this architecture lies in its ability to provide a unique design with a comprehensive view of network traffic. This design helps to adjust the rate of DD caused by excessive data exchanges in the position-based routing technique. Moreover, the proposed architecture uses the mobility metrics such as the Euclidean distance, geographical routing information, residual power ratio, and latency to improve the performance of the position-based routing protocol in reducing rate of DD and obtain energy conservation. Moreover, the proposed routing protocol is a dual-phase routing protocol with a 90% of SDN data packet delivery ratio and an 82% of SDN data loss reduction. So, when the SDN fails to deliver packets, the proposed position-based routing handles them as a parallel mechanism of SDN. The paper contributions can be organized as follows:

i. Demonstrating a dynamic vehicular-assisted architecture based on SDN and fog computing to improve message reliability in VANET.
ii. Presenting seamless collaboration between the SDN and fog computing to provide a comprehensive view helps to reduce DD caused by exchanging data among vehicles to obtain the optimal next-hop.
iii. Introducing a new routing technique using mobility metrics such as the Euclidean distance, geographical routing information, delay time, and the ratio of residual power to enhance the position-based routing performance.
iv. Proposing a mathematical energy conservation approach to decrease the power consumption between vehicular items, thus increasing the network lifetime.
v. Presenting a mathematical model to maintain the quality of link via the Signal-to-Interference-Plus-Noise (SIN) and loss rate. Therefore, the network stability and data delivery are increased.
vi. The simulation results depict that there is a 62% to 70% enhancement of the overall power consumption and VANET throughput.

The rest of this paper is organized as follows: Section 2 reviews the up-to-date literature reviews. Section 3 introduces a dynamic vehicular-assisted architecture using SDN and fog computing. Section 4 demonstrates the new routing protocol called Preparing Position-based Routing and Energy Conservation Methodology (PRECM) via the mathematical model. Section 5 measures the complexity of PRECM in terms of time complexity, communication overhead, and space complexity. Section 6 estimates the stability process of the network lifetime. Section 7 discusses the performance evaluation results. Section 8 wraps up the paper with significant contribution points.

2. Literature review

The rate of DD adjustment techniques has been investigated widely by researchers in the academic area being effective ways to deploy and develop urban transportation systems. Collaboration between SDN and fog computing has been proved to be instrumental by different recent studies. Power consumption, network bandwidth, delay time, and communication reliability among other factors side of the vehicular systems have been enhanced due to that combination.

2.1. Fog computing in VANETs

To ensure reliable transmission, fog technology has been introduced to bring new opportunities to VANET. For instance, Jorge Pereira et al. [25] suggested a solid evidence system-based fog technology for integrating computing services and their applications in the field of intelligent mobility along with contemporary vehicle design. By preserving local data analytics at the user edge and redesigning both Roadside Units (RSUs) and On-Board Units (OBUs) to represent the nodes of the fog, this architecture prevents delay time. According to the trial findings, using fog technology to the field of intelligent mobility will enable faster acquisition of accurate information. In the architecture, improvements to location awareness, message delivery dependability, and response time were all taken into account. Yet, energy consumption and battery lifetime have not been taken into account in the proposed architecture. In their research, [26] worked on improving total energy usage and network connectivity by presenting a geo-distributed computing architecture using fog computing. Likewise, network bandwidth maintains by allowing the system to control the amount of data uploaded to the cloud server. However, the scalability of the network needs to be taken into account.

2.2. SDN in VANETs

On another hand, sharing information that preserves the overall network conditions is highly recommended to reinforce the collaboration among vehicular units and to handle the data transmission rates as well. That brought the researchers to install a configured control device such as an SDN located at the edge of the customers' network. Certainly, such an idea introduced local data processing and worked effectively against high usage of the network bandwidth. For example, various techniques for enhancing the performance of the drone are presented in [27]. The paper introduced a service aggregation technique that simplifies the amount of the transferred data through the bandwidth of the drone. Moreover, they introduced an approach for a normalized throughput of a network channel to control the interference ratio which implies the medium access control (MAC) layer overhead.

Moreover, Kumar et al. [28] built a smart framework called Software-Defined Drone Network (SDDN) for configuring UAV units that monitors road traffic by offering strategies that avoid collisions. In their framework, they tried to shrink network bandwidth usage by managing large amounts of DD. Furthermore, they extended the flight time of the drone, and effectively reduced the communication overhead along with extending the sensors' battery lifetime. And the proposed road-aware routing strategy using SDN by Abbas et al. [29]. For multi-hop communication, they divided the road networks into a set of segments including RSUs. The rate of DD in VANET was handled by SDN who acted as a control unit for that purpose. In their strategy, the main contribution was reducing the delay time. Nevertheless, there is a limitation with SDN when experiencing a global network overview including all the road conditions. And there is the Routing framework based on SDN which was introduced by [30] for controlling the rate of DD over the vehicular networks. For calculating the optimal path in the network, SDN is flexible to support the switching concept; therefore, using SDN in the routing minimizes the communication overhead.

2.3. Fog computing along with SDN in VANETs

Further studies for combining the fog computing with SDN concepts in alliance systems have been proposed in the literature to raise the performance of VANET. For example, there is Darabkh et al. [31] introduced Innovative Cluster-Based Dual-Phase Routing Protocol Using Fog Computing and SDN (ICDRP-F SDVN) to confound the weaknesses of traditional VANETs routing protocols. The benefit of fog computing and SDN combined in the proposed protocol delivers a robust architecture to fulfill all the new requirements and overcome challenges raised by the high speed of vehicles. The advantage of the ICDRP-F SDVN is to provide an efficient management overhead reduction mechanism, thereby decreasing the messages' exchanges imposed. Kadhim [22] investigated the transmission power reduction in VANET by presenting an approach for a multicast routing which asserted deadline and bandwidth constraints based on both fog and SDN technologies. That fulfills the QoS constraints by applying the scheduling and classification algorithms of multicast requests priority based. Their contribution focused on shrinking the time complexity and the power consumption; yet they neglected the scalability feature.

Another routing protocol that is fog and SDN based was proposed in [17] to minimize the bandwidth usage of the excessive network and maximize the transmission reliability. This technique shall impact the quality of vehicular systems and ensure different local services such as route planning, traffic alert dissemination, elastic vehicular cloud services, traffic monitoring services, and content transfer. High stability and low delay time registered outstanding results in this protocol. [32] suggested other routing protocol based on merging fog computing with SDN for controlling DD in V2V manner. Packet loss, packet delivery ratio and delay time were the assessment features for evaluating the effectiveness of the proposed algorithm. Moreover, Truong et al. [33] who offered a fog and SDN technologies-based system which enhances the performance of the vehicular systems regarding scalability, resource utilization, delay time, reliability and location-awareness. In the proposed architecture, response time is enhanced because of using SDN which separates the data control and the forwarding functions which in turn simplifies the VANET management. However, rate of power consumption still without admitted control.

VANET Efficiency whenever implementing SDN with fog computing was tested by Pushpa et al. [34] through providing a tool that evaluates the network bandwidth, connectivity and time latency. The proposed tool controlled the traffic flow and enhanced the response time duo to virtualization feature sustained by the utilized Network Function Virtualization (NFV). Integrated fog computing with SDN system that handles network transmission flow, able to exploit the resources and offers Internet of Things (IoTs) services was proposed in [35]. Despite of ignoring the scalability issue in the proposed system, the combined features of the fog computing and SDN acted for the strength of the networks intelligence.

In [36], designed new service-based architecture that merges the models of SDN and fog computing in VANETs with presenting a dedicated data scheduling algorithm. Simplifying scheduling of data in higher dynamic environments by merging both fog computing and SDN was the main contribution of that architecture. SDN structure allows rescheduling for the requests generated by the units of data management; hence the resources usage is getting improved. Fog computing was employed to govern the fast growing in the DD through monitoring the network bandwidth usage. The proposed algorithm still suffers from complexity issues. Table 1 summarizes all mentioned papers in this section and reorder it according to its published year.

3. Proposed dynamic vehicular-assisted architecture using SDN and fog computing (DVA-SDNF)

This section introduces a dynamic vehicular-assisted architecture allowing collaboration of SDN and fog computing called (DVA-SDNF) to ameliorate VANET performance. The novelty of this architecture lies in its ability to provide a unique design that supports a comprehensive view of the networks and overcomes the challenges raised by fast-frequently fragmentation in VANET. Moreover, the DVA-SDNF presents a control strategy to adjust the excessive DD and achieves minimal communication overhead over the network.

Data transmission and traffic control are two levels at which the DVA-SDNF architecture operates. The data transmission level has controlled by FOG technology. The FOG improves the operational efficiency of the real-time networking systems by adjusting the volume of data traded over the networks. The traffic control level is established by SDN. The SDN ensures uniform resource utilization of all routing paths among the FOG nodes (fn). The proposed DVA-SDNF architecture has a hierarchical structure with scale-free topology to deliver a degree of distribution networking solution, see Fig. 1. A single procedure has broken down into several smallish activities. Each task has been assigned to a layer in the proposed architecture that works stalwartly to process the task only. The suggested design involves four primary layers will be listed as follows: the Internet of Vehicles (IoV), SDN, FOG, and cloud transport layers.

The IoV layer builds on the dynamic network topology in VANET. It consists of electronic vehicles equipped with cache memory, OBUs, Global Positioning System (GPS), Geographic Information System (GIS), and RSUs scattered on the roads to reach high coverage (connectivity) among vehicles and between vehicles and traffic management units. To provide operational resilience in delivering a network edge that serves

Table 1
Summary of closely related works that use both technologies a FOG and SDN in improving the VANET performance.

Refs. #	Objective	Solution	QoS-Factor	Drawbacks	Year
[31]	Innovative Cluster-Based Dual-Phase Routing Protocol Using Fog Computing and SDN (ICDRP-F SDVN) to confound the weaknesses of traditional VANETs routing protocols was proposed.	Fog-SDN	• Network throughput. • Packet delivery. • Packet loss. • Scalability.	• Energy consumption needs to be considered.	2022
[27]	The VANET performance was improved via introducing a management framework with two techniques: (i) a new aggregation approach for reducing the amount of DD and (ii) a normalized strategy with high dominance of the interferences on the wireless links.	Fog-SDN	• Bandwidth usage. • Energy consumption. • Latency time.	• Scalability is limited.	2022
[28]	A vehicular architecture was proposed under name Software-Defined Drone Network (SDDN) with a new strategy of collision avoidance for efficient deploying UAV units in order to monitor road traffic.	SDN	• Energy consumption. • Bandwidth usage. • Communication overhead.	• Location-awareness is limited.	2021
[29]	A geographically computing framework was built using fog technology.	Fog	• Bandwidth usage. • Energy consumption.	• Scalability needs to be considered.	2020
[26]	Increasing the ratio of the data packet delivery using SDN. Based on IoV, a new road-aware routing strategy was innovated to maximize the amount of packet delivery with avoiding the excessive rate of DD.	SDN	• Response time. • Network throughput	• Network coverage is lacking. • Concerning geographically network overview is lacking.	2020
[17]	Improving the communication capabilities in VANET by introducing position routing strategy based on the combination between SDN and fog computing technology.	Fog-SDN	• Network throughput. • Communication reliability.	• System is very complex.	2020
[35]	A vehicular system was built on IoT services to utilize network infrastructure and govern data transmission across the VANET.	Fog-SDN	• Resource utilization. • Response time.	• Scalability needs to be considered.	2020
[36]	Reducing the amount of big data transferring across VANET by providing a new smart transport system based on the combination of SDN and fog computing.	Fog-SDN	• Resource utilization. • Data scheduling.	• Bandwidth consumption is high.	2020
[25]	Fog computing services and their implementations in ST are supported by a new vehicular framework that was given to reduce the amount of DD in VANET.	Fog	• Location-awareness. • Latency time. • Communication reliability.	• Energy consumption is high.	2019
[22]	A multicast VANET routing protocol that includes deadline and bandwidth constraints to reduce transmission power was proposed.	Fog-SDN	• Power consumption. • Time complexity. • Network bandwidth.	• Figure out how to use the resources more effectively.	2019
[37]	A new vehicular framework to measure the effect of the combination between SDN and fog technology on the network throughput and DD was provided.	Fog-SDN	• Network Throughput. • latency time.	• Scalability is limited.	2019
[33]	A new robust transport framework introduced for supporting the collaboration of fog and SDN was proposed.	Fog-SDN	• Latency time. • Scalability. • Communication reliability. • Resource utilization. • Location-awareness.	• Power transmission is relatively high.	2018
[34]	A new vehicular framework to measure the effect of the combination of fog computing and SDN on reducing the rate of DD was introduced.	Fog-SDN	• Latency time. • Network Throughput.	• Scalability needs to be considered.	2017
[30]	A new routing protocol using SDN for adjusting the rate of DD across VANET was proposed.	SDN	• Routing overhead. • Latency time. • Network bandwidth.	• The performance of routing protocol needs to enhance.	2018
[32]	A new robust routing protocol using the collaboration between fog and SDN for governing the rate of DD in the V2V communication was proposed.	Fog-SDN	• Packet delivery. • Latency time. • Network throughput.	• Power transmission needs to be taken into account.	2016

as a centralized monitoring system of the forwarding message, SDN coexists with RSU in the DVA-SDNF architecture. Consider that the RSU is installed at road intersections and reconfigured to perform as SDN (data switch) to realize affordable costs. Every SDN is in charge of offering its services on a predetermined scale set by the FOG layer. To make information on the state of the roads more easily propagated throughout the VANET, each SDN is marked with a distinctive ID.

In SDN controller layer, the allowed frequency range of communication (R) between SDN and vehicles is defined according to the responsible *fn*. So, achieving reliable communication between every SDN and a set of vehicles $V = \{v_a, v_b, v_c, \ldots, v_n\}$ must be done in $v_{a|comm}\ SDN < R, \forall\ v_a \in V$. The IoV layer divides into a set of cells, every SDN propagates its ID in a specific cell to allow vehicles to connect SDN's services. Building an up-to-date local overview of VANET is a goal to ensure a continuous improvement in the next-hop selection and thus maximize link quality. To this end, SDN reproduces a periodical message for all vehicles in its R to facilitate vehicle registration operation. Then, it asks the registered vehicles about their locations, movements, and velocity. This information participates in constructing both flow and routing tables. A flow table involves information about the status forwarding and dropping data. A routing table includes a neighborhood table with knowledge about network topology, vehicle state, and well-connected routes calculated via the routing protocol. Additionally, SDN provides an abstract level of security for information transfer between the FOG and IoV layers.

