Mobility Aware Multihop Clustering based Safety Message Dissemination in Vehicular Ad-hoc Network

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Abstract- **A major challenge in Vehicular Ad-hoc Network (VANET) is to ensure real-time and reliable dissemination of safety messages among vehicles within a highly mobile environment. Due to the inherent characteristics of VANET such as high speed, unstable communication link, geographically constrained topology and varying channel capacity, information transfer becomes challenging. In the multihop scenario, building and maintaining a route under such stringent conditions becomes even more challenging. The effectiveness of traffic safety applications using VANET depends on how efficiently the Medium Access Control (MAC) protocol has been designed. The main challenge while designing such a MAC protocol is to achieve reliable delivery of messages within the time limit under highly unpredictable vehicular density. In this paper, Mobility aware Multihop Clustering based Safety message dissemination MAC Protocol (MMCS-MAC) is proposed in order to accomplish high reliability, low communication overhead and real time delivery of safety messages. The proposed MMCS-MAC is capable of establishing a multihop sequence through clustering approach using Time Division Multiple Access mechanism. The protocol is designed for highway scenario that allows better channel utilization, improves network performance and assures fairness among all the vehicles. Simulation results are presented to verify the effectiveness of the proposed scheme and comparisons are made with the existing IEEE 802.11p standard and other existing MAC protocols. The evaluations are performed in terms of multiple metrics and the results demonstrate the superiority of the MMCS-MAC protocol as compared to other existing protocols related to the proposed work.**

Keywords- Clustering • Multihop • Safety • TDMA • V2V • VANET

I. INTRODUCTION

Vehicular Ad-hoc Network (VANET) provides vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication in order to support safety, traffic-management and non-safety applications. The messages exchanged by safety applications require predictable or low delay and high reliability. Even a slight delay in delivery of messages may significantly affect the performance of safety applications. In addition, safety messages have a time bound deadline and the message should reach the destination within this time limit. In particular, the effectiveness of active safety applications depends on the ability to disseminate messages as quickly as possible with high reliability, fairness and scalable utilization of network resources [1]. In contrast to the contention-based protocol such as IEEE 802.11, clustering-based Time Division Multiple Access (TDMA) scheme attracts more attention for VANET to improve the traffic safety applications as the number of nodes is increased to a large number [2]. The approved amendments to the IEEE 802.11 standard standardized as IEEE 802.11p or Wireless Access in Vehicular Environments (WAVE) has inherent shortcomings of not being able to provide reliable broadcast services. With the random channel access, it suffers from unbounded latency and broadcast storm [3]. Consequently, it experiences huge amount of packet loss, collisions and access delays. These challenging issues are intermittently associated with contention-based Medium Access Control (MAC) protocols. Another challenging task in the implementation of VANET is to design a Quality of Service (QoS) aware protocol. Such protocol would aim to alleviate delay while guaranteeing QoS constraints with respect to the Packet Delivery Ratio (PDR), throughput and reliable message delivery. More than that, it would make efficient use of the network bandwidth. In order to overcome their challenging characteristics, most VANET routing algorithms use geographic based routing [4] and opportunistic carry-and-forward based routing techniques [4, 5]. These techniques leverage local or global knowledge of traffic statistics to implement multihop forwarding strategies in order to minimize communication overhead while adhering to delay constraints imposed by the application.

Many QoS parameters can be improved by using TDMA scheme with no central control so as to provide fair and reliable data dissemination in V2V communication [6]. Likewise, a vehicular scenario can be organized hierarchically using a clustering protocol. By clustering, the vehicles are partitioned into groups of minimum relative mobility to reduce the amount of routing information [7]. The most important criterion for any clustering method in VANET is to form stable clusters with minimum overheads. To realize this aim, nodes in the VANET are divided into different clusters based on their position, direction of movement, lanes and speed. In addition, the reliability of the safety messages is increased by assigning time slots to different nodes.

In this work, we focus on broadcasting of safety messages in the V2V scenario. Such messages demand high probability of successful delivery (PSD) and low latency, particularly in scenarios where there is no infrastructure support to coordinate communication. We propose Mobility aware Multihop Clustering based Safety message dissemination MAC (MMCS-MAC) protocol to increase reliability in VANET while delivering event-driven safety messages in multihop scenario over highway environment. Whereas many other schemes assume only a certain percentage of nodes to transmit safety message at any given point of time, the proposed scheme assures channel access to all the nodes, allowing them to transmit safety messages, no matter how severe application it demands. The novelty of the proposed algorithm lies in its dynamic adaptivity to mobility of the nodes and clustering based multihop forwarding strategies to achieve a good trade-off between delay and communication cost. This is in stark contrast with the previously proposed DMMAC [8], which aim at increasing the system's reliability, reducing the time delay for vehicular safety applications, and efficiently clustering nodes in highly dynamic and dense network in a distributed manner. An additional difference from the existing works is that no cluster head (CH) is required for allocating time slots to the nodes. This reduces an additional overhead and leverage in achieving high fairness.

We remark here the distinctive characteristics of our approach: (i) we apply multihop message routing scheme, up to four hops, so as to increase the message broadcast range in real-time event-driven applications (ii) we adopt mobility based clustering of nodes to increase the PDR and throughput of the safety messages (iii) we implement TDMA scheme to ensure reliability and fairness in the application (iv) we carry out division of the entire DSRC band into frames, and consider uniformly distributed vehicular density in order to achieve maximum channel utilization and (v) we do not require any changes to the existing IEEE WAVE stack.

Finally, we carry out extensive NS-2 simulations to evaluate the performance of MMCS-MAC with respect to different parameters. Results show that the proposed protocol outperforms several state-of-the-art protocols by achieving close to 100% reliability and faster dissemination, while the transmission overhead is much smaller.

The rest of the paper is organized as follows. Section 2 presents the related works, and in Section 3 we give the problem statement. Followed by that is the system model of the proposed protocol in Section 4. Section 5 evaluates and compares the performance of the proposed protocol with other related MAC protocols. Section 6 concludes the paper and discusses further direction of research.

II. RELATED WORKS

The main idea of cluster based routing scheme is to dynamically organize all mobile nodes into groups called clusters [9]. Support of QoS requirements in wireless ad-hoc network for distributed and real-time multimedia communication encounters a number of challenges, as specified in [10]. The authors in [11] design a cluster based aggregation–dissemination beaconing process that uses an optimized topology to provide nodes with a local proximity map of their vicinity. This would allow reliable inter-cluster bandwidth reuse during the aggregation phase. The topology is designed to minimize the inter-cluster interference by producing clusters that are separated by the maximal possible inter-cluster gaps. However, this optimization result proves to be less efficient for inter-cluster communication. Moreover, the probability of successful message reception decreases when node density increases in the intra-cluster communication. Evidently, this scheme would succumb to failure under high node density.

Several protocols have been proposed in VANET using TDMA to reduce interference and provide fairness between nodes. In [12], authors introduce a method for TDMA slot reservation based on clustering of vehicles, known as TDMA cluster based MAC (TC-MAC) for intra-cluster communications in VANET. TC-MAC integrates TDMA slot allocation with centralized cluster management technique. In this protocol, nodes are assigned time slots for collision free transmission. The work captivates on allowing vehicles to send and receive non-safety messages without any impact on the reliability of sending and receiving safety messages, even if the traffic density is high. In [13] the authors proposed a distributed mobility based clustering algorithm to increase cluster stability, where stability is realized by the time duration of the cluster members (CMs) and the CHs. These protocols generally use V2V communications for formation of clusters and for electing CHs.

