Vulnerable Road User Protection

5GAA Automotive Association

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Introduction

Road safety is a crucial aspect of mobility both for individuals as well as for policymakers. Road fatalities, in the European Union (EU), for example, have decreased by approximately half between 2001 and 2018 from 54,000 to 25,100 per year[1]. However, in recent years, the number of fatalities has been on a stable level, and additional efforts are needed to further reduce the number of deaths and severe injuries.

The most significant improvements have been achieved by increasing the safety features of vehicles, while the smallest improvements in numbers have been reached in the category of vulnerable road users (VRUs). Typically, VRUs account for almost half of road accident victims. In 2017, pedestrians accounted for 21% of road fatalities in the EU, for example, while motorcycles, bicycles and mopeds made up 26%[2].

As people nowadays are encouraged to cycle (including electric bicycles) or walk short distances for health or environmental reasons, the number of unprotected 'traffic participants' will not decrease. Moreover, every single individual is a potential vulnerable road user, bringing the total number of possible VRUs to 7.7 billion, as it can be assumed that every person occasionally crosses a street or intersection either by foot or by other non-motorised means such as cycling.

Policymakers have identified VRUs as a group of traffic participants that deserve specific attention, to reduce the number of fatalities and serious injuries[3]. In this context, **connectivity and automation** offer great potential to reduce human errors and enhance the protection of VRUs.

This White Paper therefore aims at shedding light on the safety benefit that selected **V2X use cases** offer, which can have a significant impact on the protection of the most vulnerable traffic participants. Ultimately, this also has a positive impact on health-sector costs incurred, by reducing the number of people suffering serious injuries with life-changing consequences.

5GAA has made **VRU protection a priority area.** The work began in the first quarter of 2019, when 5GAA's Board set up the VRU Protection cross-working group with a mandate to work in the following areas.

- Use cases
- Technical enablers
- Protocols and standards
- Go-to-market strategies
- Demo planning

[1] https://ec.europa.eu/commission/presscorner/detail/en/MEMO_19_1990

[2] https://ec.europa.eu/commission/presscorner/detail/en/MEMO_19_1990

[3] https://ec.europa.eu/transport/sites/transport/files/legislation/swd20190283-roadsafety-vision-zero.pdf

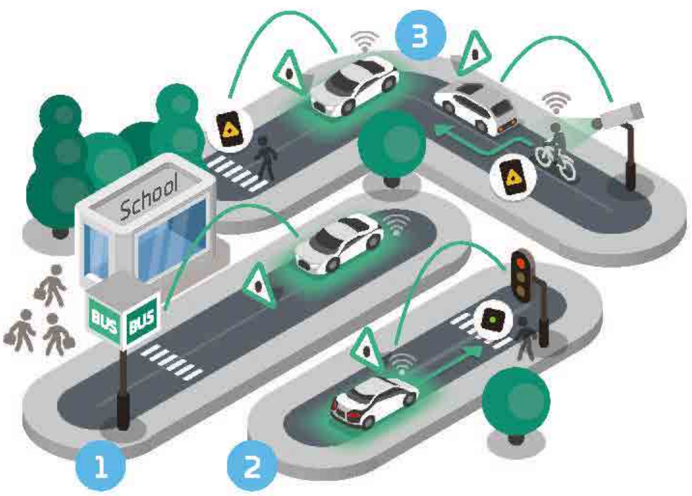
2. VRU Categories

The VRU categories are considered by 5GAA are:

- Pedestrians
- Cyclists (including eBikes)
- Motorcyclists
- Road workers
- Wheelchair users
- Scooter, skateboard and Segway users

3. Use Cases

Use cases fall into three broad scenarios which are described in 3.1 to 3.3. Some examples for each scenario are given in 3.4 and further analysis of some of the example use cases, along with illustrations, challenges, requirements and possible flows, are presented in Annex A.



3.1 Scenario 1: VRU high risk zones

In this scenario, drivers (or automated vehicles) are delivered warnings when they enter a high risk area where there is a likely presence of many VRUs. The high risk area can be static (e.g. a school during arrival and leaving times), or dynamic (e.g. a school bus or mobile ice-cream vendor). Dedicated roadside infrastructure could play a vital role in disseminating warning messages to VRUs and vehicles as well.

3.2 Scenario 2: Interactive communications between VRU and vehicles

In this scenario, there would be a negotiation between the VRU's device and a vehicle. The figure shows a VRU using an interactive crossing application, whereby the VRU asks the vehicle for permission and the response is displayed to the VRU.

3.3 Scenario 3: VRU safety messages and algorithms

The VRU awareness service scenario is expected to be the most common. It usually involves vehicles and smartphones being PC5 enabled. In this scenario, VRUs' devices send out safety messages (e.g. PSM, VAM) and vehicles send out safety messages (e.g. CAM/DENM, BSM). Risk assessment is continually performed by the most suitable unit (e.g. vehicle or infrastructure) and, if a collision is predicted, warnings are then issued. Warnings are always given to the driver/AV and sometimes to the VRU as well. Examples of the latter case are shown in the figure. On the left, the pedestrian is typing on the device whilst crossing the road and, on the right, a cyclist is approaching a parked car with the door opening into his path.

3.4 Examples of use cases within each scenario

The table below gives examples of some of the possible use case categories within each scenario.

Table 3.4.1: Example use case categories within each scenario.

