A Sensitive Metric for the Assessment of Vehicular Communication Applications

Robert Protzmann
Fraunhofer FOKUS, Berlin
Automotive Services and Communication Technologies
Email: robert.protzmann@fokus.fraunhofer.de

Björn Schünemann, Ilja Radusch
Technische Universität Berlin
OKS / Daimler Center for Automotive IT Innovations
Email:{bjoern.schuenemann, ilja.radusch}@dcaiti.com

***Abstract*—The technical evaluation of Vehicle-2-X communication properties in the field operational test sim^{TD} delivered first results. However, the need for new metrics arose to be able to measure the influences of communication characteristics on the application performance more precisely. Hence, we proposed the Consecutive CAM Period (CCP) as a suitable metric. In this paper we discuss the advantages of using the CCP compared to the classical communication metrics as the Packet Delivery Ratio (PDR). In a short evaluation study we furthermore present a method that helps to approach two issues. 1) The time and space dependent nature of the CCP facilitates to detect if use cases actually exist or not. 2) Particularly, the evaluation of the maximum CCP guaranties that certain situations are not missed compared to the usage of metrics with an arithmetic mean calculation.**

I. Introduction

Intelligent applications based on Vehicle-to-X communication have the potential to substantially increase the efficiency of and reduce the number of incidents in road traffic. These applications are currently developed and investigated with the help of simulations that have to combine aspects from different fields, at least from traffic, communication, and certainly application simulation [1]. Furthermore, field operational tests are performed to evaluate the effect of the new technology under real world circumstances. Recently, the final event of the prominent project sim^{TD} [2] took place.

One outcome of the sim^{TD} evaluation states that the successful exchange of messages between vehicles is generally important for the functioning of new developed V2X applications. The applications typically require to receive at least one message for the specific situation they aim to address. However, due to the mobility aspect of road traffic, these situations get outdated in certain timespans and have to be updated regularly to maintain a valid view of the surrounding environment. This means that at least one message in this timespan needs to be received. For different use cases, different timing requirements exist. These are in turn connected with the second essential parameter, the requirement concerning the dissemination distance. Driver assistance use cases as Lane Change Assists or Emergency Brakelight Warning have tight timing constraints towards the periodic reception of messages as the information about other nodes (position, speed) continuously changes. Traffic information and navigation use cases can be regarded as stationary, which means that received information stays valid for longer times. Nevertheless, periodic message exchange is used because these use cases are relevant for higher distances and worse reception quality. In this way, the probability increases that at least one message can be successfully received. The intermediate case consists of safety use cases regarding local danger warnings as hazardous locations or approaching emergency vehicles. Due to higher distances towards the situation, the timing constraints are not that tight.

In sim^{TD}, the evaluation of the communication properties was mainly based on classical metrics to identify 1) the transmission latency and 2) the coverage and message loss ratio. The latter one was measured by the means of the Packet Delivery Ratio (PDR), which is the percentage of all successfully received messages out of all sent messages. In this way, the PDR already includes an arithmetic mean calculation. Additionally, we introduced the metric of the Consecutive CAM Period (CCP), which is able to measure the reception and the time difference of individual cooperative awareness messages (CAMs). The CCP is not entirely new. It conforms to metrics which are already known under different synonyms. However, we show that especially the evaluation of the maximum delivers the most significant result to identify certain influences of communication properties on the applications. These need to satisfy worst case conditions compared to best effort conditions, which are often investigated in related work. Hence, we propose that communication evaluation should be generally extended to the CCP_{max}. In this paper, we present this metric in closer detail and show a successful study to promote the usage of this metric as an essential measure.

The paper is structured as follows: In the next Section II, we resume the communication requirements demanded by V2X applications. Furthermore, this section covers the capabilities of classical metrics to measure the communication properties. In Section III, we present related work about suitable communication metrics for application assessment. In Section IV, the new metric of the CCP is introduced and explained in detail. The benefits of the statistical evaluation of the CCP_{max} are demonstrated for the evaluation of a typical V2X communication scenario in Section V. Finally, the paper is concluded in Section VI and a brief outlook towards future research regarding the CCP_{max} is given in Section VII.

