V2X communication overview
and
V2I traffic light demonstrator

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Abstract—This paper gives an in-depth overview about vehicle-to-everything (V2X) and especially vehicle-to-infrastructure (V2I) communication. After that cellular V2X (C-V2X) and IEEE 802.11p are discussed. For V2X communication these technologies are the most promising ones. The contribution of this publication are the in detail explained use cases for traffic light systems (V2I). The use cases are underpinned by a demonstrator for a V2I traffic light system, which was created during this work. The target audience are engineers and students, who are new to V2X. Decision makers and experts can also benefit by reading the chapter use cases, which gives new food for thought.

Index Terms—V2X, V2I traffic light, IEEE 802.11p, LTE-V2X, Cellular-V2X

I. INTRODUCTION

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

One objective of this paper is to give an overview of V2X-Communication and related technologies for engineers and students. Therefore a short introduction of important V2X related terms follows: The term Vehicle-to-Vehicle communication (V2V) 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. Vehicle-to-Infrastructure communication (V2I) refers to shared information between vehicles and so called 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.

Next to mention is Vehicle-to-Network communication (V2N). It 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. Vehicle-to-Pedestrian communication (V2P) is similar to V2V communication except that V2P focuses on issues relating pedestrians, bicycles and other outside traffic participants.

In the past there have been many discussion which technology is the best for the requirements of V2X communication. As the requirement for V2V, V2P and V2I is primarily reliable real-time low latency communication, it is high bandwidth for V2N communication. As the decision is not yet made and the discussion in different countries and committees continues, this paper focuses on LTE-Direct/LTE-V2X and IEEE 802.11p WiFi. In the chapter Technologies both are briefly introduced and relevant aspects to V2X are mentioned.

As mentioned above conventional traffic management systems (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. Due to the targeted reader audience we decided to not only show how our ideas of a traffic light system, but also construct a physical demonstrator. 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.

A. Outline

This publication is structured as follows: at first, related work and motivation in context of V2X and especially V2I is reviewed. Next, an overview of LTE-Direct/LTE-V2X tech-

nologies and 802.11p WiFi is given. After that, the main part of the paper focuses on the V2I traffic light prototype demonstrator. This chapter concentrates on use cases of modern V2I traffic light systems. Also a description how we created our demonstrator follows with difficulties we had to face. Finally, LTE-Direct/LTE-V2X and IEEE 802.11p WiFi are compared, as well as a discussion and conclusion about the future of V2X in general are given.

II. Related Work

A. Important V2X publications

An article of Weiss [2] 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 over issues ahead. Weiss summarizes many surveys about technologies for V2X communication funded by major German car manufacturers and the Federal Republic of Germany to show how to combine these results. In the C2C-Consortium these individual results are combined to implement V2X in a real-life scenario. The project is named sim^{TD} and uses 3G UMTS as base service and IEEE 802.11p for time-critical communication. The article mentioned shows the situation in Europe and especially in Germany.

A different point of view is the publication [3] which 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. As like as in Europe the decision makers have not agreed on a standard for V2X. Also the very diverse conditions of urban and rural regions in North America adds up to this.

The situation in Japan is a bit different. The small country with its high distribution of the latest technology among the population makes it more easy to implement V2X communication. As [4] states in Japan *existing* technology is being tried to use for V2X. Instead of waiting for an arrangement defining *the* standard wireless communication Japan moves forward. Field tests with RFID or 3G-cellphones with GPS have already been used for V2P communication. Also infrared signals are used for V2I communication. Cars receive (alert) messages on their navigation system or on their board computer. State-of-the-art cellphones and on-board vehicle systems already have

a wide distribution. Mainly because of the support of Japans car OEMs and telecommunication providers.

A paper from China [5] correctly asserts that for Europe and North America probably IEEE 802.11p is the game maker. 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. Yet another wireless standard is suggested by [6]: Zigbee. Zigbee was chosen for V2I, because of its *"strong self-organizing, strong self-healing capabilities, big network capacity and good communication reliability"* [6, p. 3].