In [14] the authors propose and evaluate a contention-free TDMA-based MAC approach that uses a predetermined multihop awareness range to distribute MAC slot allocation information to neighboring nodes. Nodes use the information from surrounding slots to select unused slots, thereby avoiding collisions. The multihop strategy is employed to overcome the hidden terminal problem. The results show that the optimal performance is achieved with two hops.

A multihop clustering scheme for VANET is proposed in [15]. To construct multihop clusters, a new mobility metric is introduced to represent relative mobility between nodes in multihop distance. The scheme highlights that multihop clusters can extend the coverage range of clusters and gain more advantages compared to single hop clusters. The work in [16] presents a clustering based MAC protocol designed to reduce interferences in VANET. The scheme is intended for safety applications in highway environments, employs dynamic multihop clustering and improves network performance. This approach also does not require cluster-head selection, similar to the algorithm proposed in this paper. A cluster based MAC (D-CBM) protocol is designed in [17] to ensure timely and reliable data delivery of messages. D-CBM employs distributed technique for clustering in VANET where V2V and V2I communication are considered. It is based on collision free TDMA in order to achieve high stability, low communication overheads and real time delivery of safety messages. In this protocol, the road side unit (RSU) assigns time slots to CHs and CH assigns time slots to CMs and gateway node. The RSU functions as a central coordinator to collect and distribute the messages. As the time slots can be assigned centrally, less number of collisions are expected which consequently increases the reliability. Other related works [18-23] have investigated the performance of safety-related applications based on metrics such as probability of successful delivery, end-to-end delay, forwarding node ratio, reachability, transmission overhead, transmission and receiver throughput, slot utilization rate etc.

III. PROBLEM STATEMENT

A. SYSTEM MODEL AND ASSUMPTIONS

In the system model, we focus on multihop transmissions where the clustered mobile nodes communicate via a single channel in purely ad-hoc mode. Each node within a cluster has a unique ID, based on its MAC address. Each node operates in the ad-hoc mode and broadcasts its packets according to a routing protocol. An example of V2V communication in multihop scenario has been depicted in Figure 1. It has been shown in [24] that Carrier Sense Multiple Access with collision avoidance (CSMA/CA) based MAC is not efficient enough to handle the high message frequency of the smart driving application. However, a TDMA-based MAC can be a probable solution to this issue.

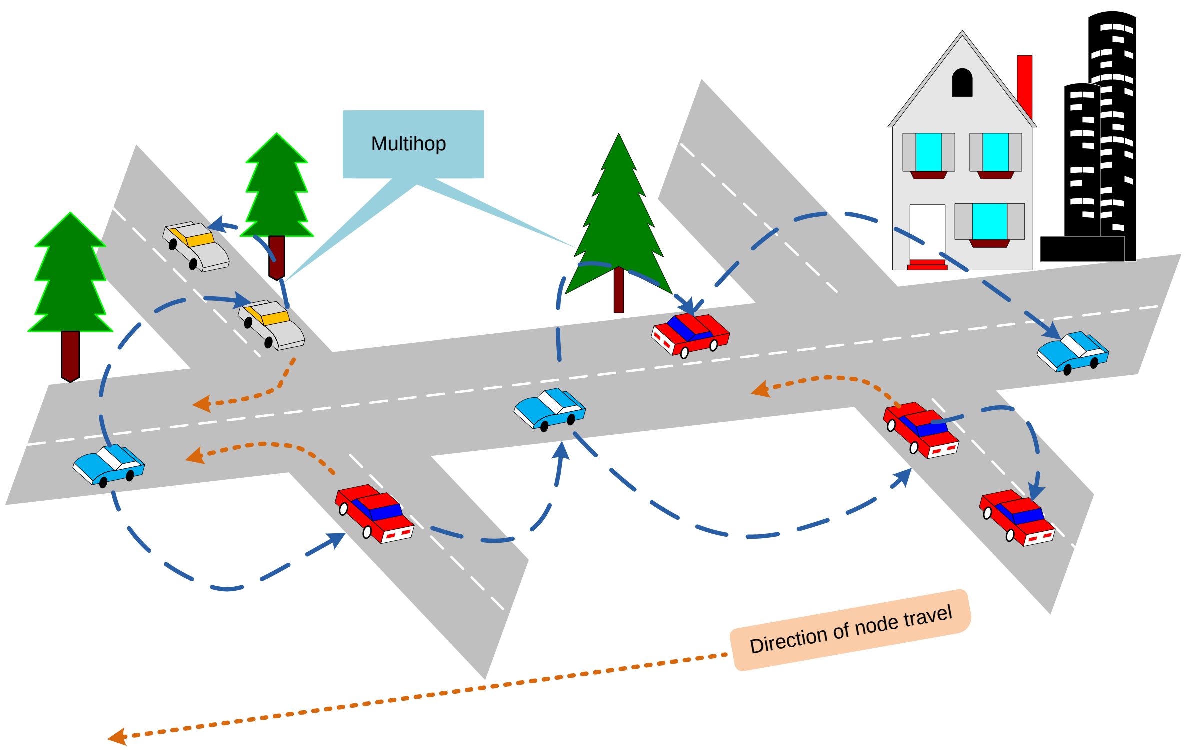

Figure 1. V2V communication in multihop scenario

We consider a 4-lane vehicular scenario and assume that each node is equipped with an IEEE 802.11p standard compliant radio device with GPS installed, which gives the location information. Each node shares information about its current position, speed, lane, and direction with only its one hop neighbors. To this aim, we impose that each safety message generated by a node within a cluster must be successfully delivered to all other clusters that are up to four hop counts (h_c), and in the direction of message travel.

B. OBJECTIVES

The MMCS-MAC protocol aims to achieve reliable dissemination and broadcast event-driven high priority safety messages by utilizing the entire DSRC band. It further aims to minimize the average delivery delay in the network by reducing interference in a long stream of vehicles. This would ensure real-time delivery of sensitive messages. In order to achieve our goal, we propose a TDMA based scheme designed for fast multihop channel access and a clustering mechanism that performs topology control and reduces interference while keeping the network connected. Data transmission of real-time safety messages is facilitated over IEEE 802.11 MAC-based channels in the allocated time slots.

IV. OVERVIEW OF MMCS-MAC PROTOCOL

MMCS-MAC protocol is divided into three different phases. The first phase is the cluster formation phase, where nodes are partitioned into different clusters according to their speed. The second phase constitutes the TDMA slot assignment. The aim of employing TDMA scheme on contention-based topology is to ensure reliable and fair transmission of safety messages. Realizing that safety related applications in vehicular communication urge for high reliability and low delay bound requirements, providing time to each node to transmit safety message without disturbing other nodes is crucial. TDMA stands out as the concept that can easily be used to allocate unique time slots to every cluster within the network. In the third phase, role of multihop forwarding in safety message dissemination comes into effect. Multihop forwarding refers to an aggressive message routing scheme where messages are forwarded to nodes that are better positioned to deliver them further to distant nodes. The aim of multihop routing is to elevate the transmission range of the broadcasted message in vehicular scenario. However, for the multihop forwarding strategy to be effective, traffic needs to be dense enough so that better positioned nodes exist within communication range [4]. We discuss each of these phases in the following sub-sections. Here, we outline the algorithm of the MMCS-MAC protocol in Algorithm 1.