II. Communication Requirements of Applications

The basic idea of V2X communication is that vehicles (and other nodes) exchange information about their own and also about environmental current states to identify specific events or situations where an action needs to be taken. It is all about reception. More specifically, it means that respective vehicles need to receive at least one message that characterizes this event. However, the term event in this sense depends strongly on the specific use case. For a safety use case as Intersection Collision Warning, the event can only appear locally at a fixed position - the intersection area. Moreover, it is only relevant when the ego-vehicle (where the respective driver needs to be informed) and another vehicle are approaching the same intersection at the same time. The event of hard braking of the front vehicle (Emergency Brake Light) even moves locally with a vehicle and can appear always as long as the ego-vehicle is in a car-following constellation. The Road Works Warning event is always important without further constraints (as long as a certain site exists), but is fixed concerning the position. In traffic efficiency use cases, the events can be interpreted as reaching a locally fixed intersection which can be used to reroute. Besides, in field tests as sim$^{\mathrm{TD}}$, it is an important challenge to choreograph the participating vehicles to generate these events. Finally, it is important to evaluate the properties in a location and time dependent manner.

The classical approach is to use the Packet Delivery Ratio (PDR) to evaluate the quality of information exchange. This metric defines the number of successfully received messages out of all sent messages. Depending on the application, either all or a certain percentage of sent messages can be required to be received that the applications can work sufficiently. In fact, not every sent message needs to be received, as messages can contain similar information. The PDR as a function of the distance already contains valuable information which should be explained at the following example. Assume the PDR trend for a typical IEEE 802.11p communication link, as displayed in Fig. 1 (black graph). The displayed PDR actually stems from the scenario, we will present in Section V. In this section we will explain the setup in closer detail. For now, it should be said that this PDR already includes the typical impairments found in realistic vehicular communication environments, as a fading radio channel and multi-access collisions. The PDR declines to 0 at the distance of 800 m, which depicts the maximum communication range. The other graphs in Fig. 1 show the number of messages that need to be sent for the reception of exactly one message. These graphs are derived from the PDR according to different approaches. The analytic approach uses merely the relation $\frac{1}{PDR}$ and can be seen as the optimistic estimation. The respective graph is the blue one in Fig. 1. The statistical approach uses the success probability for a series of retries and requires the success probability to be higher than a given confidence interval. This approach denotes the realistic case. Fig. 1 displays the case of a probability using typical confidence intervals of 95 % (green) and 99 % (red).

The diagram can be interpreted in the following way: When e.g. the $PDR = 1$, every message is received. This means for the optimistic as well as the realistic case, that one message needs to be sent in order that one message can be received. When the $PDR = 0.5$ (shaded rectangle in Fig. 1), the results for both cases are different. In the optimistic case it means that 1 message is received when at least 2 messages are sent. In the realistic case it means that 1 message is received with a probability higher than 95 % (actually 96.9 %) when 5 messages are sent. The number of sent messages for the reception success increases in the more stringent case of 99 % accordingly. Please note, if the draconic success probability of exactly 100 % of message reception would be required, the number of sent messages would tend to infinity in the case where the PDR is unequal to 1. Moreover, the number of sent messages implies the timing constraint when a certain sending rate is applied. The actual communication characteristics are then located in the corridor between the optimistic and the realistic case. This fact is one of the most important shortcomings of the PDR. The corridor between optimistic and realistic case can be very large. Furthermore, the worst case is typically more of interest, as we want to assure an error-free system and evaluate the limits where the system is not working anymore to suggest improvements. In a previous study [3], we used the PDR to measure the influence of communication properties on a navigation application. For different applied propagation models, the PDR also turned out different. In contrast, the application was not sensitive to these differences, as multiple messages with similar content could be received. Accordingly, in this case the PDR is not powerful enough to find the certain situation where the application performance changes.

Another classical metric that can cover timing properties is the transmission latency. It defines the delay from the message sending attempt to the reception. However, when it is used in the classical way and does not account packet losses, this metric is not necessarily useful. For the broadcast single-hop case it depends actually more on the packet length, furthermore on the distance and the speed-of-light. It is merely in the order of microseconds, which is negligible compared to the sending period in the order of milliseconds to seconds. However, when the PDR and the latency are combined, a more significant measure arises, which is the CCP.

III. Related Work

The need of the combination of the PDR and the latency to make statements about successful operation of applications was investigated by several researchers. Quite early, [4] presented the Inter Reception Time (IRT) to measure the delay between two successive successfully received messages. For the evaluation, the IRT was plotted over the time. [5] called this metric the Update Delay and did a statistical preprocessing of the distribution. The cumulative density function (cdf) was used for a boundary-estimation. Besides, the Inter Packet Gap (IPG) should be named as a further synonym of this metric. However, both papers investigated a freeway traffic situation that was quite static anyhow. In the case of the static scenario

