Performance Evaluation of a V2X Communication System based on IEEE 802.11p for Public Transport Priority

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Abstract - A live vehicle-to-everything (V2X) operational environment in the city of Kassel is established to achieve public transport priority at signalized intersections. In order to ensure the communication quality of this pilot environment, its communication performance was evaluated with regard to the signal strength and message transmission success rate of Road-Side Units (RSUs) as a function of their spatial positioning. This paper presents a performance evaluation method and defines an evaluation criterion. A measurement approach is described and preliminary measurement results are discussed. An average effective signal transmission range is estimated by creating statistical distributions of the success rate at different distances from multiple RSUs. Using 500 m as a suitable distance, current RSU locations have met the requirements to ensure a sufficient communication quality. In terms of spacing, the V2X environment in Kassel provides a reliable performance based on current RSU locations. Finally, a future outline is given for a detailed V2X performance evaluation.

I. Introduction

The Vehicle-to-Everything (V2X) technology is a new generation of communication technology, which applies to the communication between traffic participants and roadside infrastructures. This enables new solutions to improve public transport, optimize the traffic flow, reduce negative environmental impacts of motorized traffic and enhance traffic safety. Infrared beacons are widely used to realize the public transport priority at signalized intersections in Germany. This technology is no longer considered future-proof, since it may not provide an accurate estimation of vehicle arrival time due to the changing road condition. Hence, novel V2X communication technology is based on the IEEE 802.11p standard (ETSI ITS-G5 in EU), which operates on the 5,9 GHz dedicated short range communication (DSRC) frequency band, is considered to be a very promising alternative.

In the ongoing research project "VERONIKA" [1], funded by the German Federal Ministry of Transport and Digital Infrastructure (BMVI), connected vehicles and traffic lights should both contribute to an energy-saving driving style and an emission-reduced traffic light control. The city of Kassel and the department of Traffic Engineering and Transport Logistics from the University of Kassel are developing a real-time V2X environment, in which trams, buses and ambulances are equipped with vehicle On-Board Units (OBUs), to exchange ETSI ITS-G5 messages through wireless communication with Road-Side Units (RSUs) at traffic light systems. To obtain the public transport priority for the requesting trams, buses and ambulances, V2X technology is utilized as follows: the OBU sends a registration of a demand for a green signal at the traffic light, from which the travel time can be predicted well ahead of the arrival of the vehicle. In this way, braking or even stopping for a red signal at signalized intersections can be avoided. In this case, the communication performance of the V2X system needs to be evaluated first, with current RSU locations under real operating conditions of public road traffic.

There are several related works concerned with the performance evaluation of V2X communication systems as follows.

Beihang University in China has designed and implemented a testing platform of 802.11p-based dedicated short range communications on their campus, including a V2X communication system and a performance evaluation system. The performance of their V2X communication units was evaluated in terms of quality of service metrics such as communication range, throughput, packet loss rate, delay and jitter [2].

Researchers of the Iwate Prefectural University in Japan have experimented with V2X communication using moving vehicle and roadside server, from which they evaluated experimental results and estimated the communication range using Wi-Fi for V2X communication, to realize road condition sharing systems to prevent traffic accidents and traffic hazards. The testing environment near their university was an ideal case. Measurements using ping command were conducted, to estimate the communication range by calculating the distance between the roadside server and the point where ping command was disconnected or connected [3].

Researchers of Beijing University of Posts and Telecommunications have developed a test-bed which complies with the IEEE 802.11p standard and evaluated the system performance in terms of transmit latency and package loss rate, under different speed and different distances between two test-beds. The measurement area was 309 m in length and 298 m in width with a radius of 120 m, in an open area in Changping district, Beijng [4].

Tsinghua University provided an application-oriented performance comparison between 802.11p and LTE-V in a real world environment, which was conducted at National Intelligent Connected Vehicle Pilot Zone in Jiading District, Shanghai. The performance of Vehicle to Infrastructure (V2I) communication was evaluated in terms of latency and package deliver rate as part of their work [5].

In the paper [6], a large set of naturalistic driving data was obtained through the University of Michigan Safety Pilot Model Deployment project, from which the DSRC performance was analyzed in terms of Packet Delivery Ratio, maximum range and effective range, as well as the influence factors of DSRC performance of V2I communication between 1050 vehicles and selected road-side equipment. Vehicles were equipped with DSRC devices and continuously broadcasted Basic Safety Messages.

