V2I: Vehicle-to-Infrastructure use cases and demonstrator

Michael Wolf[1] Martin Eder[2]

Abstract: This paper starts by introducing the benefits of vehicle-to-everything (V2X) communication for autonomous driving. Especially vehicle-to-infrastructure (V2I) communication is highlighted. The contribution of this publication are the in detail explained use cases for traffic light systems (V2I). The use cases relate to intersection traffic management for cars, emergency vehicles, pedestrians and handicapped person. The use cases are underpinned by a demonstrator for a V2I traffic light system, which was created during this work. Also the two most promising technologies for V2X communication are reviewed and discussed: cellular V2X (C-V2X) and IEEE 802.11p.

Keywords: V2X, V2I traffic light, IEEE 802.11p, LTE-V2X, Cellular-V2X

1 Introduction

The impact of increasing traffic volume is a major problem for economies [Dj15, p. 1], especially in urban regions. Also the number of fatal injuries is still on a high level [We11, p. 3]. As conventional traffic management reaches its limit and improvement of passive safety nearly reached its maximum, new approaches have to be researched [We11, p. 1f.]. The development of Vehicle-to-Everything Communication (V2X) is very promising and able to reduce congestions [Dj15, p. 2] as well as accidents [We11, p. 3]. V2X also is a key technology to finally make autonomous driving ready for the market [Qu17b].

To achieve the goal of a truly autonomous driving vehicle it is absolutely necessary that the robot-vehicle knows its surrounding precisely. On-board sensors, radars and cameras are one piece of the puzzle. To achieve a world-view, further reaching information from sensors of surrounding vehicles, intelligent traffic management systems (TMS), pedestrians and a global traffic-information network have to be obtained. Transferring this data over the air to all entities is the task of V2X. With a global view of the vehicles own situation and the traffic in proximity, it is possible to drive autonomously. The required information are based on on-board sensors and V2X data, which are then processed by sensor-fusion algorithms.

- **V2V**: The term Vehicle-to-Vehicle communication implies the direct communication between vehicles in an ad-hoc local area network. Information can be sent from one car to another directly or by intermediate hops which are also represented by cars.

[1] Munich University of Applied Sciences,Department of Computer Science and Mathematics, Lothstrasse 64, 80335 München, wolf.michael@hm.edu
[2] Munich University of Applied Sciences,Department of Computer Science and Mathematics, Lothstrasse 64, 80335 München, martin.eder@hm.edu

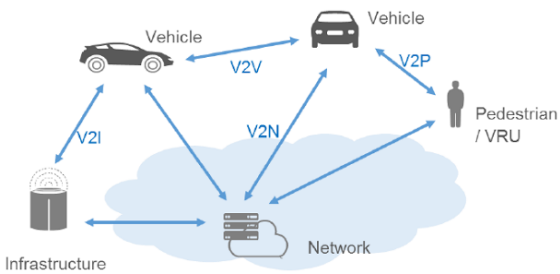

Fig. 1: V2X communication types.[3G16a]

- **V2P**: Vehicle-to-Pedestrian communication is similar to V2V communication except that V2P focuses on issues relating pedestrians, bicycles and other outside traffic participants.
- **V2I**: Vehicle-to-Infrastructure communication refers to shared information between vehicles and roadside units (RSU) or intelligent roadside stations (IRU). The roadside infrastructure dynamically manages the traffic in real-time by sending information or commands to the vehicles or by receiving relevant sensor data from them.
- **V2N**: Vehicle-to-Network communication is responsible for broadcasting global information to all cars or for streaming data to applications with a high bandwidth demand. To put it in other words, V2N means the non-real-time capable connection between a vehicle and the Internet or cloud computing services.

2 Motivation for V2I use cases and a V2I demonstrator

As mentioned above conventional TMS are not ready to tackle the major challenges of the future. This is especially true with traffic intersections. Traffic lights with periodic state changes from green to red can not react dynamically to changing traffic volumes. Therefore we introduce several ideas and use cases for smart city traffic lights with V2I aspects underpinned by a demonstrator for a V2I traffic light system. The demonstrator shows a vivid model of a V2I capable traffic light. It is focused on the near future when autonomous driving has not yet reached a very high market saturation. Therefore our system also supports standard vehicles and pedestrians without technical devices. During development special attention was paid to high priority vehicles as emergency-vehicles and public transport. Also technical assistance is provided by the traffic light system for persons with disabilities and reduced mobility.

