Challenges in communication assisted minimization of crash consequences

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Abstract: Systems aiming to increase road safety benefit greatly from recent advances in technology. However, especially when it comes to increasing safety of Vulnerable Road Users (VRUs), more work is needed to decrease accidents and mitigate their consequences. The design and development of these systems is a very complex task, as they face many challenges. This paper aims to provide an overview on tasks faced in wireless communication-based road safety systems.

Keywords: Road safety; Crash prevention; V2X; VANET; Intra-Vehicular Wireless Sensor Networks

1 Introduction

Recent data of road accidents [Bu18] show a general downward trend in accidents involving injuries and fatalities. Part of this downward trend can be attributed to the advent of new technologies used to increase road safety [OE03]. While conventional systems like the anti-lock brake and airbags contribute to direct safety in cars and trucks by reducing both, the crash possibility, as well as the consequences, recent developments have shown a trend towards cooperation between traffic participants to reach further improvements for the same goals. A major advantage of cooperation-based approaches is the possibility of improving not only the safety of the rider and passenger of a vehicle, but also protect vulnerable traffic participants like pedestrians and cyclists, which do not carry protective systems like airbags.

The potential benefits of using wireless communication both inside a vehicle between its components, as well as between vehicles and infrastructure or other traffic participants are vast. As a result a lot of research work is focused on realizing such systems and developing corresponding standards. The IEEE 802.11p [As10] and the IEEE 1609 [Co06] standards, which are used in the European vehicular communication standard European Telecommunications Standards Institute (ETSI) ITS-G5 [ET13] provide definitions to allow communication in the challenging and unique environment of V2X communication.

Apart from systems allowing communication between traffic participants, wireless communication can be used to improve efficiency, as well as security in a variety of scenarios, by

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connecting vehicular components for which a wired connection might not be feasible or even highly undesirable. A prime example for such systems are motorcycle airbag jackets utilizing a wireless connection to connect the bike with the components inside the jacket and activate the airbag in case of an accident [Be14]. In many cases crash prevention can be achieved by detecting dangerous situations and alerting the driver, thus increasing the awareness of the situation. In cars this alert could be visual, optical or haptic, whereas on a motorcycle designing a human–machine interface (HMI) suited to alert the rider can be significantly more complex [Mo17]. In [Sp10] an audio based system for driver to vehicle interaction in motorbikes based on Bluetooth communication between the drivers helmet, a smartphone and the motorbike is presented. Examples like this outline, that a reliable communication between the bike and the helmet of a motorcycle could help to increase the rider safety, by allowing the implementation of a variety of approaches to increase rider awareness in dangerous situations.

In this paper we present challenges faced in various scenarios involving communication to improve safety of traffic participants. We outline related work in section 2 and discuss challenges in section 3 before concuding the paper in section 4.

2 Related Work

The possible improvements in safety and comfort achieved by connecting vehicles to infrastructure and other traffic participants have created a large number of research fields around this topic. Giving an overview of V2X technologies available today, [AOZ16] describes the challenges and opportunities for hybrid approaches consisting of cellular and Dedicated Short Range Communication (DSRC) technologies.

When developing communication-based safety systems for VRUs, key challenges for the wireless communication associated with the wide range of unique and challenging environments have to be considered. An area of research highly exposed to these constraints are Intra-Vehicular Wireless Sensor Networkss (IVWSNs), which often aim to provide security critical real-time tasks within these conditions, which makes them especially interesting for outlining key challenges and required features.

In the analysis of possible technologies for replacing wire-based intra vehicular communication in [Ah07], important aspects for wireless data transmission are discussed. The authors present the overhead produced by many communication stacks as a major concern in designing intra-vehicular networks and name TCP/IP as an example for an undesirable standard protocol for such applications. Furthermore, the authors outline that many technologies are not designed for intra-vehicular communication and present IEEE 802.11 as an example for high power consumption and chip cost. In their simulation, an IEEE 802.15.4-based approach is evaluated. The authors conclude, that no technology exists at the time to fulfill the requirements and they state the ultra low latency as a major challenge for such systems.

