An Alternative Congestion Control using an Enhanced Contention Based Forwarding for Vehicular Networks

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***Abstract*—Many ITS (Intelligent Transportation Systems) applications require multi-hop forwarding of Decentralised Event Notification Message (DENM). If not well designed, multi-hop forwarding algorithms provide negative impact on the IEEE 802.11p vehicular systems, which already suffer from channel congestion caused by e.g., Cooperative Awareness Messages (CAM). In this paper, we propose an enhancement of the contention based forwarding (CBF) by a congestion control functionality. Specifically, we propose CBF2C packet forwarding algorithm, which is designed to fit into the distributed congestion control (DCC) framework specified by ETSI. In order to efficiently utilise the channel, CBF2C adapts retransmission count based on channel load status. Extensive simulation evaluations on communication performances and channel utilisation are carried out targeting scenarios when the wireless channel is shared by DENM and CAM packets. The performances of CBF2C is compared against those of an enhanced flooding, and an ETSI-standardised scheme, CBF-RT. Moreover, two cases, with and without congestion control on the CAM rate, are considered in the performance evaluations. The simulation results show a positive impact of the dual DCC, CAM rate control at the facilities layer and DENM retransmission count control at the networking layer.**

Keywords*—ITS, IEEE 802.11p, geonetworking, broadcast storm problem, channel congestion

I. INTRODUCTION

The IEEE standardised the 802.11p technology for communications between vehicles and everything (V2X). In Europe, five 10 MHz channels are allocated in the 5.9 GHz frequency band for vehicular communications based on the IEEE 802.11p [1]. One of the five channels is defined as Control Channel (CCH) dedicated for applications of road safety and efficiency.

ETSI (European Telecommunications Standardisation Institute) specified several message sets for traffic safety applications, notably Cooperative Awareness Message (CAM) and Decentralised Event Notification Message (DENM) [2]. CAMs are single hop broadcast messages, sent by each vehicle containing information on the vehicle's position, speed and so on, so that other road users (including vehicles) can be aware about the vehicle. DENMs are, on the other hand, sent upon detections of events, such as accidents, and can be forwarded over multi-hops if necessary. Indeed, a number of applications of DENM, such as notifications of emergency break, accidents, traffic jam require multi-hop forwarding. A number of multi-hop packet forwarding schemes are proposed in the context of vehicular communications, especially geonetworking [3]–[8], and some are included in the ETSI standard [9], namely, contention based forwarding (CBF and CBF-RT) and greedy forwarding (GF) algorithms.

Due to the limited channel resource in the 5.9 GHz band, channel congestion is one of the key issues of the 802.11p vehicular networking system. The channel congestion issue caused by CAMs is well known [10]–[12]. The previous studies show that the PDR (packet delivery ratio) can degrade down to 50% and the delay can increase to 1 second when each vehicle periodically broadcast CAM messages at 10 Hz [11]. This level of communication quality obviously cannot satisfy the requirements of the road safety applications. Targeting this issue, ETSI specified a framework of distributed congestion control (DCC) [10], an architecture that allows ITS stations (nodes) to control its communication parameters of access, networking, or facilities layers as illustrated in Fig. 1. A number of efforts have been made against channel congestion by adapting parameters of the facilities (particularly CAM frequency) and the access layer (including transmission power, data rate, carrier sense threshold) [13]. However, to the best of our knowledge, not much work is done for congestion control at the networking layer, fitting to the ETSI framework.