3 Related Work

V2X motivation An article of Weiss[We11] points out that driver indebted accidents can only be further reduced by V2X. Passive safety has reached its maximum in modern vehicles for a long time. That is why car OEMs impelled to enhance active safety components, such as radar and cameras. Although huge improvements have been achieved, the technology is limited by design. Cameras can only operate in line of sight. Even the range of radar is limited around curves and points of danger beyond the radar coverage. V2X communication can solve all these issues, because points of danger can be reported and therefore circumnavigated at an early stage. Cars or the infrastructure can send beacon messages to inform other cars about issues and dangers ahead. [We11]

Traffic management Nowadays navigation systems with TMC, GPS and GPRS get information via broadcast messages [WSR09]. These systems are provided by commercial providers like TomTom or Garmin [Dj15, p. 1]. If a driver receives a message with an upcoming traffic jam he can drive around the area by taking an alternative route. Several problems are named by [WSR09]: If too many drivers follow the suggestion of taking the alternative route they again face a traffic jam. Secondly, the information can be outdated. Traffic issues are only reported and forwarded if they reach a certain level of impact. Traffic problems which are constantly changing in the local area around the vehicle are not reported globally. Thus a driver is not informed about high traffic load on their surrounding. V2V and V2I communication can solve this, by providing real-time information tailored to the needs of every individual car by itself as well as helping to maintain the overall traffic.

In [WSR09] a traffic management algorithm is introduced. It uses the sensor data from vehicles and IRSs to balance road traffic. The necessary data is transmitted by V2X communication. The algorithm works best, when a critical mass of V2X capable cars are on the road. [We11] predicts that V2X will run trough three phases. First there will be provided better information for the driver, such as warnings ahead, which are far beyond sight (Telematic Horizon). In this phase the author concludes that cellular LTE networks can help to provide V2X communication, because at that point of time there are still too few ad-hoc V2X communication partners on the road. In the second phase already more vehicles are equipped with V2X and more RSUs are able to communicate with their surrounding. This leads to improved overall traffic management and individual safety. *"Vehicles will synchronize for higher traffic efficiency, better fuel economy, and collision avoidance“* [We11, p. 3]. In the last phase even more complex scenarios will be mastered by information provided from V2X, sensor fusion algorithms and complex TMS. These will include help for crossing intersections and automatic braking based on V2V data.

The reliability of V2V data is an issue, if the V2V market share is low. The data can not be acknowledged / peer reviewed by a critical amount of other cars. The study of [MBL11] shows how the accidents increase by a low market share of V2V vehicles.

In [LD11] a concept is introduced to open bus lanes for the regular car traffic. Some cities have roads or lanes which are reserved for public transport. If there is an upcoming traffic jam these lanes can be opened for private vehicles. This leads to more capacity of the road infrastructure and to alternatives routes for some cars. At peak times the TMS alters the traffic regulations and broadcasts the new traffic rules by V2I communication. The decision of dynamically opening the bus lane is made by different sensor information inputs, such as overall traffic velocity. The simulation in the above mentioned publication concludes that there is a measurable benefit by allowing cars to temporarily use bus lanes. [LD11].

For the scenario described by [AMSW15] it is necessary that all vehicles are capable of V2I communication. This is a requirement to successfully cross an intersection which is managed by an IRS, introduced in that paper. Each car must be equipped with an intelligent traffic system called Dashboard Traffic Lights (DTS). The algorithm, introduced in the publication is able to determine a time slot for each individual car for passing the intersection. The command to access the intersection is propagated by the intersection control station. Commonly the commands from the intersection control station would be called green light- or red light-signal. Additionally the waiting time is also transmitted to the cars via V2I communication. By comparing the waiting time between common intersection management systems with traffic lights and periodic green phases the dynamically managed system reduces the waiting time significantly. This is achieved by handling each car individually and by avoiding fixed waiting periods. A further question arises: how should pedestrians or bicyclist, which are not able to receive commands from the intersection control station, cross an intersection as mentioned above? Without a DTS device for pedestrians and bicycles this is not possible. Anyhow the mentioned paper does not address this issue. Our solution in contrast supports all kinds of inside and outside traffic participants, regardless if they are equipped with a V2I capable device or not.

