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This is the accepted version of a paper presented at *1st IEEE ICC Workshop on Dependable Vehicular Communications (DVC 2015), London, United Kingdom, June 12, 2015.*

Citation for the original published paper:

Larsson, M., Jonsson, M., Karlsson, K., Bergenhem, C., Larsson, T. (2015)

Curvature based Antenna Selection Method Evaluated Using the Data Age Metric and V2V Measurements.

In: *2015 IEEE International Conference on Communication Workshop (ICCW)* (pp. 2356-2362).

Piscataway, NJ: IEEE Press

<http://dx.doi.org/10.1109/ICCW.2015.7247533>

N.B. When citing this work, cite the original published paper.

Permanent link to this version:

<http://urn.kb.se/resolve?urn=urn:nbn:se:hh:diva-29199>

Curvature based Antenna Selection Method Evaluated Using the Data Age Metric and V2V Measurements

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Abstract: In this paper, we compare a method for selecting transmission antenna based on road curvature to a method based on periodically alternating between left and right hand side transmission antennas. Both methods aim to improve the success rate for communication between participants in a platoon of vehicles. Moreover, we propose the data age metric for online use as input to the algorithm controlling the inter-vehicle distance in platooning, e.g. to decide appropriate gap between the vehicles depending on the V2V communication quality. The methods have been evaluated through V2V communication measurements performed using heavy duty vehicles on public highway. We show that, when using the curvature-based method, a 150 ms data age deadline is only missed approximately half as often compared to when periodically alternating between left and right hand side transmission antennas. The methods have also been compared for different antenna combinations.

Keywords — Antenna Selection; Data age; PER; IEEE 802.11p; ITS; V2V; Platooning; Field Measurement;

I. INTRODUCTION

Intelligent Transportation Systems (ITS) applications have the potential to improve safety by the use of cooperative warning functionalities, improve road usability by automatic driving and reduce environmental impact by improved methods for cooperative traffic flow management (such as green wave of traffic lights). Highway platooning [1] for heavy vehicles can potentially improve safety, e.g. by introducing a higher level of automation in driving and thereby reduce the human error. It can also decrease the environmental impact of road transportation, e.g. by decreasing the aerodynamic resistance for trucks when driving with short, but safe, inter-vehicle distances [2].

In order to enable platooning with automatic control in both lateral and longitudinal direction, a number of enabling technologies are required, e.g. vehicle-to-vehicle (V2V) communication, automatic longitudinal control and automatic steering. In order to decrease the inter-vehicle distance to a minimum the vehicles need to communicate so that control loops can react on early input, e.g. by sending brake information with low latency to the following vehicles instead of letting a following vehicle wait for the local sensors to detect a change of the dynamic behavior of the vehicle ahead. The rest of this paper is focused on V2V communication.

In order to enable a widely spread V2V communication system, it is necessary to agree on a communication protocol.

In 2010, IEEE adopted an amendment to the family of WiFi standards; the IEEE 802.11p for wireless access in vehicular environments (WAVE) [3]. This amendment specifies the physical layer (PHY) and the medium access control (MAC) part of the data link layer of the OSI model. An important aspect of IEEE 802.11p is the high carrier frequency, 5.9 GHz, which makes it sensitive with respect to non-line-of-sight (NLOS) conditions [4]. The MAC protocol for IEEE 802.11p is based on carrier sense multiple access with collision avoidance (CSMA/CA), which is a nondeterministic access method. This, in combination with the fact that V2V communication is wireless and thereby error prone, implying high packet loss rate compared to wired communication, states challenges on real time performance of the communication system. In other words it is not possible to guarantee the real time deadlines of the platooning control application. Since the V2V communication link is non-deterministic, the control loop for the platooning application need to be able to handle the fact that the input control data will have varying delivery rate due to missed packets and delayed transmissions due to channel congestion. The combination of the high carrier frequency and the geometry of a heavy duty truck introduces shadowing problems, e.g. if the antenna is mounted on the right rear view mirror then the left side of other platooning trucks will be in shadow. Hence, at least two antennas will probably be necessary for an IEEE 802.11p ITS enabled truck in order to have successful transmissions, in a platooning scenario.

