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PACKETS AGGREGATION SCHEME WITH NEW DESIGNED CSMA/CA FOR VANET MULTI-HOP NETWORK

S. Ouahou S. Bah Z. Bakkoury

AMIPS Laboratory, Mohammadia School of Engineering, Mohammed V University, Rabat, Morocco
soufiane.ouahou@research.emi.ac.ma, bah@emi.ac.ma, bakkoury@emi.ac.ma

Abstract- In recent years, VANET networks have aroused enormous attraction thanks to their commercial, security and comfort advantages. However, the ad-hoc architecture managed by itself in addition to the fast mobility of nodes raises several challenges including efficient data delivery and QoS. In VANET multi-hop architecture, bandwidth and transmission time are the two costly resources to worry about for good QoS. In such dynamic environment like VANET, redundant packets problem is a recurring phenomenon that causes heavy QoS loss. For thus, we propose a packets aggregation algorithm based on an improved CSMA/CA designed for 802.11p standard in VANETs. The proposed scheme consists in a first phase of constructing a clustering architecture in which, each node designates a father and a son based on a metric to build links to reach the cluster head. In the second phase, each node designates a packet lifetime calculate based on Minimum Spanning Tree (MST) algorithm. The aim of this solution is to design a packets aggregation technique that solves the problem on inter-connection links between nodes while routing data, as it the major problem of many proposed solutions. Our scheme also allows fast sending of lost packets thanks to the path data storage approach. Analysis of the simulation results shows that the proposed solution exceeds existing schemes in packet delivery ratio, data transmission coverage and reduces the latency and overhead and average transmission delay.

Keywords: VANET, Packets Aggregation, CSMA/CA, Clustering, QoS, Multi-hop.

1. INTRODUCTION

The progress of the new networks generations, particularly ad-hoc networks, has led to the development of vehicular ad-hoc networks (VANET) which are the computational part of intelligent transport systems (ITS). VANET networks are very important due to the provided benefits in safe driving, emergency applications, interactive navigation and entertainment. In VANET network, nodes are essentially vehicles or Road Side Unit (RSU). Communication between vehicles is made by links called vehicle to vehicle (V2V), or between vehicles and infrastructure with links called vehicle to infrastructure (V2I). Most modern vehicles are equipped with equipment called on-board unit (OBU) which allows them to periodically communicate and exchange a special message called a Beacon. This message includes the vehicle location, speed, direction of travel and other driving information. The last generation of beacons can also include information on external parameters, such as traffic density, smart maps, air condition, roads state for the rest of travel, etc. Unlike mobile Ad Hoc networks (MANET), VANETs have particularities such as: the nodes have well-defined routes and the lifetime of the vehicle depends on the duration of its travel etc. These peculiarities are just a few among others that need to designed solutions dedicated for this type of ad-hoc networks.

The primary communication standard for V2V and V2I links is Dedicated Short Range Communication (DSRC). To provide quality of service (QoS) support in VANETs, DSRC uses the IEEE 802.11p [1] protocol at its media access control (MAC) layer. The Enhance Distributed Channel Access (EDCA) mechanism and the Carrier Sense Multiple Access with Collision Avoidance (CSMA / CA) algorithm are used to control the system.

Although much research has dealt with VANETs in recent years, many challenges remain for these networks. These challenges remain in the frequent disconnection and loss of links between vehicles due to their high mobility. In addition, the phenomenon of interference and flooding in the network, gravely affect the performance of wireless networks.

Figure 1. VANET network architecture

As already mentioned, in the VANET environment, data is collected by vehicles thanks to their OBU at different places in high or low density regions. Because of the high mobility of vehicles, data aggregation is a difficult and complicated mechanism to manage in VANETs. In addition, the stability of the links remains a major challenge for data routing to the destination. However, many proposed solutions transfer the data on broadcast model to ensure the data reception, thereby causing a network overload and consequently a degradation of the performances [2-3]. Therefore, it is essential to put in place approaches that take into account the network conditions to manage this complexity in the VANET network.

Several solutions based on broadcast and multicast from the source node use the concept of clustering. In [4], Ruiz et al. propose a decentralized clustering approach to ensure the continuous change of the topology, moreover the authors propose a construction algorithm to increase the cluster lifetime. In [5], the authors propose Ad Hoc on demand Multipath Distance Vector (AoMDV) based on the multicast mechanism. In this approach, the data is sent over multiple paths, so that if one path is disconnected for some reason, another path can reach the destination.

