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On the benefits of increased vehicles perception to cooperative communications: a performance evaluation study

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Abstract—Intelligent Transportation Systems (ITS) are expected to play a vital role in increasing road safety and road efficiency in the near future. The primary feature of ITS applications is to provide road safety, which is based on IEEE-802.11p technology, by transmitting safety messages to the vehicles in the surrounding. The channel congestion is a significant challenge for the IEEE802.11p, ITS is operating on. Congestion increases the data loss and degrades the ITS performance resulting from compromising passengers safety. In this paper, we analyze the benefits of exploiting vehicle's embedded sensors to enhance car perception and hence improve the efficiency of cooperative communications. To this purpose, we implemented the collaborative environment perception approach for vehicular safety applications proposed by [1] and analyze its performance and behavior in congested urban traffic. In this proposal, so-called ECAM (Extended Cooperative Awareness Message), vehicles use a different type of sensors (cameras, radars, lidars etc.) to collect the status information of the surrounding vehicles in their detection range and share this information through a collaborative beaconing scheme to reduce congestion on the communication channel. This scheme implements a dual step mechanism to function. The first phase implements the collaborative perception mechanism by adding the locally collected information in the safety message and sharing this up to date data to intensify the awareness among the vehicles in its communication surrounding. In the second phase, the recipient vehicles verify the accuracy of the information received from the collective perception enabled vehicles by leveraging the position by adding an error threshold. Performance evaluation conducted through extensive simulations shows the benefits of exploiting increased perception to enhance awareness among cars while reducing the contention on the wireless interface.

1. Introduction

In the recent couple of years, the research in the field of VANETs has been converted into Cooperative ITS systems. In the C-ITS the vehicles communicate with each other and share the information for road safety and road efficiency utilizing the IEEE-802.11p [2] technology (ETSI ITS-G5

[3] is the European version of IEEE-802.11p). C-ITS is being implemented rapidly in Europe and the rest of the world. The members of the Car-to-Car Communications Consortium have mutual allegiance to start deploying C-ITS equipment on their vehicles by the end of 2015 [8].

Cooperative Awareness Message (CAM) [21] concept relies on the periodic broadcasting of single-hop messages, known as beacons. Each vehicle disseminates the information about its position, speed, heading, and other mobility information in their surrounding through these periodic beacons. The more frequent the periodic messages, the more accurate the information, but also increases the congestion on the communication channel, especially in the urban environment, resulting in data loss. So compromises the quality of service (QoS) of the vehicular safety applications. Researchers have proposed several solutions to resolve this critical issue [4] [5] [22]. However, all these solutions have limitations with respect to the environment, network density, and equipment resources.

The primary objective of this paper is to study the benefits of exploiting vehicle's embedded sensors to increase its perception and use this feature to enhance the cooperative awareness and decrease the contention on the wireless interface by reducing beacon transmissions. To this purpose, we will expand the work proposed in [1] and study its performance in the congested traffic of the urban environment. The proposed scheme, so-called ECAM (Extended Cooperative Awareness Message), utilizes the Collective perception concept [6] [7] to decrease the frequency of beacons. We thus assume that thanks to the recent technology developments, the vehicles are equipped with multiple types of sensor devices like radars, front view cameras, lidars, etc. These sensors are used by the vehicle to have a comprehensive view of their surrounding. Precisely, thanks to these embedded sensors, vehicles have an updated position of surrounding cars. This increased perception is then shared with the other vehicles that are reachable within the communication range using beacon messages that contain in addition to the vehicle location, additional information on surrounding car positions. This enhanced cooperative awareness is then exploited to minimize the transmission of beacons in the network. Basically, a vehicle that recognizes its position in a beacon

message sent by a surrounding vehicle is exempted from transmitting its position at that period.

This paper analyzes the performances of using increased vehicle perception to cooperative awareness and communications. The assessment relies on simulations that we conducted under SUMO and NS3 tools. The ECAM performances are compared to the classical CAM scheme of IEEE-802.11p standard.