The FOG layer is the second level of data controller in the proposed DVA-SDNF architecture. It offers a control and management tool to supervise the rate of DD between the lower layers and the cloud server. With SDN assistance, the *fn* constructs a database that has information about the whole VANET. The FOG layer introduces message oriented-

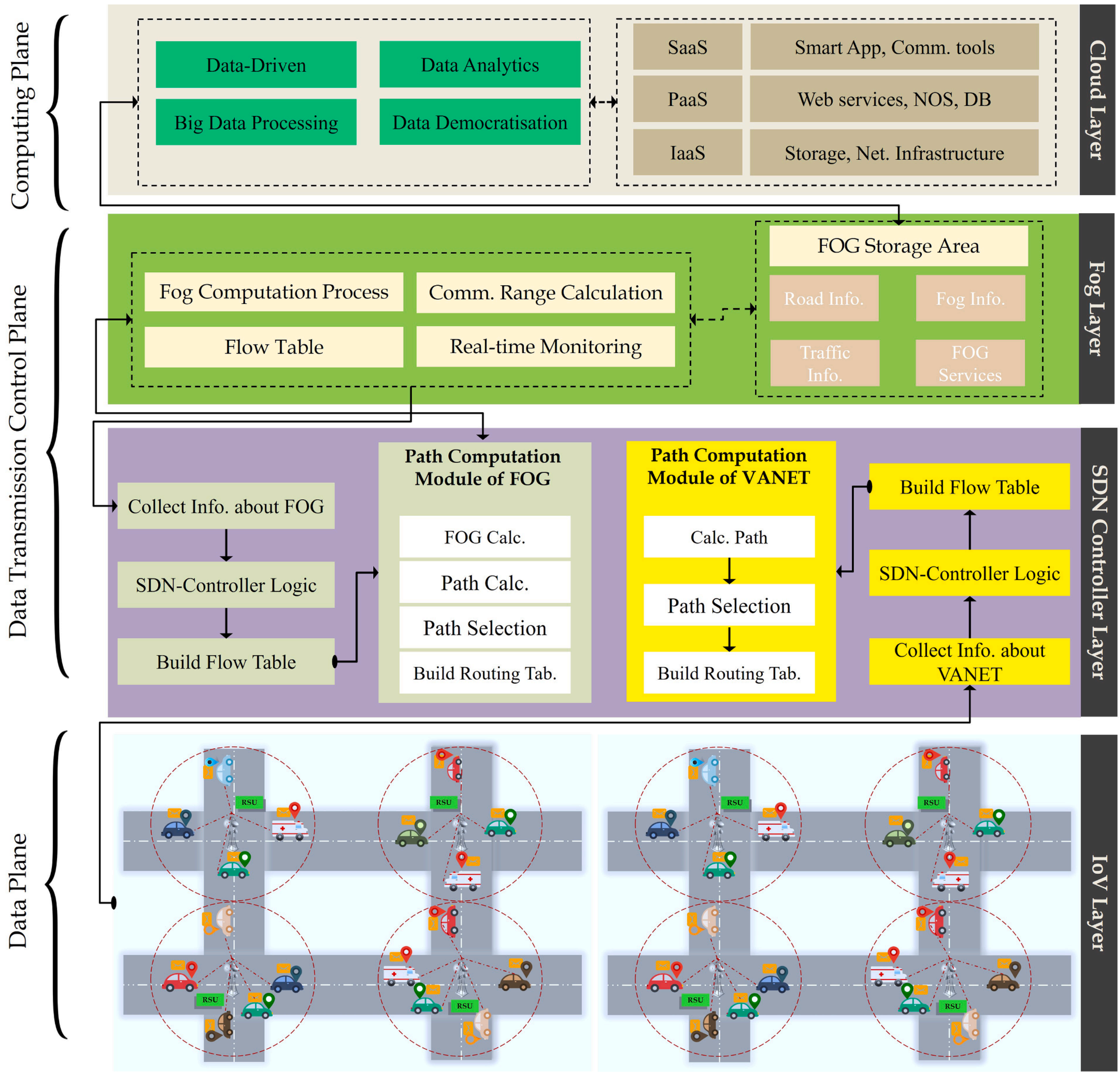


Fig. 1. Conceptual design of the DVA-SDNF architecture.

communication through a FOG-to-SDN connection instead of streaming-oriented communication, and thus the communication overhead is reduced across VANET. The *fn* receives the whole data from SDN only, which is filtered by SDN, and thus there is no need to direct connection with vehicles. The data stored in *fn* and it categorizes into two categories: (i) data sent to get local processing and (ii) data to construct a global network overview; this last category of data is stored in a flow table.

The IoV is segmented by *fn* into a set of certain cells called FOG Zone (*FZ*). To offer an uninterrupted connection with SDN, each FZ has been labeled by the responsible *fn*. With a multicast technique, the *fn* propagates their ID into each FZ allowing SDN devices to register themselves in this zone. Individual SDN sends up-to-date information to the responsible *fn* about the network status, topology, and road conditions. This collected information will be saved into a flow table generated by the *fn* as seen in Table 2. This flow table enhances the navigation process by allowing nowcasting rather than forecasting techniques. Surely, the whole packet delivery and transmission reliability are improved across VANET.

The cloud transport layer is the upper layer of the DVA-SDNF architecture. It provides a set of computing and unlimited data storage for incoming traffic from FOG. It also builds historical data about the overall VANET conditions that helps to improve the network performance in decision making. Surly, constructing the FOG layer in proximity to end-users decrease the risk of data travel for a long distance to process at the cloud server as well as it helps the cloud server makes a better-informed decision.

Table 2
The parameters of mobility metrics in the flow table.

fn_{id}	SDN_{id}	V_{id}	Location			Timestamp Time			Date			$Dest_{id}$	Next-hop	Velocity	TTL
			x	y	z	h	m	s	mm	dd	yy				
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

4. Preparing position-based routing and energy conservation methodology (PRECM)

In this section, the mathematical model of the network topology establishment and proposed PRECM is introduced. The abbreviations in this section are listed in the following Table 3.

4.1. Network model

We consider *fns* are scattered randomly in the $(3000n \times 3000m)$ dimensions, and it governs by a FOG Head (FH). Consider all *fns* to have the same R, and thus the scale of IoV will be segmented of identical dimensions called *FZ*. The SDNs are installed at road junctions. Only SDN has permission to connect to the FH, and it can transmit information about the road conditions and vehicles. On the other hand, the IoV is a set of vehicles $v_a,\ v_b,\ \ldots\ v_n$. For example, the vehicles v_a and v_b transmit a request to *SDN* to connect to *FH*. The *FH* propagates a message carrying its ID called $(FH|_{id})$ in the FZ. After receiving this message, the v_a and $v_b$store it in their cache, and they will exchange their information with the SDN. The SDN uses this information to construct a temporal database. This concept improves not only the operational efficiency of the navigation process but also communication overhead across the VANET. The primary units that are deployed in this network will be listed as follows:

i. **BSs/RSUs:** BSs and RSUs offer network connectivity and discovery across the IoV. The BS acquires information regarding the vehicle's status that get from RSUs. All information is transmitted to SDN using IEEE 802.11p to create a comprehensive view of the whole network.
ii. **SDN/RSUs:** RSUs are recognized on the road to control traffic discovery. Others RSUs that are placed at the intersections will reconfigure to perform as an SDN. SDNs are in charge of extra functions such as gathering information about traffic conditions, establishing dynamic routing paths, and transmitting routing information to FHs.
iii. ***fn*/SDN:** *fn* transmits a multi-cast message to the nearest SDN to notify it about the *fn*'s energy level and the distance between *fn* and SDN. The most appropriate node will announce itself as an FH. The position-based routing technique determines the best paths between FHs and SDN.

Table 3
A list of symbols.

Symbol	Description
V	A number of vehicles.
r	The measured value for the declaration of an initial *FH*.
r_s	The required time to realize the stability of the network.
d_o	A threshold distance of an SDN and *FH* node into a certain *FZ*.
$P_{\|breakdown}$	The measured value for a critical level of power, which denotes the rate of energy depletion of *fn*.
E_{fn}	The energy of a *fn*.
r_N	The maximum lifetime of each *fn*.
D_{fn}	The rate of energy drains of each *fn*.
E_{PE}	The prior assigned energy of a *fn*.
E_{CE}	The status of energy level of a *fn*.
T_{CT}	The current time.
T_{PT}	The prior time.
$Link_c$	The capacity of Path/Link.
P_{size}	The maximum size of data packet by bit.
$E_{rem}(fn, r-1)$	The remaining energy of *fn* at *r*.
E_{min}	The minimum bound of energy through the round $(r-1th)$.
E_{max}	The maximum bound of energy through the round $(r-1th)$.
$B_{\|delay}$	The limitation of delay values.
$\frac{(n-1)l_p}{r}$	The transmission latency of a *ith*.
l_p	The allowed packet length to transfer across the network.
$T_{\|rate}$	The amount of the data transmission.
g^{FR}	The areas out of the *R* of *FH*.
$Propagation_{\|speed}$	The rate of propagation speed.
d_{min}	The minimum radius assigned to define the minimum bound of FZ.
d_{max}	The maximum radius assigned to define the maximum bound of FZ.
$d_{FH} - d_{SDN}$	The difference distance between any *FH* and a specific *SDN*.
FZ_{areai}	The *FZ* is determined for each *FH*.
$1 - \frac{d_{max}}{d_{min}}$	The maximum and minimum bounds of *FZ*.
N_{noise}	The noises in a certain link *l*.
$E_{(trans\|rece)}$	The rate of energy consumption on both transmitter and receiver packets.
ε_{mp}	The propagation of multipath.
ε_{fs}	The propagation of free space.

To manage the amount of data transfer, SDN will broadcast the most recent information to *fn* in the form of a multi-cast message. Depending on the energy level and location degree on SDN, all *fn* in the FOG layer have an identical chance of becoming FHs. The SDN creates the flow table to store the coming information about *fn*; it will enable the system to layer *fn* in the future. Certainly, this operation assets better-informed decisions in selecting the next-hop. We consider the *fn* has GPS with Digital Maps for the distance calculations, thus improving the operational efficiency in the vehicle navigation [38]. The Euclidean distance can be employed in the local computation of FHs for the node without GPS. The following list contains the fundamental definitions that were employed in this study:

Definition 1. r is the time estimation for completing all necessary calculations to announce an *FH* and accomplish a single cluster formation of *FZ*. We consider the initial round of data transmission will take 10 ***r***.

Definition 2. r_s is the time taken to accomplish the network stability and announce the final *FH* by SDN.

Definition 3. *FH* is a selected node to be the head of a cluster characterized by a high energy level and a minimal value of location degree with *SDN* to maximize the stability of the network as long as possible.

Definition 4. $d_o = \frac{\varepsilon_{fs}}{\varepsilon_{mp}}$ is a threshold distance into a single *FZ* between an *SDN* and a specified *FH* node.

Definition 5. $P|_{\text{breakdown}}$ is the volume of energy depletion of *fn*, which may affect the lifetime of the network and result in failure. The $P|_{\text{breakdown}}$ is calculated by:

$$P|_{\text{breakdown}} = \text{Max}\ (E_{fn|r_N}$$

Here, E_{fn} denotes the energy level of *fn*. r_N denotes the maximum lifetime of each *fn*.

Definition 6. D_{fn} is the energy drain level for *fn*, and it can be measured depending upon the amount of staying energy and the draining speed of the *fn* in the FOG layer. It is mathematically expressed as:

$$D_{fn} = \frac{E_{PE} - E_{CE}}{T_{CT} - T_{PT}}$$

Here, E_{PE} denotes the previously assigned energy of a *fn*, and E_{CE} denotes the current power level for a *fn*. The T_{CT} is the current time, and T_{PT} is the earlier time. The *FH* typically produces a Time-Division Multiple Access (TDMA) schedule and sets a time slot for transmitting every packet. The network returns to the start-up phase after the transmission process of the packet is carried out to announce a new *FH*.

Definition 7. $link_c$ is the maximum link throughput that ensures the connection between announced *FH* and *SDN* is alive; it represents by:

$$link_c = \frac{P_{size}}{\nabla\ (T_r - T_s)}$$

Here, P_{size} denotes the maximum size of data packet. The term $\nabla\ (T_r - T_s)$ is the time interval by sec., it refers to the distinction between the time taken to successfully received a packet T_r and the total time for packet sent.

4.2. Routing procedures in VANET

In this section, the proposed PRECM uses a method to measure the constitutive routing approach and efficient FH selection in a mathematical way. As shown in Fig. 2, the process in the PRECM has three main operations: (i) neighbor discovery, (ii) SDN operations, and (iii) data transmission.

4.2.1. Neighbor discovery

The neighbor discovery is the preparation operation performs in a decentralized manner. It includes a single phase called the start-up phase with three operations: distance, FOG directions, and residual power calculations. In the beginning, the SDNs are distributed and reinstalled along the route at junctions. The communication between SDN and vehicles via a bidirectional connection. While the communication between SDN and the FOG layer via a multi-cast message to overcome broadcast issues. *fn* nodes share information about their status with SDN. This information is a seed to construct the flow table at SDN, which generally holds the network flow entries, the real distance between a single *fn* to an SDN, and the amount of residual energy.

Start-Up phase. With the first round (r), the start-up phase will occur with three operations are the calculations of distance, the measurements of residual power, and the measurements of location degree. These measurements are required to construct a separate flow table on both FOG and SDN. The flow table on the FOG layer is essential to pre-install routing paths that can simplify communication operations among *fn* nodes. However, the flow table on the *SDN* controller layer is influential in constructing the optimal route. After completing these calculations, the system has entered a new phase divided into four sub-phases: delay time, *FHs* declarations, *FZ* initiation, and link quality.

A-Distance

All *fns* are dispersed at random throughout the FOG layer, and they have a fully Digital Mapping System (DMS). Recently, the DMS has developed to provide automated real-time navigation services [38]. The *fns* use DMS to calculate the distance via the Euclidean distance between themself and SDN. Moreover, the DMS permits all *fns* to exchange their position information, road ID (r_{id}), and curve-metric distance with the SDN. The Euclidean distance between FOG to SDN can be computed as:

$$Dist\ (\gamma_{fn}, \gamma_{SDN}) = \sum_{i,j}^{n,m} |v_{fni} - v_{SDNi}| \tag{1}$$

The terms of $Dist\ (\gamma_{fn}, \gamma_{SDN})$ indicate the curve-metric distance through a *fn* to *SDN*, it calculates as the sum of the absolute values of the coordinate differences through the source and the current position of destination $|(v_{fni} - v_{SDNi})$.

