# Cluster-based MAC in VANETs for Safety Applications

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***Abstract*—Recently, we are witnessing increased interest in the research of Vehicular Ad-hoc Networks (VANETs). Traffic safety applications using VANETs aim to improve traffic safety in the road using messages which have to meet high reliability, low and predictable delay constraints. Moreover, due to characteristics of VANETs, such as high speed, unstable communication link, and network partitioning, information transfer becomes inevitably challenging. The effectiveness of traffic safety applications using VANETs depends up on the performance of medium access protocol (MAC). Vehicles using CSMA/CA (IEEE 802.11p) MAC algorithm the time to channel access increases randomly every time when the channel is sensed busy. The main challenge for the design of MAC protocol for VANETs is to achieve reliable delivery of messages within the time limit even when the density of vehicles varies rapidly in the network. Furthermore, MAC algorithms with good scalability, fairness, and predictable delay are needed to fulfill the requirements of traffic safety applications. Therefore, cluster-based MAC protocols that can avoid or limit channel contention, provide fairness to channel access, increases radio capacity by the spatial reuse of network resources and effectively control the topology of the network. However, due to the high mobility characteristics of VANETS, vehicles frequently join and leave clusters affects the stability of network. Furthermore, the stability become worse if the cluster heads (CH) elected are not stable. Therefore, maintaining cluster stability can increase performance of safety applications in VANETs. Finally, we propose two cluster based MAC protocols (D-CBM) based on contention based carrier sense multiple access (CSMA) and collision free time division multiple access (TDMA) in order to achieve high stability, low communication overhead and real time delivery of safety messages. Simulation results indicate the proposed protocols are able to achieve the above requirements. Furthermore, we analyze the performance of the proposed MAC design with SBCA protocol.**

## I. Introduction

In recent years, traffic accidents have increased by an enormous rate which had led to a huge amount of grief and economic loss. This motivates to the development of traffic safety applications using VANETs to avoid road accidents [1], [2]. In addition, VANETs comprises of vehicle to infrastructure (V2I) and vehicle to vehicle (V2V) communication which can support exchange of safety and non-safety messages. Furthermore, each vehicle in VANETs is equipped with an On Board Unit (OBUs). The messages exchanged by safety applications require predictable or low delay and high reliability. The delivery of messages after few tenths of a second delay may significantly affect the performance of safety applications (e.g. collision avoidance). In addition, safety messages have a deadline of 100ms and the message should reach the destination within this time limit [3]. In particular, the effectiveness of active safety applications depends on the ability to disseminate messages as quick as possible with high reliability, fair and scalable utilization of network resources [4], [5].

In VANETs, the MAC protocol is affected by several factors such as the number of one hop neighbors, communication link time period, direction of traveling, speed and vehicle position. In high density scenarios, the data congestion and packet delay increases by an enormous rate due to the lack of network resources. Specifically, using CSMA/CA there will be a long contention period among vehicles for using network resources, and this protocol is not scalable [6]. Besides, the performance of CSMA/CA decreases dramatically when the network load and vehicle density increases. For instance, several protocols (e.g., [7]–[9]) such as ADHOC MAC [10], Space Division Multiple Access (SDMA) [11] have been proposed to reduce the contention period. For example, ADHOC MAC [10] is based on a Reliable R-ALOHA (RR-ALOHA). Additionally, RR-ALOHA is based on Time Division Multiple Access (TDMA) for channel access. Moreover, TDMA protocols allocate time slot for vehicles to transmit. SDMA [11] protocol divides the entire network area into multiple space division units and one channel is allocated to each space division unit to serve the vehicles in that area. However, these protocols do not solve the hidden terminal and the contention problem, which are the performance affecting factors in high density scenarios. Consequently, this can be effectively alleviated by a cluster based MAC topology.

Clustering in VANETs means organizing the vehicles into small groups based on some common characteristics such as vehicle position, speed, and direction etc. However, cluster reconfigurations and CH changes are unavoidable in VANETS due to their dynamic nature, thus affecting stability and creating overhead. Moreover, most important criterion for any clustering method in VANETs is to form stable clusters with minimum overhead. The stability is defined by long CH duration, and low rate of change of CHs. By clustering the vehicles into groups of minimum relative mobility. In this way, the clustering algorithm can improve the lifetime of the cluster and decrease the number of CH changes and the number of cluster re configurations. Most of the previous clustering techniques are unstable in high mobility environments, because they do not elect a stable CH during initial process of CH election.

