Performance Comparison of IEEE 802.11p and ARIB STD-T109

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***Abstract*—Vehicular networking is moving from pure research to first deployments around the world. This shifts the focus of research and development to aspects like higher layer performance; yet different regions (Japan, Europe and the U.S.) employ vastly different lower layer protocols for medium access and transmission. Without means to compare their performance it remains unclear to what degree simulation results obtained for one region (that is, one set of lower layer protocols) can be transferred to the other. Our paper fills this gap by conducting an extensive simulation study comparing the performance of IEEE 802.11p and ARIB T109 taking into account both their differences on the physical layer (5.9 GHz vs. 700 MHz band) as well as in medium access (pure CSMA/CA vs. a combination with TDMA). We base this study on the first Open Source implementation of the ARIB T109 standard we developed for the vehicular network simulation framework Veins. This also encompasses parameters for a computationally inexpensive shadow fading model for urban environments. We briefly report on the results of an extensive measurement campaign that underlies these parameters.**

I. Introduction

In the last decade, vehicular networking has been continually moving from pure research to first deployments around the world. Japanese automakers are offering first car models with Intelligent Transportation System (ITS) functionality, the U.S. have announced plans to make ITS mandatory [1], and Europe might be following these developments shortly.

This shifts the focus of research and development from lower layers to upper protocol layers, investigating metrics like application performance in large deployments. To study networks at scale, performance evaluation of vehicular networks is mostly relying on simulation [2]. Thus, detailed and realistic models of lower layer effects like medium access and signal propagation are of crucial importance.

These lower layers differ between the above mentioned regions. The U.S. and Europe standards are based on WLAN in OCB mode operating in the 5.9 GHz frequency band (IEEE Std 802.11p [3], see Section III), which relies on CSMA/CA to coordinate multiple access. Japan uses the same physical layer in the 700 MHz frequency band, but employs an adapted medium access layer that mixes CSMA/CA with time slotted access (ARIB STD-T109 [4], see Section IV). This yields not only completely different physical propagation characteristics, most prominently in terms of path loss and shadow fading (owing to the different frequency), but also much different characteristics in terms of higher layer performance (owing to the different medium access scheme).

It is therefore unclear to what degree simulation results obtained for one set of lower layer protocols can be transferred to the other. This is exacerbated by the fact that existing Open Source tools for computer simulation offer physical and medium access models for only either one, but not both of the standards, limiting comparability.

In this paper, we present the first performance comparison of both approaches across layers, which allows us to point out their individual benefits and drawbacks. Our performance comparison is based on the first Open Source implementation in the vehicular network simulation framework Veins [5], which we make publicly available. In order to parameterize the shadow fading model for the 700 MHz frequency band we performed a measurement campaign for buildings in urban areas. Our framework thus encompasses detailed physical and medium access models of both IEEE 802.11p and ARIB T109.

Our contributions can be summarized as follows:

- We perform extensive simulation studies that compare the performance of IEEE 802.11p and ARIB T109 in a realistic setting, pointing out their individual benefits and drawbacks.
- Our results are based on an implementation of ARIB T109 for the vehicular network simulation framework Veins, which we make available as Open Source.[1] It includes realistic models of both the unique medium access and physical layer characteristics of ARIB T109.
- We detail results of the measurement campaign used to parameterize the model of shadow fading by buildings in urban areas for the 700 MHz band.

II. Related Work

There is a substantial body of work on Non Line of Sight (NLOS) characteristics of the 700 MHz band. One of the first channel characterization studies for 700 MHz in the context of vehicular communication for both LOS and NLOS scenarios was conducted by Sevlian et al. [6]. They conclude that many of the assumptions that hold true for IEEE 802.11p in 5.9 GHz do not transfer well to the 700 MHz band. This serves as further motivation for our work. Later, Fernandez et al. [7] investigated path loss for both 5.9 GHz and 700 MHz in LOS and NLOS conditions. They present parameters for a simple model that uses different path loss coefficients depending on the overall scenario and presence of LOS. The observed values are in

[1] http://veins.car2x.org/

line with similar works from the literature. In a later paper [8] they further correlate the used antenna height to adapted path loss coefficients in a freespace scenario. They show that the antenna height has no significant impact on the path loss of 700 MHz. However, modelling higher layer effects was not in the scope of their work.

Looking at the 700 MHz band from a communication protocols perspective, Minato et al. [9] combine message dissemination on the 5.9 GHz and 700 MHz band. They deploy relay stations near intersections which receive packets transmitted by vehicles in one frequency band, and relay them using the other frequency band. With their approach the authors can increase the packet reception ratio in comparison of using only a single frequency band. However their simulations are conducted without an adapted medium access model for ARIB T109 as well as with the ITU-R P. 1411-1 path loss model, which only contains shadow fading coefficients for 5.2 GHz.

