Enhanced Reachability and Low Latency DENM Dissemination Protocol for Platoon based VANETs

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***Abstract*—The emerging vehicular ad-hoc networks (VANETs) have paved the way to Cooperative Adaptive Cruise Control (CACC) applications. With such application, cars can travel in platoons with very small headways and thus achieve considerable capacity and fuel consumption gains. In order to ensure safety while exploiting such gains, intra/inter-platoon communications have to rely on a fast and reliable information exchange. Thus, it is important to define relaying schemes which can ensure that reliable platoon applications can be run over the unreliable wireless channel. In this paper, we propose a new dissemination algorithm for the DENMs over platoons, considering the leader as the only vehicle in charge of generating DENMs. Our dissemination algorithm is responsible for electing the vehicles among platoon members for relaying the DENMs. The reliability is met by a proper selection of the best relay based on bidirectional link quality and distance criteria. Unlike existing method for the estimation of the bidirectional link quality (BDSC), which is more suitable for unicast context, we propose an algorithm that accounts for the dissemination context in platoons. A performance comparison with four state-of-the-art relaying approaches, based on simulations, shows the high performance of our approach in terms of end to end delay, reachibility, and average number of hops.**

***Keywords*—IoT, CACC, Platoon, VANETs, Smart City, DENM**

I. Introduction

The key technology of Cooperative adaptive cruise control (CACC) system is the intervehicle wireless communications. With vehicle-to vehicle communications, it is possible to maximize the benefit of energy efficiency and road capacity. A constant small headway between vehicles can be achieved by communications between direct followers [1] introducing the drawback to be speed-dependent. In contrast, communications with both the nearest vehicles and a designed platoon leader proved to be speed independent and to offer string stability under constant distance gaps [2]. As these constant distance gaps are independent of the operating speed of the vehicles, the cooperative controllers are capable of keeping the headway small, even at high speeds, reaching the order of 5m to 7m, as proven in the PATH and SARTRE projects [3], [4]. This is one of the reasons why cooperative controllers, as used in CACC systems, can achieve a much higher road capacity.

In terms of involved standards, the wireless communications and the associated mechanisms for the physical (PHY), medium access control (MAC), network and ETSI Facility Layers, should support the level of reliability and real-time properties required by highly safety-critical applications such CACC. Indeed, The IEEE.802.11p standard is based on a random access protocol for medium access, which may cause excessive delays preventing proper functionality of the platooning application [5]. Alternatively, the required safety distance between members in a platoon may have to be extended, such that the desired gains in fuel efficiency may no longer be achievable. Regarding the PHY layer level, the adoption of the DSRC system, coupled with the European requirement to use one common 10 MHz control channel (CC) implied the need to focus more researches on the specific requirement of CACC application. Indeed, the control channel is shared by both basic status update messages used by the ETSI standard (defined as Cooperative Awareness Messages (CAM) including information about a vehicle's position, speed and driving direction periodic status updates and event-based messages DENM (Decentralized Environmental Notification Message) including safety related information. Nevertheless, due to short delay requirement that may not be fulfilled with the CC shared between platoon and non-platoon members, several researches [6] argued that this is not a suitable option and that platooning applications need a dedicated service channel (SC). Alternatively, a second transceiver pair needs to be installed and tuned to the service channel, while the primary transceiver pair stays tuned to the control channel.

It is worth mentioning here that within the 5G paradigm, vehicle communications and autonomous driving have also been defined as a targeted market by SMARTER (New Services and Markets Technology Enablers). And although dissemination algorithms discussed in this paper are built on top of IEEE 802.11p, the first release of 5G by 3GPP envisions an environment, where non 3GPP systems co-exist with 3GPP system (i.e. LTE, 5G and beyond), especially with the introduction of virtualization and network slicing [7].

In this paper, we propose a dissemination approach for DENM in Platoon based VANETs. We have presented the initial concept in [8], which shows the potential gains of our approach. In this paper, we extend the work by proposing a full algorithm description, based on considering the bidirectional link quality from and to the potential relays, the sender and all other vehicles interested in receving the DENM messages.

