ARCHITECTURE FOR VULNERABLE ROAD USER COLLISION PREVENTION SYSTEM (VRU-CPS), BASED ON LOCAL COMMUNICATION

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ABSTRACT

Current research in Intelligent Transport Systems is focussing on informing cars to make traffic more efficient and safer. However vulnerable road users are not involved or informed. In order to prevent collisions with vulnerable road users cars make use of collision avoidance systems. These systems are mainly based on camera, infrared and/or radar sensors and suffer from difficulties like road users hidden by cars and buildings. These collision prevention systems are mainly autonomous systems and are not cooperating with other detection systems. We propose to extend CALM, the communication standard for cooperative vehicular systems (16), with a local communication system for protection devices for vulnerable road users. These systems can be integrated into existing systems like bicycle navigation systems and/or smartphones. For devices which cannot rely on a navigation system we propose to use position estimation, based on the position of neighbouring devices, like parked cars, roadside units or smart devices.

KEYWORDS

Pedestrian, collision prevention, vulnerable road user, energy efficiency, smart city, safety

INTRODUCTION

To protect vulnerable road users form collisions with motorized vehicles the car industry offers or is developing solutions based on different technologies. First there are the radar based systems integrated within the vehicles, like the Lexguard system, of which as the operation is quite similar to the parking sensor systems in modern cars. The system will generate audio and/or visual warnings based on the distance of the detected object or person. When the person/object approaches, the warning level will be increased.

A second type of systems is based on visual (10 – 14) or infrared sensors (5, 8) integrated into the vehicles. Into these systems more logic can be introduced to eliminate more false positives (6-7) like for example traffic signs in the detection area. After evaluation of the hazard the driver of the vehicle will be warned or the vehicle will be stopped to avoid a collision.

A third kind of system is based on intelligent road infrastructure (9) with different type of sensors. These sensors could also be based on radar, visual or infrared technology, like in the previous systems, but are integrated into the road infrastructure. The sensors could detect approaching road users and signal this to the road users by visual and audio warnings.

To protect vulnerable road, the use of previous systems is not sufficient, because vulnerable road users are the most numerous in an urban environment where they can be hidden, by (parked) cars and buildings, and/or these systems are limited in detection range. Another disadvantage of the current systems are that they are mainly focusing on either the vehicle driver or the vulnerable road user without any cooperation with other systems. Therefore the use of communication systems, for exchanging information, can be useful. This also makes it possible to communicate GPS positions or to detect the relative distance, which may a valuable information parameter for collision prevention.

However, before providing a fully-operational system to the vulnerable road user many issues needs to be solved and additional system requirements needs to be addressed. First, pedestrians are not equipped with powerful batteries for energy consuming communication units. Therefore the use of energy efficient techniques and hardware is needed, however this will reduce the transmission range. To span the distance between the involved road users, the use of additional roadside units will be required for establishing communication between cars and vulnerable road users,.

Secondly due to the highly mobile behaviour of the road users, timely communication of often frequent changes in mobility behaviour is required.

ENABLING TECHNOLOGIES

SYSTEM REQUIREMENTS

The distance a vehicle needs to stop depends on the reaction time of the driver, the speed of the vehicle and the weather conditions. Generally the reaction time of a driver is taken as 0,675 ms, however in a report of Connekt (4) about blind spot detection- and signalling systems they specify that the reaction time of a driver is about 1,5 seconds. This means that at a speed of 50 km/u or 14 m/s (meter per second) on a straight road in a city environment and 15 km/h or 4m/s turning at an intersection, a vehicle is already displaced by 21 or 6 meter before the driver can react. This indicates the timely warning of a driver is of high importance.

