Towards Vision Zero - V2X Communication for Active Vulnerable Road User Protection

Vulnerable Road User Protection

In urban road traffic, motorized vehicles coexist and share space with less- or non-motorized road users, as for instance pedestrian and cyclists. Passenger cars and trucks have a high mass and already at low speed carry great amount of kinetic energy that can cause severe damages in an accident. Pedestrians, cyclists and motorbikes are especially exposed, since they are not surrounded by a steel cage that could protect them in case of an impact. Therefore, pedestrians, cyclists and motorbikers are also known as Vulnerable Road Users (VRU). In Europe, according to the Annual Accident Report of the European Commission 22 %, 10 % and 19 % of all road fatalities correspond to pedestrians, cyclists and motorbikers, respectively [1].

Consequently, VRU protection has gained a lot of attention over the last years. Not only the legislator has pushed towards deploying new safety measures to protect VRUs, but also the automotive industry has gradually incorporated new VRU safety features into vehicles.

Passive safety systems aim at minimizing the consequences of an accident. Helmets (worn by cyclists and motorbike) drivers are a good example of a passive safety measure. Some motorbikes are equipped with airbag systems that unfold in case of an accident to absorb the energy of the biker's body hitting the front part of the motorbike. Passenger cars have also experienced changes in their design to minimize the injuries when hitting against pedestrians and cyclists, e.g. the wipers have been hidden behind the hood. Some passenger cars also feature a system that automatically lifts the hood to absorb part of the energy when an impact with a VRU is detected.

Active safety systems aim at avoiding the occurrence of accidents. There has been a strong trend in the past two decades in equipping passenger cars with advanced driver assistance systems (ADAS) and safety systems, as for instance, the electronic Stability Program (ESP), pre-collision warning and automatic emergency brakes (AEB). Since 2016, the European New Car Assessment Programme (Euro NCAP) extended the AEB test criteria to include also the detection of pedestrians. Though, car models to obtain the highest 5-star distinction require to be equipped with pedestrian detection systems. Some truck manufacturers have also put a right-turning assistant for detecting a bicycle in the driver's dead-angle as an eligible safety system and the European Commission is considering making such systems mandatory across Europe. Active safety systems in vehicles rely on a sensor system that detects the presence of a VRU and enables the vehicle to predict a potential hazardous situation. Usually, cameras, radars or laser scanners are used to this end. These systems work well, especially when combined in a sensor fusion approach. However, they have in common that they can only detect VRUs in their unobstructed field of view.

With the introduction of V2X communication, automated vehicles are able to exchange information with other road users, the road infrastructure and back-end servers. Hence, the automated vehicle evolves into a connected and cooperative vehicle, which opens new possibilities for protecting vulnerable road users. By incorporating communication capabilities, the limitations of on-board perception sensors of automated vehicles can partly be compensated. This can be accomplished in two different ways: cooperative VRU awareness and infrastructure-side awareness. Both paradigms are further explained next.

Cooperative VRU Awareness

In this approach, VRUs equipped with a dedicated electronic device can actively make themselves aware to approaching vehicles. Especially the smartphone or wearable devices, such as smart-watches or smart-glasses, make the possibility of exchanging information between vehicles and pedestrians practical. Today's smartphones incorporate wireless communication technologies, such as Wi-Fi, cellular communication and Bluetooth and are equipped with multiple sensors, like global navigation satellite system (GNSS) receivers and motion sensors, that can help localizing accurately the device.

Smartphones feature a high-level of computational power, include a power supply and come along different human-machine interfaces, such as the display and the haptic and acoustic interfaces. The internal software architecture of these devices makes it relatively easy to deploy new software "Apps", that make use of all these possibilities.

The limiting factor for cooperative VRU protection is however still the size and weight of the devices, the prize and the battery consumption. Although, technological advancement will on the long run make these factors less heavy, a solution is required in the short term. In this regard, the strong increase in electric-bikes, pedelecs and e-scooters in the last years makes the option of cooperative VRU protection increasingly interesting. A relatively large power supply and the ability to transport more weight are key advantages to deploy active localization systems and communication technologies into these means of transport.

Cooperative VRU Awareness requires two subsystems: high accuracy localization and reliable, low-latency communication.