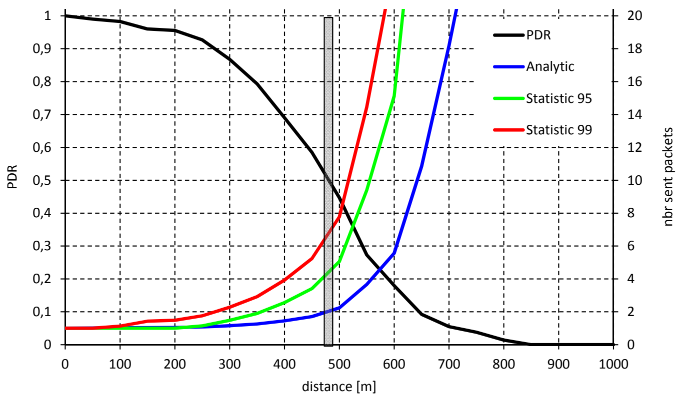

Fig. 1. PDR in relation to the implied numbers of sent messages for a successful reception

msgid	send.time	recv1.time	recv2.time	recv1.ccp	recv2.ccp
0	*1,000*	*1,001*	*1,001*		
1	1,100	-	-	-	-
2	1,200	1,201	1,201	0,200	0,200
3	1,300	-	1,301	-	0,100
4	1,400	1,401	-	0,200	-
5	1,500	-	-	-	-
6	1,600	1,601	-	0,200	-
7	1,700	-	-	-	-
8	1,800	1,801	1,801	0,200	0,500
9	1,900	-	1,901	-	0,100
10	2,000	2,001	2,001	0,200	0,100

TABLE I
EXAMPLE FOR SENDER AND RECEIVER RELATION (WITH *.TIME AND *.CCP IN S)

with homogeneous traffic pattern a cdf-aggregation might deliver a significant result. However, in a more comprehensive scenario with changing movement dynamics, an aggregation is not able to account for specific situations. In a follow up of [4], a related team measured the distribution of consecutive packet drops [6]. Consecutive packet drops in turn result in a higher inter reception time. Furthermore, they introduced the t-window reliability, which defines the probability that one message was received in a tolerance time window. The metric again confirms the importance that at least one message needs to be received for an error-free functioning of V2X applications.

[7] and [8] present a slightly different metric, which actually considers the same problem. [7] measure the number of Invisible Neighbors, which is the number of nodes that are in the vicinity of an ego-node, but their periodic messages have not been received within a certain time-frame. According to this principle, [8] calculate the ratio of visible neighbors to all neighbors and name it the Awareness Quality. Similar to the PDR, the calculation of a percentage already includes an averaging effect where certain important situations might be missed.

In this way, we see that the CCP conforms to the already proposed metric with the different synonyms IRT, Update Delay, IGP. However, here we present the approach to evaluate the maximum CCP_{max} of a clustered set of received messages to obtain the most significant result (as justified in the next Section IV). The clustering is done with a discretization according to time and space (i.e. the movement constellation and distance between two vehicles). The letter aspect allows identifying if a certain use case correlation between two vehicles actually exists or not.

IV. CCP METRIC FOR COMMUNICATION EVALUATION

In this section we shall present the method of using the CCP for the evaluation of communication properties. In addition we will compare different statistical analyses of the CCP, namely the arithmetic mean CCP_{avg} and the maximum CCP_{max}. We will show that the CCP_{max} delivers the more significant result to assess the influences of communication properties on application performance.

Basically, the CCP is the time between two successfully received CAMs. That means it can be represented in the following Equation 1, where n is the number of the successfully received messages and t_r is the time of the reception.

$$CCP(n) = t_r(n) - t_r(n-1) \tag{1}$$

In the first instance the CCP is only a metric for the relation of two individual received CAMs. It needs to be set into a statistical context for further evaluation. However, the evaluation of the simple arithmetic mean value CCP_{avg} will not deliver the most interesting outcome. It is more or less directly related to the PDR and the frequency of sent messages, as shown in the following example. The more significant result will be achieved by an evaluation of the CCP_{max}. The CCP_{max} can serve as a direct measure for burst errors. Burst errors can be caused due to shadowing and fading properties on the radio channel or uncoordinated medium access and corresponding packet collisions. In turn, failed message delivery for longer timespans has the most considerable effect on the performance of applications.

In Table I, we give an example of the communication relation between one sender and two receivers for individual messages and show the characteristics of the CCP. In this example, the sender emits CAMs with a fix frequency of $f_s = 10\ Hz$. Both receivers can either receive the CAM and then the timestamp of the reception is indicated; or miss the CAM. The transmission delay from the sender to both receivers is assumed constant with the value of 1 ms. However, it is of minor importance for the evaluation. The message with id $n = 0$ is the starting reference message and received by both receivers. The following $M = 10$ sent messages are used for the evaluation. Even though, both receiver conditions are chosen synthetically for the sake of explanation of the metric, both situations are possible. In the example the PDR is assumed to be the same for both receivers. It has an already quite low value of $PDR = 0.5$, which means each receiver can successfully receive 5 out of 10 sent messages. On the one hand Recv1 experiences steady conditions and can receive every second message. On the other hand Recv2 experiences a typical burst error situation, where it cannot receive messages for a longer period. Both conditions can be compared with the optimistic case for Recv1 and the realistic case with 95% probability for Recv2 from Fig. 1 (shaded rectangle).