This paper proposes two cluster based mac protocol (D-CBM) which forms stable clusters and elects stable CH in order to achieve high reliability and low or predictable delay. To effectuate this goal, vehicles in the VANETs are divided into different clusters based on their position, direction of movement, lanes, and speeds. In addition, the reliability of messages are increased by assigning time slots for different vehicles. Furthermore, the predictable delay is achieved by considering 100ms for the length of frame in CH. The rest of the paper is structured as follows. Section II gives an overview of the approaches related to the cluster-based MAC algorithms in VANETs. In section III, the D-CBM clustering algorithm is described. Section IV discusses the simulations and graphs obtained. Finally, the conclusions of our work are presented in section V.

## II. Related work

Clustering VANETs into small groups [12] have several advantages such as increased network stability and scalability for CMs, spatial reuse of network resources and emergence of a virtual backbone. Hierarchical Clustering Algorithm (HCA) [13], creates clusters with a range of maximum four hops. Additionally, HCA protocol schedule transmissions and channel access inside the cluster to ensure reliable communication. Furthermore, HCA does not depend on global positioning systems (GPS) which contributes to its robustness. However, it is not suitable for real time safety applications. In [12] authors uses Road side unit (RSU) for channel allocation in order to reduce management overhead, channel access and channel allocation time. Additionally, RSU divides bandwidth allocated to a unit into prefixed overlapping spatial clusters. Furthermore, channel allocated to a cluster is divided into time slots. Moreover, according to the availability of channel and priority of request each vehicle is allocated with a time slot. However, reliability and fairness is lowered due to centralized allocation of network resources. Cluster based MAC protocol (CMAC) [14], was proposed for V2I communication in VANETs. In CMAC, RSU allocates a channel to CMs and these channels are used in non adjacent clusters which enables spatial reuse of channels. Additionally, the hidden terminal problem is alleviated when all the CMs in the RSU region listens to the broadcast messages. Furthermore, contention is also avoided by efficient utilization of the network spectrum. Moreover, the predictable delay for safety messages is achieved by avoiding contention at RSU for channel access. However, the protocol may not scale at high vehicular traffic and cannot work in regions where there is no RSUs deployed.

In [5], authors propose a hybrid media access technique for cluster-based vehicular networks. Additionally, they try to minimize the total number of clusters. A distributed cluster-based multi-channel communication protocol is proposed in [15], which collaborates both contention-based and contention-free MAC protocols with clustering. However, the protocol is expensive due to the requirement of an additional transceiver. In papers [16], [17], Gunter et al introduce a concept of clustering based medium access control protocol for VANETs to reduce the effects of the hidden terminal problem. However, the scheme is not suitable for high density scenarios, because the cluster stability decreases when the density of vehicles increases. In [18], Region-based Clustering Mechanism (RCM) is introduced to improve the performance of MAC protocol

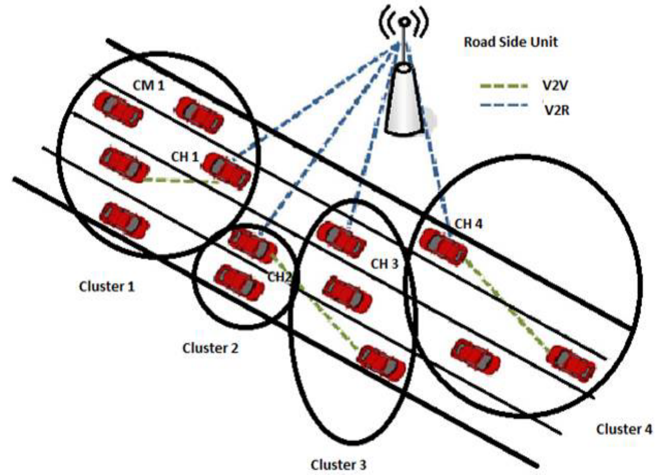


Fig. 1. Cluster based VANETs in highway scenario

for VANETs. In RCM, the service area is divided into a set of space division units, and each division unit is limited to a fixed number of vehicles for avoiding contentions of channels. Additionally, a non-overlapping radio channel pool is allocated to a region. As a result, the contention period is reduced and throughput is increased by limiting the number of vehicles in division units. However, the method in [18] provides low channel pool utilization in case of sparse traffic.

