Self-Adaptive Efficient Dynamic Multi-Hop Clustering (SA-EDMC) Approach for Improving VANET's Performance

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Abstract—Vehicular ad hoc networks (VANETs) are mainly used in the intelligent transportation field for smart applications. VANETS received maximum concentration among the researchers in academic research. Providing traffic safety at the time of high mobility in the network is a major issue. Also, it consists of a few general issues namely self-organization, link failure, and speedy variation in topology. To address this issue, we developed a novel approach namely, the Self-Adaptive Efficient Dynamic Multi-Hop Clustering (SA-EDMC) approach which is designed to reduce the delay and energy consumption in the VANETs that lead to an increase in the efficiency, and overall Quality of Service (QoS) of the network. This approach is composed of four parts (1) network construction, (2) prime cluster head selection, (3) dynamic prime CH selection, and (4) gateway creation. A network simulator is utilized to demonstrate the behavior of our SA-EDMC approach. The simulation evaluation exhibits that our proposed work achieved a high packet delivery ratio, low delay, and high throughput when compared with earlier research outputs like MCA-V2I and QMM-VANET. The comparative analysis expressed that the performance of the proposed SA-EDMC is ~5% increase in packet delivery ratio, produced 300 to 500 kbps extra throughput compared with the earlier methods and delay is comparatively low.

Keywords—ITS, traffic safety, Multi-Hop Clustering, dynamic clustering, Quality of Service and VANETs

1 Introduction

Vehicular Ad-hoc Networks (VANETs) was launched in the year 2001as a special type of mobile ad hoc network with Intelligent Transportation System (ITS) [1]-[2]. Vehicles maintain a speedy communication range to connect to the mobile network as so to share the data between them. The major type of communication is vehicle to vehicle (V2V) and Vehicle to Infrastructure (V2I) communication. In addition, multi-hop communication is done through roadside units (RSUs) [3]. Several drawbacks are identified from the various earlier studies such as traffic efficiency, traffic safety, connectivity, reliability, and flexibility [4]. Due to the huge mobility of the vehicles, the network topology is highly dynamic in nature which results in unstable connectivity. The major requirement of the VANETs application is the creation of efficient and scalable routing protocols [5].

Traditional routing protocols such as Ad Hoc on-demand vector routing (AODV) and dynamic source routing (DSR) are not suitable for V2V communication [6]-[8]. Recently a Quality of Forwarding (QoF)-based reliable geographic routing (QFRG) in urban vehicular ad hoc networks (VANETs) is developed to improve the connectivity [9]. A few other routing algorithms such as an efficient parked vehicle assistant relay routing algorithm, Penicillium reproduction-based Online Learning Adaptive Routing scheme (POLAR), and Lévy fight-based discrete CSO (LF-DCSO) are developed [10]-[12]. To improve packet delivery probability in VANETs Machine Learning (ML) based algorithms are also introduced [13].