From this short scenario, it is clearly necessary to design an efficient mechanism for aggregating and transmitting data, by allowing vehicles to make the right decision according to network conditions. In addition, this need becomes more necessary in very dynamic environments, which are often urban areas with high congestion.

Therefore, to solve these problems, we propose in this paper a new approach of aggregation and data transfer. In our solution, the routing paths to reach the cluster head are unique and the data is sent on a single path. The number of hops necessary to reach the cluster head determines the routing path and the path is built based on a clustering architecture. Each data packet has a TTL which is the number of hops it needs to reach the Cluster Head. Depending on the network metrics, our algorithm, gives each node that participates in the routing of data, the right to make the decision whether or not to update the TTL of a packet. In addition, each node of the path stores the information for a given time calculated according to the network metrics as backup in to resend the data in case of miss acknowledgment. For the network clustering construction and maintenance, our solution is based on a clustering architecture that we proposed in [14].

The remainder of the paper is laid out as follows. The second section discusses the most relevant related works on this topic. The proposed approach is described in detail in Section 3. Section 4 describes the simulation environment, whereas Section 5 describes the results and discussions. Section 6 concludes with conclusions and recommendations for future work.

2. RELATED WORKS

Over the years, the VANETs show their potential to offer important safety and comfort to passengers. However, VANETs present many challenges in providing guaranteed service with good efficiency and high stability. To do this, Ruiz et al. [4] proposed a new delivery approach for VANETs, based on clustering. The goal of solution is to decentralize source of information.

N. Wisitpongphan et al propose in [6] an approach based on probability. The main idea is to allow receiving nodes to rebroadcast packets with probability. The probabilities are assigned based on a broadcast suppression timer (p-slot persistence, p-weighted persistence, and 1-slot persistence schemes). The results show that this solution can maintain end-to-end links with an aggregation of up to 70%.

In order to reduce message redundancy, in [7], Zhang and al. propose a procedure that divides the network into small areas. In each region, the broadcast is repeated to vehicles that have just joined the region. The proposed scheme can ensure efficient aggregation, while trying to avoid a lack of important data.

In [8], each node can freely rebroadcast each data packet it receives. However, this rebroadcasting, that can be unnecessary of the same data; affects seriously the network performance by unnecessary occupations of the transmission channel. Based on the same idea, in [9], the authors propose a probabilistic rebroadcasting. The probability is determined according to the environmental specifications of the inter-vehicle exchanges. The results show that this solution effectively reduces the number of redundant retransmissions.

In [10], Soufiane et al. propose a dynamic model based on one-hop clustering architecture. The main idea is to centralize data processing in the cluster head and let it manage data aggregation. The solution also offers a fast data transmission mechanism.

In [11], the authors present an optimized diffusion solution to fight against the storm phenomenon in high-density networks. In addition, this solution deals with end-to-end link stability. However, this protocol is not based on a control scheme to reduce network overload in high-density environment.

In [12] Liu et al propose a new scheme called RPB-MD. The aim of the model is to effectively define recipients to ensure reliable and efficient delivery of data. In order to ensure a high packet delivery rate within a short delivery time, the solution introduces Directional Greedy Broadcast Routing (DGBR).

[13] Proposes model of interlayer aggregation. In fact, each vehicle broadcasts the data after having received all the requests from the vehicle. Due to the relatively high wait time, which is the average time required to receive all messages before sending, this scheme will increase the computational overhead.

In [14], the authors propose a multi-hop solution to broadcast messages. In this solution, just the vehicles designated by a better metric called Fitness as well as the number of hops to reach the Cluster head can rebroadcast the received message.

In [15], to improve data aggregation, vehicles deploy a priority calculation mechanism to retransmit the message. The solution also offers an approach for a better packet arrival ratio.

In [16], Dua et al. propose a new scheme to maintain good QoS for data broadcasting. The idea is to randomly select vehicles in the network to rebroadcast messages. Then, the intelligent transfer scheme uses different weights assigned to the path to forward data.

