Media Access Technique for Cluster-Based Vehicular Ad Hoc Networks

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Abstract—We propose a hybrid media access technique for cluster-based vehicular networks. This technique integrates the centralization approach of cluster management and the universal way of forwarding data, where the farthest vehicle forwards data in an effort to maximize the opportunity of advanced notification. This method leverages contention-free and contention-based MAC, to support the different requirements of safety and non-safety messages. Inter-cluster interference avoidance is also supported. The analysis and simulation show that using this scheme, for inter-cluster communications, provides an early notification compared to other existing clustering methods.

Keywords- Vehicular Ad Hoc Network (VANET), Vehicle-to-Vehicle communication, clustering schemes in VANET, Safety messages dissemination in VANET.

I. INTRODUCTION

The rapid advance of vehicular technology provides vehicles’ systems with a level of intelligence that is crucial for increasing drivers’ awareness and comfort. Future vehicles will be equipped with efficient computer systems and wireless communication interfaces. Employing technologically advanced tools equip vehicles with the means to readily communicate with one another. The communications in Vehicular Ad hoc Network (VANET) can be categorized into Vehicle to Roadside (V2R) units and Vehicle to Vehicle (V2V) communications [1]. In the United States, both communication types operate in the 75 MHz Dedicated Short Range Communications (DSRC) spectrum allocated within the (5.85-5.925) GHz band. The spectrum is divided into 7 channels, one of these channels is called control channel, and the remaining six are called service channels.

V2R and V2V can be used to support VANET safety and non-safety applications. The applications utilize various types of data wirelessly exchanged among vehicles. Different data types have different requirements; therefore, there is a need to distinguish between real-time data having time latency requirements (e.g., safety messages, video data) and non-real-time data (e.g., road traffic, weather) specifying different requirements. Due to the high infrastructure cost associated with V2R communications V2V is considered to be a more economical and practical approach for safety and non-safety information delivery. On the other hand, although V2V has many advantages over V2R, using V2V is also a challenge since it requires designing intelligent strategies capable of meeting the different requirements of adverse traffic data.

In VANET communications, media access techniques must cope with scenarios where densely congregated vehicles share limited bandwidth media. Therefore, there is a need to study traffic characteristics to take advantage of the mobility patterns of vehicles. Usually, vehicles moving in platoons share similar traffic patterns like the average speed, the average acceleration, and the direction of motion. This group of vehicles can be united together to form a new entity called a cluster [2, 3]. Clustering schemes [2, 3] having highly developed media access protocols can be used to reduce data congestion and increase the chance of safety and non-safety types of data delivery.

In this paper, we propose new media access techniques that can be used for clustering management and communications. This protocol integrates the centralization approach of cluster management and the universal way of forwarding data in VANET, where the farthest vehicle forwards data backward in an effort to increase the coverage area. In this technique, time is divided into cycles; each cycle is shared between service and control channels and divided into two parts. During the first part, leveraging Time Division Multiple Access (TDMA), service channel will be used for Intra-cluster management and safety message delivery within the cluster. In the second part, neighboring clusters will exchange safety messages and advertisements over the control channel using media contention-based techniques. In addition, in parallel with the second part, cluster members can use service channels to exchange non-safety data with one another and with members of neighboring clusters.

The rest of the paper is organized as follows: Section II formulates the objectives of this work. Section III describes the protocol architecture. In Section IV, we present the protocol operation. In Section V, we discuss the delay analysis. Section VI shows simulation and performance analysis. Finally, Section VII concludes the paper.

II. MEDIA ACCESS PROTOCOL OBJECTIVES

The concept of grouping vehicles into manageable clusters in VANET is used to avoid flooding the network. Generally,
media access techniques in cluster-based schemes should guarantee access fairly for all cluster members such that, every cluster member can have the chance to exchange its data. Some of the VANET clustering-based schemes existing in literature focused on cluster formation techniques [4], while others [5, 6] presented algorithms for media access techniques. Most of the techniques fall into the following categories: Scheduled-based for intra cluster communications, contention-based for inter cluster communications and cluster-head to cluster-head communications for multi-hop data dissemination. In these proposed schemes, the scheduled-based technique is used to avoid interference among cluster members, thus minimizing collisions. Interference, however, can also happen due to cluster overlapping. Consider Fig. 1, where vehicles belonging to different clusters might interfere with each other. For simplicity, the average number, \( M' \), of vehicles in cluster-\( m \) (between the bold arcs) that are susceptible to interference with vehicles in cluster-\( n \) is:

\[
M' = \frac{3r - (CH_m^{pos} - CH_n^{pos})}{2r} M
\]