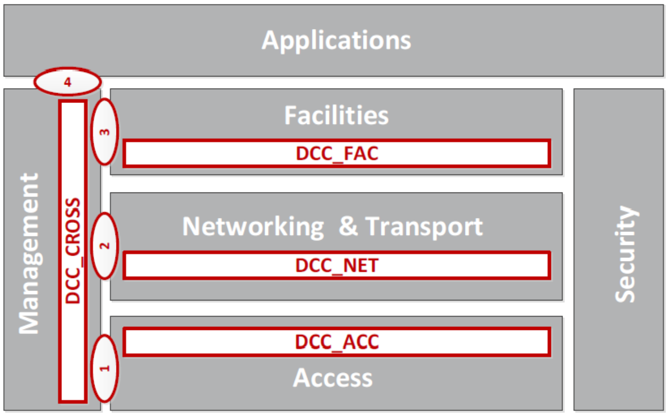

Fig. 1: ETSI DCC architecture

We can easily imagine that since the simplest forwarding scheme, flooding, creates the broadcast storm problem, its impact on channel congestion must be severe especially when the CCH, which already suffers in accommodating CAM packets. What is not clear is that if the algorithms such as CBF, which avoid creating redundant retransmissions, contribute to channel congestion, and if DENM and CAM can achieve sufficient performances when they share the wireless resource. Moreover, if a congestion control is needed for DENMs, then what approaches should be taken. Despite that DENM can exploit the efforts made for CAM, we believe that a special attention is needed especially at the networking layer. Indeed, while the DCC algorithms that adapt the MAC/PHY parameters are applicable to DENMs, they do not necessarily lead to the desired results. For example, reducing transmission power and increasing data rate shorten one-hop transmission range, consequently increasing the number of hops, resulting in an increased channel load.

In this paper, we are interested in channel congestion issue when DENM and CAM packets share the wireless channel. Targeting such scenarios, we propose to enhance the ETSI standardised packet forwarding algorithm, CBF by a distributed channel congestion (DCC), designed to fit into the ETSI DCC architecture [10]. Specifically, we propose a forwarding algorithm, CBF2C, which is an enhanced version of CBF, that adapts retransmission count based on channel load status. Using the NS3 network simulator, the performance of CBF2C is compared against those of an enhanced flooding and CBF-RT, targeting for scenarios, where DENMs and CAMs share the wireless channel. Two cases, with and without DCC on the CAM rate, are considered in the simulations. Simulation results show benefits of the dual DCC control, DCC on CAM rate at the facilities layer and DCC on retransmission count at the network layer using CBF2C.

The paper is organized as follows. Section II describes the related work. Section III introduces two types of packet forwarding algorithms, flooding and contention based forwarding, which will be compared against the proposed algorithm (in Section V). Section IV presents the proposed packet forwarding algorithm, CBF2C. Section V is dedicated to performance evaluations. Finally, Section VI concludes the paper.

II. RELATED WORK

Channel congestion problem in the IEEE 802.11p systems has been well addressed in the literature. A number of papers reported that periodical broadcast of CAM messages at each vehicle can easily lead to channel congestion problem [13]–[16]. As mentioned earlier, ETSI specified a framework of distributed congestion control (DCC), in which each ITS stations (ITS-S, nodes in the vehicular network) measure channel load based on channel business ratio (CBR) and adapt communication parameters, such as CAM generation rate, transmission power, and data rate, carrier sense threshold, and so on [10]. It has been shown that controlling the CAM generation rate alone can alleviate channel congestion [11], [15], [16]. However, since a large reduction of the CAM generation rate may provide a negative impact on the road safety, it is desirable to control other parameters in parallel. The authors of [13] compared the impacts of controlling different parameters and showed that in adding to the message generation rate control, power control can also provide a large impact. When it is necessary to disseminate DENM packets, DENMs will also add more load to the wireless channel, and hence it is necessary to consider to control the channel congestion when DENM and CAM share the wireless channel. The algorithms that control the access layer parameters, such as transmission power, data rate, carrier sense and so on, [13] are applicable to DENM packets. However as mentioned earlier, these algorithms would not necessarily provide a positive impact on dissemination of DENM packets, that often require multi-hop forwarding. Hence we believe that for DENM packets, it is important to consider channel congestion at the design of the forwarding mechanism.

Due to highly dynamic topology of vehicular networks, multi-hop forwarding (routing) have always been a challenging research subject. Besides mobility, too sparse or too dense network topologies create great challenges in forwarding of a packet. A number of carry-and-forward algorithms including TBD [17], VADD [18], and DiRCoD [19], proposed for sparse network topologies allowing vehicles carry packets until they meet other vehicles to forward. Carry and forward approaches do not fit to the applications with strict delay requirements, such as emergency break. Obviously, if the network is too sparse, channel congestion problem would not be an issue. Channel congestion becomes an issue in connected network topologies that necessitate store-and-forward mechanisms. The simplest and probably the most robust store-and-forward mechanism is flooding, in which each node in between the source and the destination retransmits the packet [20]. The key drawback of flooding is that it creates a large number of redundant retransmissions leading to the broadcast storm problem (i.e., channel congestion problem) [20]. A great number of ”lighter” forwarding algorithms are proposed and they can be classified into two groups depending on if forwarding decision is made at the senders or at the receivers. The algorithms including GPSR [4], GPCR [3], ToGo [5] belong to the former group, in which senders select the next hop forwarders based on the position of the nodes [4] and the road structure [3], [5], utilising beacon exchanges among vehicles. The contention based forwarding (CBF) mechanisms [6]–[8] behave in more opportunistic manner in the sense that they do not require nodes to know their neighbours, because the receiver nodes decide whether or not forward the packet utilising a countdown timer. While these algorithms create relatively low overhead compared to flooding, none of them are intentionally designed to control channel congestion.