The rest of the paper is organized as follows: Section II goes through the literature of the C-ITS and discusses the different approaches proposed to cope with the channel congestion in a vehicular environment. In section III, we detail the ECAM scheme. The assessment methodology and obtained results are discussed in section IV. Finally, section V summarizes the paper contributions.

2. Related Work

The beaconing is the key aspect of the Cooperative ITS for road safety and road efficiency. The more periodic beacons, the more accurate information. However, due to the limited channel resources, it can lead to channel congestion and resulting in the data collision. There have been several solutions proposed to tackle the channel congestion and can be classified in the following categories based on the mechanism used.

Authors of [4] proposed an autonomous driving framework where Vehicles share any incident through the base station with a small and large scale. This happens across a large geographical area enhances network efficiency. The authors in [5] proposed an algorithm to reduce the congestion at an optimum level through data rate control. The algorithm maintains a certain channel load threshold based on data rate by shifting different data rate levels. At a specific time, the CBR of the network determines the data rate transition from a certain level to the other. If the CBR is higher than the mean threshold, the algorithm increases the data rate at the next higher level and maintains the same level if the CBR is lower than the mean threshold and higher than the specific lower threshold. The data rate level decreases down a step whenever the CBR is lower than the minimum threshold.

In [9], the authors have implemented a dynamic packet reception model and an adaptive transmission power control mechanism to reduce the congestion control and increase the packet reception rate by using the Model Predictive Control (MPC) approach [10]. In this work, first, they have proposed a dynamic packet reception model and then estimated the vehicle density through velocity and vehicle flow rate [11]. Based on these two factors, then they have designed an algorithm for adaptive power control. The authors showed through simulations that this mechanism had improved the congestion in a vehicular network. The [13] proposes a Distributed fair power adjustment scheme to avoid the congestion on the control channel. This scheme uses a dynamic control strategy by using the node density to adjust the transmission power of beacons for the safety applications. In this scheme, the transmission power squeezes down to

limit the number of nodes in the network, resulting in a decreasing congestion on the channel.

In the same way, [14] introduces a two-level transmission power scheme, named bi-beacon scheme to reduce the collision. This Transmission Power Control scheme applies two different transmission ranges decided by the vehicle's speed for disseminating the beacons. In this scheme, the vehicles transmit long-range and short-range beacons alternately with an equal generation rate. Moreover, in the dense vehicle environment, the authors used a contention window control scheme to minimize the collision. In [15], a protocol selects minimum transmission power to transmit the CAM for keeping the vehicles connected within a safety zone called Cooperative Safety Zone. In this method, the distance between the source vehicle and its nearest neighbors, called critical nodes, select the transmission power. Finally, Cooperative piggybacking has been used to extend the awareness beyond the safety zone in the network.

In the other work [12], the authors tried to reduce the congestion through transmission rate control. This scheme uses the channel busy time as a counting metric for estimating traffic density, and the number of vehicle nodes in the vicinity. Also, the transmission rate is adjusted to a predefined threshold, or the estimated traffic density in the network and adjusts the transmission rate accordingly. In this paper [18], introduced a two-fold structure to improve the performance of MAC layer in VANETs by controlling the CAM message rate. In the first phase, a vehicle-ID based analytical model is proposed and second designed a fuzzy-based congestion control system for vehicular networks. In this fuzzy-assisted mechanism, vehicles select a random back-off number from the contention window (CW). It then combines its vehicle-ID with the selected back-off number forming a unique back-off number. This prevents the probability of CAM collision if the same back-off number is chosen by any other vehicle in the network. This paper also proposed a method to prevent the Consecutive Freeze Process (CFP). It means it does not allow vehicles to select zero as its back-off timer. In this case, it returns the vehicle in DIFS state to select another number. In the second phase, the proposed fuzzy-assisted congestion control system takes vehicle-ID, and collision probability (derived from the analytical model) as input, and the output of this fuzzy-ccs is considered as CAM broadcast rate.