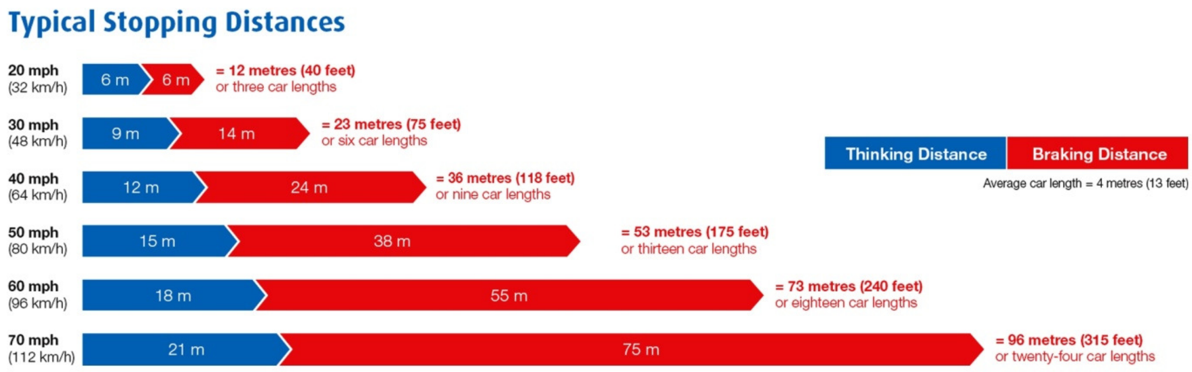

Figure 1 – Typical stopping distances (Source: The Highway Code UK)

The communication range of the selected technology will be the main factor for the swiftness of delivering a warning to the other collision prevention system. When the communication range of the selected technology is not sufficient to cover the distance, multi-hopping can be used, however this will influence the end-to-end latency.

The distance that will be covered by the transmission of a message will also be influenced by the transmission power of the sender. Increasing the transmission power will of course lead to a higher energy consumption and hence a lower battery lifetime. Therefore the trade-off between maximal transmission range, minimal latency and minimal consumed energy needs to be investigated.

Another requirement of a warning system is the reliability of the provided information. This means false positive warnings need to be as much as possible avoided. The reduction of wrong information requires extra processing of the information and may introduce an extra delay for the transmission of warnings.

To minimize the energy consumption of the battery powered devices, these devices can make use of sleep cycles, like in sensor networks, during which the communication unit is turned off. However sleep cycles will increase the latency as the node cannot receive an urgent warning during the sleeping period.

COMMUNICATION TECHNOLOGY

For information exchange, between vehicles and vulnerable road users, different possibilities for communication paths are possible. First of all, if direct communication between the involved car and vulnerable road user is possible, this communication type should be preferred. For the communication from and to the vulnerable road user, a technology has to be selected which is balancing between low energy consumption, maximal distance, low latency, and good bandwidth. When the transmission range is too low, the technology must provide milti-hop capabilities.

The low energy consumption is the most important restriction, making Zigbee (IEEE 802.15.4) and Bluethooth very attractive (table 1). However the use of multi-hop communication is not efficient when using the Bluethooth technology. We therefore propose to extent the existing CALM architecture with an IEEE 802.15.4 communication layer for communication with vulnerable road user (VRU). With a range between 10-70 meter, it will enable communication between the VRU and roadside infrastructure and slow moving vehicles.

	Distance	Latency	Bandwidth	Mesh capable	Power consumption
IEEE 802.15.4	low	high	low	yes	very low
Bluethooth	low	medium	medium	limited	low
cellular networks	very high	medium/high	(very) high	no	very high
IEEE 802.11	high	medium	very high	yes	high