Scenario Category	Scope	Use Case (UC) Categories
S1: VRU high risk zones	Drivers or AVs are delivered warnings when they enter the area	**UC-1.1:** Pedestrian in crosswalks – send out alerts to motorists when pedestrian in a mid-block crossing. (Can be infrastructure-based messages to motorists). **UC-1.2:** Pedestrians in crosswalks at intersections. Provide alerts to motorist when pedestrians are crossing a side street on right or left of vehicle. Also provide alerts when pedestrian in crosswalk and signal is green for vehicle. (Can be infrastructure-based messages to motorist). **UC-1.3:** School Zone Warning – Send out alerts to motorist when they are entering a school zone area that is active. High concentration of pedestrians around the area at specific times, such as arriving and leaving times. **UC-1.4:** School bus warning. Similar to 1.3, but a dynamic high risk area (e.g. school bus, ice cream truck).
S2: VRU communicating directly with vehicles	Negotiation between VRU's device and approaching vehicle	**UC-2.1:** Car doors opening in the path of a cyclist **UC-2.2:** Interactive VRU crossing.
S3: VRU safety messages and AI	PC5 enabled vehicles and smartphone VRU devices send PSM, VAM Vehicles send out CAM/DENM, BSM	**UC-3.1:** Pedestrian/Motorists Collision alert – Alert provided to motorist (and pedestrian) if vehicle is driving over a certain speed and has a predicted collision path with a pedestrian. **UC-3.2:** Cyclist/Motorists Collision alert – Alert provided to motorist (and cyclist) if vehicle is driving over a certain speed and has a predicted collision path with a Cyclist. **UC-3.3:** Send alerts to smartphone mounted on eBikes. **UC-3.4:** Cyclist/pedestrian collision alert. **UC-3.5:** High density VRUs in urban crosswalk.

More details of some of the use case categories, along with illustrations of the sub-category use cases with underlying challenges, requirements and possible flows, are presented in Annex A.

4. Technical enablers

Some of the technical enablers required to deliver VRU protection services are described in this section.

4.1 How does a smartphone detect a VRU situation?

In short, a VRU situation will be detected by sensors, sensor fusion and artificial intelligence (AI).

The VRU protection service relies upon knowledge of:

- Category of VRU (whether a pedestrian, cyclist, scooter, etc.)
- If status changes (e.g. cyclist gets off bike, or a pedestrian gets into a car, or VRU is active/passive)
- That the VRU is still in possession of the device

In order to achieve this in a reliable way, fusion of sensing or perception or path prediction from the VRU's device, vehicle and infrastructure will be employed. The sensors in the VRU's device include motion, compass, gyroscope, etc. functions; the vehicle carries cameras, radar and LIDAR; and roadside infrastructure includes cameras and VRU-activated equipment such as push-to-cross buttons. Vehicles and infrastructure usually receive sensing/perception data from all of these (VRU's device, vehicle and infrastructure) sensors. However, VRUs may not be capable of receiving sensing/perception information from vehicles. Infrastructure may play a vital role in bridging the gap by sharing sensing/perception results from vehicles to the VRUs through proper messaging like CPM/VAM.

The VRUs cannot be relied upon to manually update their status. However, a profile of the VRU would be useful and could be done when the VRU sets up a new device. If, for example, the VRUs say in the profile that they own a scooter it is likely that this mode of travel will be used. Pairing of the smartphone with a mode of transportation that the VRU owns, such as a scooter, e-bike or motorcycle, would assist in determining the VRU category.

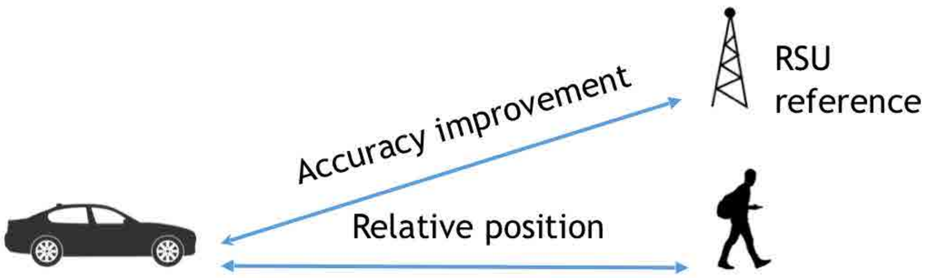
A consequence of AI and sensor fusion is that smartphone battery consumption will be increased. Ways to address this will be helpful.

4.2 How does the vehicle know where the VRU is heading?

In order to predict and avoid collisions in a reliable way, accurate location and path prediction are needed.

Location accuracy requirements for a pedestrian protection service depend on the use cases but can be as low as 0.1m, which would determine if the pedestrian is on the curb or the road. Such accuracy can be achieved by Global Navigation Satellite (GNSS) supplemented with Real Time Kinematic (RTK) (3GPP Release-15) or PC5 ranging (3GPP Release-18).

The figure below illustrates PC5 positioning. Either GNSS accuracy can be improved by using an RSU reference point, or relative position between two points (vehicle and VRU) can be calculated. The accuracy achievable with PC5 positioning depends on the bandwidth available for the ranging signal.



In order to anticipate collisions, path prediction of the VRU relative to the vehicle will be calculated. Path prediction is relatively easy for a motorcycle, which generally moves with car traffic (except when it is mid-lane), and the rider signals his intended manoeuvres. Also for cyclists, path prediction is considered to be possible based on two-wheeler dynamics similar to motorcycles, but with some more complexity due to higher dynamics (e.g. changing direction), and cyclists might not only use the road, but also bike lanes or sidewalks. At the other extreme, path prediction for pedestrians is very difficult because they move more randomly. Together with sensor fusion, pedestrian path prediction will rely on knowledge of the pedestrians' behaviour, learned over a period of time, and on detection of high risk situations. A high risk pedestrian may be a child or someone who is typing on their smartphone while stepping onto the road or into traffic, listening to loud music on a headset, or running to catch a bus. A high risk place would be somewhere that pedestrians frequently step into the traffic. Vehicles or infrastructure may be the right place to run computationally heavy processing (including complex AI-based prediction) to determine a VRU's heading, location/position and other relevant activities. Close collaboration among vehicles and infrastructure may also be beneficial to enhance the reliability of such prediction/determination of VRU location, VRU heading and other VRU activities. Infrastructure and vehicle-assisted prediction/determination of VRU location, VRU heading and other VRU activities becomes critical in non-equipped VRU cases.