Sai et al. [10] compare NLOS communication in the 5.9 GHz and 700 MHz band for urban environments using intersection collision avoidance as an application example. In essence they show that with 700 MHz the communication distance and overall packet delivery ratio in NLOS scenarios is higher than on 5.9 GHz. Yet, they use a proprietary network simulator and do not mention details of their medium access model. Further, the work is based on the ITU-R P. 1411-6 path loss model which (like the above mentioned standard) only contains obstacle shadow fading parameters for 5.2 GHz.

More recently, Abunei et al. [11] studied the impact of buildings on the communication of 5.9 GHz and 700 MHz from an application point of view. They conclude that communication on 700 MHz is much less affected by building shadowing, and thus recommend it as back-up for vehicular communication. Their simulation model uses building obstacle shadowing according to Sommer et al. [12], however they are using the same set of parameters for both frequency bands. Moreover their investigation did not consider medium access characteristics of ARIB T109.

Summing up, vehicular communication at 700 MHz has, to date, been predominantly investigated only *(a)* at the physical layer (abstracting away from higher layer protocols) or *(b)* at the application layer (abstracting away from medium access and/or physical layer characteristics). Our work fills this gap by providing an investigation of vehicular communication that combines accurate modeling of ARIB T109 medium access with realistic propagation models for 700 MHz in urban areas.

III. IEEE 802.11p

The IEEE 802.11p standard [3] is an IEEE 802.11 WLAN standard amendment to support Inter-Vehicle Communication (IVC) and Roadside-to-Vehicle Communication (RVC). It was created for vehicular communications, since these have different characteristics than usual wireless communications, for example short connection times. It extends the Orthogonal Frequency Division Multiplexing (OFDM) physical layer (from IEEE 802.11a [13]) to operation in the 5.9 GHz band. Most importantly it also introduces a novel operation mode, which allows nodes to operate without being part of a Basic Service Set (BSS), called Outside the Context of a BSS (OCB) mode. Instead of a lengthy join procedure to establish parameters like modulation and coding scheme, the node uses well-known parameters for accessing the channel. Building upon this standard, later the IEEE 1609 WAVE family of standards was designed to represent a complete ITS stack in the U.S. [14]. Similarly, in Europe, the ETSI ITS-G5 family of standards [15] builds on IEEE 802.11p as an access layer for vehicles and Roadside Units (RSUs) to provide IVC and RVC.

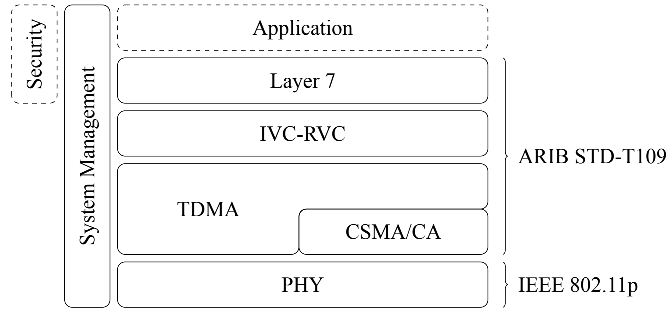

Figure 1. The protocol stack of ARIB STD-T109. Dashed lines indicate entities which are out of the scope of the standard.

For accessing the radio channel, access layers building on IEEE 802.11p inherit the CSMA/CA mechanism of IEEE 802.11: A node performs Clear Channel Assessment (CCA) before accessing the channel; if unsuccessful (channel sensed *busy*), it enters a backoff state and tries again later.

IV. ARIB STD-T109

In parallel to the developments in the U.S. and Europe, the Japanese research and standardization organization for radio telecommunication and broadcasting developed ARIB STD-T109 [4], a standard for operating ITS in the 700 MHz band. One of the major goals was to reduce the number of traffic accidents by informing vehicles and their drivers about current traffic conditions and other vehicles in the near field.

Figure 1 shows its protocol stack, which contains:

1) the physical layer defined in IEEE 802.11p,
2) the medium access layer (MAC), which realizes a combination of TDMA and CSMA/CA channel access,
3) the *IVC-RVC Layer*, which maintains channel access parameters, synchronizes clocks, and handles communication control,
4) *Layer 7*, which represents an interface for communicating with end-user applications and dealing with security.

ARIB T109 specifies wireless communication using a physical layer very similar to IEEE 802.11p, but operating on a center frequency of 760 MHz. In contrast to IEEE 802.11p, however, its medium access layer makes a much clearer distinction between the following two classes of traffic. First, IVC: traffic between vehicles (called *mobile stations*). Second, RVC: traffic sent to vehicles from RSUs (called *base stations*). For this, it employs a TDMA medium access scheme on top of CSMA/CA, as follows.