VRU Localization

For collision avoidance purposes it is necessary to pinpoint all road users on a common map. VRUs can compute their position using the GNSS-receiver embedded in their smartphone. However, a high positioning accuracy is required for collision avoidance purposes and it is difficult to achieve using only GNSS, especially in urban environments. Particularly, a position uncertainty (1σ) of less than half a meter is required to obtain a high detection rate keeping the false positive rate under 10%. **Fehler! Verweisquelle konnte nicht gefunden werden.** shows the receiver operating curves (ROC) in dependence of the vehicle and VRU position uncertainty at the collision instant.

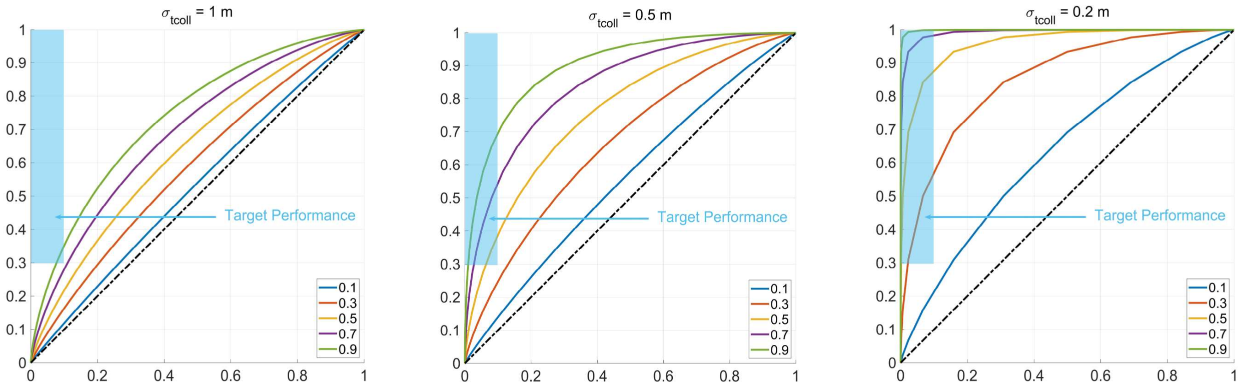

Figure 1 Collision detection performance for three different positioning uncertainties (σ = [1m, 0.5m, 0.2m]).

The position accuracy deduced with the information provided by the GNSS receiver embedded in commercial smartphones can be increased using the inertial sensors available in the smartphone as well or maps, among others. Our study shows that the position accuracy reached by GNSS aided by inertial sensors is still not enough for reaching the half a meter accuracy required for collision avoidance purposes.

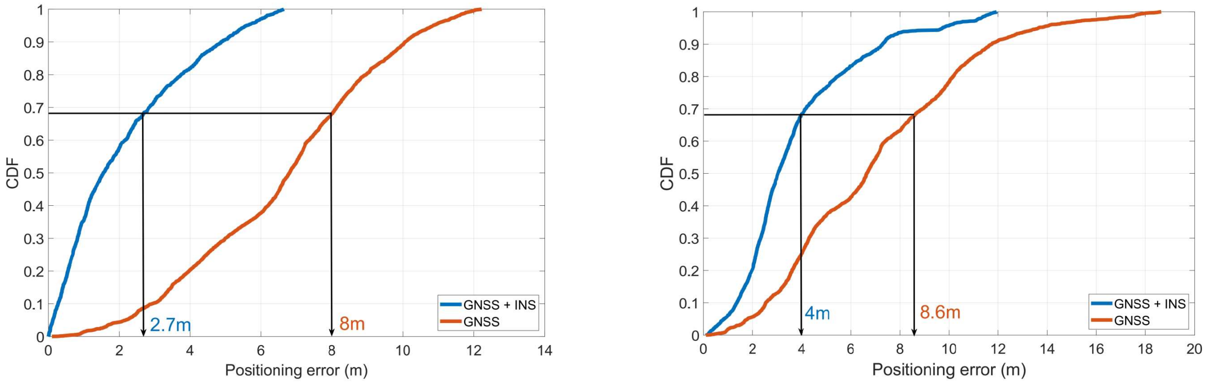

Figure 2 CDF positioning error curves for pedestrian localization (left) and bicycle localization (right) using a smartphone in a suburban environment.