In the current paper, we will present a communication performance evaluation of a V2X system based on the IEEE 802.11p standard, under real operating conditions of public road traffic, in terms of the signal strength and transmission success rate of ETSI ITS-G5 messages broadcasted by Road-Side Units (RSUs) at traffic light systems, as a function of their spatial positioning, to achieve public transport priority at signalized intersections.

This paper is structured as follows: Section II gives a brief overview of the live V2X environment of the VERONIKA project. In Section III the V2X-Monitoring-System is introduced and Section IV describes the measurements, while in Section V the measurement approach is presented. The measurement results are summarized in Section VI and lastly, conclusions and future works are outlined in Section VII.

II. The live V2X environment

A V2X communication system in Kassel's live test environment contains 15 signalized intersections equipped with RSUs, and multiple public transport vehicles equipped with OBUs. The test site is located in the city center of Kassel. Urban conditions within the coverage area, including such as curves, road inclines, buildings, foliage and constructions. It consists of two test tracks, as shown in Fig. 1. The 15 RSUs are distributed on both test tracks. One track with 12 RSUs and another with 3 RSUs. The distance between every two adjacent RSUs varies from 100 m to 1000 m. RSUs are mounted on mast arms or signal poles of traffic lights. Mounting heights are between 6 and 8 m. RSU and OBU as main components of the V2X system are provided by Cohda Wireless [7][8]. Each RSU has two 5.9 GHz omnidirectional antennas [7], each antenna has a uniform signal strength in all horizontal directions. V2X messages sent by RSUs and OBUs are Cooperative Awareness Messages (CAMs), Decentralized Environmental Notification Messages (DENMs), Signal Phase and Timing (SPaT), and MAP (Map

Data), in addition, Signal Request Messages (SRMs) and Signal Status Messages (SSMs). The communication is based on IEEE 802.11p standard (ETSI ITS-G5 in EU), which operates on the 5,9 GHz dedicated short range communication (DSRC) frequency band.