Another substantial paper is worth mentioning. Its focus is on traffic management with V2I communication based on IEEE 802.11. The papers [Dj15] idea is to replace common TMS such as SCOOT and SCATS. To avoid traffic congestion the idea is to use a so called Belief-Desire-Intention (BDI) architecture. This means that a vehicle has a certain view of itself such as its geolocation, driving speed, surrounding vehicles and infrastructure, obstacles and so on. These information are based on its own sensors. This is called Belief, because the assessment could be wrong. Desire corresponds to a state, which the car would like to achieve, for example crossing an intersection. At all times the knowledge of the vehicle of itself is double checked with information provided by the infrastructure periodically (V2I) and by cars in proximity (V2V). According to these information the beliefs are updated and hence a new desire is calculated, which all together results in an new intention (action) [Dj15, p. 2]. With this improved global knowledge about the traffic situation vehicles can adjust their acceleration and speed. This results in less stoppages and an overall better traffic flow, especially by collective decision of several cars. [Dj15, p. 6]

V2I misuse cases A misuse case, regarding V2I, would be to pretend that your car is an ambulance. Consequentially TMS grants emergency vehicles a higher priority, for example, to cross an intersection. The improvement of traffic management for emergency vehicles is the topic of [Dj13]. To reduce the response time and accidents with emergency cars involved, V2I and V2V communication is used. Especially crossovers are critical. Therefore TMS can temporarily adapt the traffic rules. For example reducing the allowed maximum speed. It is also suggested by the authors to inform cars early of an approaching emergency vehicle so the cars can form an emergency lane. Each car can forward the message of an approaching emergency vehicle by passing the message to the car next to it. This is supported by the Infrastructure by V2I communication. The traffic lights are accordingly adjusted as needed. In the paper the misuse of this system is addressed. As mentioned above a hacker could pretend to be an ambulance and switch the traffic lights to green. The idea to prevent this is categorized in three parts: Firstly, a potential emergency vehicle is *"authenticated by the infrastructure through V2I and I2I (Infrastructure to Infrastructure)"*[Dj13, p. 3]. Such a infrastructure could be a TMS or a traffic light system. Secondly, the vehicle could be identified by the corresponding responsible of the vehicle itself. Lastly, the emergency vehicle can be verified by peer review of other cars via V2V- in combination with V2I-communication. A suiting verification process should be chosen by the priority level of an emergency vehicle and its urgency. Depending on the priority the TMS chooses different routes and verification methods.[Dj13]

Technologies for V2X Next, C-V2X and IEEE 802.11p are introduced for V2X communication. [MBL11] represents the development of V2X in North America. After analyzing the market the paper concludes that for V2V and V2I communication, a technology like IEEE 802.11p and WAVE (Dedicated Short Range Communication) suits best because of its low latency. This is necessary for the time critical ad-hoc networks between several moving cars or the infrastructure driven past. For high bandwidth scenarios such as V2N communication they suggest the use of existing 3G/4G cellular networks or WiMAX systems. Also the very diverse conditions of urban and rural regions in North America adds up to this.

A paper from China [Su16] asserts that for Europe and North America probably IEEE 802.11p will dominate. The paper from China discusses LTE and LTE-Direct as a general solution. It is argued that the costs of V2X infrastructure deployment can dramatically be reduced by LTE networks. Given that LTE networks are already wide spread and a commercial success it is the breakthrough for V2X. The former problem of cellular networks was that UMTS and 4G LTE are not suitable for time-critical scenarios. With 5G and LTE-Direct a low latency point to point communication between several cars and a RSU can be established. However it is conceded that there are still problems with 5G, for example the Doppler effect [Su16, p. 2].

3.1 LTE-V2X

LTE-V2X is based on LTE-Direct, which continues the idea of IEEE 802.11p to connect vehicles to each other and to RSUs. LTE-Direct standardization was released in 2014, 3GPP Release 12 [Y.17, p. 10]. Meanwhile LTE-V2X Release 14 is still under standardization process [Qu17b]. The 3GPP will be finished with the relevant releases 14 and 15 in 2017 and 2018, respectively [3G16c], [3G16b]. The latest term for LTE-V2X is Cellular-V2X (C-V2X) [5G16, p. 1]. A sustainable recommendation for the bandwidth of LTE-V2X is 70 MHz [Qu17b, p. 13]. Like LTE-Direct the direct communication link for LTE-V2X is called PC5-Interface (Side-link). The local V2V and V2P communication is based on the

PC5-Interface for low latency use cases [Qu17b, p. 16]. The direct connection is equivalent to the ad-hoc mode of IEEE 802.11p WiFi. The network-interface named Uu-Interface is used to connect to the Internet (V2N). For V2I communication the PC5-Interface as well as the Uu-Interface are used. This depends on the requirements of real-time capability and bandwidth.[5G16, p. 2] According to the 5g Automotive Association (5GAA) LTE-V2X will be ready for the market by 2018 [5G16, p. 3]. This date also depends on how frequency-regulators and telecommunication providers are willing to pave the way for 5G [Li16].