The blue curve in Figure 2-Left shows our combined GNSS and inertial sensor solution with a 2D position accuracy of 2,7 m (1σ), while the red curve uses only the GNSS position provided by the smartphone. We have used the smartphone Samsung Galaxy S20 in suburban environment. Likewise, Figure 2-Right shows the positioning results for bicycles. The blue curve represents the position accuracy for the combined GNSS and inertial sensors solution, while the red curve represents the GNSS-only position accuracy. For these experiments the same smartphone was attached to the handlebar of the bicycle in semi-urban environment.

For VRU protection and robust collision avoidance, not only the position is important, but also speed and direction of movement are needed. Since these parameters are not known at infinite precision, also a measure of the accuracy is required. Further, since the aim is to avoid collision that are about to happen, reliable prediction of the movement is required. For a speed of around 40 km/h, 1.5 seconds are required to get a vehicle to standstill. Hence, this is also the prediction time for the trajectory of the vehicle and the VRU. Whereas vehicle's future trajectory might be well predicted in this timeframe due to its high mass, it will be more challenging for the case of a bicycle or even a pedestrian. Here dedicated movement and intention models for pedestrians and cyclists are the key to success.

V2X Communication

Mainly two communication technologies are regarded for exchanging information between VRUs and vehicles: ad-hoc wireless communication or cellular communication. Ad-hoc communication is a broadcast communication without centralized coordination and link establishment. Example of ad-hoc wireless communication are ITS-G5 (or DSRC), which are based on IEEE 802.11p/bd, or Cellular-V2X over the LTE-PC5 interface. In principle, also traditional cellular communication over a base-station (Uu interface in 3GPP-LTE nomenclature) can be used to transmit the information from VRUs to vehicles.

This, however, requires a central server to disseminate and geographically filter the information amongst nodes.

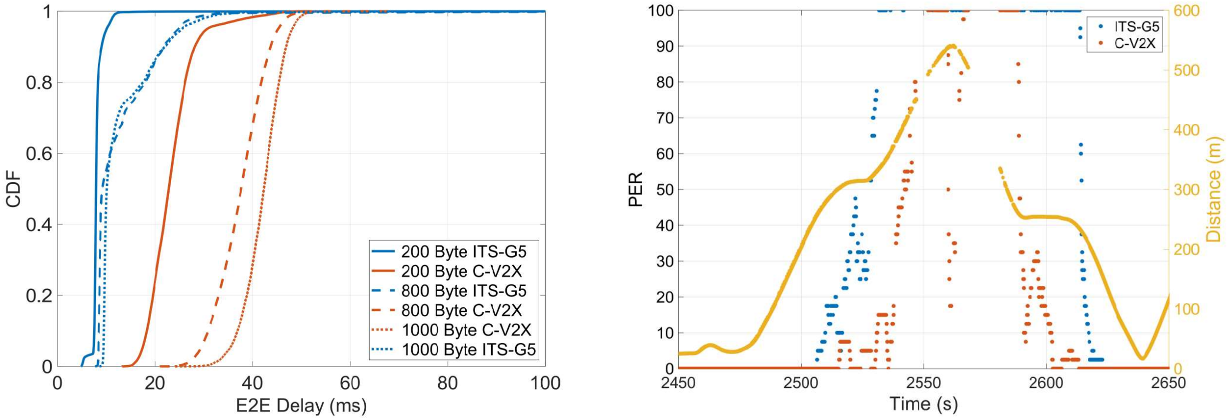

Figure 3 Left: E2E-delay for V2V link using ITS-G5 (blue) and C-V2X (red) for different message lengths. Right: PER for a V2V link in urban environment using ITS-G5 (blue) and C-V2X (red).

The relevant performance metrics for the communication are the update rate, the end-to-end latency, the packet error rate (PER) and the communication range. The highest update rate foreseen for V2X is 10Hz, although an adjusted update rate in dependence of the node dynamics is used. The end-2-end latency for the ad-hoc communication technologies is usually below 50ms, as our link-level tests with ITS-G5 and C-V2X on an apron showed [2]. The maximum communication range is dependent on the transmit power and possible obstructions and blockage due to vehicles and buildings. Here we can expect slightly better performance for C-V2X than for ITS-G5 due to the physical layer with improved coding mechanisms and hybrid automatic repeat request (HARQ). Our direct performance tests for a V2V link showed that C-V2X had indeed a better performance in terms of a lower PER compared to ITS-G5 when driving around buildings in an in an urban environment (see Figure 3-Right). However, packet errors will occur not only due to low signal strength but also due to mutual interference with other nodes. Here, network simulations with different technologies will answer, which technology is mostly suited for crowded urban environments.