In this paper, we propose to use a data age metric as an input parameter to the platooning control algorithm so that the level of service can be adapted with respect to the quality of the communication link. In this context the level of service relates to the inter-vehicle distance achieved by the platoon controller. To minimize the data age we assume, in this paper, that the trucks are equipped with two antennas – one on each side of the cabin, and propose a method for selecting the transmission antenna based on curvature of the road. The method selects the antenna positioned towards the inner curve and we show that the data age is decreased compared to the most straightforward method of simply alternating transmission antenna. The curvature based transmission antenna selection method has been evaluated with real world V2V measurements using IEEE 802.11p radio nodes and heavy duty trucks on public highway.

In [5], the system age metric is presented and an attempt to minimize it, by decreasing the transmission queue in the MAC layer, is made. This is done by changing the parameter setting

of the MAC layer offline. Böhm et al. suggest to use the CAM up-to-dateness metric in order to measure the age of a CAM message and the DENM dissemination delay to evaluate the time it takes for all assigned vehicles to receive a DENM message [6]. The mentioned studies do not consider online (run-time) use of the data age, which we propose. Moreover, the CAM up-to-dateness usage is constrained to CAM transmissions, which is not expected to be feasible for the control communication between the vehicles in a platoon.

A number of scientific papers are published concerning different diversity approaches on the receiver side [7-10]. However, as far as the authors are aware, there are no publications regarding antenna selection method or algorithm based on geographical information on the transmitter side.

Several measurement campaigns have been performed for V2V communication. In [4, 11] issues concerning the problem of having NLOS conditions for passenger cars are presented. The authors of [12] have performed measurements on heavy vehicles and suggest that when choosing antenna position between roof and rear view mirrors, the rear view mirrors are superior. In this paper, however, we report on measurements where all vehicles are heavy duty vehicles and investigate the data age when using a dynamic choice of transmission antenna.

In this article, three main contributions are presented:

- A definition of the data age (DA) metric to be used for both V2V field measurement offline evaluation and as an *online* input parameter to the platooning control algorithm, where the latter usage is new according to our knowledge.
- A simple curvature based transmission antenna selection method for selection of transmission antenna based on road curvature for heavy duty vehicles driving in a platoon.
- Results from IEEE 802.11p V2V field measurements performed in a platooning like driving scenario on public highway using heavy duty vehicles. Evaluation of the curvature based transmission antenna selection method is included.

The rest of the paper is organized in the following sections. Section II introduces the data age metric and its usability, while Section III presents the curvature based transmission antenna selection method. Section IV presents the measurement setup, followed by section V containing the results of the performed measurements. Conclusions and future work close the paper in Section VI.

II. DATA AGE METRIC

Data age is a metric defined to be used both for evaluation of V2V measurements and as an input parameter for the platooning control algorithms.

Definition: Data age is defined as the age of the information in the last correctly received sample of data in a receiving node.

Data age is calculated according to:

$$T_{data_age} = t - t_{tsLRS} \pm t_{clocksync} \quad (1)$$

where t is the current time in the node performing the platooning control loop calculation, t_{tsLRS} is the time stamp of the last correctly received sample from the remote node with the data of interest and $t_{clocksync}$ is the clock-synchronization error between the transmitter and receiver internal clocks.

Data age is proposed as a metric for two main reasons. First, the metric is simple; it only takes a subtraction action to be calculated. Second, data age as an input parameter to the platooning control algorithm can make the controller adapt its level of service with respect to the communication quality, e.g. if the data age is increased, over time, then also the inter-vehicle distance needs to be increased in order to maintain the same level of safety.

A. Data age for offline evaluation of V2V field measurements

For the evaluation of measurements, i.e. offline analysis, data age is used in order to evaluate the freshness of the information that is available in the receiving node, this is directly related to the quality of the communication link. The better the quality of the communication link the lower the data age. An illustration of how the data age is changing depending on the success of transmission is given in Fig. 1, where TX indicates the sending node and RX the receiving node. The shown data age values are just examples for illustration purpose, while the data age in reality continuously increases until a new sample is received.