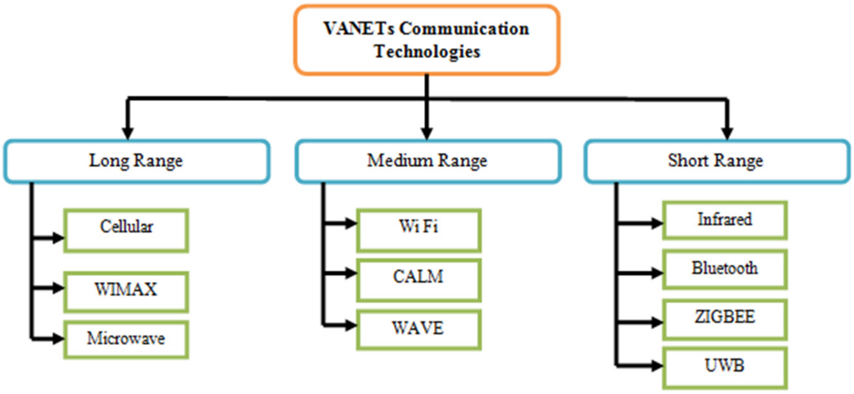

Fig. 1. VANETs communication technologies

2 Related works

Xiang Bi et al. [14] used the Affinity Propagation (AP) clustering approach with three scaling functions to improve the performance. The simulation results indicate the proposed algorithm provides better performance in terms of cluster stability, improved throughput, and low packet loss. Fakhar Abbas et al. [15] used packet delivery ratio and throughput as the evaluation criteria of the efficient clustering model. An efficient cluster-based resource management technique is developed for high mobility-based VANETs. The simulation proves that the performance of this model is affected by node density. Mustafa Banikhalaf et al. [16] CH lifetime, cluster member lifetime, and other variables as the evaluation factor for efficient routing. Here the author proposed a routing model namely Efficient Cluster Head Selection (ECHS) for realizable CH selection. Khalid Kandali et al. [17] developed a clustering-based routing protocol combining a modified K-Means algorithm with Continuous Hop field Network and Maximum Stable Set Problem (KMRP) for VANETs. Here K-Means algorithm is combined with clustering to develop an efficient Link Reliability Model. The author used the packet delivery ratio as the evaluation factor for routing efficiency.

Ravneet Kaur et al. [18] explain the latest communication technologies in VANETs and new designs to enhance the technologies of VANETs. Abdul Karim Kazi et al. [19] focus on minimizing the routing overhead to improve the packet delivery ratio of the network. This improvement is attained by creating a clustering technique using the geographical position and the reliability factor. This concept had better performance on overhead. Takashi Koshimizu et al. [20] presented a sophisticated clustering mechanism for cellular systems to provide effective communication between huge numbers of mobile Machine Type Communication (MTC) objects. The author proposed Normalized Multi Dimension-Affinity Propagation Clustering (NMDP-APC) approach and applied it to cluster-based VANETs.

Peixoto et al. [21] presented a scheme to monitor the network traffic information in vehicular networks. Two methods are used in this scheme namely (i) an ordinary traffic congestion detection approach and (ii) two adapted clustering methods such as the Ordering Points To Identify the Clustering Structure (OPTICS) and the Density-Based Spatial Clustering of Applications with Noise (DBSCAN). This method results in the creation of effective traffic conditions with reduced communication costs. Muhammad Asim Saleem et al. [22] presented a fuzzy-based CH selection for CR technology-based VANETs. A stable and reliable CH is elected by this method. The effectiveness of the proposed approach is analyzed in the simulation and it has better performance on network lifetime and efficiency. Singh et al. [23] have developed a clustering-based VANET network with Vehicle to Vehicle (V2V) communication. The author proposed a graph-based algorithm to considerably improve the V2V connectivity of clustering-based VANET. Oussama Senouci et al. [24] introduced a novel multi-hop clustering method in the vehicle to internet-based network mainly to improve the network performance in the condition of dynamic topology. The idea is implemented in NS2 with a VanetMobiSim environment. This model provides good results in terms of lifetime, packet success ratio, and latency but throughput is not concentrated in this research. Fatemidokht [25] presented a clustering-based routing protocol namely QMM-VANET to improve the overall QoS of the network. The main challenge which is concentrated in this work is link failure due to speedy change in topology. The simulation is done in NS2 and the protocol achieves a high delivery ratio and low delay but energy is not concentrated in this research. To overcome the drawbacks of the earlier research, in the proposed work a self-adaptive efficient dynamic multi-hop clustering approach is developed to improve the performance of the VANETs.

3 Assumptions

In this section, VANETs architecture is designed and the supporting models such as the network model and vehicle model are elaborated.

3.1 Network model

A few assumptions are followed here to construct the network model. At the initial condition, each vehicle maintains its ID, which contains the MAC address and interface details. Secondly, the network includes three roads and four lanes present on all the roads. At last, RSUs are present in the essential places to cover the entire network and we assume that L represents the length of the road. The RSUs counts are fixed according to the following equation.

$$C_{RSU} = \frac{L}{4} \tag{1}$$

3.2 Vehicle model

The proposed system vehicles were intelligently equipped with communication capability, effective multi-sensors, computational entity, and Internet Protocol (IP). It becomes well-organized to work in several vehicular and transportation applications. Here every vehicle maintains its ID and has a navigation system with a Global Positioning System (GPS). GPS is used to get mobility information as well as geographical location. An on-Board Unit (OBU), Road Side Unit (RSU), and Application Unit (AU) are equipped with the entire vehicle. A single Dedicated Short-Range Communications (DSRC) channel is used in the wireless transceiver of the vehicle which can able to communicate around 300 meters surroundings.

