An Approach for Performance Analysis of ETSI ITS-G5A MAC for Safety Applications

Bernhard Kloiber, Thomas Strang, Fabian de Ponte-Müller, Cristina Rico Garcia, Matthias Röckl
Department for Communications and Navigation
German Aerospace Center
82234 Wessling, Germany
{bernhard.kloiber,thomas.strang,fabian.pontemueller,cristina.ricogarcia,matthias.roeckl}@dlr.de

***Abstract*—ETSI ITS-G5 is the current vehicle-to-vehicle communication technology in Europe, which will be standardized by ETSI TC ITS[1]. It is based on IEEE 802.11p and therefore uses a CSMA/CA scheme for media access control (MAC). In this paper we analyze the performance of ETSI ITS-G5 MAC in a challenging scenario with respect to MAC issues: A suitable freeway segment with 6 lanes in each direction. The freeway scenario is thoroughly modelled and implemented in the well known ns-3 simulation environment. Based on this model, the paper shows the performance of ETSI ITS-G5 MAC under MAC challenging conditions. We provide a particular performance metric which incorporates the key requirements of safety applications.**

I. Introduction

After the huge success of passive safety systems and similar success indicators seen with recent advanced driver assistance systems towards a "zero accidents" vision in future Intelligent Transport Systems (ITS), the next big potential is seen in cooperating systems [25]. For this to become reality, a robust and reliable vehicle-to-vehicle and vehicle-to-roadside communication is a necessary prerequisite as an enabling technology. ETSI TC ITS is paving the way towards this by standardizing ETSI ITS-G5 [2], a Vehicular Ad-hoc NETwork (VANET) communication standard based on IEEE 802.11p [4]. Using this communication technology, vehicles can inform each other about their current status and certain events, providing the necessary means to establish a cooperative situation awareness. Safety applications, which are in the focus of our work, can process the received information either to warn the driver about some upcoming dangerous situation, up to eventually automatically control the vehicle to avoid the situation entirely or at least to significantly decrease its effect.

Currently, the following two message types are being standardized and used [26]:

- **CAM (Cooperative Awareness Message):** This message is used to inform the other vehicles about the current status of the sending vehicle, such as the current geographical position, speed and heading. CAMs are typically broadcasted as periodical beacons with a frequency of 1-10 Hz.
- **DENM (Decentralized Environment Notification Message):** This message is used to inform the vehicles in a certain area close to an event about a special event such as roadwork construction or an accident.

As mentioned we will focus our analysis on safety applications such as a lane merging assistant. However it has to be kept in mind that the application using a certain message is usually determined on the receiver side, i.e. the same message which is broadcasted by a vehicle can be used for safety and non-safety applications at the same time, which means that basically all communications has to comply to a certain minimum set of requirements. This set includes in particular the following parameters:

- **Availability:** The information must be available to the safety application when it is required.
- **Accuracy:** The information must be accurate enough so that the safety application can work correctly, i.e. within well-defined boundaries. For instance, a lane merging assistant should be able to decide reliably if an approaching vehicle is driving on the same lane, or on the lane beside it, according to the position information in the message.
- **Reliability:** Reliability is the measure of consistency for an information distributed in a VANET and the safety application using this information. The application should yield similar results over time with similar populations in similar circumstances. In other words, reliability is the extent to which a measurement instrument yields consistent, stable, and uniform results over repeated observations or measurements under the same conditions each time.
- **Up-to-dateness:** The information of a message should be up-to-date. The older the message, the more useless the information is for the safety application under normal conditions. This is valid for periodic messages, where the time between two consecutive CAMs should not be too high, as well as for event-driven messages, where the latency should not exceed a certain threshold.
- **Integrity:** To get reliable outputs from any safety application, the information of a message must be intact. That means the message should not be damaged or falsified. Obviously this is part of a set of security requirements, which are very important for VANETs.