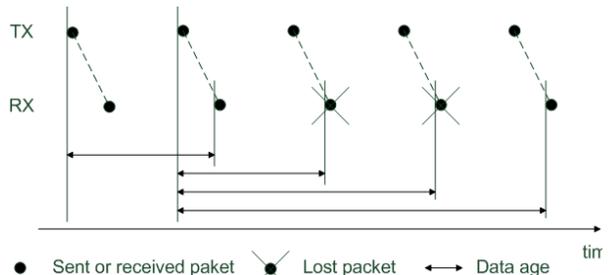


Fig. 1. Illustration of how the data age changes depending on the success of packet reception.

B. Data age as an online input parameter for the platooning control loop

The data age metric can also be used as an online input parameter to tune the platooning. The distance to the platoon vehicle ahead of the ego vehicle has strong correlation to the amount of fuel saved by driving in a platoon [2]. With respect to fuel savings the inter-vehicle distance shall be kept as short as possible. Of course, other parameters, such as comfort and driver acceptance, also need to be taken into account when setting the limits for the inter-vehicle distance. If the speed of the platoon is known, then the distance to the vehicle in front can be expressed as a time, e.g. driving in 90 km/h with a 25 m inter-vehicle distance can be expressed as an inter-vehicle “distance” of 1 s. This implies that when designing the control algorithm the data age can be used as input to setting the performance level of the controller, e.g. if the data age is low, then the controller can be set to high performance with a short inter-vehicle distance and if the data age is increasing then the

performance level of the controller need to be lowered with respect to the inter-vehicle distance.

If the data age can be kept at a low level, the inter-vehicle distance when driving in a platoon can be reduced still maintaining a high level of safety, compared to when driving with a short inter-vehicle distance only relying on local sensors, e.g. radar, laser scanners, ultra sound etc.

III. TRANSMISSION ANTENNA SELECTION METHOD

We propose a curvature based transmission antenna selection method that selects the most appropriate transmission antenna based on the road curvature, see Fig. 2 for a flowchart description of the method. The method selects the antenna that has the highest probability of having LOS conditions to the rest of the platoon members, which is the antenna positioned on the rear view mirror pointing towards the inner curve, see Fig. 3. If transmission is performed where the LOS condition has the highest probability, the data age will most likely be low.

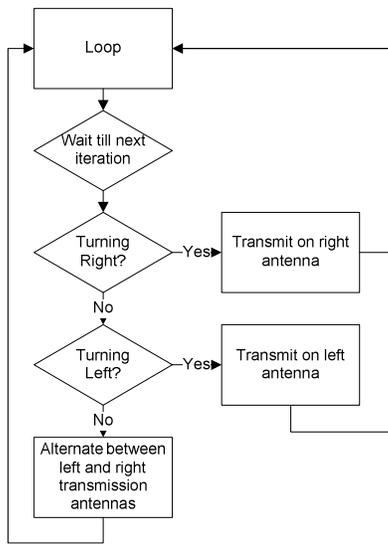


Fig. 2. Flowchart describing the transmission antenna selection method.

The method takes the yaw rate of the leading vehicle as input, and based on the yaw rate identify the antenna positioned in the inner curve. When the most appropriate antenna is identified, the system will transmit only using this antenna. The yaw rate is monitored continuously and when a change occurs, the most appropriate transmission antenna is selected. When the yaw rate indicates that the leading vehicle is driving straight ahead, transmission antenna will be selected by alternating between the left and right hand side antennas.

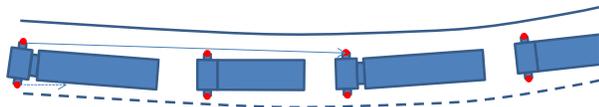


Fig. 3 Vehicle constellation, vehicle 1 sending to vehicle 3. Right side antennas has LOS, but for the left side antenna, the LOS is obstructed by the second vehicle, giving NLOS conditions for the left antennas.