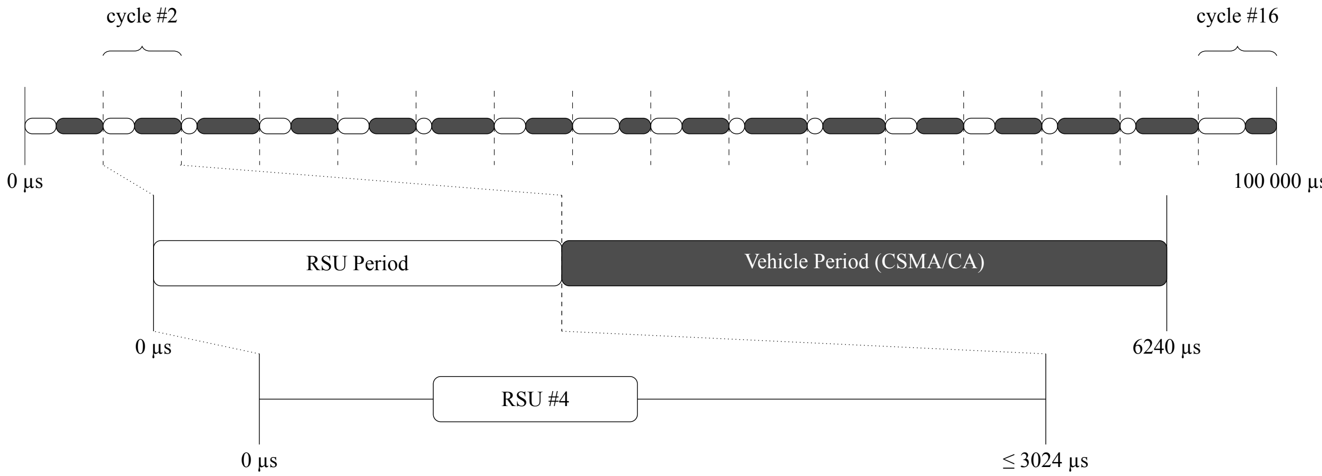

Figure 2. The 100 ms control cycle for transmission control which is split into 16 smaller cycles. Those cycles are again divided into two parts by the TDMA scheme. Within those parts a second channel access coordination among nodes of the same type is done.

Medium access is subject to two carrier sense functions:

- A *virtual* carrier sense function which utilizes a TDMA scheme in every node.
- A *physical* carrier sense function which additionally utilizes a CSMA/CA scheme in mobile stations.

For the TDMA scheme, time is divided into long control cycles of 100 000 µs each, an example of which is shown in Figure 2. Each of these cycles is split into 16 smaller periods of length 6240 µs. The actual TDMA scheme happens within those short cycles, each of which is flexibly divided into two parts again. The part from 0 µs until at most 3024 µs is called *RVC period* and represents time where no vehicles are allowed to access the channel. The reasoning for this prioritization is that, since the base stations are connected to several sensors deployed along the roads [10], they have more knowledge about the current situation and therefore deserve a higher priority for distributing safety information.

Each base station can be assigned an arbitrary *transmission period* within each RVC period, during which it (and only it) is allowed to access the channel. A utilization of another medium access scheme (such as CSMA/CA) is not needed, as it is assumed that transmission periods are well-configured in base stations to avoid concurrent channel access by RSUs in physical proximity.

The remaining time in each cycle (from the end of the RVC period until 6240 µs) represents time where vehicles are allowed to compete for access to the channel. For this, they use the physical carrier sense function (i.e., CSMA/CA) to avoid concurrent channel access with other mobile stations. Vehicles learn about RVC periods in each of the 16 cycles from information embedded in the header of each frame. This information is disseminated in a multi-hop fashion, originating from RSUs and propagating until a hop limit is reached.

Time synchronization among nodes is achieved via *over-the-air* synchronization. Frame headers include the current local time at the sender, which mobile stations use to adjust their local clocks (compensated for processing delays). RSUs synchronize their clocks preferably from an external time source like GPS; optionally, they can rely on the same mechanism as mobile nodes (but will only trust other RSUs to provide accurate enough values).

V. Radio Propagation Model

Since protocols' coping with different shadow fading characteristics of 5.9 GHz and 760 MHz is at the heart of our performance studies, these characteristics need to be represented in computer simulations.

Packet level simulations commonly derive the success probability of an incoming transmission from its Signal to Interference and Noise Ratio (SINR). For this, the received power P_r of a signal is commonly calculated using the simple link budget equation

$$P_r[\mathrm{dBm}] = P_t[\mathrm{dBm}] + G_t[\mathrm{dB}] + G_r[\mathrm{dB}] - \sum L_x[\mathrm{dB}], \quad (1)$$

where P_t denotes the transmit power, $G_{t,r}$ are the antenna gains, and individual terms L_x model attenuation due to path loss, slow fading, and fast fading.

