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Leveraging the Collective Perception Service for CAM Information Aggregation at Intersections

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***Abstract*—Intersections are prone to accidents due to poor visibility and complex traffic situations. Vehicle-to-X communication enables vehicles to announce themselves by sending Cooperative Awareness Messages or Basic Safety Messages and thus helps to greatly improve the time they are aware of each other before arriving at an intersection. However, similar to the drivers' vision, communication can be obstructed by buildings, too. To mitigate this issue, different approaches to message relaying have been suggested in the past. While they discussed the general idea, this paper gives a detailed proposal on how Road Side Units can aggregate and relay messages using the Collective Perception Service which is currently being standardised. A simulation study analyses the performance of direct and aggregated relaying using a complete ITS-G5 communication stack. Especially, the influence of Decentralized Congestion Control is discussed which earlier studies did not include. It is shown that aggregating Cooperative Awareness information in Collective Perception Messages can greatly improve the drivers' reaction time while at the same time adding only a small amount of load to the communication channel.**

***Index Terms*—Intelligent Vehicles, Vehicular ad hoc Networks, Wireless Communication**

I. Introduction

The introduction of Cooperative Intelligent Transport Systems (C-ITS) and Vehicle-to-X (V2X) communication to the streets of the world has various goals, the most prominent of which are road safety applications [1]. A significantly large proportion of overall road accidents occur at intersections. According to the road accident statistics of the U.S. National Highway Traffic Safety Administration, intersections accounted for roughly 40 % of all road accidents in the United States in 2008 [2]. Consequently, research and standardisation efforts in the domain of C-ITS specifically target intersections. The European Telecommunications Standards Institute (ETSI), e.g., specifies the Intersection Collision Risk Warning (ICRW) Service [3]. It detects potential collisions between vehicles approaching a road intersection and warns the affected vehicles about the collision risk by sending a Decentralized Environmental Notification Message (DENM) [4]. This in turn can then either be used to warn the driver or even to stop the vehicle immediately by automatic braking. In [5] it was shown that with the help of the warnings of an ICRW service, drivers react to potential collisions earlier, they drive slower before intersections and the rate of intersection collisions drops significantly.

Such a service heavily relies on the evaluation of received Cooperative Awareness Messages (CAMs) [6]. Communication at urban intersections, however, can be challenging since the Line Of Sight (LOS) is often obstructed by buildings at the corners of the streets. An analysis of urban intersections in Munich, Germany shows that 70 % to 90 % of all four leg intersections have buildings at each corner which are positioned relatively close to the street [7]. As a result, vehicles approaching the same intersection from different arms will be communicating in Non-Line of Sight (NLOS) conditions most of the time. While this is possible to some extent, studies have shown that the communication of connected vehicles can be significantly obstructed in NLOS conditions due to buildings [8]–[11] and the Time To Arrival (TTA), i.e. the available reaction time of vehicles approaching the same intersection after they become aware of each other, can be rather short. To increase that time, Road Side Units (RSUs) can be placed at intersections to relay received messages. [12]–[17] indicated that the increased channel load caused by relaying would limit its potential benefits. Hence, aggregation of multiple messages was generally proposed [16]. Detailed information on how to achieve this using existing protocols was not published, yet. This paper does so and proposes to leverage the Collective Perception (CP) Service [18] for the aggregation. It gives details on how the respective Collective Perception Message (CPM) can be used for that and analyses how and when CPMs should be generated in order to balance channel load and TTA improvements. A multi-parameter simulation study was conducted to assess that trade-off. While other studies have analysed direct relaying and payload aggregation before, this paper is the first to use a complete and realistic ITS-G5 network implementation based on the most recent European C-ITS standards. This is especially important since Decentralized Congestion Control (DCC) [19], which other studies were missing, plays an important role for the effectiveness of the relaying as this study shows. The remainder of this work is organised as follows: Section II summarises earlier studies and other related work. Afterwards, Section III details how CPMs could be used for aggregated CAM relaying. In Section IV, the effects of direct relaying and Collective Perception based relaying are compared under the influence of DCC in a simulation study. Finally, Section V concludes the paper and outlines future work.

