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Congestion Aware Objects Filtering for Collective Perception

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Abstract: This paper addresses collective perception for connected and automated driving. It proposes the adaptation of filtering rules based on the currently available channel resources, referred to as Enhanced DCC-Aware Filtering (EDAF).

Keywords: V2X, Decentralized Congestion Control, Collective Perception.

1 Introduction

Collective Perception (CP) is a communication service that enables vehicles and roadside stations to exchange messages containing sensor data to enhance the perception range of the local sensors. It is currently standardized by the European Telecommunication Standardization Institute (ETSI) [ETS19] and is the basis for future applications such as cooperative traffic safety and vehicle automation. Collective Perception Messages (CPMs) contain locally pre-processed objects and are transmitted at a rate between 1 to 10 CPMs per second. With many objects detected and vehicles within communication range, the CP Service (CPS) can create a considerable load on the wireless channel. To avoid the CPS overloading a channel, rules needed to be defined that limit the inclusion of detected objects in a CPM. Currently, two main approaches for filtering the objects are considered by ETSI [ETS19]: utilizing the local perception of the vehicles and based on information received from other vehicles. The former rules only rely on the local sensor and filter objects depending on their dynamics, i.e., the faster an object moves or changes the direction, the more often a vehicle will send an update about it. The latter approach filters an object when the information about the same object is already received by other vehicles or roadside stations. While previous work has shown that the filtering rules are efficient in reducing the generated channel load, these rules are currently applied independently of the instantaneously available channel resources. This results in underutilization of the wireless channel and reduced perception quality in situations such as low vehicle density. In this paper, we propose the adaptation of the filtering rules based on the currently available channel resources.

2 Solution

To understand our approach, the considered CPS implementation needs to be explained. Figure 1a shows our reference implementation using the ITS-G5 protocol stack. We emphasize that this implementation is not standardized but follows, for most of its components, the current approach developed by ETSI in [ETS19]. At startup and during execution, the CPS checks every `T_check` if it is required to generate a message. A normally assumed value for `T_check` is 100 ms. The first step to decide if a CPM needs to be generated depends on three parameters: $T\_GenCpmMin = 100 ms$, $T\_GenCpmMax = 1 s$, and $Toff$. As currently defined in the

CPS standard, a CPM should be generated within the interval $[T\_GenCpmMin, T\_GenCpmMax]$ since the last generated one. These are fixed and soon standardized values. The last parameter $Toff$ comes from the Decentralized Congestion Control (DCC) mechanism. The DCC mechanism has a purpose to control and fairly share the channel resources among the vehicles. DCC operates on all layers of the ITS-G5 protocol stack but more especially on the Access layer and soon the Facility layer. The parameter $Toff$ corresponds to the time that a vehicle needs to wait between the transmission of two consecutive messages. If more messages are generated than DCC allows, messages are queued or even dropped at the access layer. In our implementation, the CPS decides to trigger the generation of a CPM if the last time a CPM has been generated is higher than $T\_GenCpmMin$ and $Toff$ or higher than $T\_GenCpmMax$. The second step of CPM generation consists of filtering the detected object to determine the objects to transmit. As explained in Section 1, this filtering is based on the dynamics of the perceived objects. After selecting the objects, if the CPM contains at least one object to transmit or the last time a CPM has been generated is higher than $T\_GenCpmMax$, it is passed to the lower layers for transmission.

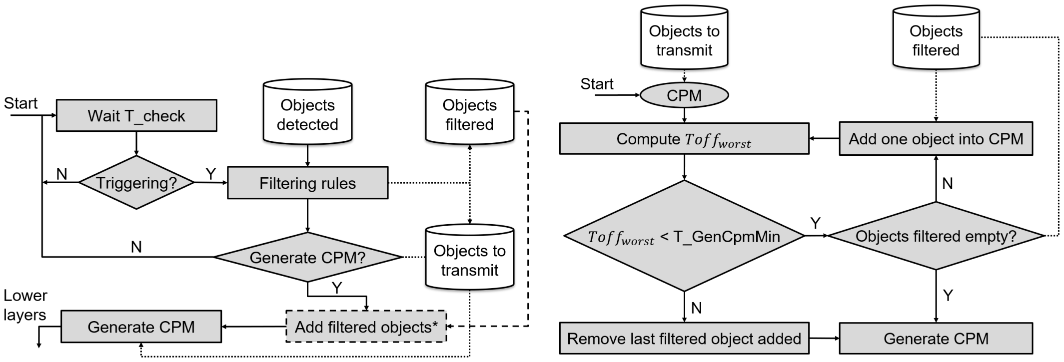
In this paper, we propose to extend the CPM generation process with a new step referenced as "Add filtered objects*" in Figure 1a. This step occurs before sending the CPM to the lower layers and applies our solution, called Enhanced DCC-Aware Filtering (EDAF), to address the problem defined in Section 1. The general principle of the EDAF rules is the following: if a CPM is to be generated and the addition of an object from the set of filtered objects does not impact the Next Generation Opportunity (NGO) of CPM, the object will be included into the CPM. Before entering into the details of the EDAF rules, we need to define NGO and $Toff_{worst}$. The NGO corresponds to the next time that the CPS will have the opportunity to generate a new CPM. The NGO depends mostly on `T_check` and $Toff$. For example, if $Toff = 125$ ms, due to `T_check` = 100 ms, the NGO will be equal to 200 ms. Indeed, at the first check, only 100 ms of the $Toff$ has elapsed and the CPS needs to still wait 25 ms to generate a CPM. Therefore, the CPS waits another `T_check`=100ms which results in a waiting time of 200 ms.