ETSI ITS-G5 mainly describes the physical (PHY) and medium access control (MAC) sublayer of ITS stations operating in the 5.9 GHz frequency band. It covers the frequency

[1]European Telecommunications Standards Institute Technical Committee for Intelligent Transportation Systems.

ranges G5A, G5B and G5C, of which G5A is dedicated for safety and safety related applications. Other applications have to use the G5B or G5C frequency bands. ITS-G5A PHY defines three 10 MHz channels, one control channel (CCH) and two service channels (SCH1 and SCH2). ITS-G5A allows vehicles to send with a transmit power of up to 33 dBm, thus communication ranges up to 1000 m can be expected under ideal conditions. The modulation scheme which is used for ITS-G5A is Orthogonal Frequency Division Multiplexing (OFDM). This technique provides data rates from 3 MBit/s up to 27 MBit/s.

The MAC layer of ITS-G5A uses a Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) scheme to access the shared media. CSMA/CA is known to perform well in uncongested networks, but degrades dramatically with a strong increase in network load [15]. A reason for this is that the collision avoidance mechanism of CSMA/CA relies on acknowledgement messages which do not make sense for broadcasted messages such as the CAM beaconing messages used as the core of safety applications. Similarly, there is no RTS/CTS mechanism available to avoid the hidden terminal problem in VANETs.

As we will describe in the related work section, several simulations as well as analytical calculations of the art have been done to analyze the performance of VANETs. Most of them use common networking metrics such as throughput, latency and packet collision probability to compare variations of MAC schemes. In contrast to this other work, we will analyze the performance of CSMA/CA in VANETs from the particular perspective of the needs for safety applications.

In this paper we want to present three contributions according to the performance analysis of ITS-G5A MAC:

- First we describe a simulation scenario, which is suitable for MAC performance analysis, because of it's particular MAC challenging properties.
- We introduce a special metric which incorporates the key requirements of safety applications as mentioned above. We also give a suitable representation of this metric, which is very helpful for safety application designers.
- Finally we present a set of simulation results, for the MAC challenging scenario, according to our performance metric.

The reminder of this paper is organized as follows. Section II discusses some relevant related work. The scenario which was designed to be particularly challenging for MAC schemes is introduced in section III. The performance metric we used to evaluate the MAC schemes in our simulations is described in section IV. Finally section V reports the results of our simulations.

II. Related Work

Several papers have been published, which analyze the performance of VANETs. Most of them use throughput, latency and reception or collision probability as performance metrics. [6] evaluated the performance of IEEE 802.11p WAVE, including the influence of the different access classes. They used the average packet throughput, the collision probability and the end-to-end delay to measure the performance. Brakemeier [15] analyzed VANETs analytically by treating them as a stochastic process with Poisson distributed message arrivals. He calculated the average packet delay and the packet loss probability for evaluation purposes. In [11] the packet reception probability was analyzed. Therefore the authors have concentrated on the distance based interference effect, if an emergency vehicle approaches a traffic jam. Bilstrub [8] simulated the performance of 802.11p MAC to compare it with their proposed STDMA approach. They measured the distributions of the channel access delay, of the distance within nodes which are sending at the same time and of the number of consecutive packet drops. A similar study was published by [9]. They also compared 802.11p with an own MAC scheme called RR-Aloha+ and it's improved version MS-Aloha. For comparison they used mainly the well known latency metric and the packet delivery ratio (PDR) which is just an equivalent to the packet reception probability. [7] did some simulations of a city scenario. To analyze the performance, they used the packet latency and throughput as metrics. In [12] the authors chose among others the probability of successful reception, the channel busy time and the channel access time to evaluate the VANET communication. A real world experiment with a fleet of three vehicles was done in [14]. There the packet delivery ratio and the distribution of consecutive packet drops were used as performance metric. They also characterized a kind of application-level reliability, which is the most important information for safety application designers. [10] simulated a freeway scenario and used the packet inter-reception time, the cumulative number of packet receptions, the packet success probability and the per-packet latency to do a performance evaluation. The packet inter-reception time basically conforms our special performance metric, but in their paper they only presented this metric over simulation time and did no statistically preprocessing for a more precise analysis. In contrast our paper is really concentrating on this metric and is working out it's great importance for CAM based safety applications. Furthermore we will show a detailed statistical analysis, including a suitable representation of this metric, which is very significant to evaluate the MAC performance with respect to key requirements for safety applications.

Unsurprisingly, the performance results of all these differ significantly, given the variations in performance metrics. Also many models are too simplistic, same making unrealistic assumptions. Therefore the results of the different performance analyses are not directly comparable. In particular, one cannot derive reliable statements whether the current MAC scheme is sufficiently robust and reliable for safety applications or not.