Table 1 – Communication protocols

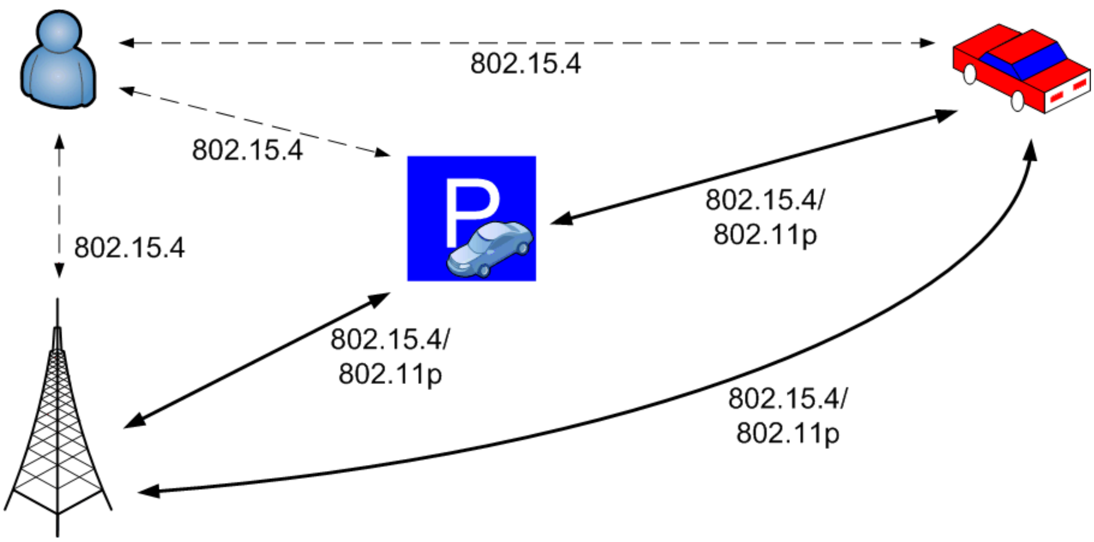

Figure 2 – Communication paths

However, when direct communication between VRU and the involved vehicle is not possible, the use of one or more intermediate hops is needed (Figure 2). An intermediate hop can be a parked car or a roadside unit (RSU), like an intelligent traffic light, an intelligent speed warning sign or information panel (for example Variable Message Sign). The RSU or parked car will then collect the information from the VRUs and cars in the neighbourhood and decide to warn the road users that risk a collision. The communication between the VRU/parked car and the RSU will occur by an energy efficient technology, will the communication between RSU and car will occur by an energy efficient technology or the less energy efficient IEEE

802.11p technology. In the latter case, the use of IEEE 802.11p will be preferable, because of the bigger transmission range and bandwidth, which will result in a more timely delivery of the warning information, as intermediate hops can be avoided.

ROUTING OF INFORMATION

To forward warning information, a suitable routing protocol is required. Due to the high mobility of the different road users, the communication paths will change constantly. To keep the routes up to date every node will have to transmit, receive and process many routing control messages. These control messages may consume a considerable amount of energy (compared to the actual warning information). Therefore the number of routing control messages and update frequency of the routes needs to be minimized, while still guaranteeing low latency communication of warning information.

Dynamic routing strategies could be considered that dynamically adapt to the current situation, like the presence of other safety systems in the surrounding or the mobility behaviour of the road users. However the adaption to the situation will also demand extra processing from the system and/or extra information exchanges, which comes with extra delay and energy consumption.

POSITIONING

To determine the location of the vulnerable road user (VRU) the use of GPS-localization system is not always possible: for energy efficiency reasons, a mobile device will not always be equipped with a GPS module. Therefore the position needs to be estimated.

A first localization approach can be made by using the coordinates, of the (known) fixed position of the RSU’s and/or parked cars, and RSSI-based multi-lateration (1) of the VRU. When the position is determined and exchanged, a decision algorithm such as P-VCASS (2) can be used to determine and warn if a danger of collision occurs.

When other vulnerable road user systems in the neighbourhood are equipped with a GPS localization system (for example in a smartphone) these systems could help other systems in the neighbourhood, not equipped with GPS, to determine their position.

In city environments GPS will be less accurate due to worse signal-noise ratio and more multipath fading. Therefore the technique described in the previous paragraphs, for devices not equipped with GPS, is also useful in urban environments. With a high density of road users (vehicles and vulnerable road users) and roadside units more reference points will be available to estimate the current position.

However in rural environments with very few road users, the previous positioning algorithm is not applicable due to a lack to reference points (GPS equipped neighbouring devices). In rural environments the position of vulnerable road users can be estimated by the sequence of

position calculation of the VRU done by the passing cars. The passing cars relay these positions and future moving pattern into the vehicular network.
When no vehicles have passed in the surrounding of a vulnerable road user, there will be a lack of information in the vehicular network. Therefore the vulnerable road user system will need to warn approaching vehicles early enough. This can for example be done by dynamically increasing the transmission power, in rural environments with few road users.

HETEROGENITY

A vulnerable road user protection system, can have different specifications, depending on the device into which it is integrated. It could be integrated into existing devices like a smartphone or bicycle navigation system. Based on the device capabilities of the existing device, the protection system can provide more or less functionality: for example a GPS enabled device can serve as a reference point to non GPS enabled devices; a device with routing capabilities can act as an intermediate hop for the communication of a low range device to the vehicular network.

The devices need to have a type and state of user, to react differently and adapt the warning protocol to the user and the situation. An example of different behaviours for the user state is the difference in reaction on an fast running person and a slowly moving elderly person. The fast running person will have a much less predictable movement pattern (with possibly many changes of direction) compared to the elderly person. Positioning fast running persons will hence be much more difficult and may require a different approach for positioning, for routing or communication.
The type of user will also affect the system. An example is the difference between a child and an adult user, whereby the child will be more unpredictable in terms of movement pattern. The type of user can also be useful to let smart roadside units adapt their behaviour, like prolonging the time between traffic light switch for elderly pedestrians or by playing audio information or warnings for blind people at road crossings.

