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[2] Christian Doppler Laboratory for Wireless Technologies for Sustainable Mobility, Technische Universität Wien, Vienna, Austria

# Effects of co-located transmissions in the performance of DCC IEEE802.11p MAC and Self-Organizing TDMA for VANETs

Arrate Alonso[1,2] and Christoph F. Mecklenbräuker[1,2]
Gusshausstrasse 25 - 29 / 389
1040 Wien
AUSTRIA
Phone: +43 1 58801 38991
Fax: +43 1 58801 38999
Email: arrate.alonso@nt.tuwien.ac.at

# Effects of co-located transmissions in the performance of DCC IEEE802.11p MAC and Self-Organizing TDMA for VANETs

Arrate Alonso[1,2] and Christoph F. Mecklenbräuker[1,2]

[1] *Institute of Telecommunications, Technische Universität Wien, Austria*

[2] *Christian Doppler Laboratory for Wireless Technologies for Sustainable Mobility, Technische Universität Wien, Austria*

arrate.alonso@nt.tuwien.ac.at

***Abstract*—IEEE802.11p MAC (Medium Access Control) protocol has drawbacks when it comes to scheduling safety-related data. An enhancement has been proposed by the European Telecommunications Standards Institute (ETSI), decentralized congestion control (DCC) mechanism. Implemented on the MAC Layer, it leads to improve the priority channel access under high load scenarios. Although, self-organizing time division multiple access (SoTDMA) clearly defines a suitable alternative for road traffic safety applications. It copes with low and predictable delay constraints. Still both MAC protocols experience co-located transmissions, which affect their performance. Our contribution presents a comparative study of the effects of co-located transmissions in the performance of DCC IEEE802.11p MAC protocol and SoTDMA for vehicular ad-hoc networks (VANETs). In order to evaluate their impact, new performance indicators are defined, awareness and emergencency coverage and their evolution in time is studied. Results show that for DCC IEEE802.11p MAC edge nodes, both coverage ranges are narrowed in case of co-located transmissions or cancelled due to the excessive back-off. On the other hand DCC IEEE802.11p MAC centre nodes and SoTDMA results show more reliable performance where coverage ranges are narrowed in case of co-located transmissions but never cancelled.**

## I. INTRODUCTION

In the field of vehicular communications a new kind of applications (i.e. e-safety, traffic management, enhanced driver comfort and vehicle maintenance applications) arise, which lead to new communication scenarios. Road traffic safety applications are the ones with the strongest requirements on the communication. European Telecommunications Standards Institute (ETSI) has defined two types of messages for safety-related applications, namely cooperative awareness messages (CAM) [1] and decentralized environmental notification messages (DENM) [2]. CAMs are broadcasted periodically and contain position, speed, heading of the vehicle, they are time-triggered and always present. DENMs, however, are event-driven and will be triggered when a dangerous situation is about to happen. Both message types require predictability, whereas CAMs have modest reliability requirements as it is repeated periodically and DENMs have high reliability requirements. By predictability is meant that the medium access control (MAC) layer should have a known maximum delay, such that a message can be delivered to the receiver before a predefined deadline. The MAC layer protocol for scheduling safety-related data traffic must be predictable, self-organizing and support both event-driven and time-triggered data traffic.

Carrier sensing medium access with collision avoidance (CSMA/CA) of IEEE802.11p provides low channel access delay given that the channel is sensed idle. If the channel is busy, a node waits a random time until it attempts to access the channel again. This random amount of time is calculated via the exponential back-off algorithm. The main drawbacks of CSMA/CA when scheduling safety-related data are: the stochastic nature of the exponential back-off which makes CSMA/CA (*i*) *unpredictable* as the maximum delay is unbounded and (*ii*) *causes co-located transmissions* when two nodes select the same back-off value which leads to a degradation of the reception performance and finally (*iii*) *blocking*, which means that as long as the node senses the channel busy, it keeps waiting and never gets to transmit.