These infrastructure-based services are considered very effective, therefore it would be desirable to have as many crossings as possible equipped. For all crossings or streets without such equipment, VRU protection needs to be based on intelligent algorithms built into the VRU devices and vehicles, and means of communication that do not depend on infrastructure.

Sensor fusion is a key technical enabler. Vehicles, infrastructure (lamp posts, traffic lights) and VRUs could share sensor data so that, for instance, 'crossroads' (or a section of road) have a more complete understanding of the present 'situation' (traffic, environment) along with individual vehicles/VRUs/RSUs. This could augment many vehicle functions and offload data transmission to/from vehicles and the 'local' in-vehicle processing power needed.

Pedestrian path prediction technology is not mature at the time of writing. Further research is needed.

4.3 How can false warnings be avoided?

False warnings will annoy users and damage confidence in the VRU protection service, which could ultimately counteract the intention of protecting such vulnerable road users.

To reduce false warnings, minimum triggering conditions for when a warning should be given are needed. These conditions should be based on:

- Vehicle speed
- Predicted VRU speed and heading
- VRU profile (adult pedestrian versus children, young children on bikes, elderly people)
- Predicted VRU position
- Probability of collision
- Time to collision

There could be two or more degrees of warning (e.g. caution, danger). Collaboration among vehicles, VRUs and infrastructure for collective perception is beneficial to enhance the reliability of such prediction/determination of VRU location/position, VRU profile, VRU speed and VRU heading. More reliable determination of the VRU position, VRU speed and VRU heading minimises false alarms.

There will be an optimum time to warn of a potential collision, and this also depends on what activities vulnerable road users are involved in and their VRU profile. For example, an earlier warning is needed for VRUs doing something which puts them at greater risk such as typing on a smartphone while stepping into the road, listening to music on a headset, or running to catch a bus. Similarly, children or the elderly require an earlier warning compared to adults who tend to be more alert.

Generally, an earlier warning gives more time for evasive action to be taken, but a later warning is easier to achieve. A target of 4 seconds is proposed. Less than 2 seconds is less beneficial due to driver reaction time and braking time.

Warnings should be similar across all implementations. This will avoid confusion if a driver changes vehicle or a VRU changes smartphone. Some guidelines on how to display warnings to drivers and VRUs in a broadly consistent way are recommended. Sudden danger warnings to VRUs should be avoided or minimised whenever possible as there is a risk of uncoordinated and unexpected actions by VRUs which may create another safety risk to avoid detected safety risk.

4.4 How does an RSU improve VRU protection?

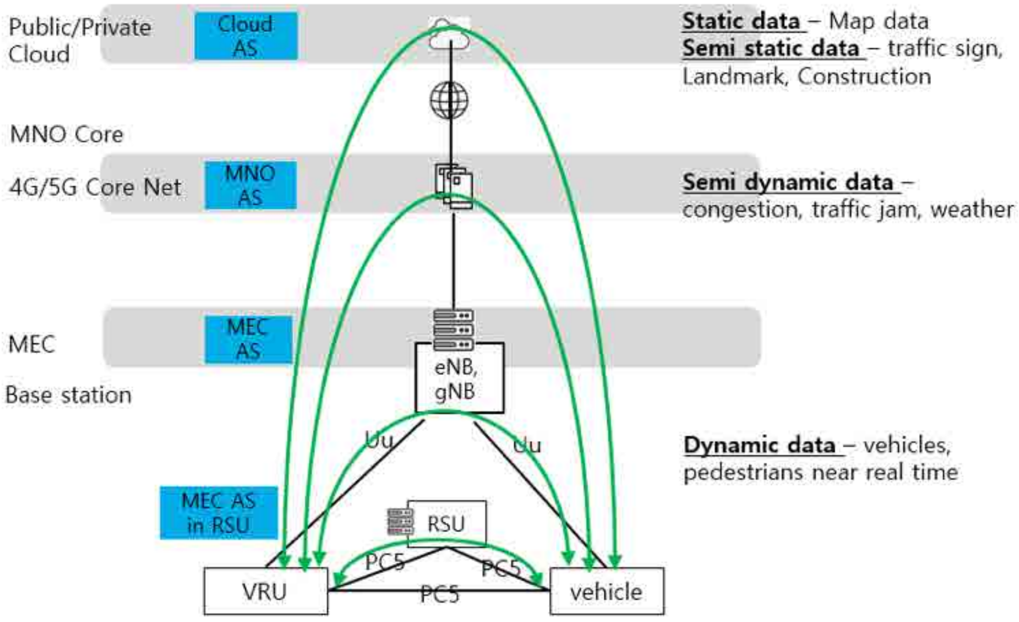
An RSU could be used to help improve VRU protection based, for example, on features that detect and predict a collision between a VRU and a vehicle (or other type of VRU i.e. cyclist), and detect non-equipped VRUs.