Another issue worth rethinking and discussing is the distribution of V2X capable vehicles, RSU and devices from pedestrians and so on. Which problems arise at a certain level of market share? Nowadays navigation systems with TMC, GPS and GPRS get information via broadcast messages [7]. These systems are provided by commercial providers like TomTom or Garmin [1, 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 [7]: 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. Thus a driver is not informed about high traffic load on their surrounding. V2V and V2I communication can solve this, because it is capable of relevant real-time information tailored to the needs of every individual car by itself as well as helping to maintain the overall traffic.

In [7] 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. [2] 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. This is achieved by more detailed information provided to the driver. *"Vehicles will synchronize for higher traffic efficiency, better fuel economy,*

and collision avoidance" [2, p. 3]. In the last phase even more complex scenarios will be mastered by information provided from V2X, sensor fusion algorithms and complex traffic management systems (TMS). These will include help for crossing intersections and automatic braking based on V2V data. Talking about the distribution of V2X capable vehicles it is especially relevant for V2V communication. V2N communication does not depend on a high market share of V2X cars. In fact cellular based V2N communication can be used in the first phase of V2X. It supports cars with global information from cloud services. This is useful if the vehicle is in an area where are not enough other V2V capable cars to share data. This will be the case in phase one and even in later phases in rural regions.

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. In [3, p. 11] it is even argued that active V2V with a low deployment rate is worse than having no V2V at all. The study of [3] shows how the accidents increase by a low market share of V2V vehicles. Therefore they suggest to activate the V2V system not before a critical V2V deployment is given [3, p. 11].

On the other hand certain use cases can benefit by a low V2X market share. In [8] 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, which may be an advantage for some cars. At peak times the TMS alters the traffic regulations and broadcasts the new rules by V2I communication. For example the dynamic traffic regulation could change the speed limit temporary. 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. However this is only true, if not too many cars use the alternative (bus lane) route. So if more cars are V2I capable, the more cars know about the alternative route and therefore no benefit is given [8, p. 5]. The solution could be that an IRS allows only certain cars to use the extra lane.

In contrast [9] necessarily assumes 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 light system called Dashboard Traffic Lights (DTS) [9, p. 1]. 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 new dynamically managed system reduces the waiting time significantly. This is achieved by handling each car individually and by avoiding fixed waiting periods. The overall betterment for the traffic flow are noticeable as well as the improvement for each single vehicle. This paper will focus on a traffic light system which can handle regular and V2X capable vehicles alike. 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.

In the following related work on the subject, security of V2X will be discussed. Regardless of the underlying technology it is worthy of discussion how information received from V2X entities is treated. Driver assistance systems need to be able to trust data received from IRS via V2I or from another car via V2V. In [4, p. 7f.], this trust of information issue is addressed. A hacker could take advantage by sending fake messages to the victims car. The vehicle would believe the message was sent by the IRS and react accordingly. In the knowledge of not being able to prevent this scenario for sure, the paper suggest to only send messages with a recommendation. The driver assistance system or the motorist does not react to this warning/recommendation message automatically. Therefore the received message can be verified and checked for plausibility. These types of "light" messages are proven to be sufficient for getting the drivers attention [4, p. 7f.].

Another misuse case 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 [10]. 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 also supported by the Infrastructure by V2I communication. The traffic lights are accordingly adjusted as needed. Later 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)"* [10, 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. The paper suggest a priority from high over medium to low. Depending on the priority the TMS chooses different routes and verification methods. [10]

Another two substantial papers are worth mentioning. They both focus on traffic management with V2I communication (based on IEEE 802.11p). The first [1] wants 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 is 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) [1, 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. A simulation proofed this. In a future work selfish drivers could be punished to further improve the overall flow of traffic. [1, p. 6]

The second paper [11] uses a fuzzy-logic based control algorithm for an intelligent traffic management system to regulate the flow of traffic and to prevent car crashes. The provided solution was verified by a survey about IEEE 802.11p (WAVE). The publication also includes concrete implementation of a data structure used for V2I-messages. This is of special interest, because ideas can be carried over to the traffic light demonstrator. The contribution of the mentioned paper is an evaluation system to show how drivers are using their car. This leads to sending optimized data to the vehicles. Another major role is that the paper shows how a AUTOPIA experiment is accomplished by real cars. AUTOPIA refers to a research program for autonomous vehicles.