They propose the ultra wideband (UWB) PHY as an interesting opportunity, while maintaining that MAC modifications of the IEEE 802.15.4 standard are needed for the special kind of real-time applications. The additions to IEEE 802.15.4, like Time Slotted Channel Hopping (TSCH) and Deterministic and Synchronous Multi-Channel Extension (DSME), which were published after [Ah07], could address some of the points outlined by the authors. However, performance and latency influencing factors like interference and shading are not considered in the paper.

IVWSNs are evaluated in an interference environment consisting of Bluetooth and WiFi in [LTT13]. The study analyses the throughput of Wireless Sensor Networks (WSNs) using Bluetooth and IEEE 802.15.4, with the standard Carrier Sense Multiple Access (CSMA) MAC on a single channel. The authors conclude that both technologies perform adequate for many applications in the no-interference case and that BLE shows greater robustness against interference, thus concluding BLE to be more suited for IVWSNs. The comparison presented in this study fails to address the improvements made to IEEE 802.15.4 with the additional MAC modes like TSCH and DSME, which specifically aim to provide reliable real-time communication in challenging environments.

The concept of using the plethora of wireless technologies available today, which are partly deployed to VRUs in the form of smartphones already, certainly is not new. General cooperative system architectures to improve the safety of pedestrians have been discussed in [Mo09]; yet, no real system has been built and tested at that time. In [Li10], projects equipping VRUs like pedestrians or cyclist with special communication hardware in order to increase detection rate in vehicles are discussed. The authors present an architecture for the detection and communication, which resembles the functionality of a secondary radar. Using this approach enables systems to overcome many of the technical limitations of conventional sensors systems like those used in cars. Furthermore, it could allow for the detection of VRUs which are currently not detectable due to physical constraints, such like missing line of sight between the traffic participants.

Research performed in [LTT15] describes a blind zone alert system based on Bluetooth Low Energy (BLE) beacons which are placed on the side of cars above the wheel. Using the BLE beacon mode and received signal strength indication (RSSI) measurements, the system detects the presence or absence of a car in close vicinity and alerts the driver. Thus, essentially it performs the task of blind zone alert systems present in cars today. The presented evaluation shows the feasibility of such a system and outlines its low cost compared to existing systems.

A system aiming to warn distracted VRUs by WiFi communication between a car and the VRUs smartphone is presented in [Dh14]. The approach outlines the possibility of using WiFi for this type of application in different scenarios and for the speed expected in these.

A lot of research is focused on developing and standardizing the communication between vehicles and other road users, as well as infrastructure [ET13]. The performance of

IEEE 802.11p in combination with IEEE 1609.X is studied in a stimulative performance evaluation in [GMR10]. The authors conclude that the standards provide the required base for V2X applications and outline its adequate delay performance and range.

A use case for the emerging V2X standards focusing on VRUs is giving in [Ta17], where a system architecture for a car2x communication between a car and VRUs carrying DSRC-enabled smartphones based on IEEE 802.11p, IEEE 1609.X and SAE J2735 is proposed and evaluated. As a conclusion, the authors evaluate the prolapsed architecture to be a viable system for increasing VRU safety.

3 Challenges

The introduction of wireless communication in vehicular networks offers possibilities for advantages in terms of cost savings and ecological improvements by weight reduction. While these aspects are of high relevance for large and complex systems such as cars, the improvements could also allow for new concepts to be realized. Providing lightweight real-time wireless communication between parts of a vehicular system, could enable VRUs like cyclists to benefit from security systems typically found in larger vehicles. As an example for such systems stand wireless motorcycle airbag jackets as provided by manufacturers like Dainese which are able to be triggered by a motorcycle in case of an accident [Be14].

Wireless communication based applications offering improved functionality or safety for VRUs pose a set of complex challenges and solving these is a crucial part of development when designing these systems. To aid development and increase availabi1lity of security systems to a broader range of users, especially VRUs, we aim to present challenges going along with these types for communication systems.