An RSU could generate, send and relay ITS messages between VRUs and vehicles. Furthermore, AI features on top of a camera-based solution could be adopted to enhance the quality of detection and for predicting collisions. This could also be applied to detect non-equipped VRUs. An RSU could play a role in highlighting the presence of non-equipped VRUs, by effectively including VRUs hidden from vehicles' field of view, or by further enhancing equipped VRUs' (relative) position accuracy. In some cases, such as at busy intersections, zebra crossings, school drop-off and pick-up areas, public bus stops, school bus stops, busy crossings near shopping malls, construction areas, and so on, both equipped and non-equipped VRUs are present.

Infrastructure and RSUs can play a role in detecting potential VRU clusters/groups in such scenarios, including equipped and non-equipped VRUs and sending alerts on their behalf. A static RSU may be installed at a busy intersection, zebra crossing, school drop-off and pick-up area, busy crossing near shopping mall, etc, while a mobile RSU can be installed on or in designated vehicles such as school buses, city buses, and service vehicles.

In terms of geolocation and distance, an RSU could be located near VRUs in a road environment. The RSU could play a role in VRU protection at an intersection via a camera-based solution and the delivery of V2X messages (i.e. CAM, DENM, CPM, MCM, PSM and VAM) to participant devices.

In terms of data characteristics (i.e. static or random) some form of layered network architecture organised into a data hierarchy could be envisaged. Static data (i.e. map data) could be handled in a cloud service (cloud AS) as it does not change frequently. Dynamic (i.e. temporal and spatial) data, which offer a snapshot of the situation, could be handled in an RSU. For example, an RSU monitors the situation at an intersection and reports an event (i.e. heavy traffic jam or car accident) to a cloud AS to add the local information to the full map.



Assumption: RSU can be connected to RTA AS via Uu or private IP network.

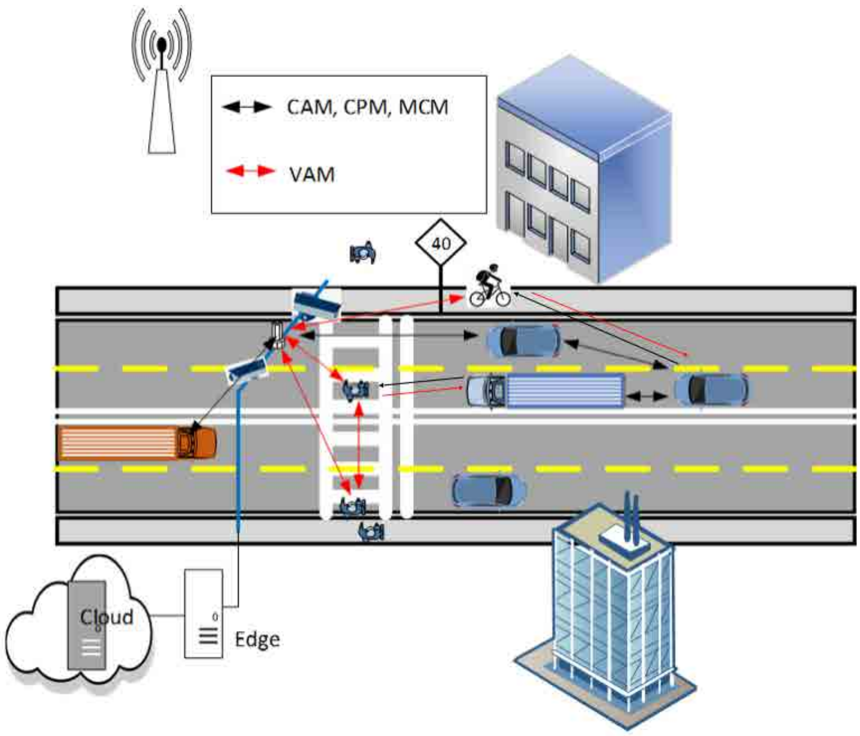
From a communication perspective, a smartphone is the most common device carried by a VRU and supports several communication protocols including Uu and PC5. An RSU will deploy Uu, PC5. Furthermore, there is an option to adopt communication protocols to enable a VRU protection service within legacy smartphone devices in cases where PC5 is not supported.

Various communication paths could be deployed in terms of V2X message delivery. For example, an RSU could be an intermediate node to deliver V2X messages from a VRU to a vehicle and vice versa, the use of Uu and PC5 being assumed. Alternatively, a VRU could send a V2X message via a Uu interface and the message is delivered to the RSU, which then sends the message to the vehicle via a PC5 interface.

4.5 How does MEC improve VRU protection?

The presence of roadside infrastructure facilitates accurate environment perception in the surrounding areas by deploying sophisticated sensors including cameras, Lidars, radars, GNSS sensors, etc. The semantic information is extracted using computer vision techniques. The extracted objects from multiple sensors may be fused to improve the detection accuracy. The decision-making element may use them to come up with a set of actions for the safety of VRUs, vehicles and property. This processing could be performed at the edge or at a central location. The raw sensor data is normally large in size and requires significant backhaul bandwidth to transport it to a central location for processing, and would incur additional operating expenses. Larger latencies could be introduced in the transport and routing. To prevent these pitfalls the processing and decision-making could be performed at the edge (in the close proximity to the RSU). The figure below depicts such an edge-computing deployment scenario. The main benefits of these deployments are lower latency, efficient use of network resources and lower operating expense.

Edge-computing deployment for VRU safety. List of possible interactions and



message types is not complete (might be extended to e.g. SPAT, MAP, DENM, etc.)