Several protocols [5], [19] have been proposed in VANETs using TDMA to reduce interference and provide fairness between vehicles. In [19], authors introduce TDMA cluster-based MAC (TC-MAC) for intra-cluster communications in VANETs. TC-MAC integrates TDMA slot allocation with centralized cluster management technique. In TC-MAC, vehicles are assigned to time slots for collision free transmission. In [20], the authors proposed a distributed mobility-based clustering algorithm to increase cluster stability, where stability is meant by the time duration of the cluster members and the cluster head. These protocols generally use V2V communications for formation of clusters and for electing cluster heads. Nevertheless, RSU will be widely deployed on the highway as well as other important locations (safety zone), and should be fully utilized to carry out the traffic safety applications.

Design of cluster-based MAC protocols for VANETs should consider delay bounded (i.e., the messages should be delivered within the deadline ), bandwidth efficiency (i.e., the network resource should be utilized in a fair and efficient way), mobility (i.e., the MAC protocol should support vehicles to leave and join clusters at high speed), scalability (i.e., VANETs should scale in high and low density scenarios), and fairness (i.e., every vehicle should get a fair chance to access the channel). The challenge of successfully deploying safety applications is to ensure timely and reliable data delivery of messages. In this paper, a cluster based MAC (D-CBM) is designed to overcome above problems. In D-CBM, CH assign time slots to the members of the CMs. As the time slots can be assigned centrally, fewer number of collisions have to be expected which consequently increases the reliability.

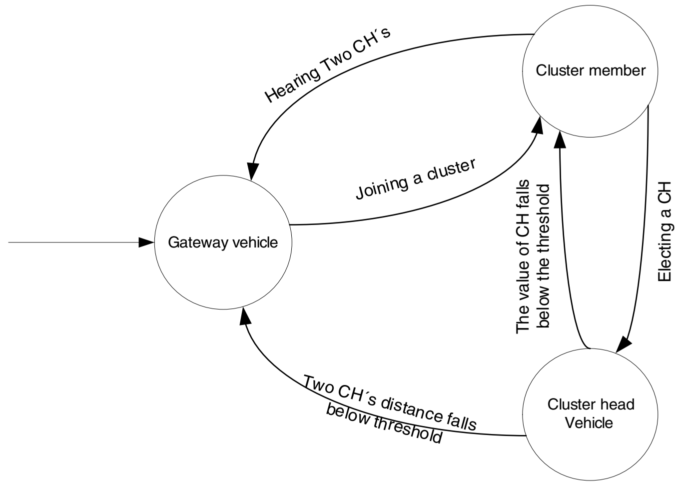


Fig. 2. Vehicle states

## III. D-CBM PROTOCOL

In this section, we illustrate the operation of the cluster based MAC protocol (D-CBM) for VANETs that is introduced in this paper. D-CBM employ, the distributed technique for clustering in VANETs, where V2V and V2I communication are considered. In the proposed scheme, each vehicle has a GPS installed which gives the location information. A highway scenario shown in figure 1 with vehicles and RSUs is considered in this paper. RSU is fixed and uniformly spaced in the side of the road. They are homogeneous in nature and assigned with a unique identifier. They are able to function as a central coordinator to collect and distribute the messages. Vehicles send periodic messages to CHs. In this scheme, each vehicle shares information about its current position, speed, lane, and direction with only its one hop neighbors and registered RSUs. The vehicles in this scheme will be in three different states and transformation to each modes are shown in figure 2. The modes are described in detail below.

*a) Cluster Head:* A vehicle in this mode gathers information regarding speed, direction, lane, and location from its members and it uses TDMA technique for allotting communication slots for its members. In addition, it receives transmission slots from the RSUs first and during the rest of the time frame it allocates slots to its CMs. In D-CBM approach, CHs are responsible for gathering, aggregating and forwarding the data to the RSUs. Thus, they are responsible for conveying the complete information of its CMs. CH is then responsible to transmit these data towards the RSUs and adjacent CHs. There are two types of communication for CH, Intra cluster communication and Inter cluster communication. Intra cluster communication is between CH and its cluster members. Inter cluster communication is between CH and its adjacent CHs or RSUs.

*b) Cluster Member:* A cluster member is a vehicle that belongs to a particular cluster and it regularly transmits the data to its cluster head.