The contribution of this paper can be summarized as follows:

1) We propose a new promising approach,called Platoon Dissemination based on the Bidirectional Link Qualitity (PDBQ), for reliable DENMs dissemination over a platoon by a dynamic selection of the best relay among platoon members, based on bidirectional link quality estimation that takes advantages of platoon particularity.

2) We present a comprehensive evaluation campaign of the proposed system through simulations.

3) Simulation results show that our algorithm performance is comparable to the best performing algorithm in terms of all evaluation metrics, while outperforming all compared algorithms in reachibility especially in very large size platoons.

The rest of the paper is organized as follows. In Section 2, a brief survey of the state-of-the-art is presented. The system model is explained in Section 3. We introduce our proposed enhanced algorithm in Section 4. Section 5 showcases the simulation setup and the evaluation results. Section 6 concludes the paper.

II. Related Works

Multi-hop broadcasting is usually needed to forward messages over a relevance area that is larger than the communication range or to increase the reception probability of safety related message among vehicles. Several algorithms were proposed in order to ensure reliable multihop dissemination of message. The ETSI Geonetworking Geobroadcast [9] is one of the simplest approaches, where a node rebroadcast to all other vehicles within a geographical target area. Although with Flooding based approaches high packet delivery can be achieved, broadcast storm problem presents a major drawback. Therefore, more recent works have opted to the concept of electing some nodes based on topology and connectivity suitable criteria to keep the packet delivery rate high, while minimizing the number of transmitters. One class of these protocols is the contention based approach (CBF), also called Further Distance approach (FD) [10]. With CBF, every node overhearing a packet sets a timer that is proportional to its distance from the sender. If a vehicle overhears the packet for a second time, the packet is discarded. Otherwise, the vehicle forwards the packet upon timeout. Thus, the node, furthest from the sender, is elected as a relay. Although distance-based approach aims to reduce the End to End delay, FD approach might lead to extra wasted waiting time in case there is no node at the border of the communication range. Research works [11] and [12] tackle this problem by the use of random CBF timer and by the selection of the neighbor with the highest forward progress towards destination as relay.

All those distance based forwarding algorithms do not take into consideration that the furthest node in the communication range is not always the best relaying option. Indeed, the medium can be subject to important propagation loss and by electing a relay that did not receive the message or is not the best forwarding node, severe reachibility problem may occur. Basically, they do not consider the selection of closer relays that may offer better coverage, for instance, a closer truck with higher antenna, or with more favorable radio conditions.

Toward the aim of improving reachibility, several efforts focused on other metrics than location for the choice of the best potential relay. In [13], authors suggest a scheme that elects the relay whose neighbor node has the highest reception probability with a contention based approach. Simulation results showed that such approach offers higher reliability on the expense of end-to-end delay. The metrics, required to deduce the reception probability, are inferred from the theory model of wireless channels and not from dynamical and empirical metrics that are really experienced by nodes. In [14], a similar scheme considering link quality metric, but more dynamically, was suggested. The best relay is the node offering the highest expected progress distance (EPD). The EPD considers both forwarding distance and the transmission quality of wireless links. Following the same concept, the work in [15] takes a step forward towards tailoring the link quality metric for the context of wireless radio channel. The authors suggest an algorithm that considers bidirectional link quality metric for the establishment of bidirectional stable communications (BDSC). Within the algorithm, nodes periodically report the active communication nodes list (ACNL). A link is considered to be valid in both direction and thus satisfying the BDC condition, if the receiving node finds its ID in the beacon sent by the potential relaying node. The sender periodically chooses as relay the node from which the highest number of HELLO packets satisfying the BDC conditions was received. In [10], reversibility metric was encompassed by an application-level requirements in a flooding-based dissemination method. However, the relayed messages are periodic status messages and not event-driven messages. Eventually induced overhead requires more future studies given the context of highly dense networks.

As discussed above, most of the dissemination techniques emphasized on either the improvement of the end-to-end delay or the reachibility. Additionally, all quoted link quality based approaches consider that a link quality can be satisfied, if the quality of the direct link (from sender to potential relay) and reverse link (from relay to sender) is higher than a fixed threshold. The work in this paper emanates from the idea that such approach is more suitable for unicast routing than for broadcast dissemination, because of its definition of two-directions of the link. In the following sections, we present the details of our dissemination approach.