The research going into V2X standards is facing many of the same challenges and consequently provides solutions on many aspects. For VRUs, some special considerations have to be taken into account. The potential number of communication devices could be significantly higher if V2X technology is deployed to VRUs like pedestrians, compared to scenarios where only vehicles and infrastructure are covered. The feasibility of such a scenario needs to be evaluated for any given use case. However, potential problems could involve the overall channel usage as well as the potentially costly licensing, given the case that every VRU needs a certificate. The ETSI standard [Et11] contains information on a maximum transmission rate, effectively limiting the lowest achievable worst case latency for the communication. Considering systems like a wireless motorcycle airbag and considering an approach utilizing this V2X standard, this could pose a major problem. Therefore, depending on the use case, safety systems for VRUs could bring special requirements and alternative wireless technologies might be desirable for the implementation.

3.1 Situation awareness

To provide effective crash prevention or mitigation of crash consequences, creating situative awareness is a key challenge. Modern cars use a vast amount of sensors and complex data processing in order to create a model of their current surroundings which is then used to interpret the current situation and create predictions in order to detect dangerous situations before they unfold. VRUs, like pedestrians and cyclists, on the other hand are not equipped with such sophisticated systems. Therefore, developing safety systems for VRUs faces the challenge of either requiring the development of new and innovative safety systems or relying on communication with other road users in order to increase safety by mutual awareness. The latter lies in the scope of the research and standardization in the field of V2X communication, whereas the former is receiving comparatively little attention from the research community. In general, size, weight and power requirements, as they are present in many safety systems tend to be much more stringent on VRUs.

3.2 User acceptance

The opportunities for increasing road safety by means of smart technology, especially for VRUs, are vast and diverse. But as for any wearable technology its use is determined not only by the system itself but rather is depending on the willingness of potential users to buy, maintain and use it. Therefore, although it might not seem as a technological challenge at first glance, user acceptance will greatly influence the effectiveness of future systems and when designing such systems, the impact of design choices in the user experience has to be considered.

Key factors influencing user acceptance include easy of use, cost, battery life, security and weight. Unfortunately, from an engineering standpoint, these often are orthogonal criteria, meaning that increasing one generally has a negative impact on the other.

Recent development in Internet of Things (IoT) devices, wearable computing and WSNs provide technologies for energy and cost efficient communication and protocols suited to a variety of scenarios spanning a wide range of throughput, duty cycles and network sizes. Moreover, the weight of wearable devices decreased significantly, which allows for the development of complex systems that can be used without spoiling comfort for the user. Communication devices, for instance, could be integrated into clothing, such as not to create a requirement of additional objects to be actively remembered and taken by the user. Applications benefit from a great variety of off-the-shelf components, technologies and techniques, which allows developers and manufactures to provide advanced systems at an ever decreasing price point.

For a road safety system to be accepted and used, a reasonable level of security has to be provided for the user. Implementations are very likely to require sensitive personal data that have to be protected from unauthorized access, so as to prohibit attackers from performing malicious activities with this data. Many technologies provide mechanisms for encryption, thereby helping to prevent unauthorized access to the communication channel. However, in terms of authentication, special care has to be taken as the nature of many road safety applications require communication with a huge amount of other parties.

A critical factor for user acceptance is battery life and while many ultra low power devices are available to allow operation for extended periods of time between charging or battery replacements, this still presents a big challenge for the design of systems. A very common trade-off to be made is between duty cycle and battery run time. While a low duty cycle is one of the approaches with huge potential for energy savings, it also means increased worst-time latency, which is a problem especially for road safety applications, where in an accident scenario, often fractions of a second matter.

A viable option for many of the aforementioned challenges could be the use of smartphones, as many VRUs are carrying those with them anyway. Modern phones contain a variety of communication technologies such as WiFi or Bluetooth, as well as localization devices such as Global Positioning System (GPS) receivers, which opens up opportunities for safety applications that require no additional hardware to be deployed.

3.3 Medium access

Arising from the large range of possible speeds in transportation, an often vital factor for systems aiming to increase road safety is speed. While many technologies are able to provide transmission with very low latency between given endpoints, the road safety environment comes with its own set of challenges making implementation of systems in this environment a challenging task. Apart from the data rate, which is a key factor for the transmission speed, real-time systems require bound latency, which results in a range of challenges that need to be overcome in the communication technology.