The radio channel is a limited resource and the MAC-to-MAC delay for safety-related data is deadline limited. The IEEE802.11p MAC can not ensure priority channel access under high load scenarios without co-located transmissions. A potential remedy to the problems experienced with CSMA/CA could be to use decentralized congestion control (DCC) mechanism. DCC reduces load by sensing the current channel load and dropping packets according to their priority before they are put into the PHY layer queues (located in the DCC Access layer), predicting future channel load by analyzing the Local Dynamic Map (LDM, located in the DCC NET layer), reducing repetition rate of cyclic messages (located in the DCC Facilities layer) or balancing the load between different radio channels (located in the DCC Access layer). Applying the DCC mechnism in the lower (DCC Access) layer guarantees lower delays, which is a key requirement for scheduling safety-related data.

A suitable alternative MAC protocol for scheduling safety-related data traffic is self-organizing time division multiple access (SoTDMA) [3]. It provides channel access, regardless of the channel occupancy. SoTDMA has a periodic structure, where the channel is divided in timeslots, and further grouped into frames. These features are translated into predictable channel access delay, non-blocking and better ability for scheduling periodic traffic. However, it requires CAMs to be present in the system since the scheduling of transmission slots is based on position information.

There has been a lot of research work carried out comparing performance indicators for IEEE802.11p MAC and SoTDMA. The work in [4] and [5] shows the simulation of a highway scenario where only the time-triggered CAMs are present. The results show that SoTDMA is very suitable for VANETs, and that SoTDMA outperforms CSMA/CA. Previous work carried out by our team also shows a comparative study of the stabilization time of IEEE802.11p MAC protocol and SoTDMA for different channel loads [6]). In this article we outline how the DCC mechanism works on the IEEE802.11p MAC, as well as the effects of co-located transmissions in DCC IEEE802.11p MAC and SoTDMA performance. First we study the effects of co-located transmissions on the probability of packet reception (PPR). Then we define two new performance indicators to evaluate the severity of the impact of the co-located transmissions: awareness coverage and emergency coverage.

## II. ETSI Algorithm for Decentralized Congestion Control

ETSI has proposed a DCC scheme in order to mitigate the IEEE802.11p MAC layer congestion issues at high vehicle densities. As stated in [7], the DCC mechanism is based on an underlying state machine where the transmit parameters are chosen, based on the observed channel load. It does not require changes in the underlying PHY/MAC standards as defined in IEEE802.11p ([8]). In Europe a profile standard of IEEE802.11p has been approved by the European Telecommunication Standards Institute (ETSI), called ITS-G5 [9].

The state machine proposed is depicted in Fig. 1. The transmission parameters associated with a state may include transmit power (P), packet transmission interval (PI) and carrier sense threshold (CST), coding schemes (MCS) among other parameters. The channel load (CL) is defined to be the fraction of time where received power was greater than the CST. A state transition to a higher congestion state occurs when all measured CLs for the past second are larger than $CL_{UP}$. The transition towards lower congestion state occurs if the CLs measured during the past five seconds are lower than $CL_{DOWN}$.

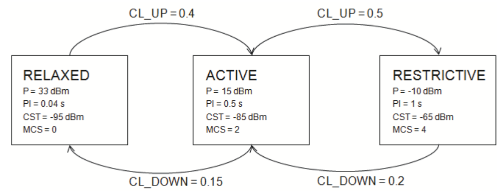


Fig. 1. DCC Algorithm. The state machine proposed by ETSI DCC framework

The proposed state machine consists of three states and associated transmit paramenters and state transition rules. When CL is too high, the DCC algorithm tends to change all three parameters simultaneously to ease congestion.

In this work we have implemented this machine in order to fully analyze the performance of the MAC layer: DCC IEEE802.11p. As CAMs and DENMs have got a fixed PI and MCS, we just change P and CST parameters from state to state.