3.3 Vehicle architecture

The architecture of the proposed work is illustrated in Figure 2. The main unit of the model is Vehicles, OBUs, Gateway, Trusted Authority, and Internet, cloud network. Vehicles are the model nodes outfitted with a GPS device. OBUs are embedded in the vehicle which helps the vehicle to communicate in the wireless medium. Its general standard is Wireless Access in Vehicular Environment (WAVE) with the MAC standard of IEEE 802.11p. In this architecture, fixed Gateways are present which helps to access the support system like Internet, Cloud network, and Trusted Authority. The trusted authority will act as an interface between the real world and the support system. Cloud Network acts as a virtual server with standard server features. It finally stores all the information and resources. The types of communication which are taken into consideration are V2V communication, V-to-Gateway Communication, Gateway-to-V communication, and V2I communication via Gateway and Trusted authority.

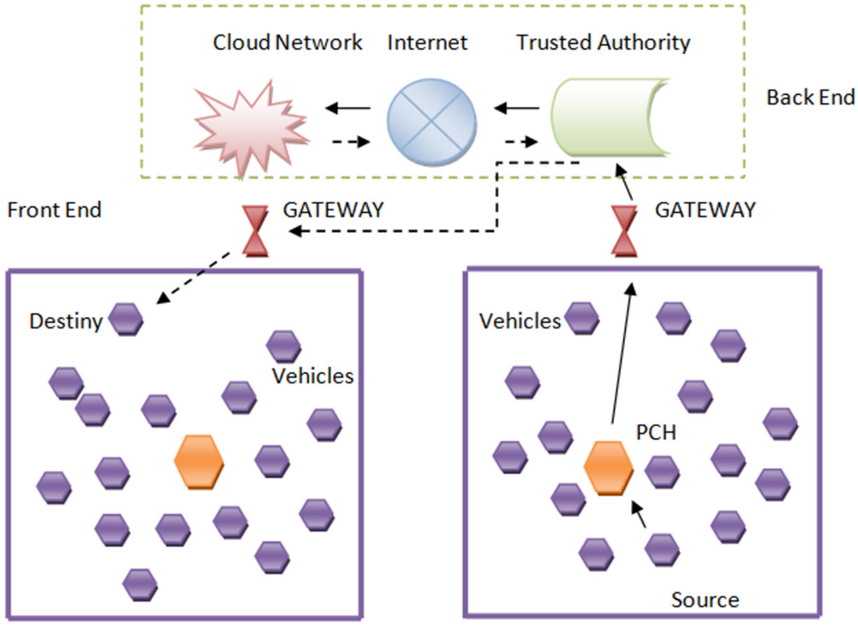

Fig. 2. VANET system architecture

4 Self-adaptive efficient dynamic multi-hop clustering approach (SA-EDMC)

To enhance the VANET network performance we introduced a novel approach in this section namely Self Adaptive Efficient Dynamic Multi-Hop Clustering Approach (SA-EDMC). The main aim of this approach is to accomplish our clustering model in the network with the assistance of internet access. As so to perform the clustering operation we need to maintain the multi-hop neighbors using the mobility model. In SA-EDMC, Mobility Rate (MR) is calculated for the entire vehicle in the network and the network with low MR is chosen as a Prime-CH (PCH). Simultaneously, Backbone CH (BCH) is also selected to enhance stability. Our proposed approach is subdivided into the following phases. They are the registration phase, hop node selection, PCH election, dynamic PCH election, Gateway election, and maintenance.

4.1 Registration phase

At the initial condition, for each new vehicle entry, the OBU is turned on. At the same time gateway transmits the hello information which consists of ID and vehicle location. The vehicle those who are present inside the coverage area of the gateway will receive the information and it sends registration information to the support system and the gateway. Once receiving the registration information, the gateway forwards that information to the trusted authority for address confirmation.