B. Contribution of this V2X paper

Many differences have already been mentioned. In summary this papers contribution is the overview of existing work on V2X and related technologies. Targeting readers who are new to V2X, this work gives a brief introduction, which is underpinned by the V2I traffic light demonstrator. For decision makers and experts the presented use cases for V2I traffic light systems are well fitted to give new food for thought. In contrast to the reviewed papers, issues concerning pedestrians are highlighted.

C. Important standards and associations

Following standards and committees are relevant for the discussion about V2X in this paper:

- **C2C-Consortium**: The Car-to-Car Communication Consortium is a group of leading car manufacturers, component suppliers, technology companies and research institutions. Their goal is to develop a standard for a Cooperative Intelligent Transportation System (C-ITS) in Europe. They also focus on a validation process for V2V and contribute to European standardization authorities. [12], [2]
- **5GAA**: The 5G Automotive Association is group of telecommunication providers, car manufacturers, component suppliers and technology companies. The members are less in number as in the C2C-Consortium, but several companies are represented in both groups. The focus here is on pushing 5G LTE services for V2X use cases. They want to globally convince regulators, standardization committees and businesses to adopt cellular 5G technology for V2X. [13]
- **3GPP**: The 3rd Generation Partnership Project is a standardization body for specifying mobile communication standards. In the context of this paper the 3GPP releases 14 and 15 are important. They focus on the specification of 5G LTE for V2X communication. [14], [15], [16]
- **IEEE**: The Institute of Electrical and Electronics Engineers is known for its standardization committees of a wide range of technologies. In this context it is notable for the IEEE 802.11p Wireless standard. This wireless technology is used for mission-critical V2V and V2I communication. [17]

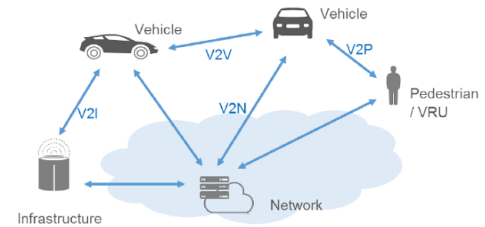## III. MOTIVATION FOR V2X COMMUNICATION

Fig. 1. V2X communication types. [14]

A. Why is V2X a key concept for autonomous driving

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 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.
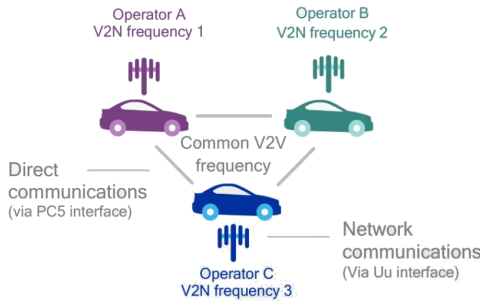
Fig. 2. C-V2X in cellular network coverage: V2V and V2N. [19, p. 16]

Figure 1 on page 4 shows different types of V2X communication. Below use cases are given for each form of V2X communication.

- **V2V**: cooperative collision avoidance/warning, warning of an hazardous area behind a bend, improving traffic flow, emergency vehicle warning, road condition information
- **V2P**: Attention warnings of approaching pedestrians and bicyclists
- **V2I**: traffic light signals, warning of an hazardous area, traffic regulation update, information for improving traffic flow
- **V2N**: Route planning, traffic news, cloud services for infotainment

An even more extensive list of use cases can be found at [18].