(1)

where \( r \) is the cluster radius, \( CH_m^{pos} \) is the position of the Cluster Head (CH) in cluster-\( m \), \( CH_n^{pos} \) is the position of cluster-head in cluster-\( n \), and \( M \) is the average number of total vehicles in cluster-\( m \) as given by [5]:

\[
M = \frac{2rL}{G + Vl}
\]

(2)

where \( Vl \) is the average length of the vehicle, \( G \) is the average gap between two consecutive vehicles, and \( L \) is the number of lanes per road. On the other hand, cluster-head to cluster-head communication is not an efficient way to disseminate data to the farthest possible area. Therefore, we propose a new media access technique for VANET cluster-based schemes. The objective of our design is to have a simpler algorithm capable of delivering safety and non-safety data to all nodes in the vicinity. Thus data collision is minimized by avoiding intra-cluster and cross-cluster interference, and finally, relaying safety messages backward to the farthest possible area

III. MEDIA ACCESS PROTOCOL ARCHITECTURE

We propose a hybrid protocol that uses scheduled-based and contention-based approaches for Intra-Cluster and Inter-Cluster communications, respectively. The design of our protocol is motivated by the fact that DSRC interface uses 7 non-overlapping 10 MHz channels. While the communication range of the control channel is 1000 or more meters, it is in the range of 30 to 400 meters for the service channels. Similar to [5], our proposed protocol takes advantage of the variation of communication ranges of service and control channels such that, the control channel, CRL, will be used to deliver safety data and advertisements across neighboring clusters, and a service channel, called SRV, will be used to exchange safety and non-safety data within the cluster. Unlike [5] where each vehicle is assumed to have two DSRC interfaces, we think vehicles are very unlikely to have more than one DSRC interface. Therefore, we assume that each vehicle is equipped with a single DSRC interface and a GPS device. But, with one DSRC interface installed, the protocol must be designed to challenge the fact that DSRC interfaces demodulate one channel at a time. This means, even though the DSRC interface has 7 channels, it can’t use more than one channel at the same time. To solve this problem, we introduce the so called system cycle, which is divided into Scheduled-Based (SBP) and Contention-Based (CBP) sub-periods and repeat every \( T \) msec.

Once a cluster-head is elected (in this paper we adopt cluster formation techniques where the cluster-head is always in the middle of the cluster), CH utilizes SRV channel and takes over the responsibility of intra-cluster management. This task includes: assigning time slots to all cluster members, processing and disseminating all received messages and advertisements (link establishment requests and announcements on the availability of certain services), and finally, selecting the Cluster Forwarder (CF) that will forward all safety messages backward via the CRL channel.

A. The Cluster System Cycle

The proposed protocol assumes a single system cycle that is shared between the SRV channel, the remaining service channels, and the CRL channel. As shown in Fig. 2, the SRV channel consists of Cluster Members Period (CMP) and Cluster Head Period (CHP). CMP is divided into time slots. Each time slot can be owned by only one cluster member. The end of the CHP period is followed by the CBP period during which CRL is used by only CF and CH.

At the beginning of each cycle, all vehicles switch to SRV channel. Each system cycle starts with a frame sent by the cluster-head called the Start Frame (SF). This frame specifies the number of time slots before the SBP of the next cycle. All cluster members receive the frame and become synchronized with the cluster-head. During CHP period, each cluster member uses its time slot to send its status, safety messages and advertisement. The CHP period follows CMP period and is allocated to the cluster-head to process all collected messages. During the CHP period, the cluster-head processes the received messages and responds to all cluster members’ requests. Vehicles remain listening to the SRV channel until the end of
The cluster-head maintains two sorted lists. The Cluster Back List (CBL) and the Cluster Front List (CFL). The CBL list contains all cluster members whose position is less than the CH’s position sorted in ascending order. The CFL list contains all cluster members whose position is greater than the CH’s position sorted in descending order. The CH node of the cluster is allowed to use the CRL channel. The cluster-forwarder relays safety messages backward via CRL channel to send messages to neighboring clusters. Our protocol requires that the CBL and CFL lists are always outside of each other transmission ranges. Note that, concurrently during CBP, cluster members can exchange data with one another and also with neighboring clusters via service channels.