Without loss of generality, we calculate path loss L_{path} using the simple Friis [16] model

$$L_{\text{path}}[\mathrm{dB}] = 10 \log_{10} \left(\left(4\pi \frac{d}{\lambda} \right)^2 \right), \quad (2)$$

where λ is the wave length of the radio transmission and d is the distance between sender and receiver.

To account for NLOS characteristics, we add a loss term L_{obs} as described in Sommer et al. [12]. This term models shadow fading due to static obstacles, calculating

$$L_{\text{obs}}[\mathrm{dB}] = \beta n + \gamma d_{\mathrm{m}}, \quad (3)$$

where n is the number of exterior walls of an obstacle intersected by the direct line of sight between sender and receiver, d_m is the total length of the intersection, and β and

Figure 3. Experiments in a suburban area. The yellow car uses SDRs to transmit at 5.9 GHz and 868 MHz. The red car logs received signal strength at both frequencies.

γ are empirically determined. While this model abstracts away from microscopic effects such as reflections it can provide a computationally inexpensive approximation of macroscopic effects that is suitable for medium to large scale simulations.

Commonly used values for β and γ for shadowing effects of a building on IEEE 802.11p transmissions at 5.9 GHz are in the range of $\beta = 9$ dB per wall and $\gamma = 0.4$ dB/m.

Naturally, these values will not apply to transmissions in the 760 MHz band, which is less impacted by shadow fading effects as reported by Fernandez et al. [7]. Thus, in order to adjust the obstacle model to this frequency, we conducted experiments measuring the influence of buildings in an urban area on the signal. Our measurement area was a suburban part of Paderborn, illustrated in Figure 3.

We used two Ettus USRP N210 SDRs to transmit simple bursts of power at 868 MHz and 5.9 GHz, respectively. We chose 868 MHz since it is available for civil use while still being reasonably close to the target frequency of 760 MHz. Measurements with 5.9 GHz were conducted for validating results against the existing model parameters. Two more SDRs logged the signal strength at the receiving side. We used roof-mounted omnidirectional antennas to minimize the influence of the cars' orientation. Two u-blox NEO-7N GPS receivers, also equipped with roof-mounted antennas, logged the cars' position every 500 ms.

Figure 4 illustrates an exemplary excerpt of the measurement campaign: The sending car is parked next to the street. The receiving car passes the sender, then rounds two corners, disappearing behind buildings. The total length of the trajectory is around 130 m, whereas the linear distance between sender and receiver is at minimum 3 m, and around 48 m at point A. The excerpt is thus comprised of segments with direct line of sight between sender and receiver, segments with one, and segments with multiple buildings obstructing the line of sight. Lines connect sender and receiver positions, color coded (from red, to yellow, to green) by the received signal strength. Of special interest is a point on the receiver trajectory, marked *point A*, where a small line of sight corridor between two buildings exists.

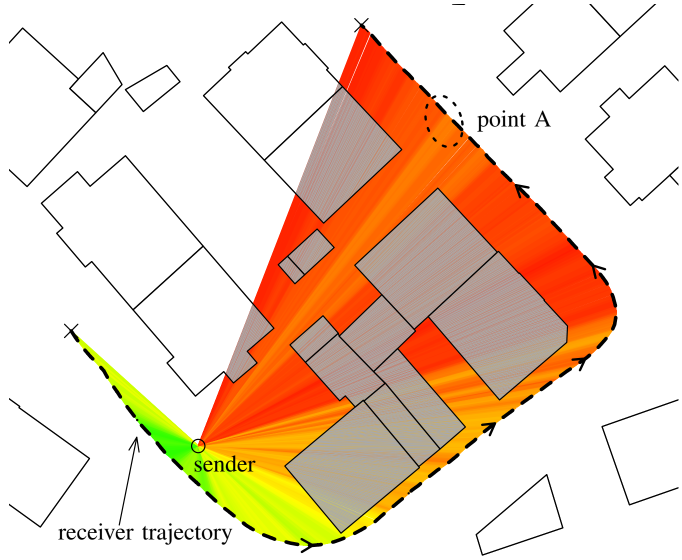

Figure 4. A map around Andreasstraße in Paderborn where we conducted our measurements: The colored lines show the signal strength for 868 MHz along the receiver trajectory. At *point A* a small LOS corridor leads to an increased signal strength.