To obtain good reliability and low collision, the authors in [17] propose a new packet transmission solution based on probabilistic diffusion. The proposed solution is designed for distributed architectures in VANET. In this scheme, each node receiving a data packet rebroadcasts it according to a calculated probability. This probability combines all the factors of the environment and each vehicle can assess its probability to retransmit a message.

3. PROBLEM STATEMENT

In the solution [14] that we have already proposed, the VANET network is clustered in a multi-hop architecture. In each cluster, cluster members collect data around them and then send it to CH. At any time, each node of the cluster knows its children (vehicles within one hop) and its father (the closest node to reach the CH in one hop).

Figure 1 shows a simple scenario of the major problematic of the proposed schemes for data aggregation in VANETs. In this figure, it can be seen that at time T0, the source has the possibility of routing the data over two paths; after choosing the shortest path and starting to send data, a vehicle disconnects from the network and leaves the optimal path previously set. In the proposed system moel, each packet sent is limited by a lifetime which is the number of hops it takes to reach the CH. The particularity of our solution is that each vehicle participating in the routing can update the packet TTL as well as the destination (CH) if it has changed in the meantime.

In addition, an improved mechanism based on CSMA/CA is also provided which allows vehicles to store and recover packets during routing. The mechanism allows the vehicles of the routing path to save the data for a determined duration and calculated according to the state of the network. in the absence of an Acknowledgment after a calculated time, the node closest to the CH and which still owes the data can send it back.

4. SYSTEM ASSUMPTIONS

1. The network architecture is clustered based on the [14] solution and data is routed on a single path defined by the number of hops and the Fitness of the CH (destination).
2. Each node knows at any time the CH fitness as well as the number of hops to reach it.
3. The cluster depth cannot exceed five hops ≈ 1000 m.
4. Vehicles can exchange data in all directions
5. Each vehicle in the network can send and receive information with its neighbors, including speed, position and Fitness metric by periodically broadcasting beacons;

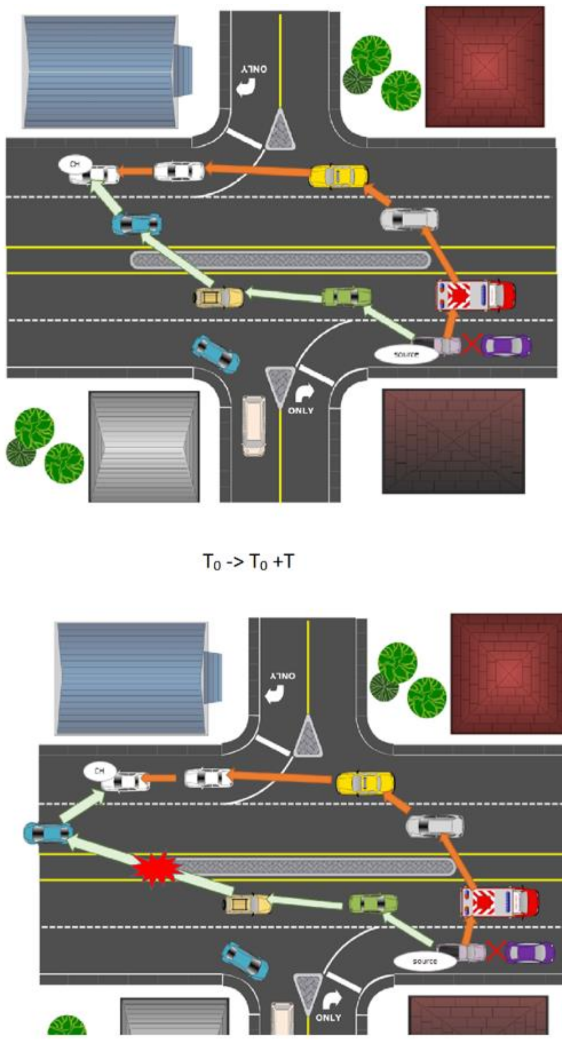

Figure 2. Case of study

Table 1. Vocabulary and definitions

Notation	Description
cv	Current vehicle executing the algorithm
CH_P	Cluster Head of the processed packet has the following form: (distance; fitness; IDCH; IDGT)
CH(*cv*)	Cluster Head of *cv*, CH has the following form: (distance; fitness; IDCH; IDGT)
GT(*cv*)	Selected gateway in *N*+1 hop to reach the cluster Head of *cv*
Child(*cv*)	Child of *cv* in the cluster and Which can send the packet because it is part of the routing path
TTL(p)	Number of hops necessary for the packet to reach *CH*
Sender	Any vehicle in the routing path that can receive and send data
Listener	All vehicles in the cluster that cannot send the data just they are listening
ClusterMes	Message having the form: (*ID*(*cv*); *CS*(*cv*); *F*(*cv*); *BF*(*cv*); *CH*(*cv*)

