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Networking Road Users to Increase Traffic Safety through Collision Avoidance using Smartphones

Waldemar Titov and Thomas Schlegel
Institute of Ubiquitous Mobility Systems,
Karlsruhe University of Applied Sciences,
http://iums.eu
iums@hs-karlsruhe.de

Abstract. The automotive industry has always strived to make driving more enjoyable and safer. Therefore different approaches were developed. Beside passive safety concepts the vehicular industry uses active concepts to increase the vehicular safety. Based on the latest development, it can be seen that the trend is leading to more and more electronic supporters in the vehicle. Vulnerable road users like pedestrian and cyclists currently only passively participate in this new digital traffic. In the current work, we examine to which extend the traffic related communication process can be extended to vulnerable road users outside the vehicular field of vision using mobile devices. Therefore we determine user and technological requirements for realizing the communication process. Based on the raised requirements we developed a concept for a cooperative collision avoidance deploying device-to-device communication. Thereafter the concept is implemented into a prototype using a peer-to-peer architecture based on the Wi-Fi Direct standard. Finally we report on the evaluation of our prototype in real world scenarios. The results show the general ability of smartphones being used for cooperative collision avoidance. While the Wi-Fi Direct standard revealed some crucial issues while being used for this purposes.

Keywords: networking traffic participants, vulnerable road users, X-to-Y- communication

1. Introduction

As a driving force in the transport industry, the automotive industry has always tried to make driving more enjoyable and safer. In addition to the passive safety concepts that include safety-enhancing inventions such as seatbelts, airbags and deformation elements, there are also active safety concept such as ABS, ESP, ASR, ACC, emergency brake assistants, etc. However, the usage of public roads is far from being limited to motorized vehicles only - instead many different types of road users meet in different situations. Based on the efforts towards autonomous driving initial solutions have already been developed allowing vehicles to communicate with one another (car-to-car C2C) and with the infrastructure (car-to-infrastructure C2I). The concept of the car-to-x (C2X) communication focuses only motorized vehicles, which make up only a fraction of the actual road users on public roads. Although the latest technical developments for autonomous driving already allow the prediction of various dangerous situations concerning vulnerable road users, such as pedestrians or cyclists, using a variety of sensors. However, the described approaches raise two main challenges. First, the vehicle assistance systems only function within the field of vision of the sensor systems (Klotz M. & Rohling H., 2000 & AUDI, 2017). Second, the resulting solution of networking vehicles with each other and the infrastructure, making possible the detection of hazards even before the direct line of sight, has up to now been limited exclusively to motorized traffic (BOSCH, 2017; C2C-CC, 2017 & DAIMLER, 2017). Thus, the vulnerable road users currently only passively participate in the new digital traffic.

The aim of this work is the analysis to which extend the communication process can be extended to vulnerable road users outside the field of vision. Subsequently, these participants are integrated into the inter-vehicle communication and the exchange of traffic-critical data to realize an X-to-Y communication. The purpose is achieved following the consecutive approach. First, based on literature research we create five typical scenarios that often lead to traffic accidents. Second, utilizing those scenarios, we raise functional, non-functional and technological requirements for communication systems between road users. Third, we describe an implementation approach using Wi-Fi Direct as the communication technology. This way vulnerable road users are able to take part in the communication process, allowing them to be perceived before the line of sight of vehicle sensor systems and thus participating in the cooperative collision avoidance. Finally the evaluation of our developed prototype and the results complete the current work.

2. Defining Traffic Scenarios

Much work has been done analyzing the causation of road traffic accident. Therefore, historical accident data is taken into account. By literature review, the most important risk factors for traffic accidents were independently identified to be speed, alcohol intake, male gender, young age, cell phone use, and fatigue (Schick S., 2009). Causally contributing factors found by accident investigations that are most often mentioned, are connected to unadapted speed and inattention. However, due to different information content within the collected factors, a direct comparison is not always possible. Nevertheless the presentation of the most frequently occurring factors gives an overview of the accident analysis situation in Europe and serves as a basis for our five scenarios.

The developed scenarios are intended to show how such a system helps to prevent potential conflict between different modes of transport, to minimize the consequences of accidents or, at best, to prevent accidents altogether. From the scenarios described above, functional, non-functional and the technological requirements for such a system are worked out. Those requirements provide the basis for the implementation of the prototype. The five typical accident scenarios are listed below (Fig. 1 - 5). The scenarios included different accident pandering factors like: lack of local knowledge, inattention, incorrect assumptions as well as difficult visibility and weather conditions.