[16] proposes a method Random Transmit Power Control (RTPC) to control the channel load through transmission power and data rate. This method uses the awareness as function to adopt feasible transmission power, this can reduce the channel load and then the authors proposed to combine the RTPC with the data rate to benefit from the channel resources and increase the data rate to improve the quality of awareness.

The authors of [17] proposed a multi-state active transmit data rate control mechanism based on DCC. In this mechanism, channel load is calculated in terms of CBR, and the multi-state active DCC protocol adopts data rate according to the currently available channel load. The simulation results show that this multi-state data rate control

mechanism's performance is better than any transmit power control mechanism. This mechanism can be useful in non-safety applications where the network's performance mainly depends on the data rate.

All the works mentioned above based on varying the data rate, transmission power, or contention window size to improve the quality of service of the CAM, and eventually compromise the transmission range and fairness. However, a suited mechanism needs to increase the quality of service without affecting the transmission range, data rate, or contention window. We believe that a cooperative approach that uses vehicles' embedded sensors does not degrade these parameters while increasing the communication range and awareness of the vehicles while reducing the channel load.

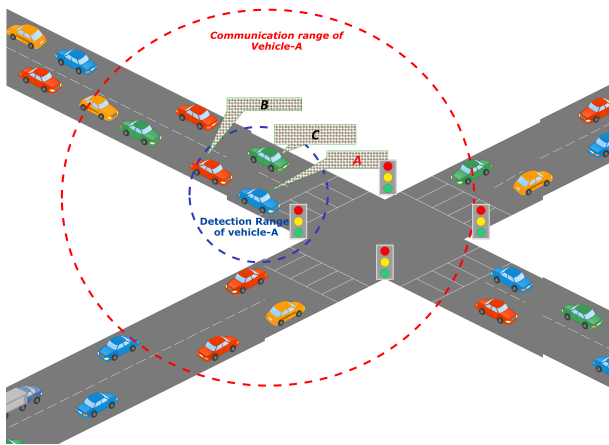


Figure 1. ECAM working mechanism

3. ECAM mechanism

ECAM (Extended CAM) [1] enhances the classical CAM scheme and provides a collective perception approach by sharing the information collected from embedded sensors among connected vehicles. The objective is to take advantage of some safety features using sensors integrated to recent vehicles, such as acoustic sensors, cameras, radars, lidars, etc. to allow a more precise vision of the environment. Basically, thanks to the data provided by these sensors, a vehicle can send very precise information on the position and speed of other vehicles in its vicinity. We will demonstrate in this paper how this approach can result in a reduction of congestion and contention on the access channel while extending the awareness in the participating vehicles beyond their Field of View (FoV).

As illustrated in Figure.1, collective perceptions vehicles are characterized by two ranges: a detection range and a communication range. The on-board sensors allow each vehicle to detect, with a given accuracy, all vehicles within its detection range. This detection range strongly depends on the technology used by the on-board sensors. On the other hand, the communication range gives the set of vehicles that can receive ECAM messages generated by the vehicle. This

communication range depends on several factors, such as density, speed, and the amount of traffic generated by each vehicle.