Algorithm 1	MMCS-MAC protocol
Step 1	hello message signalling
Step 2	bandwidth division into frames
Step 3	mobility based cluster formation
Step 4	priority wise frame assignment to clusters in decreasing order of mobility
Step 5	safety message generation at node i
Step 6	message broadcasted to (i+h_c) hop distance clusters. (Initially, the value of h_c is assumed to be 1)
Step 7	check for h_c
Step 8	broadcast the message

Step 9	increment h_c
Step 10	if $h_c \leq 4$, route the message to $(i+h_c)$ hop distance clusters
Step 11	goto step 7 and repeat the loop till $h_c = 4$
Step 12	if $h_c > 4$
Step 13	discard the message
Step 14	endif
Step 15	endif

A. CLUSTERING MECHANISM

The proposed scheme harnesses clustering based topology for safety message dissemination process. Nodes are clustered based upon their mobility. Nodes having near about same average speed form a cluster. Each node within a cluster is connected by one-hop intra-cluster link and different clusters link to each other through multihop topology. Since, the clustering algorithm is mobility based it does not require additional messages other than the dissemination of node's status messages (HELLO message signaling). Therefore, when nodes are on the road for the first time, they start sending their status messages without an elected CH. Once these messages are received by all nodes in the network range, they form a cluster following each other's mobility pattern. Cluster having maximum average speed is given highest priority to disseminate the safety message, which is implemented using the TDMA mechanism. We discuss this procedure here and outline it in Algorithm 2.

Each node in the network maintains positioning information by broadcasting HELLO messages. The HELLO message includes preliminary information such as node ID, position, mobility range etc. The HELLO broadcast period is defined as T_{HELLO}. When any node Y receives any other node X's HELLO message, Y will first check its similarity with X. A node will only consider neighbors moving in the same direction, and ignores broadcasts from traffic in the opposite direction. By means of broadcasting HELLO messages, each cluster records the neighboring cluster's positional information. This information serves as input to the clustering algorithm.

Algorithm 2	HELLO beacon signaling
Step 1	Every T_{HELLO}, X broadcasts HELLO beacons
Step 2	Each receiving neighbor checks for the similarity with X
Step 3	If true, Y calculates the coordinates of X
Step 4	X adds and updates its neighbor entry list

Cluster-based routing protocols involve four stages; CH selection, cluster formation, data aggregation and data communication [5]. In figure 2, nodes are shown to be clustered based upon their mobility. This clustering scheme negates the CH election overhead and produces relatively stable clustering structure. A cluster having longer travel duration (low mobility) has lower eligibility value to access the channel. Similarly, a cluster having shorter travel duration (high mobility) has higher eligibility value to access the channel. However, along with the inclusion of the speed difference, we need to know how to partition the network into minimum number of clusters such that when they are finally formed, the distribution of the nodes among them based on their mobility patterns is achieved with high probability. The proposed design employs a clustering approach whereby each cluster itself manages the intra-cluster communication using a TDMA scheme slot allocation. It is done by specifying when a node can transmit a message according to the availability of the slots in the cluster. Clusters are formed by nodes travelling in the same direction (one way). Therefore, all neighboring nodes used in our analysis are limited to those travelling in the same direction. However, the speed levels among them vary and this variation might be very high; thus, all neighboring nodes may not be suitable to be included in a cluster.

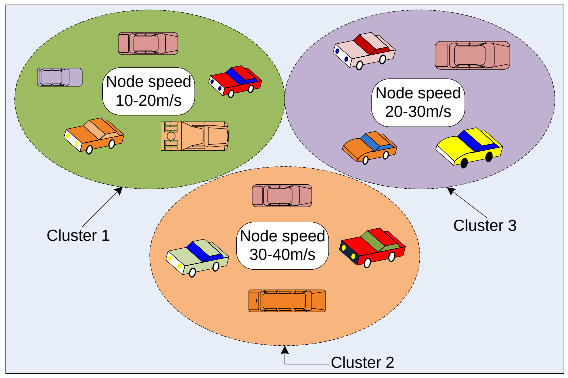

Figure 2. Mobility based clustering of nodes

The proposed algorithm results in maximum bandwidth utilization and minimum interference when the nodes are uniformly distributed on the roads. However, if the vehicular density is non-uniform, the slot requirement will differ, leading to interference, broadcast storming and inefficient bandwidth utilization. For that reason, we have assumed to have unvarying vehicular density, and that the nodes are moving with uniform speed for the duration of the simulation. The simulation time of 150 sec makes this assumption realistic and justifies the approach. The advantage of making such assumptions is to get rid of the overhead that the CH election process carries.

B. TDMA TIME SLOT ASSIGNMENT

The logic behind employing TDMA scheme is that it leverages contention less channel access by allocating time slots in one-hop radius distance to every cluster. However, when the destination of the message is several hops, the CM has to wait till its transmission slot arrives. We eliminate this delay by prioritizing slot assignment to clusters in decreasing order of their mobility. The slot assignment process assumes that each node may forward messages only to its one-hop neighbor, in the direction opposite to the direction of the node movement.

The proposed scheme rules out the implementation of channel switching during the synchronization interval as described in the legacy IEEE 1609.4 WAVE standard. A message can be delivered to any of the channels, irrespective of control channel interval (CCHI) and service channel interval (SCHI). More than that, entire DSRC bandwidth (75 MHz) is divided into frames. In order to enable multihop broadcast with minimal delay, every cluster is assigned a frame. Each frame is further divided into a number of slots. Frames are allocated to the clusters in a prioritized manner, assigning priority to the cluster having highest mobility. The cluster with maximum speed will have less time to access the channel. It has to be given higher priority with respect to other clusters. Similarly, based upon the mobility of clusters, different numbers of frames are assigned to them. Higher is the mobility, more numbers of frames are assigned. Figure 3 depicts the above discussed clustering based slot assignment process.

Since the proposed scheme follows a distributed approach, at the beginning of every TDMA frame the node randomly selects a transmission slot to transmit. All slots are equally likely to be selected. Each TDMA frame comprises 20 slots, each of 1 millisecond duration, so as to make it comparable to WAVE's CCH. Any event-driven message can be assigned to any of the slots to immediately broadcast the safety message. The nodes deliver the messages and vacate the slot within the frame assigned to them for the next messages from other nodes. Evidently, each node within the network becomes aware of the unallocated slots in the frame which gives them the opportunity to assign the slots amongst themselves. The number of frames per cluster is determined by the clustering algorithm during the clustering process and is given as input to the MAC layer. The slots are assigned to nodes in such a way that when a node receives a message travelling in a certain direction, it would immediately be able to forward the message to its next hop in the same direction [16].

In order to design a framework for intra and inter cluster communication in the proposed MMCS protocol, we need to design time slots in TDMA frames.