*c) Gateway Vehicle:* This is a initial state when vehicle enters the network. In this state, vehicle can be cluster member of two clusters or belong to no clusters. This vehicle have different capability it can have time slots to the RSU in free period and can transmit the information to RSU.

D-CBM protocol operation is divided into section. We perform clustering in sections and each section results in selection of different CH. One section means when the value of the CH obtained from equation 10 falls below a particular threshold. The CH is elected from vehicles in each cluster. In addition, these re-election can avoid the re-clustering of vehicles and increasing the stability of the cluster.

D-CBM protocol is divided into two phases. The first phase is the setup phase, where members are classified into certain clusters according to the speed, direction of motion, lane and position. In the initial start of the phase the vehicles entering the road send beacon messages to the RSU and registers in the RSU. After waiting for certain period RSU elects the CH at a random time and after that CH adds members to cluster. This increases the initial cluster stability of the network. After initial selection of the cluster, cluster reconfiguration happens when one of the CH goes below a threshold. Next CH election will be based on combination of average relative speed between the neighbors in the CH, relative distance to RSUs in the highway compared with itself and its neighbors in cluster, and the relative distance between itself and all its neighbors in cluster.

$$D_{xavg} = \frac{D_{x1} + D_{x2} + D_{x3} + ...D_{xn}}{n} \quad (1)$$

$$D_{yavg} = \frac{D_{y1} + D_{y2} + D_{y3} + ...D_{yn}}{n} \quad (2)$$

$$\triangle\, D_{i,neighbors} = \sqrt{|D_{xi} - D_{xavg}|^2 + |D_{yi} - D_{yavg}|^2} \quad (3)$$

The equation 3 represents average distance between all neighbors and itself. It means how close are the neighbors to one vehicle. In addition, equation 5 represents the average difference of speed between one vehicle and all its cluster members.

$$S_{avg} = \frac{S_1 + S_2 + S_3 + ...S_n}{n} \quad (4)$$

$$\triangle\, S_{i,neighbors} = |S_i - S_{avg}| \quad (5)$$

Equation 6 represents the distance between one of its cluster member and its registered RSU. Additionally, equation 7 and 8 represents average distance of all its cluster members to the registered RSU and the distance between one vehicle to its registered RSU.

$$R_{nei,rsu} = \sqrt{|R_{xnei} - R_{xrsu}|^2 + |R_{ynei} - R_{yrsu}|^2} \quad (6)$$

$$R_{avgnei} = \frac{R_{nei1,rsu} + R_{nei2,rsu} + R_{nei2rsu} + ...R_{nein,rsu}}{n} \quad (7)$$

$$R_i = \sqrt{|R_{xi} - R_{xrsu}|^2 + |R_{yi} - R_{yrsu}|^2} \quad (8)$$

$$\triangle\, R_{i,rnei} = |R_i - R_{avgnei}| \quad (9)$$

From equation 9 the relative distance between one vehicle and its all other cluster members to registered RSU is calculated. Additionally, distance to RSU is considered here to elect a CH neared to RSU in order to reduce the delivery time. Finally, the relative speed, distance to the neighbors and distance to the RSU is combined using weighting factors $W1, W2, W3$ in equation 10. The values of $W1, W2, W3$ are varied according to the application requirements. The vehicle with lowest value for equation 10 is elected as CH.

$$F_i = W_1 \times D_{i,neighbors} + W_2 \times S_{i,neighbors} + W_3 \times R_{i,rnei} \quad (10)$$

In transmission phase, we propose two protocol for CH to RSU communication. First protocol is contention based and other is contention free communication. Contention free protocol is based on TDMA communication. In this protocol, RSU assign time slots to CHs and CH assign time slots to CMs and gateway vehicle. From figure 3 the RSU time frame is divided into CH time slots, RSU down link, and free period. In this protocol, we assume there is a time synchronization between RSU, CH and CM. In addition, we assume that one CH can be in the range of maximum two RSUs and CHs are registered to the nearest RSUs. In CH time slots, the frame is divided into fixed number of slots and each CH is assigned with a transmission slot. In RSU down link, it sends information to all its registered CHs and in free period it assigns slots to gateway vehicles to transmit information. Additionally, CH frame is also divided into four sections. In first section, it assigns first time slot for itself for communicating to the RSU. Secondly, CH assign slots for cluster members in the CM slots section. Thirdly, listen period is that it listens to RSUs information and last is the CH to CM transmission,it sends all information send by RSU to its CMs. In RSU and CH frame, the length of each sections can be varied according to density of vehicles.