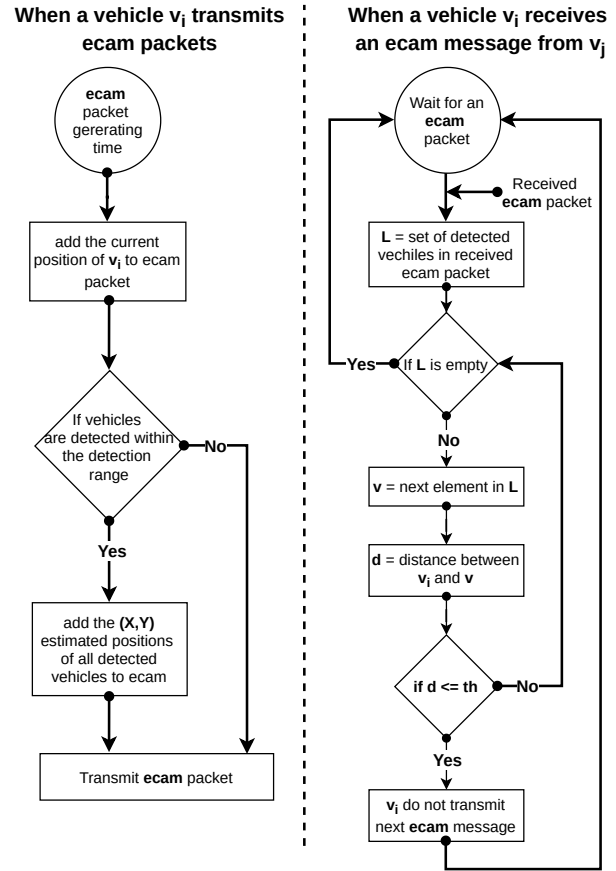


Figure 2. ECAM flowchart

ECAM scheme implements two folded mechanisms to achieve its goal. Figure-2 briefly illustrates the working mechanisms of ECAM. First, when a vehicle (ex. vehicle A) generates an ECAM message, it collects information (position) about vehicles (vehicles B and C in the figure) that are within its detection range and add this information in its ECAM along with its own. If no vehicle is detected, then the latter generates an ECAM message containing only its own state information. This message is similar to a classical CAM message.

Secondly, when a vehicle (ex. C) receives an ECAM packet (for example, from A), it starts by extracting the list of vehicles included in that packet. Each vehicle is identified by its position. If this list is empty, then C updates its FoV by adding only the vehicle A as a neighbor vehicle. Otherwise, it compares the distance between its position and the position of each of the vehicles in the received list. If one of the computed distances is less than a given threshold then it assumes that this entry corresponds to its own position. In this case, C starts by updating its FoV by adding all announced vehicles, in addition to vehicle A, as neighbor vehicles. Also, it decides to cancel the transmission of its

upcoming ECAM message. Indeed, vehicle C considers that it is no longer necessary to transmit its information (position) since another vehicle, A, has announced its (C) position in the most recent ECAM message.

In this way, ECAM reduces the transmission of beacons at a considerable rate without effecting the awareness in the network, which reduces the channel load leveraging the more vehicles to participate with improved quality of service.

4. Performance Evaluation

4.1. Methodology

To show the benefits of the collaborative environment perception approach implemented in ECAM we conducted extensive assessment studies based on Urban Mobility (SUMO) [19] version-1.6.0 and Network Simulator-3 (NS-3) [20] version-3.30.1 simulation tools. We designed a Manhattan mobility model of $1000 m^2$ area using SUMO and generated vehicle traffic with 50, 100, 200, 300, 400, and 500 vehicles that are simultaneously present in the topology. Initial positions were generated randomly, following a uniform distribution. We checked that the density of vehicles is constant throughout the simulation time for each scenario. The average speed of the vehicles is 15 m/s, legal maximum speed in the urban environment. We used the SUMO built-in facility to convert the mobility traces compatible to NS-3 format.

Simulation parameter	Value
Simulation Time	100 s
Simulation Area	$1000 m^2$
Mobility Model	Manhattan Mobility Model
Vehicle Average Speed	50 km/h
Number of Runs (per scenario)	20
Packet Size	200 bytes
Perceived Node data size	20 bytes per node
Data rate	6 Mbps
Bandwidth	10 MHz
Transmission power	7.5 dbm
Beacon Interval	100 ms
Sensor's detection range	50 m

TABLE 1. SIMULATION PARAMETERS

NS-3 was used to create network infrastructure among the vehicles. We have used the IEEE-802.11p OFDM physical model with a 6Mbps data rate and Friis propagation loss model. CAM messages were generated accordingly to the standard interval of $100ms$. Detection range of Vehicles embedded sensors was set to 50 meters. The total simulation time for each scenario was fixed to 100 seconds. All the scenarios were run 20 times. We ran all these simulations in parallel on a cluster of servers, but it tooks several days to complete and it generated a massive amount of data. Important simulation parameters are given in table-1. Finally, in a seek for presentation simplicity, we use (E)CAM annotation in the remaining sections to denote CAM and ECAM schemes indifferently.