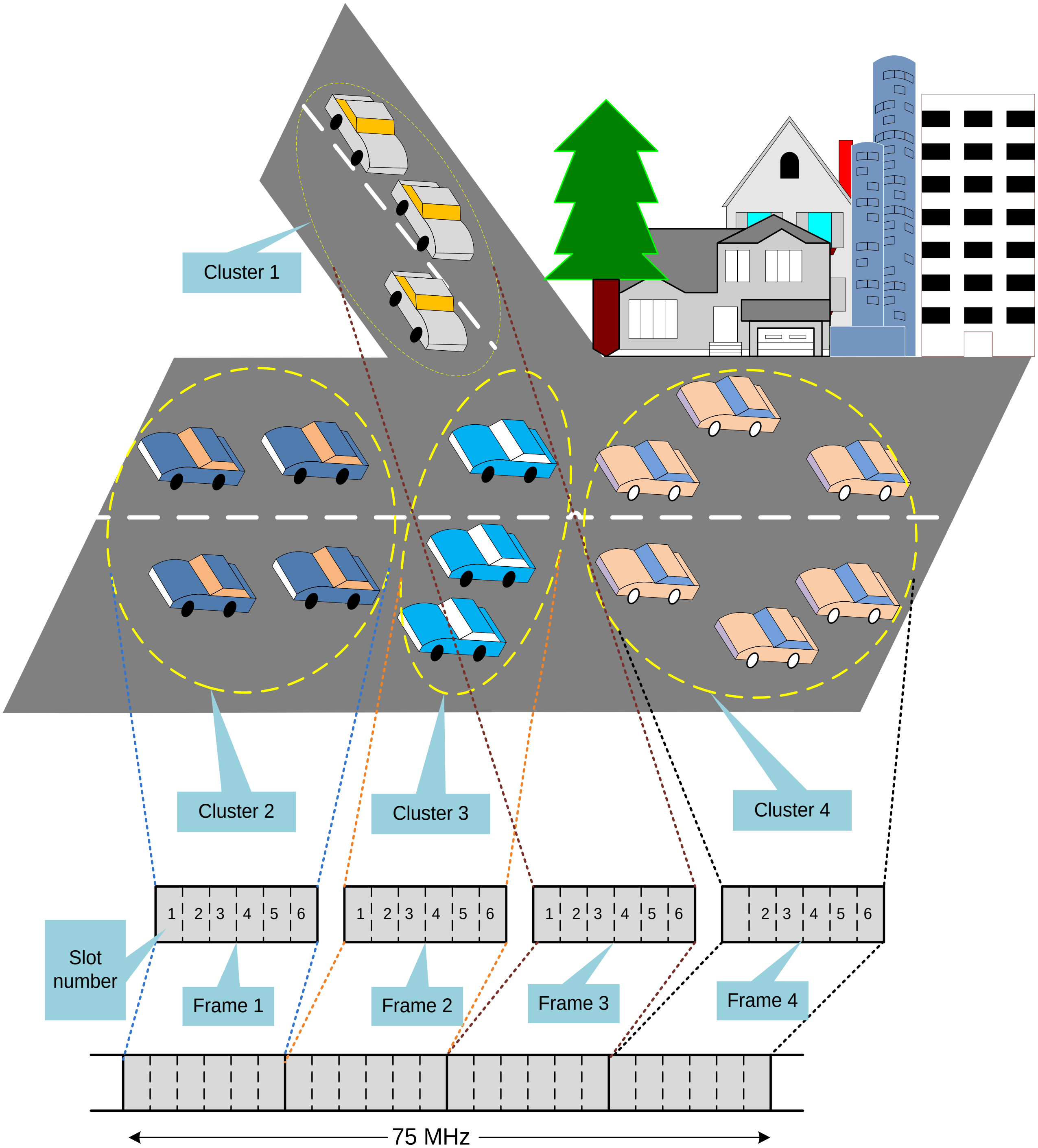

Figure 3. TDMA slot assignment based on clustering

As shown in figure 4, a TDMA frame consists of *n* time slots (slot 0 to slot n-1). Slot 0 is used to synchronize the first TDMA frame with the start of slot 1. Secondly, it broadcasts the slot-assignment state (SAS) within the cluster so that every node has a designated time slot for transmitting data. Slot 1 to slot n-1 of the TDMA frames are designated time slots used for data transmission.

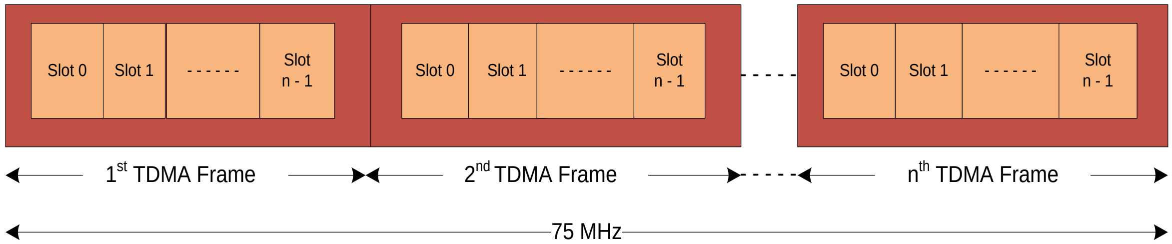

Figure 4. TDMA frame format

C. MULTIHOP MESSAGE ROUTING

In multihop message delivery, major issue lies in selecting the next hop path for data routing. The next hop is chosen from the nodes that lie in the direction of the destination node. This increases the probability of finding the shortest route [6]. For simplicity, we assume that there are n nodes in a network, and the position of any cluster c_1 in the network is Xc_1. From equation (1) it can be proved that any two clusters c_1 and c_2 are within the RF range of each other at any timestamp t if they satisfy the condition

$$\frac{\dfrac{Pn_1(t)}{\left(Xc_1(t)-Xc_2(t)\right)^2}}{\dfrac{\sum Pc_1(t)}{\left(Xc_1(t)-Xc_2(t)\right)^2}} > SINR \qquad (1)$$

where $Pn_1(t)$ is the transmit power of node n_1; $Xc_1(t) - Xc_2(t)$ is the distance between c_1 and c_2; SINR is the signal-to-interference-plus-noise ratio; and $\sum P_{c_1}(t)$ is the average transmit power of c_1.

Using equation (2), it can be shown that c_1 and c_2 are connected at time t if the distance between them is smaller than the transmission range T_r. That is,

$$\left(X_{c1}(t) - X_{c2}(t)\right) < T_r \qquad (2)$$

In multihop scenario, the messages can be quickly broadcasted among the connected nodes through a message routing scheme in which a node in a cluster broadcasts a packet to its neighboring clusters and each cluster that successfully receives the packet, rebroadcasts it to its immediate neighboring cluster. To make sure the messages transmit efficiently and correctly, the routing method in the multihop and dynamic topology network is very important [9].