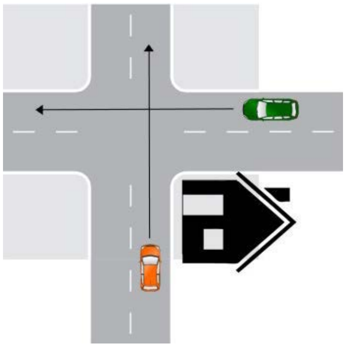

Fig. 1: scenario I: left yields to right situation with visibility occultation

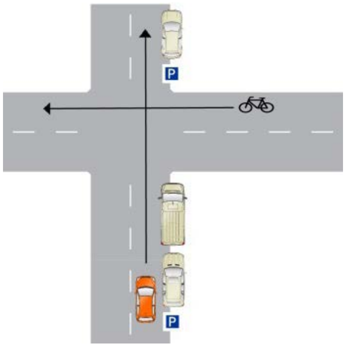

Fig. 2: scenario II: left yields to right situation with visibility occultation

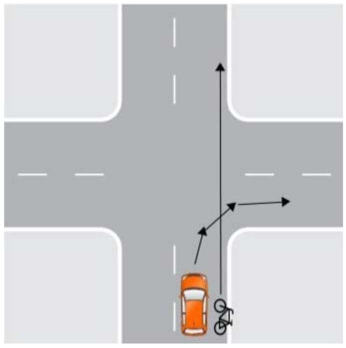

Fig. 3: scenario III: vehicle crossing bike path with bike in blind spot

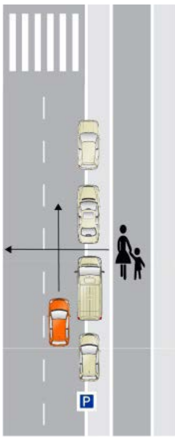

Fig. 4: scenario IV: pedestrian crossing road with visibility occultation and under difficult weather conditions

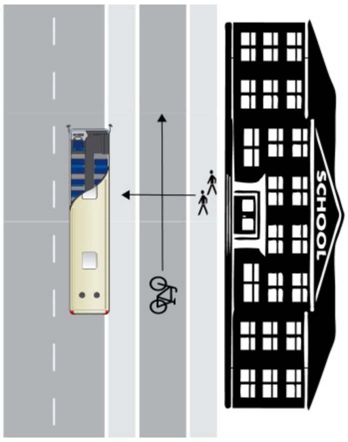

Fig. 5: scenario V: pedestrian crossing bike path with visibility occultation

3. User- and Technological Requirements

Aiming to network road users in order to avoid traffic incidents, the requirements of a communication system connecting different road users are raised. Particularly, based on our real life scenarios we raised functional and non-functional requirements for a system and examined them. Additionally, we conducted an extensive technological research to detect which communication technologies of smartphones could be deployed for the given purpose.

3.1. Functional Requirements

Based on the above given scenarios the functional requirements of the described networking system are provided in table 1. Functional system requirements describe the desired functionalities of the communication system between vulnerable and motorized road users.

Table 1: functional system requirements

label	description
automatic transport mode detection	automatic detection of users transport mode
automatic peer discovery	automatic and independent detection of peers as soon as in radio range
automatic peer connection	automatic connection to detected peers
streaming data exchange	exchange of traffic related data
automatic accident prediction	automatic and periodic collision prediction based on shared movement data
monitoring vehicle status	monitoring current status of own vehicle
context sensitivity	user current prevailing context
warning	warning of the users of detected dangerous situations

3.2. Non-functional Requirements

Based on the above given scenarios the non-functional requirements of the described networking system are provided in table 2. Non-functional system requirements are requirements for the quality in which the communication system between vulnerable and motorized road users will be provided.

Table 2: non-functional systems requirements

label	description
real-time	system operating g in real-time
reliability	reliability and error-free functioning of the system
punctual warnings	punctual warning of detected dangerous situations
data security	protected networking and streaming of traffic related user data
scalability	scalability of the system
coverage of different traffic modes	considering of many traffic modes participating in real traffic (according to X-to-Y communication)
efficient on resources	efficient in usage of resources like power and network
effective radio range	early collision avoidance due to large radio range

3.3. Technological Requirements

Modern Smartphones support a broad variety of communication technologies that allow them to connect and exchange data with each other. An extensive analysis was carried out to identify the best technology for the proposed application. An overview of the examined technologies is given in table 3. In the beginning, we considered many different technologies but quickly focused on Wi-Fi Direct and Bluetooth Low Energy (BLE). The use of classic Bluetooth was discarded because the specification limits the number of simultaneously connected devices to only eight. With the use of scatternets this limitation can be extended but this will reduce the data rate, create a single point of network failure and increase the energy consumption of mobile devices. Other technologies like Wi-Fi Aware and LTE Direct (while being very interesting and promising) were determined to be too futuristic at that time.