IV. MEASUREMENT SETUP

A. Radio nodes

The EVK-3300 [13] delivered by Kapsch TrafficCom was used for transmitting, receiving and logging data during the measurements. The nodes used a modified version of ETSI ITS-G5, where modifications were made to, e.g. avoid the use of the Decentralized Congestion Control (DCC), sending at a fixed update rate of 10 Hz and setting the packet size suitable for the test. For the measurement results presented in the next section the nodes were configured according to Table I.

TABLE I CONFIGURATION SETTINGS OF THE TRANSCIEVER NODES.

Parameter	Value
TX power	23 dBm
Data rate	6 Mbps
Carrier frequency	5.9 GHz
Payload	100, 500, 1500 byte
Update rate	10 Hz
Channel	Control Channel (G5CC)

Each truck hosted two nodes in order to enable communication on both left and right hand side, i.e. eight nodes in total was used during the measurements.

B. Antennas and vehicles

Two types of antennas were used; one stacked dipole with 5 dBi gain in the front and back directions and 8 dBi gain orthogonal to the body of the truck, and one antenna, named by the project, Aztec, with 6 dBi gain in the front and back directions, but -5 dBi gain orthogonal to the body of the truck.

Four heavy duty trucks were used in the measurements in order to create the platoon. Two rigid Volvo trucks with containers of length 9.5 m, at platoon position one and three, and two Scania tractors, one with a metallic semi-trailer and one with a tarpaulin covered semi-trailer, both of length 18 m, at platoon position two and four. The antennas were mounted inside the rear view mirrors (RVM) on the Scania trucks, but beside the mirror glass itself since it contains a metallic film that would disturb the transmission. On the Volvo trucks the antennas were mounted on the outside of the mirror cabinet.

Three antenna combinations were evaluated, see Table II. All of them with the antennas positioned on or in the rear view mirrors. The first antenna combination used stacked dipole antennas mounted at the same height on both sides of the vehicle on the rear view mirrors. Antenna combination number two is similar to antenna combination number one but have the antennas mounted on different heights in order to decrease the effect of ground reflections through the use of vertical spatial diversity [14]. The Aztec antenna type is used in the third antenna combination and is mounted at the same height on both sides of the vehicle on the rear view mirrors.

TABLE II ANTENNA TYPE AND POSITION ON VOLVO

Antenna combination	Position on truck	Antenna type
1	RVM (same height)	Stacked dipole
2	RVM (left high, right low)	Stacked dipole
3	RVM (same height)	Aztec

C. Surrounding environment

The measurements were performed in February 2014 on highway E4 south of the Swedish city Södertälje, the outdoor temperature was 3° C and the cabin temperature was 20° C (where the radio nodes where located). The surrounding landscape shifted from open fields to forests to rocky mountain walls. There was a road barrier on the left hand side of the traffic lane and on the right hand side a metallic wild life fence was situated approximately nine meters from the lane. The traffic situation during the measurements where perceived as normal with a mixture of passenger cars and heavy duty trucks passing and surrounding the platoon under test. At no time any other vehicle was mixed within the platoon.

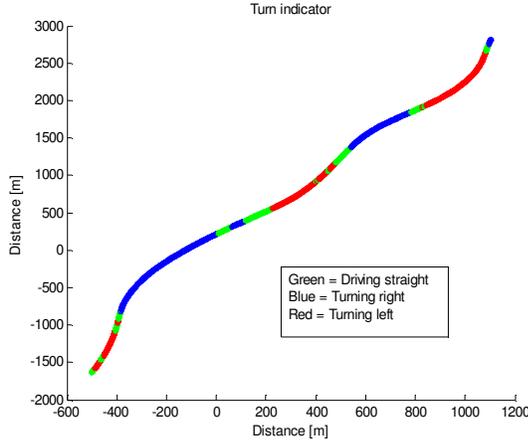


Fig. 4 The turning behavior of the platoon, the platoon is moving from bottom left corner to upper right corner. This is only a cutset of the road to visualize the turning behavior.