Second protocol proposed is based on CSMA CA communication where the CH wait for the channel to be free to communicate with CM. The difference between two protocol is the CH to RSU communication and that it uses two transceiver. Furthermore, RSU frame shown in figure 4, contention period is considered for CH transmission. In order to achieve the real time requirements of the safety messages the total frame length of the RSU and CH is considered here as 100ms. Cluster delay means the time required for sending one message from CM to the RSU. The delay parameter is very crucial for safety message delivery. The end to end delay should be minimized by selecting proper MAC protocol to reduce the channel access time, selection of stable CH nearer to the RSU. In addition, the time delay required for sending one message from RSU to one CM in cluster is also considered here. $T_{delay,RSU}$ is the total time delay for delivering one message from RSU to CM. Furthermore, $T_{CH2CM}$ are the average time delay for sending message from CH to CM respectively in their clusters. $T_{RSU2CH}$ are the average time delay for broadcasting message from RSU to CH and vice versa. To assure the timely delivery of active safety messages, the maximum delays for delivery with and without RSU should be less than the required delivery delay of safety message i.e, $T_{delay,RSU} \leq T_{Safety}$.

$$T_{delay,RSU} = T_{CM2CH} + T_{RSU2CH} \quad (11)$$

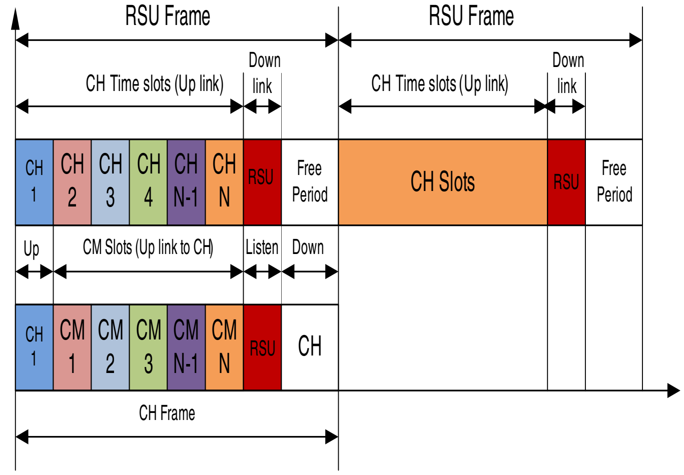


Fig. 3. TDMA in both RSU and CH Frames

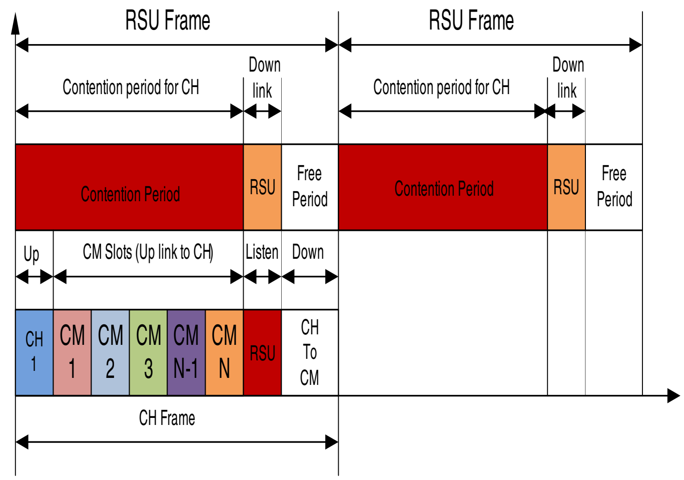


Fig. 4. Contention based in RSU and TDMA in CH

$$CH_t = \frac{L_{ch \to rsu}}{R} + n \times (\frac{L_{cm \to ch}}{R}) + \frac{L_{rsu \to ch}}{R} + \frac{L_{ch \to cm}}{R} + (n+3) \times d_{ifs} \quad (12)$$

$$L_{ch \to rsu} = L_{rsu \to ch} = L_{ch \to cm} = L_{crs} \quad (13)$$

$$CH_t = 3 \times \frac{L_{crs}}{R} + n \times (\frac{L_{cm \to ch}}{R} + d_{ifs}) + 3 \times d_{ifs} \quad (14)$$

$$CH_t = \frac{(3 \times L_{crs} + n \times L_{cm \to ch})}{R} + (n+3) \times d_{ifs} \quad (15)$$