B-Direction

The optimal route between *fn* and SDN will be computed later by SDN based on accurate information about the correct address of *fn*. Since the SDNs have a stationary place, it thus becomes crucial to predict the current location for each *fn* nodes for determining the possible number of hops to reach the destination. This operation controls the power consumption in data transmission, therefore enhancing network lifetime. As shown in Fig. 3, consider *fn* nodes are traveling in a frequent behavior in a distance of 2*d*. The distance between the first deployed node will be equal to $\frac{\pi}{2d}$. All possibilities for the movements of *fn* can be given by:

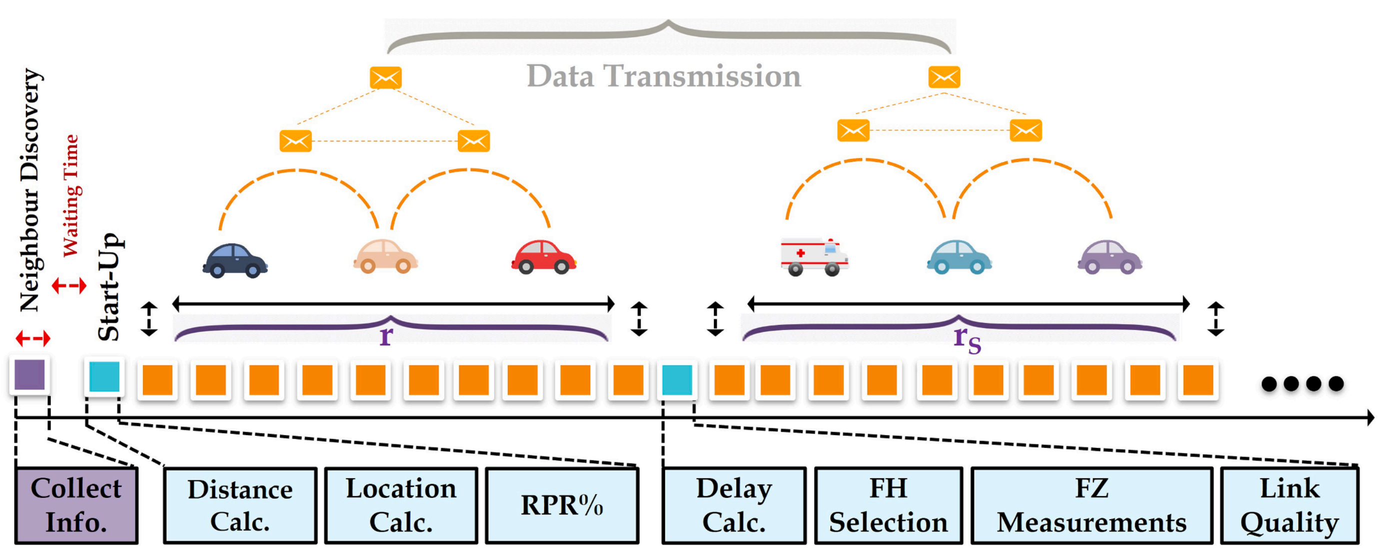


Fig. 2. The process of routing construction.

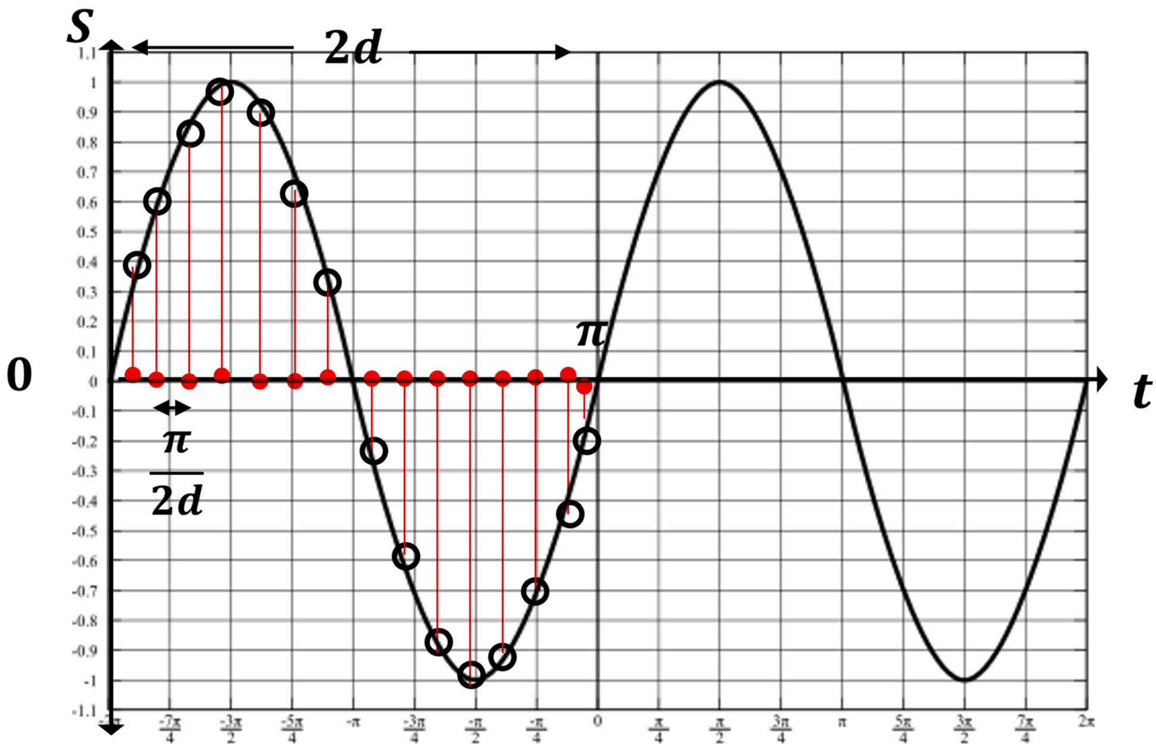


Fig. 3. The *fn*'s movements.

$$fn|address = \begin{cases} -1\ fn\ is\ immobile; \\ \dfrac{\pi}{2d}\ for\ v_a = 0\ \delta\ v_b > 0; \\ \dfrac{3\pi}{2d}\ for\ v_a = 0\ \delta\ v_b < 0; \\ \dfrac{2d\ -\ 1}{2d}\ for\ v_a = 0\ \delta\ v_b = \infty; \end{cases} \tag{2}$$

C-Residual Power

With the network discovery, another essential parameter computed by *fn* is to Residual Power Ratio (RPR%), which is a necessity to sustain the network alive and guarantee high data packet delivery. All *fn* nodes deployed in the FOG layer have a requirement to interact with others to transmit up-to-date information about the network. This operation of data transmission should be done under real-time restrictions, to keep their batteries up and the network lifetime inline. Therefore, calculating RPR% for each *fn* is significant to avoid the network lifetime ending prematurely. RPR% is given by:

$$RPR\% = \frac{E_{rem}(fn,\ r-1)}{E_{total}(fn, r-1)}\ \geq\ P_{|breakdown} \tag{3}$$

Here, $E_{rem}(fn,\ r-1)$ denotes the remaining energy of *fn*, *r* denotes the time taken to establish the first cluster and data gathering process among all *fns*. The term E_{rem} is given by: $E_{total} - (I \times Volt \times T) Joule$, the *I* is a current (in Ampere), *Volt* is the total voltage, and *T* is the time taken to transmit and receive the data across the network. The $E_{total}(fn, n-1)$ denotes the whole level of energy of *fn*. The value of the right side must be greater than or equal to the breakdown value in the left side. The energy level of *fn* is given by the Eqs. (4) and (5) as follows:

$$E_{total}(fn, r-1) = \mu_i \Delta t \tag{4}$$

$$\mu_i = \ rand(E_{min}(r-1),\ E_{max}(r-1)) \tag{5}$$

Here, μ_i denotes the energy level of *fn* at the round $(r\ -\ 1th)$, Δt is the round duration at time *t*. The μ_i carries the allowed energy bounds confined within the lowest bound is E_{min}, and the highest bound is E_{max} during the round $(r\ -\ 1th)$. Based on the bounds of $P_{|breakdown}$, the energy levels will be adjusted. According to Eqs. (4) and (5), the bounds of energy are defined for each *fn*. Thus, the *fn* that has an energy level less than the E_{min}will be automatically blocked in the first round *r*. Only *fn* that have an energy level more than or equal to E_{max}will participate in the next round (r_s). After completing this stage, each SDN will arrange all eligible nodes to select the most proper one.

4.2.2. Dual phase using SDN and PRECM

The essential role for creating a flow table in SDN is to the traffic status and the topology managers collaboratively. Pre-installing a routing table with accurate topology prediction is an aim of the flow table update policy. Based on the information collected from the vehicles, the SDN controller can predict the vehicle's potential trajectory and specify its topology adjustment when a vehicle is connected to the controller. This operation helps the *fn* to provide its services for IoV in an end-to-end manner, thus a considerable reduction in the communication overhead by controlling number of Route Request (RREQs) messages . Even if the vehicle disconnected from SDN in a short period, the pre-installed paths in the flow table still are used to predict its position [39].

The controller in SDN is a software program created by OpenFlow to manage and monitor the table flow contents. The controller is the only device responsible for notifying *fn* about the connection corruption instead of dominating the whole VANET with details about all the path changes. In this case, the process of routing convergence is less affected. The controller acquires the redirected path and forces the redirected path information to the concerned switches [40]. If the packet transmits from the source to the destination, the flow table looks for the header packet at the source and destination as well as matches the path that was taken by the data packet, and another saved in the flow table. If the error occurs in this process, several actions will be taken such as the responsible SDN-controller will notify *fn* and other controllers across the network, and the OpenFlow will encapsulate the data packet and re-transmit it or drop the data packet directly.

Another aspect of the OpenFlow network is that the OpenFlow switch can govern the traffic flow once it fits the flow table and does not require further communication from the OpenFlow controller. This makes switches forward data more efficiently. However, the issues come up once the flow table's laws no longer match the state of the network. Herein, the controller in SDN will filter the collected data from the *fn* and recast it to obtain the optimal selection of an FH. An SDN can filtrate data according to a set of metrics. In this case, three measurable factors are considered such as distance, latency time, and level of power. To reach a smooth data flow and thus deliver a better routing solution, the weights for selected paths should be calculated. In this section, we discover the procedure for selecting a suitable *fn* and a way for maximizing link quality between the selected node and SDN.

A. Delay Time

One important QoS indicator for assessing network performance and validity is End-to-End (E_2E) delay. It is defined as the estimated time taken for a packet to transmit from a source node (mean *fn*) to a destination node (mean SDN). Since the nature of VANET is the highly dynamic topology and fast fragmentation. So, it becomes difficult to estimate this time accurately. Here, several parameters must be taken into account such as the bit rate of data, distance, propagation time, and transmission time. The E2E can be expressed as:

$$E_2E_{|totalDelay} = \sum_{i=1}^{n}\left(OneHop_{|delay} + B_{|delay}\right) \tag{6}$$

The $i \in \{1, 2, 3, 4, \ldots, n\}$ denotes the number of *fn*, the oneHop term will be measured as follows: $OneHop_{|delay} = t_{|\mathrm{processingDelay}} + t_{|\mathrm{propagationDelay}} + t_{|\mathrm{transmissionDelay}} + t_{\mathrm{channelDelay}} + t_{\mathrm{receptionDelay}} + t_{|\mathrm{queuingDelay}}$ [38]. $B_{|delay}$ denotes the allowed bounded delay values. Form the Eq. (6), the E_2E delay time estimation of *fn* can be formulated as:

$$fn_{|delay} = \frac{(n-1)l_p}{T_{|rate}} + \frac{\sum_{i=1}^{n-gap-1} d_{o+g^R}}{Propagation_{|speed}} + \sum_{i=1}^{n-1} t_{|queuingDelay} + \sum_{i=1}^{n-1} t_{|\mathrm{processingDelay}} \tag{7}$$

The $fn_{|delay}$ is a measured value determined by a set of variables: the term $\frac{(n-1)l_p}{T_{|rate}}$ denotes the delay of data transmission of a *fn* for each *ith*, the n denotes the maximum number of deployed *fn*, the l_p denotes the length of the data packet allowed to transfer across the VANET bandwidth, and $T_{|rate}$ is the amount of data transmission. The term $\frac{\sum_{i=1}^{n-gap-1} d_{o+g^R}}{Propagation_{|speed}}$ denotes the propagation delay time, d_o denotes a threshold of distance, the g^R denotes the number of areas out of R, and the $Propagation_{|speed}$ denotes the total of propagation speed.

B. FH Selection

This section is going to pick the much more proper *fn* to be an FH. OpenFlow will save the data gathered from the FOG layer into a flow table. The nodes of *fn* are by default positioned and reconfigured in accordance with their proximity to the closest SDN. As shown in Fig. 4, if the distance between the *fn* and SDN is less than or equal to the threshold d_o, the *fn* will be in the nearest layer to SDN that is the 1st layer. Otherwise, the *fn* will rearrange according to their d_o.

Once an SDN acquires the required information, an SDN initiates instantly to the transformation of this information to be more consequential for announcing FH and producing the optimal routing path. To this end, the weights (W) will be calculated by the OpenFlow in the SDN. The degree of location, RPR%, and E_2E delay are significant parameters for weight calculations. The lower weights denote the short path between the SDN and *fn*. Therefore, the optimal route can achieve via a set of measurable values: the shortest distance between the *fn* and SDN, high RPR%, and low latency. Consequently, an SDN denotes the optimization of path selection by a general equation, which can describe as follows:

$$W_{(fn,SDN)} = \sum_{i,j=1}^{n,m} \omega_i \left[\frac{\max(RPR\%)}{\min\left(dist(fn, SDN) + T_{|delay}\right)}\right] \tag{8}$$

Based on Eqs. (1), (3), and (7), W between any pairs $(fn,\ SDN)$ can be calculated as follows:

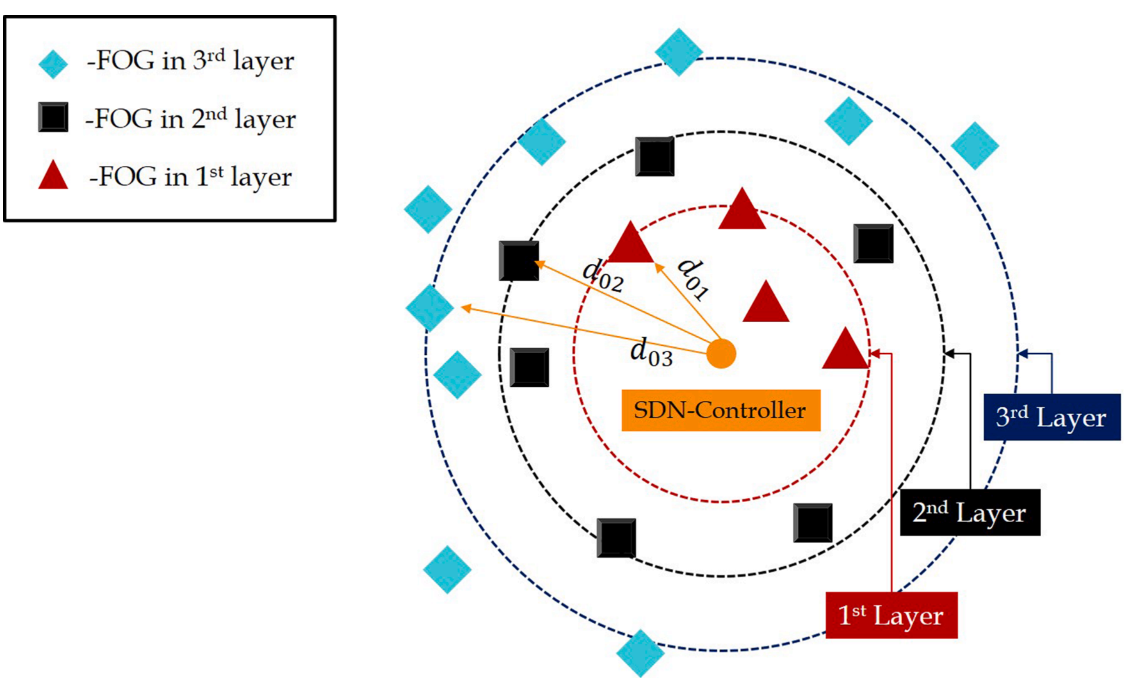


Fig. 4. The nodes of *fn* layered by the controller in SDN.

$$W_{(fn_i,\ SDN_i)} = \omega_1 \frac{RPR\%}{dist(\gamma_{fn1}, \gamma_{SDN1}) + T_{|delay_{fn1}}} + \omega_2 \frac{RPR\%}{dist(\gamma_{fn2}, \gamma_{SDN2}) + T_{|delay_{fn2}}} + \dots + \omega_n \frac{RPR\%}{dist(\gamma_{fn_n}, \gamma_{SDN_n}) + T_{|delay_{fn_n}}} \tag{9}$$

Here, $i \in \{1, 2, 3, 4, \dots, n\}$, the n denotes the number of *fn* and $j \in \{1, 2, 3, 4, \dots, m\}$, n denotes the number of SDN devices. W the weight of the link between two nodes (*fn*, SDN) with different constant-coefficient values ($\omega_1,\ \omega_2,\ \dots,\ \omega_n$). The total should not be greater than (1), and they can represent as follows:

$$\text{Coefficient factor (constant) } (\omega) = \begin{bmatrix} \omega_1 \\ \omega_2 \\ \dots \\ \omega_n \end{bmatrix} \approx 1$$

Otherwise, the total value of W is determined by three factors: the estimation of delay time taken from sending one packet from any *fn* until receiving this packet by an SDN, the Euclidean distance from an SDN to each deployed *fn*, and the real value of energy. Fig. 5 shows the illustration of how to calculate W before selecting FH, and Fig. 6 shows the flowchart of the FH election process. The pseudocode for selecting an FH is illustrated in the Algorithm 1.