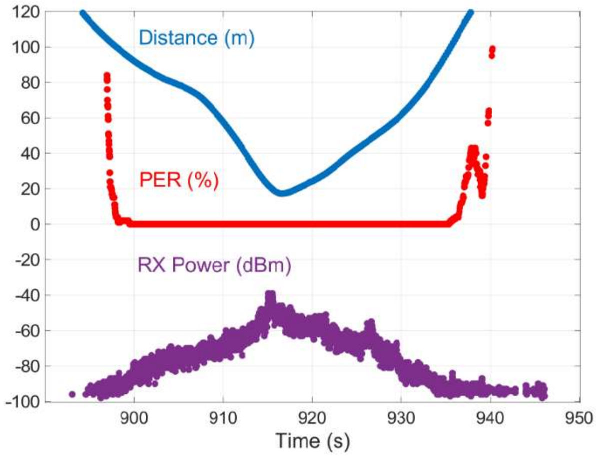

Figure 3 Pedestrian-vehicle collision scenario in urban canyon. Distance between a pedestrian and a vehicle, PER for a direct ITS-G5 communication link and Rx power at the vehicle oder time.

To keep mutual interference at an adequate level, one approach is to lower the update rate or the TX power. These techniques are as well in the interest of a thrifty power consumption at the VRU's wearable device. A vehicle driving at 50 km/h (14 m/s) will travel 22m in 1.5 seconds. Hence, a 30 to 50m transmission range seems appropriately to warn an approaching vehicle on time. We tested a bicycle-vehicle scenario in an urban canyon using ITS-G5 communication and using a TX power of 23dBm. Figure 4 shows the RX power, the range and the PER over time. It can be seen how 80 to 100m range were achieved with a PER of less than 50% with this setup. By extrapolation and visual inspection, it can be stated that even with a TX power between 0 to 5 dBm a coverage up to 50m could be achieved.

The line between localization and communication vanishes, when communication technologies are used for localization. This is possible with technologies as for instance IEEE 802.11bd Next Generation V2X, IEEE 802.15.4 Ultrawide Band (UWB) and IEEE 802.11az. The latter two use large radiofrequency bandwidths to perform precise round-trip delay measurements and estimate the distance between a moving node and several fixed anchor nodes. Out of several of these ranging measurements the position can be estimated [2].

Infrastructure-side awareness

Cooperative VRU Awareness requires the VRUs to carry a dedicated electronic device and, thus, creating a hurdle to a broad system deployment and to a measurable impact to accident statistics. Infrastructure-side awareness represents a paradigm shift in VRU protection. It is not the VRU who actively makes other vehicles aware of its presence, but the road infrastructure. By using a suited perception system, as for instance a camera installed on a nearby pole, road users, including VRUs, are detected, localized and tracked. This information can be encoded into a Collaborative Perception Message (CPM) and transmitted over V2X communication. This approach has been tested at the test field for cooperative and connected driving in Düsseldorf in the frame of the KoMoDnext project. A camera system was placed above a pedestrian crossing and was able to detect crossing pedestrians and generating CPMs, which were broadcasted over ITS-G5, C-V2X and LTE [4].

Not only cameras are suited to detect VRUs at urban intersections. In the frame of the German-funded project VIDETEC, DLR and IMST have tested radio-based detection systems for VRU protection [5]. IMST develops 24 and 77GHz Radar chips that are able to classify road users anonymously by processing micro-Doppler signatures with dedicated machine learning algorithms. Another very promising technology based on processing radio signals is termed Joint Communication and Sensing and it is foreseen to be a key technology for the future 6th Generation cellular communication. Every node of a distributed array of antennas around the intersection transmits periodic beacons that are received by all other nodes. By intelligent signal processing of the distorted incoming signal, the location and speed of road objects can be obtained.