Given a required throughput and an ideal, dedicated medium for a unidirectional communication, the data rate can be used to calculate the transmission delay. However, in scenarios relevant to VRU safety, neither an ideal nor a dedicated medium can be assumed for any given participants making special techniques required in order to ensure an acceptable worst case latency. In real world scenarios, often accessing a shared medium can account for a significant portion of the total transmission time, making this an important factor to consider.

With an increasing number of participants in networks sharing a medium, the possibility for collisions while transmitting increases, which can be mitigated by means of CSMA and backoff algorithms. However, while providing low overhead and therefore comparably low average transmission times, this approach quickly results in high jitter in the transmission times, which makes it highly undesirable in real-time applications. Using techniques like Time-Division Multiple Access (TDMA) on the other hand allows much greater control in terms of transmission time by using contention free timeslots. Therefore a maximum latency can be calculated, which makes it the go to approach for many real-time applications.

In a scenario where a great number of traffic participants needs to communicate in order to enhance the mutual awareness two major problems result from the use of TDMA. Firstly, as each participant needs to wait for its turn to transmit data, average transmission latency increases drastically with growing network sizes. How fast this will become a problem depends on the standard and application at hand, as it depends on message length, required throughput, and nominal data rate. Longer time slots allow for a greater amount of data to be transmitted in each slot, while also increasing the time that each node has to wait until it can transmit again. Timeslots that are longer than required for the amount data to be transmitted quickly result in a very large overhead. Smaller timeslots on the other hand can be used to reduce the time between transmissions, and reduce the amount of overhead created by partially used timeslots. However, when reducing the size of the timeslots, guard times that might be required at the beginning of slots or in between transmissions and acknowledgements quickly start to add up and the overhead increases as the quotient of time used for transmission and the total timeslot length gets lower.

3.4 Interference

Systems designed for motorcyclist, like the one mentioned in section 1, often rely on off-the-shelf technologies for their cost effectiveness and widespread availability. The same motivation could apply to possible systems for other VRUs, like pedestrians or cyclists. While many cost effective and license-free wireless communication technologies with a variety of different target applications exist [Ca09], some common challenges remain.

When developing applications, the use of a dedicated frequency is not possible in most cases for a variety of reasons, one of the most prominent being cost, as licensing a dedicated frequency is very expensive. To overcome this issue, many technologies operate in the industrial, scientific and medical (ISM) band, which allows license-free communication. As a result of the huge popularity of these technologies and their widespread use in a variety of applications, the ISM band is very saturated, which results in a lot of interference being present. Especially when real-time requirements need to be met using wireless communication, interference becomes a major concern and needs special approaches.

A possible approach is the use of UWB communication, as it is generally considered rather robust against interference [IE07, Zh09]. However, the increased power consumption that goes along with this technology is undesirable in many applications, especially considering the fact that in many cases, the power that can be provided in a VRU safety system is very limited compared to a system integrated into a larger vehicle.

Another way to mitigate the interference present in the ISM band is to create frequency diversity by employing a channel hopping scheme [WMP09]. This approach is used in technologies like Bluetooth and was also added to the IEEE 802.15.4 standard by the DSME and TSCH MAC schemes.

Applications utilizing the ISM band need to consider the expected interference scenario and utilize appropriate counter measures. Predicting the noise and interference level present on a final deployment in various scenarios is a very complex task in itself, as the number and nature of noise sources is extremely hard to estimate for a large number of environments that might be present when looking at VRU road safety systems. This is especially relevant in situations where real-time operation is necessary and therefore special care to interference needs to be taken, if such application aim to use an unlicensed band.

4 Conclusion

Recent developments in the field of technology for increased road safety, outlines the potential of wireless applications in this area. While advanced vehicular systems are available today, a lot of open questions are present when it comes to increasing safety for VRUs. Progress in V2X technology certainly offers great advantages and opens up new opportunities. Many open research areas are present in the field of IVWSNs, which could help to improve the safety of VRUs, like motorcyclists, as well. To aid research and development in this area, we present challenges often encountered when designing systems for the challenging environment often faced by road safety systems.

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