- Illustrative Example

We consider the area study has six intersections equipped with six *SDN* devices. Each *SDN* controller must designate the most suitable *fn* as an *FH*. The proper *FH* must be the closest to an SDN to decrease the latency; it also has the maximum energy balance to keep the network alive as long as possible. Additionally, the *FH* offers several functions that would prevent expanding access to the cloud server. This operation enables the vehicular community to employ the computing services from *fn* and saves bandwidth usage.

The deduction of *FH* depends on the W calculation of edges. To accomplish this task, the highest rate of PRP%, the shortest distance between each *fn* to SDN, and the lowest time of delay are the important metrics required to discover the optimal weight value. Suppose that the connection has been established between a set of *fn* and SDN_1, as seen in Fig. 5. The values of the QoS metrics are gained by the local computing unit in *fn*. The constant-coefficient values ($\omega_1,\ \omega_2,\ \dots,\ \omega_n$) are assigned based on both distance and delay time. While the SDN's decision about *fn* is exclusion/inclusion given based on the balance of PRP. Table 4 displays a sample of these values. Hence, the *SDN* starts to calculate W_i as follows:

$$W_{(fn_{22},\ SDN_1)} = \left(0.3\ \frac{90\%}{200.44 + 3.8}\right) = 13.2$$

$$W_{(fn_{23},\ SDN_1)} = \left(0.6\ \frac{89\%}{245.11 + 5.0}\right) = 21.3$$

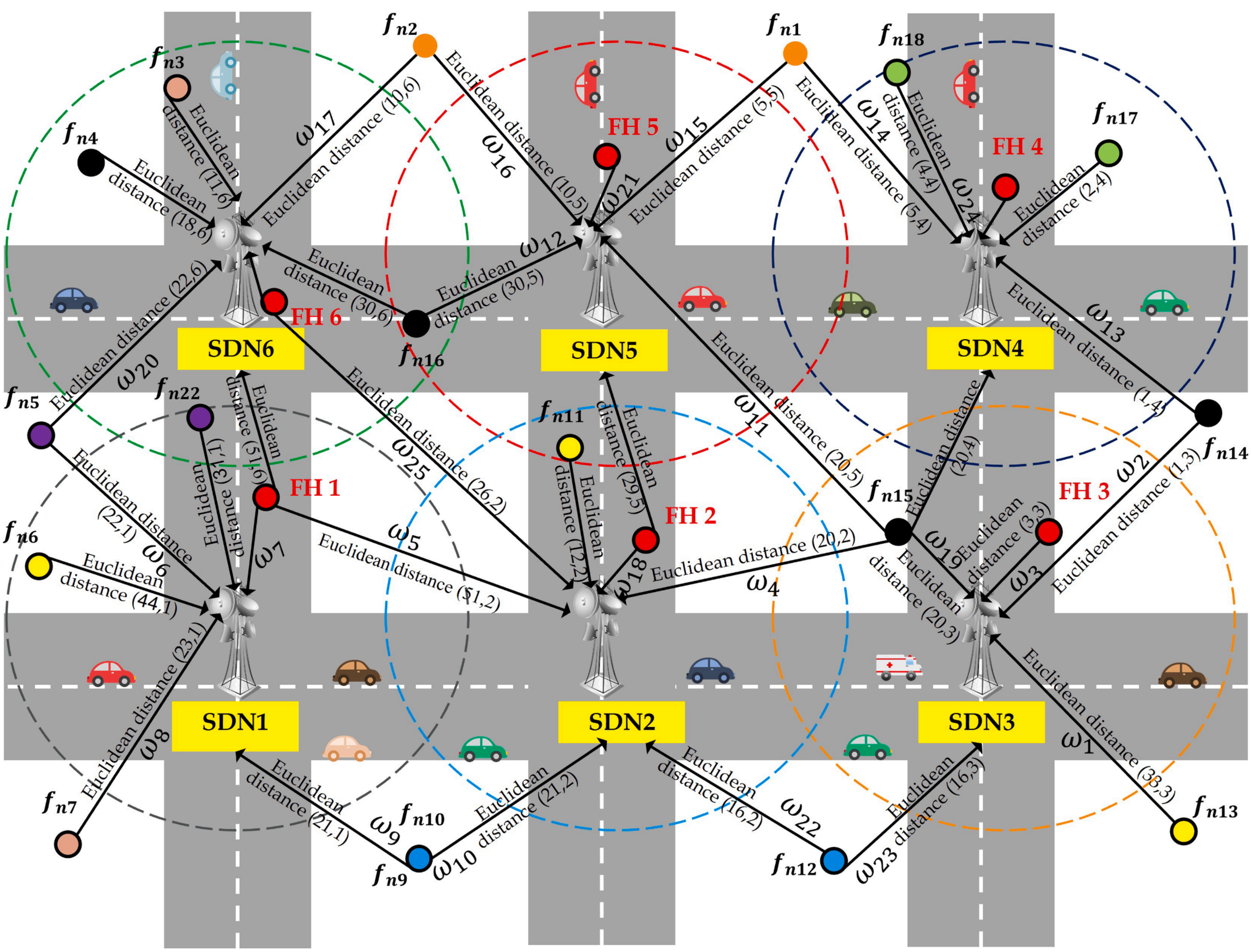


Fig. 5. The illustration of how to calculate W and select *FH*.

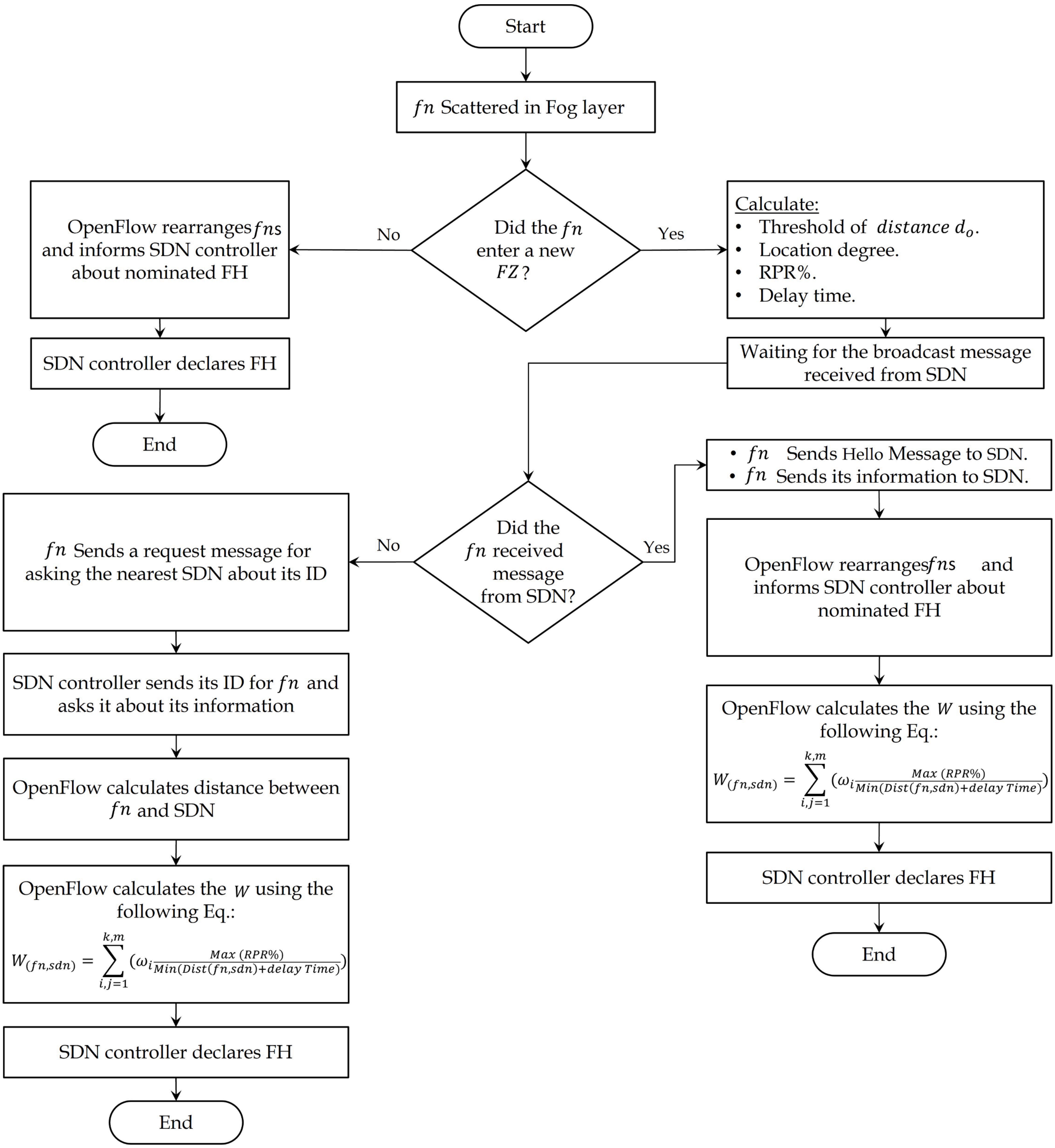


Fig. 6. Flowchart of the process of FH election.

$$W_{(fn_{44},\ SDN_1)} = \left(0.1\ \frac{70\%}{198.43 + 4.0}\right) = 3.4$$

$$W_{(fn_{51},\ SDN_1)} = \left(0.02\ \frac{98\%}{99.12 + 0.5}\right) = 1.9$$

Based on the previous calculations, the *fn* with a number (51) has the lowest weight, and thus *SDN* controller can declare it as an *FH*. The second step is to define the bounded of the *FZ* by fn_{51}.

C. Measurements

To achieve high connectivity sufficient to maximize packets delivered and avoid the interruption of communication across the network, the coordinates of the *FZ* should be markable. As mentioned in Table 4, SDN_1 announces fn_{51} is an FH. The fn_{51} starts to initialize the bounds of its *FZ* according to its *R*. The SDN_1 begins to be layered other *fn* nodes within three levels relied on their signal strength. The fn_{51} is responsible for tracking the limitation of bounds (internal and external) of these

Algorithm 1
W calculation and an FH election.

Result: *W*, an FH election
For T=anytime & $T <= \Delta T_r - T_s$ **{**
For $X = 1$ to X= (*fn*TotalNumber) **{**
A flow table created by the collected information from *fn*;
While Location (*fn*) $\in$ Location (*SDN*) **{**
fn transmit information to *SDN*;
If $Dist\ (\gamma_{fn}, \gamma_{SDN}) \leq d_o$ **{**
fn is located in 1st layer;
// Calculate PRP%;
If $P_{|\mathrm{breakdown}} = Max(E_{fn|r_N}) = 0$ **{**
$RPR\% = \dfrac{E_{rem}(fn,\ r-1)}{E_{total}(fn, r-1)} \geq P_{|breakdown}$;
// Calculate $fn_{|\mathrm{delay}}$;
$fn_{|delay} = \dfrac{(n-1)l_p}{T_{|rate}} + \dfrac{\sum_{i=1}^{n-gap-1} d_{o+g^R}}{Propagation_{|speed}} + \sum_{i=1}^{n-1} t_{|queuingDelay} + \sum_{i=1}^{n-1} t_{|\mathrm{processingDelay}}$;
// Calculate W;
$W_{(fn,SDN)} = \sum_{i,j=1}^{n,m} \omega_i \left[\dfrac{\max(RPR\%)}{\min(dist(fn, SDN) + T_{|delay})}\right]$;
}}
{
fn does't have any chance to be *FH*;
}
}
}
}

Table 4
A sample of mobility factors for calculating *W* and declaring *fn* as the first *FH*.

Sender	Receiver	Euclidean-distance	E_2E (μs)	PRP (%)	ω	Decision
fn_{21}	SDN_1	154.13	2.3	40	0.03	Exclusion
fn_{22}	SDN_1	200.44	3.8	90	0.3	Inclusion
fn_{23}	SDN_1	245.11	5	89	0.6	Inclusion
fn_{31}	SDN_1	199.15	4.1	10	0.02	Exclusion
fn_{44}	SDN_1	198.43	4.0	70	0.1	Inclusion
fn_{51}	SDN_1	44.12	0.5	98	0.02	Inclusion

levels to guarantee the degree of connectivity. As depicted in Fig. 7, there are two important calculations that are: (i) minimum radius ($d_{\min}$) that has allocated to the first layer for specifying the internal edge of *FZ*, and (ii) maximum radius ($d_{\max}$) that has allocated to the third layer for specifying the external edge of FZ. We consider the term $d_{\min}$ is defined as the difference distance through FH and SDN, and it measures as:

$$d_{min} = d_{fn} - d_{SDN} \tag{10}$$

In our case, the formula $d_{fn} - d_{SDN}$ indicates the difference between fn_{51} and SDN_1 that indicates the smallest range that covered by fn_{51}. Otherwise, the $d_{\max}$ should not exceed the allowed R for fn_{51}. The $d_{\max}$ indicates the difference through $fn_{51}$and the farthest node deployed in the 3rd layer, and it will be calculated as follows:

$$d_{\max} = d_{fn_{51}} - d_{farthest} \tag{11}$$

From the Eqs. (10) and (12), the total area of *FZ* can be modeled as:

$$FZ_{areai} = \pi\left[1 - \frac{d_{\max}}{d_{\min}}\right] \tag{12}$$

The FZ_{areai} denotes the *FZ* for each *FH*, the π denotes a constant help to find the circumference of a circle by measuring the radius, and the term of $\left[1 - \frac{d_{\max}}{d_{\min}}\right]$ uses to define the internal and external bounds of *FZ*. The pseudocode for identifying the bounds of *FZ* is illustrated in Algorithm 2.