IV. Technologies

A. LTE-Direct and 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 [20, p. 10]. Meanwhile LTE-V2X Release 14 is still under standardization process [19]. The 3GPP will be finished with the relevant releases 14 and 15 in 2017 and 2018, respectively [15], [16]. The latest term for LTE-V2X is Cellular-V2X (C-V2X) [13, p. 1]. A sustainable recommendation for the bandwidth of LTE-V2X is 70 MHz [19, p. 13]. Like LTE-Direct the direct communication link for LTE-V2X is called PC5-Interface (Side-link). Additionally it is intended to establish a network-interface named Uu-Interface. In Figure 2 on page 5 it is shown how the cars are booked in to various cellular networks operated by different operators. By this V2N connection link (Uu-Interface) they are connected to the cellular network (Internet). The local V2V and V2P communication is based on the PC5-Interface for low latency use cases. [19, p. 16] The direct connection is equivalent to the ad-hoc mode of IEEE 802.11p WiFi. An additional communication link is V2I, which uses the common network infrastructure (not shown in the illustration). [13, p. 2] According to the 5g Automotive Association (5GAA) LTE-V2X will be ready for the market by 2018 [13, p. 3]. This date also depends on how frequency-regulators and telecommunication providers are willing to pave the way for 5G [21].

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. he cellular network of a provider *can* be used for establishing a connection. After initialization the communication does not use the cellular infrastructure of a provider anymore. [22, p. 2]

a) 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 first is responsible, inter alia, for following tasks: Direct Discovery, Direct Communication, Network-Assisted Discovery, Authorization, Configuration of peers (UE). The latter is used for direct communication between two UEs. [23], [24, p. 5f.] While this is true for LTE-Direct it is not entirely necessary for LTE-V2X, but still recommended to gain all features of this technology [13, p. 2]. Providers may refuse to replace the core of their network with EPC, because first of all this a major investment.

2) Technical details:

a) 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) [13, 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. [23]

b) 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, because it is very power consuming and inefficient. By using Network Assisted, the connection setup is established by the help of an eNodeB (cellular base station) as a intermediary. Network Assisted can be further subdivided in full- and half-assisted. The eNodeB collects and 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. [25, p. 14f.]

B. 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 as it is called, 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. For explaining 802.11p as a V2V and V2I technology this is secondary. The following relates to the situation in the United States of America. 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. [17, p. 1f.]

a) 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. [17, p. 4]

b) 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. [20, p. 6]

c) Frequency: 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. [17, p. 1] In Europe the spectrum is 30MHz [20, p. 6].

d) Communication setup between devices: As known from common WiFi the connection to an access point is time consuming. A fast moving vehicle does not have the time to scan the environment for channels and BSSIDs, which it wishes to connect to. It cannot wait for a beacon of a BSS and it cannot wait for the handshake process. 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"* [17, 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, as mentioned before. [17, p. 2ff.]

V. 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. The use cases developed by this work for V2I based traffic lights will also be discussed.

A. Motivation

The intention of this paper is to introduce students and engineers to the subject of V2X and especially V2I. Therefore to demonstrate the statements of this paper, a V2I demonstrator was created. It also underpins the use cases for V2I traffic lights. Eventually, it is a perfect supplement for the ongoing research topic "Autonomous driving" at the Munich University of Applied Sciences.

B. Setup demonstrator

The budget for the demonstrator was 200€. The conceptional prototype includes following parts worth mentioning:

- plastic traffic light (70cm) with light signals for vehicles and pedestrians
- illuminated button for pedestrians to cross an intersection
- camera for object recognition for vehicles
- computer-based embedded control system (Raspberry Pi)
- mobile app for showcasing and simulating use cases which interact with the V2I traffic light over its radio interface
- control system based WiFi access point (IEEE 802.11n)
- I2X communication interface (RESTful Web service)

C. Use cases

The ideas for a V2I traffic light system explained here are all listed in the appendix as use case forms. Not all use cases are actually implemented in the demonstrator. Due to limitations in time, budget and overwhelming complexity. As shown in the chapter related work, the impact of traffic jams and slowly moving vehicles on the economy is immense. Therefore a truly "green wave" is desirable. 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.