The ETSI ISG MEC[4] provides a framework for edge computing to roadside infrastructure equipment vendors, and software application developers. Industry consortia such as 5GAA and AECC, are also focusing on automotive safety applications including VRUs. In some situations, vehicles and VRUs may offload their computing or processing workloads to an edge-computing platform via the RSU. The distributed nature of the edge computing gives flexibility to an entities

[4] ETSI GS MEC 003: Multi-access Edge Computing (MEC); Framework and Reference Architecture

involved in road infrastructure deployment in terms of managing, scaling and upgrading their network.

5. Protocols and standards

To achieve greater VRU protection in the scenarios described, global standards would be preferred over regional ones which can vary (e.g. the VRU message in North America is the PSM, while in Europe it is the VAM).

Standardisation needs to find the right balance to achieve interoperability and good user experience without stifling innovation. For communications protocols, detailed standards are needed, but for prediction algorithms just guidelines are sufficient.

The guidelines for algorithms should include:

- Harmonised warnings
- Triggering conditions for sending safety messages
- Techniques to reduce channel load (e.g. VRU clustering)

Existing VRU messages are the SAE PSM and the ETSI VAM. Additional processed data fields which should be included in future versions of these messages need to be identified.

For cyclists, the additional processed data fields are:

- Stability indicators e.g. cyclist competence derived from rider behaviour and inertia sensors
- Predicted hazard e.g. slippery road based on temperature and humidity sensors
- Predicted future path and velocity calculated from sensor data, bicycle dynamics models, path history and VRU profile
- Reaction indicator e.g. braking, stopped pedalling, or no reaction as a result of an earlier message

6. Commercial viability of a VRU protection service

A VRU protection service will reduce deaths and provide an overall benefit to society, but direct payment by the VRU alone may not be enough to guarantee its commercial viability. It is expected that governments would have to contribute toward roadside infrastructure and provide incentives. A significant factor is that in many cases the VRU already has the device (i.e. smartphone). There could be

indirect sources of revenue such as vehicle insurance premium reductions, tolling rebates, and acceptance of advertisements.
5GAA has studied in detail a go-to-market strategy for five use cases:

- Pedestrian/Motorist collision alert
- School bus warning
- Send alerts to smartphone mounted on eBikes
- Interactive VRU crossing
- Mid-block pedestrian crossing

Conclusion

VRU protection services will save lives and provide societal benefits.

It is expected that use cases in scenarios 1 and 2 could be brought to market quickly. Some use cases in scenario 3 can be brought to market rather quickly, whereas others – notably V2P – are not yet ready. The main challenge for V2P is reliability and the avoidance of false warnings, which in turn requires 0.1m position accuracy and pedestrian path prediction. Sensor fusion and cooperative awareness are key future technologies in this respect.

This paper has identified that work is needed in the following areas (stakeholders identified in brackets):

- Define minimum triggering conditions for delivery of VRU warnings (handset makers, OEMs)
- Provide guidelines for common presentation of VRU warnings, i.e. haptics, audio, visual (user groups, handset-makers, OEMs)
- Define minimum triggering conditions for transmitting VAM/PSM (MNOs, handset-makers, OEM)
- Set requirements for efficient use of spectrum, e.g. reduction of VAMs/PSMs in clusters (SDOs)
- Identification of high risk situations regarding pedestrians and places (user groups, OEMs)
- Research into pedestrian path prediction (research institutions)
- Minimise power consumption in smartphones operating VRU protection services (handset manufacturers)
- Identify containers for sensor fusion data, in each VRU category (SDOs, OEMs, handset manufacturers)
- Sensor fusion (research institutions, handset-makers, OEMs)
- VRU profile (user groups, handset-makers, OEMs, SDOs)
- How to integrate with already existing systems

Annex A: Further example use cases

Scenario 1: Example use cases

UC Category 1.1: Pedestrian in crosswalk
UC1.1.1: Occluded VRU in crosswalk without V2P/P2V, P2I/I2P capability (V2N/V2I available)

As shown in Figure A.1, this type of case arises when a VRU may not necessarily be in possession of a communications device. For example, a child without a smartphone device crossing a road may fit this use case because having the VRU and approaching vehicle in close proximity makes this situation more dangerous. There are two practical challenges in this situation:

1. VRU is occluded from vehicle's field of view and thus is without awareness of the approaching vehicle. On the other hand, the vehicle does not have any awareness of the VRU

2. VRU is not equipped with communications-enabled devices

So, there is a greater chance that the vehicle could become dangerously close to the VRU by the time the vehicle's driver (or sensors in the AV case) is able to see the pedestrian on the crossing and apply the brakes. However, depending on the reaction time of the driver (or sensors), the vehicle may or may not be able to stop in time. Thus, the VRU is at high risk of being struck by the vehicle.

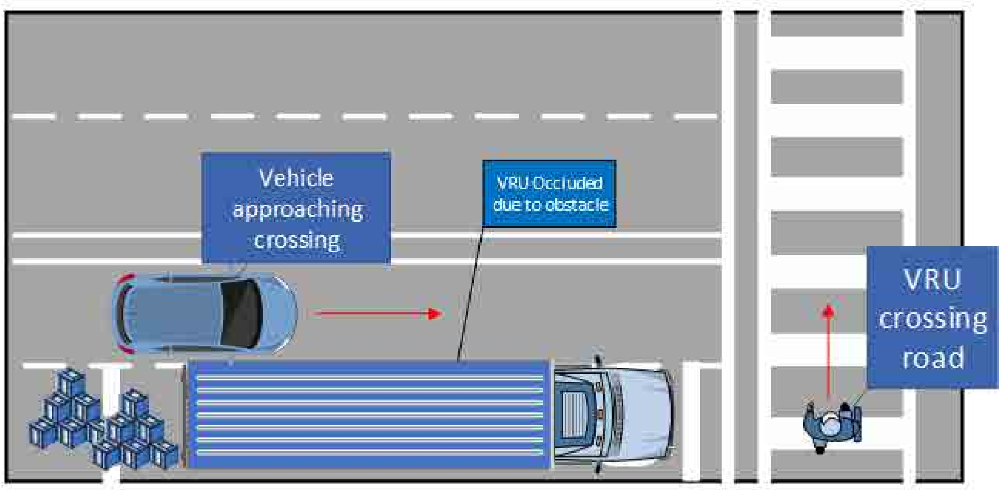


Figure A.1: VRU crossing road with approaching vehicle. VRU is non-communications-enabled (no V2P/P2V capability)

