Towards a Dynamic Vehicular Clustering Improving VoD Services on Vehicular Ad Hoc Networks

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Abstract. Nowadays, video-on-demand (VoD) applications are becoming one of the tendencies driving vehicular network users. In this paper, considering the unpredictable vehicle density, the unexpected acceleration or deceleration of the different cars included in the vehicular traffic load, and the limited radio range of the employed communication scheme, we introduce the "Dynamic Vehicular Clustering" (DVC) algorithm as a new scheme for video streaming systems over VANET. The proposed algorithm takes advantage of the concept of small cells and the introduction of wireless backhauls, inspired by the different features and the performance of the Long Term Evolution (LTE)- Advanced network. The proposed clustering algorithm considers multiple characteristics such as the vehicle's position and acceleration to reduce latency and packet loss. Therefore, each cluster is counted as a small cell containing vehicular nodes and an access point that is elected regarding some particular specifications.

Keywords: Video-on-demand · Vehicular ad-hoc network · Mobility · Vehicular traffic load · Small cell · Wireless backhaul · LTE-Advanced · Latency · Packet loss

1 Introduction

Vehicular Ad-Hoc Networks (VANET) are highly mobile wireless ad-hoc networks that were implemented to support passenger safety, driving assistance and emergency warning services. VANET is designed to grant vehicular self-organized formation [1, 2]. Generally, smart car designers have shown increasing attention to the employment of Dedicated Short Range Communication (DSRC) based on IEEE 802.11p [3–5]. However, DSRC is not a suitable solution for vehicle to infrastructure communication because of its limited radio range [6]. Therefore, there have been various studies in the literature [7, 8] suggesting the deployment of the fourth-generation Long Term Evolution

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(LTE) systems, as well as the next-generation LTE, advanced to deal with vehicular communications [9, 10].

Video streaming applications' requirements in terms of network resource management and QoS specifications have been the main issue for numerous studies during the last decade [11–13]. Vehicular networks are more concerned with video streaming issues due to their high mobility, dynamic topology, and unpredictable user density. Therefore, video streaming among vehicular networks raises more QoS requirements challenges. The wireless network supporting vehicular communication must deal carefully with interference, frequent handover issues, and video storage locations to enhance the streaming quality in terms of content availability, low latency, and minimum frame loss.

We have more communication challenges to report considering video streaming over vehicular networks [14, 15]. High mobility and unpredictable users' density make the process of delivering video content with the desired QoS, challenging in terms of resource allocation, content distribution, and interference reduction. Therefore, the use of heterogeneous schemes to separate signaling traffic links and content flows seems to be a promising paradigm to reduce interference among vehicular networks [16]. However, mobile nodes among a VANET system are not restricted to a predefined traffic network since its multiple degrees of freedom (i.e. high mobile node) [17].

In this paper, we propose a dynamic algorithm called Dynamic Vehicular Clustering (DVC) to enhance both vehicle-to-vehicle and vehicle-to-Base station connectivity among high mobility networks. The proposed algorithm exhibits the impact of small cell deployment on connectivity and mobility performance in Long Term Evolution (LTE)-Advanced-based vehicular network. Furthermore, the introduction of 5G features into vehicular ad-hoc networks [18, 19] such as the concept and communication of the small cell over wireless backhaul networks will enhance video content transmission due to its low latency and the utilized schemes to deal effectively with congestion and interference issues.

The remainder of the paper is organized as follows: Sect. 2 introduces an overview of the related issues to video streaming and vehicular networks; Sect. 3 illustrates the proposed algorithm and highlights the different features of the clustering scheme; Sect. 4 evaluates the solution based on simulations results analysis and compares its performance to existing studies; Finally, Sect. 5 concludes the paper.

2 Related Work

In the literature, there are numerous schemes to boost V2V and V2I communications regarding their features [20–23]. The common strategy promotes the use of a separate solution for each type of link. V2V communication links two or more vehicles directly (i.e. without infrastructure's relaying) to minimize control traffic and cope with range limitation among the mobile network [24]. Moreover, smart vehicles are nowadays equipped with high-performance processors and large caches. Hence, short-range networks can perfectly support this type of vehicular link since data management and storage are available using the car's smart-board without the infrastructure's involvement. DSRC has been a highly recommended scheme to serve V2V communication with effective support, high throughput, low latency, and low cost. V2I communication needs a robust wireless network to deal properly with interference between different vehicles communicating with the infrastructure. The devoted scheme must support long-range communications to manage the vehicle's high mobility. Therefore, LTE and LTE Advanced are becoming very popular as the most promising techniques for V2I communications. The next generation will be more attractive to be deployed in vehicular networks, especially with its tendency to establish communication with almost no latency, no more concerns about bandwidth capacity, very high throughput, etc. [25, 26]. However, the case of dense cells remains a critical concern for vehicular networks that need effective employment of the existing schemes.