## III. Co-located Transmissions: Problem Statement and Classification

The goal of this paper is to analyze the effects of the co-located transmissions on the performance of both MAC protocols: DCC IEEE802.11p MAC and SoTDMA. When a transmission by two transmitters at the same time happens, we say that a co-located transmission has occurred. If a receiver is within the coverage of both transmitters, it receives:

- A predominant signal,
- a weak signal or interfering signal and
- background noise.

We speak about a *collision* if the predominant signal is not strong enough to be correctly decoded and a *reception* if the predominant signal is strong enough. So co-located transmissions can lead to both: *collisions* or *receptions* at the receivers within the umbrella of co-located transmitters.

The effects of co-located transmissions can be observed in the PPR evolution in time:

- If there are no co-located transmissions, the PPR will be larger than zero within a larger distance from the transmitter and the receiver (there will be a wider coverage range).
- If there are co-located transmissions:
  - If co-located transmitters are far away from each other, the coverage range is narrowed.
  - If co-located transmitters are close to each other, the coverage range disappears completely (a *collision* occurs).

Studying the IEEE802.11p MAC protocol and SoTDMA two types of co-located transmissions have been identified. On one hand, if the co-located transmission is generated due to the simultaneous expiry of the internal counters of the co-located transmitters, it is an *unintended co-located transmission*. These co-located transmissions can not be avoided, occur randomly throughout the whole simulation time, depend on the initialization values of the counters and are not time persistent. They are present in CSMA/CA and SoTDMA. On the other hand, if the co-located transmission is generated due to full occupation of the SI in SoTDMA, it is an *intended co-located transmission*. It happens because one of the co-located transmitters has chosen the same timeslot as its furthest away located node (in order to diminish the interference amongst them). These co-located transmissions occur as soon as the channel is loaded enough. They are time persistent.

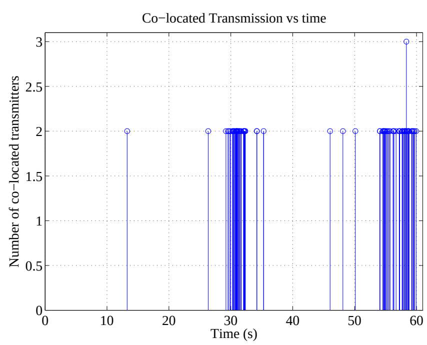


Fig. 2. Co-located transmissions of DCC IEEE802.11p MAC.

Fig. 2 shows co-located transmissions in time of DCC IEEE802.11p MAC. The train displays that there are more co-located transmissions as the channel is more loaded.

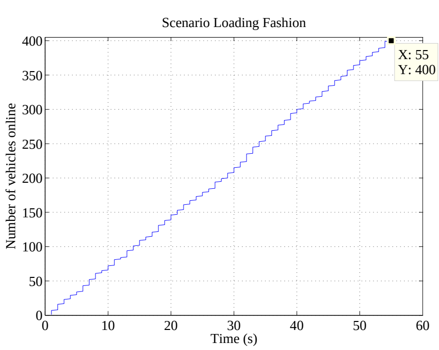


Fig. 3. Scenario loading fashion of DCC IEEE802.11p MAC.

In Fig. 3 the loading fashion of the channel (amount of active vehicles during simulation time) is depicted. As it is more loaded, the width of the co-located transmissions region is wider, i.e. it takes longer to get back to a non co-located transmissions scenario.

In the case of SoTDMA, Fig. 4 shows how in comparison to the DCC IEEE802.11p MAC results, there are more co-located transmissions (2449 co-located transmissions in contrast to the 109 co-located transmissions got with DCC IEEE802.11p). There are also more co-located transmitters (2, 4 or 5 co-located transmitters in contrast to the 2 or 3 co-located transmitters got with DCC IEEE802.11p MAC), for similar scenario.