Motivated by this, we are interested in studying channel congestion when CAM and DENM packets share the wireless resource, and propose to enhance CBF mechanism with a distributed congestion control.

III. FLOODING AND CBF

As illustrated in Fig. 2, many ITS applications require transmissions of DENMs, including informing traffic jam, sudden weather change, collision, and so on. Majority of these types of information require multi-hop forwarding of the DENM packets. In this chapter, we introduce common packet forwarding algorithms that can be used for dissemination of DEMN packets in VANET.

A. *Flooding and advanced flooding*

The flooding approach, where each node located between source and destination retransmits the packet, is the simplest message dissemination algorithm. The flooding is known to

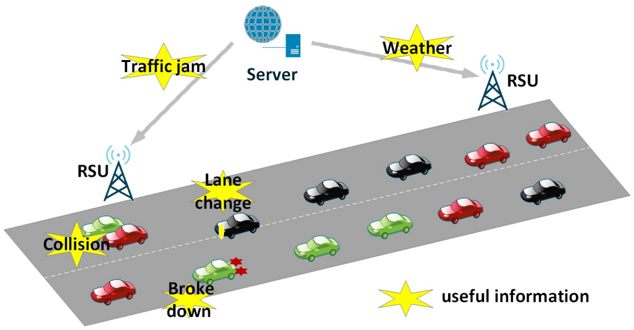

Fig. 2: Scenario description

be extremely robust in dynamic network topologies. This advantage is coming from its simplicity and redundant retransmissions. A key weakness of flooding is that the approach creates too many packet duplications, causing congestion and collisions in dense networks. Yet another weakness is, since multiple nodes receive a same packet at the same time, they forward it at the same time, creating synchronized channel accesses, i.e., packet collisions. The problem is severe especially when the network is sparse, where the MAC (Medium Access Control) protocol to take the immediate channel access procedure, i.e., accessing to the channel without invoking backoff [21].

The latter problem can be easily solved by utilising a countdown timer to asynchronize forwarding operations. Calling this approach as FloodingAdv, the functionality of FloodingAdv is described in Algorithm 1.

Algorithm 1 FloodingAdv Algorithm

```
- Node $N$ receives a packet for the first time
if ($N$ is positioned between the source and the destination area) then
    Node $N$ starts a countdown timer with length $wt$ randomly taken from [0, $WT_{max}$].
end if
if ($wt$ expired) then
    Re-transmit packet()
end if
```

B. CBF and CBF-RT

Contention based forwarding, CBF [8], uses a countdown timer to eliminate redundant retransmissions, consequently avoiding the broadcast storm problem. Upon reception of a packet, each forwarding candidate sets a timer, and only the node, whose timer expired first, forwards the packet, while other nodes refrain from forwarding as soon as they detect that the packet has been forwarded. The timer value is set in such a way that the farthest node from the source transmits first, for example:

$$wt = WT_{max}(1 - \frac{d_{SN}}{d_{SD}}). \tag{1}$$

Here WT_{max} is the maximum wait time, d_{SN} and d_{SD} are the distances between the source and the node, and the source and the destination, respectively. In an ideal case, CBF can perfectly eliminate redundant forwarding, consequently avoids congestion. However, this also means that since there is no redundancy, CBF is extremely sensitive to packet losses.

The authors of [8] proposed an enhanced CBF approach, called CBF-RT (Contention based forwarding with retransmission threshold). As described in Algorithm 2, in CBF-RT, during the countdown timer, the node counts the number of retransmissions of the same packet made by its neighbours. If the number of retransmissions reaches a given threshold RC_{th}, then the node cancels the timer and gives up forwarding of the packet. Finally it should be mentioned that both CBF and CBF-RT are adopted as the ETSI geonetworking protocols.