To avoid a collision between the VRU and the vehicle in such cases, an entity is needed such as a smart RSU which can perceive the environment that the VRU is in and send a notification message to approaching vehicles within the coverage range of the RSU. As shown in Figure A.2, assume there is an RSU equipped with sensors (e.g. camera, LIDAR, radar, etc.), flashing lights and/or siren stationed near the scene. Then, the RSU can 'intelligently' perceive the scene and be aware of the approaching vehicle, as well as the VRU, and thus can broadcast safety messages to the V2N- or V2I-enabled vehicle, to indicate the VRU presence. Such action at the RSU-level can then alert the vehicle about the VRU's presence. At the same time, the RSU can also activate its flashing lights and sirens to warn the non-equipped VRU that there may be a potentially dangerous vehicle approaching the crosswalk.

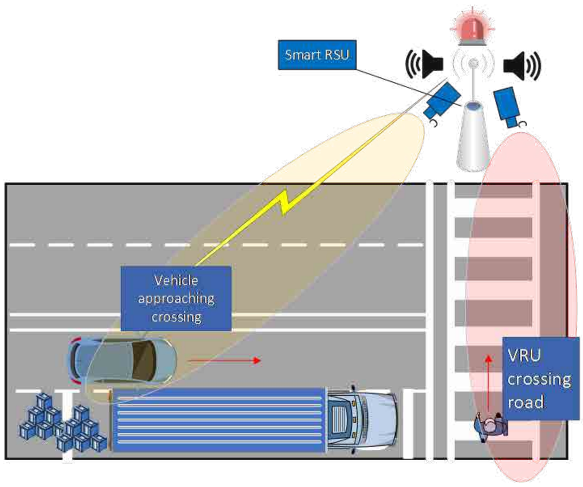


Figure A.2: Solution for case shown in Figure A.1, with presence of RSU at crosswalk for detecting and notifying vehicle about VRU crossing the road.

UC1.1.2: Occluded VRU in crosswalk with V2P/P2V, P2I/I2P, P2N capability (V2I, V2N available)

As an alternative to the extreme situation of Figure A.1, here in Figure A.3, a VRU is crossing the road and has a V2P/P2V-enabled device with PC5 or Uu compatibility. In this case, it is possible to raise the vehicle's awareness of a VRU's presence, as shown in Figure A.4., where the VRU and approaching vehicle may be periodically exchanging safety broadcast messages (such as PSM, VAM, CAM) so that both VRU and vehicle are aware of each other in the surrounding environment. Such awareness is critical to improving the vehicle's response time, to avoid any potential collision with the occluded VRU by taking the necessary course of action; deceleration and/or braking. The VRU meanwhile may choose to stop and wait until the vehicle has yielded or passed by.

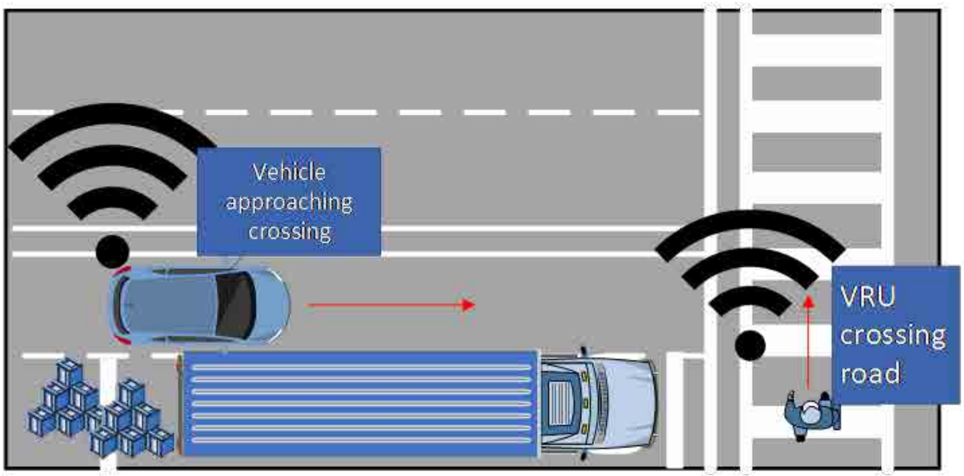


Figure A.3: Occluded VRU crossing road with approaching vehicle. VRU is communications enabled (V2P/P2V), capable possessing PC5 or Uu compatible device.