III. The Freeway Model

A. Scenario

In this paper we focus on the MAC performance. That means, we have to look for a really MAC challenging scenario. Because we consider safety and safety related applications here, we first analyzed official accident statistics provided

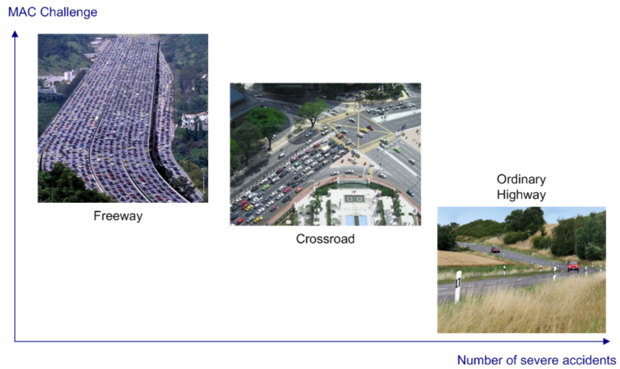

Fig. 1. Classification of three main scenarios by means of accident statistics.

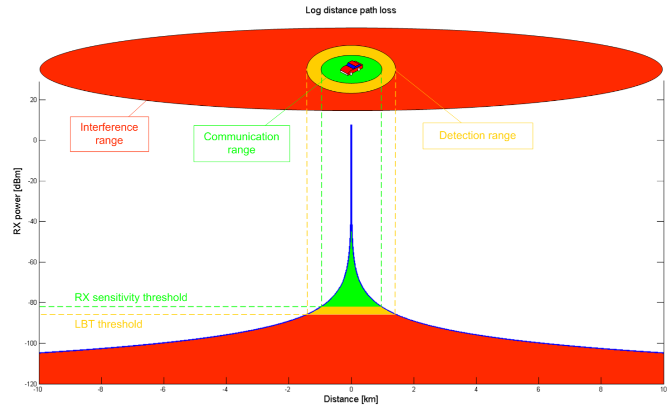

Fig. 2. According to the path loss a propagating message passes three spatial sections during transmission.

by the "Statistisches Bundesamt" in Germany [23]. Here we identified three main scenarios which are top-ranked according to the amount and severity of accidents. We tried to classify them correctly according to 'MAC challenge' and the 'number of severe accidents', as depicted in figure 1.

The most dangerous scenario has exposed to be the *ordinary highway*. Because most of the crashes are self-imposed here, vehicle-to-vehicle communication might not support the prevention of these kind of accidents. Infrastructure-to-vehicle communications using roadside units could help, but would be very expensive in deployment to cover ordinary highways in a sufficient manner. According to the MAC challenge, there is typically not enough vehicle density on ordinary highways, due to their spatial distribution.

The second type of scenarios are *crossroads*. They have to cover a lot of traffic, and cause many accidents. Crossroads have usually the property that they are confusing and therefore they cause a lot of accidents by overlooking traffic participants. Vehicle-to-vehicle communication could have a great impact here, by informing the road user about the correct situation on the roads or about arising hazards in time.

The last identified scenario is the *freeway*. In comparison with the first two scenarios, the freeway is relative safe, as reflected by the total number of accidents compared to the other two scenarios (although the severity of an accident on a freeway is usually more critical than on other scenarios as the speed of the vehicles is higher in average). However, according to the MAC challenge, a freeway can cause very high vehicle densities (in particular on freeways with many lanes), and therefore a lot of data traffic, which may cause problems in particular for the MAC scheme in use. To sum up, the following characteristics of a freeway are the main reasons for choosing the freeway as our target scenario for the remainder of the paper:

- **High vehicle density:** On a multi-lane freeway, a high vehicle density can be achieved. A lot of vehicles causes a lot of data traffic, what challenges the MAC.
- **Rapid state changes:** The states of the vehicles usually change rapidly (e.g. positions). Therefore a lot of information exchange is needed to keep other vehicles in the vicinity up-to-date (see accuracy, availability, reliability, up-to-dateness, integrity etc. above).