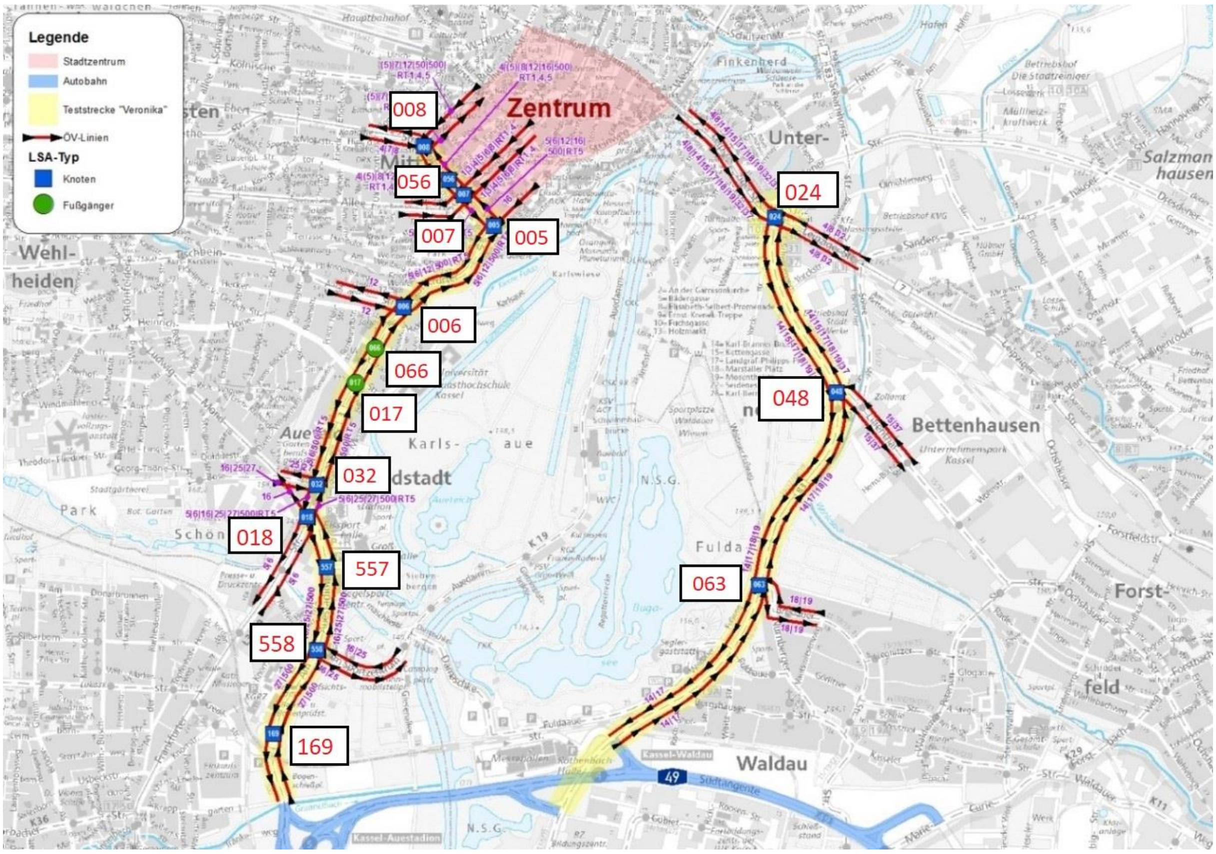

Fig. 1. RSU locations in the V2X environment in Kassel
(Source: City of Kassel - Road and Traffic Authority, 2018)

III. V2X-Monitoring-System

According to the requirements of the VERONIKA project, a V2X-Monitoring-System has been developed by ifak [9], to live monitor, measure and evaluate the quality of V2X communication.

The main functions of the V2X-Monitoring-System are:

- Live monitoring of V2X messages
- Receive and decode V2X messages within the communication coverage
- GPS positioning of received V2X messages
- User defined measurement rules
- Measure signal strength
- Measuring the message transmission loss rate
- Result diagnosis
- Data storage

IV. Measurements

In this paper, the communication performance of a V2X system is evaluated in particular with regard to the communication quality (signal strength and message transmission success rate), as a function of the spatial positioning of RSUs. A series of measurements were implemented in the live V2X environment in the city of Kassel, to evaluate the quality of signal transmission at different distances from current RSU locations. The obtained performance results, e.g. the signal strength and transmission success rate from received V2X messages, are analyzed to deduce an average effective signal transmission range. Due to the urban nature of Kassel, various factors in the V2X environment may affect the communication quality; hence the measurements in this paper provide a valuable insight into spatial limitations for applying V2X technology in realistic settings.

V. Measurement approach

The live V2X environment in Kassel consists of 15 signalized intersections which are equipped with RSUs. Each RSU can send messages such as Cooperative Awareness Messages (CAMs), Signal Phase and Timing (SPaT) and MAP (Map Data). This extensive V2X environment enables researchers to perform field measurements of signal strength and message transmission success rate, as evaluation parameters of the V2X communication performance in an urban region. Of course, the evaluation takes into account the message receiving position and frequency of V2X messages.

During a field measurement of RSU signals, data such as message type, station ID, timestamp and message receiving position are decoded from each received V2X message, along with the measured signal strength value; the live V2X-monitoring-system from ifak [9] displays this information on user terminal monitors. For post-processing, all received information and diagnostic results are stored in a database. The message transmission success rate is computed by comparing the measured rate of incoming messages with the expected message arrival rate that the RSU should provide. In this way, success rates can be computed for different types of messages from different RSUs.

All measurements were taken with respect to a reference position, namely the location of RSU 005 as shown in Fig. 1, towards different directions. From this reference position, the V2X-Monitoring-System was moved 1500 m in the directions north, west and south, and the signal strength of each received V2X message was collected. For the success rate computation, each 100 m was taken as a measurement position, including the reference position. At these positions, a 3-minute measurement was taken to accumulate sufficient signals for a reliable computation. The measuring method described above was also carried out at two different receiving heights, 1 m and 2 m, at each measurement position. In total, signals from 6 involved RSUs are measured in this research. The distance away from RSU 005 was measured using a Roller-type meter-counter in an (almost) straight line; the distances from the other 5 RSUs were obtained using Google Maps.