III. System Model

In this paper, we consider the same system model used in [8]. The model is essentialy based on the ITS full protocol [16] on a dedicated SC for sharing messages related to the dynamic control and management of the platoon, with the hypothesis of perfect synchronization and platoon string stability. At the MAC layer, IEEE 802.11p CSMA/CA is used for CAM/DENM broadcast on the CC. Ensuring high reliability of safety messages while using such a random MAC protocol is quite challenging and requires tailored schemes for

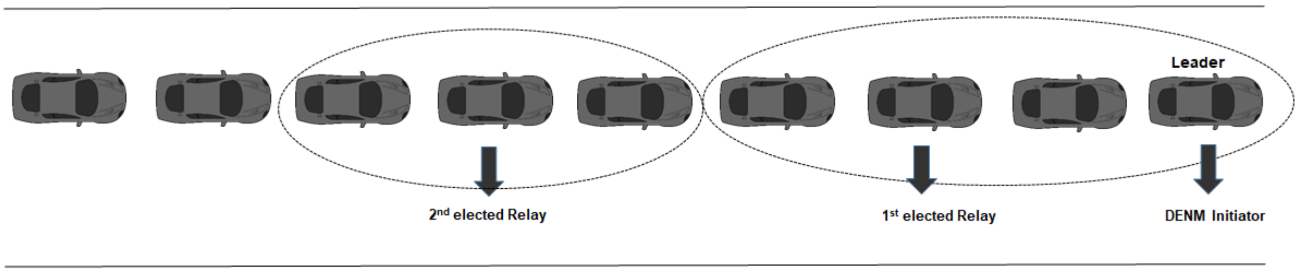

Fig. 1: Ilustration of the relaying approach for platooning

ensuring a balance between end to end delay and reachibility. Figure 1 shows a platoon with multiple vehicles and the multiple relaying of DENMs among platoon members.

Some system assumptions are:

- The ID field is included in every sent CAM, the receipt probability every period of time T_{cumul};
- The communication Range R is symmetric and the same for all platoon members;
- The number of vehicles in the platoon (n), as well as the number of vehicles in the communication range, are known for all vehicles.

IV. Proposed Dissemination approach

A. Contribution and Overview

Our proposed algorithm, (PDBQ), relies on the idea that the platoon is meant to be linearly string stable and that independently from the fact that all platoon members are in the same range of each other or not, DENMs messages may not be received by all platoon members from the first time, not only because of losses due to the propagation distance but also because of shadowing and fading phenomena. It also accounts for (long) platoon, whose length exceeds the transmission range of the leader. The idea of deputing the relaying task to one of the platoon member can improve the intra-platoon reliability as a first target and resolve unnecessary contentions over the channel. In order to meet those two requirements, the best relaying option among platoon members must be the best node in terms of new bidirectional dissemination link quality in the context of platoon and distance. That is, the forwarding and the reverse link quality should be estimated with respect to the following two conditions:

(1) The best relay is the node, whose neighbors along the direction of the propagation of the DENM, as well as the sender of the message, have high reception probability from that node.

(2) The best relay is the node that has high reception probability from the neighbors along the direction of the propagation of the DENM, as well as the sender of the message.

The two conditions would be weighed by the distance criteria, to favor the furthest nodes among two or more nodes having the same bidirectional link quality. The election of relays in our proposed approach is distributed, event-driven and receiver based. In the following section, we detail the algorithm that nodes run periodically for the computation of their link quality in respect to platooning broadcast and for the election of the relaying node.

B. Algorithm for link estimation and selection

The algorithm for link estimations stipulates the following:

- Upon the reception of a DENM message, the receiving nodes look into a local updated table of different reception ratios $PRPs$ based on which they calculate with respect to platooning dissemination context the link quality that they present as potential relays denoted by $Q_{PDBQ(r)}$.

- During each period of collection named T_{cumul}, CAMs are exchanged between nodes. Upon the reception of a valid CAM from a node j, the receiver node i increments the PRPij counter: It is the packet reception ratio of node i from all members of the platoon j belonging to its range.

- After T_{cumul} each node include in its CAM a table of the computed PRP_{ij}s.