D. Test procedure

The measurements started when the four trucks were driving in a stable platoon-like formation. The following trucks were driven in a semi-automatic fashion using adaptive cruise control (ACC) for longitudinal control with an inter-vehicle distance of approximately 22 meters (~1s) and controlled by the driver in the lateral direction, while the leading truck was driven manually in both the longitudinal and lateral direction. For one complete measurement the platoon drove approximately 8 km south on highway E4 starting at Saltå, stopped the logging and went off the highway to turn the platoon around, started the logging and went back the 8 km to Saltå. Total time per measurement was approximately 12 minutes.

During the measurements all nodes were sending and receiving, enabling evaluation for all vehicle combinations and on both left and right hand side. Each packet sent was logged in a send log containing, e.g. send time, sequence number and packet size. In the receiving node corresponding information was logged but with some additional information, e.g. RSSI and time stamp.

When the platoon is “turning” on the highway the turn is of course only a very slight change of heading, see Fig. 4. However, this slight change of heading created NLOS

condition for the antennas at the outside of the curve, while the inner-curve antennas experienced a LOS condition, see Fig. 3.

V. MEASUREMENT RESULT

In this section the results of the field measurements are presented. All of the following measurement results are for the communication link between the leading vehicle and the third vehicle, see Fig. 3. This link has been chosen due to the following reasons; the vehicles are identical, i.e. rigid with no trailer, both vehicles have the same combination of antennas and there is one vehicle in between. The second vehicle can possibly obstruct the LOS, especially when the platoon is changing heading and shift the “inner” curve from one side to another. At all times the sending vehicle is only sending on one side at the time and the receiving vehicle uses both sides for receiving data packets. However, both transmitter antennas are (sequentially) activated during each period in order to test different transmitter antenna selection methods on the same measurement data. The packet size for the presented results is 500 bytes.

A. Data Age as a function of elapsed time

In Fig. 5 and Fig. 6, the data age for antenna combination two is plotted as a function of elapsed time. The turning behaviour is visualized in the figures by a thick line at Y-axis value 0.7 when the platoon is turning left and a thin line when turning right. The gaps at 0.7 indicates that the platoon is moving straight ahead. In the top plot of Fig. 5 the data age is shown for the left hand side antennas only, while the lower plot is for the right hand side antennas only. In general terms it can be seen that the data age is decreasing for the left hand side antennas when the platoon is turning left and vice versa for the right hand side.

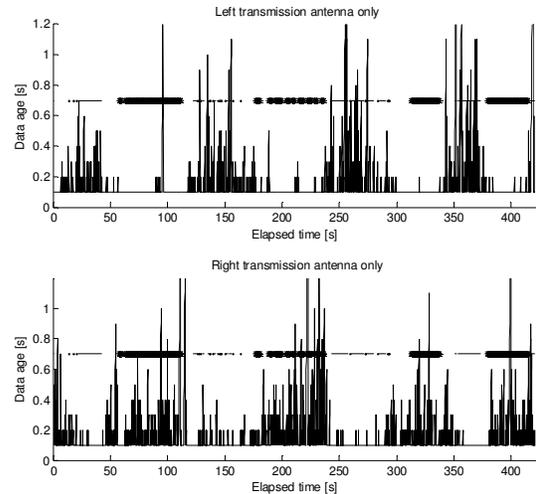


Fig. 5. Left transmission antenna compared to right transmission antenna. A thin line at Y-axis value 0.7 shall be interpreted as turning right, while a thick line shall be interpreted as turning left.

In the lower plot of Fig. 6 the alternating transmission antenna selection method has been applied to the same measurement data as in Fig. 5 and we can here see a decrease of the data age compared to using either right or left hand side

transmission antenna only. In the upper plot of figure Fig. 6 the curvature based transmission antenna selection method has been applied and we can see an even lower level of the data age. However, there are still a lot of data age values of 200 ms and also quite a few peaks of data age values up to 1.2 seconds.