3.1.1 Operating principle

The term LTE-Direct and Device-to-Device Communication (D2D-C) refers to a technology, which allows direct communication between two user equipments (UE). A UE can be a smartphone or a V2X-capable vehicle. The cellular network infrastructure from a Communication provider *can* be used for establishing a direct connection between to UEs. After the initialization process the communication is continued without the cellular infrastructure.[Qu17a, p. 2]

Network infrastructure Prior launching LTE-Direct in a providers cellular network, two components have to be added to its network infrastructure: LTE Evolved Packet Core (EPC) and PC5-Interface. The EPC is responsible, inter alia, for following tasks: Direct Discovery, Direct Communication, Network-Assisted Discovery, Authorization, Configuration of peers (UE). The PC5-Interface is used for direct communication between two UEs.[JS],[Si17, p. 5f.] For direct connection between UE this infrastructure is not necessarily needed, but highly recommended to gain all features [5G16, p. 2]. Providers may refuse to replace the core of their network with EPC, because first of all this a major investment.

3.1.2 Technical details

Frequency As a basic service the existing LTE cellular network is used. For direct communication and low-latency critical use cases LTE-Direct, more specifically LTE-V2X, is used. As LTE-V2X supports various transmission modes, it can therefore operate in the commercial licensed frequency range (V2N) and in the intelligent transport system spectrum (ITS) of 5.9 GHz (V2V, V2I, V2P) [5G16, p. 3]. LTE-Direct and LTE-V2X support Frequency Division Duplexing (FDD) and Time Division Duplexing (TDD). These are two variants which use the broadband spectrum differently. FDD uses separate frequency bands for up- and downlink. TDD uses one frequency for both. TDD is commonly designated as the superior technique.[JS]

Communication setup between devices The initial communication setup for LTE-Direct is one of the most challenging tasks. In fact there are two general approaches: Distributed and Network Assisted. In the first case, a UE periodically sends broadcast messages and listens for a direct connection request. This kind of approach is only used if there is insufficient network coverage. By using Network Assisted, the connection setup is established by the help of an eNodeB (cellular base station) as a intermediary. The eNodeB measures signal strength and interference of each UE. With this information the eNodeB can set the correct parameters, such as frequency and signal strength, to establish a direct LTE connection. After this process the connection proceeds between the UEs without the eNodeB middleman. In total, Network Assisted communication establishment ensures that the normal cellular LTE-frequency is not disturbed and prevents a polling broadcast. [WT16, p. 14f.]

3.2 IEEE 802.11p

For mission critical low latency V2X use cases IEEE 802.11p was introduced. IEEE 802.11p is a continuation of the IEEE 802.11 radio standard. It is optimized for ad-hoc networks between vehicles that are in motion to each other (V2V) and between a moving vehicle and a RSU (V2I). 802.11p WAVE, stands for Wireless Access in Vehicle Environments and operates in the Dedicated Short Range Communication (DSRC) spectrum band. Europe, North America and Japan use slightly different frequencies for DSRC. IEEE 802.11p is responsible for the MAC and physical-layer of the ISO/OSI model. Upper layers are covered by IEEE 1609.3. This handles the management and the setup of connections in WAVE. The standard IEEE 1609.4 is also needed for ISO/OSI layers on top, to operate on multiple channels, without knowing the underlying physical-layer. [JD08, p. 1f.]