- Upon the reception of a CAM messages with flag containing measurement is true , the receiving member update his local 2D PRP table with the extracted table of PRP_{ij}s.

- Upon reception of a DENM message, a member r estimates the bidirectional link quality in a platooning broadcast context $Q_{PDBQ(r)}$ that it can offers. This quality accounts not only for the capability of the potential relay to initially receive the DENM message, which is similar to the conventional bidirectional link quality, but also to the quality of the reception of interested nodes, if the message was relayed by this potential relay. Towards estimating such quality, the node performs the following calculations:

1) Quality of forwarding direction : From potential relay $\rightarrow$ to all interested receivers of the platoon members in the range of the relay and to the source member (s)): $PRP_{forwarding(r)}$, calculated by (1).
2) Quality of reverse direction: From interested platoon members receivers(j) and from the source member(s)$\rightarrow$ potential relay): $PRP_{reverse(r)}$, calculated by (2).

$$PRP_{forwarding(r)} = \frac{\sum_{j=r+1}^{n} PRP_{jr} + PRP_{sr}}{n-r+1} \quad (1)$$

$$PRP_{reverse(r)} = \frac{\sum_{j=r+1}^{r} PRP_{rj} + PRP_{rs}}{n-r+1} \quad (2)$$

Thus, the average quality of the dissemination link is :

$$Q_{PDBQ(r)} = \frac{PRP_{forwarding(r)} + PRP_{reverse(r)}}{2} \quad (3)$$

Members of the platoon that received the DENM message enter a contention period proportional to their link quality $Q_{BDPC(r)}$ and inversely proportional to the distance that separates them from sender. We denote this phase as $ContentionPhaseQ()$. The time to wait before transmitting for each node is as follows:

$$T_{(r)} = T_{max}(1 - \frac{D(r)Q_{PDBQ(r)}}{RQ_{PDBQ_{threshold}(r)}}) \quad (4)$$

where $D(r)$ is the distance between the sender and potential relay and R is the transmission range.

The member, whose contention timer runs out, relays the message. Other members, who receive the relayed message, discard the message. Depending on the length of the platoon, multiple relaying nodes might be elected, which accommodate for the future need of platoons with extended length. Figure 2 illustrates the case where platoon members are consecutively elected, based on our proposed algorithm, to relay a message initially generated by the leader. Upon reception of the DENM, competing nodes will compute their link quality $Q_{PDBQ(r)}$, based on the receipt probabilities stored in their 2D PRP table.

For sake of illustration, the different links considered for the computation of the average link quality for node 3 is illustrated by the figure. The $PRP_{forwarding(r)}$, based on (1) is as follows: The first term PRP_{jr} is the average PRP that all nodes j (nodes following the potential relay; i.e. nodes 4 and after) had with regards to node 3. The second term PRP_{sr} is the PRP that the sender (node s) had related to node 3. As for the reception probability for the reverse direction, $PRP_{reverse(r)}$ given by (2), it accounts for the average PRPs that node 3 has as a receipt from all nodes j in addition to the leader s. After computing the link quality, all potential relays calculates their waiting time before rebroadcasting the DENM using (4).

The details of our proposed algorithms are further elaborated, through the pseudocode of the two algorithms below; i) Algorithm for transmission of DENMs by leaders; ii) Algorithm for reception of DENMs by members.

Algorithm 1 Transmission of DENMs by leaders

Procedure DENMTxbyLeaders()
if (Leader) **and** (detectEmergency) **or** (ReceiveEmergency) **then**
  if (AlongWithDirection(myPostion,senderPosition)) **and** (EventNotinLDM(Location(msg),Situation(msg))) **then**
    $TransmitDENMMessage()$
  else
    $abort$
  end if
else
  $abort$
end if

Algorithm 2 Reception of DENMs by members

Procedure DENMMsgRx(msg)
if LastForwarderIsPlatoonMember **then**
  if (AlongWithDirection(myPostion,senderPosition)) **and** (EventNotinLDM(Location(msg),Situation(msg))) **then**
    $ContentionPhaseQ()$
    $abort$
  else
    $abort$
  end if
else
  if (AlongWithDirection(myPostion,senderPosition)) **and** (EventNotinLDM(Location(msg),Situation(msg))) **then**
    $ContentionPhaseR()$
  else
    $abort$
  end if
end if