VI. Results

Measurements were taken from the reference position of RSU 005 towards three different directions. Measurement data from 6 involved RSUs, namely RSU 008, 056, 005, 006, 066 and 017 as shown in Fig. 1, were used to obtain a preliminary V2X performance evaluation. By comparing the message transmission success rate at different distances from these 6 RSUs, first statements about the effective signal transmission range were obtained.

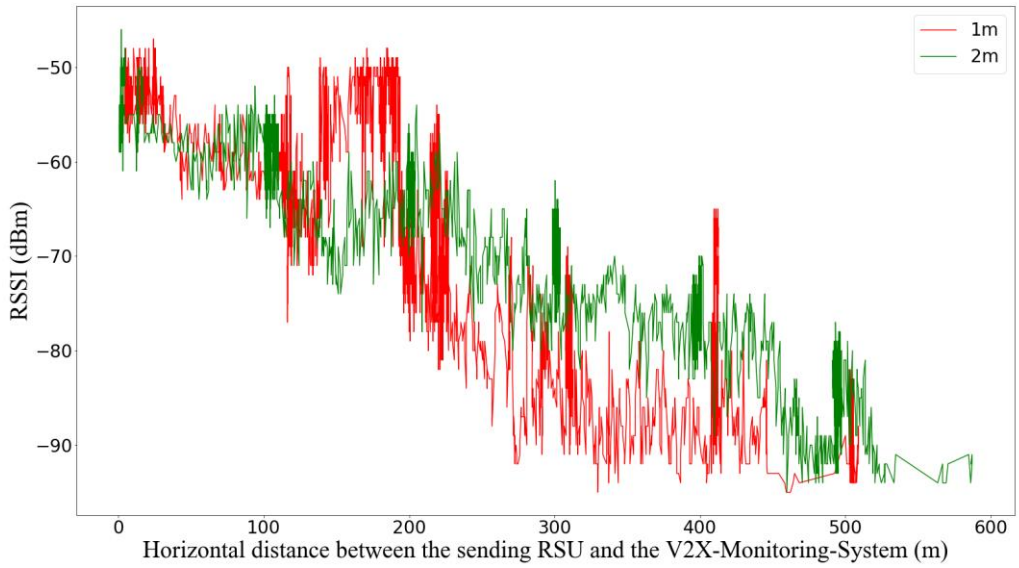

Fig. 2. Signal strength of V2X messages produced by RSU 005 at receiving height 1 m (red) and 2 m (green).

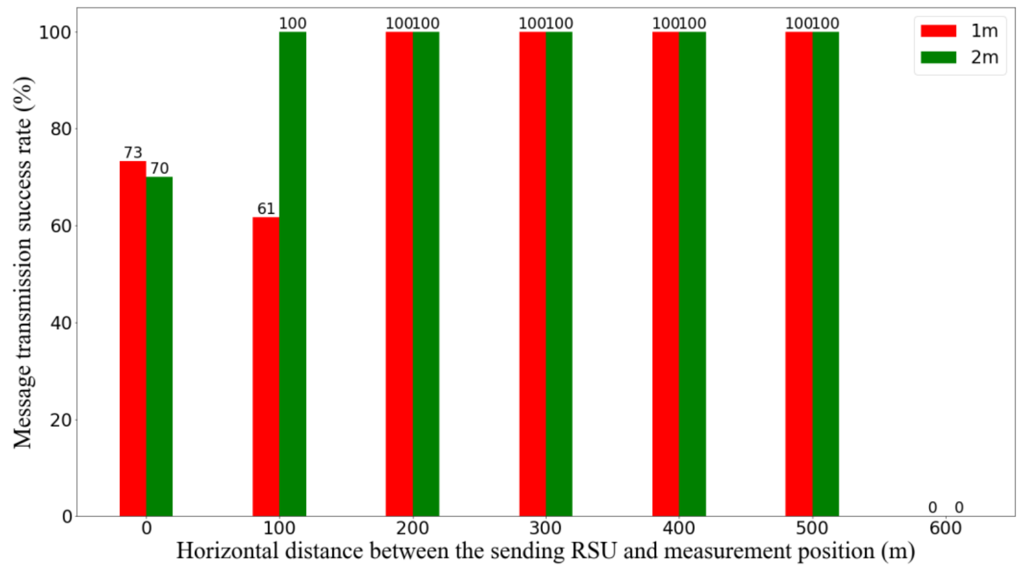

Fig. 3. Transmission success rate of MAP messages produced by RSU 005 at receiving height 1 m (red) and 2 m (green).