4.2 Neighbor discovery

A periodical BEACON message is created from each vehicle to claim its existence to its hop nodes. This message consists of an ID, location, transmission range, etc. Once after collecting the BEACON message from the selected hops, the mobility rate calculation is done as per the mobility model. Now each vehicle saves its clustering records and transmits them to the support system using the gateway.

4.3 Prime-CH (PCH) election and cluster formation

PCH selection. PCH is the master CH that controls the overall cluster operations in that particular cluster. Each cluster consists of a PCH. The selection process of PCH is given in a systematic manner below. At the initial stage, the network is divided into four different segments considering the direction, velocity, and stability of the groups. The angle between the velocity of vehicles is defined as θ_{sv} ($s, v \in [1, V]$) of the vehicle 's' and 'v'. In case if $\theta_{sv} \in [-\frac{\pi}{2}, \frac{\pi}{2}]$ and vehicle 's' and 'v' travel in a similar path. The velocity of the vehicles (1, 2, 3…n) is (v_1, v_2,…v_n) correspondingly. The angle between the vehicles is analyzed. The main values are $\theta_{24}, \theta_{25}, \theta_{26} \in [-\frac{\pi}{2}, \frac{\pi}{2}]$ and $\theta_{27} \in [-\frac{\pi}{2}, \frac{\pi}{2}]$, so vehicle 2 has the same path as vehicles 4, 5, and 6 but vehicle 7 travel in a different path.

In this PCH selection process to preserve the cluster stability, the PCH must maintain a similar direction, position, and velocity with normal vehicles in that area as well as it must contain more neighbor vehicles. Primarily the principal factor P(s) for vehicle s is described in equation 2. The vehicle s arbitrarily generates its individual $p(s) \in (0,1)$. In case the p(s) = P(s), then the vehicle s is chosen as a PCH.

$$T(s) = \frac{1}{V_s + 0.5} \times \frac{1}{G_s + 0.5} \times \frac{N_s}{100 \times N} \tag{2}$$

Where, N_s represents the Indistinguishable Direction Neighbor (IDN) counts of the vehicle s and V_s represent the Standard Deviation (SD) of the vehicle s where its IDN is described in equation 3, G_s represent the average geometrical distance among the vehicle s, where its indistinguishable direction neighbors are described in equation 4.

$$V_s = \sqrt[n]{\frac{\sum_{m=1}^{N_s} (|v_s| - |v_{sm}| \cos\theta_{sm})^2}{N_s + 1}} \tag{3}$$

$$G_s = \frac{\sum_{m=1}^{N_s} \sqrt{(x_s - x_m)^2 + (y_s - y_m)^2}}{N_s + 1} \tag{4}$$

Where, $|V_{sm}|$ represents the velocity of m^{th} IDN of the vehicle s, $\cos\theta_{sm}$ represents the cosine of the integrated velocity of vehicle s and its m^{th} IDN. If the velocities of both the current vehicles and the IDN are more or less similar then the probability of selection of PCH is high. After the process of vehicle initialization, the entire vehicle broadcast a Hello packet. The format of the Hello packet is shown in Figure 3.

preface	Transmit Time	Vehicle ID	Vehicle Location	Vehicle Velocity	Check List

Fig. 3. Hello packet format by vehicle

If the vehicle s collects the hello packet from any hop then it evaluates the direction of that vehicle is identical or not. If yes, then the vehicle s documents the collection time T_c as well as compared that with the transmit time T_t. If $T_c - T_t \geq t_{hn}$, vehicle s releases the packet, if not vehicle s document the data in its neighbor list. Here t_{hn} represents the waiting time for the neighbor's Hello packet.