Algorithm 3	Multihop message routing
Step 1	start routing
Step 2	while true
Step 3	if REQ received
Step 4	get the source ID and h_c
Step 5	endif
Step 6	if the Tx and Rx outside cluster
Step 7	update SAS
Step 8	endif
Step 9	rebroadcast REQ
Step 10	$h_c = h_c + 1$

Step 11 rebroadcast REQ
Step 12 if $h_c > N$
Step 13 discard the REQ
Step 14 end if
Step 15 endofwhile

Figure 5 represents the flow diagram of the proposed MMCS-MAC protocol. Initially, HELLO message signaling allows all the nodes in the network to get acquainted with each other's coordinates. Secondly, we divide the entire DSRC band into frames so that full bandwidth remains available for safety message transmission. Next, based upon the mobility pattern gathered to HELLO message beaconing, clusters are formed. Moving ahead, priority wise frames are assigned to the clusters in decreasing order of their mobility. That is, cluster with maximum speed is assigned more number of frames to transmit. This not only ensures reliability but leverages better channel utilization as well. These frames are further divided into a number of slots. Each node is assigned a slot to transmit its message. Now, let us assume that a safety message is generated at node i. This message is broadcasted to ($i+h_c$) hop distance clusters where h_c is the hop-count of the message. Initially, the value of h_c is assumed to be 1. When the message is received by one-hop distant cluster, it checks for the current h_c. If $h_c < N$, where N=4, it broadcasts the message and increments the h_c by 1. Likewise, the message is broadcasted and relayed up to N hops distant clusters. We take h_c to be 4 because when h_c becomes greater than N hops, the message is no longer relayed and is discarded as obtained from the simulation results.

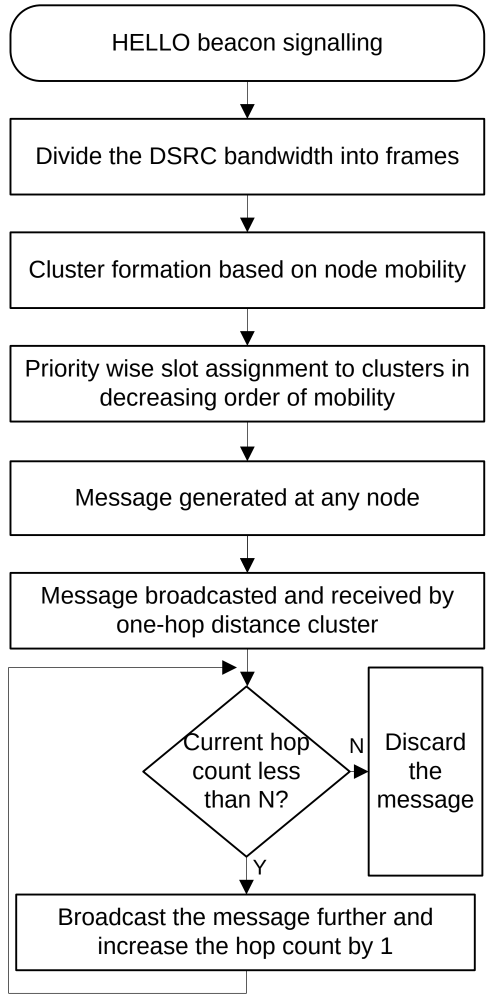

Figure 5. Flow diagram of MMCS-MAC

V. PERFORMANCE EVALUATION

In this section, we evaluate and compare the performance metrics of the proposed protocol with (i) IEEE 802.11p standard and (ii) other existing protocols such as Distributed Multichannel Mobility-Aware Cluster-Based MAC protocol (DMMAC) [8], Cluster-Based Beacon Dissemination Process (CB-BDP) [11], and WAVE-enhanced Service message Delivery (WSD) [18] with respect to the vehicular density. We show that clustering reduces delay in multihop broadcasting scenario. The results also raise concerns about the existing standard's capability of providing safety at the road level, and thus justify the need for protocol enhancements that take into account the QoS requirements of vehicular applications. Due to the impact of relative speed in V2V communication, an effective MAC protocol should provide priority to a node with higher mobility to transmit before it moves out of the communication range.

A. SIMULATION SETUP

The simulations are carried out for a 4-lane highway with nodes moving in both directions. Node speed varies between 10 to 40 m/s. All nodes have the same IEEE 802.11p standard MAC parameters for V2V communication in multihop ad-hoc region. The simulation time is set to 150s, and the transmission range of each node is up to 300 m.

The message size is arbitrarily taken to be 512 bytes which is transmitted at the rate of 6 Mbps since it is the prescribed data rate for DSRC safety applications [25]. The data transfer rate and ad-hoc coverage range is taken as per the IEEE 802.11p standard. Vehicular density is assumed to be uniform and the number of nodes contending for the channel varies from 5 to 40, in steps of 5. For the sake of a diversified comparison, the proposed MMCS-MAC protocol is compared with the related performance metrics of various existing protocols since they carry near resemblance to this work. Table 1 summarizes the parameters used in our simulation. The parameters are taken to model a simplified, yet realistic vehicular traffic scenario on highways.

TABLE 1
Simulation parameters

Parameter	Values
Number of nodes	5 - 40
Node’s speed	10 - 40 m/s
Simulation area	10000 x10000 (m^2)
Simulation time	150 sec
Data rate	6 Mbps
Number of lanes	4
Scenario	Highway
Transmission range	300 m
Interface queue type	Queue/DSRC
Interface queue length	50
Network interface	Phy/WirelessPhyExt
MAC interface	802. 11Ext
Message size	512 Bytes
Propagation model	Two Ray Ground
Modulation type	BPSK
Antenna type	Omni Antenna

B. PERFORMANCE METRICS

In order to evaluate the proposed protocol’s performance for safety message dissemination, following metrics are defined:

i) Packet delivery ratio (PDR): it measures the success ratio of the transmissions, that is, the ratio of the number of packets successfully received to the total number of packets sent. PDR is analyzed as

$$PDR = \frac{\sum_{i=1}^{n} x_i}{\eta_{T_{RF}} \sum_{i=1}^{n} y_i} \tag{3}$$

where x_i is the number of packets received by node i, y_i is the number of packets transmitted by node i and $\eta_{T_{RF}}$ is the average number of neighboring nodes in the RF transmission range. The value of $\eta_{T_{RF}}$ is approximated using the vehicular density. Figure 6 shows the comparison among the proposed protocol, CB-BDP and IEEE 802.11p standard for the PDR with respect to the vehicular density. As the number of nodes increase, the PDR tends to increase because the probability of more packets getting delivered rises. The proposed MMCS-MAC protocol is seen to perform better when compared to the other two protocols for this metric. This is because the proposed protocol attempts to transfer messages up to four hops, thereby enhancing the probability of message reception.