D. Link Quality

The link quality is an essential factor in achieving transmission reliability and network stability. Building a resilience channel between the sender and the receiver increased the total message delivery ratio, reduced link failure rate, and maximized network throughput. The concept of Channel State Information (CSI) is a measurable value for adjusting the consumption of power transmission, attainable data packet rate, and faultless link quality via the Signal-to-Interference-Plus-Noise Ratio (SINR) and loss rate [38,41].

The link (l) is a direct line (or path) decided between transmitter and receiver to permit the network systems to establish a successful transmission operation. In general, if two wireless nodes are using the same radio connection and pass through the same interference zone, their communication activities on one link may interfere with those on the other. The communication process in VANET accommodates varying

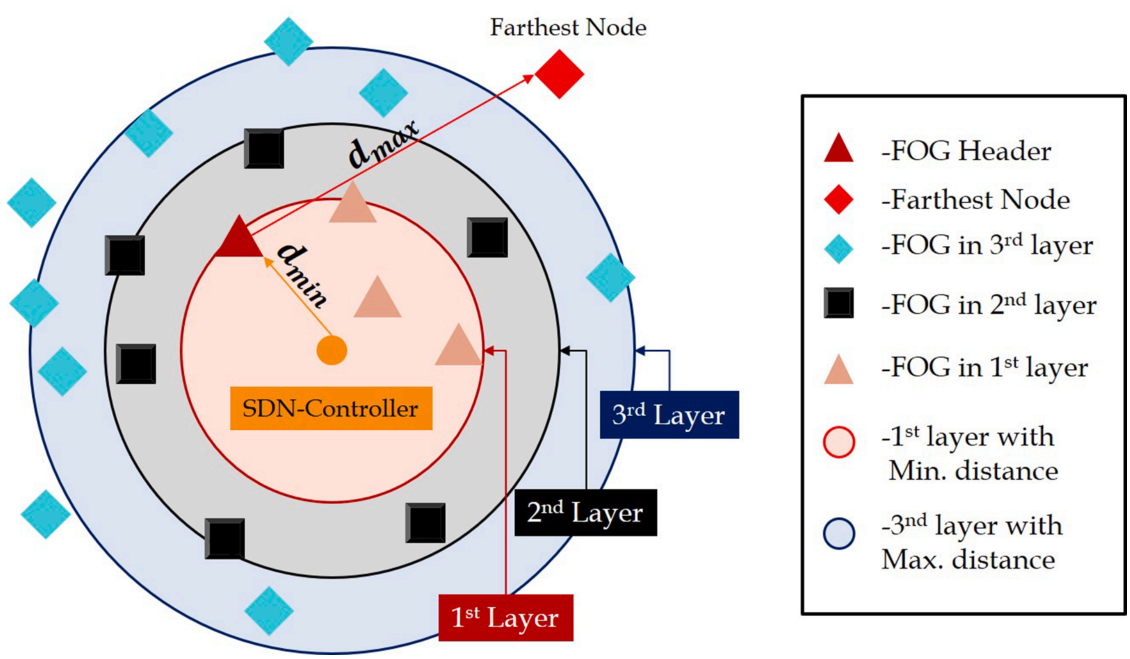


Fig. 7. A layered system within the *FZ*.

Algorithm 2
Determining the bounds of FZ.

Result: Determining the bounds of FZ
For T=anytime & $T \leq \Delta\ T_r - T_s${
// Each fn calculates its distance to SDN based on its signal strength;
For $Y = 1$ to $Y = \forall fn$ **{**
$Dist\ (\gamma_{fn}, \gamma_{SDN}) = \sum_{i,j=1}^{n,m} |d_{fn_i} - d_{SDN_j}|$;
}
While $d_{\min} \geq$ Y $\leq d_{\max}$ **do**
//Determine distance via FH;
If $Y \leq\ d_o$ **do**
fn is located in 1st layer;
//FH determines the difference through itself and SDN;
FH ← $d_{\min}$;
else
fn is located in 3rd layer;
//FH determines the difference through itself and farthest node;
FH ← $d_{\max}$;
//Set the bounds of FZ;
SDN ← FZ_{areai};
}
}
}

levels of interference, which results in sounds and distortion that have adversely impacted the connection capacity. Consequently, network bandwidth usage balloons to uncontrollable heights. By identifying the route with the least amount of interference and bandwidth, position-based routing is a technique that could be used to achieve quick transmission times [42].

To find the optimal route that has high quality of link and low *SINR*, we consider the *fn* sends the number of packets (P) to SDN_j via a certain link l. P is successfully received at SDN_jbased on the following Eq.:

$$l_m(fn_i, SDN_j) = \left[l_{thrput} - \frac{P_{|size}}{\mathrm{N}_{noise} + BW + D_{fn}}\right] \geq \psi \tag{13}$$

l_{thrput} denotes the total throughput of link, and $P_{|size}$ denotes the packet size requires for transmitting from any *fn* to *SDN*. Certainly, the packet size should not exceed the total $link_c$. The N_{noise} denotes the noises appear in a certain link l. BW denotes the estimation of total bandwidth of l, which is given by:

$$BW = IR_l \times link_c \tag{14}$$

IR indicates the ratio of interference on l. IR_l can be given by: $\frac{SINR_{(l,BW)}}{SNR_{(l,BW)}}$. So, $SINR_{(l,BW)} = \frac{P_{(l,BW)}}{1-\mathrm{N}_{(noise,l)}}$ and the $SNR_{(l,BW)} = \frac{P_{(l,BW)}}{\mathrm{N}_{(noise,l)}}$ Here, $SNR_{(l,BW)}$ indicates the amount of signal-to-noise of l. D_{fn} indicates the energy drain for each *fn*. The last term in the Eq. (13) uses ψ as a constant value. $Path_{|\mathrm{loss}}$ indicates the path loss that measures the power gains and expected attenuation in the signal in telecommunication systems. Here, $Path_{|\mathrm{loss}}$ can measure by the differences between the packet loss in forward and reverse transmission, and it calculates by:

$$Path_{|loss} = \frac{1}{P_{|forwred} - P_{|reverse}} \tag{15}$$

Here, $P_{|forwred}$ and $P_{|reverse}$ are defined as the expected number of the packet loss in the forward and reverse situation in a l_i. While $P_{|forwred}$ and $P_{|reverse}$ rely mostly on the possibility of successful delivering a data packet $P_{|\mathrm{success}}$and undelivered packet $P_{|\mathrm{unsuccess}}$ from *SDN* to *fn*. The $P_{|\mathrm{unsuccess}}$and $P_{|\mathrm{success}}$ are given by:

$$P_{|\mathrm{unsuccess}} = 1 - \left(1 - P_{|forwred}\right)\left(1 - P_{|reverse}\right) \tag{16}$$

$$P_{|\mathrm{success}} = P^{s-1}\left(1 - P_{|\mathrm{unsuccess}}\right) \tag{17}$$

Where P^{s-1} indicates the total number of attempts to retransmit data packet across the l.

5. Complexity of PRECM

This section aims to measure the complexity of PRECM in different terms include the time complexity, communication overhead, and space complexity.

5.1. Time complexity

The time complexity of PRECM consists of three factor of complexity (i) computational complexity ($Path^{\Theta}$) to obtain all possible paths, (ii) computation time complexity for selecting a reliable path ($\mathscr{R}_{\ell}^{\Theta}$), and (iii) running time for the PRECM.

The $Path^{\Theta}$ of PRECM for the undirect graph (G) with a set of vehicles $V = \{v_a, v_b, v_c, \ldots, v_n\}$ and edges (e) could be determined by:

$$Path^{\Theta} = \mathscr{O}(V + e) \tag{18}$$

Assume that $\mathscr{R}_{\ell}^{\Theta}$ is a constant equal $\mathscr{O}(1)$. The cost of the computation complexity of $\mathscr{R}_{\ell}^{\Theta}$ for $\mathscr{N}$ path can be calculated as:

$$Cost\ \left(\mathscr{R}_{\ell}^{\Theta}\right) = \mathscr{O}(\mathscr{N}) \tag{19}$$

Assume that the complexity of the computation time that use to determine the path score of all paths is a constant equal $\mathscr{O}(1)$. The time complexity of PRECM for all available paths can be given as:

$$T_{|complexity} = \left(Path^{\Theta} + \mathscr{N}\right) \times \left(Cost\ \left(\mathscr{R}_{\ell}^{\Theta}\right) + Cost_{|total}\right) \tag{20}$$

$$T_{|complexity} = \mathscr{O}(\mathscr{O}(V + e) + \mathscr{O}(\mathscr{N} \times l)) \tag{21}$$

Based on Eqs. (20) and (21), the worst case of the complexity of PRECM can be calculated as follows:

$$T_{|complexity} = \mathscr{O}\left(V^2 + (\mathscr{N} \times l)\right) \tag{22}$$

5.2. Communication overhead

In the communication overhead, the energy consumption estimation ($\mathscr{O}E$) via network lifetime is the proportion of the energy consumed in transmitting control packets to that used for data packet transmission. Assume that the energy cost of network setup during one round r is $Cost\ E_{|setup}(r)$, and the energy cost of one complete data-gathering process during one round r is $Cost\ E_{|data-gathering}(r)$, wherein each *fn* transmits at least one packet to SDN for complete communication. For low communication overhead, the energy consumed in network construction must be significantly less than the energy consumed in the data-gathering process $Cost\ E_{|setup}(r) \ll Cost\ E_{|data-gathering}(r)$. Herein, it is possible to compute the ratio of energy overhead $\mathscr{O}E\%$ by:

$$\mathscr{O}E\% = \sum_{r=1}^{r_s} \frac{Cost\ E_{|setup}(r)}{Cost\ E_{|data-gathering}(r)} \tag{23}$$

5.3. Space complexity

Space of complexity (S^{Θ}) is determined by identifying all neighborhood in the network via V and all available paths $\mathscr{N}$ established among V. So, the S^{Θ} can be calculated by:

$$S^{\Theta} = \mathscr{O}(V + \mathscr{N}) \tag{24}$$

6. Estimation of network stability and lifetime

The major objectives of the different routing strategies used in VANET are to maximize network stability and longevity. As a result, network stability and the preservation of link quality among vehicles are tightly related. Whereas the lifetime of the network refers to maintaining the power of nodes up to survive a long period [6,18]. According to 4, all nodes of *fn* are linked to SDN at least once at the start of the connection, and the packet transmission process continues until the end of the stability period. The total power consumption in the negotiation operation between FOG and SDN can defined as follows:

$$\Delta E_{(fn,SDN)} = \begin{cases} l_m(fn_i, SDN_j)\left(\Delta E_{(trans|receive)} + \varepsilon_{mp} d^4(fn, SDN)\right) + \\ r_s p_{|size}\left(\Delta E_{(trans|receive)} + \varepsilon_{mp} d^4(fn, SDN) + \Delta E_{dagg}\right), \; d_{(fn_i, SDN_j)} \geq d_o \\ l_m(fn_i, SDN_j)\left(\Delta E_{(trans|receive)} + \varepsilon_{fs} d^2(fn, SDN)\right) + \\ r_s p_{|size}\left(\Delta E_{(trans|receive)} + \varepsilon_{fs} d^2(fn, SDN) + \Delta E_{dagg}\right), \; Otherwise \end{cases} \tag{25}$$

$$E_{(fn,SDN)} = \begin{cases} l_m(fn_i, SDN_j)\left(E_{(trans|receive)} + \varepsilon_{mp} d^4(fn, SDN)\right) + \\ r_s p_{|size}\left(E_{(trans|receive)} + \varepsilon_{mp} d^4(fn, SDN) + E_{dagg}\right), \; d_{(fn_i, SDN_j)} \geq d_o \\ l_m(fn_i, SDN_j)\left(E_{(trans|receive)} + \varepsilon_{fs} d^2(fn, SDN)\right) \\ + r_s p_{|size}\left(E_{(trans|receive)} + \varepsilon_{fs} d^2(fn, SDN) + E_{dagg}\right), \; Otherwise \end{cases} \tag{26}$$

The Δ denotes the various degrees of *fn*. The $E_{(trans|receive)}$ denotes the energy consumption in the case of sending and receiving data. ε_{mp} denotes the propagation of multipath, and ε_{fs} denotes the propagation of free space. d^4 denotes the multipath fading (power loss), and d^2 denotes the free space (power loss). $P_{|size}$ denotes the estimation of data packet size. r_s denotes the time taken to network stability. d_o denotes the allowed threshold distance from *fn* to *SDN*. E_{dagg} denotes the power consumption in the case of data aggregation. The network topology does not substantially change after network stability has been obtained. Due to the enormous amount of data that must be transferred through the internet, energy losses continue to be a bottleneck. As a result, the proposed PRECM's usefulness has been demonstrated.

From the perspective of the network lifetime, the stability of the route denotes the link's capacity to be endured for a long time without failure. Herein, the link's capacity does not affect the period of the network stability but also the effectiveness of the communication operation and the lifetime network topology. In this case, we calculate the period of network lifetime for all nodes of *fn* that was already declared as *FH*. $link_{c|\max}$ indicates the link capacity in case the connection through (*FH*, SDN) is established. Therefore, the lifetime of the network is defined based on Eqs. (25) and (26) as follows:

$$E_{|init} = \begin{cases} l_m(fn_i, SDN_j)\left(2E_{(trans|receive)} + \varepsilon_{mp} d^4(fn, SDN) + FZ^4_{areai}\right) \\ \quad + r_s p_{|size}\left(E_{(trans|receive)} + \varepsilon_{mp} d^4(fn, SDN) + E_{dagg}\right), \\ \quad \left(FZ, d_{(fn_i, SDN_j)}\right) \geq d_o \\ l_m(fn_i, SDN_j)\left(2E_{(trans|receive)} + \varepsilon_{mp} d^2(fn, SDN) + FZ^4_{areai}\right) \\ \quad + r_s p_{|size}\left(E_{(trans|receive)} + \varepsilon_{mp} d^2(fn, SDN) + E_{dagg}\right), \\ \quad d_{(fn_i, SDN_j)} < d_o \leq FZ \\ l_m(fn_i, SDN_j)\left(2E_{(trans|receive)} + \varepsilon_{fs} d^2(fn, SDN) + FZ^2_{areai}\right) \\ \quad + r_s p_{|size}\left(E_{(trans|receive)} + \varepsilon_{fs} d^2(fn, SDN) + E_{dagg}\right), \\ \quad Otherwise \end{cases} \tag{27}$$

7. Performance evaluation

7.1. Simulation setting

A discussion of simulation results along with our assessment tools is going to be introduced in this section. All setup has been conducted on the operating system Ubuntu 20.04.5 LTS that installed on the laptop with picked Intel's 10th Gen Core i7–1065G7 on the 15-inch Book 3, 32GB RAM, Nvidia GeForce GTX 1660 Ti Max-Q. Simulation of Urban Mobility (Eclipse SUMO) has been employed for monitoring the transportability speed of the vehicle [5], which was estimated between 15 Mph to 85 Mph as an average. Eclipse SUMO uses the .net file that was generated by the Netconvert tool [43], Fig. 8 shows the study area corresponds to the Giza, Egypt, which is 8 km^2. The Netedit tool uses to adjust the maximum vehicle speed on the road. Urban scenario parameters using Eclipse SUMO is illustrated in Table 5. A representation of the correlations between every pair in the topology of VANET besides modeling the entire topology has been simulated by using ns2.35 [44]. As an assumption, simulation time has been set to 1000 s, and for designing the network topology and generating VANET range from 10 to 100 nodes, a file named Tool Command Language (TCL) has been in a 6 × 6 Manhattan grid road network. The PRECM has been implemented on NS2.32. The entire configurations of the network have been demonstrated in Tables 6 and 7. The behavior of *fn* is configured by the reference guide called Fog Hierarchical Deployment Model from OpenFog Reference Architecture.