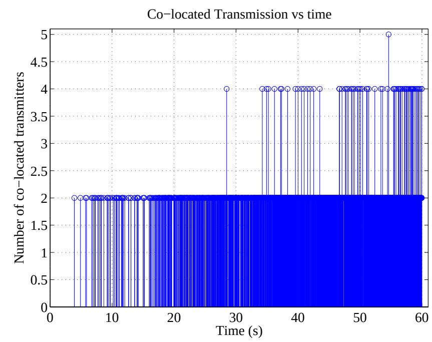


Fig. 4. Co-located transmissions of SoTDMA.

Higher amount of co-located transmitters and higher amount of co-located transmissions lead to narrower PPR ranges. But how does this sectorization affect the performance of the MAC protocols?

## IV. Results

The scenario simulated is a six lane, 6000 m highway highway scenario where 400 vehicles (200 per driving direction) are traveling in both directions, as depicted in Fig. 5.

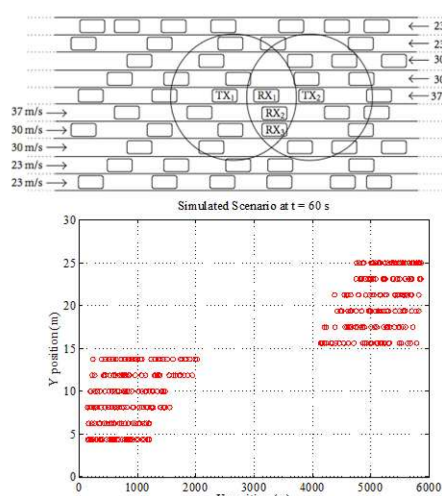


Fig. 5. Simulated scenario description.

Nodes appear Poisson distributed and start to send uniformly distributed messages. Vehicles enter the scenario at 0 m or 6000 m depending on the direction they are driving in. Each circle in Fig. 5 is corresponding to a vehicle.

The performance indicators used for analyzing the effects of co-located transmissions on the MAC performance are :

- *Probability of packet Reception, PPR*: It represents the probability of receiving one specific packet within a certain distance to the transmitter (*x axis:* distance between TX-RX in meters; *y axis:* PPR in [0..1]).
- *Awareness Coverage*: It represents the coverage range up to which low priority safety messages can be received (i.e. CAMs) with a certain awareness effectiveness limit [PPR value] (*x axis:* maximum covered distance between TX-RX in meters; *y axis:* simulation time in seconds).
- *Emergency Coverage*: It shows the coverage range up to which high priority safety messages can be received (i.e. DENMs) for a certain emergency effectiveness limit [PPR value] (*x axis:* maximum covered distance between TX-RX in meters; *y axis:* simulation time in seconds).

### A. DCC IEEE802.11p MAC Results

In this simulation scenario there are two types of node behaviours identified, because of the DCC mechanism : *edge node* and *centre node* behaviour. An *edge node* is located at the edge of the VANET. It senses less neighbour nodes within range and works in the RELAXED state (P = 33 dBm, CST = -95 dBm). A *centre node* (located in the centre of the VANET) senses more neighbour nodes and works in the ACTIVE state (P = 15 dBm, CST = -85 dBm).

*1) PPR Results:* PPR figures display two traces, as Fig. 6: red dashed line and the blue dotted line.

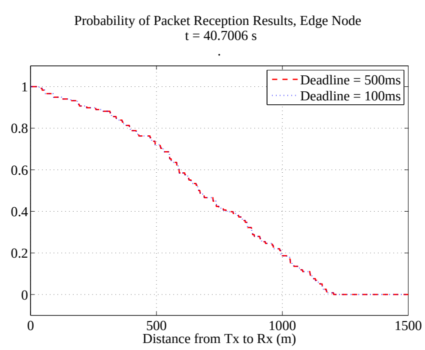


Fig. 6. PPR of DCC IEEE802.11p MAC for an Edge Node. CAM and DENM services are provided.