II. RELATED-WORK

Previous works have already investigated several relaying schemes at road intersections. The simulation studies in [20], [21] used parked cars as relay nodes, and it was shown that the earlier notification of the vehicles can be increased substantially in this way. However, relying on privately owned vehicles to be present and willing to relay messages is a risk in safety critical situations. In [12], the effect of relaying using RSUs at intersections on the packet delivery ratio was studied and the results indicated that relaying with omnidirectional antennas improves the packet delivery ratio only moderately due to packet collisions caused by hidden terminals. Equipping the RSUs with multiple directional antennas on the other hand improves the performance of relaying considerably by reducing the number of packet collisions. The authors of [14] came to similar conclusions. In our work, the RSUs are similarly equipped with a separate directional antenna for each intersection arm and the impact of the antennas on relaying is not investigated further.

Several relaying strategies have been proposed to mitigate the impact of relaying on the channel load. In [15], separate channels were employed for original and relayed messages and the results indicated that channel congestion and the resulting packet collisions could be reduced. However, this requires additional spectrum, which is scarce, and an additional radio transceiver which is expensive and not necessarily available on all vehicles. In order to reduce the packet overhead of relaying each message separately, payloads of multiple safety messages were stored by RSUs and combined in a single message before forwarding in [16]. Moreover, the payload combining scheme is used together with directional antennas in [17] and it was shown that using both schemes yields better results than each of them separately. The payload combining scheme is similar to the usage of CPMs in this work, however, CPMs in this work aggregate only the relevant information from multiple messages instead of attaching their payloads. Moreover, the messages in the payload combining scheme are transmitted after the number of messages received by the RSU exceeds a predefined threshold. CPMs in our work, on the other hand, are transmitted at a fixed rate and the impact of the generation interval is also investigated.

The potential of CP was demonstrated in [22]–[24] together with a message format of the CPM. After having released an informative Technical Report on CP including a dissemination concept and a complete message format [18], the ETSI is currently in the process of establishing the according normative Technical Specification. The Technical Report mentions CAM information aggregation as one use-case but no details are given on how to implement it. Neither an analysis of the practicality is provided, nor is it satisfactorily reflected in the proposed generation rules.

None of these works use a full ITS protocol stack and the impact of the ITS-G5 DCC regulations on the performance of relaying schemes in dense traffic conditions has not been studied before.

III. PROPOSED CPM-BASED RELAYING APPROACH

This paper proposes a relaying strategy in which RSUs located at intersection centres aggregate multiple CAMs received from surrounding vehicles in the intersection area in one single message. For this purpose, we propose to leverage the Collective Perception Service, the main goal of which is to share information about objects detected with on-board sensors like, e.g., radar or lidar [18]. Although the CP Service is defined for both vehicles as well as RSUs as transmitters, we propose to let only RSUs relay CAM information because they are strategically well positioned and usually have a much higher elevation. When also equipped with directional antennas, their resulting transmission capabilities are very advantageous when compared those of vehicles. Furthermore, it is not straightforward to decide which station should forward information which would either require significant coordination (and thus signalling) overhead when using vehicles or congest the channel heavily if the forwarding is done in an uncoordinated manner.

A. CAM Data Representation in CPMs

The Collective Perception Message can consist of a Management Container, a Station Data Container, a Sensor Information Container (SIC), a Perceived Object Container (POC) and a Free Space Addendum Container. The POC contains information about the respective objects perceived by the sender, including their dimensions and dynamic status. The structure of that container and the contained information is similar to the High Frequency Vehicle Container of the CAM (c.f. [6], Clause 7). Therefore, the POC should be filled with the information received from the objects themselves in those containers. The only exception is the reference position of the object provided as absolute latitude and longitude values in the CAM's Basic Container. They need to be transformed into x and y distances relative to the sending RSU's reference position because that is how the position of Perceived Objects is represented in the CPM.

The SIC contains information about the sensors of the sender and their capabilities. Perceived Objects can have references to that container in order to indicate how they were perceived. In the context of the CP use-case envisioned in this paper, the sensor type "itssaggregation" should be used. The SIC also includes the mandatory field Detection Area which can be expressed as different geometrical shapes. Its usage is not specified for the aggregation of CAMs. One option would be to set it to the reception range of the RSU which could be determined by the farthest object a CAM was received from. However, care should be taken as this metric is rather volatile as it depends on the sender's transmission power, the weather and many other factors. As a simpler and less misleading option, that field could be made optional in the CPM such that it can be omitted in case of uncertainty.