USE CASES

For the prevention of collisions with vulnerable road users the combination of different technologies can provide a more efficient protection system. In the next paragraphs we will describe in which way communication technology can assist in improving the detection of dangerous situations.

RIGHT TURNING VEHICLE

The typical collision prevention use cases for radar based systems are based on right turning vehicles which can collide with vulnerable road users which are moving straight ahead (Figure 3). In these cases the radar systems can provide good detection. However in city environments traffic lights and signs can influence the detection possibilities.

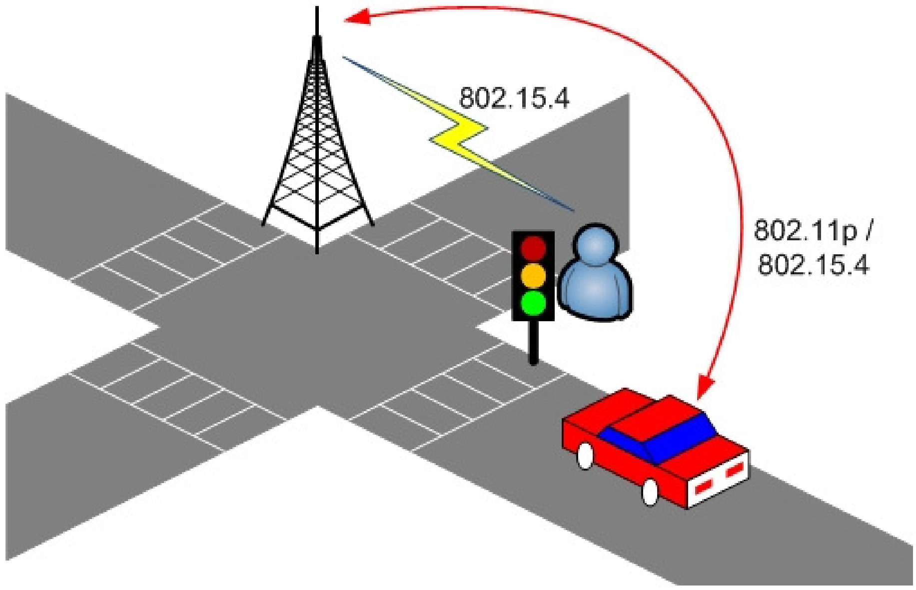

Figure 3 – Right turning vehicle which can collide with crossing VRU

When we use local communication in this situation the vehicle can be warned of the presence of a vulnerable road user behind the corner. The communication can go directly between car and vulnerable road user or via a road side unit.

STREET CROSSING

A vulnerable road user crossing the street (Figure 4) is difficult to detect with the current safety systems. However on straight roads there can be made use of radar or vision technology, like the Volvo city safety systems (17), which prevent collision at low speed.