The next use case is similar. It is named "Dynamic traffic light signal cycles". The focus here is on the single traffic

light system and not a group of traffic light systems or a TMS. It also switches the traffic light in real-time depending on camera, V2I or on pedestrian-to-infrastructure data.

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.

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 [9], there will still be the need of a device which ensures a safe crossing of an intersection for people without a technical device.

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.

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 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.

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.

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).

D. Problems during the project

It turned out, that the setup of the build environment was a major problem. Compiling directly on the Raspberry Pi is not suitable, since the used code base is huge and would need several hours to complete the compiling process. In particular during the beginning of development, when things have to be figured out and redone multiple times until they are in a working condition, it is impossible to wait this long.

There is an officially provided toolchain for cross compiling on a more powerful host for the Raspbian operating system. The toolchain was not usable by us, since newer versions of Microsoft's C++ REST SDK presume at least GCC 4.9 and the toolchain is based on GCC 4.8. We switched to another ARM toolchain provided by the Linaro organization for this project, which is based on GCC 4.9. This led to the problem, that the C++ standard library from this toolchain differed from the one on the Raspbian host. The resulting run-time errors could be avoided by statically linking the standard library into the binary.

For the object detection part the OpenCV library was used. This library can be build with CMake, but it relies during build configuration on the "pkg-config" command for finding its dependencies. CMake in the current version did not handle this correctly for our cross compiling environment and it took some time to figure out, which environment variables have to be set to point it to the Raspbian root directory.

For GPIO handling there is a library called WiringPi. WiringPi's build file is intended to be directly invoked on the Raspberry Pi, so a custom CMakeLists.txt file had to be written. Without this file it wouldn't be possible to cross-compile the library with the CMake build system.

The object detection of cars is still not in an acceptable condition. There are various parameters (number of samples, distortion angles of generated samples, sample size, ...) influencing the training process and some time will be needed to figure out the best fitting adjustment of them. Nevertheless the detection based on Haar feature-based cascade classifiers is fully integrated into the code and a better file with training data will result in a good detection outcome. At the moment the false-positive rate is rather high.

VI. DISCUSSION

A. Comparison between Cellular-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, 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 probably be the global standard [21]. As long as the market share of V2V communication is still low it is very likely that 4G/5G services will support V2V communication [2, p. 6]. Notwithstanding the benefits each technology brings along, it is a decision of competing committees, global player bluishness 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 [21]. 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 [13, p. 5f.], [20, 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 [13, p. 4], [26] and [5].

VII. 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.

References

[1] S. Djahel, N. Jabeur, R. Barrett, and J. Murphy, "Toward v2i communication technology-based solution for reducing road traffic congestion in smart cities," in *2015 International Symposium on Networks, Computers and Communications (ISNCC)*, May 2015, pp. 1–6.

[2] C. Weiß, "V2x communication in europe–from research projects towards standardization and field testing of vehicle communication technology," *Computer Networks*, vol. 55, no. 14, pp. 3103–3119, 2011.

[3] J. A. Misener, S. Biswas, and G. Larson, "Development of v-to-x systems in north america: The promise, the pitfalls and the prognosis," *Computer Networks*, vol. 55, no. 14, pp. 3120–3133, 2011.

[4] M. Fukushima, "The latest trend of v2x driver assistance systems in japan," *Computer Networks*, vol. 55, no. 14, pp. 3134–3141, 2011.

[5] S. h. Sun, J. l. Hu, Y. Peng, X. m. Pan, L. Zhao, and J. y. Fang, "Support for vehicle-to-everything services based on lte," *IEEE Wireless Communications*, vol. 23, no. 3, pp. 4–8, June 2016.

[6] J. Li, Y. Zhang, and Y. Chen, "A self-adaptive traffic light control system based on speed of vehicles," in *2016 IEEE International Conference on Software Quality, Reliability and Security Companion (QRS-C)*, Aug 2016, pp. 382–388.