Cluster creation. For assumption, V_n is the normal vehicle and V_{PCH} are the PCHs. Then the distance between the vehicle s ($s \in [1,V_n]$) and prime cluster head PCH_j ($j \in [1,V_{PCH}]$) is the minimum hop calculation among them and it is represented as HOP_{sPCHj}. If the vehicle s united in the j^{th} cluster, the PCH of the vehicle s is PCH_j as well as the distance among the vehicle s to PCH_j is represented as HOP_s

After the selection of PCH, it transmits the Selection packet as given in Figure 4. The transmit time is the time taken by the PCH to send the selection packet. PCH ID is the ID given to the prime cluster head. The location and velocity are the parameters for the PCH. Relay node ID is used to document all the additional details of the PCH. Hop count is the intermediate vehicle count among the PCH and the vehicle that collects the selection packet.

preface	Transmit Time	PCH ID	PCH Location	PCH Velocity	Relay Vehicles ID	Hop Count	Check List

Fig. 4. Selection packet format by PCH

Once the normal vehicle s collects the selection packet, it initially confirms whether $HOP \geq Max\_hop$ and Max_hop is not used already for the reason that one vehicle may collect many selection packets from various PCH. If yes, then the vehicle s releases the packet; or else it changes the selection packet by adding its ID to the relay nodes' ID which results in $HOP = HOP + 1$ as well as transmits that selection packet.

If vehicles collect more than one selection packet also it confirms that $HOP_{sPCH_j} \leq Max\_hop$ for the similar PCH_j and the direction is also identical to vehicle s, it documents all paths to PCH_j and accepts PCH_j is its prime cluster head. If the vehicle s collects more selection packets from various PCH with identical directions then it calculates the fitness value F_value for all the paths from the vehicle s to the PCH which satisfies the condition $HOP_{sPCH_j} \leq Max\_hop$. Finally, the PCH with the highest F_{value} has selected as its PCH. Finally, the bond packet format of the normal vehicle is shown in Figure 5 where it additionally consists of vehicle ID, a fittest path between the vehicle and PCH, best path documents, other PCH documents, location, velocity, and all the IDNs of the vehicle s.

preface	Transmit Time	PCH ID	Vehicle ID	Fittest Path	All Documents	Hop Count	Location	Velocity	Neighbors	Check List

Fig. 5. Bond packet format by the normal vehicle

Following the process of bond packet collection from the vehicle *s*, PCH saves the data of all the normal vehicles as the same as the details given in Figure 8 and transmits the confirmation packet to all the vehicles along the fittest path.

4.4 Prime-CH (PCH) election and cluster formation

Certainly, if the vehicle s has not collected any selection packet in the time t_{col} at that condition, dynamic PCH model will be activated. This DPCH selection is done using the weight value W_{V_s}. The weight value of the vehicles is calculated with the help of degree difference Dd_{V_s} and average speed AS_{V_s} of each vehicle. For the process of cluster balancing Dd_{V_s} is calculated and it also provides the best Cluster Child (CC) to each cluster. To reduce the most dynamic nature of the transmission channel and vehicle communication, high-speed mobility is monitored periodically. As a result, the vehicle which maintains the best average speed is considered to control the cluster. Dynamic nature considered the weight value of the vehicle. The mathematical expression for the calculation of weight value is given in equation 5.

$$W_{V_s} = \alpha(|N_{V_s}| - M_{V_s}) + \beta\left(\frac{1}{|N_{V_s}|}\sum_{j\in N_{V_s}}^{|N_{V_s}|} |RS_{V_j} - RS_{V_s}|\right) \tag{5}$$

Where $|N_{V_s}|$ represents the neighbor count connected to the vehicle V_s, M_{V_s} represents the CC count, RS_{V_j} represents the neighbor's relative speed V_j and RS_{V_s} represents the RS_{V_s} is the relative speed of V_j. After finding the weight values followed by this difference Dd_{V_s} and average speed AS_{V_s} need to be calculated. Here α and β are the weighting factors for the system parameters. Finally, the vehicle V_s which does not collect any selection packet and transmits a request packet along with the weight value. And the neighbors which contain maximum weight are chosen as a DPCH and transmitted the selection packet to the particular vehicle V_s. The further process will get continue as mentioned previously.

4.5 Cluster updates

Timeout is assigned to the entire vehicle if it goes beyond the fixed threshold; the vehicle V_s connectivity between its neighbors V_j is not accessible. In case the vehicle V_s is the DPCH or PCH then neglect the V_j from its neighbor table. If V_s is a cluster child and V_j is the DPCH or PCH in the same cluster then it proceeds by checking the weight value of another vehicle like V_k in the same direction. If anyone V_k respond to this criterion then V_s transmits the selection packet. Or else it becomes DPCH or PCH as well as transmit the CH message to all the neighbors.