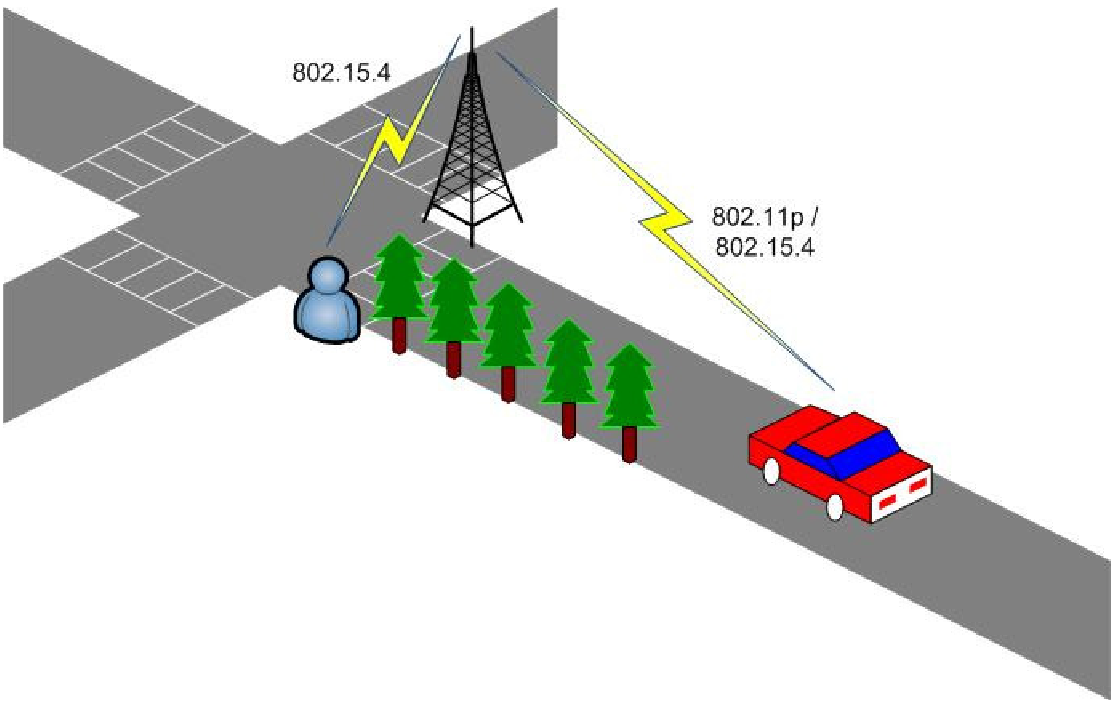

Figure 4 – Pedestrian crossing the road

The use of local communication systems can assist in the detection of a crossing vulnerable road user (VRU) by the use of an intelligent roadside unit which captures the VRU's messages and transit them to the approaching vehicles.

BICYCLE CROSSING AT INTERSECTION

When a bicycle crosses the road at an intersection (Figure 5), it can only efficiently be detected by vision based detection systems. However these are limited by the possibility that the bicycle is hidden.

When the position, speed and/or direction of the bicycle can be estimated and communicated to the approaching vehicle, the driver can be warned to prevent a possible collision. When integrating this system into a bicycle, the cyclist can also be warned with a visual and/or audio warning.

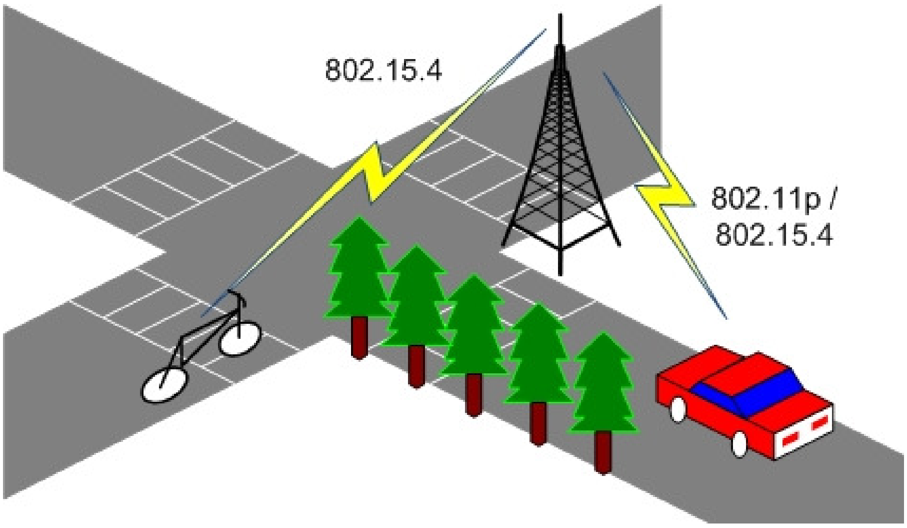

Figure 5 – Bicycle crossing at intersection

When integrating this system into a bicycle, the cyclist can also be warned with a visual and/or audio warning.

REMARKS

The use of local communication systems for collision prevention with vulnerable road users require that both road users, vehicle and vulnerable road user, require a system which is capable to transmit and receive the safety information. This is a typical problem with cooperative safety systems. But by integrating the system into smartphones and navigation systems, which already have a large penetration rate or by miniaturizing it and integrate it into watches or bicycles, an accelerated introduction and adoption of protection systems can be expected.

CONCLUSION

The combination of the existing collision prevention systems and new wireless technologies can improve the protection of vulnerable road users and enable the integration of these systems into the CALM technology.

Further work will be required for the extension of the CALM standard and the specification integrated protection system. The main research challenges are to deal with the different trade offs: low latency, low energy consumption, high position accuracy and high warning reliability.

The introduction of the protection system into the market will also be an important barrier. However introduction of the proposed safety system can fit in the construction of a smart city and deliver extra information to the policymakers. The system rollout will be the most likely to happen in a city environment where the density of users will be the highest. In this environment the speed of the different road users will be lower, which may favour direct communication between road users.

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