B. Modelling the Scenario

A generic freeway scenario for VANET performance analysis can be modeled as follows. Given the theoretical range of ITS-G5A transmissions (cf. figure 2), the length of a freeway section has to be at least 5 km. To take care of the edge effect [2], an edge of 1 km at both ends of the freeway section have to be foreseen, as is depicted in figure 3. To incorporate a variability in the number of lanes of a freeway, n lanes should be foreseen in each direction. The lane width is 3.5 m, the road shoulder has a width of 2 m.

We propose to use a stochastic approach for modeling the traffic on the freeway. To describe the process of the arrival of events typically the well known Poisson process is used. Within a Poisson process the random number of events until a certain point in time is Poisson distributed. The random waiting time until the n^{th} event occurs is Erlang distributed. The related probability density function is defined by the equation

$$f_{Erlang}(x) = \begin{cases} \frac{(\lambda \cdot x)^{n-1}}{(n-1)!} \cdot \lambda \cdot e^{-\lambda x} & x \geq 0 \\ 0 & x < 0 \end{cases} \quad (1)$$

with $mean = \frac{n}{\lambda}$ and $variance = \frac{n}{\lambda^2}$. In the special case that $n = 1$, the Erlang distribution leads to an exponential distribution, which describes the random waiting time between two consecutive events. In this paper we propose to model the traffic on each lane separately following an Erlang distributed random variable parameterized by the so called *Mean Time Ahead Distance (MTAD)*. The mean of this random variable per lane (see E_1 to E_{12} in figure 3) can be varied and represents the mean time ahead distance between consecutive vehicles, i.e. $n = 1$ and $\lambda = \frac{1}{MTAD}$ with respect to equation (1). The vehicles are generated for each lane with driving speeds of 20 m/s on the outer (slowest) lane up to 40 m/s on the inner (fastest) lane. We do not consider lane changing

[2]The edge effect is caused by missing vehicles outside the freeway section, because they would influence the communication between vehicles at the edge of the freeway section.

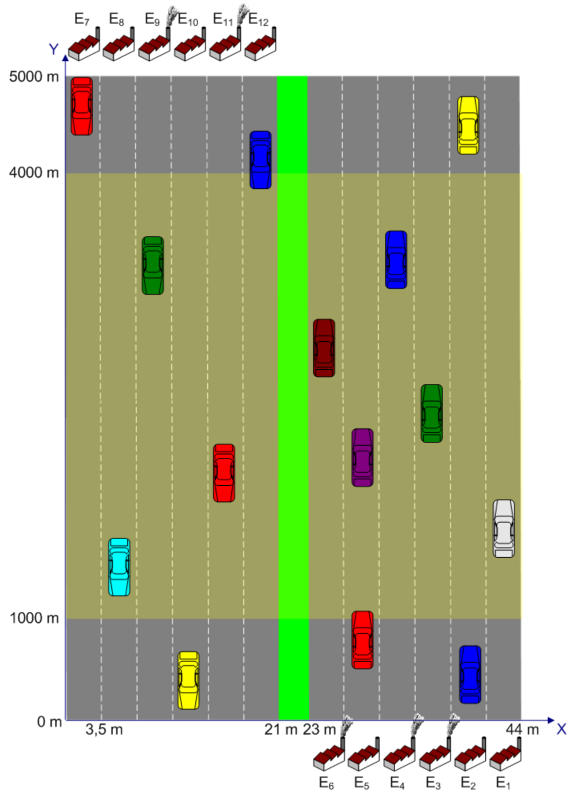

Fig. 3. The generic statistical freeway model.

here because our purpose is to model a lot of data traffic for challenging the MAC and not to model the traffic as accurate as possible.

Therefore all the vehicles are equipped with virtual beaconing communication units, which implement the ITS-G5A technology explained in section I. Here the core parameters are on PHY layer a maximum transmit power of 33 dBm, a channel width of 10 MHz and a data rate of 6 MBit/s, which is the default data rate on the CCH. To simulate the radio propagation, a proper channel model of the VANET freeway communication channel would be required. Since we are focusing on the MAC layer here, we use a simple log-distance path loss model for radio propagation, which is a sufficient approximation. This has the advantage, that unwanted PHY layer effects will be neglected and mainly the MAC layer effects influences the results. To compute the attenuation A of a transmitted signal at a certain distance d the following equation is used,

$$A = A_0 + 10n \lg \left(\frac{d}{d_0} \right) \tag{2}$$

where A_0 is the attenuation at reference distance d_0.