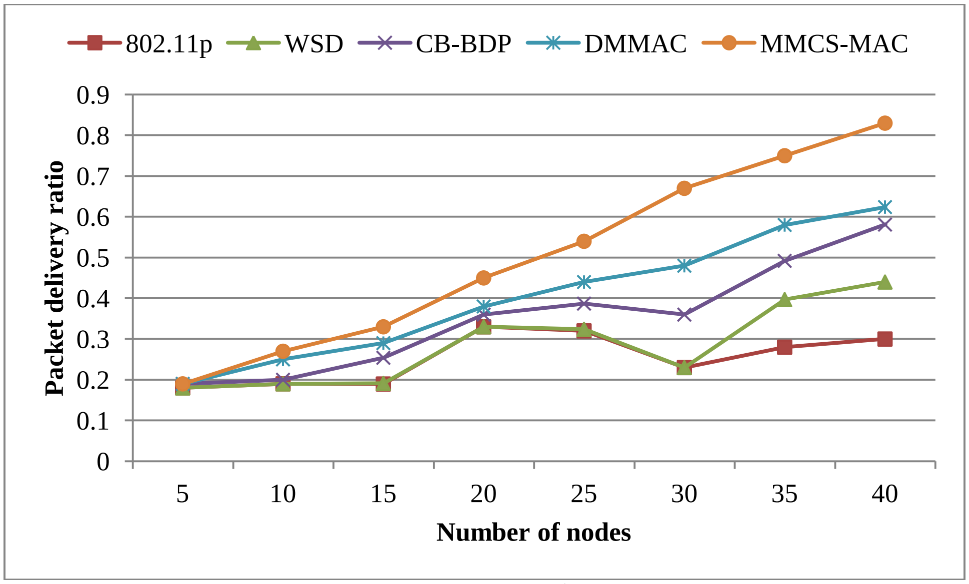

Figure 6. Comparison of PDR

ii) Throughput (δ): defined as the rate of successful data delivery in the network per unit time. This metric gives the measure of the how much data is received in the network. It is averaged per node and analytically defined as

$$\delta = \frac{\sum_{i=1}^{n} x_i}{T_s n} \tag{4}$$

where x_i is the number of packets received by node i, T_s is the simulation time in seconds, and n is the total number of nodes in the network and. Figure 7 shows the throughput range attained by different protocols under study. Clearly, MMCS-MAC outperforms the other two protocols. It attributes to the TDMA based clustering whereby the nodes within a cluster self-assign the slots to disseminate the safety messages, avoiding the cluster maintenance overhead. This results in higher rate of successful message reception. For all the three protocols, throughput rises till 25 nodes. However, beyond this range it surges between the range of 30-35 nodes and rises again as the vehicular density increases.

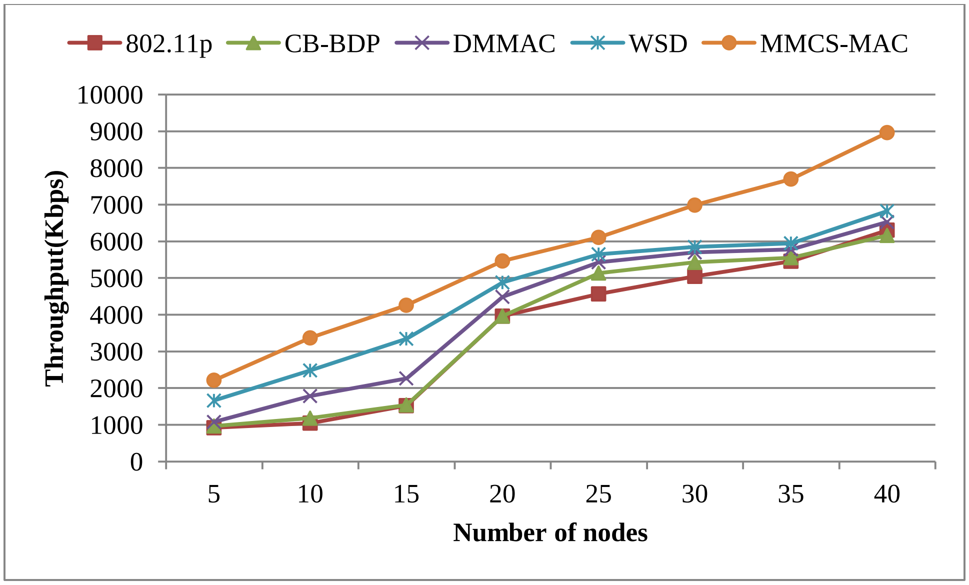

Figure 7. Comparison of Throughput

iii) Packet loss ratio (P_{LR}): data packets fail to reach their destination and are lost during transmission. Major cause of packet loss is typically network congestion. Packet loss is measured as a ratio of number of packets lost with respect to total packets transmitted. It can be formulated as

$$P_{LR} = \frac{\text{number of packets lost}}{\text{total number of packets transmitted}}$$

Figure 8 shows the P_{LR} for different protocols. Whereas the MMCS slightly performs better than CB-BDP, the performance of IEEE 802.11p degrades drastically as the vehicular density increases.

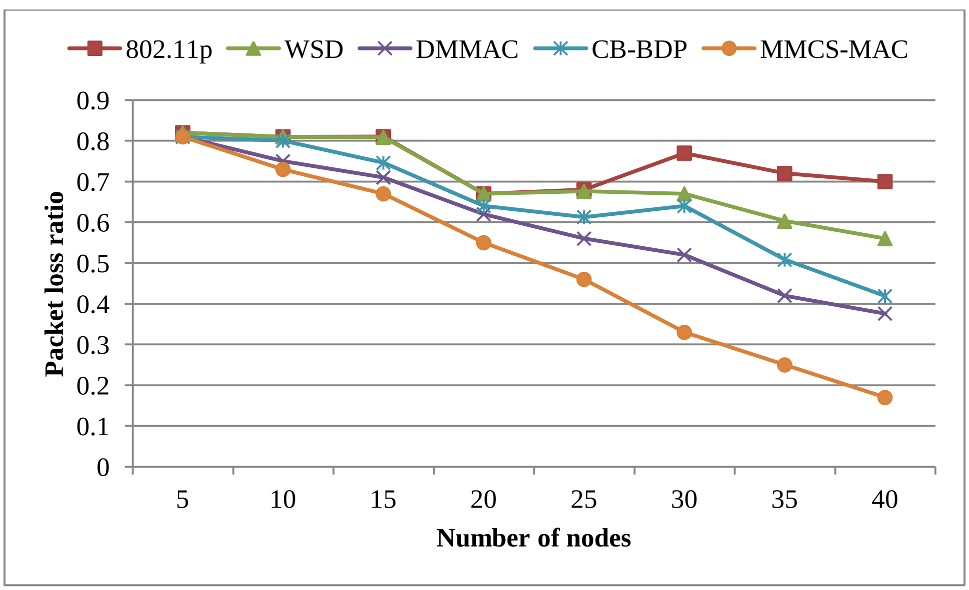

Figure 8. Comparison of Packet Loss Ratio

This attests to the fact that the DCF of the standard protocol is not suitable for safety message dissemination under highly dense vehicular scenario. The reason for the improved performance of the proposed protocol relates again, to the high probability of message reception.

iv) Average end-to-end delay (t_{avg}): time elapsed during sending a packet from the source node and reception of the packet at the destination node is the end-to-end delay of that packet. The total delay of all delivered packets divided by the total number of packets delivered gives the average end-to-end delay of the network. It is given by

$$t_{avg} = \frac{\sum_{i=1}^{n} t_i}{n} \tag{5}$$

Figure 9 evaluates and compares the proposed protocol with the WSD and IEEE 802.11p standard. We introduce WSD scheme here as it recognizes delivery delay as a stringent QoS requirement as far as safety-related applications are concerned. It is observed that as the number of nodes increase, the delay rises. This is pretty obvious owing to the multihop scenario where each intermediate cluster follows a protocol so as to route the message to its one-hop distance cluster. The delay encountered in the MMCS-MAC protocol is comparable to that of WSD, perhaps with slight improvement being seen over the latter. This improvement is attributed to the fact that the proposed protocol focuses on multihop dissemination, unlike to WSD scheme that targets single hop dissemination.