Algorithm 2 CBF-RT Algorithm

```
- Node $N$ receives a packet
if ($N$ is positioned between the source and the destination area) then
    if it is the first time receiving the packet then
        RetransmissionCount=0
        Start a countdown timer $wt$ following Eq. (1).
    else
        RetransmissionCount++
        if RetransmissionCount $> RC_{th}$ then
            Cancel the timer; drop the packet
        end if
    end if
end if
if ($wt$ expired) then
    Re-transmit packet()
end if
```

IV. PROPOSED ALGORITHM: CBF2C

In this paper we propose a forwarding algorithm, CBF2C, which extends contention based forwarding with a congestion control functionality. More specifically, CBF2C contributes to congestion control following the ETSI DCC framework illustrated in Fig. 1. Same to other DCC algorithms [13], [15], [16], CBF2C monitors the channel load status and adapts the number of redundant retransmissions, retransmission count. As specified in [15], the channel load is measured by the channel busy ratio (CBR), which is the ratio of the time the channel was busy over the monitor interval:

$$CBR_N = \frac{T_{busy}}{T_{monitor}}. \tag{2}$$

Retransmission count, RC_{th}, is adapted following Algorithm 3.

Algorithm 3 CBF2C retransmission count control

```
- CBR2C protocol is informed with the current CBR value
if ($CBR > CBR_{max}$) then
    $RC_{th}$=MAX(1,$RC_{th}$-1)
else if ($CBR < CBR_{min}$) then
    $RC_{th}$=MIN($RC_{max}$,$RC_{th}$+1)
end if
```

As we see in Algorithm 3, when the channel busy ratio CBR exceeds a threshold CBR_{max}, implying that the channel is congested, the node reduces the retransmission count. If CBR is below a threshold CBR_{min}, the node increases the retransmission count. Note that retransmission count, RC_{th}, takes value in the range of [1, RC_{max}]. The authors of [20] studied the impact of redundant retransmissions on the additional coverage under the assumption that nodes do not transmit at the same time (no collisions). Results show that when a number of re-transmission is higher than 4, the expected additional coverage is less than 5 % implying that more than 4 retransmissions at each hop is not necessary for multi-hop forwarding. Based on this insight, it seems enough to fix RC_{max} to 4.

While the relative distance is most commonly considered to calculate wait time at forwarding nodes, the equation can lead to the cases, where nodes which are in the proximity of each other get timers that expire at the same time. Hence, we propose to further improve the algorithm such that the calculation of wait time is not only based on the distances between the node and source, and the source and the destination (see (1)), but also the number of neighbouring nodes, n, which are within the distance of Δd, as follows:

$$wt = WT_{max}(1 - \frac{d_{SN}}{d_{SD}}) + \tau k. \tag{3}$$

where k is an integer randomly taken in the range of [0, n] and τ is a fixed time value. Finally, forwarding algorithm of CBF2C is same as that of Algorithm 2, except that the RC_{th} is found following Algorithm 3 and wt is calculated following Eq. (3).

V. PERFORMANCE EVALUATION

In this section, we compare the performances of CBF2C against FloodingAdv and CBF-RT for the scenarios when DENM and CAM packets share the channel. We first evaluate performances of CAM and DENM packets for the different forwarding algorithms, when the CAM generation rate is not adapted by DCC. Then we evaluate the performances of CAM and DENM packets, when the CAM generation rate is controlled following the asynchronous reactive DCC algorithm [11], which adjusts CAM rate in an asynchronous manner following Table I.

The simulation setup follows the ETSI recommendations for evaluations of congestion control algorithms [10]. Specifically, as illustrated in Fig. 3, vehicles are distributed on a highway with 6 lanes. The length of the road is 1 km, and the width of each lane is 3 meters. Three types of road densities, sparse, medium, and dense, are considered, where inter-vehicle distance is 100, 45, and 20 meters, respectively (see Table. II).