4.6 Gateway selection

The gateway acts as an intermediate between each cluster and performs data transmission among them. PCH selects the fittest node to become gateways. To perform PCH to PCH communication, it transmits z forward packets to 2 or 3 hop nodes by fixing the field of type as zero, likewise, z is the hop count between the receiver PCH. Once collecting this packet, it calculates the QoS factor as well as documents in its QoS field. When the forward packets reach its receiver PCH then it adds the list of vehicles and its QoS factor. The receiver PCH executes the path's QoS factor by summing the QoS factor of intermediate hop vehicles. Finally, the vehicle with the utmost QoS factor is found and chosen as a gateway. Subsequently, the field type id changes to 1, and the backward packets transmit from the receiver PCH in the finalized fittest path. Once after collecting the backward packet the source PCH the vehicle which presents in that particular path is chosen as a gateway. As a result, PCH communication via the gateway is initiated.

5 Self-Adaptive Efficient Dynamic Multi-Hop Clustering approach (SA-EDMC)

In this section, initial simulation settings and the major parameters which are calculated for performance analysis are given. Secondly, the results are analyzed as well as compared with the earlier approaches.

5.1 Gateway selection

To evaluate the performance of proposed model, we use the simulation software NS-2.35 under Linux Ubuntu 12.04. Compared to other software NS2 software is very much suitable for academic research. It is a discrete event-driven object-oriented simulator as well it supports other network models such as Wireless LAN, MANET, VANET, and satellite. It is generally based on two languages which are C++ and OTcl (Object Tool Command Language) interpreter. To construct the VANET network in NS2 we use SUMO with an open street map to build urban mobility. To build network features link vehicles, velocity, transmission time, and location XML codes are generated. The network coverage area is 2000 * 2000 meters. For peer-to-peer data, transmission vehicles create constant bit rate (CBR) traffic as [26-28]. The simulation parameters are shown in Table 1. The major parameters which are used for this analysis to calculate the results are packet drop, packet delivery ratio, end-to-end delay, and network throughput.

Table 1. Simulation parameters details for SA-EDMC protocol

Parameters	Values
Simulator	NS-2.34
Simulation Duration	200 sec
Dimension	2000*2000
Data Packet Size	512 bytes
Mobility Generator	SUMO [25]
No of Vehicles	20, 40, 60, 80, 100 [19]
IEEE Standard	IEEE-802.11p
Propagation Model	Two Ray Propagation Model [24]
Antenna Type	Onmi directional Antenna [19]
Traffic Type	Constant Bit Rate
Traffic rate	0.01 sec to 0.50 sec
Agent Layer Protocol	User Datagram Protocol
Routing Protocol	AODV [28]
Residual Energy	100 J
Idle Energy	0.1 J
Queue Type	Drop-Tail

Packet Delivery Ratio: It is defined as the ratio of the number of packets received by the destination to the number of packets sent by the source.

End to End Delay: It is defined as the delay time calculated across the network during the process of communication between all the sources and the destination.

Throughput: It is the calculation of the amount of data transmitted across the network during the network simulation for overall transmission time.

The number of packets lost: It is the calculation of the overall loss of packets of the network during the period of the progression of data transmission.