Procedure ContentionPhaseQ()
$Time \leftarrow Random(0, T1)$
$Contending \leftarrow true$
$Contend(Time)$

Procedure: Contend (Time)
while $Time > 0$ **do**
  $Time \leftarrow Time - slotTime$
  if $Time = 0$ **and** (notReceivMessage) **then**
    $TransmitMessage()$
  end if
end while

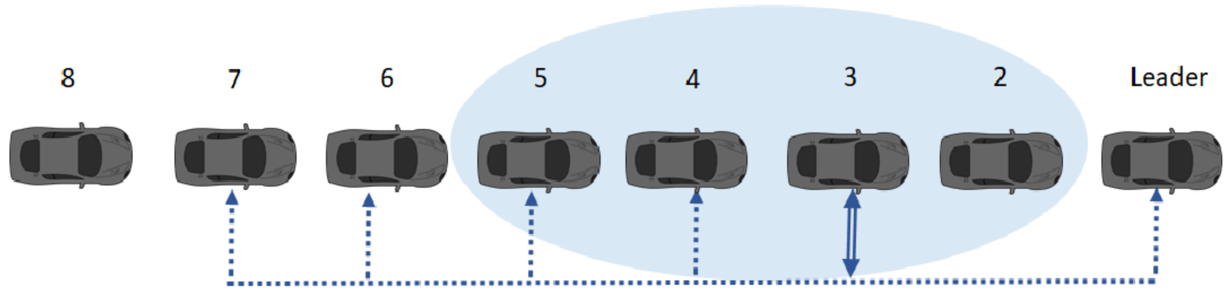

Fig. 2: Ilustration of Link Quality Estimation

V. SIMULATION AND PERFORMANCE EVALUATION

A. Simulation Setup

In order to evaluate the performance of our proposed dissemination approach, we setup simulations using the NS3 simulator. We also used SUMO [17] for the generation of realistic VANET Scenarios over a 4 km lane snippet of the highway (A25) in the city of Aveiro, Portugal. The considered performance metrics are reachibility, end to end delay metric, and average number of hops. Reachibility is computed for all scenarios, whether the DENM message reached the last vehicles in the platoon or it did not. As for the end to end delay, we have only taken into consideration scenarios, where the DENM message was received by all platoon members. At each run, a DENM is generated by the leader and evaluated considering in terms of the chosen metrics. During the first 390 seconds, only CAM messages are exchanged, in order to reach a steady state for relaying the DENM, as elaborated in our proposed protocol. The simulated platoon scenarios include vehicle number that varies from 5 to 175 with a step of 25 vehicles per simulation scenario. During simulation time,the platoon inter-vehicle distance was kept constant at 10 m, and the transmission power was set to 11.27 dBm. The log-distance model in addition to m-Nakagami model are chosen to simulate distance, fading and shadowing losses. Based on the simulated parameters, platoons' length has reached up to multiple times the transmission range of the leader (reaching almost 12 times). In order to provide a clear view on the performance of our relaying method, we compare it to 4 of the most cited existing protocols which are: Further Distance (FD) [10], bidirectional stable communications (BDSC), expected progress distance (EPD), and Flooding. To provide a fair comparison and account for the effect of contention based relaying, the EPD and the BDBC are implemented as receiver based relaying approach. We also use the recommended weight value $\alpha = 6$ as in [14] for the EPD implementation. Table 1 summarizes the parameters that we used in our simulations.

TABLE I: Simulations Parameters

Parameter	Value
Nodes densities	5 to 175 (with increment of 25)
Simulation Time	1200s
Physical Propagation Loss Model	Log distance Model: 3 m-Nakagami with m = 4.5
TX power	11.27 dbm
CCA threshold	-125 dbm
Transmission Range	230
CAM message Size	300
DENM message size	300
Phy/Mac standard	IEEE 802.11p
Frequency	5.9Ghz
CW slot duration	16 micro-seconds
Data Rate	6 Mbps
T_cumul	5 sec
Number of Run	100 runs