The red dashed line is the PPR for CAMs (MAC-to-MAC delay deadline: 500 ms) and the blue dotted line is the PPR for DENMs (MAC-to-MAC delay deadline: 100 ms). The most of the simulation time they grow or decrease simultaneously, as in Fig. 6. This means that all the MAC-to-MAC delays are low enough to provide both CAM and DENM services equally. The effects of a co-located transmission will affect both traces equally.

If a co-located transmission happen where co-located transmitters are too close to each other both PPR traces are cancelled. Figure 7 shows how in this case neither CAM nor DENM services can be provided. If co-located transmitters are far from each other, the PPR range will be narrowed. Still the service could be provided to neighbour nodes located close to each co-located transmitter.

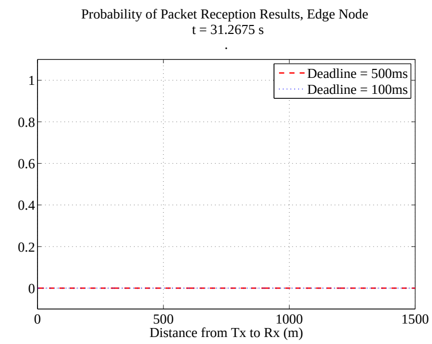


Fig. 7. PPR of DCC IEEE802.11p MAC for an Edge Node. No service is provided (i.e. collision).

One *special case* arises in the case of the edge node (depicted in Fig. 8 and in Fig. 9). Fig. 8 shows that there is a non-zero PPR range for CAMs but not for DENMs. This means that this broadcast (occurred at 32.0142 s) had higher MAC-to-MAC Delay than 100 ms for all its receptions. In other words, CAM service can be provided but a DENM message would not reach any of its neighbours.

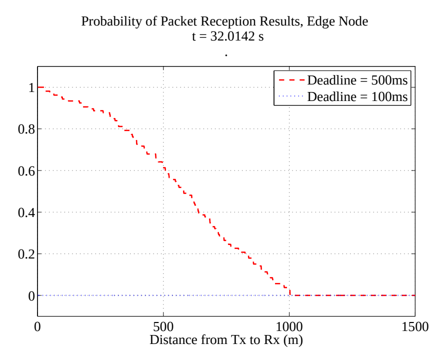


Fig. 8. PPR of DCC IEEE802.11p MAC for an Edge Node. Only CAM service is provided.

This *special case* is a consequence of the excessive back-off. Every time the vehicle backs-off, the channel access delay grows and so does the MAC-to-MAC Delay. Fig. 9 displays how neither CAM nor DENM services can be provided. This effect is inherent to all contention-based algorithms (i.e. IEEE802.11p MAC).

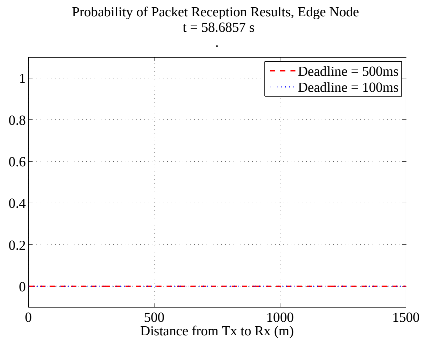


Fig. 9. PPR of DCC IEEE802.11p MAC for an Edge Node. No service is provided (i.e. excessive back-off).

Fig. 10 shows PPR for a centre node. It shows an homogeneous performance throughout the simulation time and there is no *special case* due to excessive back-off. The narrower PPR range is because of the DCC and the lower transmit power.

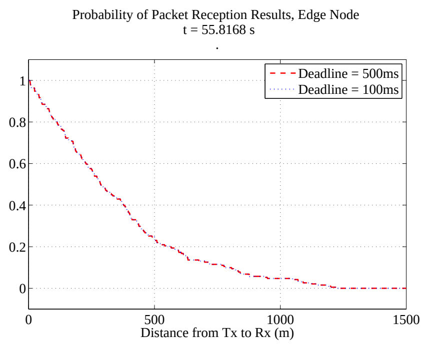


Fig. 10. PPR of DCC IEEE802.11p MAC for a Centre Node.