5. PROPOSED SOLUTION

The goal of our solution is to remove redundant packets while ensuring safe and reliable delivery. Unlike the majority of VANET schemes that uses the classic CSMA/CA concept; designed for the 802.11 standard called WIFI; our solution takes into account the high mobility of vehicles and it offers a new version of the CSMA / CA concept for the standard. 802.11p.

As we have already mentioned, in our diagram the vehicles can exchange data in all directions. Therefore, the types of applications concerned are:
Comfort Applications: Weather forecast, petrol station, historical monuments, traffic jams and city information, road navigation.
Efficiency Applications: intersection management systems, traffic light controller, traffic jam management.
Interactive Entertainment: Internet access, games and social networks, music and video downloads, file sharing, e-commerce, home control, etc.

All the applications mentioned above require a large bandwidth ensured by good reliability, high data availability and short broadcast time.

5.1. Packets TTL Assignment

As our solution is clustered, once the cluster construction is finished, all the members of the cluster exchange a periodic message that contains Cluster head *ID*, cluster head fitness as well as the number of hops between the current vehicle and the cluster head. In case a member of the cluster sent the message, the periodic message can contain the *ID* of the sender as gateway to reach the cluster.

Based on this information, each vehicle can deduce the TTL that can affect the packages sent by the Equation (1).

$$TTL_p = \sum_{cv}^{CH} hops \quad (1)$$

By limiting the lifetime of the packets, we will improve network performance and avoid the phenomenon of lost packets, which are one of the reasons for collisions and channel overloads, and consequently reduce network performance.

5.2. *TTL* and *CH* Update

Thinking about the particular characteristics of VANET, we have implemented a mechanism with an improved CSMA/CA. To ensure the packets delivery our mechanism allows the vehicles of the single routing path to update the information of the packet if the environment has changed in the meantime, including parquets *TTL* and the cluster head *ID* if it has also changed. The *TTL* and cluster head update algorithm is described as follows:

Algorithm 1: TTL and CH ID update

1: if $(CH_p.ID_{CH} \ != CH_{cv}.ID_{CH})$ then
2: $CH(p) \leftarrow (CH_{cv}.)$;
3: if $(TTL_p \ != CH_{cv}.distance)$ then
2: $TTL(p) \leftarrow (CH_{cv}.distance)$;

Figure 1. TTL and CH ID update algorithm

Unlike the classic CSMA/CA, all vehicles in our solution of the routing path are considered as senders and they can resend the message if they have not received an acknowledgment after the waiting time has elapsed. The waiting time can be calculated by the following equation.

$$WT_{cv} = 2\left(OHBT \times \sum_{cv}^{CH} hops \right) \quad (2)$$

where,
OHUT (one hop unicasting time) is the required time to send the packet to the next vehicle in the routing path.
$\sum_{cv}^{CH} hops$ is the sum of hops between the current vehicle and the *CH*.

Since it is necessary to wait for the packet to travel the outward path and the return of the acknowledgment, we multiply by 2.

5.3. Data Recovery Function

During data routing, all vehicles in the routing path can save data for a defined time. Our recover algorithm consists of calculating the required time (WT_{cv}) for a vehicle in the routing path to receive an acknowledgment from the cluster head. If the *cv* receives an acknowledgment, it deletes immediately the saved data. Otherwise, after the end of the waiting time (WT_{cv}), it updates the *TTL*, *CH*, *GT* and *Child*(*cv*) received from *ClusterMes*. If the *CH*, *GT* and *Child*(*cv*) have changed, it is considered that the *cv* has left its old cluster and it must delete all the stored data from the old cluster. If only the *CH* that has changed, it is considered that, a new *CH* has been elected and it must receive the stored data, therefore the *cv* must send the data regardless of its state.