B. Simulation Results and Discussion

Figure 3 shows the results of the comparison between the 5 approaches in terms of end-to-end (E2E) delay. Flooding exhibits the lowest delay followed by the Further distance. Such results are trivial. Indeed, with Flooding, all nodes relay the message. Moreover, the FD opts for the furthest nodes to relay the message. Combining this distance criteria to the receiver bsed approach, implies a reduced dissemination time for the FD. As it can be seen from the figure, the E2E delay offered by the FD tends to increase in the context of platoons scenarios with more than 125 members. The reason of this progressive increase is that the probability that furthest node experience bad link quality increases as platoon length increases. Compared to the two other link quality-based methods, our approach presents the lowest E2E delay while achieving slightly higher delay compared to FD. The reason our proposed protocol oferrs an E2E delay between that of FD and that of link quality-based protocols is the fact that our approach provides a tradeoff between the link criteria and the distance criteria. As it can be seen from the figure, the effect of sacrificing the rigid further distance criteria for the link quality criteria is more accentuated as vehicle density increases. The assessed metric tends to significally increase for all approaches including the further distance and except the flooding, when the platoon is composed of more than 100 member. This case

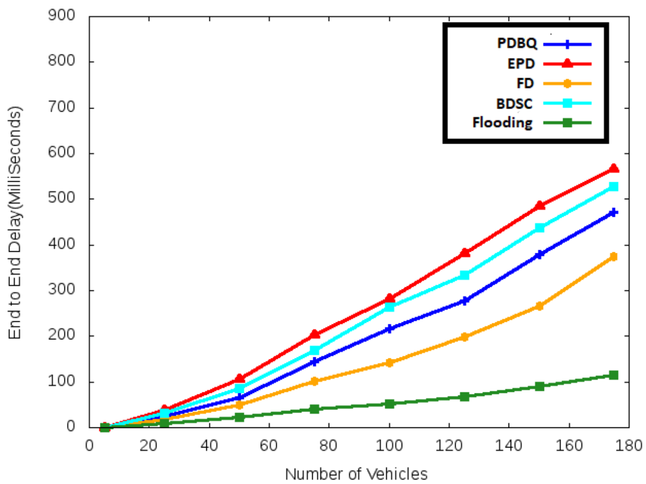

Fig. 3: Average End to end Delay for all approaches

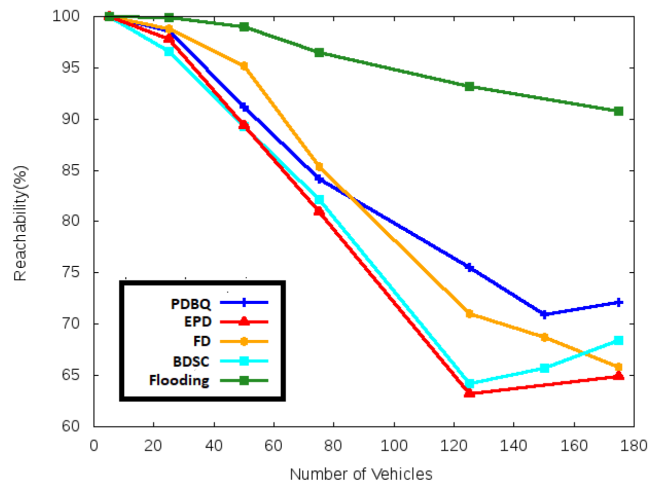

Fig. 5: Reachability of DENM messages for all approaches

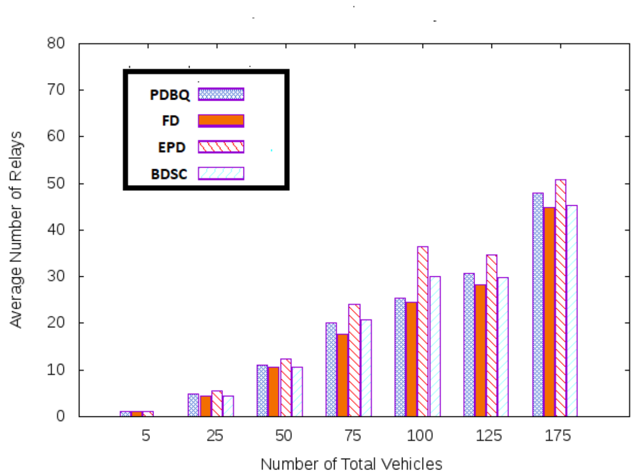

Fig. 4: Average Number of Retransmissions for all approaches

reflects the effect of a multi hop communications, required to disseminate messages over platoon members located more than three time the transmission range away from the leader. It is important to elaborate here that all approaches, with the exception of the EPD, provide an E2E delay considerably smaller than the delay requirement set for the cooperative collision warning applications [16] for all platoon sizes.