*2) Coverage Results:* The following results show the maximum distance from the transmitter that a packet (with a certain PPR) got to, i.e. the covered range by each transmission. We define these PPR limit value so that they provide different reliability for CAMs and DENMs (awareness effectiveness limit [PPR value] = 0.75 and emergency effectiveness limit [PPR value] = 0.9). The y axis is set this way in order to see the time evolution properly. Coverage range increases with time because the number of vehicles within range also does so. The fluctuations in Fig. 11 are due to co-located transmissions or excessive back-offs (edge node behaviour).

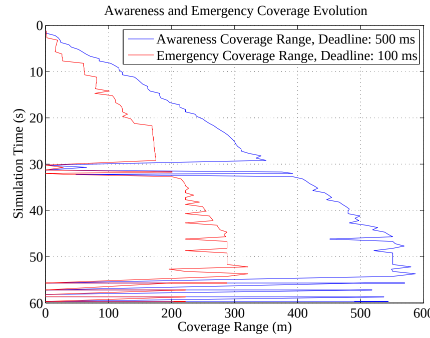


Fig. 11. Coverage Ranges for Edge Node.

Comparing Fig. 12 with the previous one, it is observed that the vehicle was generated later (y axis begins in 35 s). The coverage ranges are much narrower (the messages will not get that far from the transmitter) and they also fluctuate less. This is because the behaviour in such a narrow range is more robust.

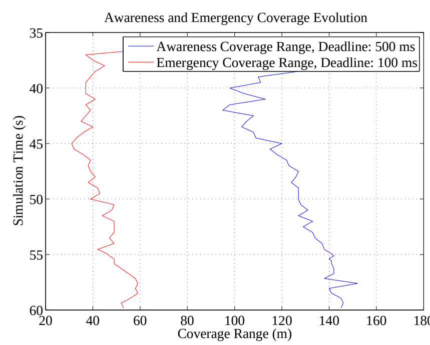


Fig. 12. Coverage Ranges for Centre Node.

## B. SoTDMA Results

SoTDMA has the same parameter setting for all the nodes (unique state, P = 20 dBm). Still for sake of comparison the results for an edge and a centre node are studied.

*1) PPR Results:* Fig. 13 depicts PPR results for an edge node. The PPR is stable for both 500 ms and 100 ms deadlines. In comparison to the DCC IEEE802.11p MAC results, the maximum distance TX-to-RX is smaller because the output power is 20 dBm and the effects of co-located transmissions. In order to see the effects of the different number of co-located transmitters, Fig. 13 and Fig. 14 are compared.

For two co-located transmitters a larger than 1500 m distance TX-to-RX is achieved where PPR $> 0$. For three co-located transmitters a shorter distance TX-to-RX is achieved where PPR $> 0$.

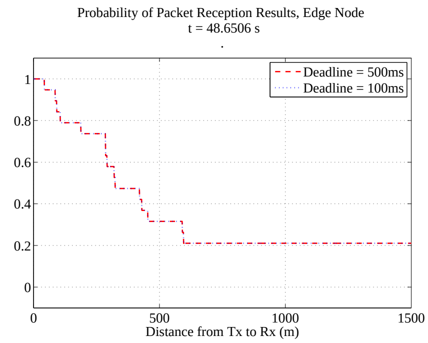


Fig. 13. PPR of SoTDMA for an Edge Node. For two co-located transmiters.

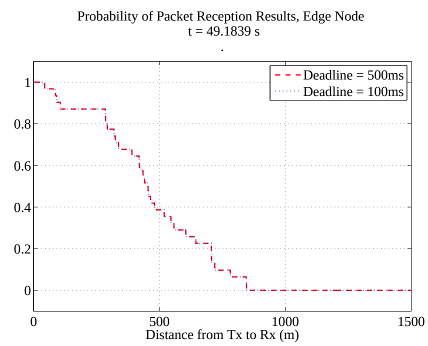


Fig. 14. PPR of SoTDMA for an Edge Node. For three co-located transmiters.