The statistical evaluation of the CCP_{avg}

$$CCP_{avg} = avg(CCP(n)) = \frac{1}{N}\sum_{n=1}^{N} CCP(n) \qquad (2)$$

yields the same result for both receivers Recv1 and Recv2.

$$CCP_{avg}(Recv1) = CCP_{avg}(Recv2) = 0.2\ s \qquad (3)$$

As already explained before, one can see that the result depends directly on the PDR and the sending frequency f_s.

$$CCP_{avg} = \frac{1}{PDR \cdot f_s} = \frac{1}{0.5 \cdot 10\frac{1}{s}} = 0.2\ s \qquad (4)$$

As recently as the CCP_{max} is evaluated, the different receiving characteristics of Recv1 and Recv2 appear. With

$$\begin{aligned} CCP_{max} &= max(CCP(n)) \qquad (5)\\ &= CCP(n_0)\,\{n_0 | \forall n : CCP(n_0) \geq CCP(n)\} \end{aligned}$$

the concrete results for the example turn out different.

$$CCP_{max}(Recv1) = 0.2\ s \qquad (6)$$
$$CCP_{max}(Recv2) = 0.5\ s \qquad (7)$$

In this manner, the burst error in case of Recv2 can be clearly distinguished from the steady communication of Recv1.

Since the range of the CCP in general is determined by the sending frequency f_s, the CCP_{max} would tend to $\frac{1}{f_s}$ in case of a perfect reception quality. In contrast the CCP_{max} would tend to ∞ when the sender and the receiver are never in communication range. This means the intermediate values can arise due to a sender and a receiver being out of range anyway for a long term or due to a short term fading condition. This is why the CCP should always be evaluated as a function of the distance between the communicating nodes. We will show the practical evaluation method in the next section.

V. Evaluation Study

In this section, we shall illustrate the capabilities of the CCP for the assessment of vehicular communication applications. In particular, we will show several significant situations where use cases might be influenced. In sim^{TD}, we used the CCP for field operational tests, but it is suited as well for simulations. For the presentation in this paper, we have used VSimRTI [9] to set up a simulation scenario. VSimRTI couples well-established simulators from the different domains that are important for V2X communication. This allows us to use a traffic simulator to create realistic movement patterns for the simulated vehicles. Moreover, we use a communication simulator to reproduce the IEEE 802.11p communication stack [10] with all important characteristics, as a fading radio channel and the MAC protocol that is prone to packet collisions due to hidden terminals. The application simulator is used in this scenario as the data traffic source. In particular, we have used SUMO as the traffic simulator, OMNeT++ as the communication simulator, and the internal application simulator VSimRTI_App. As a further convenient effect, we were able to choose from the broad set of recording and evaluation tools provided by this simulation environment.

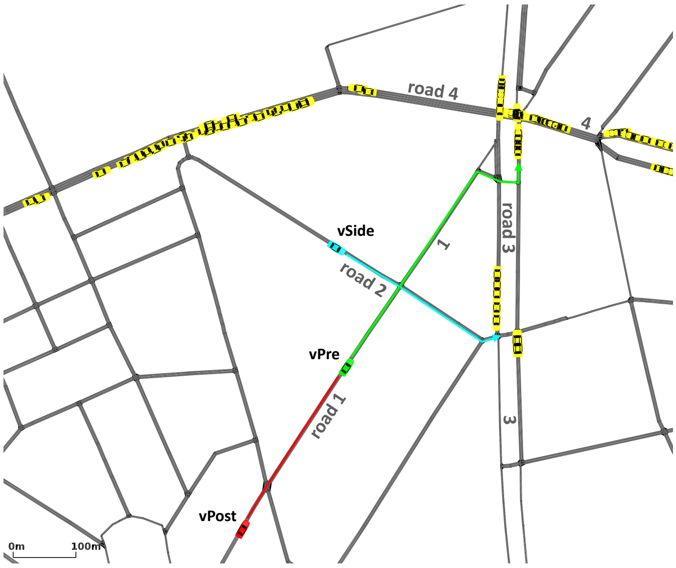

Fig. 2. Traffic situation with vehicles in a residential area in Berlin (road 1 - Kastanienallee, 2 - Oderberger Str., 3 - Schönhauser Allee, 4 - Danziger Str. to Eberswalder Str.)