In this protocol, the frame length of CH and RSU is considered to be $100ms$. In addition, the maximum number of CM slots in CH frame is obtained from equation 15. Furthermore, these can be used for the optimizing maximum number of CM in the cluster. The performance of the both approaches are validated using simulations in next section.

| | |
|---|---|
| Length of the CH frame | $CH_t$ |
| Length of the ch to rsu message | $L_{ch \to rsu}$ |
| Length of the cm to ch message | $L_{cm \to ch}$ |
| Length of the rsu to ch message | $L_{rsu \to ch}$ |
| Length of the ch to cm message | $L_{ch \to cm}$ |
| length of inter frame space | $d_{ifs}$ |
| RSU transmission range (m) | 300 |
| OBU transmission range (m) | 150 |
| Data rate (Mbits/sec) | 6 - 24 |
| IFS (ms) | 0.016 |
| Period for CAM (ms) | 100 |
| Packet length of RSU broadcast (bits) | 800 |
| Packet Deadline (ms) | 100 |
| Frame length of CH and RSU (ms) | 100 |

TABLE I
PARAMETERS

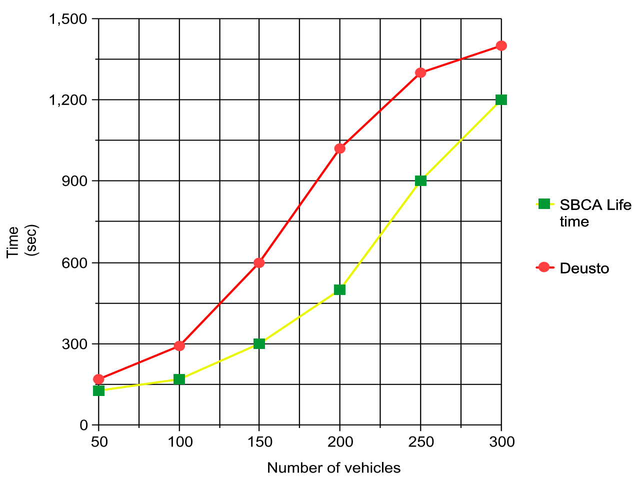


Fig. 5. Cluster Lifetime vs Density

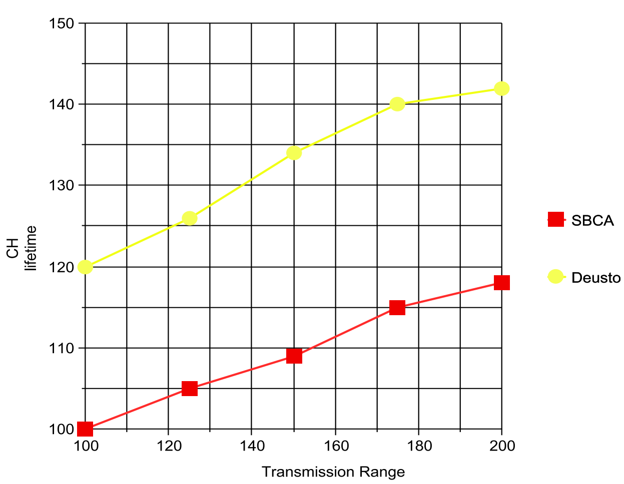


Fig. 6. Cluster Lifetime vs Transmission Range

## IV. SIMULATIONS

In our simulations, performance of the proposed protocol is evaluated in highway scenarios generated by the micro-traffic simulator SUMO. Vehicles move in two lanes and in opposite directions on the road with varying speeds. They also change to different directions at intersections in highway. Furthermore, each vehicle can change its lane in road segment and near intersections. When the destination is reached the vehicle stops for a random time and then repeat the same process. The road segment patterns have features such as safety distances between two vehicles and speed limit. Finally, these generated movement patterns are used as input in NS-2. The parameters are summarized in Table. I. The other PHY layer parameters follow the default settings of IEEE 802.11p. Where the Nakagami propagation model is used.