For assessing the proposed PRECM, a scale of traffic rates (Pkt/Sec) and vehicle speeds (km/h) has been prepared. For obtaining Constant Bit Rate (CBR) as a source of traffic between *fn* and the VANET, 10 communication connections were installed randomly. Every 2 s, a traffic agent Node-UDP and 512 bytes packets are generated via CBR. The connections of the network have been tested by passing the HELLO test message between *fn* and RSUs, and the interval time of the message was selected to be 1.5 s. Because of the probabilities of loss and possible collisions, details from a HELLO-delivered message have been retained for (2.5 × hellointerval) for each neighbor. Yet, it is in the identified *R* for every *fn* node. In Section 4.2.2, a configuration for the values of the constant-coefficient has been shown as: $\omega_1 = \omega_2 = \omega_3 \cdots = \omega_n \approx 1$.

7.2. Assessment metrics and discussion

Due to the obtained results, the proposed PRECM based on SDN, and Fog technologies has outperformed other competitive research in terms of the effectiveness of selecting the appropriate path and excessive data dissemination management over VANET. Enhancing the VANET performance via exploiting the network bandwidth and the rate of power consumption has been recognized due to the adoption of the proposed PRECM. Many assessment metrics have been used to evaluate the performance of PRECM, including normalized routing overhead, power consumption, network throughput, percentage of the delivered and loss of packets, and E$_2$E delay time. During 12S experiments, the performance of proposed PRECM has been tested against EMHR with BwEst [38], EERD [27], SFSR [17], and enhanced AODV [45]. The network setting for these modern algorithms vs. the PRECM is discussed in the Table 8. The upcoming sections discuss with analysis of the outperforming results according to applying PRECM versus other competitive proposals.

7.2.1. Impact PRECM in terms of routing overhead

At the beginning, capability of PRECM to deliver the data packet efficiently had to be measured through monitoring the ratio of the network control packets. Normalized Routing Overhead (NRO) has been exploited to study the impact of PRECM from this perspective. NRO can be obtained by applying the following formula Eq. (27):

$$NRO = P_{|fail} + T_{|meg} + Tri_{|meg} \tag{27}$$

Where $P_{|fail}$ represents the number of failed data packets that couldn't reach the destination, $T_{|meg}$ is the periodic messages, and $Tri_{|meg}$ represents the trigger messages for arriving at the packet to the destination.

For evaluating the strength of the proposed routing technique in the VANET network in terms of routing overhead avoidance problems, the efficiency of PRECM was tested on data traffic rate. As shown in Fig. 9 (a), the effect of adopting PRECM in VANET has been spotted on the rate of the data traffic. A comparative study has been conducted among

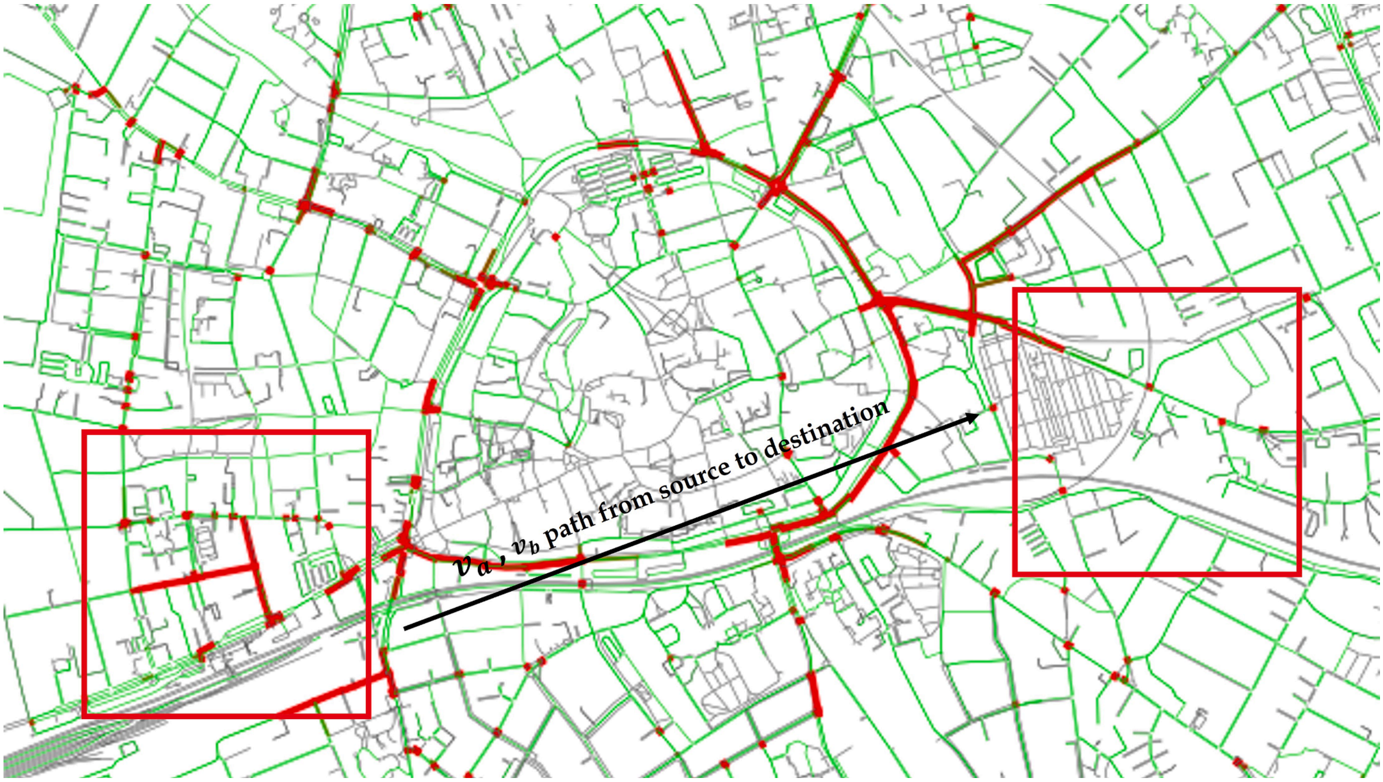


Fig. 8. Giza, Egypt study area (8 km^2).

Table 5
Urban scenario parameters using Eclipse SUMO.

Parameter	Value
Vehicle Number	100 vehicles
Simulation Time	1000 s.
Area	8 km^2
Avg. Speed	15 Mph to 85 Mph
Junction Number	65

Table 6
Topology setting.

Parameter	Value
Simulation tool	NS2.35
Vehicle range	1–100 vehicles
Simulation time	1000 s.
Transmission rage	150m
Mobility generator	SUMO
Propagation Model	Nakagami
Mobility model	Manhattan
Interface type	WirelessPhy
Channel type	WirelessChannel
Velocity	5, 20, 60 km/h
Number of seed	1
MAC protocol	IEEE 802.11p
Max. packet size	512-Byte
Traffic agent	Node-UDP
Energy model	Battery
Initial power	Random [0,1000] Joule
CBR	1 packet/s
Traffic type	CBR

different network systems before and after applying PRECMs. As shown in 9(a), applying PRECM introduced a level of excellence in terms of NRO reduction. Further comparisons between PRECM and other earlier routing algorithms such as EMHR with BwEst [38], EERD [27], and enhanced AODV proposed in [45] were delivered in Fig. 9(b). As can be seen in Fig. 9(b), noticeable improvement has been reached by PRECM versus the enhanced AODV protocol proposed in [45]. For avoiding the issues of the routing overhead, PRECM had come in the first place outperforming the enhanced AODV by a difference ratio estimated by 6%. PRECM's selection methodology along with its link capacity and sustainable stable path have ensured the advanced behavior of PRECM. PRECM has recorded a slight difference over EMHR with BwEst [38]. In this comparison, EERD [27] stuck to the third rank, while enhanced AODV was the fourth and last ranked. Affirmatively, the performance of the routing protocol is highly affected by the speed of the vehicle. So, the NRO ratio is directly proportional to the average vehicle speed.

Table 7
IEEE802.11p configuration [42].

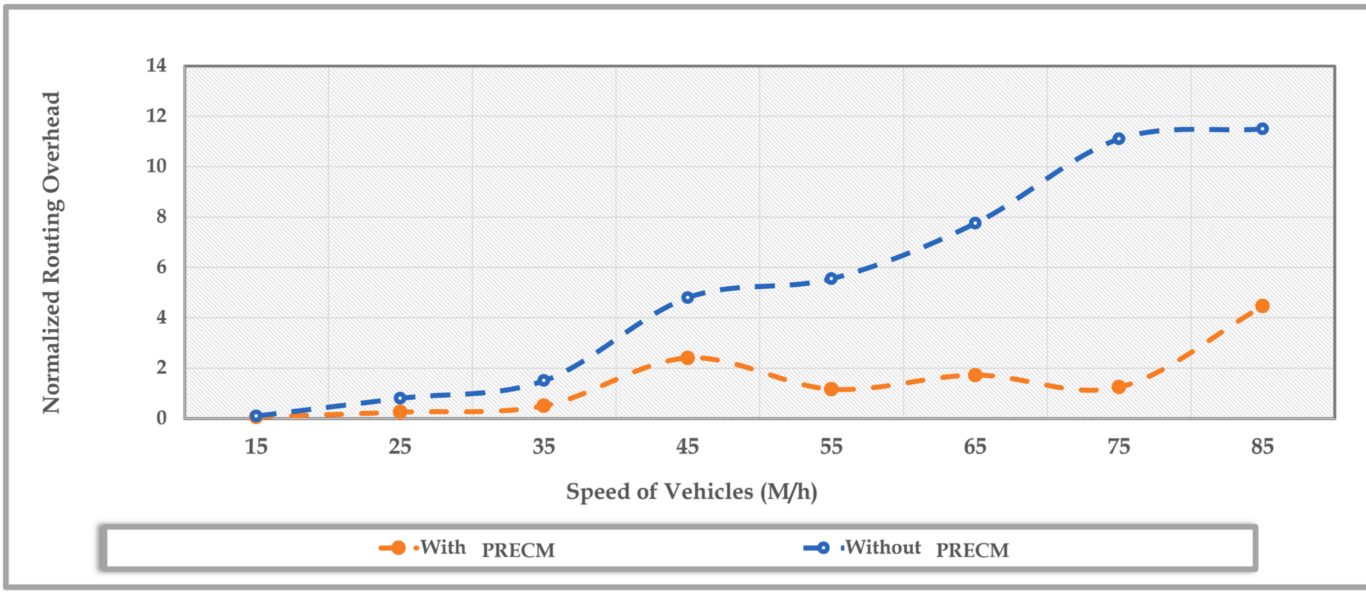
Parameter	Value
Center Frequency	5.875 GHz
Receiver sensitivity	- 95.2 bBm
Network Bandwidth	10 GHz
Antenna Gain	2 bBi
Channel	175
Setup TxPower	23 bBm/18 bBm

7.2.2. Impact precm in terms of power consumption

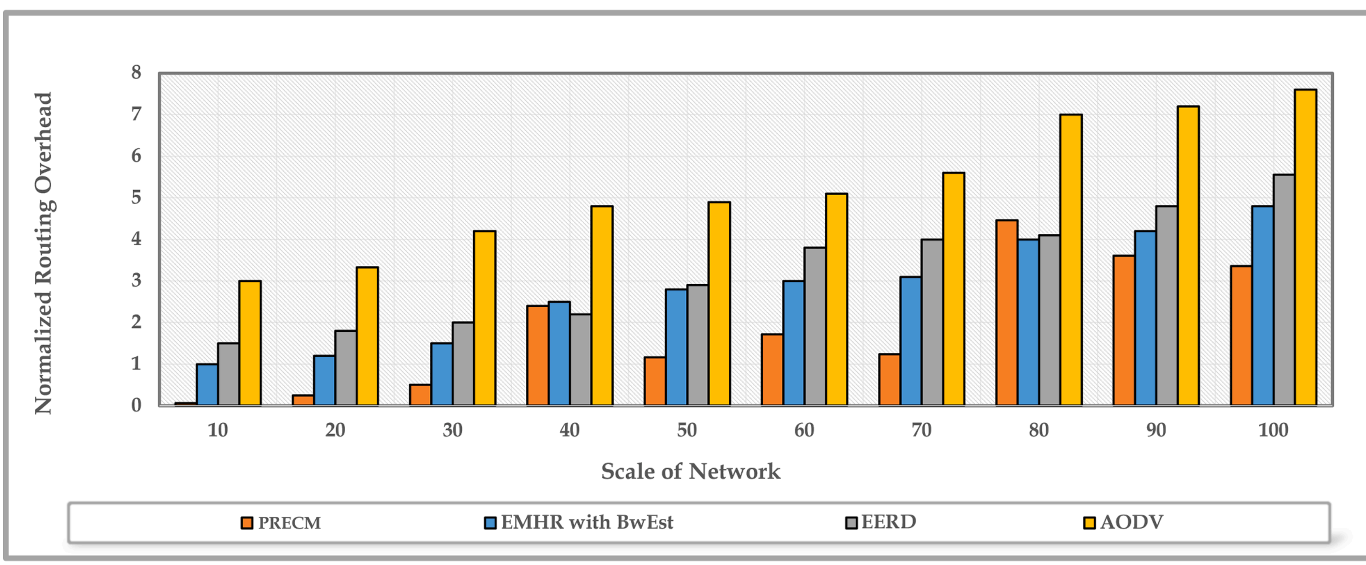
Path optimization was not the only judging metric for testing the quality of PRECM. On the other hand, further analysis has been delivered to evaluate the performance of the proposed routing algorithm considering power conservation regarding the data transmission factor. PRECM has been employed for decreasing the overall consumed energy in BS via a wireless radio network. Additionally, normalization to the number of roadside sensors is applied in VANET. Fig. 10(b) shows that maximum energy depletion has been reached by AODV, while the minimum value has been achieved by PRECM with an enhancement estimated by 7% for PRECM regarding the overall consumed power.

Table 8
Network setting for all algorithms used in our experiments.