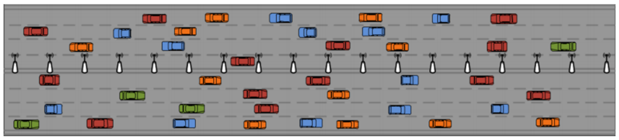

Fig. 3: Highway Scenario

Communication parameters are listed in Table III. As can be seen in the table, each vehicles periodically broadcast 400 Bytes of CAM packets with the default rate of 10 Hz. RSUs broadcast 500 Bytes of DENM packets in every 10 Hz. The destination area of the DENM packets are the 1km x 18m road. Transmissions of DENM packets have higher priority than CAM packets, specifically, DENMs are sent using the VIDEO access category while CAMs are sent using Background access category. The CBR_{max} and CBR_{min} are set to 70% and 55% respectively in CBF2C. RC_{Th} is 2 for CBR-RT [8].The WT_{max} is 5 ms for the flooding and 20 ms for CBF-RT and CBF2C. τ in Eq. 3 is 1 ms.

TABLE I: Reactive DCC control lookup table

States	CBR (%)	T_{off} (ms)	R^{ms} (Hz)
$Relaxed$	[0,19[	60	16.7
$Active_1$	[19,27[	100	10.0
$Active_2$	[27,35[	180	5.6
$Active_3$	[35,43[	260	3.8
$Active_4$	[43,51[	340	2.9
$Active_5$	[51,59[	420	2.4
$Restricted$	[59,100]	460	2.2

TABLE II: Highway Scenario Settings

Class	Inter-distance	Node density (Nodes/Km)
Sparse	100 m inter-distance (3 lanes/ 2 directions)	11
Medium	45 m inter-distance (3 lanes/ 2 directions)	23
Dense	20 m inter-distance (3 lanes/ 2 directions)	51

TABLE III: Simulation parameters

Parameters	Value
Channel bandwidth	10 Mhz
Transmission power	23 dBm
Propagation model	Log-distance
CBR monitor interval	100 ms
Number of RSUs	5
DENM sources	RSUs
DENM generation rate	10Hz
DENM size	500 Bytes
DENM destination area	[1000m x 18m] road
CAM default rate	10 Hz
CAM size	400 Bytes
Access category CAM/DENM	BK/VI

Figures 4 and 5 show the average packet delivery ratio (PDR) of DENM packets without and with DCC on CAM rates, respectively. PDR for DENM is calculated at each vehicle on the road for all the DENMs transmitted by the RSUs. By comparing the two figures, we can say that the DENM performances are similar for the cases with and without CAM congestion control for individual forwarding algorithms. This is due to the fact the DENM packets are assigned with a higher priority w.r.t CAMs; this prioritisation could protect the DENMs from channel congestion. On the other hand, it is clear that the CBF2C algorithm shows the best PDR performance followed by the CBF-RT. Specifically, PDR of CBF2C does not degrade when the CAM congestion control is made.

Figures 6 and 7 show the average PDR of CAM packets without and with DCC on CAM rates, respectively. PDR of

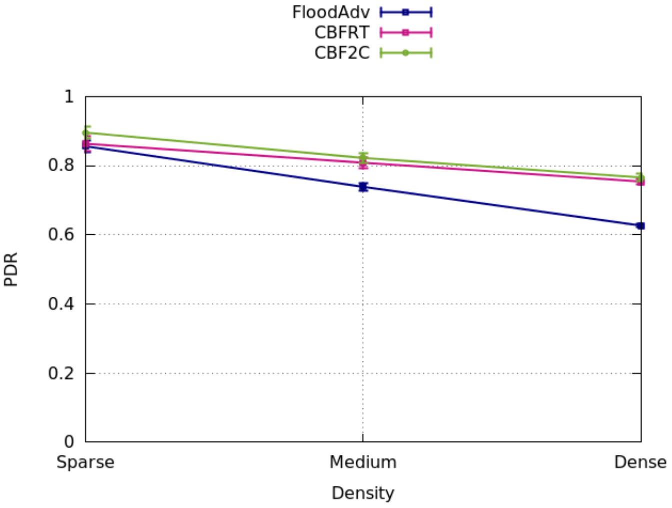

Fig. 4: Packet Delivery Ratio of DENM packets when there is no DCC on the CAM rate.