Figure 5 illustrates the measurement results gathered on this trajectory, along with the results of model fitting of Equation (3) to all measurement results. As can be seen, measurement data and model are closely aligned on a macroscopic scale: As the distance between sender and receiver first decreases then increases, the received signal strength (RSS, given in dB relative to the maximum measured) first climbs then falls off, as predicted by Equation (2). When the receiver rounds the first corner and disappears behind the first building (approx. at the time sample 1750 is recorded), the received signal strength drops; and it keeps dropping as more buildings get between sender and receiver. It is also apparent that the macroscopic model is unable to capture two effects on a finer scale. First,

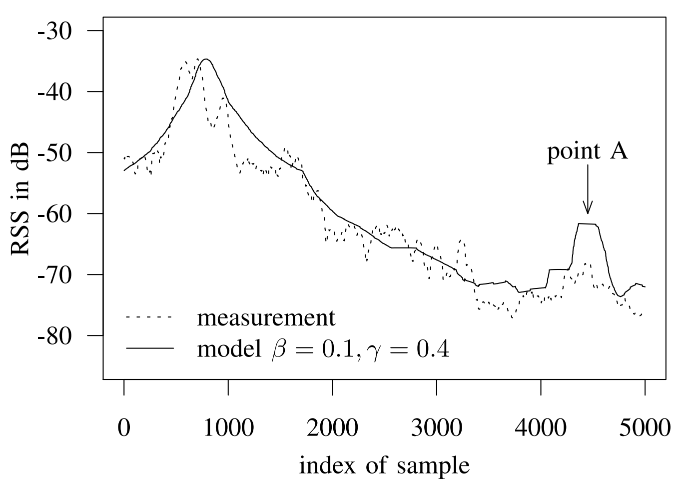

Figure 5. The received signal strength for 868 MHz fitted to the analytical model. At point A we see the increased signal strength due to the LOS corridor.

none of the quick oscillations are captured by the slow fading model, as can be expected. Second, the line of sight corridor at *point A* is overestimated, as the model ignores the impact of partly (obstructed) Fresnel zones and only focuses on the line of sight.

Overall, the computed model parameters of $\beta = 0.1$ dB per wall and $\gamma = 0.4$ dB/m can be seen to allow Equation (3) to closely model the real world measurements. As expected, these model parameters also reflect the effect that lower-frequency transmissions are affected less by building shadowing.

VI. Simulations

For our comparison of IEEE 802.11p and ARIB T109 we used the Open Source vehicular network simulation framework Veins [17]. It consists of two parts: OMNeT++ as a discrete event simulation kernel for network simulation and SUMO [18] for modeling vehicular movement. As it already contains models that are specific to the simulation of vehicular networks (albeit with a focus on the European and U.S. family of standards), it already contained a fully functioning implementation IEEE 802.11p which is frequently used in academic research.

A. Model Implementation

To simulate nodes using ARIB T109 we developed a model representing the standard as OMNeT++ modules for the Veins framework. The set of modules is closely aligned with the standard, that is, we include no security functions, which are out of the scope of the standard.

We distinguish between the different node types (base station and mobile station) to capture their differences in medium access (physical and virtual carrier sense functions) according to the standard. The medium access layer implementation follows the design outlined in Eckhoff et al. [19], but also includes an additional model of the *IVC-RVC Layer*, which is predominantly tasked with enforcing the TDMA scheme for accessing the channel and to handle information exchange for communication cycle configurations and time synchronization.

For realizing the physical layer we could rely on the already existing implementation of IEEE 802.11p in Veins, adapting parameters like carrier frequency and transmission power to match the ARIB T109 standard.

Validation of the ARIB T109 implementation followed a comprehensive test document [20]. It does not only contain test cases for the communication control and the maintenance protocol, but also technical requirements in terms of physical behavior and limits. Since the implementation of the physical layer by Eckhoff et al. [19] is commonly used in several publications and, therefore, can be assumed to be correct, we did not consider tests for the physical layer functionality. The correct functionality of the medium access, however, had to be validated. We focused on functionality for updating the parameters and values for the *IVC-RVC Layer* and the time synchronization. For this we used the corresponding test cases of [20] to validate our model before proceeding to the simulation study.

B. Simulation Scenario

For our simulations we chose the LuST scenario developed by Codeca et al. [21], which models traffic in the city of Luxembourg. Since we want to do an in depth analysis of the protocols and their behavior, we need to do multiple experiments with heterogeneous environments. The scenario provides different kinds of environments such as Luxembourg City downtown, suburbs, or highways. Furthermore, it does not only contain 24 h of vehicle mobility but also street and building information recreated in detail.

Its total area is around 156 km^2 with a total of 13 553 buildings and between 200 000 and 300 000 vehicles being simulated. During rush hour which is around 8:30h in the morning and 18:30h in the evening it simulates nearly 6000 vehicles simultaneously. We determined different regions which we used for our simulations, each representing one scenario. These regions are located in the inner city as well as in different sub-urban areas.

Figure 6 shows a detailed view of the scenario we focus on in this paper. An average of 92 vehicles are driving on an area of 800 m $\times$ 1500 m located in the south east of Luxembourg City. We ensured that our conclusions are equally valid for two similar scenarios we selected. The scenario also includes three RSUs (illustrated as blue dots in Figure 6).