A. Scenario

The setting is located in a residential area in Berlin, depicted in Figure 2. We especially put the focus on three vehicles of this scenario in the later evaluation. The vehicles vPre (green) and vPost (red) drive exactly the same route along the minor road of Kastanienallee (road 1) towards the main road Schönhauser Allee (road 3). The vehicle vPost is introduced with a time delay and follows vPre. The third vehicle vSide (blue) drives along the road 2, Oderberger Str. and crosses the route of the other vehicles at the intersection of road 1 and road 2. VPre and vSide reach this intersection at the same time (around the timestep of 130 s), while vPre has the right of way and vSide has to wait. The following vehicle vPost crosses the intersection at a time of 150 s. Consequently, the distance to vPost is long enough for vSide, to pass safely before vPost reaches the intersection. Regarding the correlation between vPre and vPost, both vehicles drive in a convoy situation with a certain distance between 200 and 300 m until vPre slows down before reaching the main road and vPost catches up. Finally, we introduce a traffic flow of additional vehicles (yellow) in both directions of the main roads 3 and 4. In this way, we have created a typical urban traffic situation. It can be seen as a step forward, compared to the simplified homogeneous movement models in the related work [4], [5].

parameter	value
transmit rate	10 Hz (100 ms)
carrier frequency	5.9 GHz
mac bitrate	6 MBps
tx power	50 mW (17 dbm)
rx sensitivity	-85 dBm
radio channel model	Rayleigh Fading

TABLE II
COMMUNICATION PARAMETERS USED IN THE SIMULATION SERIES

Regarding the simulated communication behavior, the vehicles exchange periodic CAMs with a sending frequency of 10 Hz. All vehicles use the default parameterization of the IEEE 802.11p communication stack. The radio channel is modeled as a Rayleigh Fading Channel. This means that only non-line-of-sight paths exist between the vehicles, which in turn denote the most severe fading conditions. For the CCP we can expect considerably high results, even for close-distance communication without collisions due to probable hidden terminals. The essential parameters for the simulation setup are depicted in Table II. Fig. 1 (see previous Section II) already contains the resulting PDR characteristic for all participating vehicles in this setup. Due to the simulated conditions the PDR decreases already at close distances. At a distance of 800 m the PDR equals zero, which denotes the maximum communication range using the given parameterization. Now, we mainly examine the communication behavior between the vehicles vPre, vPost and vSide. The other vehicles generate background communication and may disturb the reception quality of the examined vehicles. They are intended to create a realistic multi-access scenario.

As our evaluation is focused on the communication behavior, we have not implemented a specific application behavior for a certain use cases. Nonetheless, the scenario is set up in the way that use case situations are present. Prominent examples should be briefly named. A first situation for the Intersection Collision Warning exists between vPre and vSide in a bidirectional way. In this use case the movements of other vehicles (received by CAMs) are recorded and the drivers are warned when two vehicles approach an intersection in a critical way. Since the distance between vPost and vSide is too long, they would not correlate in this use case. When vPost is assumed to be an emergency vehicle, vSide is as well as vPre in the relevance area for an Emergency Vehicle Warning. In this use case all vehicles in the vicinity are informed about the route of an emergency vehicle to give right of way. It is definitely of interest for vPre, because it is on the same route as vPost. However, this information is also important for vSide to identify the direction of the siren. Furthermore, many use cases are possible for vPre to vPost, due to the follower constellation. For example with a Hazardous Location Warning vPre could inform vPost of obstacles on the street. The Emergency Brakelight Warning informs vPost of a hard braking event of vPre to prevent a possible rear end collision. The latter use case is only of interest for shorter distances between the vehicles, which will not always exist in the

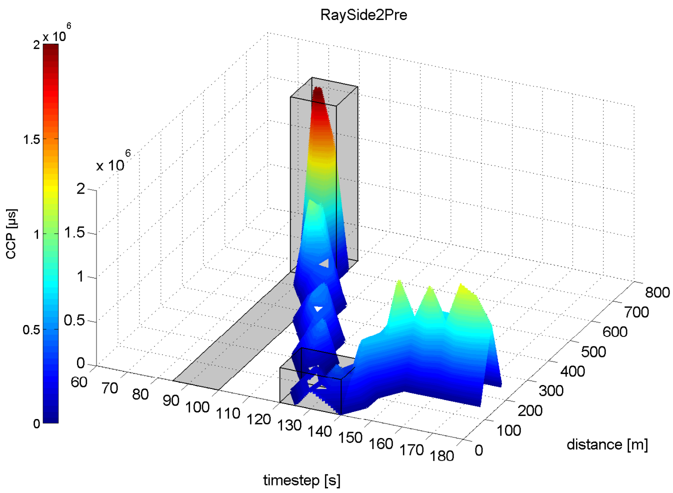

Fig. 3. CCP_{max} Diagram for vSide as sender and vPre as receiver. Vehicles meet at intersection at timestep of 130 s

scenario. We will address this issue in more detail when we present the results. Finally, for a Decentralized Floating Car Data use case for enhanced navigation and rerouting, all correlations between the vehicles are relevant to gather the current state from surrounding roads.