4.2. Results Analysis

To analyze the effectiveness of ECAM in improving the cooperative perception of vehicles, we introduce the *Awareness level* metric. The latter is defined to assess the accuracy of the vehicle's knowledge, gained from (E)CAM dissemination messages. It reflects these communication schemes' capacity to provide an accurate perception of the surrounding cars. To this purpose, the awareness accuracy obtained through (E)CAM schemes is computed for an optimal awareness reference model. The latter is generated using SUMO traces, which allow us to determine at each time period and for each vehicle, the set of neighbor vehicles located within a given radius, which we choose to set to 120 meters. This set, denoted $S_t^*(v)$, defines for each vehicle v and at a give time-period t the *optimal awareness set* of surrounding vehicles. The instantaneous (E)CAM *awareness level*, denoted $A_t(v)$ is computed at each time-period t and for each vehicle v as follows:

$$A_t(v) = 1 - \frac{\|\hat{S}_t(v)\|}{\|S_t^*(v)\|} \quad (1)$$

where $\hat{S}_t(v)$ is the set of surrounding vehicles obtained through (E)CAM beacon messages, and $\|S\|$ denotes the dimension operator of the set S . The mean *awareness level* is then obtained by averaging over time the related instantaneous values of all vehicles involved in a simulation scenario set and over the 20 simulation runs.

Figure 3 represents the mean *awareness level* obtained for different vehicles densities. The density is dependent on the number of vehicles that are simultaneously present in the topology during the simulation. As shown in the figure, we varied this number from 50 to 500 vehicles. Error bars represent Awareness standard deviation.

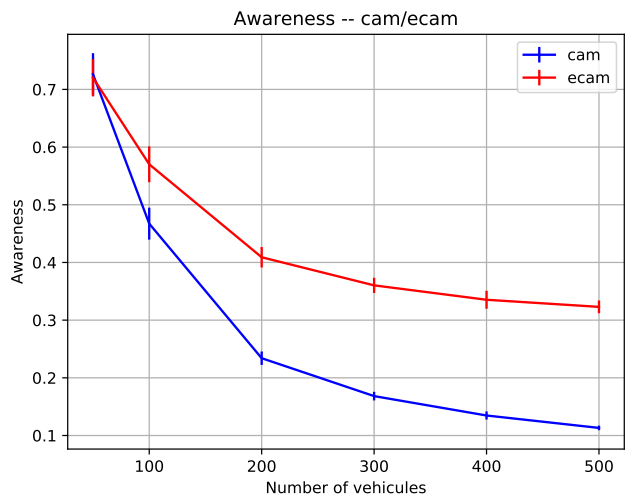


Figure 3. Awareness level

Figure 3 shows that ECAM outperforms CAM, confirming thus, the benefits of using increased perception enable

by embedded sensors to improve the awareness of vehicles on their surrounding environment. One can also notice in this figure that for a lower number of nodes, the awareness level is quite high. For 50 vehicles, the awareness level is above 0.7 for both CAM and ECAM schemes. Actually, under this setting, the vehicles are sparse, and the density is thus low. This is confirmed in figure 4, which shows the average degree as a function of the number of vehicles in the simulated topology. The theoretical curve gives the mean size of the *optimal awareness set*. According to figure 4, one can see that for 50 vehicles scenario, the average number of surrounding vehicles within a radius of 120 meters is below 3, which is quite low. The other two plots in figure 4, refer to the mean number of surrounding vehicles perceived by each vehicle thanks to CAM and ECAM schemes. For 50 cars, the perceived (E)CAM degree is around 2.