IV. PROTOCOL OPERATION

A. Intra-Cluster Organization

As shown in Fig. 3, our protocol requires that the CBL members occupy the first half of the CMP period, while the CFL members occupy the second half. At the beginning of each cycle, the cluster-head announces the allocated time slots by distributing these lists to all members. Each member will have a time slot assigned to it as follows: the first time slot, after SF, is assigned to the first member of the CBL, which is the CRL channel. The second time slot is assigned to the next CBL member and so on, until all the CBL and the CFL members have time slots assigned to them. After that, the protocol starts working, and the communications between the CH and CM take place.

B. Clustering Communication and Interference Avoidance

The propagation direction of safety and non-safety messages is very important to the protocol architecture design. Safety messages are propagated backward (against vehicles’ motions) most of the time, but it’s very rare that safety messages propagate forward (in the vehicles’ motion direction). Non-safety data is exchanged in both directions. Our protocol serves both types of traffic such that, safety messages are delivered to neighboring clusters on the CRL channels, and the non-safety data is delivered on the service channels. Fig. 4 illustrates the protocol operation. The basic components of protocol operation are as follows:

- A bidirectional communication via all service and CRL channels is supported between neighboring clusters.
- The CF node relays safety messages backward via CRL and the CH node receives safety messages, distributing them locally to all cluster members via SRV channel.
- The CH node of the cluster is allowed to use the CRL channel to send only safety messages needing sent forward, which is very rare, and advertisements.

V. DELAY ANALYSIS

The delay parameter is very crucial for safety message delivery. All safety messages generated by cluster members are propagated to their destination via three steps as follows: Message transmission via the SRV channel within the cluster; message delivery to neighboring clusters via the CRL channel; and finally message dissemination in the receiving cluster via the SRV channel. The delay of the safety message, while transmitted on the SRV channel, is deterministic and subject to the upper bound of the SBP period, $t_{SBP}$, which can be expressed as:

$$t_{SBP} = \frac{\text{message size}}{\text{data rate}}$$
\[ t_{\text{skip}} = \frac{M S}{R} + t_{\text{CIP}} \]  

where, \( R \) is the channel transfer rate, \( S \) is the size of the safety message, \( M \) can be defined using (2), and finally \( t_{\text{CIP}} \) is the time needed by the CH to process all messages. But, the delay of the safety message is undeterministic while it’s on the CRL channel, because of the IEEE 802.11 [7] competition based method. So, in order to study the impact of the competition based method on safety message delay, we need to take into account the following types of nodes contribute to the delay of the safety message, while on the CRL channel: the CF and CH nodes belonging to different nearby clusters and nearby individual nodes in a non-clustered state. Due to space limitation, we can’t show the mathematical equations used to analyze the impact of the competition based method on the safety message delay, and for now, it will suffice to show the simulation results later.

If we denote the maximum tolerable delay of a safety message by \( t_{\text{safety}} \), and the length of the system cycle period by \( T \), then, in order to deliver safety messages on time, the following condition: \( T < t_{\text{safety}} \), must be satisfied. Once a safety message is sent by any cluster member, all cluster members and neighboring cluster members must be notified on time. The max delay, denoted by \( t_{\text{cluster}}^{\max} \), to notify cluster members is: \( t_{\text{cluster}}^{\max} \leq t_{\text{skip}} \). The max delay, \( t_{\text{neighbor}}^{\max} \), to notify neighboring cluster members is: \( t_{\text{neighbor}}^{\max} \leq T + t_{\text{skip}} \). (\( t_{\text{skip}} \) represents the time on the receiver’s side). If the vehicle generates safety message during the CBP, then, \( t_{\text{cluster}}^{\max} < T \), and \( t_{\text{neighbor}}^{\max} < 2T \). Note that, as mentioned earlier, if some vehicles in the receiving cluster listen to the control channel while the CF node is sending safety messages, they can receive safety messages within a time less than \( t_{\text{cluster}}^{\max} \), or even less than \( T \).