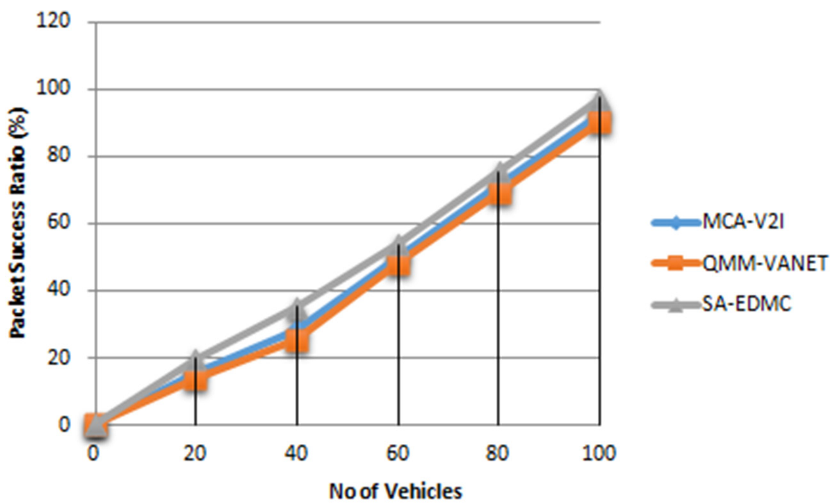

Fig. 6. Packet delivery ratio of the VANETs

From Figure 6 the packet delivery ratio results are calculated and it is compared with the earlier methods MCA-V2I and QMM-VANET. In this graphical output, the x-axis stands for the no of vehicles as well as the y-axis stands for the packet delivery ratio of the network. The packet delivery ratio analysis of SA-EDMC is 97.47 %. Whereas the earlier protocol values are given here, MCA-V2I produces 92.86 % and QMM-VANET produces 90.34 %. After analysis, it proves that the proposed model produces a high packet delivery ratio when compared with the existing methods.

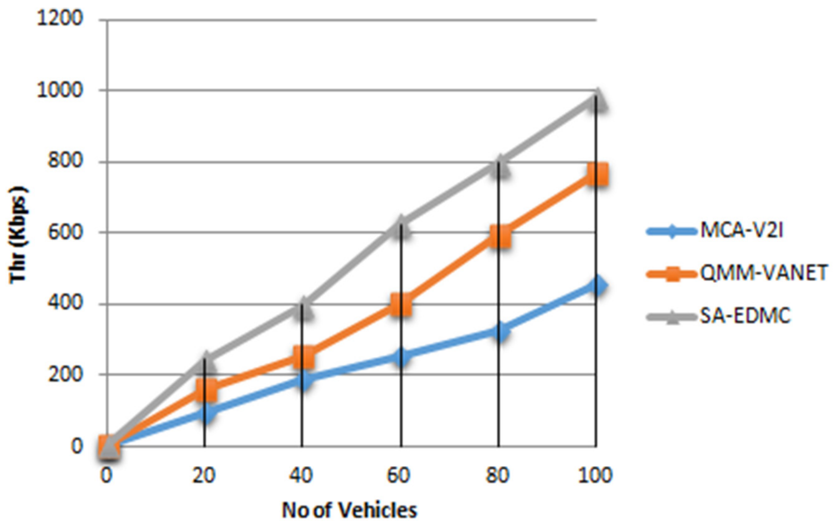

Fig. 7. Throughput of the VANETs

From Figure 7 the throughput results are calculated and it is compared with the earlier methods MCA-V2I and QMM-VANET. In this graphical output, the x-axis stands for the no of vehicles as well as the y-axis stands for the throughput of the network and its unit is kbps. The throughput analysis of SA-EDMC is 983.45 kbps. Whereas the earlier protocol values are given here, MCA-V2I produces 459.78 kbps and QMM-VANET produces 768.93 kbps. After analysis, it proves that the proposed model produces around 20% high throughput when compared with the existing methods.