B. CPM Generation for CAM Information Aggregation

The generation of CPMs as standardised by the ETSI is closely related to the CAM generation rules. According to

ETSI, a CPM shall be generated whenever one of the known objects needs to be transmitted. The transmission rules of perceived objects in turn is closely related to the triggering conditions of the CAM and depends on their respective dynamic state. An object is, e.g., included in a CPM when it's position changed by more than $4\,\mathrm{m}$ with respect to the last time it was included. The same thresholds are used as for the Cooperative Awareness (CA) Service to decide when a vehicle needs to transmit a CAM [18], [25].

As a result, every object an RSU perceives (i.e. it received a CAM from), automatically needs to be included in the next CPM. Therefore, we propose RSU-CPMs containing only information from CAMs, to be generated using fixed intervals as this saves redundant checking and allows for a better control of the induced channel load. RSUs should store CAM information received from the surrounding vehicles until the fixed CPM generation interval elapses and broadcast the relevant information from all stored CAMs in one single CPM. After the CPM is transmitted, stored CAM information is discarded in order to ensure only recent information to be relayed. If an RSU receives multiple CAMs from the same vehicle within the generation interval of the CPM, information of older messages is replaced and only the latest information is stored and used. This provides the CPMs the additional benefit of deduplication and the information of each vehicle is included only once in a CPM, even though it might have been received multiple times during the aggregation period.

IV. Simulation

In order to evaluate the proposed relaying mechanism compared to either not relaying at all or directly relaying without aggregation, a simulation study was conducted using the V2X simulation framework Artery [26]. It comes with a complete open source implementation of the European ITS communication stack based on ITS-G5 which we complemented with an implementation of the CP Service. A 10x10 Manhattan grid scenario with 100 square buildings of $100\,\mathrm{m}$ side length, 121 intersections and two lanes of $3.5\,\mathrm{m}$ width and $3\,\mathrm{m}$ sidewalks per direction was used. One RSU was deployed above the centre of each intersection at $4\,\mathrm{m}$ height. In line with some studies discussed in Section II, we used one directional antenna per intersection arm for the RSUs. A total of 500 vehicles enter the scenario at the beginning of the simulation at random intersections. The simulation duration was $32\,\mathrm{s}$ but no data was recorded in the first $2\,\mathrm{s}$ (warm-up). The mobility model used for the traffic flow is the *Manhattan Mobility Model* with a maximum speed of $50\,\mathrm{km\,h^{-1}}$. GEMV2 [27] was chosen as the path loss model for its realism.

Since especially in the first years of V2X deployment, not all vehicles will be equipped and this influences the performance of the services as well as the induced channel load, all simulations were repeated with market penetration rates of $20\,\%$, $40\,\%$, $60\,\%$, $80\,\%$, $100\,\%$. Statistics were only recorded for equipped vehicles. In line with the CAM specification, vehicles broadcast CAMs with generation intervals between $100\,\mathrm{ms}$ and $1\,\mathrm{s}$ depending on their dynamics [6].

Depending on the relay mode, RSUs either relay each CAM immediately upon reception (Mode: Relay) or they transmit CPMs (Mode: CPM) aggregating the data of received CAMs as described in Section III. The CPMs are transmitted with fixed intervals varied between $100\,\mathrm{ms}$ and $1\,\mathrm{s}$. As explained in Section III, vehicles are not supposed to relay CAM information in CPMs. Hence, they do not transmit any CPMs at all. This allows for a more precise analysis of the impact of relaying itself without vehicle CPMs as "noise".

Earlier studies showed a substantial influence of the DCC on the CP service [24], [25]. DCC is controls the channel congestion using a traffic shaper called gatekeeper. It allows packets from upper layers to be forwarded to the MAC layer with a rate which depends on the current Channel Busy Ratio (CBR). Until a message is allowed to pass the gatekeeper, it is stored in a queue. If the queue is full and a new packet arrives, the first (i.e. the oldest) packet is dropped from that queue. This means that if services create more messages than can be accommodated in the channel at that moment, it is basically random which of them are actually transmitted in the end and which will not be transmitted at all. To investigate the influence of that mechanism on relaying, all simulations were performed with the reactive approach of DCC according to ETSI TS 102 687 in place [19]. The values from Table A.2 of that document were used as required by the Basic System Profile of the Car2Car Communication Consortium [28]. The remaining network parameters used for the vehicles and RSUs are summarised in Table I.