B. Results

In the next part, we visualize the outcome of the measured CCP_{max} in the following Figures 3, 4 and 5. Therefore, the CCP_{max} is plotted with a colored contour plot as a function of the increasing simulation time and the distance between sender and receiver vehicle. The data for the diagrams is prepared in the following manner: Every message transmission is annotated with a sequence number to be able to evaluate the successful delivery at the receiver side. For every possible sender and receiver constellation the time difference between the current and the last successful transmission is calculated. This CCP value is then stored according to the time step and the distance between both communicating nodes. Finally, a discretization is performed with time intervals of 5 s and distance steps of 50 m and the maximum value of the CCP is derived. In the visualization, only measurement points are assigned with a color. The color map for the CCP_{max} has blue color values for smallest CCP_{max} and red color for the highest CCP_{max}. Due to the sending period of 10 Hz, the smallest value for the CCP_{max} can be 100 ms in any case. On the other side, higher values than 2 s are possible, but they are omitted in the visualization. The consideration of both dependencies time and distance between vehicles is important, as it allows following the respective movement constellations between each pair of vehicles. We have selected three examples of the communication relation between two vehicles:

1) vSide as sender and vPre as receiver in Fig. 3
2) vPre as sender and vPost as receiver in Fig. 4
3) vPost as sender and vPre as receiver in Fig. 5

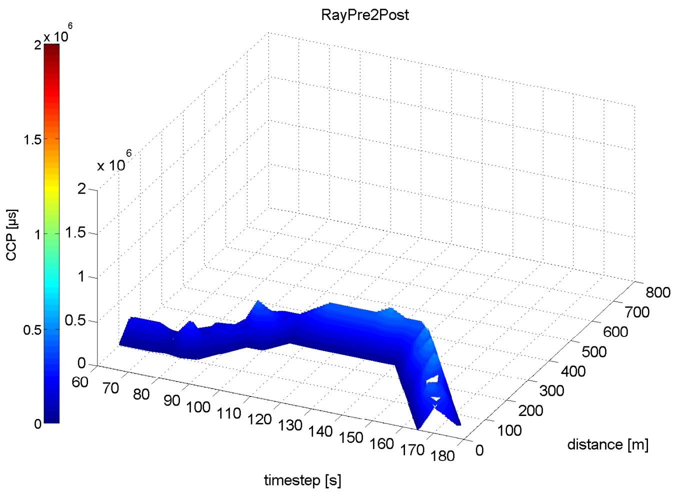

Fig. 4. CCP_{max} Diagram for vPre as sender and vPost as receiver. Due to following situation of vPost, CCP is of interest all time

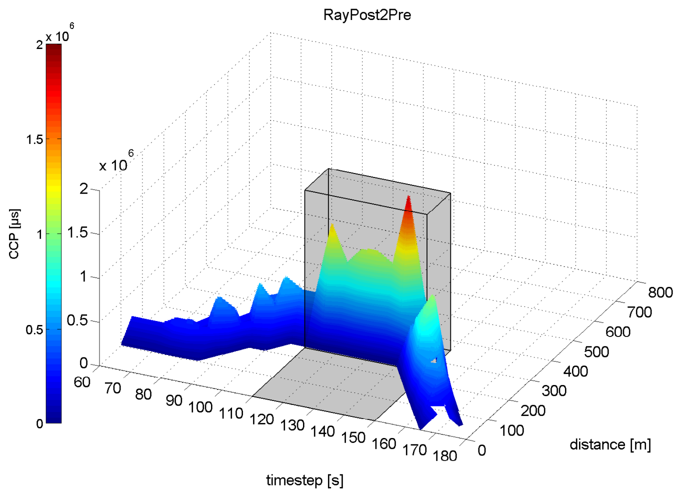

Fig. 5. CCP_{max} Diagram for vPost as sender and vPre as receiver. Visible Hidden Terminal effect in timeinterval starting at 110 s

In these exemplary correlations, the previously described use cases can occur. In fact, the identification of the correlation for a use case is one of the main tasks for the analysis of the scenario. For a more comprehensive evaluation, it would be realized with an automated workflow.