Independent of the perception means, the information about the presence, the movement, the direction and the type of VRU needs to be delivered into the automated vehicle to be fused with the on-board perception sensors, incorporated into its local dynamic map and considered by the vehicle's automation [6]. To this end, three competing technologies for V2X have been tested in the Düsseldorf field test. At a roadside intersection three radio devices for ITS-G5, C-V2X and LTE were placed on a pole at a height of four meters. The coverage of all three technologies was tested by driving around the south-east block. It could be observed, that CPMs were received over the direct links before having visual connection to the intersection. Figure 4-Left shows that a minimum coverage of 114m could be measured. This represents more than 8 seconds when driving at a maximum speed of 50km/h and seems to be sufficient for warning the vehicle about crossing pedestrians. With LTE the highest coverage was obtained. However, a centralized approach will need to decide which information to forward to which vehicle according to distance or route. On the right figure, the E2E delay for all three technologies can be compared to each other. Again, C-V2X has slightly higher delay than ITS-G5, while LTE doubles the latency reaching values above 350ms. VRUs, unlike vehicles, are not restricted to move on roads and can very suddenly change their curse. For sudden events, as for instance a pedestrian making a "last-second" turn onto the street, this timeframe might be already too large to timely react. Especially, if further time for processing and actuation has to be considered.

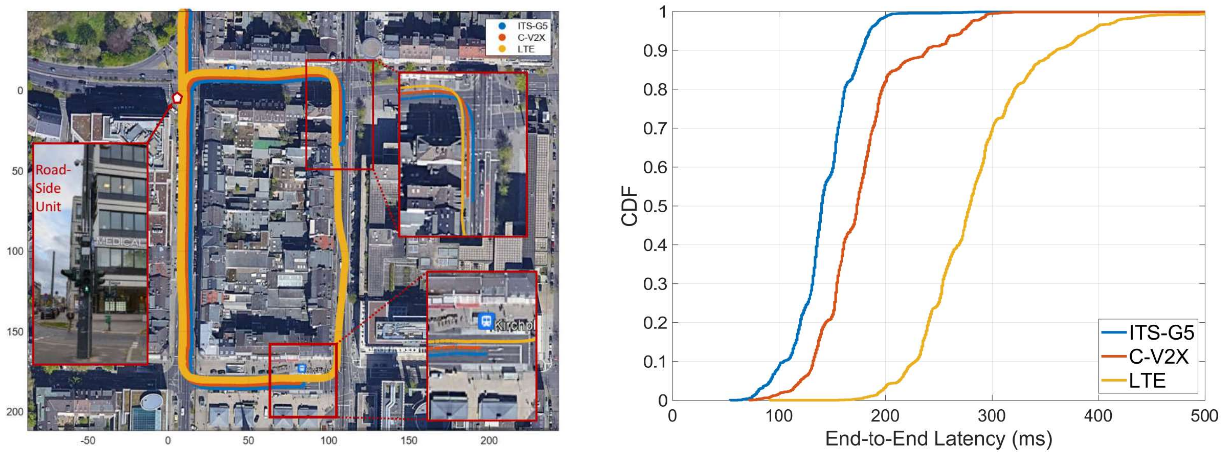

Figure 4 Left: Coverage of CPM transmissions from RSU at a vehicle during in Düsseldorf. Blue with ITS-G5, Red with C-V2X and Yellow with LTE. Right: E2E delay with all three technologies.

Towards Vision Zero

The Vision Zero goal is to reduce the road traffic casualties to zero. V2X enabled connectivity and cooperation will support the highly automated vehicle to drive more efficient in urban environments, while maintaining a high level of safety. We have presented in this article that ad-hoc V2X communication, either through ITS-G5 or C-V2X, is able to convey information about the presence of VRUs in less than 100 ms making it possible for a vehicle to safely maneuver or come to standstill. Therefore, the V2X communication has a great potential to contribute to the Vision Zero.

However, in real environments two key aspects of V2X communication have to be guaranteed, namely the robustness of the communication against mutual interference in highly congested environments and semantic “trustworthiness”. These two aspects are key to the vehicle automation that is necessary to avoid hazardous situations between vehicles and VRUs.

Furthermore, we have discussed that the VRUs can contribute to their own safety by sharing their position computed e.g. with their own smartphone. However, the position accuracy required for this safety critical application is difficult to meet in urban environments with the current technology. Last but not least, we have seen that RF-based perception system, as for instance Joint Communication and Sensing, are promising candidates to support and enhance camera-based systems for infrastructure-based VRU perception.

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