Table 3: communication technologies used in modern smartphones [7, 8, 9, 10, 11, & 12]

technology	**BLE**	**Bluetooth BR/EDR**	**Wi-Fi**	**Wi-Fi Direct**	**Wi-Fi Aware**	**LTE Direct**
data rate	1or 2 Mbit/s	3 Mbit/s	6 936 Mbit/s	250 Mbit/s	250 Mbit/s	13.5 Mbit/s
range	100 or 200 m	100 m	200 m	200 m	200 m	500 m
number connected devices	approx. 10	max. 8	approx. 64	approx. 10 - 15	no data	no data
frequency	2.4 GHz	2.4 GHz	2.4 & 5.8 GHz	2.4 & 5.8 GHz	2.4 & 5.8 GHz	LTE frequency
mobile OS	Android, iOS	Android, iOS	Android, iOS	Android	Android	-
encryption	128 Bit	128 Bit	256 Bit	256 Bit	256 Bit	128 Bit

4. Networking Road Users for Cooperative Collision Avoidance

As shown in previous chapters, networking vulnerable road user with motorized vehicles is a key issue to increase their traffic safety. At the same time, perception and communication between the individual road users exposed to be the major challenge. While modern vehicles have an on-board diagnostic system (OBD), vulnerable road users lack such facilities. The OBD systems include a variety of built-in sensors such as distance and acceleration as well as communication infrastructure such as Wi-Fi and Bluetooth. In the absence of sensors and communication infrastructure among cyclists and pedestrians, which would allow them to be perceived prior to the direct line of sight, they must be equipped with additional sensors. Sensor technology, that allows precisely positioning, indications about direction of movement and other intentions to communicate with other road users in proximity. For this purpose we focused of using smartphones for collision avoidance between different means of transport on public roads. Smartphones meet all listed requirements and already have a high user acceptance and a deep market penetration.

The crucial step of networking road users is the analysis of the data basis needed for collision prediction. Our concept is based on the concept of C2C communication, where participants communicate their location as well as other traffic critical data among each other using a specific Wi-Fi protocol. The vehicular communication is based on the IEEE 802.11p standard which modern smartphones for several reasons do not support. In table 4 the differences of the Wi-Fi protocols of the automotive variant IEEE 802.11p and the IEEE 802.11a/g supported by smartphones are presented.

Table 4: characteristics of the Wi-Fi standards IEEE 802.11p (C2C), IEEE 802.11a and IEEE 802.11g (smartphones) [13]

characteristics	**802.11p**	**802.11a**	**802.11g**
user mobility (usage)	high mobility (vehicle)	low mobility (personal)	low mobility (personal)
frequency	5.85 – 5.925 GHz	5.15 – 5.825 GHz	2.4 – 2.484 GHz
canal width	10 MHz	20 MHz	20 MHz
transmission power	760 mW	40 / 200 mW	100 mW
data rate	3 – 27 Mbps	6 – 54 Mbps	6 – 54 Mbps
modulation	BPSK – 640QAM	BPSK – 640QAM	BPSK – 640QAM
OFDM symbol duration	8 us	4 us	4 us
guard interval	1.6 us	0.8 us	0.8 us
preamble time	32 us	16 us	16 us
Subcarrier distance	156 kHz	312 kHz	312 kHz

Even though from a business point of view utilizing smartphones for vehicular ad hoc networking seems attractive because smartphones already enjoy a successful user adaption and provide most of the hardware required for cooperative road safety applications. From the technical point of view, the discrepancy in used Wi-Fi protocol proves to be an insurmountable problem (Vandenberghe W. et al., 2011). Based on the discrepancy in used Wi-Fi protocols for our prototypical implementation of the X-to-Y communication we have chosen a device-to-device communication approach (Gao H., & Peh S., 2016; Vandenberghe W. et al., 2011). In our concept, we realize an ad-Hoc peer-to-peer connection between smartphones based on dedicated short-range communication (DSRC). Furthermore, it can be assumed that most of the vehicular traffic participants likewise carry their smartphones while driving and could potently also participate in the communication process. Hence the mobile devices are networked in a common network and sharing traffic relevant data like: position, direction, speed and type of vehicle among each participating device. Based on the shared data each peer is able to forecast the presence of collision potential. If collision potential between peers is detected, an acoustic and tactile warning is given to both peers calling for attention and action.