Algorithm	Network Scale	Packet size	Mobility Model	Propagation Model	MAC Specification	Simulation Tool
EMHR with BwEst [38]	15–100	512	Manhattan	Nakagami	IEEE 802.11p	NS3
EERD [27]	10–100	512	Manhattan	Shado	IEEE 802.11p	NS2
SFSR [17]	50–150	512	–	–	IEEE 802.11p	NS2
Enhanced AODV [45]	10–100	512	Manhattan	Nakagami	IEEE 802.11p	NS2
Our Proposed PRECM	10–100	512	Manhattan	Nakagami	IEEE 802.11p	NS2



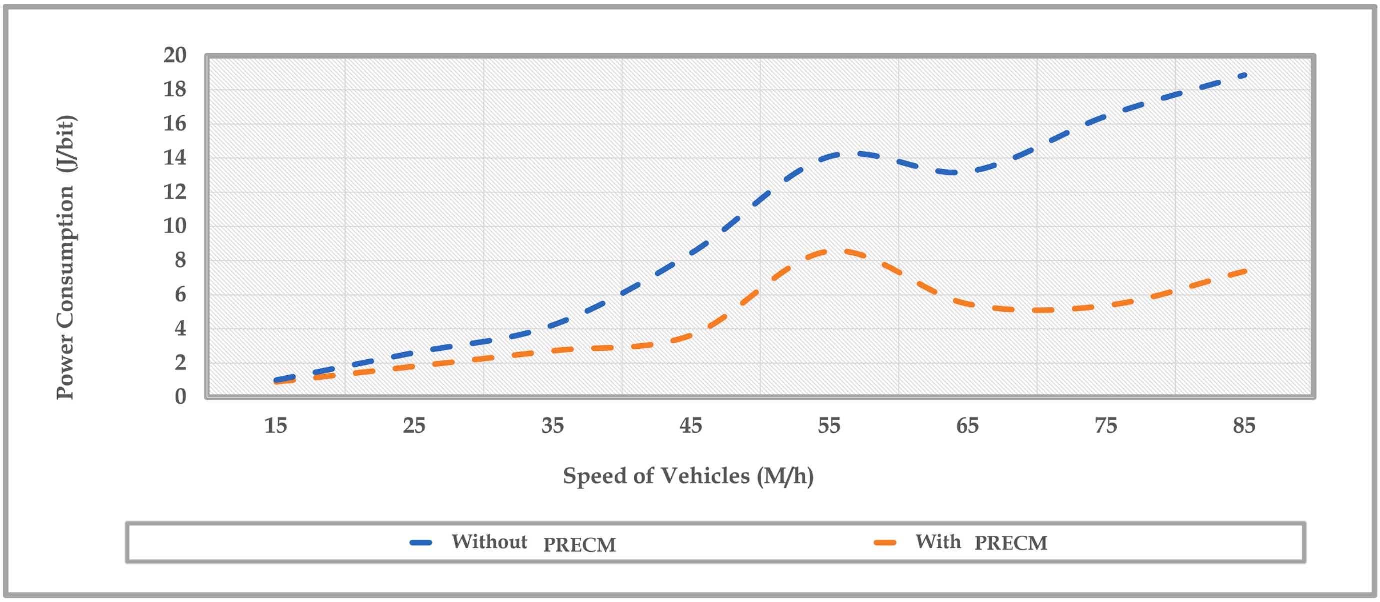
(a)



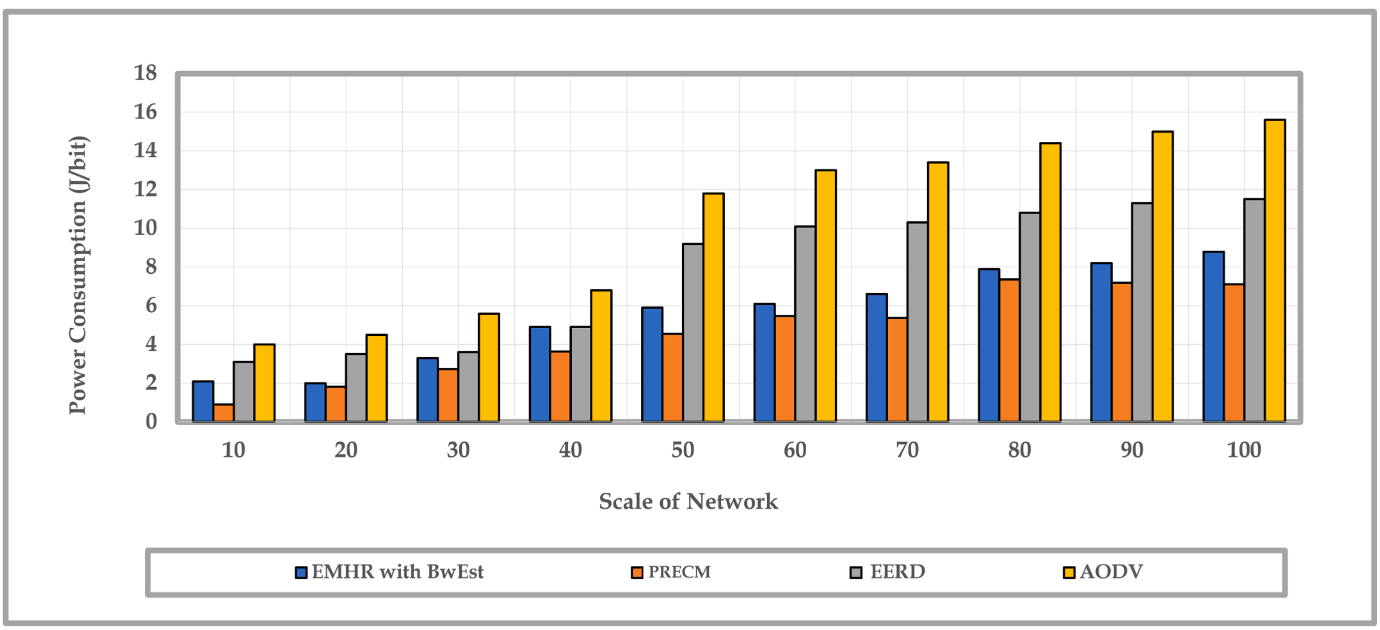
(b)

Fig. 9. The performance of PRECM in term of NRO is tested in Figure (a). The efficiency of PRECM against EMHR with BwEst, EERD, and AODV vs. the VANET scale is tested in Figure (b).

Fig. 10(a) and (b) show the improvement that took place in the consumed power rate achieved by PRECM because of setting SDN and fog server nearest to the requests of the vehicles. Localized data processing and the minimum rate of data transmission along with an efficient computing model can be guaranteed by adopting the fog computing concept with SDN. The PRECM has provided the minimum packet loss in VANET with close scores recorded by EMHR with BwEst. Values recorded by PRECM, EMHR, and BwEst were significant compared with those scored by EERD [27] and AODV [45]. Eventually, PRECM outperformed other state-of-the-art algorithms such as EMHR with BwEst [38], EERD [27], and enhanced AODV [45] to introduce a data computing system with minimum power consumption.



(a)

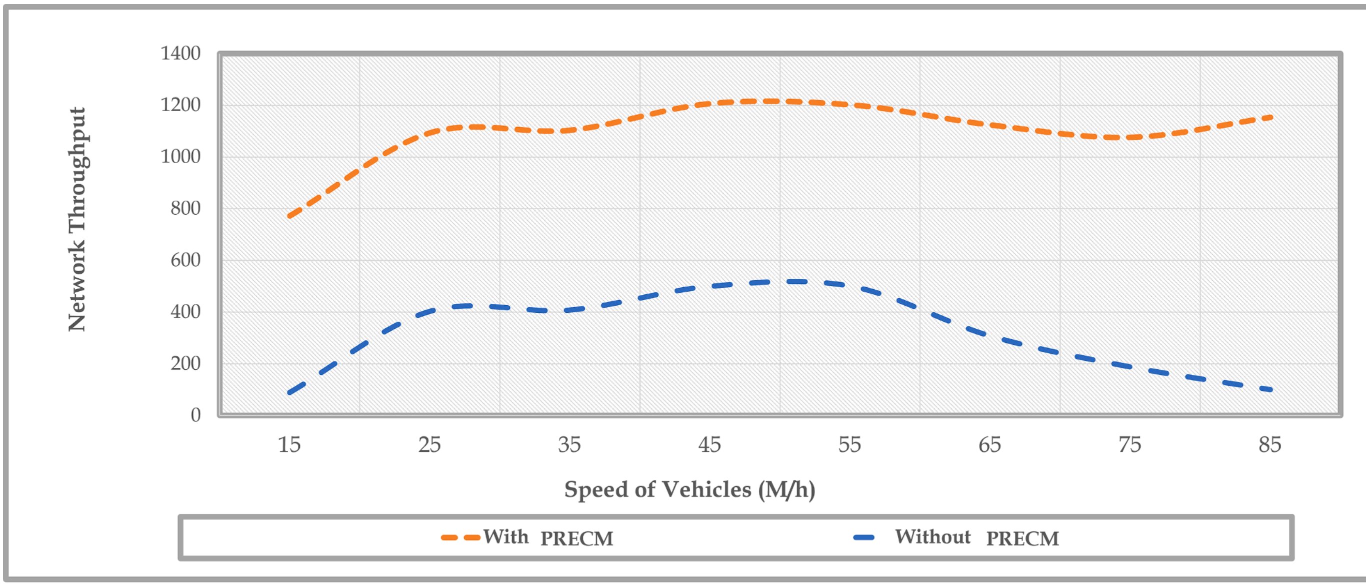


(b)

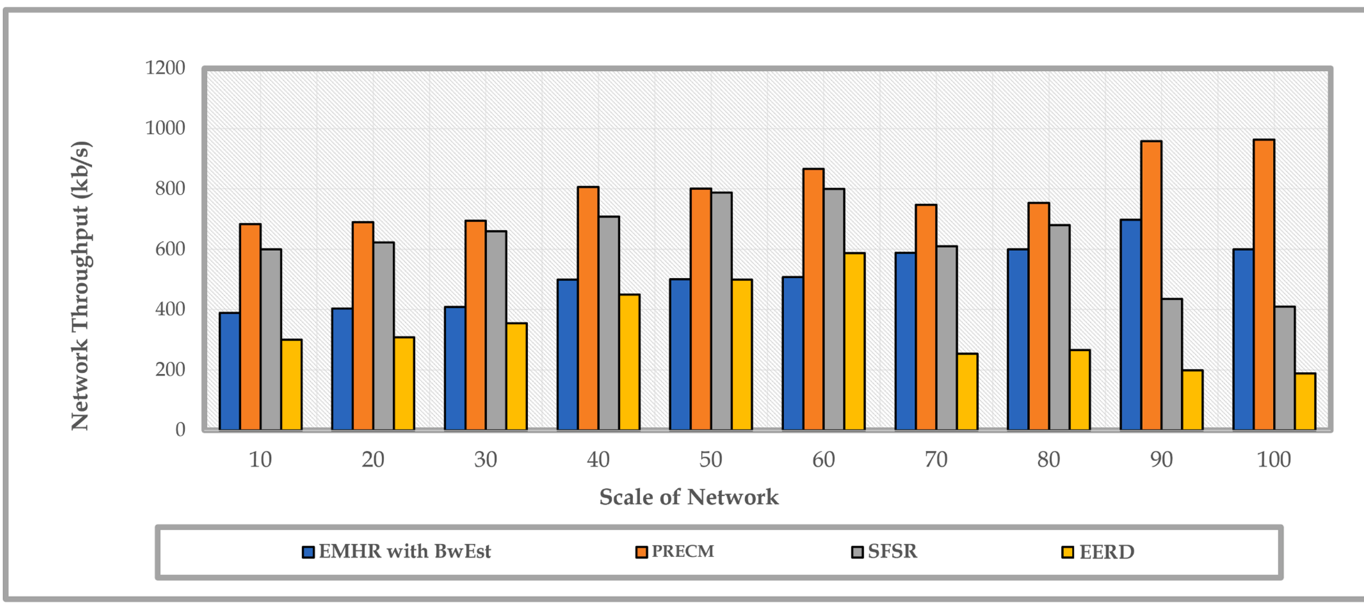
Fig. 10. The performance of PRECM in term of power consumption is tested in Figure (a). The efficiency of PRECM against EMHR with BwEst, EERD, and AODV vs. the VANET scale is tested in Figure (b).

7.2.3. Impact precm in terms of network throughput

An evaluation of the effectiveness of the proposed routing algorithm considering link quality and network bandwidth is going to be demonstrated by monitoring the network throughput. As shown in Fig. 11(a), vehicles' speeds varying from 15 to 85 Mph are represented on the x-axis by adjusting the network bandwidth at 10 MHz and representing the network throughput on the y-axis. The obtained results revealed PRECM has outperformed other state-of-the-art vehicular systems, hence this maintains the network bandwidth controllable. High link quality which guarantees the lowest interference rate provided by PRECM is the main reason behind this outstanding performance of PRECM. A comparative analysis between PRECM versus EMHR with BwEst [38], SFSR [17], and EERD [27] in terms of the average throughput of the network can be found in Fig. 11(b). The scale of the VANET network (ranging from 10 to 100) was represented on the x-axis, while average network throughput was represented on the y-axis as can be seen. Local data processing operations of PRECM raise the likelihood of keeping the bandwidth controllable all the time. Thus, PRECM's quality in terms of the network throughput has outperformed that achieved by other traditional algorithms. It was observed that SFSR was relatively the closest algorithm to PRECM regarding the network throughput. EMHR with BwEst has been ranked in third place due to the exercised bandwidth estimation module that goes to define the packet size in advance, which leads to successful throughput packet normalization. Finally, the last rank has been occupied by the EERD. Owing to its capability to provide packet size control and high-quality network links, PRECM outperformed other algorithms in terms of network throughput despite not introducing techniques for packet normalization.



(a)



(b)

Fig. 11. The performance of PRECM in terms of Throughput is tested in Figure(a). The efficiency of PRECM against EMHR with BwEst, SFSR, and EERD vs. the VANET scale is tested in Figure (b).

7.2.4. Impact precm in terms of on delivery and loss of packets

It is crucial to demonstrate packet delivery success with the lowest loss ratio while evaluating the dependability of PRECM data transmission. Fig. 12 approximates the performance of PRECM with other algorithms in terms of packet delivery and packet loss ratio. The x-axis in Figs. 12(a) and (c) depicts the range of vehicle speeds from 15 to 85 Mph, while the y-axis shows the average data packet delivery (Pkt/*sec*) in Fig. 12(a), however, it shows the packet loss ratio (Pkt/*sec*) in Fig. 12 (c). Fig. 12(a) shows a comparison between the network system before and after applying PRECM. As can be noticed, the link quality and the method of selection adopted by PRECM lead to the outstanding performance of PRECM over the conventional vehicular system in terms of successful data packet delivery that works on avoiding data packet loss.

Fig. 12(b) and (d) show a comparison between our proposed algorithm and other state-of-the-art algorithms for a crystal view of the effect of PRECM. The range of vehicles number is represented by x-axis in both Fig. 12(b) and (d), while packet delivery ratio (Pkt/*sec*) number is represented by y-axis in Fig. 12(b), however packet loss ratio (Pkt/*sec*) is represented by y-axis in Fig. 12(d). The proposed algorithm affects the vehicular network positively and outperforms earlier algorithms such as EMHR with BwEst [38], SFSR [17], and enhanced AODV [45] regarding data delivery and packet loss. The excellence of PRECM over the mentioned algorithms has been achieved owing to three reasons. Firstly, service provider identification is brought by the supported selection methodology which causes enhanced oriented vehicular services. Secondly, frequent monitoring for the entire set of the registered nodes in the local zone by SDN as a routing method adopted by PRECM enhances the decision-making process by the routing algorithm in PRECM. Thirdly, link quality with low interference by PRECM enhances the usage of the network bandwidth. It can be deduced that through the conducted experiments, PRECM achieved the best data delivery without loss due to its network bandwidth maintainability versus other traditional algorithms. As well, it is worth mentioning that PRECM has a stable performance against vehicle speed variations.