According to our used propagation model based on equation (2), a propagating message passes three spatial sections during transmission as depicted in figure 2. The first section (green part) is the communication range, within the message can be decoded by the receiver. The second section (orange part) is called detection range, within the channel can be sensed as busy, but the message can no longer be decoded. The coverage of both sections is limited by the RX sensitivity threshold and the Listen Before Talk (LBT) threshold respectively. The last section (red part) is the interference range, within the channel is sensed to be free, but the message can still interfere with other transmissions. To achieve communication ranges nearly up to 1000 m which is the target under ideal conditions of vehicle-to-vehicle communication, we chose a value of 2.25 for the path loss exponent n in equation (2). We further made use of the SNIR (Signal to Noise and Interference Ratio) based YANS error rate model which is described more detailed in [28]. That implies that also the capture effect[3] will be considered.

IV. Performance Metric

To analyze the applicability of ETSI ITS-G5A for safety applications which rely on periodic beaconing of CAMs, an appropriate performance metric is required. Most of the current literature which analyzed the MAC performance in VANETs have used standard network metrics such as throughput, latency and reception probability. However, these metrics do not allow to derive direct conclusions with respect to the key requirements of safety applications, such as accuracy, availability, reliability, up-to-dateness and integrity like reliability and up-to-dateness etc. as described above.

A much more suitable performance metric for this purpose has been introduced in [21]: The so called *update delay* represented as *Complementary Cumulative Distribution Function (CCDF)*. In [21], the update delay distribution is used to analyze the MAC performance for railway collision avoidance applications based on periodic messages similar to CAM beaconing. The update delay is a metric used at the receiver side and represents the time difference between two consecutive CAMs for a certain specific sender.

In this paper we propose to use the update delay performance metric also for analyzing the road based inter-vehicle communication. According to CAM based safety applications, we think that the update delay distribution is an excellent performance metric because of the following reasons:

- The main purpose of CAMs is to distribute latest status information of every vehicle to all other vehicles in the surrounding, to establish so called *cooperative situation awareness*. A reliable cooperative situation awareness is a necessary prerequisite in particular for any safety application. Depending on the time the last CAM was received, the vehicles have a more or less up-to-date knowledge about the adjacent vehicles. The update delay represents implicitly the up-to-dateness of the information available at the receiver about a certain transmitter (see figure 4), which is a key requirement for safety applications as mentioned above.
- Furthermore, the CCDF for an update delay presents the reliability for not exceeding a maximum update

[3]The capture effect means that in spite of interferences the message can be received correctly because of a sufficiently high SNIR.

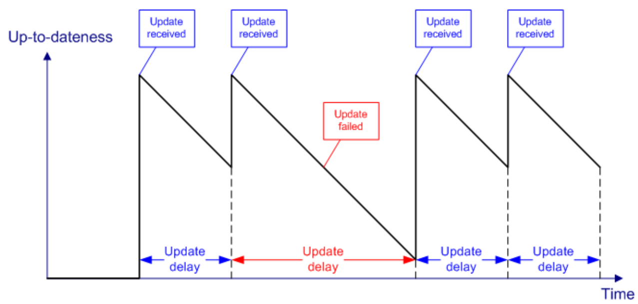

Fig. 4. The behaviour of the up-to-dateness about a certain vehicle in the vicinity.

delay value. It can thus be used to formally specify a boundary to classify protocol variations with respect to their reliability.

- Additionally the update delay performance metric inherently contains other performance metrics. Because it is receiver based, the latency (end-to-end delay) metric is implicitly included by the update delay metric. Also the number of consecutive packet drops is covered by the update delay because it's only an alternative representation of it.

The update delay represented as CCDF has exposed to be a very good performance indicator for ITS-G5A MAC according to CAM based safety applications. It incorporates important key requirements for safety applications as mentioned in section I, and implicitly covers also other metrics. Thus we will use the update delay performance metric as our key metric in the evaluation section below.