Stability of CHs significantly affects the performance of MAC protocol, when CHs change their status to cluster members, then it has to re adjust to the new structure. In this case, vehicles have to wait for another frame for slot allocation. CH Duration means the time duration of the vehicles, remaining its function role as CHs. Long CH lifetime means few CH changes and good stability. We observe from figure 5 that as the density of vehicles increases, CH lifetime increases. Also CH lifetime increases when the transmission range of each CH is increased from figure 6, the CH stability is high in high transmission range. Another important parameter to be considered is the packet delivery rate. We checked the RSUs reception rate, the number of packets successfully delivered divided by the total number of packets generated. In addition, from figure 7 delivery rate is compared with the number of CHs as the number of slots in RSU for CH transmission is important for the reception of packets. The packet delivery rate decreases as the number of CHs increases, but it shows better performance as compared to SBCA [21]. Furthermore, delay is another important parameter for safety applications. We evaluate the delay in $ms$ for the reception of safety messages in the RSU. In general, messages of safety applications have latency constraints and should be received within the time limit. As can be seen in figure 8, the delay is compared with both CSMA/CA and TDMA based D-CBM approach with SBCA approach. Additionally, both D-CBM protocols perform better compared to SBCA. Furthermore, both protocols achieve the deadline of 100ms but the delivery rate for CSMA/CA is compromised.

## V. ACKNOWLEDGMENT

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## VI. CONCLUSIONS

This paper has presented a cluster based MAC protocol (D-CBM) suitable for traffic safety applications in VANETs. The goal was to define a protocol able to scale over the number of vehicles and deliver the messages within the deadline. Our algorithm elects stable cluster heads periodically by using a

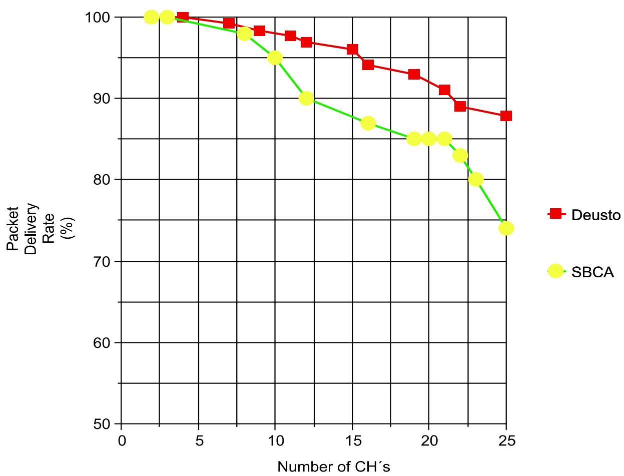


Fig. 7. Packet delivery rate vs number of CHs

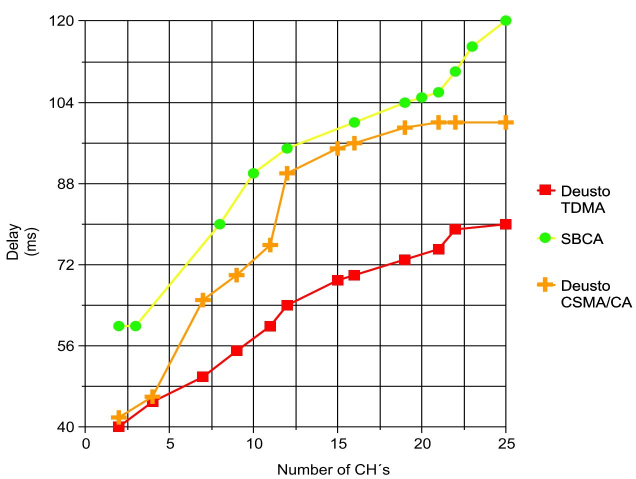


Fig. 8. Packet delay vs number of CHs

weighting equation, which combines minimum relative distance to all its neighbors, relative speed and relative distance to registered RSU. The clusters heads elected are stable with long average cluster head duration, and low average rate of cluster head change. In this work, we have evaluated the effect of cluster head duration versus transmission range. The RSU allocates time slots to the moving cluster head vehicles based on the registration and cluster heads allocate time slots for CMs. We show how it could significantly improve the packet delivery rate. The RSU and CH broadcast messages is heard by all the CH and CMs vehicles in the cluster region and this solves the problem of hidden stations and results efficient utilization of the allocated slot by avoiding contention. The synchronization between RSU, CH, CM allows the protocol to ensure reliable and timely delivery of safety messages. However, the protocol may not work in areas where there are no RSUs deployed.

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