TABLE I
Network parameters

Parameter	Value	Parameter	Value
Transmission power	$23\,\mathrm{dB\,m}$	Vehicle antenna height	$1.5\,\mathrm{m}$
Data rate	$6\,\mathrm{Mbit\,s^{-1}}$	RSU antenna height	$4\,\mathrm{m}$
DCC Queue Length	2	RSU antenna beam width	$35°$
CAM DCC profile	DP2	RSU antenna min gain	$-50\,\mathrm{dB}$
CPM DCC profile	DP2	RSU antenna max gain	$10\,\mathrm{dB}$

A. Results

The motivation for the summary of objects in CPMs is to lower the amount of messages sent. This is important because every message is wrapped in Basic Transport Protocol, Geonetworking and IEEE 802.11 headers. Reducing the amount of messages thus reduces the amount of overhead which in turn should lead to a lower channel load.

Figure 1 shows the median CBRs resulting from the different relaying strategies which were recorded by all vehicles every $100\,\mathrm{ms}$. The CBRs in general are notably low, even with high market penetration rates. This results from the design of the Manhattan Grid scenario with solid buildings at every intersection corner, blocking a large proportion of RF emissions. The lowest line in the plot represents the baseline where vehicles and RSUs sent CAMs but no messages were relayed. As expected, both relaying modes add additional load to the channel. The CBR in the CPM mode is much higher and grows faster with increasing market penetration than the

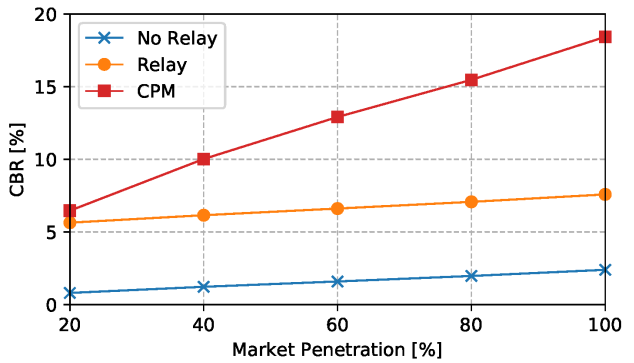

Fig. 1. Channel Busy Ratio for different market penetration rates at a CPM generation interval of 100 ms

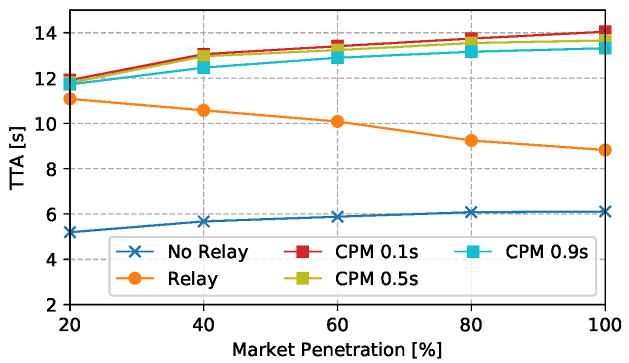

Fig. 2. Median Time To Arrival when vehicles become aware of each other

TABLE II
AVERAGE ATTEMPTED RELAYING FREQUENCY OF RSUS AND ACCORDING DROP RATES

Market Penetration [%]	20	40	60	80	100
Relaying Frequency [Hz]	40.6	90.8	134.9	180.1	226.3
Discarded Messages [%]	56.3	79.9	86.4	89.8	91.9

direct relaying mode. This results from DCC intervention as becomes evident in Table II, which shows the attempted average message relaying frequency per RSU for different market penetration rates in the Relay mode and the resulting ratio of messages discarded by the DCC gatekeeper.

At the present CBR of below 30 %, DCC's transmission limit is 20 Hz. Since the RSUs are trying to relay messages at much higher rates, more than 50 % of all relayed CAMs are dropped at the gatekeeper even at only 20 % market penetration. Since the CAMs in our simulations are small, as they include neither a path history, nor security envelopes, and only a maximum of 20 is relayed per second, the resulting CBR in Figure 1 is rather small. The increase in CBR at higher penetration rates is only caused by an increase of the total number of vehicles transmitting CAMs and not by an increase of relayed messages resulting in the relaying line having the same slope as the baseline.