First, it was investigated if the receiving height of the V2X-Monitoring-System has an impact on the signal strength and message transmission success rate. If this is the case, the remaining measurements will be performed at the height with the highest success rate and signal strength. Measurements were implemented at two different receiving heights, 1 m and 2 m. As stated before, the reference position is fixed at the location of RSU 005, the height of RSU 005 is about 8 m. During this test, the V2X-Monitoring-System was moved 1500 m in the north direction with respect to the reference position.

Figure 2 shows the signal strength of V2X messages produced by RSU 005 at receiving height 1 m (red) and 2 m (green). The x-axis represents horizontal distance between the reference and measurement position. The y-axis represents signal strength of each received V2X-message. The longest measurement distance was 1500 m with respect to the location of RSU 005, however, the V2X messages reached only as far as 508 m at 1 m receiving height and 587 m at 2 m receiving height. This was due to the street layout in Kassel, with a curve that begins at 450 m and surrounding buildings, which interfered the reception of V2X messages. RSSI values are between -95 and -47 dBm at receiving height 1 m, and between -95 and -46 dBm at receiving height 2 m. Figure 2 shows that the signal strength decreases with increasing distance; RSSI values at receiving height 1 m and 2 m are similar, however, the signal strength variation at receiving height 2 m is relatively stable.

Figure 3 shows the transmission success rate of MAP messages produced by RSU 005 at receiving height 1 m (red) and 2 m (green). Again, the x-axis represents the horizontal distance between the reference position and each measurement position, while the y-axis is the message transmission success rate. At the reference position, the V2X-Monitoring-System was placed directly below RSU 005 and the success rate reached 73% at 1 m and 70% at 2 m receiving height. With increasing distance, the success rate at receiving height 1 m first decreases to 61% at 100 m and then reaches 100 % at the measurement position of 200 m. For larger distances, it remains at 100 % until the measurement position of 500 m. The message transmission success rate at receiving height 2 m has already reached 100% at the measurement position of 100 m, and remains at 100 % until the measurement position of 500 m. When computing the message transmission success rate, the MAP message was expected to be sent per second, which is used to estimate the number of messages that should be sent by RSU 005 within an one-minute time interval.

The measurement result comparison from different receiving heights also shows that the message transmission success rate is worse when the V2X-Monitoring-System is positioned directly below an RSU. The values are similar, however, receiving height 2 m provides a larger effective signal transmission range. In summary, the receiving height has an impact on signal strength and success rate. For future applications, the limit of the receiving height will be further investigated. A receiving height of the V2X-Monitoring-System at 2 m was used in the remainder of this research.

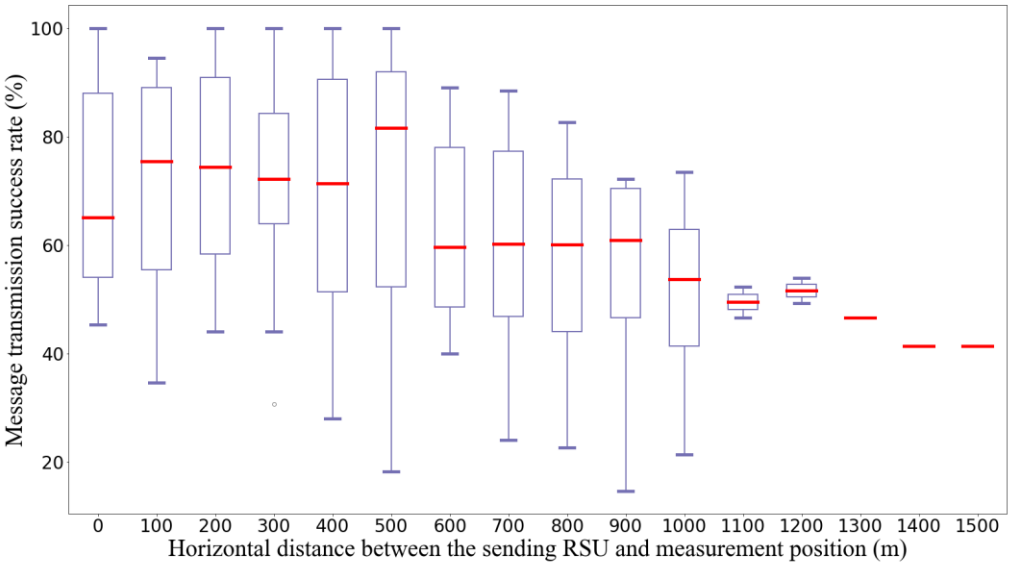

Fig. 4. The statistical distribution of the message transmission success rate from 6 RSUs.