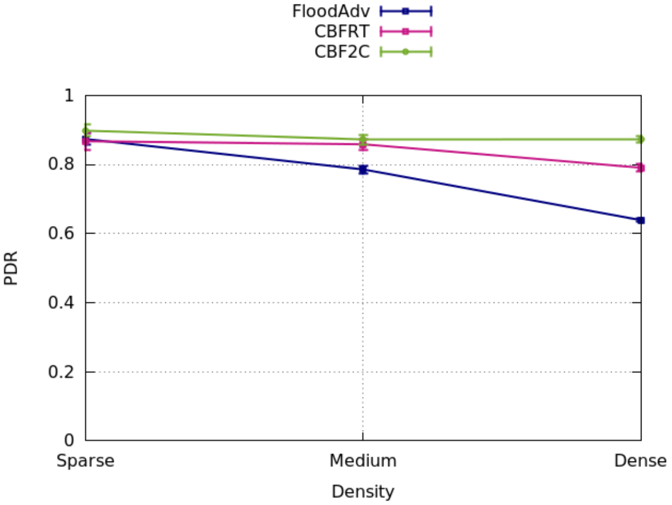

Fig. 5: Packet Delivery Ratio of DENM packets when there is DCC on the CAM rate.

CAMs is calculated at each vehicle for all the CAMs broadcasted by its neighbouring vehicles in the range of 400 meters. In comparison to Fig. 7, Fig. 6 clearly shows that when there is no DCC on CAM rate, the PDR performance degrades with the increase of the road density. This is especially significant if we compare the performances against the PDR of DENM packets (Fig. 4), indicating that the data traffic at the low access category ”pays” for the channel congestion. On the other hand, when there is DCC is made on CAM, PDR performances of CAM packets are largely improved. The improvement is significant for CBF2C, which provides congestion control on DENM packets. Figures 5 and 7 clearly show the benefit of dual congestion control on CAM and DENM packets.

Figures 8 and 9 depict the average packet reception interval for CAM packets without and with DCC on CAM rates, respectively. Packet reception interval is the time between the two consecutive CAMs arriving from the same sender. Packet reception interval increases due to packet losses or DCC on the CAM rate. Figure 8 shows that if there is no DCC on CAM rate, the CAM reception interval is large especially when the an enhanced flooding approach (called FloodADV) is used for DENM packets. On the other hand, the interval is much shorter when CBF2C and CBF-RT are utilised for dissemination of DENM packets. Now we compare the results of Figs. 8 and 9. Roughly speaking, the results shown in Figures 8 and 9 are similar, except the case of CBF2C in the dense scenario (the interval is 300 ms shorter in Fig.9). Nevertheless, by considering Figs. 6 and 7, the following insights can be drawn. In general, thanks to the DCC control to CAMs, less number of CAMs will be lost, which is significant when CBF2C is used for DENMs. Nevertheless, the level of cooperative awareness (information reception interval) is similar for the cases with and without CAM DCC, especially for an enhanced Flooding and CBF-RT. When congestion control is made for both

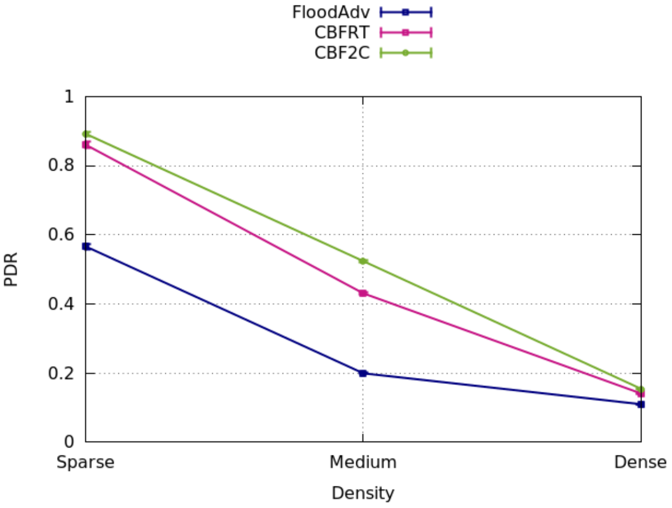

Fig. 6: Packet Delivery Ratio of CAM packets when there is no DCC on the CAM rate.