The average number of hops is plotted in Figure 4, to consolidate the above E2E delay discussion. Indeed, the FD presents the lowest average number of hops. On the other hand, our approach exploitates slightly higher number of average relays as the number of platoon members increases. It can be noticed that by using the BDSC or our approach, the average number of hops obtained for all vehicle densities, is quite competitive. Nevertheless, EPD uses the highest average number of relays.

The tradeoff between E2E delay and reachability is mainly highlighted by Figure 5, which displays the reachibility of all compared protocols. As expected, Flooding exhibits the highest reachibility among other protocols for all platoon sizes, since all nodes relay the DENMs. The performance of the other protocols depends highly on the platoon length. Mainly, two categories of scenarios can be distinguished, when comparing the reachibility of the all four protocols. The first category include small size platoons, up to 100 vehicles, i.e. platoon length up to 8 times the transmission range of the leader with respect to our chosen platoon configuration. The FD outperforms all the other approaches during these scenarios, with our approach just lagging a bit behind. Our proposed protocol outperforms both the BDBC and the EPD, for all platoon sizes. However, The reachibility performace of our proposed protocol is comparative to FD. As for the category of longer platoons once number of platoon members starts exceeding 100 vehicles, the reachibility of FD detorierates rapidly with the increase in number of platoon members. Indeed, the scenarios of this second category represent those scenarios, where the rigid distance criteria of FD reaches its limitation, by choosing relays that impede the reachibility metric. From the figure, it can be clear that our approach provides the highest reachibility ratio after flooding, and outperforming all 3 compared algorithms. The FD continues to provide better reachibility than BDBC and EPD up till platoons with 160 vehicles. The BDBC starts outperforming the FD and EPD for larger densities.

In this section, we have evaluated the performance of our proposed dissemination protocol compared to other protocols, based on either flooding, distance or link quality, in terms of E2E delay, number of relays and reachability. The simulation results show that our proposed protocol provides a balanced trade-off between E2E delay and reachability. Our proposed algorithm always outperforms both link quality based protocols (EPD and BDSC) in both E2E delay and reachability, for all platoon sizes, with similar average number of relays. When compared to Further Distance (FD) algorithm, the merits of our proposed algorithm are highlighted. Our algorithm offers a trade-off between delay and reachability. Our proposed protocol sacrifices E2E delay a bit, in order to guarantee the reachability of the DENM messages to, as many platoon members as possible. This fact is emphasized in the results of reachability, when the size of platoons increases above 100 vehicles. In those scenarios, our algorithm provides better reachability than FD, with very close E2E delay. This trade-off is the main contribution of our protocol. In the dissemination of safety related messages, delay is important, as much as reachability, since message reaching all vehicles is the main purpose of the DENM dissemination protocols.

VI. Conclusion

This paper proposes an innovative dissemination protocol of DENM messages for platoons, named (PDBQ). The proposal uses bidirectional link quality with respect to the broadcast context coupled with distance criteria for the selection of proper relays. Our proposal differs from existing ones in that it considers link quality in both directions, especially including the link quality between the potential relay and the interested potential receivers of the DENM message. The proposed protocol was evaluated using simulations. The performance of our proposal was compared to 4 existing protocols. Simulations Results show that our protocol outperforms the two link quality-based relaying protocols. The results also highlights the competitiveness of our approach compared to Further Distance (FD) protocol. Although FD provides slightly lower delay, our protocol outperforms FD in reachability, when size of platoon increases above 100 vehicles. Those results highlight the main contribution of our proposal, which is a balanced trade-off between E2E delay and reachability.

Future extension of this work will include the optimization of the period of exchanging CAMs, as well as the validation of the performance of our proposal for different platoon configuration and parameters, mainly variation in transmission Range.

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