Challenges Issues like interferences between channels might occur. A car (Alice) sending on channel 170 could prevent another car (Bob) from receiving data from a third car (Carol), which is sending on channel 172. To prevent this, a policy for channel management has to be introduced. IEEE 802.11p helps addressing this problem by enhancing the receiver's adjoining channel rejection mechanism.[JD08, p. 4]

Network infrastructure Vehicles supporting V2V and V2I communication must implement a WiFi radio equipment for IEEE 802.11p. The road infrastructure has to provide network access points for V2N communication or the vehicle has to have another device for cellular network connectivity, such as LTE. The latter is more likely, because V2N communication does not need a low latency interface like IEEE 802.11p. Furthermore for V2I communication RSUs have to be equipped with a WiFi radio module.[Y.17, p. 6]

Frequency In the U.S.A the DSRC spectrum which is used by IEEE 802.11p is divided into seven 10MHz channels. The used frequency in the licensed ITS/DSRC band is 5.9

GHz. This band is free of charge, but still licensed. The usage of the DSRC band is restricted in usage and in technology. All applications have to meet the standard and the appropriate rules.[JD08, p. 1] In Europe the spectrum is 30MHz [Y.17, p. 6].

Communication setup between devices A fast moving vehicle does not have the time to scan the environment for channels and BSSIDs, which it wishes to connect to. The time for receiving a beacon and preforming a handshake process are too time consuming. The connection for V2V and V2I must be established faster. Thus, all IEEE 802.11p networks operate on the same channel and have the same BSSID. *"A station in WAVE mode is allowed to transmit and receive data frames with the wildcard BSSID value and without the need to belong to a BSS of any kind a priori"* [JD08, p. 3]. This technique is called Wave BSS (WBSS). It saves the overhead of establishing a connection and therefore data can be transmitted straight away. To join a WAVE BSS it is only necessary to receive one advertisement message from the counterpart. However, all of this disables the security features of known WiFi standards. As a result security must be managed in ISO/OSI layers above.[JD08, p. 2ff.]

4 V2I use cases and V2I traffic light demonstrator

Within the frame of this work a V2I traffic light demonstrator was implemented. The following chapters will introduce the setup and the ideas around this conceptional prototype. Consideration has to be taken, that the demonstrator is not a technical prototype. For demonstration purpose a mobile Android App was developed to interact with the demonstrator. The source code and the build instructions of the demonstrator and the App can be found online on [Ma17]. The use cases developed by this work for V2I based traffic lights will also be discussed. Eventually, it is a perfect supplement for the ongoing research topic "Autonomous driving" at the Munich University of Applied Sciences.

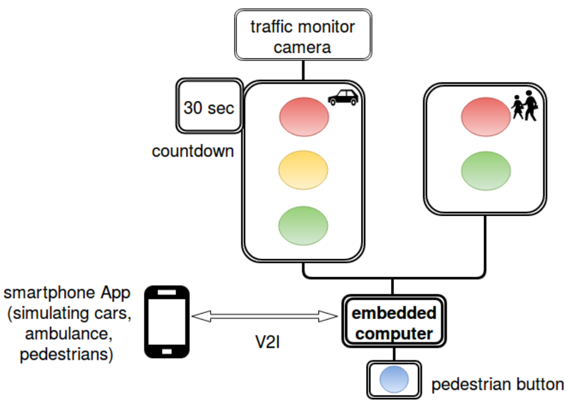

Fig. 2: V2I demonstrator model.

Fig. 3: V2I demonstrator.

4.1 Use cases

The ideas for a V2I traffic light system explained here are all listed in the appendix as use case forms [Ma17]. As shown in the chapter related work, the impact of traffic jams and slowly moving vehicles on the economy is immense.

Green wave Intelligent traffic light systems can support the TMS, to guarantee that vehicles can pass several successive intersections without stopping. Our system detects vehicles early, to dynamically optimize waiting time. This is a major improvement compared to common periodic waiting times and it is also a fair system, which does not favor a specific traffic lane. For this a camera with a object recognition software detects the approaching vehicles. Also passing by vehicles could inform the traffic light system of approaching vehicles from behind by V2I communication.

Dynamic traffic light signal cycles This use case is similar to one mentioned above. The focus here is on the single traffic light system and not a group of traffic light systems or a TMS. It switches the traffic light dynamically in real-time depending on camera, V2I or on pedestrian-to-infrastructure data. The goal is to avoid static traffic light signal cycles.

Traffic light status request In this context a third use case is promising: Providing useful information for road users, which are waiting for a green signal on a intersection. Vehicles, pedestrians and others can obtain the current signal cycle time, traffic light state and predicted waiting time. By sending a request over an air-interface the traffic light system responses with the mentioned data. Vehicles can, for example, reduce speed early or stop the engine, if a longer waiting time is predicted by the system. Pedestrians are reassured about the traffic light state and know how much time is left for crossing the road. To use this service pedestrians have to be equipped with a smartphone, wearable or other V2X capable device.
All above use cases reduce congestions, save fuel and CO_2 emissions, by intelligently managing the traffic flow and providing useful information to the road users.