For these RSUs, we purposely chose uniformly distributed random values for the RVC period information to look at the systems behavior in a not perfectly constructed but more realistic and dynamic situation, ensuring that periods were large enough to accommodate at least one frame. We allocated one third of the RVC period information time each to all three base stations. Since most of the safety information being distributed will be sent by the base stations [10], we consider each of them to be of equal importance.

We also implemented a simple application layer which sends periodic broadcasts (beacons). Table I lists all parameters of the application layer, of the ARIB T109 and IEEE 802.11p models, and of the simulation.

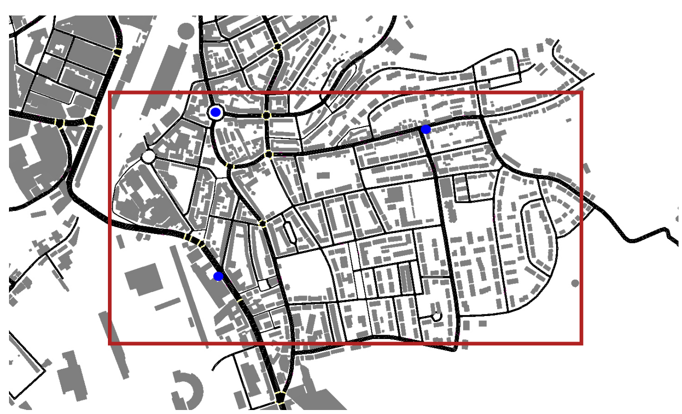

Figure 6. A region of interest in the south east of Luxembourg City indicated by the red rectangle. Three blue points indicate the positions of the RSUs.

Table I
SIMULATION PARAMETERS USED FOR COMPARISONS.

MAC	ARIB STD-T109	IEEE 802.11p
Physical layer	IEEE 802.11p	IEEE 802.11p
Shadow fading constants, eq. (3)	$\beta = 0.1$ dB, $\gamma = 0.4$ dB/m	$\beta = 9$ dB, $\gamma = 0.4$ dB/m
Frequency	760 MHz	5.89 GHz
Bitrate	6 Mbit/s	6 Mbit/s
Maximum transmit power*	10 mW	20 mW
CCA threshold*	−53 dBm	−65 dBm
Sensitivity*	−89 dBm	−89 dBm
AIFS (802.11p)		2 slots
CW	64 slots	min 3 slots max 7 slots
Beacon size	100 B	
Beacon frequency	1 Hz	
Number of RSUs	3	
Simulation time	60 s	

*default value of corresponding standard

C. Evaluation Metrics

As the simulation has probabilistic components we perform 60 independent repetitions with different pseudo random number generator seeds for both network simulation and road traffic models.

In order to get a holistic insight on the performance of ARIB T109 and IEEE 802.11p we chose the following metrics in the application and medium access control layer:

1) *Communication distance*: For each successfully received packet we measure the distance between receiver and sender. For lower path loss effects on the physical signal we expect a higher communication distance.
2) *Frame detection rate*: On the physical layer we measure the number of frames detected (that is, above the sensitivity threshold) per second. This metric scales with the vehicle density: a higher communication distance intuitively leads to more nodes within range, thus a higher number of detected frames per second.
3) *Channel utilization*: We periodically measure the channel utilization
$$b_t = \frac{t_{\text{busy}}}{t_{\text{busy}} + t_{\text{idle}}} \tag{4}$$
as the fraction of the time the wireless channel was sensed busy since the last measurement of this metric. In ARIB T109 these results are recorded separately for both the RSU and vehicle period, and the measurement is performed at the end of each period. In IEEE 802.11p the measurement is performed every 100 ms.
4) *Packet loss rate*: As a reliability metric for the communication we chose the rate of lost packets as
$$p_{\text{loss}} = \frac{n_{\text{coll}}}{n_{\text{rx}} + n_{\text{coll}}}. \tag{5}$$
Here, n_{rx} denotes the number of successfully received packets, and n_{coll} denotes the number of observed packet collisions – frames which could have been decoded if there would not have been any interference on the channel. This is possible, as random processes are under control of the simulation framework, thus we can distinguish between lost packets due to interference, lost packets due to low signal strength, and lost packets due to bit errors.
5) *End-to-End delay* Finally we observe the delay at the application layer. This metric mainly depends on the amount of time packets stay queued at the medium access layer plus the time needed to transmit the packet. We expect this metric to be higher in TDMA based schemes like ARIB T109 compared to pure CSMA/CA approaches like IEEE 802.11p, as packet generation processes are independent of the time slotting. Again this metric scales with the vehicle density and thus, channel load. A higher channel busy fraction increases the probability for a failed clear channel assessment (IEEE 802.11p, and ARIB T109 in the vehicle period), thus leading to backoff. However, in TDMA approaches (ARIB T109 in the RSU period) no other node accesses the channel, thus no backoff is necessary.