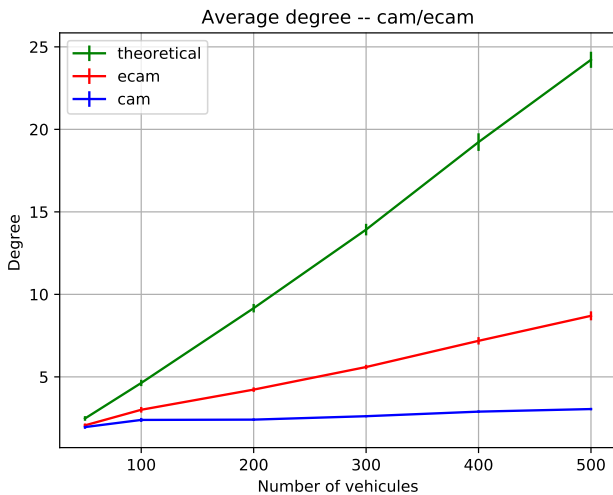


Figure 4. Average Degree of Nodes

While the discrepancy between ECAM and CAM grows when the number of vehicles increases, the awareness level drops, reaching for 500 vehicles 0.11 and 0.32 for CAM and ECAM, respectively. This decline is corroborated in figure 4, which shows that the difference between the theoretical degree and those obtained through (E)CAM is exacerbated when the topology is denser. Yet, the degree measured thanks to ECAM is at least three times better than CAM one.

To investigate (E)CAM awareness level reduction reasons, we plot in figures 5 and 6 the number of transmitted and received (E)CAM beacons, respectively. These curves were generated after counting the total number of transmitted/received messages during a simulation and then averaged over the 20 runs.

Given that CAM messages are broadcasted by each vehicle every 100ms the total number of transmitted CAM beacons increases linearly following the number of simulated vehicles, as shown in figure 5. The significant number of transmitted CAM beacons for a large number of vehicles