It is considered a promising paradigm to have cooperative communication established directly between two or more wireless nearby devices (i.e. without having the base station involved). Device-to-Device communication shows major benefits in terms of reliability, spectral efficiency, storage capacity, and transmission range issues. A D2D communication involves source, destination, and device relays which are the intermediate devices utilized as relaying nodes to transmit content over a massive ad-hoc mesh network. In the context of vehicular networks, video content relaying requires device dynamic location discovery to ensure durable communication within its neighbors to enhance content availability and minimize packet loss rate [27, 28].

The BS will normally continue supervising and serving the devices through the macro cell regardless of the established D2D link. However, in the case of congested cells, the devices will create an ad-hoc mesh network and the BS services will be abolished. This type of D2D link is established and supervised by the BS which continues its communication with the devices (Fig. 1).

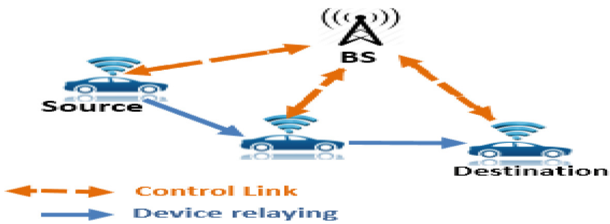

Fig. 1. D2D communication with BS controlled link.

Another possible scenario for D2D communication is when the BS control is replaced by device-controlled links (Fig. 2). Hence, a direct link is established between devices from the source to destination to carry content over device relays without the BS control. Each device should be self-assisted to use effectively system resources. On the other hand, devices should exchange content using smart interference management schemes to reduce packet loss rate and performance degradation. Compared to the schemes surveyed above, our work introduces a dynamic clustering process to deal with road load frequent updates and high mobility environments problems. Moreover, the scheme does not rely on broadcasting but it is more target-oriented communication. For each cluster, a head node is elected not as a "forwarding node" but as an access point to handle all exchanges between the cluster and the roadside units. In the following section a detailed description of our proposed algorithm.

Fig. 2. D2D communication with self-controlled links.

3 The Proposed Solution

The small cells concept is considered an unavoidable solution for the next-generation 5G network's architecture. Regardless of its drawbacks, we are developing in this paper an adaptive system model inspired by the features of small cells and a 5G wireless backhaul network's management in ultra-dense small cells.

3.1 System Model and Problem Formulation

We introduce the concept of Dynamic Vehicle Clustering (DVC) for video content delivery over next-generation macrocells (MC). A cluster contains the Client Vehicle (i.e. the car requiring the video content), the Peers having already stored the video, the Relaying Vehicles, and the Access Point (AP).

The network's design that we introduce includes a single macro-cell with a Macro Base Station (MBS), a random number of clusters called 'Friendly Groups' (FG), and car users (CU), the MBS coverage overlaps with all the other FG.

Architecture. We consider a set $FG \triangleq \{fg(1, AP_1), \ldots, fg(K, AP_K)\}$ of K Friendly Groups contained in the macro cell, a set $CU \triangleq \bigcup_{n=1}^{K}(FG_n)$ of car users, a set.

AP $\triangleq \{(AP_1), \ldots, (AP_K)\}$ of K selected access points and a set $V = \sum_{i=0}^{n} V_i$ of videos pre-stored in the Cloud data centers [29, 30].

We take into account the use of disjoint sub-channel allocation among different APs while we are defining the friendly groups' formation referring to the concept of small cells [31]. Furthermore, to improve system performances we recommend the use of enhanced Inter-Cell. Interference Coordination Techniques (eICIC) are proposed in LTE Rel. 10 to deal with interference between neighboring APs. It offers resource partitioning between the macro cell and small cell to improve the offload of traffic to the small cell layer [32, 33]. Hence, the technique optimizes the scheduling process by offering the possibility to coordinate the resource usage between the MBS and each AP.