DCC influences the generation of CPMs through $Toff$. This parameter is computed based on the size of the last message accepted by DCC for transmission and the current available channel resource, so-called duty-cycle, as defined in [ETS18]. Because the duty-cycle is updated every 200 ms by DCC, $Toff$ needs to be updated at the same time to match the new available resource. The parameter $Toff_{worst}$ is the anticipated value of $Toff$ for a CPM when considering that the duty-cycle will always be decreased by the maximum authorized value as defined in [ETS18]. This asserts that the resulting $Toff$ will always be lower or equal than the $Toff_{worst}$ for a CPM.

Because $Toff$ depends on the size of the message, it depends directly on the number of objects included in a CPM. The EDAF rules exploit this principle to control the NGO based on the objects included. Figure 1b shows the the process of the EDAF rules: at first, $Toff_{worst}$ is computed for the CPM containing only the objects selected for transmission, i.e., that have not been filtered. Than if $Toff_{worst}$ is lower than $T\_GenCpmMin$, i.e., 100 ms, a filtered object is added to the CPM. This process is than repeated until either there is no more filtered objects to add or $Toff_{worst}$ becomes higher than 100 ms.

The advantage of the EDAF rules is that they adapt to the channel resources allocated for the CPS. If there are only few vehicles using the channel, the CPS sends most of times all the perceived objects, wheras the CPS acts as the default process when the channel is congested.

In a previous paper [DRFV20], we defined the DCC-Aware Filtering (DAF) rules. The im-



(a) CPM generation process

(b) EDAF rules

Figure 1: CP Service implementation and EDAF rules for the filtering of objects

provements brought by the EDAF rules are the following: simplicity, no CPS implementation dependency, limitation of the inclusion of the filtered objects. The main difference between the DAF and EDAF rules is that the EDAF rules only operate when $Toff_{worst}$ is below $T\_GenCpmMin$, which is not the case for the DAF rules. This makes the EDAF rules independent of the CPS implementation as the CPS needs to wait, independently of the implementation, at least $T\_GenCpmMin$. Furthemore, the EDAF rules limit further the inclusion of filtered objects when the channel starts to be congested and the required number of operations is reduced.

3 Performance Evaluation

To evaluate the EDAF rules, we used the large scale simulation scenario InTas[1] at 7 am of the city of Ingolstadt/Germany. The urban scenario contains around 2,500 vehicles. For our simulations, we varied the Percentage of Vehicle Equipped (PVE). A vehicle considered as equipped has two radars mounted with 60 and 174 m range, 90° and 20° field of view, respectively, and is exchanging CPMs with other vehicles within the communication range. We compare the default rules and EDAF ones with the following metrics: Channel Busy Ratio (CBR) that represents the channel load ("1" means the channel is fully congested and "0" means that it is not used), the CPM size and CPM rate, the Number of Objects Detected (NOD) from received CPMs, and the Time Between Update (TBU) for each of these objects detected.

With the equipped sensors, vehicles perceived in average 4.5 objects. As shown in Table 1, the obtained CBRs for the EDAF rules are slightly lower than if using only the default rules. In general, the higher the PVE, the larger the CBR gets, independent of the filtering rule. The maximum CBR can be observed at PVE = 100,% with CBR = 0.59.

Regarding the CPM related metrics, the results show that the EDAF rules provide the same average size until PVE = 100 % where the the CPM size decreases by around 28 %. As the CBR increases, $Toff$ for the messages increases, resulting in less filtered objects added in the CPMs in average. The default rules have a quite lower CPM size (up to twice smaller) in average than the EDAF. It is expected as these rules do not allow any inclusion of filtered objects. For the

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[1] https://github.com/silaslobo/InTAS

Table 1: Results for the different metrics collected

	Default				**EDAF**			
PVE [%]	**20**	**50**	**70**	**100**	**20**	**50**	**70**	**100**
CBR	0.12	0.35	0.47	0.59	0.12	0.34	0.46	0.55
CPM size [B]	81.9	82.0	82.5	101	157	158	157	123
CPM rate [CPM/s]	6.16	6.20	6.09	4.78	3.85	3.94	4.17	3.96
NOD [Object]	208	237	215	177	228	274	248	192
TBU [s]	0.21	0.15	0.13	0.11	0.15	0.12	0.10	0.10

CPM rate, the default filtering rules result in average around 6 CPM/s while the the EDAF rules around 4 CPM/s. The explanation of these results come from the consideration that a CPM is not generated if it does not contain any objects, i.e., if no objects were at first selected in the “Object to Transmit”. The EDAF rules generate CPMs with more objects and therefore is more likely to have to transmit CPMs less often. The CPM rate of the default rules at PVE = 100 % decrease and it is due to DCC starting to restrict the generation of CPMs, i.e., $Toff > 100ms$.

The NOD for both rules increases up to PVE = 50 %, and then decreases for higher PVE values. These results can be explained by the communication interference between the vehicles. Still, in average, the EDAF rules result in around 10 % of additionally detected objects. For the TBU, the EDAF obtains up to 25 % smaller TBU compared to the ETSI rules. The higher the PVE, the smaller the TBU. This is expected as the number of vehicles sharing their surroundings increases.

In this paper, we showed that the EDAF rules perform better than the default ones. By reducing the CPM rate and creating larger CPMs, the EDAF rules resulted in slightly higher number of object detected and significant reduced time between update than with the default ones. These improvements do not come with significant additional costs in terms of channel resources. However, with the EDAF rules it is expected that with a growing number of detected objects, the usage of the channel resources will be higher.

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