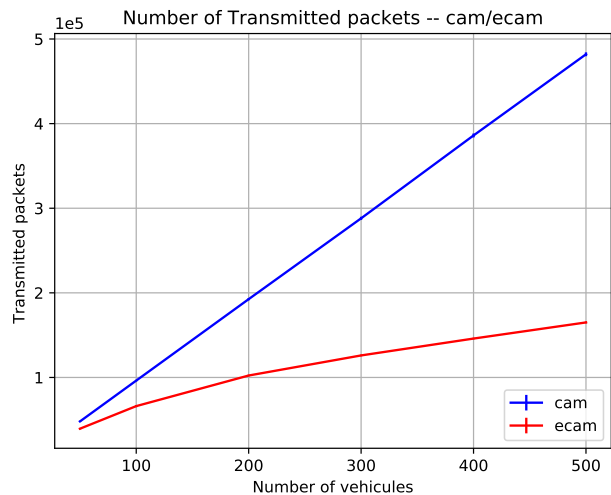


Figure 5. Total Number of Transmitted (E)CAM beacons

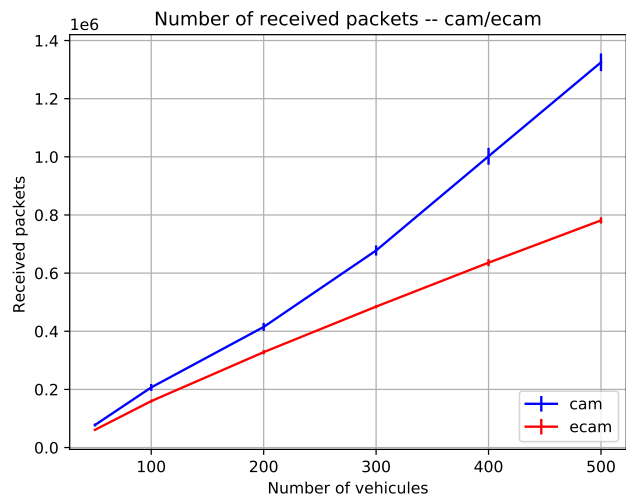


Figure 6. Total Number of received (E)CAM beacons

(e.g., 500) simultaneously present in the topology generates congestion at the radio interface. This is confirmed in figure 6, which shows that the number of CAM received messages is not proportional to the theoretical degree multiplied by the number of transmitted beacons. We can also notice that the number of received ECAM messages is lower than CAM ones. This is due to the substantial reduction of ECAM transmitted beacons, compared to CAM, as shown in figure 6. This saving is obtained thanks to ECAM strategy, which exploits embedded sensors to improve vehicle perception and avoid disseminating redundant awareness information. This saving also contributes to reducing the contention on the wireless channel and helps in maintaining better communication quality, compared to CAM.

Because of its broadcast nature and the difficulty of char-

acterizing the optimal receiving nodes formally, it is hard to define a beacon loss metric. To characterize the communication quality, we introduce the *communication range*. This metric is defined for each received message as the distance separating the receiver from the beacon's transmitter. Figure 7 represents maximum, and average communication ranges obtained for (e)CAM. The maximum communication range is the highest distance measured in a simulation run. In each of the 20 runs, a maximum range of 120 meters was measured for (E)CAM, which led us to choose this value in the radius defining the optimal awareness set.

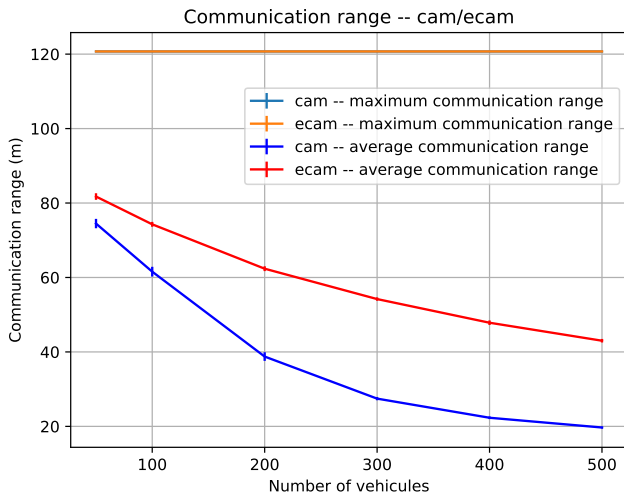


Figure 7. Communication range

More interestingly, figure 7 shows that the average communication range of ECAM outperforms CAM ones. While this metric barely attains 20 meters for CAM with 500 vehicles, it is doubled with ECAM, reaching 41 meters. Hence, reducing the channel load with ECAM helps in reducing congestion for dense typologies. It also benefits to increase the communication ranges between vehicles and hence to improve the awareness level obtained with ECAM, compared to CAM. Doubling the average communication range among surrounding vehicles offers a more significant reaction time in case of accident risk and hence enforces safety.

5. Conclusion

In this paper, we analyzed the utilization and benefits of the vehicle's embedded sensors to enhance car perception and improve cooperative communication efficiency. To this purpose, we implemented the Collaborative Environment Perception Approach for vehicular safety applications proposed by [1] and analyze its performance and behavior in congested urban traffic. In this ECAM (Extended Cooperative Awareness Message) mechanism, vehicles share information of their neighboring vehicles through a collaborative beaconing scheme to reduce congestion on the

communication channel collected by their various type of sensors. This scheme implements a dual step mechanism to function. First, they add the locally collected information in the safety message and sharing this up to date data to intensify the awareness among the vehicles in its communication area using the collaborative perception mechanism. On the receiving end, the recipient vehicles verify the accuracy of the information received from the collective perception enabled vehicles while considering a specific amount of error threshold in the position. Our simulation results clearly show that vehicle embedded sensors greatly benefit in collaborative communication in terms of vehicle awareness. It increases their field of view (FoV) while decreasing the channel load, resulting in improving the quality of service (QoS) compare to the standard CAM.

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