VII. SIMULATION RESULTS

We plot simulation results for the metrics in the form of one empirical Cumulative Density Function (eCDF) each. This allows to quickly compare metrics' median (i.e., the value associated with an eCDF value of 0.5), first and third quartile (0.25 and 0.75), as well as any other quantiles.

Figure 7 plots the results of the first metric we investigated, plotting the distribution of distances at which packets were received. It is immediately apparent that ARIB T109 transmissions were able to reach substantially farther than IEEE 802.11p transmissions: the 95[th] percentile reached as far as 990 m (as opposed to 265 m for IEEE 802.11p). Even though the few straight stretches of road in the scenario (shown back in Figure 6) allowed individual IEEE 802.11p transmissions to reach comparable distances, most attempts at data exchange were cut short by the presence of buildings. In contrast, the much less pronounced building shadowing in ARIB T109 allowed these transmissions to reach much further. This effect is in line with findings in the literature [7].

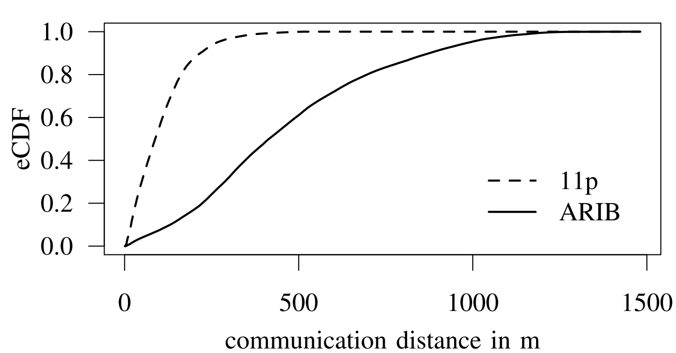

Figure 7. Communication distance of ARIB T109 in comparison to IEEE 802.11p.

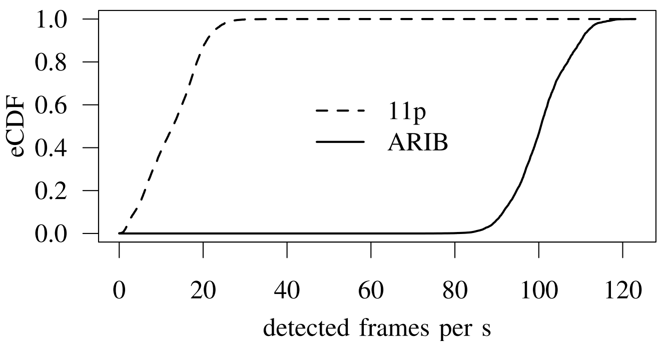

Figure 8. The total number of detected frames ARIB T109 in comparison to IEEE 802.11p.

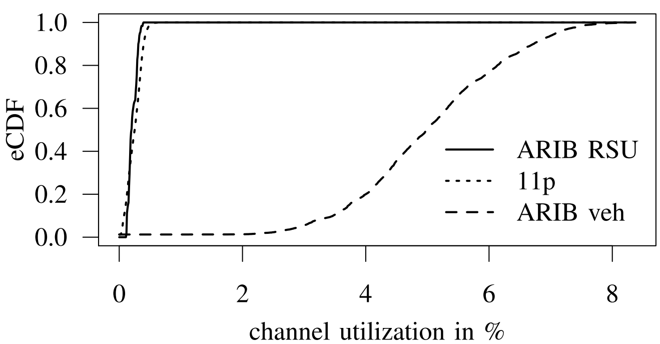

Figure 9. The MAC utilization of ARIB T109 in comparison to IEEE 802.11p.

Figure 8 illustrates both the positive and the negative consequence of this increased reach of ARIB T109: The median number of frames detected each second at each node increased almost eightfold. While this has obvious benefits, e.g., for safety applications it is indicative of a much more crowded channel. It is well known that a CSMA/CA access scheme becomes increasingly inefficient as the channel gets more saturated [22]; therefore, ARIB T109 (following its philosophy that RSUs are the more important participants) addresses this problem via its TDMA mechanism.

Figure 9 reveals the consequences of this decision: On the plus side, channel utilization of ARIB T109 during RVC periods (that is, during time periods allotted to RSUs), remains at negligible values which are comparable to IEEE 802.11p (with median values of 0.20 % and 0.25 %, respectively). On the negative side, the average channel utilization perceived by nodes using ARIB T109 during periods of time allotted to vehicles climbs to a median value of 5 %, for some vehicles as high as 8 %.

Figures 10 and 11 demonstrate the impact this has on packet loss. The downside of TDMA manifests in noticeably increased packet loss rates during periods of time allotted to vehicles, as these now suffer from less overall channel capacity, compounded by higher overall channel load. However, no frames sent by RSUs are lost in ARIB T109 (Figure 10), owing to each RSU having a reserved transmission period. Transmissions using IEEE 802.11p, in comparison, encounter packet loss, though at negligible levels (Figure 11).