V. The Simulation

For our performance analysis we used ns-3, an open-source event based simulation environment written in C++, which provides a lot of useful features. The stable release at that time was ns-3.6. In order to be able to simulate with the current ETSI ITS-G5A communication technology, we had to extend a standard 802.11 protocol towards the latest version of the definition of ITS-G5A, i.e. we implemented many of the specific communication protocols as they were not available for ns-3 at that time.

To be able to analyse the performance of ITS-G5A MAC, we implemented the freeway model introduced in the last section with 6 lanes in each direction.[4]

Data traffic is generated by the simulation using the virtual ITS-G5A units "on board" of every virtual vehicle. The vehicles start with beaconing CAM messages immediately after their generation. The beaconing rate is varied by several simulation runs. The message size is 500 Byte, security aspects included, which was derived as a good average from datasets collected at a car-to-car demonstration event in 2008 [1].

The simulation time is 10 minutes for each run. The tracing procedure is receiver based and doesn't start until the freeway is completely filled with vehicles (initialization phase). Only messages received within the freeway core (yellow area in figure 3) are considered in the evaluation to take care of the edge effect. Each vehicle within the freeway core records the time difference between two consecutive CAMs of the same transmitter. By means of these time differences the receiving vehicles build up a common histogram of all accumulated update delays. When the simulation ends, this histogram is used to derive the so called Complementary Cumulative Distribution Function (CCDF) as mentioned above. In the next section we will explain the CCDF in more detail. Table I summarizes the most important simulation parameters.

[4]For those who are interested in our ns-3 implementation of the freeway model, please contact one of the authors.

TABLE I
Simulation parameters

Simulation time	10 min
Length of freeway section	5 km
Length of freeway edge	1 km
No. of lanes per direction	6
Mean time ahead distance	2 s, 5 s, 10 s
Vehicle speed for each lane	20 m/s, 24 m/s, 28 m/s, 32 m/s, 36 m/s, 40 m/s
Transmit power	33 dBm
Channel bandwidth	10 MHz
Datarate	6 MBit/s
EDCA Priority Queue	AC_VO
Pathloss model	Log-distance with exponent 2.25
Communication range	up to 1000 m
Error model	SNIR based
Beaconing rate	1 Hz, 2 Hz, 4 Hz, 8 Hz
Message size	500 Byte

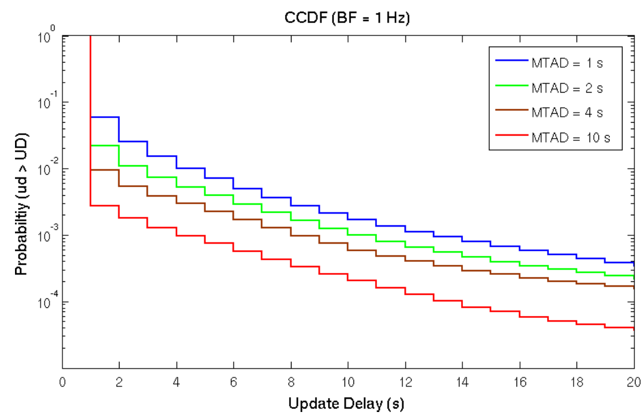

Fig. 5. Update delay distribution for a fixed beaconing frequency and different mean time ahead distances.

VI. Results

To analyse the behaviour of the MAC performance under a variety of node densities, we varied the data traffic density by different simulations. In the simulation, this variation is mainly controlled with two parameters, the Mean Time Ahead Distance (MTAD) between consecutive vehicles and the Beaconing Frequency (BF).

Figure 5 shows the results of our simulations with a fix BF setting of 1 Hz and increasing data traffic by decreasing the

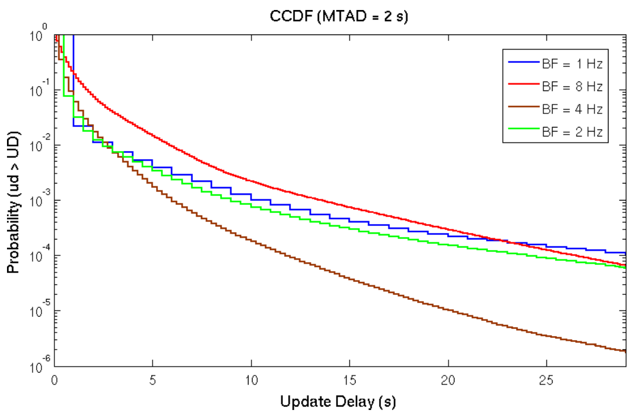

Fig. 6. Update delay distribution for a fixed mean time ahead distance and different beaconing frequencies.