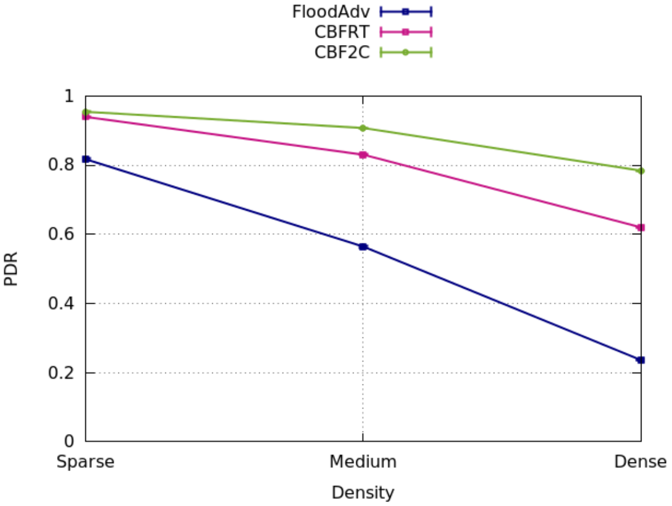

Fig. 7: Packet Delivery Ratio of CAM packets when there is DCC on the CAM rate.

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CAM and DENM (i.e., CBF2C) an improved level cooperative awareness is achieved.

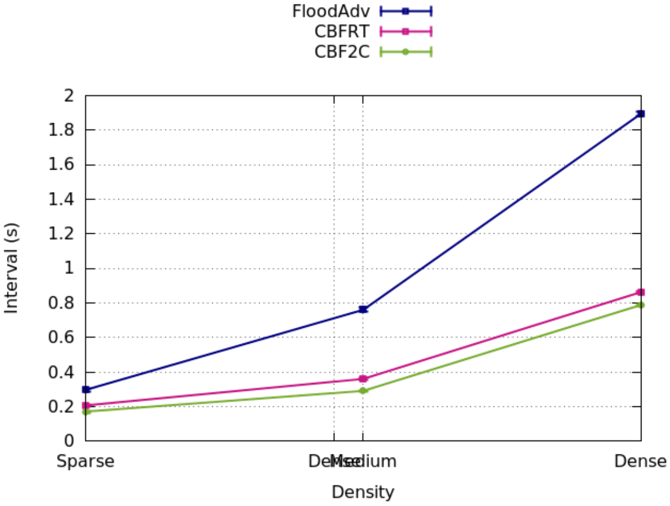

Fig. 8: Packet inter-reception time of CAM packets when there is no DCC on the CAM rate.

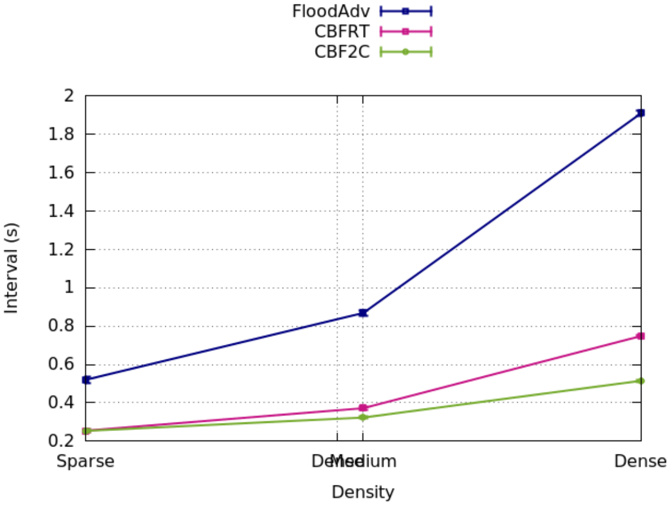

Fig. 9: Packet inter-reception time of CAM packets when there is DCC on the CAM rate.

Figure 10 compares the communication overhead created by the individual forwarding algorithms when DCC is made on the CAM rate. Note that almost the same results are obtained for the case when no DCC is made on CAM. Communication overhead is measured by the number of copies transmitted per DENM packet. As shown in the figure, for an enhanced flooding approach creates a large amount of overhead. In contrast, the overhead of CBF2C is significantly low, without depending on the density. CBF-RT shows higher overhead compared to CBF2C. Finally Figs. 11 and 12 compare the channel busy ratio (CBR) for the cases without and with DCC on CAMs, respectively. From Fig. 11, if there is no DCC on CAM, CBR exceeds 60% without depending on the forwarding approach for DENMs, and the channel is almost always saturated for an enhanced Flooding approach. In contrast CBR is low for CBF2C followed by CBF-RT, especially if DCC on CAM is made.

Finally, Figs. 5, 7, 9, 10, and 12, we can conclude that the impact of DCC on CAM is significant, and DCC on DENM can further improve the communication performances.