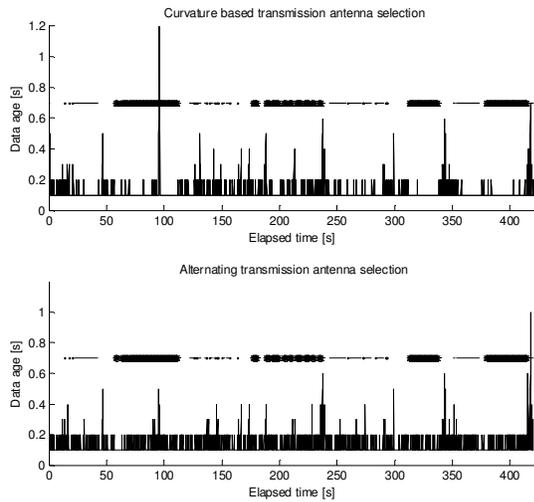


Fig. 6. Curvature based transmission antenna selection compared to alternating left and right transmission antenna. A thin line at data age value 0.7 shall be interpreted as turning right and a thick line shall be interpreted as turning left.

B. Ratio of missed Data Age deadlines

In order to evaluate the performance of the curvature based transmission antenna selection method, deadlines for the data age are introduced. Each deadline is set to multiples of the update rate of transmissions plus 50 ms, these 50 ms is chosen in order to catch the packets that experience delays due to transmission jitter.

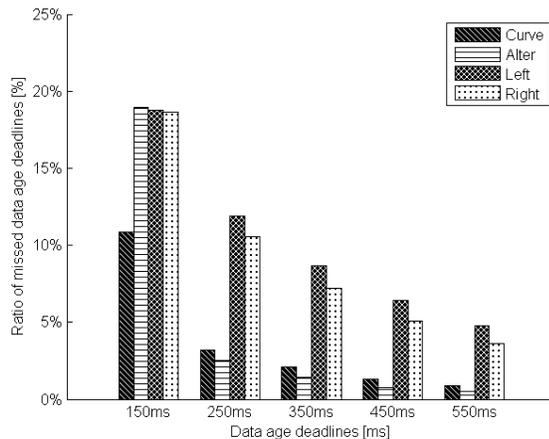


Fig. 7. Comparison of missed data age deadlines for antenna combination one.

In Fig. 7, Fig. 8 and Fig. 9, for the three different antenna combinations, respectively, the ratio of missed data age deadlines are visualized for different deadlines. For each deadline, e.g. 150 ms, 250 ms, etc., the curvature based transmission antenna selection method is compared to three

alternatives: 1) alternating transmission antenna, 2) only using the left and 3) only using the right hand side transmission antennas.

For antenna combination one it can be seen, in Fig. 7, that for the complete measurement set, the data age has a value above 150 ms for approximately 11% of the set when using the curvature based transmission antenna selection method. This can be compared to when alternating transmission antenna for which the data age is above 150 ms for nearly 20% of the set. When the deadline is increasing, the difference in performance between the two methods is decreasing, but we can also see that alternating between left and right hand side antennas show better results for data age deadlines of 250 ms and above.

For antenna combination two, where the left and right hand side antennas are mounted on different heights, the observed data age values are similar to the ones for antenna combination one, see Fig. 8. However, we can also see that periodically alternating between the left and right hand side antennas becomes better first at data age deadlines equal to or above 450 ms.

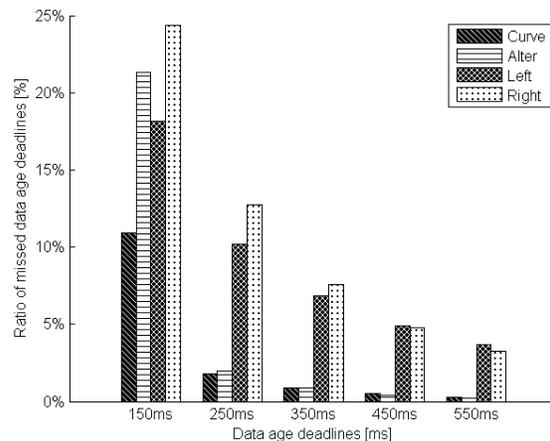


Fig. 8. Comparison of missed data age deadlines for antenna combination two.