MTAD. The complementary update delay distribution plot is shown for MTAD values 1 s, 2 s, 4 s and 10 s. The CCDF plot uses a logarithmic scale to give insight into the behavior of the curves in the range of low probabilities.

Note: The CCDF is a step function becaue the periodic CAM transmission schedules the sending events at discrete equidistant points in time. The step size is dependent on the beaconing frequency, i.e. the higher the BF, the smaller the step size.

The CCDF plot in Figure 5 can be used to directly derive a reliability value. To do so, one picks one of the curves (e.g. the red one which represents a relative sparse density of vehicles on the freeway with a MTAD of 10 s) and chooses a maximum update delay, e.g. 5 s which depicts the maximum time a certain safety application allows as uncertainty about the state of a relevant vehicle in the vicinity to work correctly[5]. Than the CCDF can be used to analyse that the safety application would achieve a reliability of $1 - probability = 99.925$ percent. On the same freeway with very high vehicle density (MTAD = 1 s), safety applications can only reach a reliability of 99.3 percent.

With respect to the PHY layer, safety of life communication systems are considered reliable if bit error rates of 10^{-8} and less can be achieved. By comparing these values with the curves in Figure 5 it is easy to see that the failure probability of most safety applications is in the range of 10^{-3} for BF set to 1 Hz.

For comparison, figure 6 shows the CCDF for the different BF values of 1 Hz, 2 Hz, 4 Hz and 8 Hz given a fix MTAD of 2 s and increasing the data traffic by increasing the BF.

Just like in the previous simulation result, the failure probability is again in the range of 10^{-3} for safety applications which allow a maximum update delay of $5 - 10$ s, too.

The plot in figure 6 shows another very interesting property. As usually assumed, the update delay distribution with 1 Hz BF is the best for low maximum update delay numbers. But with increasing update delay values, the curves with higher BFs outperform the distributions with lower BFs. The reason for this behaviour can be explained as follows. The update delay distribution is driven by two main influences. The first one is the redundancy by increasing the BF, i.e. increasing the number of CAM transmission trials per vehicle. The second one is the number of dropped CAMs, caused by the escalation of interferences due to the increasing data traffic. Because the two influences are not proportional dependent, the redundancy predominates the number of dropped CAMs for higher update delay values.

[5]For some applications a maximum update delay of 5 s still is not enough, e.g. a vehicle driving with 200 km/h (which is not uncommon in some countries) would travel 277 m within 5 s.

VII. Summary, Conclusions and Future Works

This paper makes three contributions to the performance analysis of ITS-G5A MAC for safety applications. First of all, we described a simulation scenario which is particularly MAC challenging. We identified the freeway to be a suitable scenario for that purpose. After that, we introduced the update delay as a special suitable receiver-side performance metric. It has exposed to be an excellent metric for MAC analysis according to safety applications based on periodic CAMs. The update delay considers important key requirements for safety applications, like reliability and up-to-dateness. Finally we presented some simulation results for the freeway scenario. To analyze the behaviour of the update delay distribution in high dense scenarios, we increased the data traffic density by varying two parameters. As a result we have shown by means of a suitable update delay representation, which reliability boundary safety applications can achieve in a certain scenario. We particularly conclude that the CCDF is an adequate metric to determine reliability and up-to-dateness performance characteristics of MAC schemes in VANETs. In search of MAC challenging scenarios, we also identified crossroads to be suitable for that purpose. A similar MAC performance analysis of crossroad scenarios is up to future works.

References

[1] ETSI TR 102 698 V1.1.1, "Intelligent Transport Systems (ITS); Vehicular Communications; C2C-CC Demonstrator 2008; Use Cases and Technical Specifications.

[2] ETSI ES 202 663, "Intelligent Transport Systems; European profile standard on the physical and medium access layer of 5 GHz ITS", Draft Version 0.0.6, October 2009.

[3] ETSI EN 302 571, "Intelligent Transport Systems (ITS); Radio communications equipment operating in the 5 855 MHz to 5 925 MHz frequency band; Harmonized EN covering the essential requirements of article 3.2 of the R&TTE Directive", Draft Version 1.2.1, October 2009.