Video requests. In this paper, user requests are modeled by RQ_m. We consider as well a set of users friendly lists $FL \triangleq \bigcup_{k=1}^{S}[fl(V_K, Z_1), \ldots, fl(V_k, Z_N)]$ where:

- $\boldsymbol{Z_i}$ (I = 1…N) refers to a sub-region consisting of the subset of users in the same location as the user CU_j.
- ***fl*** ($\boldsymbol{V_K}$,$\boldsymbol{Z_i}$) is the friendly list containing users nearby the user CU_j (at a sub-region of 60 GHz) having already downloaded the requested video V_K and having accepted to share it?
- S refers to the total number of videos having been delivered in the macro cell.

The main use of Dynamic Vehicles Clustering (Fig. 3) is to reduce signalization messages exchanged among the macro cell. Therefore, this scheme can help reduce interference, which will normally decrease the frame loss rate. On the other hand, it defines a heterogeneous scheme for vehicular communications, which deals separately with V2V and V2I links. Direct V2V communication can be ideally supported by the DSRC scheme described in the Sect. 2, while the next-generation 5G network's features will be used for AP to MBS backhaul link. Hence, combining these communication schemes can provide a streaming service with low latency and better performances.

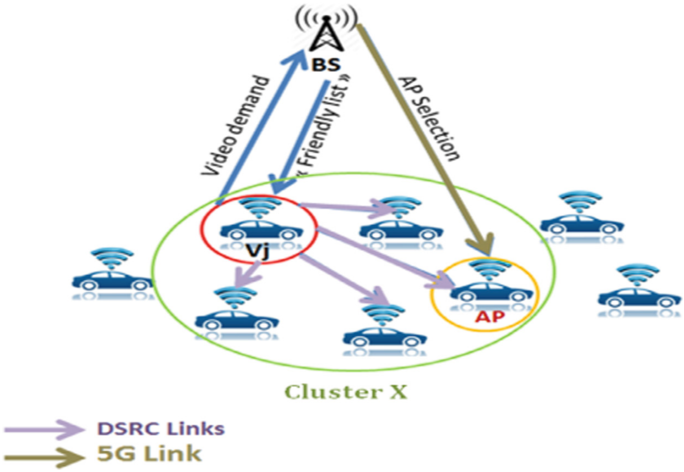

Fig. 3. Dynamic vehicles clustering architecture.

3.2 Dynamic Vehicles Clustering Features

Friendly List. The MBS creates dynamic lists of vehicles storing each video to facilitate content location. The macrocell is subdivided into N sub-region Z(i = 1..N) based on users' density (i.e. a sub-region is a geographical zone where the number of users is upper than a predefined Density-Threshold DT). Among each sub-region where users have already downloaded the video V_K, all considered users are invited to join the friendly list of video V_K corresponding to the sub-region Z_i. Hence, users who have sent back an acknowledgment to the MBS are automatically added to the concerned friendly list.

Moreover, the idea of the deployment of friendly lists is used for security measurements besides its role in content location. It makes sure that the MBS in charge is permanently aware of the identity of the members ensuring the content delivery among the macro cell.

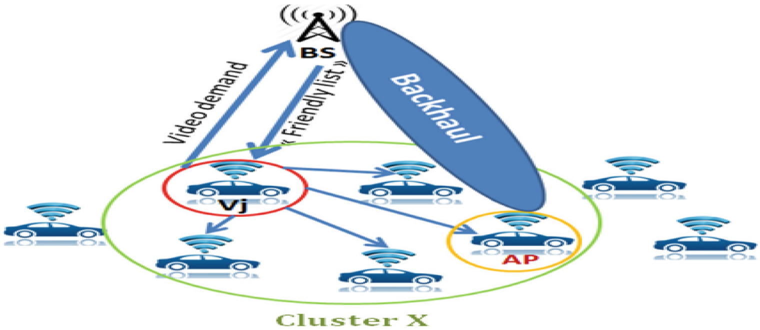

Fig. 4. Dynamic vehicles clustering architecture with backhaul establishment.

Access Point Selection. The definition of an AP among vehicles contained in a cluster aims mainly for the limitation of backhauls' congestion. Therefore, the proposed strategy intends to discard all backhauls established between vehicles inside the cluster and the MBS, other than AP's backhaul (Fig. 4). This scheme can be useful for backhauls congestion avoidance. However, the selection of the appropriate AP in each cluster is a critical decision. The MBS should be permanently at the sight of the selected AP to maintain the best Signal-to-Interference-plus-Noise-Ratio (SINR) for the backhaul link. The base station should verify that the current SINR keeps not being below a predefined threshold (SINR_Back_Tresh). Otherwise, the MBS triggers a new AP selection process (i.e. When current < SINR_Back_Tresh >).