The important part of our analysis is to check whether the CF nodes are able to send safety messages over a CRL channel during the CBP before the next cycle starts. For analysis and simulation, we refer to [8] where the authors demonstrated several types of VSC applications, and based on their results, we set \( t_{\text{safety}}^{\max} = 300 \), and the length of \( T = 90 \) msec.

VI. SIMULATION AND PERFORMANCE EVALUATION

The protocol performance was evaluated via simulation by using C++ with graphical interface. Table I contains the input parameters for the generation of different simulation scenarios. Vehicles create clusters, and move on the highway using the following distance model. We varied the distance between consecutive clusters, and varied the average speed of the clusters, so the clusters in the back move faster. Eventually, clusters in the back enter the CRL channel transmission area of the CF of the cluster in the front. For convenience, we refer to our protocol as CF-Based protocol, because cluster-forwarder is used to relay safety messages backward, and we refer to protocols that rely on the cluster-head to send safety messages as CH-based protocol. Three performance metrics are used: The first one is called earliest notification, which shows how early in time CF-based protocols can forward safety messages compared to the CH-based protocols. The second one is a topology-related metric, depicting the ratio of the CF lifetime to the cluster lifetime. Lifetime is defined as the point in time the cluster is created, to the point in time the path is completed. The third one is a data-related metric showing the impact of the contention-based technique on the delivery of safety messages. In this metric, we show the worst case scenario, and for this purpose, we increased the transmission range of the CRL channel, so more CF nodes compete to access the media. In addition, we force every vehicle to send safety messages during its time slot. At once, all safety messages are collected and sent in one package.

### Table I. Simulation Parameters

<table>
<thead>
<tr>
<th>Road and Clusters</th>
<th>Safety message</th>
<th>IEEE 802.11</th>
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<tbody>
<tr>
<td>SRV range = 200 m</td>
<td>S = 200 bytes</td>
<td>DIFS = 64μsec</td>
</tr>
<tr>
<td>CRL range=800 m</td>
<td>T = 90 msec</td>
<td>aSlotTime = 16 μsec</td>
</tr>
<tr>
<td>Vl = 5 m</td>
<td>t_{\text{CIP}} = 10 msec</td>
<td>Max. contention window = 31</td>
</tr>
<tr>
<td>L = 4</td>
<td>s_{\text{safety}} = 300 msec</td>
<td>Number of retries = 7</td>
</tr>
<tr>
<td>Path length = 10</td>
<td></td>
<td></td>
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</table>
In Fig. 5, x-axis shows the average speed difference between two consecutive clusters, and the y-axis represents the average time difference for notification between CF-based and CH-based protocols. When the cluster in the back is 5 meters/sec faster than the cluster in the front, CF-based protocol can notify the approaching cluster 28 seconds, on average, earlier than CH-based protocol. Due to the close proximity of the CF node to the approaching cluster, an early notification time is achievable. Therefore, our model performs more efficiently as compared to the CH-based model. In Fig. 6, the x-axis shows the average gap between vehicles within a cluster, reflecting cluster density: the smaller the gap, the higher the cluster density. The y-axis is the CF lifetime to Cluster lifetime ratio. Form Fig. 6, we see that both the cluster density and the average cluster speed have an impact on the average CF lifetime. When density increases, more nodes either join or leave the cluster, thus resulting in an increase in CF elections which means a decrease in CF lifetime. Similarly, the lower the speed, the higher the travel time, meaning more nodes either join or leave the cluster, thus resulting in an increase in CF elections. When CF lifetime increases, the management overhead decreases. Fig. 7 shows the delay of safety messages for different data transfer rates. The x-axis is similar to Fig. 6 and the y-axis represents the delay of safety messages in msecs. This figure demonstrates the worst case scenario, where the current CF node competes with three CF nodes from neighboring clusters to access the media. Safety messages collected and simultaneously broadcasted as a single package (without compression) from all clusters.

VII. CONCLUSION

We proposed a hybrid media-access method for VANET clustering schemes. This method relies on CH for intra-cluster management and on CF for safety message dissemination. A simple algorithm is used to avoid inter-cluster interference. This protocol uses only one DSRC as apposed to two DSRCs in a previously published algorithm. This algorithm also provides an earlier notification compared to that of the existing CH to CH algorithms.

REFERENCES