Crossing priority for emergency vehicles Emergency vehicles can safely cross an intersection without waiting time. An approaching rescue vehicle or a police car sends an emergency signal to the V2I traffic light system via radio interface. The traffic light turns red for pedestrians and vehicles and ignores any further crossing request. The emergency vehicle informs the traffic light system, when it left the intersection, by sending a message. Now the traffic light system can switch back to normal operation mode.

Numeric signal cycle indicator for pedestrians For pedestrians that do not have a V2X capable device at hand, a numeric signal cycle indicator can show the remaining time of a traffic light period. This already common for vehicles, but not yet widely spread for pedestrian traffic lights. In a future without physical traffic lights, as mentioned in [AMSW15], there will still be the need of a device which ensures a safe crossing of an intersection for people without a technical device.

Communication interface for pedestrians The well-known button for pedestrians to request the wish of crossing the road is extended by an radio interface. Pedestrians can also use the radio interface by an mobile app installed on a smartphone or wearable to request a green light signal. This can for example be a hygiene benefit, because the pedestrian-buttons does not have to be touched at all. Also people with a handicap or reduced mobility can benefit from a button-less system. If the person is physically not able to reach the pedestrian-button a mobile app on his wheelchair-computer could do the job of requesting green for him. Those computers/apps are much easier to handle, because they are adapted to the needs of the disabled.

Simplified crossing for handicapped pedestrians Again pedestrians with reduced mobility might need an extended time for crossing the road. This considered by the use case: Simplified crossing for handicapped pedestrians. They can request additional time for crossing.

Road toll collection Road authorities have an interest in collecting toll from road users. As radio interface based toll collection is already established for trucks it still not very wide spread among car owners. Therefore it is worth mentioning that V2I communication is an ideal use case for toll collection. Vehicles send there number plate ID to the traffic light system via radio interface. The ID and a timestamp are saved in a database and transmitted to the authorities to process the road toll.

Traffic education As already tested in the field, traffic education for vehicles speeding can be achieved by modern traffic light systems. If a vehicle exceeds the maximum speed the traffic light is switched to red. As a result the driver gets trained that speeding is useless. Our idea is to measure the speed with a camera based computer vision software.

Augmented reality advertisement The last use case is about advertisement. The traffic light system is perfect place for sending data, over the air, containing ads for passing by or waiting vehicles. Especially by highlighting shops and businesses in the surrounding shapes up well. This can be done by augmented reality. The windscreen of the car could add artificial objects to the environment, much like a headup-up-display (HUD).

5 Discussion

5.1 Comparison between C-V2X and IEEE 802.11p WAVE for V2X communication

As outlined in the chapters regarding C-V2X and IEEE 802.11p WAVE the approaches for implementing V2X communication are quite different. The former is based on 5G cellular network services for V2N communication and gets extended by a direct communication link for low latency services (V2V, V2I, V2P). The latter is based on IEEE 802.11 WiFi standard and provides a low latency communication technology (V2V, V2P, V2I). It is not clear yet which one will make the race for mission critical use cases (V2V, V2I, V2P). For high bandwidth applications like V2N it is quite clear that cellular based services as LTE will be the global standard [Li16]. As long as the market share of V2V communication is still low it is very likely that 4G/5G services will support V2V communication [We11, p. 6]. Notwithstanding the benefits each technology brings along, it is a decision of competing committees, global player enterprises and regulators. Regulators have to release required frequencies for C-V2X or IEEE 802.11p WAVE. Also telecommunication providers have to invest in new infrastructure and replace their network core system with EPC for supporting 5G [Li16]. Road authorities have to invest in new infrastructure to support WAVE. Finally, return of investment has to be considered. 5G based technologies seem to have a more versatile and future proof number of use cases [5G16, p. 5f.], [Y.17, p. 8]. According to the papers reviewed, it seems that IEEE 802.11p will have good chances in Europe, while Asia and North America will go for 5G based technologies.

A comparison between both based on technical facts can be found in [5G16, p. 4], [HSW16] and [Su16].