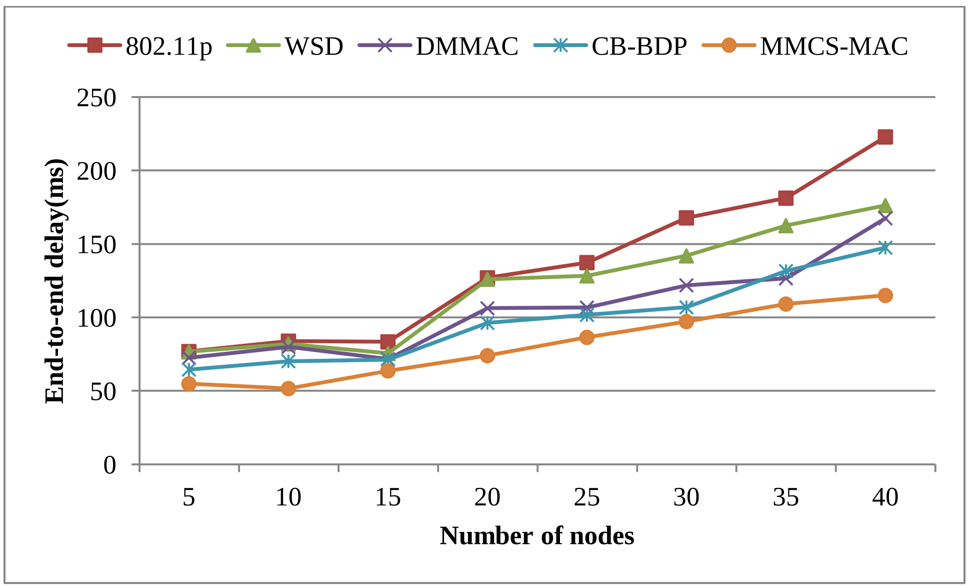

Figure 9. Comparison of Average End-to-End Delay

v) Probability of successful delivery (PSD): a high level of certainty is required while delivering safety messages. It not only relates to the reliable data delivery but also with the overall efficiency of the network. Figure 10 compares the MMCS-MAC with WSD and 802.11 p MAC protocols. Whereas the standard protocol doesn't show credible performance, WSD demonstrates better results. Notwithstanding, MMCS-MAC shows high probability of successful message delivery. However, all protocols show a decreasing trend with increasing vehicular density. For the proposed protocol, the probability lies in the range of 70% to 95% for low density (up to 20 nodes). As the number of nodes increase, the probability decreases. This shows that as the number of hops increase, the certainty of a message getting delivered falls.

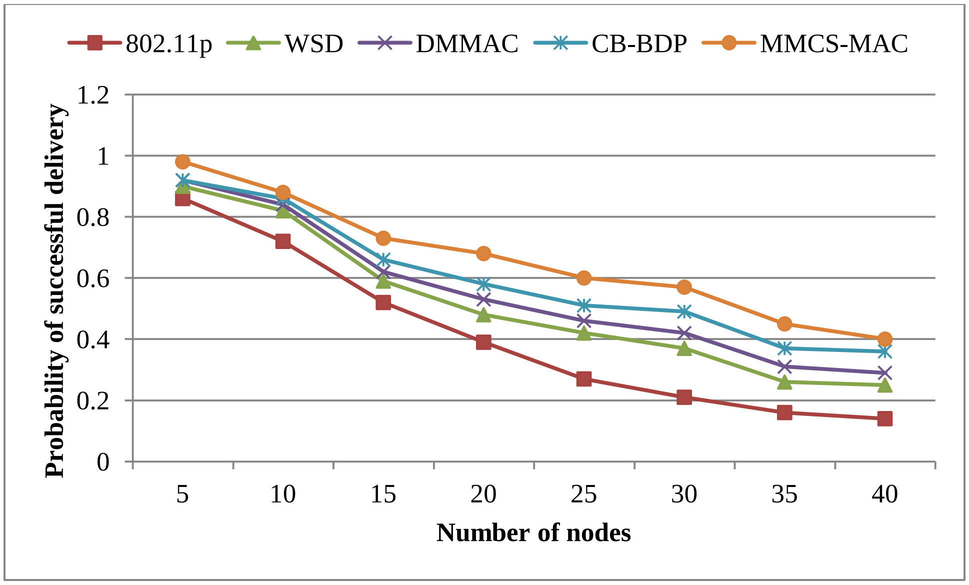

Figure 10. Comparison of PSD

vi) Reliability: probability that a cluster and its one-hop distant neighboring cluster will transmit and receive the message successfully. Reliability is one of the most important parameter when we focus on safety message dissemination. In figure 11, MMCS-MAC is compared with DMMAC and the standard protocol. DMMAC protocol focuses on reliability in delivering safety messages under similar vehicular scenario. It can be seen that both DMMAC and MMCS-MAC performs consistently well under the specified simulation conditions. This justifies the reason for comparison with DMMAC. The system's reliability is seen to be high in low-density network, and slightly decreases as the vehicular density increases.

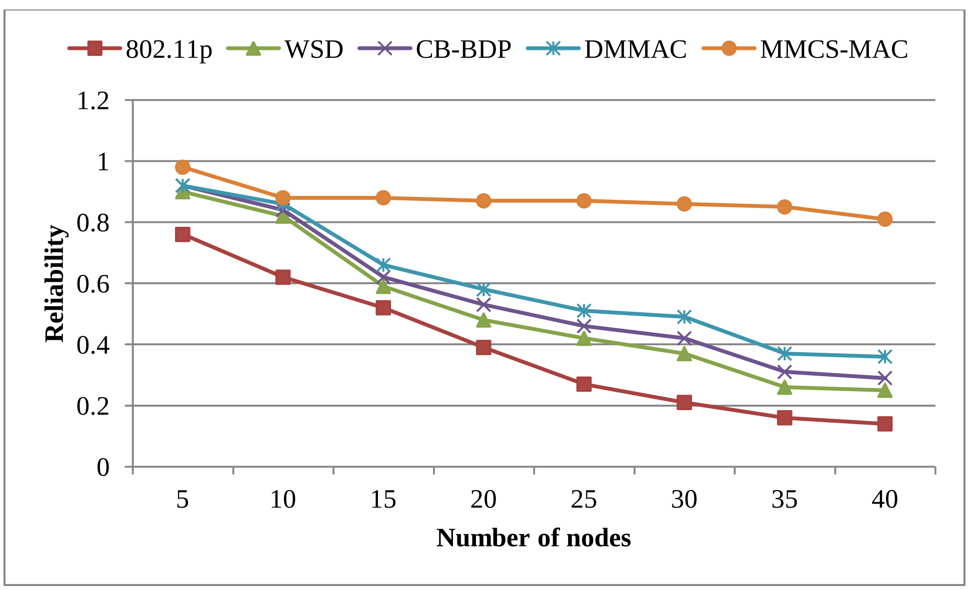

Figure 11. Comparison of Reliability

This is possibly due to the increasing number of hops which tends to increase with increasing density. However, the standard protocol fails to demonstrate high level of reliable transmission with increasing vehicular density which again questions its applicability to cater to dissemination of safety messages.

vii) Safety message travel time: the time taken by a safety message sent by a node to reach its one-hop distance neighbor. In figure 12 it is shown that as the number of nodes increase, the travel time decreases. It so happens because with increasing node density, hopping will increase, resulting in faster message delivery. This result goes in favor of the fact that more is the number of clusters, better will be the multihop broadcasting. Moreover, the decrease in the node density results in increasing the safety message travel time since nodes may struggle to find a neighboring node to carry the message forward. MMCS-MAC is seen to perform better than the other two protocols because of two reasons. Firstly, MMCS-MAC does not require a cluster-head selection. This reduces the additional time that would have been consumed in the process. Secondly, since the vehicular density is assumed to be constant for the simulation duration, HELLO message beaconing is performed only once, when the nodes are on the road for the first time. This further helps in reducing the travel time.