[7] J. W. Wedel, B. Schnemann, and I. Radusch, "V2x-based traffic congestion recognition and avoidance," in *2009 10th International Symposium on Pervasive Systems, Algorithms, and Networks*, Dec 2009, pp. 637–641.

[8] B. Laura and K. Daniel, "Evaluation of opening bus lanes for private traffic triggered via v2x communication," in *2011 IEEE Forum on Integrated and Sustainable Transportation Systems*, June 2011, pp. 48–53.

[9] M. Al-Mashhadani, W. Shu, and M. Y. Wu, "Enhancing traffic flow using vehicle dashboard traffic lights with v2i networks," in *2015 IEEE Global Communications Conference (GLOBECOM)*, Dec 2015, pp. 1–5.

[10] S. Djahel, M. Salehie, I. Tal, and P. Jamshidi, "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)*, March 2013, pp. 340–343.

[11] V. Milanes, J. Villagra, J. Godoy, J. Simo, J. Perez, and E. Onieva, "An intelligent v2i-based traffic management system," *IEEE Transactions on Intelligent Transportation Systems*, vol. 13, no. 1, pp. 49–58, March 2012.

[12] C2C-Consortium. (2017, 1) C2c-consortium. [Online]. Available: https://www.car-2-car.org

[13] 5GAA. (2016, 11) The case for cellular v2x for safety and cooperative driving. [Online]. Available: http://5gaa.org/

[14] 3G4G blog. (2016, 11) The 3g4g blog. [Online]. Available: http://blog.3g4g.co.uk/search/label/Release/%2014

[15] 3GPP. (2016, 10) 3gpp release 14. [Online]. Available: https://portal.3gpp.org/Specifications.aspx?q=1&releases=189

[16] 3GPP . (2016, 10) 3gpp release 15. [Online]. Available: https://portal.3gpp.org/Specifications.aspx?q=1&releases=190

[17] D. Jiang and L. Delgrossi, "Ieee 802.11p: Towards an international standard for wireless access in vehicular environments," in *VTC Spring 2008 - IEEE Vehicular Technology Conference*, May 2008, pp. 2036–2040.

[18] ABIresearch. (2017, 1) Abiresearch. [Online]. Available: https://www.abiresearch.com/market-research/product/1016485-v2v-and-v2i-applications-and-use-cases

[19] Qualcomm. (2017, 1) Leading the world to 5g cellular vehicle-to-everything (c-v2x) technologies. [Online]. Available: https://www.qualcomm.com

[20] Y. Shi. (2017, 1) Lte-v: A cellular-assisted v2x communication technology. [Online]. Available: https://www.itu.int

[21] Liam Proud. (2016, 9) Europe may end up behind the curve on 5g internet. [Online]. Available: http://blogs.reuters.com/breakingviews/2016/09/01/europe-may-end-up-behind-the-curve-on-5g-internet/

[22] Qualcomm. (2017, 1) Creating a digital 6th sense with lte direct. [Online]. Available: https://www.qualcomm.com

[23] A. R. J. Schlienz. Device to device communication in lte.

[24] Signals Research Group for Qualcomm. (2017, 1) Expanding your horizons with lte direct. [Online]. Available: https://www.qualcomm.com

[25] L. Wang and H. Tang, *Device-to-Device Communications in Cellular Networks*. Springer, 2016.

[26] J. Hiltscher, R. Streiter, and G. Wanielik, "Is ieee 802.11 p v2x obsolete before it is even deployed?" in *Advanced Microsystems for Automotive Applications 2016*. Springer, 2016, pp. 31–41.