Besides the V2V link's control inside the cluster, an AP has to define the best Relays Vector (RV) that ensures content transmission with low latency. An RV refers to the different relaying nodes transporting the video content from the destination source.

A summary of the proposed approach is presented in the algorithm below:

Algorithm: *Dynamic Vehicles Clustering*

1- *Initialize a video* V_k *request* RQ_m *from* CU_j *to MBS*

2- *MBS defines the location* Z_i *of the* CU_j

3- *MBS checks the availability of* $\mathrm{fl}(V_K, Z_i)$ *in* $FL \triangleq \bigcup_{k=1}^{S}[fl(V_K, Z_1), \ldots, fl(V_k, Z_N)]$

if *(* $\mathrm{fl}(V_K, Z_i)$*: available) {*

4- *MBS sends* $\mathrm{fl}(V_K, Z_i)$ *to* CU_j

5- CU_j *establishes the clustering process*

6- *AP_i selection*

7- V_K *segments' transmission is trigged }*

else *{MBS initializes* V_K *to* V_K*}*

4 Simulation Results and Analysis

In the proposed study, the major intention is to develop a suitable technique based on the exceptional features of the LTE-Advanced network (small cells and wireless backhauls) for the controlling of video streaming services over VANET systems and to providing trust-based communication. DVC algorithm is implemented using MATLAB in the windows platform on the PC with Intel Core i7 and 8 GB RAM. The proposed system is analyzed based on the performances such as packet failure, bandwidth utilization, response time, and network scalability. The simulation parameters of VANET using the DVC algorithm are given in Table 1.

Table 1. Simulation parameters

Parameters	Setting
Number of nodes/Vehicle	100
Simulation area	100 m × 100 m
Paquet size	512 bytes
Transmission range	50 m – 150 m
Traffic type	Two Ray Ground
Vehicle speed	0–50 km/h
Number of clusters	4
PHY/MAC layer	IEEE 802.11p

The vehicle nodes (VN) act as 802.11p wireless access points (APs) to communicate between them in the coverage range in 100 m x 100 m and we set the bandwidth as 20 Mbps. In created network given in Fig. 5, we have included 100 vehicles moving on the paths in random directions and uniformly distributed and with a speed between 0–50 km/h.

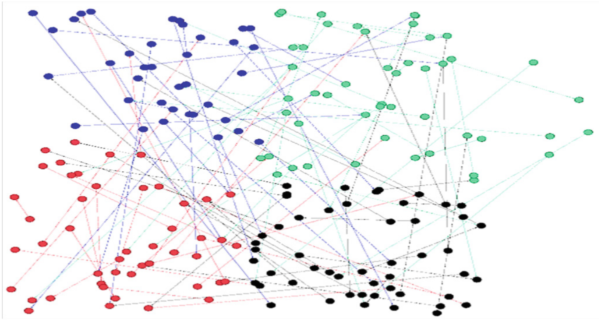

Fig. 5. Initial topology for the experiments.

The virtual topology of the VANET network is created with four clusters as given in Fig. 5 and each cluster has a node to analyze the trustability. The nodes are represented as “●” and the four clusters are differentiated by spotting different colors.

The packets failure report without application of a management algorithm is given in Fig. 6. This report (packet loss) shows the measurement of the number of lost packets compared to the total number of transmitted packets. We can discover that packet loss randomly increases with the number of vehicle nodes.

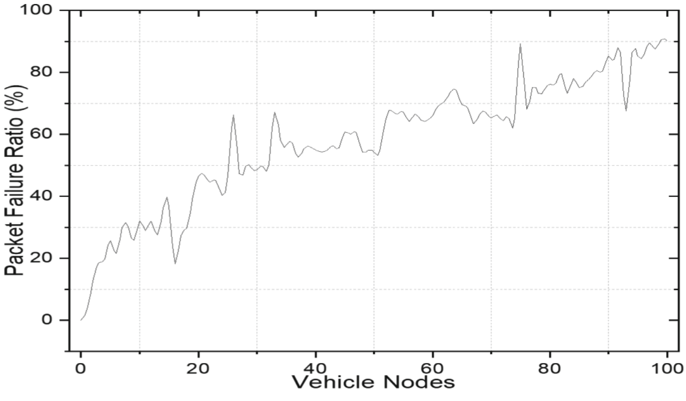

Fig. 6. Packet failure ratio.