Algorithm 2:

1. On receive Packet(CHp, , TTLp , DATA) :
2. if $(CH_p.ID_{CH} \ != CH_{cv}.ID_{CH})$ then
   a. $CH(p) \leftarrow (CH_{cv})$;
3. if $(TTL_p \ != CH_{cv}.distance)$ then
   a. $TTL(p) \leftarrow (CH_{cv}.distance)$;
4. Recover(DATA)
5. While(Stored(Data)){
6. If(acknowledgment is received){
7. Delete (DATA)
8. }
9. Else{
   a. if $(CH_p.ID_{CH} \ != CH_{cv}.ID_{CH}$ &&
   b. $GT_P \ != GT_{CV}$ && $Sender_p != $ Child(cv))){
   c. Delete (DATA)
   d. }
   e. Else if($WT_{cv} == 0$){
   f. $CH(p) \leftarrow (CH_{cv}.)$;
   g. $TTL(p) \leftarrow (CH_{cv}.distance)$;
   h. Resend(Packet(CH_p, TTL_p, $DATA$))
   i. Delete (DATA)
10. }

Figure 4. Resend and recover algorithm

6. THEORETICAL ANALYSIS

6.1. Assumptions

We are assuming:

- The architecture of our solution is clustered and each node knows its father and sons (at least one) at any time.
- All nodes in our system are synchronized.
- Each node *cv* forwards the message only to its father.
- In each round, each vehicle store data and recover it.

6.2. Communication Complexity

The clustering issues versus without clustering complexity are collected in Table 2.

Table 2. Clustering vs without clustering complexity

With our clustering architecture	Without clustering architecture
Send to father: • O(distance(cv,CH)) • O(distance(cv,CH) $\times\lvert E\rvert$) • If a node fails to send message, in the path will be lost (recovered and resent by the nearest node).	Broadcast to all nodes: • $O(\lvert E\rvert)$ cost per node • $O(n\times\lvert E\rvert)$ total cost: expensive • Each node needs $\Omega(n)$ storage to store data from n nodes • Good fault tolerance.

6.3. Performance Evaluation

Our solution is evaluated on the Omnet simulator [18] using the VEINS framework (vehicles in network simulation) [19]. Sumo [20] has also been used as a regenerator and emulator of road mobility and which offers several mobility models. To have realistic measurements, we implemented the Obstacle Shadowing model proposed by the veins framework [21, 22].

Our simulation results are compared with LAODAF solution [23]. In this scheme, the authors propose an opportunistic data aggregation and transfer scheme based on learning automatons (LAODAF). Using an automaton, the collected data is aggregated and sent based on the opportunistic aggregation and transfer metric (OAF). LA can predict vehicle mobility and adaptively select transfer path vehicles based on their OAF. After each round, LA updates its learning rate based on the OAF values and the probability of action vector. Simulations show that LA reduces congestion and network load by transmitting only on demand using a proposed opportunistic data aggregation and transmission algorithm. Number of successful transmissions, connectivity, link failure rate, traffic density, packet reception rate, and delay are among the metrics considered.

In the rest of this section, we present our simulation scenario with performance metrics before analyzing our simulation results.

Table 3. Simulation parameters

Parameters	Values
Bandwith	10 MHz
Vehicle density	20-100 /KM
Vehicle speed	<80 km/hr
Transmission Range	~400m
Simulation Runs	10
Simulation Time	800 s
PHY Model	Nakagami-m
Mac Model	IEEE 802.11DCF
Broadcast Interval	0.05 s
CBR packet	512 Bytes
Queue Length	50 ackets

6.4. Simulation Scenario

Our simulation scenario is an urban environment as shown in Figure 5 with a length of 5 km as represented in Figure 5. Exchanges between vehicles take place in all directions. The MAC and physical layers are defined by the IEEE 802.11p implementation of the Veins framework [19]. We use a default bandwidth of 10 MHz and a bit rate of 6 Mbps at the MAC layer. The transmission coverage of vehicles is around 400 m. The round interval is 0.05 s and the maximum message size is 100 bytes. The network density is 10 to 100 vehicles for each kilometer. It is considered that 10 vehicles per kilometer represents a light density increasing over time to reach a high density of 100 vehicles per kilometer. All simulation parameters are summarized in Table 2.