This is different in case of the CPM relay mode as the CPMs are transmitted with a fixed rate in this paper and that generation frequency can be chosen to be between 1 Hz and 10 Hz according to TR 103 562 [18]. This is well below the maximum rate allowed by DCC resulting in the CPM not being affected by DCC (i.e. no CPMs are dropped at all).

The higher CBR in the CPM relay mode is a result of the CPMs being much larger than the single CAMs as they contain the information of multiple CAMs. However, since the CBR in general is rather low, a higher CBR in this case is actually good as there is much information to transmit and a higher CBR here simply means that the channel is *utilised* better.

Figure 2 proves this better channel utilisation to directly translate to better application performance. It shows the median TTA of the vehicles, defined as the available reaction time of the vehicles approaching the same intersection from the moment they perceive each other for the first time until they arrive to the intersection centre if they keep driving with constant speeds. Perception possibilities are the own radar sensor, receiving a CAM from the vehicle itself or relayed by an RSU directly or in the aggregated form of a CPM. The bottom line shows the general trend to be increasing with increasing market penetration rate because receivers are aware of others by receiving a CAM before they perceive them with their radar sensor. Non-equipped vehicles however can only be perceived via radar and thus have small TTAs. As TTAs were only recorded by equipped vehicles and DCC drops an increasing proportion of directly relayed messages with increasing market penetration rates, the TTAs achieved are decreasing. Nevertheless, direct relaying improves the TTA over not relaying at all across all penetration rates.

A considerably larger improvement, especially at higher penetration rates, can be achieved by aggregating to be relayed CAMs in CPMs like proposed in Section III as Figure 2 proves. The TTAs are more than twice as high for all penetration rates when compared to not relaying. Figure 2 also shows the influence of different generation intervals. To improve readability of the figure, only 100 ms, 500 ms and 900 ms are shown. While shorter generation intervals do lead to higher TTAs, the influence of the generation intervals is relatively small when compared to the overall improvement. E.g., with 100% market penetration, using an interval of 0.9 s instead of 0.1 s results in a 0.8 s decrease in the TTAs as expected, which is small compared to the overall increase from 6 s to 14 s.

This is not true for the channel load as becomes evident from Figure 3. It shows the CBRs resulting from different generation intervals. Their influence is higher with higher market penetration as more messages are sent and relayed. At 100 %, the CBR resulting from 100 ms is more than three times higher when compared to 1000 ms generation interval. Since the CBR can be greatly reduced with longer generation intervals while the resulting TTAs are only slightly affected, too short generation intervals should be avoided if possible. The specific value should be adapted to the current CBR

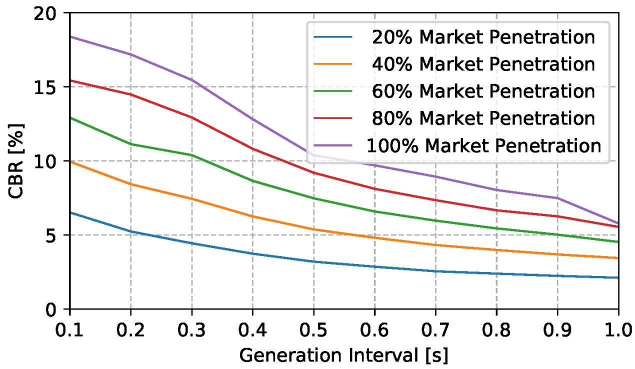

Fig. 3. Channel Busy Ratio depending on CPM Generation Interval for different market penetration rates

in order to best utilize the channel without overloading it. However, this requires the CP Service to have some indication about the channel load situation. The ETSI currently works on that in the yet unpublished TS 103 141.

V. Conclusion

In this paper we proposed to leverage the CP Service to enable aggregated message relaying by RSUs at intersections and gave detailed instructions how this can be done. We conducted the first simulation study in the domain of CAM relaying using a realistic network stack and confirmed the infeasibility of direct relaying. Contrary to what other studies indicated, the problem is actually not a resulting channel congestion but a high number of discarded messages because DCC prevents high channel loads. Our suggested CPM relaying approach on the other hand was found to provide large improvements in terms of TTA while at the same time adding only a small amounts of channel load if the generation interval is chosen wisely. In future work, it is planned to use more realistic scenarios and to further analyse the trade-off between the CPM generation interval and the channel load in specific situations.

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