Figure 7 illustrates the average probability of packet loss on the arrival rate of vehicle nodes with the application of our DVC algorithm and by comparing it with other algorithms such as VTD [34], NDN (Named Data Networking) [35], and SASMF [36]. The arrival rate of packets varies between 50 and 100 packets/s. It is clear that more than 80% of packets are delivered so that the loss is reduced by less than 20% with DVC in the interval from 0 to 50 vehicle nodes, also more than 50% of packets are delivered, so that the loss is reduced by less than 50% in the case of higher loads, in particular between 50 and 100 vehicle nodes. In cases where the arrival rate (n) of vehicle nodes is low (n < 20), the packet loss rates between DVC and VTD are almost similar. Indeed, with this low number of vehicle nodes, the collisions are limited. When n becomes big ($n > 50$), our algorithm gives better results to avoid excessive packets collisions and reduce the packet error rate. Take $n = 100$, the probability of packet loss decreases by more than 20% with our proposed algorithm compared to the VTD algorithm, more than 25% compared to the NDN algorithm, and more than 40% compared to the SASMF algorithm. Figure 7 clearly shows that the proposed DVC algorithm has reduced the average packet failure rate of normal VANET communication. Consequently, the proposed technique then improves the packet delivery rate. The use of bandwidth is shown in Fig. 10.

Figure 10 clearly shows that the bandwidth with the DVC algorithm is efficiently used in our VANET network. Our VANET network uses around 98% of the bandwidth, while the DVC algorithm reduces it and uses up to 92%. Therefore, integrating the DVC algorithm into VANET has effectively managed bandwidth usage.

We can see that our new algorithm gives better results of simulation in all the spectrum of n, notably, an average and equitable use of the bandwidth in all load situations.

On the other hand, the other algorithms give either a maximum or minimum use of the bandwidth which is not preferable for VANET networks.

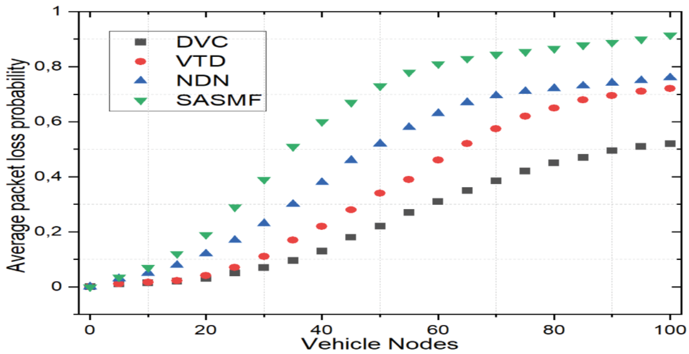

Fig. 7. Average packet loss probability vs the number of vehicle nodes.

As n increases, the use of bandwidth increases and decreases with DVC but in an interval of 89% to 92% which is still bearable by the VANET network. The figures also show that bandwidth usage increases and decreases randomly, rather than growing completely with n.

In Fig. 9 we compare the scalability of our VANET network. We evaluate the scalability of the network according to the response time. As the rate of arrival of vehicle nodes increases, the average response time is calculated and illustrated in Fig. 9.

Figure 9 shows the comparison results of response time for DVC, VTD, NDN, and SASMF algorithms under different numbers of vehicle nodes. Figure 8 shows the network scalability by varying the number of vehicle nodes. We can observe that the DVC algorithm has reached between 0.2 and 4 ms response time in terms of 50 at 250 vehicle nodes. On the other hand, compared to the other algorithms, one can also observe that DVC reached between 10% and 25% of the value of response time less than VTD, NDN, and SASMF algorithms with the same density of traffic. However, in the scenario of 100 car knots or less, DVC produces better response time values with less than 1 ms.

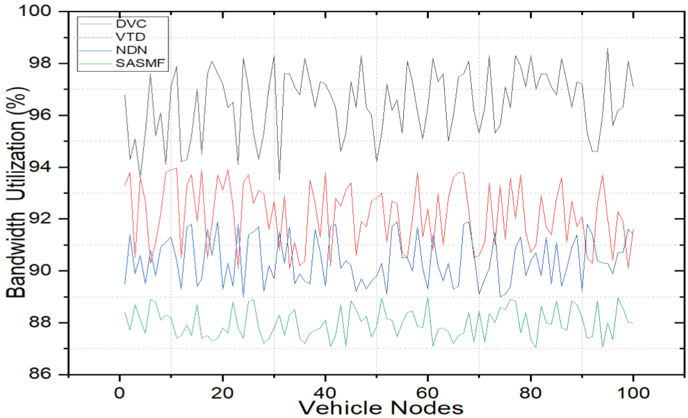

Fig. 8. Bandwidth utilization with and without DVC algorithm.