6 Conclusion

The paper gives an overview over V2X in general and related technologies. It was made clear that there is still a long way to go before V2X is ready for market. As mentioned V2X will be implemented in several phases. We are now in the beginning of the first phase. The demonstrator and the presented use cases for V2I traffic light systems are a contribution to this, as well as a step forward for better understanding the needs of V2X and autonomous driving in general. As future work the demonstrator could be combined with further traffic light systems to demonstrate more complex traffic scenarios, such as optimized traffic flow control.

Please refer to the use cases, source code, build instructions and pictures online on [Ma17].

References

[3G16a] 3G4G blog: , The 3G4G Blog, 11 2016.

[3G16b] 3GPP : , 3GPP Release 15, 10 2016.

[3G16c] 3GPP: , 3GPP Release 14, 10 2016.

[5G16] 5GAA: , The Case for Cellular V2X for Safety and Cooperative Driving, 11 2016.

[AMSW15] Al-Mashhadani, M.; Shu, W.; Wu, M. Y.: Enhancing Traffic Flow Using Vehicle Dashboard Traffic Lights with V2I Networks. In: 2015 IEEE Global Communications Conference (GLOBECOM). pp. 1–5, Dec 2015.

[Dj13] Djahel, S.; Salehie, M.; Tal, I.; Jamshidi, P.: Adaptive traffic management for secure and efficient emergency services in smart cities. In: 2013 IEEE International Conference on Pervasive Computing and Communications Workshops (PERCOM Workshops). pp. 340–343, March 2013.

[Dj15] Djahel, S.; Jabeur, N.; Barrett, R.; Murphy, J.: Toward V2I communication technology-based solution for reducing road traffic congestion in smart cities. In: 2015 International Symposium on Networks, Computers and Communications (ISNCC). pp. 1–6, May 2015.

[HSW16] Hiltscher, Johannes; Streiter, Robin; Wanielik, Gerd: Is IEEE 802.11 p V2X Obsolete Before it is Even Deployed? In: Advanced Microsystems for Automotive Applications 2016, pp. 31–41. Springer, 2016.

[JD08] Jiang, D.; Delgrossi, L.: IEEE 802.11p: Towards an International Standard for Wireless Access in Vehicular Environments. In: VTC Spring 2008 - IEEE Vehicular Technology Conference. pp. 2036–2040, May 2008.

[JS] J. Schlienz, A. Roessler: , Device to Device Communication in LTE.

[LD11] Laura, B.; Daniel, K.: Evaluation of opening bus lanes for private traffic triggered via V2X communication. In: 2011 IEEE Forum on Integrated and Sustainable Transportation Systems. pp. 48–53, June 2011.

[Li16] Liam Proud: , Europe may end up behind the curve on 5G internet, 9 2016.

[Ma17] Martin Eder and Michael Wolf: , Appendix and Souce Code for: 'V2I: Vehicle-to-Infrastructure use cases and demonstrator', 1 2017.

[Online] available: https://shreaker.github.io/V2I-Traffic-Light-Demonstrator.

[MBL11] Misener, James A; Biswas, Subir; Larson, Greg: Development of V-to-X systems in North America: The promise, the pitfalls and the prognosis. Computer Networks, 55(14):3120–3133, 2011.

[Qu17a] Qualcomm: , Creating a Digital 6th Sense with LTE Direct, 1 2017.

[Qu17b] Qualcomm: , Leading the world to 5G Cellular Vehicle-to-Everything (C-V2X) technologies, 1 2017.

[Si17] Signals Research Group for Qualcomm: , EXPANDING YOUR HORIZONS WITH LTE DIRECT, 1 2017.

[Su16] h. Sun, S.; l. Hu, J.; Peng, Y.; m. Pan, X.; Zhao, L.; y. Fang, J.: Support for vehicle-to-everything services based on LTE. IEEE Wireless Communications, 23(3):4–8, June 2016.

[We11] Weiß, Christian: V2X communication in Europe–From research projects towards standardization and field testing of vehicle communication technology. Computer Networks, 55(14):3103–3119, 2011.

[WSR09] Wedel, J. W.; Schnemann, B.; Radusch, I.: V2X-Based Traffic Congestion Recognition and Avoidance. In: 2009 10th International Symposium on Pervasive Systems, Algorithms, and Networks. pp. 637–641, Dec 2009.

[WT16] Wang, Li; Tang, Huan: Device-to-Device Communications in Cellular Networks. Springer, 2016.

[Y.17] Y. Shi: , LTE-V: A Cellular-Assisted V2X Communication Technology, 1 2017.