Second, the transmission success rate of MAP messages from the 6 RSUs was investigated, which is visualized as a statistical distribution (box plot), as a function of horizontal measurement distance to any of the RSUs. From this, an effective signal transmission range can be estimated, being the distance where the entire success rate distribution decreases significantly.

Fig. 4 presents the distribution of the transmission success rate of MAP messages from 6 RSUs. The location of each RSU is taken as an independent reference position and the message transmission success rate from each RSU, at the same distance to its reference position, has been sorted to the same data bins. The x-axis represents the horizontal distance between each RSU and its signal measurement position. The y-axis represents the message transmission success rate. The red horizontal lines represent the median of a set of data. For instance, the distribution at 100 m contains message transmission success rate from 6 RSUs, at the measurement position of 100 m with respect to their locations. When computing the message transmission success rate, the MAP message was expected to be sent with the measured maximal rate of incoming signals of each RSU per minute, which is used to estimate the number of messages of selected type that should be sent by each RSU within the one-minute time interval.

The entire success rate distribution decreases significantly from the measurement position of 600 m. At the location of each RSU, the V2X-Monitoring-System was positioned directly below each RSU, the median of the set of the message transmission success rate is 65%. With increasing distance from the measurement position of 100 m, until the measurement position of 500 m, medians of the message transmission success rate are between 81% and 71%. For distances between 600 and 900 m, medians of the message transmission success rate are decreased to approximately 60%. For distances between 1000 and 1500 m, medians of the message transmission success rate between 53% and 41% are observed. From the measurement position of 1300 m until 1500 m, message transmission success rates were computed based on the measurement data from RSU 005, which is the only one RSU that managed to provide data at these distances. As shown in Fig. 4, an average effective signal transmission range is up to 500 m due to the urban nature of Kassel.

VII. Conclusions

In the paper presented here, the communication performance of a V2X system was evaluated, in particular with regard to the signal strength and the message transmission success rate as a function of the spatial positioning of RSUs, in order to ensure the communication quality in the live V2X pilot environment in Kassel for realizing public transport priority.

The evaluation was based on measurements from the V2X-Monitoring-System, which emulates a vehicle On-Board Unit. Preliminary results appeared to be promising:

- The receiving height of the V2X-Monitoring-System has an impact on signal strength and transmission success rate of messages from the RSUs. A receiving height of 2 m provides a larger effective signal transmission range than 1 m. This result helps to find an optimal location to place the OBU on public transport vehicles to ensure a better communication quality.
- The message transmission success rate is not proportional to the signal strength. The message transmission success rate is worse when the V2X-Monitoring-System is positioned directly below an RSU.
- In terms of spacing, the tested RSUs in this paper seem to provide a reliable performance. Based on current RSU locations, the distance between every two adjacent RSUs varies from 100 m to 1000 m on the test tracks, with an average effective signal transmission range of each RSU that was successfully tested up to 500 m, the live V2X environment in Kassel has met the requirements to ensure a sufficient communication quality for public transport priority.

The message transmission success rate is currently computed based on the expected (measured) message rate that the RSU should provide, in the near future, success rate computation will use number of messages actually been sent by RSUs instead. A more complete performance evaluation of the V2X communication system in Kassel will be investigated further in subsequent works, using all available RSUs. A grid topology with different measurement distances will be used at each RSU, to obtain sufficient data to analyze the whole V2X environment. This could be valuable for cases such as the communication quality for e.g. ambulances, which drive on side streets while using V2X technology. In such cases, V2X communication could be affected by obstacles such as street layout, buildings, foliage or constructions. Future work will also focus on finding the solutions to improve the communication performance.

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