The comparison between the different algorithms shows that the performance degrades while increasing the number of vehicle nodes, among other techniques using the DVC algorithm the performances are better and have reached better scalability. These results indicate that DVC is an algorithm well suited for an application that requires reliable delivery of video packets in a high traffic VANET network.

As shown in Fig. 10 our VANET network will be busier when the rate of video requests from each vehicle node increases. From our results presented in Fig. 10, We can conceive that the guarantee of optimal performances of transmission of real-time video packets requires a delay of at least 1.8 ms with the DVC algorithm.

Likewise, even in the case where the number n of vehicle nodes is 100, the transmission delay is also acceptable (no more than 3 ms) mainly due to our algorithm and the high bandwidth of the VANET network.

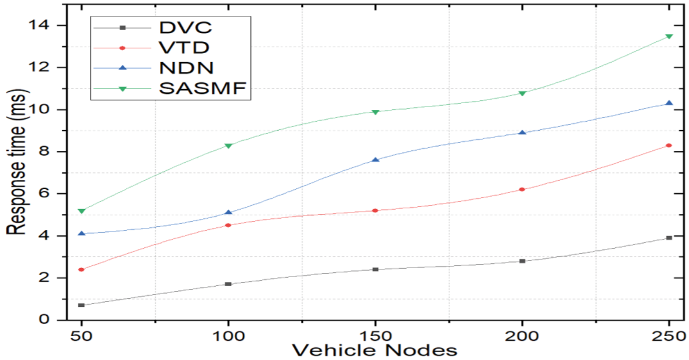

Fig. 9. Response time with and without DVC algorithm.

Increasing traffic generally leads to frequent changes in the network topology. Thus, the results show that the transmission delay increases in high-speed scenarios. The proposed algorithm allows a significant reduction in the transmission delay compared to other schemes. DVC creates stable clusters that can guarantee sufficient connectivity and a reliable link.

As a result, the retransmission times and the transmission delay are reduced, which results in a reduction of the transmission delay. Another reason is that using stable connected clusters, packets can be delivered to the next hop with reduced conflict, which leads to short network latency.

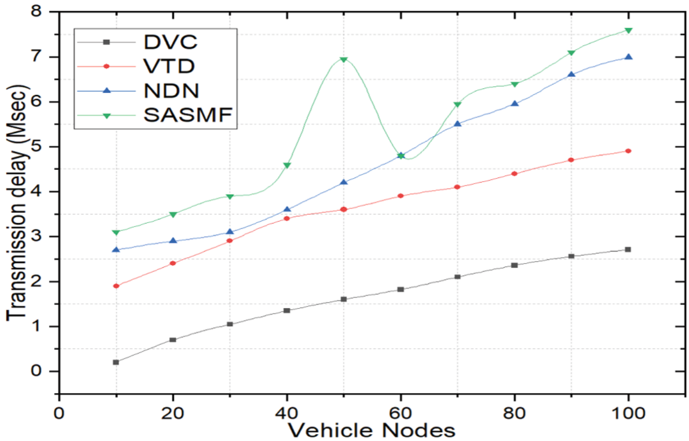

Fig. 10. Transmission delay for varying vehicle node number.

5 Conclusion

In this paper, we have proposed a dynamic algorithm "Dynamic Vehicle Clustering" (DVC) as a new scheme for video streaming systems on VANET taking into account the unpredictable density of vehicles, unexpected acceleration or deceleration of different cars included in the vehicle traffic load and the limited radio range of the communication scheme used. We have introduced a wireless link inspired by the different functionalities and performance of the Long Term Evolved Network (LTE)-Advanced. Our algorithm is proposed to enhance both vehicle-to-vehicle and vehicle-to-Base station connectivity among high mobility networks.

Our policy has allowed us to dynamically divide traffic into several clusters. Another objective of this article is to guarantee a certain balance of load and resources available between the various VANET network vehicle nodes. We also noted that the cooperation and the distribution of the load between the various clusters simplify the calculations and accelerate the task of diffusion of the packets and also reduce the time of convergence of the VANET network towards the state of equilibrium.

The results of theoretical analysis and experiences illustrate the effectiveness of our application of "Dynamic Vehicle Clustering" (DVC) due to the reduction of delays for the VANET network and the convergence towards a steady-state is greatly improved.

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