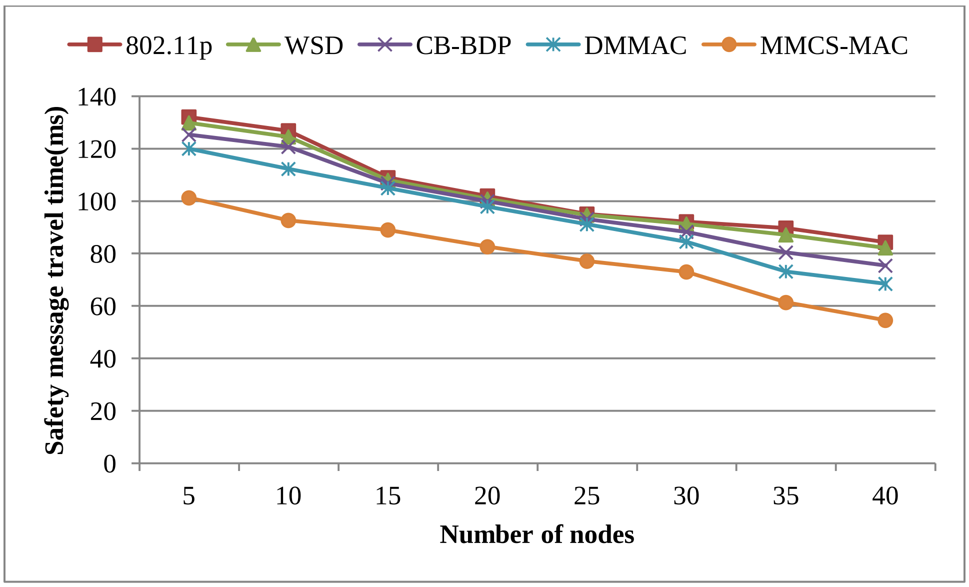

Figure 12. Comparison of Message Travel Time

viii) Packet inter-reception time (PIRT): defined as the time elapsed between the receptions of two successive beacons at any specific node. Evaluating the PIRT is justified by the observation that it is an important beaconing metric, as well as an important class of active safety applications, such as collision warning, emergency braking and transit node signaling etc. These applications mandate its requirement in terms of maximum tolerable PIRT [26]. In figure 13, we compare MMCS-MAC with the DCF of the IEEE 802.11p standard. The reason for comparing the proposed protocol only with the standard protocol is that till now, no such MAC scheme showing resemblance to the proposed protocol has evaluated this metric and hence comparison could not be made.

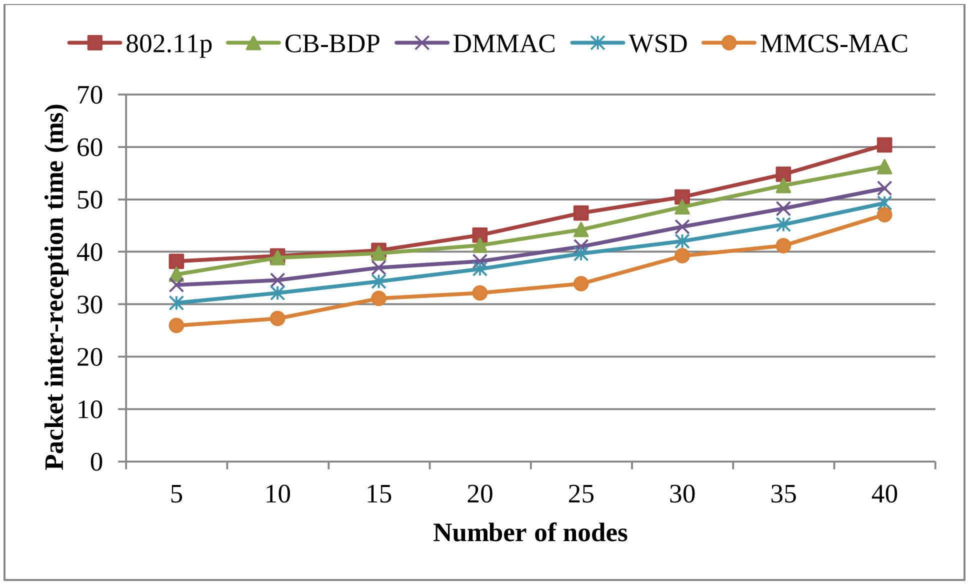

Figure 13. Comparison of PIRT

From the obtained results upon evaluation, it is observed that with increasing node density, PIRT increases for both the protocols. Moreover, PIRT for MMCS-MAC is lower than the legacy standard which is a desirable observation. This improvement over the IEEE 802.11p standard protocol is due to the adoption of mobility based clustering scheme that leverages faster transmission and reception of safety messages. This attests that the proposed protocol performs better under dense vehicular scenario.

VI. CONCLUSION

This paper presented a novel mobility dependent MAC protocol suitable for traffic safety applications in VANET. The aim was to define a scheme that is able to scale over a number of nodes and deliver the messages in real-time scenario. The protocol harnesses the clustering based TDMA scheme for multihop message dissemination in inter-vehicular communication which is fully distributed and does not require a cluster-head selection. Clustering the nodes based on their speed increases the stability. The decision of not electing the CH helps in reducing the overhead of cluster maintenance. The scheme leverages on the fact that real-time traffic having higher-sensitivity should gain more priority to acquire time slots than non-real-time traffic with lower-priority. The TDMA mechanism allocates time slots to the clusters based on their mobility pattern. Frame synchronization between different clusters allows the protocol to ensure reliable and timely delivery of safety messages. We show how it could significantly improve the efficiency and PDR. Multihop routing has been accomplished for up to four hops. Simulations have been performed using NS-2.34 network simulator. From the simulation results, it is observed that with the formation of small-sized cluster, the network spends less time than IEEE 802.11p. Moreover, it attests to the fact that the existing WAVE standard succumbs to perform under high vehicular density and is incapable to ensure reliable dissemination of safety messages. Additionally, when the node density is increased, the protocol takes less waiting time before a node can effectively transmit data.

From comparison with other related works, it can be clearly stated that the performance of MMCS-MAC outshines not only the performance of the IEEE 802.11p standard but also of other protocols it is compared with in delivering safety messages to the intended recipients. The designed algorithm helps MMCS-MAC to maintain a high level of reliability, particularly under high vehicular density along with assuring high packet delivery ratio and throughput.

A direction for future work could be to extend the proposed scheme for different traffic types based on the assigned priorities to them; provisioning of non-safety messages; and integrating the concept of adaptive contention window while allocating slots.

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