5. Implementation and Prototyping

Out of the technological research, Wi-Fi Direct appeared to be the most suitable technology for the intended application. We developed an application prototype based on Wi-Fi Direct for testing and evaluating our approach. First, the prototype is located by the satellite positioning system, simultaneously scanning the surrounding for available peers. As soon as peers are available, a binding process connects the peers enabling the sharing of traffic relevant data. As soon as a connection is established, the collision forecast algorithm analyses the shared data for the presence of traffic conflict situations. Therefore the collision forecast algorithm is monitoring the own movement and the movement of each surrounding peer based on their location and speed. Due to positions, direction of movements and the speeds of the own and all connected peers, movement vectors are created. Those dynamic movement vectors are examined for the presence of intersections. If any intersections were found, time and distance left to collision is calculated. Furthermore, based on the current speed the critical warning time is calculated. If neither the speed nor the movement vector of the both conflict peers changes essentially, an acoustical and tactile warning is played on both mobile devices. The warning supposed to notify the participants in good time to react appropriate. In the next chapters the specifics of the communication protocols used in the implementation and prototyping are examined.

Wi-Fi Direct also called peer-to-peer (P2P) enables the creation of a local peer-to-peer network for connecting mobile devices without the usage of an access point (AP). With the discovery protocol, Wi-Fi Direct allows for relatively quick discovery and interaction with other nearby devices as well as group formation. The radio range and transmission speed of Wi-Fi Direct significantly exceeds that of Bluetooth (Wi-Fi Direct, 2017). Although Wi-Fi Direct is not an IEEE standard, it is a specification of the Wi-Fi Alliance as "Wi-Fi Peer-to-Peer (P2P) Specification". Wi-Fi Direct is widely used in many short-range communication applications using WPA2 encryption.

Despite Wi-Fi Direct is also referred to as a peer-to-peer network, it is not a real P2P network as defined. It is really a server-client architecture. However, peers available on the network independently decide what role they play in the network. Thus, similar to a peer-to-peer network, the user does not have to worry about the connection management between peers and their role. For this purpose, Wi-Fi Direct introduces a "negotiation process" that assign the roles. In this process, the resources of mobile devices like battery power, number of connections supported and processor speed decide on its role in the network. The device with the better rating proceeds as the group owner (GO) while the ones with the lower rating are considered clients automatically connecting to the GO.

6. Experimental Evaluation and Results

From a business point of view utilizing smartphones for networking vehicular traffic with vulnerable road users seems attractive, because smartphones enjoy a successful user adaption and provide most of the hardware required for cooperative road safety applications. However, from the technical point of view, the discrepancy in used Wi-Fi protocols: automotive variant IEEE 802.11p and the IEEE 802.11a/b/g supported by smartphones, proves to be an insurmountable problem (Vandenberghe W. et al., 2011). Furthermore, it can be assumed that most of the vehicular traffic participants likewise carry their smartphones while driving and could potently participate in the communication process. Out of these considerations, the implementation of our X-to-Y communication prototypes was conducted using ad-Hoc device-to-device communication. Generally, the results indicate that smartphones have all the necessary sensors for inter-vehicle communication and are therefore suitable for this application.

Evaluating the Wi-Fi Direct based prototype, the connection distance between the mobile devices was measured at 150 to 200 meters. This made possible a substantially increase of road users visibility, even without direct line of sight. Additionally to the large connection distance, the evaluation indicates the rapid peer detection as well as the connection establishment between peers.

Negatively we would like to highlight the relatively high battery usage of the system. Caused by the ongoing peer detection service the battery resource of a mobile device is drained essentially. Another major drawback is the required user interaction accepting each first connection requests of a certain device (Stackoverflow, 2017; Thinktube, 2017). This circumstance eliminates all conceivable scenarios in which peer connection, and data exchange takes place in the background, ruling out the chosen ad-Hoc approach.

6.1. Results

This project showed that the inclusion of vulnerable road users in the communication process based on X-to-Y communication is an important contribution to increasing the traffic safety of all road users. Furthermore, the use of smartphones for collision avoidance between different means of transport on public roads makes sense, as they already have a high user acceptance and a deep market penetration.

7. Limitations and Future Work

In our future work, we will implement another prototype based on Bluetooth Low Energy (BLE). This should allow a much faster connection time between devices. Additionally using BLE as the communication protocol eliminates the user interaction while connecting peers and will help to save more battery while using the system. Furthermore, we experienced some problems with the GPS sensor of the tested android smartphones. It was only possible to obtain a new GPS position every second. A higher rate should produce much better results. In addition, the achieved accuracy of approximately ten meters was too bad for a precise collision avoidance algorithm. Newer smartphones use dual-band GPS sensors that promise an accuracy of about 30 cm.

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