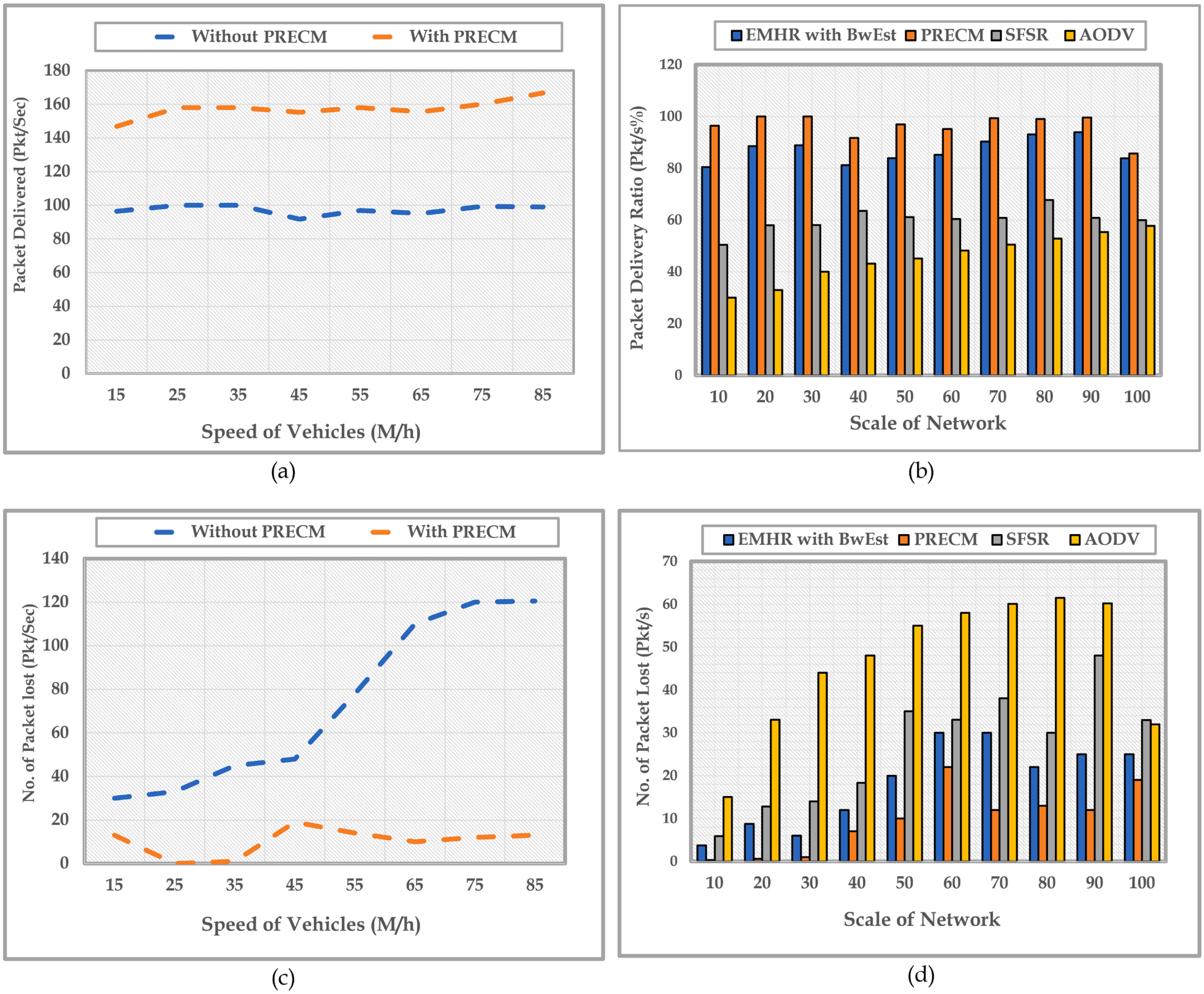


Fig. 12. The performance of PRECM in terms of on delivery packet is tested in Figure(a). The efficiency of PRECM against EMHR with BwEst, SFSR, and EERD vs. the VANET scale is tested in Figure (b).

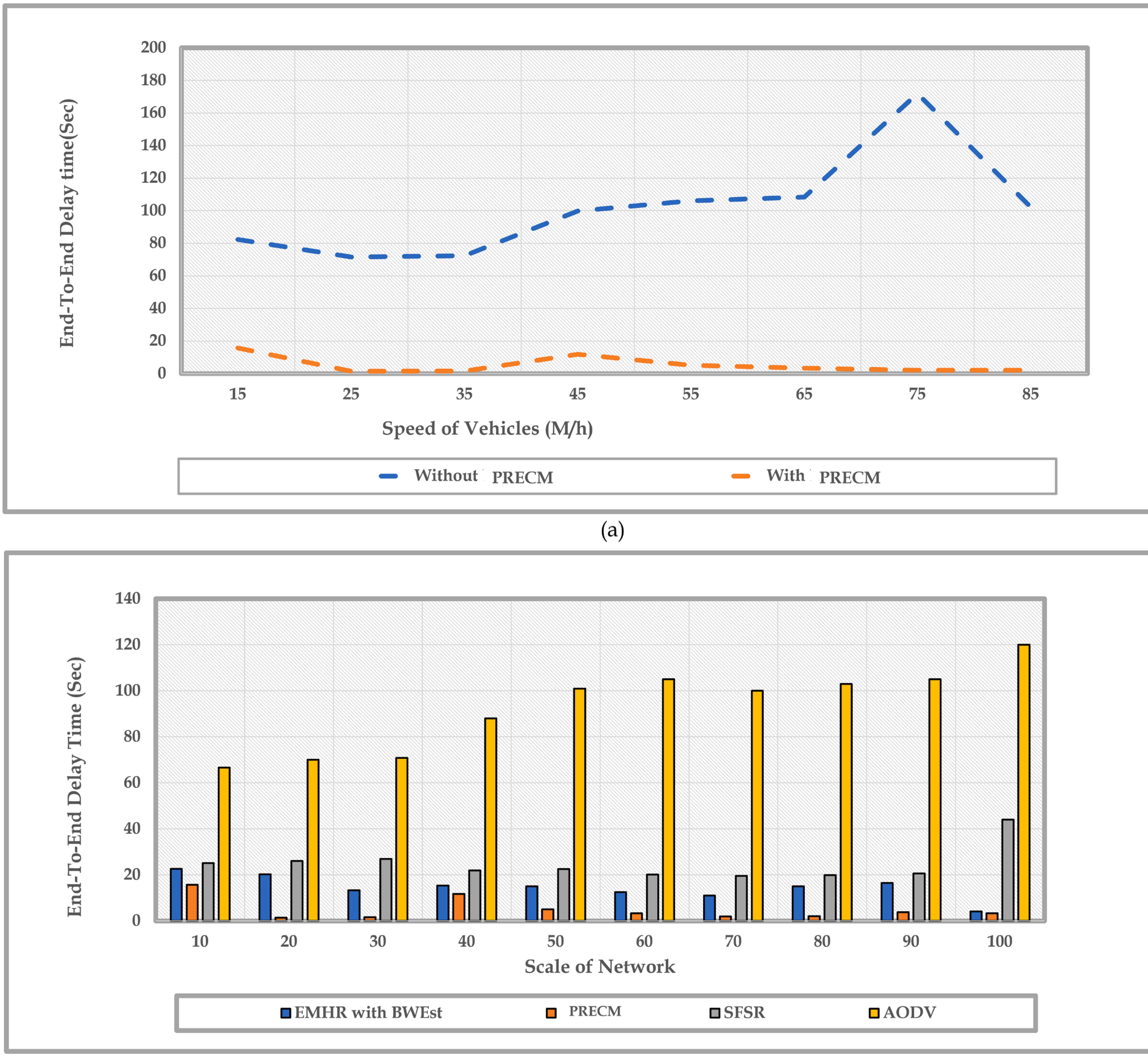
7.2.5. Impact PRECM in terms of delay time

The final assessment of the effectiveness of PRECM can be performed by evaluating network latency as a crucial performance metric. The average time consumed for transmitting the data packet between two nodes over the network can be considered as the E_2E delay time. As well as the consumed time for sending a packet of data from the source node and reaching the destination successfully with all the possible delays because of processing, reservations, and acquisition of the available routes in the network or even the buffering [46]. As shown in Fig. 13(a), the speed of the vehicles varying from 15 to 85 Mph has been represented on the x-axis. The average E_2E delay time or latency for transmitting the packets of data has been represented on Y-axis. Fig. 13(a) displays a clarification of the performance of VANET before and after adopting PRECM. PRECM was superior to other conventional methodologies in terms of transmitting the data packets over the network due to its ability to adjust the packet size and the communication channel improvements resulting from providing high link quality.

VANET scale varying from 10 to 100 nodes has been represented on the x-axis, while the average E_2E delay is represented on the y-axis in Fig. 13(b). For validating the performance of PRECM algorithm, a comparative study was conducted between PRECM and EMHR with BwEst [38], SFSR [17], and AODV [45]. Computing E_2E delay time is counting on the delay time average for all the data packets that have crossed the journey from the source to the destination successfully. Hence, packet loss ratio and packet delivery are the judging factors for obtaining this metric which illustrates the outperforming performance of PRECM regarding the delay time rather than other compared algorithms. As shown in Fig. 13(b), PRECM was achieved a significant improvement in terms of the E_2E delay time that estimated by 7%. EMHR with BwEst [38] comes in the second order with an enhancement estimated by 6% on SFSR [17], and AODV [45]. As can be noticed, PRECM has outperformed EMHR with BwEst, SFSR, and enhanced AODV in terms of latency reduction. Furthermore, PRECM introduced the stable performance with network scalability changes.

8. Conclusion

Despite of ST brought to urban transportation systems, challenges including power consumption, network bandwidth, and response time have been appeared due to adopting modern information and communication technologies to upgrade their services. This paper presents a real-time integrated dynamic framework for vehicle interaction that



(a)

(b)

Fig. 13. The performance of PRECM in terms of E_2E delay time is tested in Figure (a). The efficiency of PRECM against EMHR with BwEst, SFSR, and AODV vs. the VANET scale is tested in Figure (b).

supports the alliance between fog computing and SDN technologies with an effective path detection facility. Moreover, it introduces an energy-optimized routing algorithm with QoS awareness for taking control of periodic fragmentation, shorter network lifetime, and network bandwidth usage across vehicular networks. An entire improvement in the real time performance with controlling the data dissemination rate in VANET is achieved successfully owing to the proposed approaches. The experimental results show that the proposed DVA-SDNF framework has an outstanding performance that gets over the mentioned challenges by adopting the concept of integration between SDN and fog technology which efficiently adjusts the data transmission rate. The performance of the DVA-SDNF framework has been verified by conducting a set of experiments.

Another contribution in this study has been introduced by implementing a new routing algorithm called PRECM that employs an efficient mathematical model ensuring an effective performance for VANET link quality in terms of network throughput, data packet delivery, and power consumption along with controlling the normalized routing overhead. As a result, PRECM affects packet loss rate and data packet delivery and enhances the entire consumption of power exceeding other traditional algorithms by a percentage estimated by 62% to 70%.

Additionally, the proposed routing protocol is a dual-phase protocol with 90% of SDN data packet delivery ratio and 82% of SDN data loss reduction. Therefore, when the SDN fails to deliver packets, the proposed position-based routing handles them as a parallel mechanism of SDN.

Future work will explore the modification of our proposed framework to consider increasing network performance by applying machine learning and deep learning on a real dataset. Moreover, increasing the network scale with different values of packet size (i.e., 127, 512, 265, 1024) are also required to make the proposed framework more effective.

Data availability

Data available on request due to ethical restrictions. The QoS metrics that are used in this paper are available on the following public link: https://github.com/Z-HAli/Awk-Files.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Zainab H Ali is a lecturer at Embedded Network Systems Technology Department, Faculty of Artificial Intelligence, Kafrelsheikh University. In 2021, she participates in teaching at the Faculty of Graduate Studies for Statistical Research, Cairo University. Zainab did her Ph.D. and master's degree in telecommunication networks particularly, the vehicle transportation and Internet of Things (IoT) field in 2016 and 2020 respectively.

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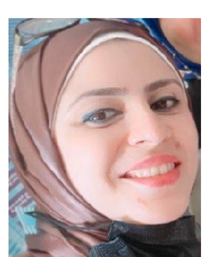

Noha **Sakr** received PhD. and MSC degrees in Computer Science and Control Systems from MU (Mansoura University, Egypt) in 2016 and 2010 respectively. Since 2016 she works as a Lecturer in the Computer Science and Control Systems Department in the Faculty of Engineering, Mansoura University. Her research interests include algorithms, data structures, big data applications, image processing, text mining, and information retrieval.

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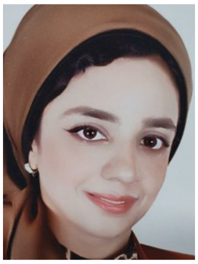

Nora Mahmoud El-Rashidy is a lecturer at Machine Learning and Information Retrieval Department, Faculty of Artificial Intelligence, Kafrelsheikh University. She received PhD. and MSC degrees from the Faculty of Computer Science and Information, Mansoura University, Egypt in 2020 and 2016 respectively. Machine Learning and Information Retrieval department, Faculty of Artificial Intelligence, Kafrelsheiksh University, Kafrelsheiksh, Egypt.

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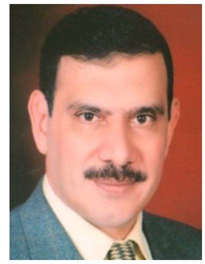

Hesham Arafat Ali is a Prof in Computer Engineering and systems and an associated Prof. in Information systems and associated Prof. in computer Engineering. Faculty Artificial Intelligence, Delta University for Science and Technology, Gamasa 35,712, Egypt. He received a BSc in electrical engineering (electronics), and MSc and PhD in computer engineering and automatic control from the Faculty of Engineering, Mansoura University, in 1986,1991 and 1997, respectively. He was assistant professor at the University of Mansoura, Faculty of Computer Science In 1997 up 1999. From January 2000 up to September 2001, he was joined as Visiting Professor to the Department of Computer Science, University of Connecticut, Storrs. From 2002 up to 2004 he was a vice dean for student affair the Faculty of Computer Science and Information, University of Mansoura. He was awarded with the Highly Commended Award from Emerald Literati Club 2002 for his research on network security. Since 2003 he has been an associate professor at the Computer Engineering Department, Faculty of Engineering, University of Mansoura. He is a founder member of the IEEE SMC Society Technical Committee on Enterprise Information Systems (EIS). He has many book chapters published by international press and about 160 published papers in international (conf. and journal). He (supervised and co- supervised) more than 50 students for (M *Sc* and PhD degree). He has served as a reviewer for many high-quality journals, including Journal of Engineering Mansoura University. International Arab Journal of Information technology- The International Journal of Information Technology and Web Engineering- The Journal of Computers (JCP)- International Journal of Information Processing and Management. His-interests are in the areas of network security, mobile agent, Network management, Search engine, pattern recognition, distributed databases, and performance analysis.

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