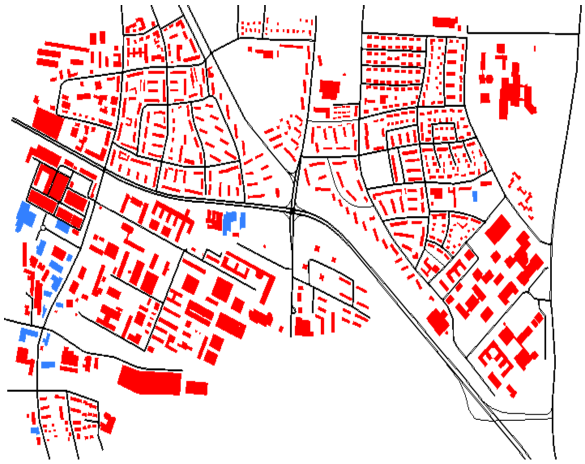

Figure 5. Simulation map

6.5. Performance Evaluation Metrics

The metrics chosen to evaluate the performance of our solutions are given below:

- Average transmission time: the average time that a message sent by a source node took to arrive at the destination (CH).

$$\Delta T=\frac{\sum_{i=1}^{n} t_i}{\lvert n\rvert} \tag{2}$$

where, t_i is the average transmission time of an end-to-end message.

- Packet delivery ratio: the ratio between all the packets successfully received by the CH and the total sent by all the nodes of the cluster: [28]

$$PDR=\frac{\sum CH_{PR}}{\sum C_{PS}} \tag{3}$$

where, CH_{PR} is number of packets received by CH and C is the number packets sent

- Connectivity ratio: the number of broken connections in relation to the total number of links available from the same source to reach the CH.

$$CR=\frac{e^{-\lambda t}}{\sum_{i=1}^{n} l_i} \tag{4}$$

6.6. Simulation Results and Performance Analysis

Figure 6 illustrates the average transmission time according to network density. Since our Cluster Based Packets Aggregation (CBPA) scheme sends the packets on a single path, the safety of the packet delivery depends on path stability. Indeed, the more the density increases, the more the paths have several hops and the risk that a vehicle leaves the single path becomes high.

Given that the rate of failure affects the performance of the network, the impact becomes more important with the high densities. Figure 6 shows that the transmission time also becomes high due to repetitive retransmission of the same lost packet before its successful delivery to *CH*. We also see that with a high density (100 vehicles/km), the transmission time goes from 175 to 523 ms. For other scheme like LAODF, the impact is heavier because of the lack of any approach that can minimize the effect of the breaking links. For CBPA, thanks to the store and recover approach, the retransmission is done by the vehicle closest to the *CH*, which saves us the time that the packet can lose from the source.

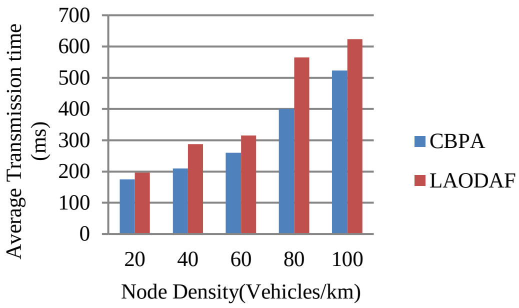

Figure 6. Average transmission delay vs density

As the other network measurements change depending on the density, the coverage within the network also changes as shown in Figure 7. We can see that, the coverage increases as the density of the network increases. Even with light density, network coverage remains low; indeed, the network with a light density is sparse and consequently the links between the vehicles are quickly lost. With the increase in density, the links to reach the destination are more stable and the network coverage as well. With a density of 60 vehicles/km our diagram shows remarkable stability of the links and the transmission unlike LAODAF. Thanks to our clustered architecture and thanks to our unicast approach. However, we note that the broadcast problem has a serious effect on the network coverage for LAODAF, indeed with high density the phenomenon of storm and will cause isolated areas in the network.

Figure 8 shows the impact of density on the packet Delivery ratio. The Delivery ratio is the number of successfully received packets compared to the total number of packets sent by the source. It can be seen in the figure that the variations in the reception rate are linked to the density of the network. The impact is due to the stability of the links between the vehicles, indeed, with the light density, the network is still sparse and the links are broken quickly because of the speed of the vehicles.