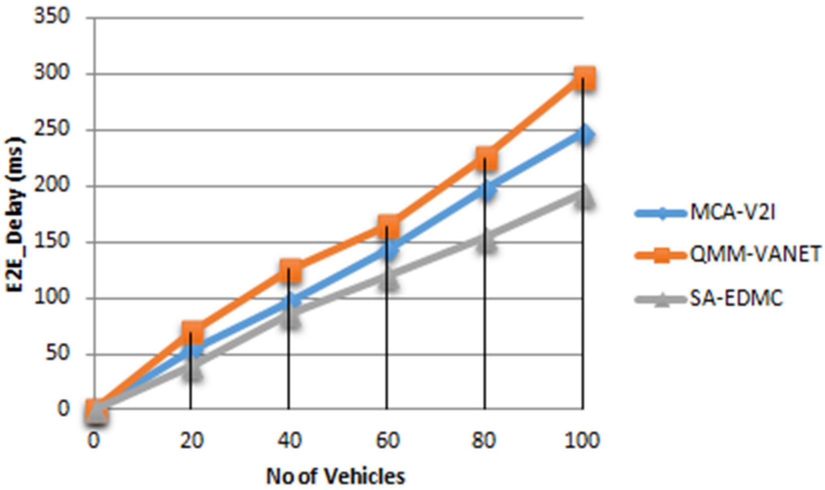

Fig. 8. End to end delay of the VANETs

The end-to-end delay results are calculated and it is compared with the earlier methods MCA-V2I and QMM-VANET shown in Figure 8. In this graphical output, the x-axis stands for the no of vehicles as well as the y-axis stands for the end-to-end delay of the network and its unit is ms. The end-to-end delay analysis of SA-EDMC is 193.47 ms whereas the earlier protocol values are given here, MCA-V2I produces 246.17 ms and QMM-VANET produces 296.54 ms. After analysis, it proves that the proposed model produces around 5% low end-to-end delay when compared with the existing methods.

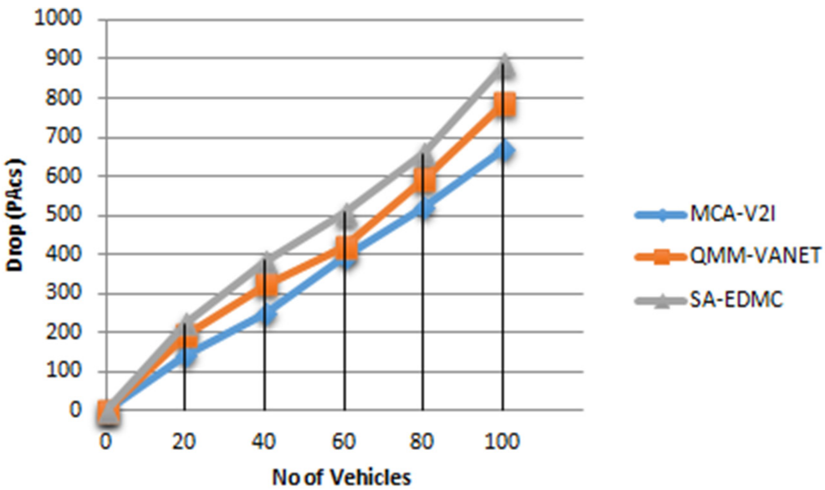

Fig. 9. Drop calculation of the VANETs

The packet drop results are calculated and it is compared with the earlier methods MCA-V2I and QMM-VANET shown in Figure 9. From the graph, it is shown clearly.

In this graphical output, the x-axis stands for the no of vehicles as well as the y-axis stands for the packet loss (packets) of the network. This simulation is performed using 100 nodes. The packet loss analysis of SA-EDMC is 887 packets. Whereas the earlier protocol values are given here, MCA-V2I produces 669 packets and QMM-VANET produces 789 packets. After analysis, it proves that the proposed model produces high packet loss when compared with the existing methods but the throughput of the proposed method is around 1000 kbps. It is very high when compared with the earlier works. For 1000 kbps the packet drop is 887 packets only. But the earlier produced low throughput around 500 and 700 kbps which is have around 700 to 800 packets drop. While comparing the throughput the loss ratio is very low compared with the earlier methods.

6 Conclusion

VANETs are used in several real-time applications. The major drawback in VANETs is that the performance of the network is reduced due to its huge dynamically varying traffic scenario. Due to this issue, the link failure occurs which leads to an increase in the delay and energy consumption of the network. To increase the network performance a novel self-adaptive efficient dynamic multi-hop clustering approach is proposed. Self-adaptive clustering method helps to find the fittest path to transmit the packets. The dynamic Clustering model is mainly used to reduce network delay which also helps to reduce energy consumption in a better way. Simulation analysis is done in NS2 and the performance is calculated in terms of packet delivery ratio, network throughput, end-to-end delay, and packet drop. The results show that SA-EDMC improves the network lifetime compared with MCA-V2I and QMM-VANETs. In the proposed SA-EDMC ~5% increase in packet delivery ratio, produced 300 to 500 kbps extra throughput compared with the earlier methods and delay is comparatively low. Hence this approach deals which very high traffic compared to the earlier method the number of dropped packets is 10% high when compared with the earlier work. In future work, the concentration is to reduce packet drop in this network scenario.

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