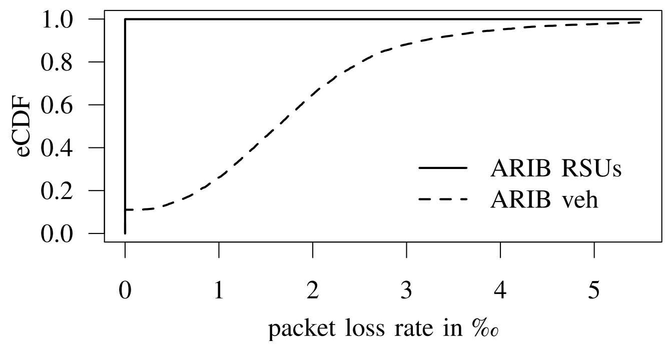

Figure 10. The packet loss rate of frames sent by RSUs and vehicles in ARIB T109.

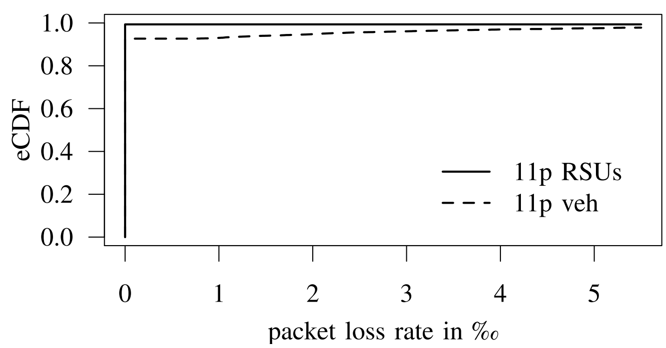

Figure 11. The packet loss rate of frames sent by RSUs and vehicles in IEEE 802.11p.

Figure 12 illustrates that, for all its benefits for RSUs, the application of TDMA brings with it an increase in (application layer) message delay. While in IEEE 802.11p, transmissions can be sent almost instantly (we record a median below 0.2 ms), in ARIB T109, transmissions cannot be sent at arbitrary times, but might need to be delayed until they fit into the next available time slot. This manifests in an approximately uniformly distributed delay of up to 6.240 ms (the length of each of the 16 communication cycles), plus additional delays while waiting for an idle channel depending on the channel load (here, below 13 ms for 99 % of all nodes).

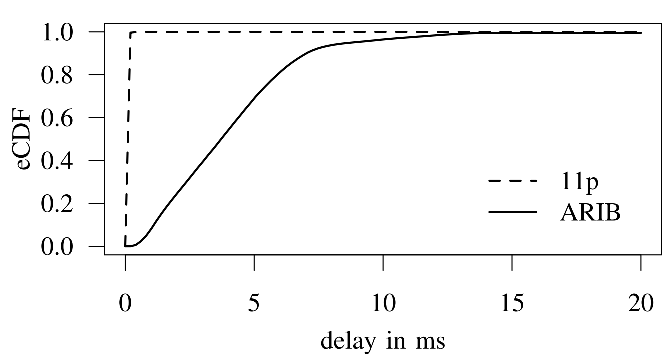

Figure 12. The delay of ARIB T109 in comparison to IEEE 802.11p.

VIII. Conclusion

In this paper we presented a first performance comparison of the two very different standards for vehicular communication IEEE 802.11p and ARIB T109 that respects not just their differences in terms of physical layer (5.9 GHz vs. 700 MHz band), but also their very different medium access characteristics: While IEEE 802.11p uses pure CSMA/CA to coordinate multiple access among different vehicles, ARIB T109 uses TDMA to reserve time slots for exclusive use by Roadside Units (RSUs).

We based this comparison on our new Open Source implementation of the ARIB T109 standard for the vehicular network simulation framework Veins. This also encompasses parameters for a computationally inexpensive shadow fading model for urban environments. We briefly reported on the results of an extensive measurement campaign that underlies these parameters.

Our performance comparison demonstrates that, in urban environments, ARIB T109 transmissions reach much farther as they suffer much less from obstacle shadowing by buildings, backing up earlier results. This can benefit safety applications in Non Line of Sight (NLOS) conditions as well as multi-hop information, e.g., for efficiency applications. When investigating higher layer performance, however, this characteristic also leads to increased load and increased interference on the channel. Moving still higher in the protocol stack, it can be seen that the TDMA mechanism of ARIB T109 can compensate the negative impact of this effect by allocating dedicated transmissions for RSUs guaranteeing ideal channel conditions for them. The flip side of this are somewhat increased delays and even further reduced channel capacity (and, thus, increased packet loss) for vehicles.

Acknowledgements

The authors would like to thank M. Nabeel, B. Bloessl, J. Blobel, and D. S. Buse for their kind support during the measurements.

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