As mentioned before, the scenario is set up in a way that vSide approaches the intersection of road 1 and road 2, crosses the intersection at the time around 130 s and departs afterwards. The characteristic movement constellation between vSide and vPre can be retraced very well in Figure 3. In the diagram, the distance between the vehicles declines up to the time of 130 s, where both meet at the intersection. The distance there is in the interval of 0 to 50 m. Afterwards, it increases again. Additionally, we introduced two shaded cuboids as markers for significant situations. The first marker indicates the situation where both vehicles come into communication range for the first time. It occurs at the simulation time step of around 85 s and a distance between both vehicles in the order of 700 m. The situation is characterized by CCP_{max} values of around 2 s. With the given constant message sending rate of 10 Hz, it implies burst errors of more than 20 lost messages. The behavior goes along with the presented statistics of the PDR in Figure 1. There is no reception over 800 m and at most one received message out 20 between 700 m and 800 m, which causes the CCP_{max} of 2 s at 700 m. As expected, the communication characteristics improve at shorter distances and the CCP_{max} declines up to the time step of 130 s. At the second marker, the CCP_{max} has a value in the order of 0.4 s, which means that at most 4 messages need to be send that one message is received. Compared to the capabilities of the PDR evaluation, we now have a precise estimation in contrast to the statistical corridor, which can be derived using presented probabilities. Of course, the PDR evaluation delivers the same result as the CCP_{max} for certain points. However, the CCP_{max} allows a convenient assessment towards the expected performance of use case applications over the complete data range. For example, navigation use cases such as Decentralized Floating Car Data could be facilitated with infrequent messages up to distances of 700 m single-hop. Furthermore, the situation for the Intersection Collision Warning would be approximately the following. With a speed of 40 km/h, a vehicle would cover a distance of 4.4 m in the timespan of 0.4 s. An according warning application needs to be able to handle these conditions to work correctly. A comprehensive use case evaluation might, certainly, account further issues.

The following Figures 4 and 5 show at the first glance the same movement constellation. Both vehicles are in communication range from the beginning. The distance slightly increases in between, due to the change of the roads speed limit from 30 km/h to 50 km/h. As vPost is in the follower position of vPre, many use case situations would exist over the whole observed timespan. For instance a hard braking event of vPre can always occur, so that vPost needs to be informed. In contrast, only few use cases exist, where vPre needs to be informed by its following vehicles. When vPost senses a hazardous event, vPre might have already passed the according location. However, an approaching emergency vehicle from behind would be a relevant example. Regarding the analyzed communication characteristics, both figures show a different trend. The CCP_{max} for the communication from vPre to vPost (Fig. 4) exerts quite low values. At shorter distances (of around 150 m) at the beginning of the simulation, even CCP_{max} values in the order of 0.1 s are measured. It denotes the case when every message can be received successfully by vPost. At higher distances the CCP_{max} slightly increases to 0.4 and 0.5 s. In contrast the communication in the opposite direction from vPost to vPre (Fig. 5) shows a more dynamic behavior. While the CCP_{max} is similar to the first case, it changes seriously at the simulation time around 110 s. This effect is marked with the shaded cuboid in the diagram. The effect of the degradation of successful message delivery can be explained with the Hidden Terminal Problem. Circa at the time of 110 s vPre enters the communication range of the background vehicles on the main roads 3 and 4. These vehicles also communicate with periodic messages. However, they are not able to sense message transmissions of vPost, as it is still out of communication range. Hence, they are not able to coordinate their sending attempts. This leads to frequent collisions at vPre. For the capabilities of the CCP it means that it is suitable to directly measure dynamic changes in the according situation. In contrast, the PDR was only able to give average results of the whole scenario. We can conclude the evaluation with the statement that it is favorable to use the CCP_{max} in any cases where dynamic changes are considered. This applies for typical use case evaluations, but also validations of newly developed communication protocols and investigations of the influences of propagation models.

VI. Conclusion

In this paper, we have presented the Consecutive CAM Period (CCP) as a suitable metric for the assessment of vehicular communication applications. The CCP measures the time between two successfully received packets. In this way it can be seen as a combination of the well-established communication metrics of the Packet Delivery Ratio (PDR) and the Packet Delay. When the PDR is used for evaluation, typically the arithmetic mean value is analyzed. The CCP is not an entirely new metric. It conforms to metrics from related work under different synonyms, as Inter Reception Time, Inter-Packet Gap or Update Delay. However, in a brief derivation, we have identified that especially the evaluation of the statistical maximum, namely the CCP_{max} is able to achieve the most significant result to measure burst errors due to fading conditions or packet collisions. The maximum evaluation gives a worst case estimation, which has several advantages over a best effort estimation concerning the performance of the V2X use case applications.