Use case:	**Green wave**
Description:	Early detection of vehicles and therefore optimized waiting time
Actor:	Vehicle

Preconditions:
1. Camera-detection: detection logic is trained for the particular background
2. V2I: Passing vehicle informs Traffic light system about number of approaching vehicles from behind

Basic flow:
1. Vehicle drives up to a traffic light
2. Traffic light System detects traffic flow with camera or by V2I message
3. Information exchange between consecutive traffic light intersections
4. Optimizing signal cycles

Use case:	**Dynamic traffic light signal cycles**
Description:	Avoiding static traffic light signal cycles
Actor:	Vehicle, Pedestrian
Preconditions:	Camera-detection logic is trained for the particular background

Basic flow:
1. Road user reaches traffic light
2. Traffic light system checks if crossing is possible
3. Crossing is possible, traffic light switches to green
4. Traffic light stays on green as long as there are following vehicles and no pedestrian is noticed

Alternate flow:

Appendix B
V2I traffic light use cases

1. Road user reaches traffic light

2. Traffic light system checks if crossing the intersection is possible

3. Crossing is not possible, so traffic light stays on red and saves the pedestrians crossing request

4. After a defined time the traffic right switches to green for the pedestrian and to red for the vehicles

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Use case:	**Traffic light status request**
Description:	Road users can request the traffic lights current status
Actor:	Road user: vehicle, pedestrian and other
Preconditions:	Air-interface receives a status request
Postconditions:	The road user has information for improving its individual and overall traffic flow, saving fuel and reducing CO_2 emission

Basic flow:
1. Road user connects to the traffic light via radio interface

2. Road users sends request

3. Traffic light system responds with a response containing the current signal cycle time, traffic light state and predicted waiting time

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Use case:	**Crossing priority for emergency vehicles**
Description:	Rescue vehicles can safely cross an intersection without waiting time
Actor:	Rescue vehicle, police car
Preconditions:	Air-interface receives an emergency request
Postconditions:	System is back in regular operation mode

Basic flow:
1. Rescue vehicle sends emergency request via radio interface

2. Traffic light turns red for pedestrians and vehicles

3. Traffic light ignores crossing requests of pedestrians and vehicles

4. The emergency vehicle sends a message to the traffic light system that it has left the intersection

5. Traffic light system switches operation back to normal

Use case:	**Numeric signal cycle indicator for pedestrians**
Description:	The traffic light shows the signaling cycle to pedestrians
Actor:	Pedestrian

Basic flow:
1. The current signaling cycle time is displayed on a numerical display

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Use case:	**Communication interface for pedestrians**
Description:	Pedestrians can indicate their wish to cross the road
Actor:	Pedestrian
Preconditions:	Traffic light system is not in emergency mode

Basic flow:
1. Pedestrian uses a button to indicate his wish to cross the road

2. Traffic light turns green on next occasion

Alternate flow:
1. Pedestrian uses the radio interface (smartphone, wearable) instead of the button

2. Traffic light turns green on next occasion

Use case:	**Simplified crossing for handicapped pedestrians**
Description:	Handicapped pedestrians can indicate their wish to cross the road and receive additional time for crossing
Actor:	Pedestrian with reduced mobility
Preconditions:	Traffic light system is not in emergency mode

Basic flow:
1. Pedestrian uses the air interface (wheelchair computer, wearable, smartphone) to indicate his wish to cross the road and his requests for extended cycle time

2. Traffic light turns green for a extended time period on next occasion

Use case:	**Road toll collection**
Description:	The traffic light logs passing vehicles for toll collection
Actor:	Vehicle
Postconditions:	Toll data is transmitted to a central storage entity

Basic flow:
1. Vehicle sends its ID to the traffic light via radio interface

2. Traffic light verifies and stores timestamp and number plate ID in a database

3. Road toll is transmitted to a central storage and processed

Use case:	**Traffic education**
Description:	Custom reaction based on the speed of road users
Actor:	Vehicle with excessive speed
Postconditions:	Driver is trained, that speeding is useless

Basic flow:

1. Vehicle detection measures the speed of approaching vehicles

2. If the vehicle exceeds the permitted speed, the traffic light turns red

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Use case:	**Augmented reality advertisement**
Description:	Advertisement about local stores are transferred to vehicles and stores are highlighted by augmented reality
Actor:	Vehicle
Preconditions:	Car accepts advertising data

Basic flow:
1. Traffic light system sends advertising data to passing by or waiting vehicle

2. Vehicle displays and emphasizes stores in the local environment