Antenna combination three shows the best performance with respect to keeping the data age at a low level. In Fig. 9, the 150 ms data age deadline is missed for only 6% percent of the measurement set when using the curvature based transmission antenna selection method. When alternating between left and right hand side transmission antennas the 150 ms deadline is missed in 10% of the measurement set. Also, the curvature based transmission antenna selection method shows best results for all data age deadlines. This can be compared to the previous antenna combinations where alternating between left and right hand side antennas were getting better than the curvature based method for higher deadlines. It can also be seen in Fig. 9 that the right hand side antenna shows good values in keeping the data age at a low level. This could possibly be an effect of the Aztec antenna being more sensitive to reflections from the wild life fence on the right hand side of the highway, enabling a more rich environment. However, the authors believe that a method which constantly transmits on the right side could fail seriously in other road environments.

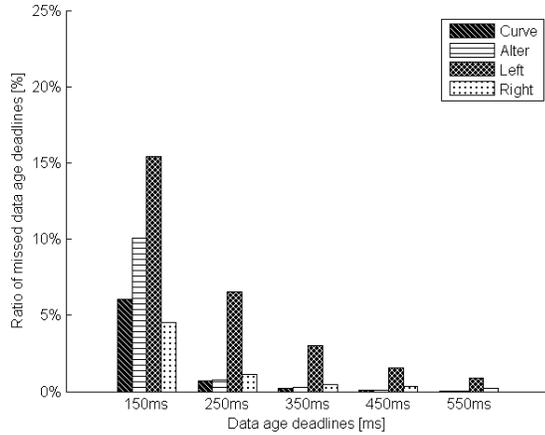


Fig. 9. Comparison of missed data age deadlines for antenna combination three.

C. Packet error rate

In Table III, the resulting average packet error rate (PER) is given for the three antenna combinations using the four ways of selecting transmission antennas. The packet error rate is the ratio between the number of not correctly received packets and the number of sent packets.

TABLE III. PER VALUES FOR THE DIFFERENT ANTENNA COMBINATIONS

Antenna combination	PER [%]			
	Curve	Alter	Left	Right
1	10.9	19.0	18.8	18.7
2	10.9	21.3	18.2	24.4
3	6.1	10.1	15.4	4.5

D. Concluding summary of measurement results

For all antenna combinations, we can see a significant improvement of reaching the 150 ms deadline when using the curvature based antenna selection method compared to only alternating between left and right hand side antennas. This is explained by the higher probability of getting LOS conditions for the antennas located in the inner curve. As the deadlines increases we can see that they are met more frequently. It can also be mentioned that when the deadlines are increased the performance difference between the curvature based transmission antenna selection method and the alternating between the left and right hand side antennas is decreased. Also, the alternating method shows slightly better results when the deadlines are increased compared to the curvature based transmission antenna selection method. In curves, alternating the antenna normally increases the average data age since every second transmission normally has worse conditions. On the other hand, as seen, alternating the antenna can be more robust if a bit higher values of the data age are allowed. Still, both the curvature based and the alternating methods shows much better performance with respect to meeting the data age deadlines compared to only transmitting on the left or the right hand side of the vehicle. The PER values of Table III also indicate performance in the same direction as the ratio of the data age deadlines.

VI. CONCLUSIONS AND FUTURE WORK

In this paper, we have presented a curvature based transmission antenna selection method for V2V communication in a platooning scenario for heavy duty trucks. The method has been evaluated using the data age metric on data collected during measurements on public highway. We have seen that when using the method, packets are received within the 150 ms data age deadline approximately twice as often compared to only alternating between left and right hand side antennas. We can also conclude that for heavy duty vehicles, with its challenging geometry, at least two antennas are required, one on each side of the vehicle.

We propose, as future work to extend the curvature based transmission antenna selection method with a dissemination strategy based on the data age metric.

ACKNOWLEDGEMENT

This work has partly been financed by The Swedish government agency for innovation systems (VINNOVA) within the RelCommH project and the KK-Foundation.

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