After that, we have set up a simulation scenario to illustrate the capabilities of the CCP_{max}. We employed the same workflow, which we have used for the technical evaluation of the communication properties in the sim^{TD} project, a German field operation test. Important for the analysis of the CCP is, that it is evaluated in dependence of the time as well as the distance. Consequently, it is possible to identify situations for the use case applications, which might be missed with an evaluation using the average PDR. Even though our specific scenario was set up with the focus on the presentation of the metric, one additional interesting outcome is that it is very important to consider the vehicle movement constellation. The scenario featured a more realistic, unstatical movement choreography. The results showed that when two vehicles approach a crowded area the communication from the leading vehicle towards the following vehicle works acceptable. In contrast, the opposite direction is strongly impaired by the Hidden Terminal Problem. This means that for the development of protocols or applications it is favorable to avoid stationary scenarios for verification. Moreover the analytic approach of VCOM for the communication simulation [1], [11] might be of limited use in a more realistic traffic scenario where vehicle densities change dynamically.

VII. Outlook

We have identified two work packages for future activities. First investigations should address the communication properties more in detail. In a previous work we introduced detailed communication models to our simulation infrastructure [12]. The CCP is qualified for measuring the influences of these models. Thus, we plan on doing a study where we evaluate especially time critical safety use cases. A second package will include the evaluation of multiple use case applications running in parallel in one scenario. As use cases have different requirements concerning the CCP this needs to be considered, too. For example safety critical use cases require a short CCP, but operate at shorter distances. Navigation use cases allow higher CCPs, but need a high communication range for efficient functioning.

References

[1] H. Hartenstein and K. Laberteaux, *VANET: vehicular applications and inter-networking technologies*. Wiley Online Library, 2010, vol. 1.

[2] H. Stubing, M. Bechler, D. Heussner, T. May, I. Radusch, H. Rechner, and P. Vogel, "simtd: a car-to-x system architecture for field operational tests [topics in automotive networking]," *Communications Magazine, IEEE*, vol. 48, no. 5, pp. 148–154, 2010.

[3] R. Protzmann, B. Schünemann, and I. Radusch, "The influences of communication models on the simulated effectiveness of v2x applications," *Communications Magazine, IEEE*, vol. 49, no. 11, pp. 149–155, 2011.

[4] T. ElBatt, S. K. Goel, G. Holland, H. Krishnan, and J. Parikh, "Cooperative collision warning using dedicated short range wireless communications," in *Proceedings of the 3rd international workshop on Vehicular ad hoc networks*. ACM, 2006, pp. 1–9.

[5] B. Kloiber, C. Garcia, J. Härri, and T. Strang, "Update delay: A new information-centric metric for a combined communication and application level reliability evaluation of cam based safety applications," in *ITS World Congress*, 2012.

[6] F. Bai and H. Krishnan, "Reliability analysis of dsrc wireless communication for vehicle safety applications," in *Intelligent Transportation Systems Conference, 2006. ITSC'06. IEEE*. IEEE, 2006, pp. 355–362.

[7] H. Lu and C. Poellabauer, "Analysis of application-specific broadcast reliability for vehicle safety communications," in *Proceedings of the Eighth ACM international workshop on Vehicular inter-networking*. ACM, 2011, pp. 67–72.

[8] R. Schmidt and T. Leinmüller, "A spatio-temporal metric for the evaluation of cooperative awareness," in *18th World Congress on Intelligent Transport Systems*, 2011.

[9] B. Schünemann, "V2x simulation runtime infrastructure vsimrti: An assessment tool to design smart traffic management systems," *Computer Networks*, 2011.

[10] "Ieee standard for information technology–telecommunications and information exchange between systems–local and metropolitan area networks–specific requirements part 11: Wireless lan medium access control (mac) and physical layer (phy) specifications amendment 6: Wireless access in vehicular environments," *IEEE Std 802.11p-2010 (Amendment to IEEE Std 802.11-2007 as amended by IEEE Std 802.11k-2008, IEEE Std 802.11r-2008, IEEE Std 802.11y-2008, IEEE Std 802.11n-2009, and IEEE Std 802.11w-2009)*, pp. 1 –51, jul. 2010.

[11] M. Killat and H. Hartenstein, "An empirical model for probability of packet reception in vehicular ad hoc networks," *EURASIP Journal on Wireless Communications and Networking*, vol. 2009, p. 4, 2009.

[12] R. Protzmann, K. Mahler, K. Oltmann, and I. Radusch, "Extending the v2x simulation environment vsimrti with advanced communication models," in *ITS Telecommunications (ITST), 2012 12th International Conference on*. IEEE, 2012, pp. 683–688.