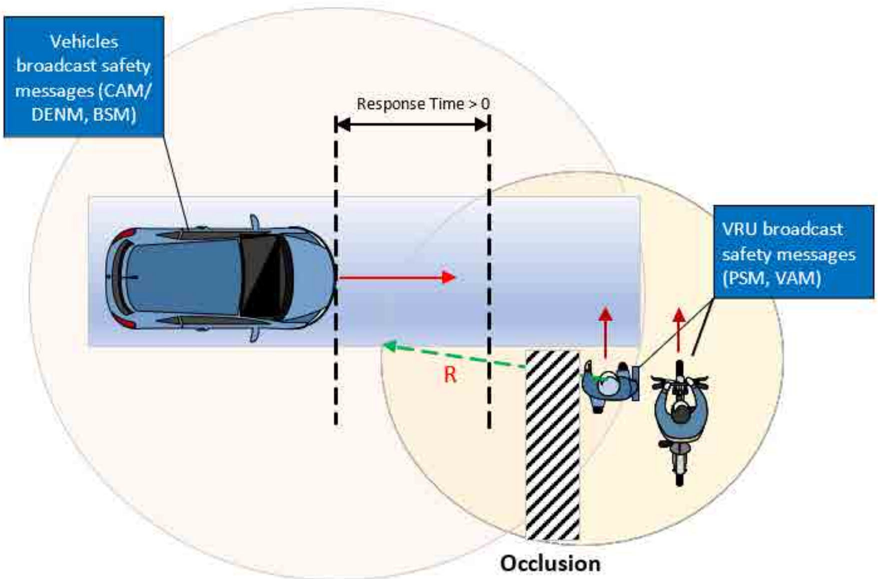


Figure A.4: Messaging mechanisms between VRU and approaching vehicle leading to an increase in the response time that the vehicle takes to avoid a collision (such as deceleration, braking).

UC Category 1.2: Pedestrian in crosswalk at intersection

UC1.2.1: Occluded VRU at intersection without V2P/P2V, P2I/I2P (V2I, V2N available)

Similar to the UC1.1 above, the situation of a non-equipped VRU at an intersection as shown in Figure A.5 (a) may arise. As in the situation described before, the installation of a smart RSU with various sensor capabilities can detect the presence of a VRU and inform the approaching vehicle to take avoidance action.

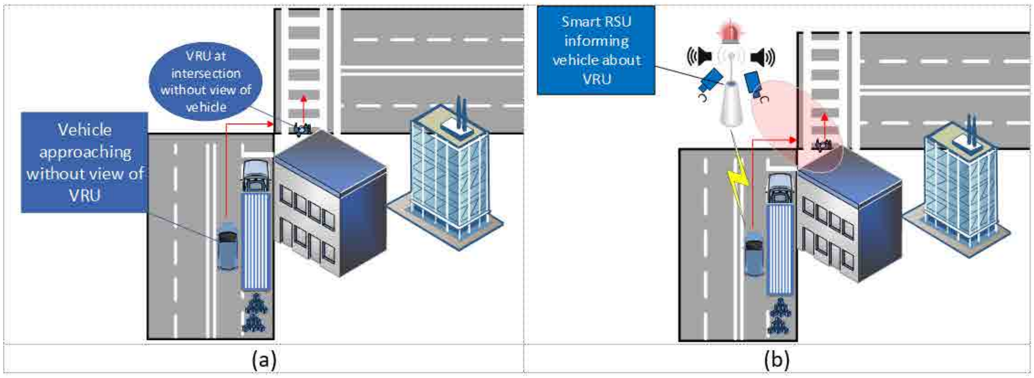


Figure A.5: (a) Non-equipped VRU (no V2P/P2V, P2I/I2P capability) crossing intersection with an unaware approaching vehicle, (b) smart RSU at the intersection to communicate its awareness of VRU to the vehicle.

UC1.2.2: Occluded VRU at intersection with V2P/P2V, P2I/I2P capability (V2I, V2N available)

As shown in Figure A.6, an alternative situation to UC1.2.1, if the VRU happens to be equipped with a communications-enabled PC5 or Uu interface, then it can exchange a safety message with the vehicle and thus alert the driver (or sensors) of the VRU's presence, leading to a proactive action/response (braking, deceleration) that increases the safe distance. Meanwhile the VRU may come to a complete stop and wait until the vehicle has yielded or passed by.

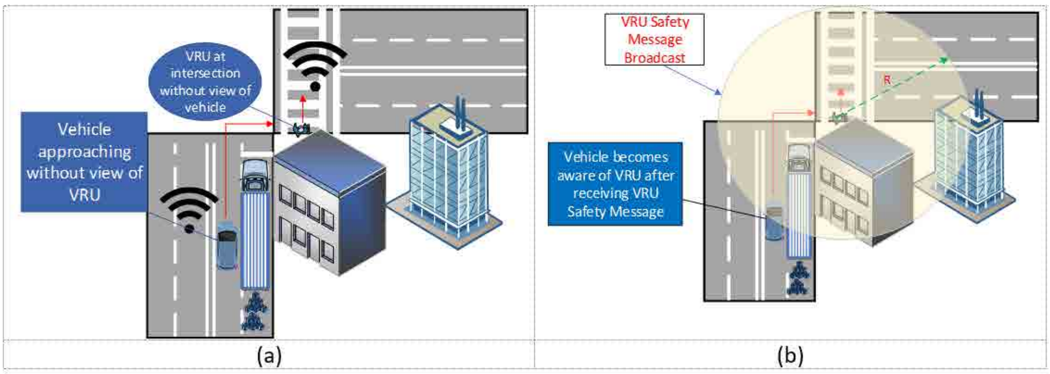


Figure A.6: (a) VRU with V2P/P2V capability crossing intersection with an occluded approaching vehicle, (b) VRU broadcasting safety message leading to the vehicle's awareness of the VRU's presence.