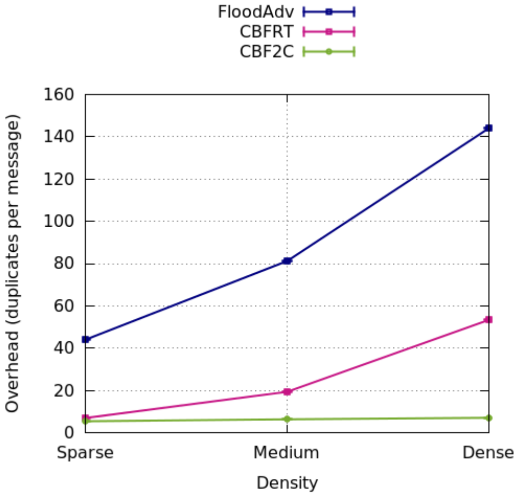

Fig. 10: Communication overhead i.e., number of duplicate packets per message for different forwarding schemes.

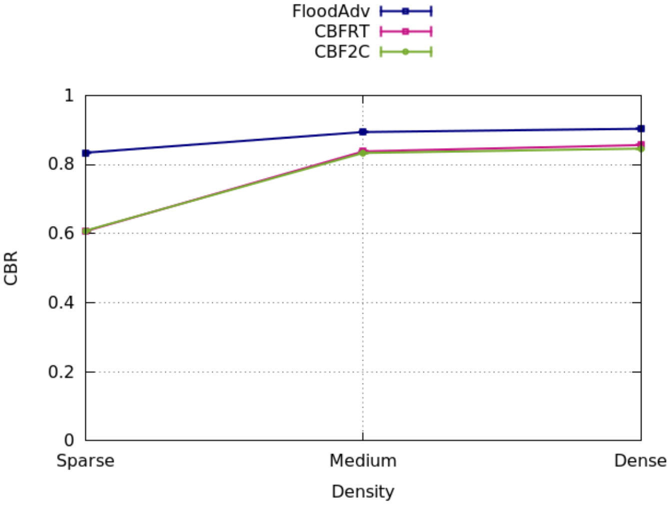

Fig. 11: Channel busy ratio for the case when there is no DCC on the CAM rate.

VI. CONCLUSION

Motivated by luck of efforts on congestion control for multi-hop DENM dissemination, we proposed CBF2C forwarding algorithms that takes account of both the communication performance and the channel utilisation. CBF2C is designed to fit the ETSI DCC architecture: it adapts its retransmission count based on the channel load status. Extensive evaluation of CBF2C is made in comparison to an enhanced flooding and CBF-RT schemes, when the channel is shared with CAM messages. In the simulations, we consider the

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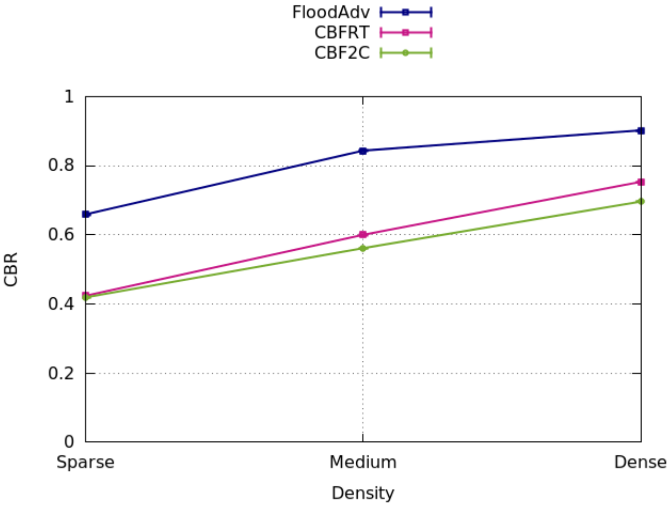

Fig. 12: Channel busy ratio for the case when there is DCC on the CAM rate.

cases with and without congestion control on CAM rates. The achieved insights are as follows. Prioritised channel access can greatly protects the packets with higher priority (DENMs) and the packets with lower priority largely suffer from channel congestion, especially if there is no DCC on CAM neither on DENM. Congestion control on CAM provides great benefits on performances of both the CAM and DENMs, and congestion control on DENM further improves the performances.

Our future work includes evaluation of the schemes for more complex scenarios with considerations of vehicles' mobility.

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