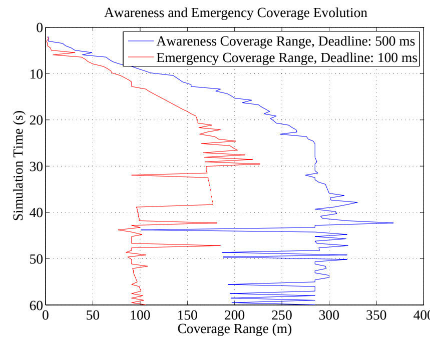


Fig. 15. Coverage Ranges for Edge Node for SoTDMA.

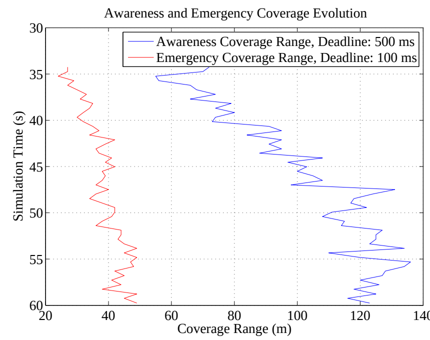


Fig. 16. Coverage Ranges for Centre Node for SoTDMA.

The PPR for a centre node also shows an homogeneous performance throughout the simulation time. There is a similar behaviour to the edge node (Fig. 14) because with SoTDMA they have the same parameter setting.

*2) Coverage Ranges Results:* These results show maximum distance from the transmitter that a packet (with a certain PPR) got to, i.e. the covered range by each transmission. The PPR limit values are defined so that they provide different reliability for CAMs and DENMs, and are the same as in the DCC IEEE802.11p MAC simulations. The difference in Fig. 15 is that the fluctuations are only due to co-located transmissions.

Comparing Fig. 15 and Fig. 16, it is appreciated that the centre node vehicle was generated later (y axis begins in 35 s). Coverage ranges are narrower in Fig. 16 due to the effect larger number of co-located transmissions and co-located transmitters.

## V. Conclusions

When a transmission by two transmitters at the same time happens, we say that a *co-located transmission* has occurred. Depending on the distance between co-located transmitters, co-located transmissions lead to:

- Reception (it narrows PPR range because co-located transmitters are located far away from each other).
- Collision (it makes PPR range disappear because co-located transmitters are located too close to each other).

Results have shown that SoTDMA is collision-free, whereas DCC IEEE802.11p experiences collisions in its edge nodes.

*Comparing DCC IEEE802.11p MAC with SoTDMA*

DCC IEEE802.11p MAC differentiates the behaviour for edge and centre nodes thanks to the DCC mechanism. SoTDMA has the same behaviour and parameter settings for all nodes (regardless of their location in the VANET).

### *A. Results for EDGE nodes*

DCC IEEE802.11p MAC has wider coverage ranges due to higher output power configuration but suffers from instabilities due to excessive back-off. SoTDMA has narrower coverage ranges due to lower output power configuration and shows more stable and reliable coverage ranges than DCC IEEE802.11p MAC.

### *B. Results for CENTRE nodes*

DCC IEEE802.11p MAC has narrower coverage ranges due to lower output power configuration and shows more stable and reliable coverage ranges than for edge nodes. SoTDMA shows narrower coverage ranges due to a higher number of co-located transmissions (with higher amount of co-located transmitters). Both trends are similar, but absolute values show slightly better performance for DCC IEEE802.11p MAC for centre nodes (maximum emergency coverage range: 53 m; maximum awareness coverage range: 145 m) than for SoTDMA (maximum emergency coverage range: 49 m; maximum awareness coverage range: 123 m)

## ACKNOWLEDGMENT

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