With a moderate density around 60 vehicles/km, the links between the vehicles are stable and the network can support the load of the messages exchanged. however, with the high densities, our solution shows its ability to support high loads thanks to its aggregation approach as well as the clustered architecture. Indeed, with clustering the links between vehicles are already established and our approach allows messages to be sent on unique end-to-end paths. Unlike LAODAF, with its send opportunist approach, many vehicles broadcast the packet simultaneously, resulting in data storms.

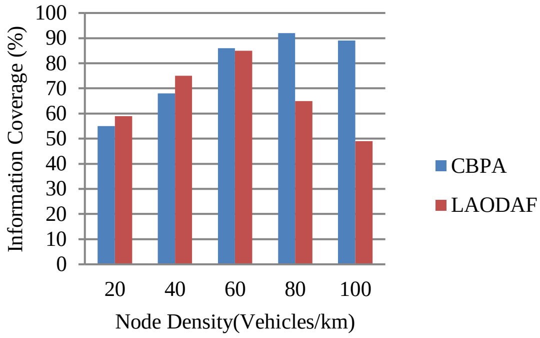

Figure 7. Information coverage vs density

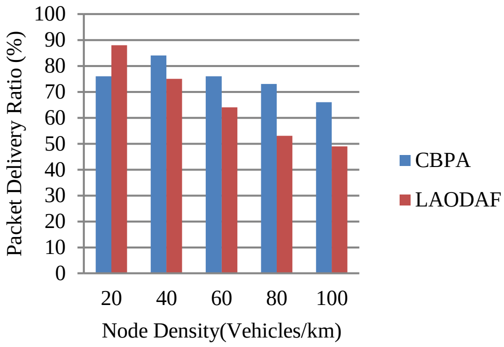

Figure 8. Packet delivery ratio vs density

7. CONCLUSIONS

Ad hoc networks for vehicles (VANETs) have become a major key to the development of new generation wireless networks. They are used in different applications thanks to their implication in road safety and passenger comfort. However, due to the high mobility of the nodes, it is complicated to maintain link stability and ensure package delivery. To solve this problem, in this article, we propose a data aggregation approach. The approach is to design a CSMA/CA for the 802.11p standard. Each sending node assigns a TTL for its packets to reach the *CH*. In addition, each node of the send path stores the data until receipt of the acknowledgment from the *CH*. The proposed solution is evaluated using various parameters, traffic density, packet reception rate and delay as well as coverage.

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BIOGRAPHIES

Soufiane Ouahou holds a master's degree in computer science at Hassan 1st University, Settat, Morocco. Currently, he is a data scientist and technical lead on behalf of Aerospatial Clients, Toulouse, France. He has participated in international conferences and workshops where he has published research works around vehicular networks. He has also carried out research stays in research laboratories such as the LABRI laboratory in Brodeaux, France.

Slimane Bah is a professor at the Computer Science Department, Mohammadia Engineering School, Rabat, Morocco. He has an experience as adjunct professor at the Department of Computer Science, University of Moncton, Moncton, Canada. He holds a Ph.D. in computer networks from the Electrical and Computer Engineering Department of Concordia University, Montreal, Canada. During his Ph.D. research he was an intern at Ericsson Canada. He also holds an M.Sc. in Computer Networks from University of Montreal (Université de Montréal) and an engineering degree in computer science - Networking, from National School of Computer Science and Systems Analysis (ENSIAS), Morocco. His research interests include end-user services, self-organizing and challenging networks, services and protocols engineering. He is also a technical committee member for several international conferences and journals (SITA, NETYS, AFRICATEK, MEDCT, Elsevier Journal).

Zohra Bakkoury holds a Ph.D. in Engineering from Exeter University in UK and a degree of engineer in computer science from Mohammadia Engineering School (EMI), Rabat, Morocco. She is a Full Professor at the Computer Science Department of EMI and founder and director of AMIPS research group and Head of MASI research Laboratory in EMI. Her current research interests are focused on business process management, process mining, data mining and intelligent systems. She has published book chapters beside numerous articles in scientific journals and conferences. She was the co-chair of the eight and 12th SITA conference on Intelligent Systems in 2013 and 2018.