[4] IEEE 802.11 WG, "IEEE P802.11p/D8.0, Draft 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 7: Wireless Access in Vehicular Environments", Draft Version 8.0, July 2009.

[5] IEEE 802.11 WG, "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, IEEE Std 802.11-2007, June 2007.

[6] Stephan Eichler, "Performance Evaluation of the IEEE 802.11p WAVE Communication Standard", WiVeC, September 2007.

[7] Jijun Yin et. al., "Performance Evaluation of Safety Applications over DSRC Vehicular Ad Hoc Networks", *VANET'04*, ACM, October 2004.

[8] Katrin Bilstrub et. al., ”On the Ability of the 802.11p MAC Method and STDMA to Support Real-Time Vehicle-to-Vehicle Communication”, EURASIP Journal on Wireless Communications and Networking, Volume 2009.
[9] Hector A. Cozzetti et. al., ”Comparative Analysis of IEEE 802.11p and MS-Aloha in Vanet Scenarios”, International Workshop on Vehicular Networking (VON-09), IEEE, December 2009.
[10] Tamer ElBatt et. al., ”Cooperative Collision Warning Using Dedicated Short Range Wireless Communications”, *VANET’06*, ACM, September 2006.
[11] R. K. Schmidt et. al., ”Degradation of Transmission Range in VANETs caused by Interference”, January 2010.
[12] Felix Schmidt-Eisenlohr et. al., ”Simulation Platform for Inter-Vehicle Communications and Analysis of Periodic Information Exchange”, IEEE/IFIP WONS, January 2007.
[13] Marc Torrent-Moreno, ”Inter-Vehicle Communications: Assessing Information Dissemination under Safety Constraints”, IEEE/IFIP WONS, January 2007
[14] Fan Bai, Hariharan Krishnan, ”Reliability Analysis of DSRC Wireless Communication for Vehicular Safety Applications”, ITSC 2006, September 2006.
[15] Achim Brakemeier, ”White Paper on Network Design Limits and VANET Performance”, Version 0.5, Car2Car Communication Consortium, November 2008.
[16] Chuan Heng Foh et. al., ”A Markovian Framework for Performance Evaluation of IEEE 802.11”, IEEE Transactions on Wireless Communications, Volume 6, April 2007.
[17] Hongqiang Zhai et. al., ”Performance analysis of IEEE 802.11 MAC protocols in wireless LANs”, WCM, John Wiley & Sons, 2004.
[18] P. Chatzimisios et. al., ”Throughput and delay analysis of IEEE 802.11 protocol”, IEEE, 2002.
[19] Omesh Tickoo and Biplab Sikdar, ”Queuing Analysis and Delay Mitigation in IEEE 802.11 Random Access MAC based Wireless Networks”, INFOCOM, 2004.
[20] Zhen-ning Kong et. al., ”Performance Analysis of IEEE 802.11e Contention-Based Channel Access, IEEE Journal on Selected Areas in Communications, Volume 22, December 2004.
[21] Cristina Rico Garcia et. al., ”Performance of MAC protocols in beaconing Mobile Ad-hoc Multibroadcast Networks”, 3rd International Workshop on Multiple Access Communications (MACOM), September 2010
[22] Tony K. Mak et. al., ”A Multi-Channel VANET Providing Concurrent Safety and Commercial Services”, *VANET’05*, ACM, September 2005.
[23] Statistisches Bundesamt, Fachserie 8, Reihe 7, 2008.
[24] ITU, ”Information Technology - Open Systems Interconnection - Basic Reference Model: the Basic Model - Data Networks and Open System Communications Open Systems Interconnection - Model and Notation”, ITU-T X.200, January 1994.
[25] Juhani J”a”askel”ainen, ”Cooperative Mobility and the importance of harmonized international standards”, 2nd ETSI TC ITS Workshop, February 2010.
[26] COMeSafety, ”D28 Standardisation Activities”, December 2009.
[27] ns-3 documentation, http://www.nsnam.org/doxygen-release/index.html.
[28] Mathieu Lacage, Thomas R. Henderson, ”Yet Another Network Simulator”, ACM, 2006.