UC Category 1.3: VRU in high-risk zones with or without communications capability but near smart RSU (static/mobile)

UC1.3.1: Static or portable smart RSU for road workers without communications capability

One example of VRUs in a high risk zone is road construction workers who may not necessarily be communications capable or indeed may not be carrying the device with them. This is a typical example use case where there should be a nearby RSU to protect the VRUs. As shown in Figure A.7 (a), a smart RSU with sensor-based perception capability can simultaneously be aware of the approaching vehicles and the constructor workers' activities, and is thus crucial to notifying the approaching vehicle (comm-based or visual-based) as well as to the road workers (via sirens and flashing lights).

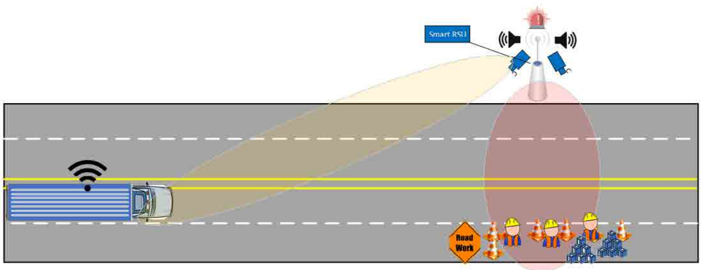


Figure A.7 (a): Static RSU deployed at a high risk VRU zone with road workers perceiving both approaching vehicle and the road workers.

UC1.3.2: Mobile or portable smart RSU for road workers with communications capability

As an extension of the case shown in Figure A.7 (a), the road workers' parked vehicle or construction equipment may serve as a mobile RSU. Here, the term 'mobile' means not fixed in place or being able to change location based on where the road workers are deployed. As such, the mobile RSU can share awareness messages with the approaching vehicles and thus increase the vehicle's VRU awareness, and vice versa.

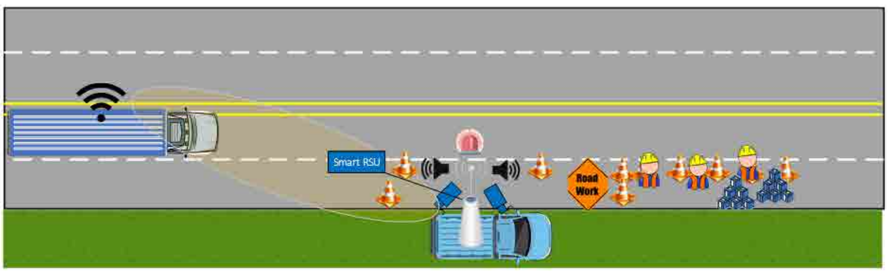


Figure A.7 (b): Mobile RSU truck for road workers perceiving the approaching vehicle (may or may not be comm capable).

UC1.3.3: Mobile RSU on school bus

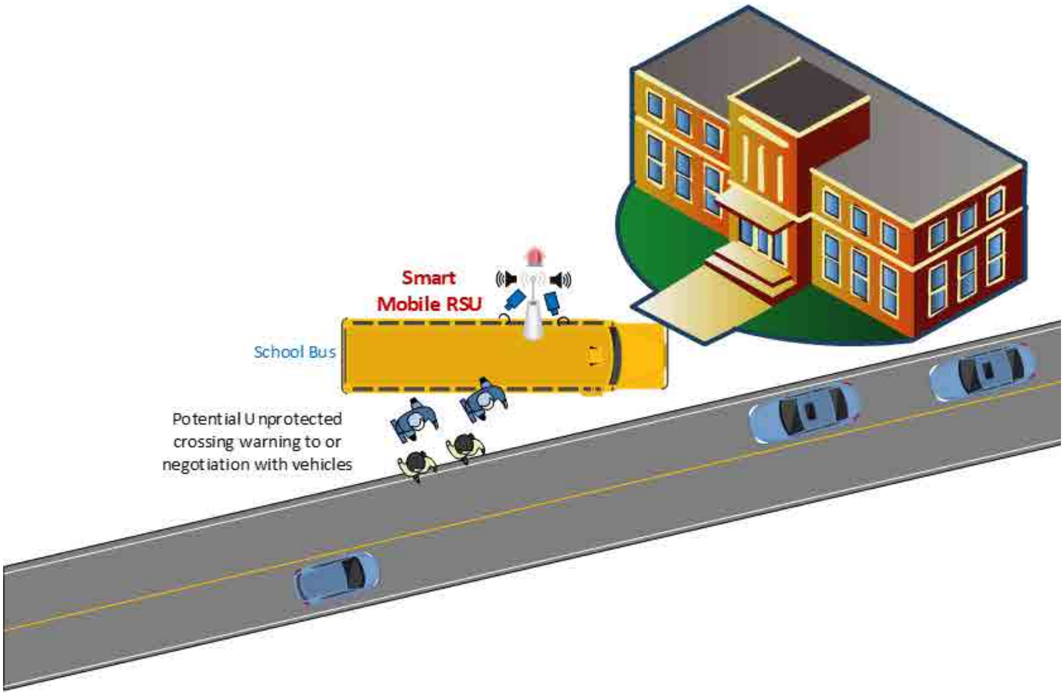


Figure A.8: Mobile RSU on school bus

Another example scenario where a mobile RSU is mounted on a school bus is shown in Figure A.8. Such a mobile RSU may be authorised by the city, county or police to send VAM/PSM-type messages on behalf of the children who may not be equipped with communications devices. In such cases, the children's movement profile can be included in the broadcast message periodically including the number of children as well as their speed, direction, heading, etc. Moreover, this case may also be used for raising awareness of the children or adults near the school bus by activating a siren or flashing lights in the event of an emergency situation (when the vehicle is fast-approaching the pedestrians).

Scenario 3 Example use cases

UC Category 3.1: Pedestrian/Motorists collision alert
UC3.1.1: VRUs in busy parking lot or garage

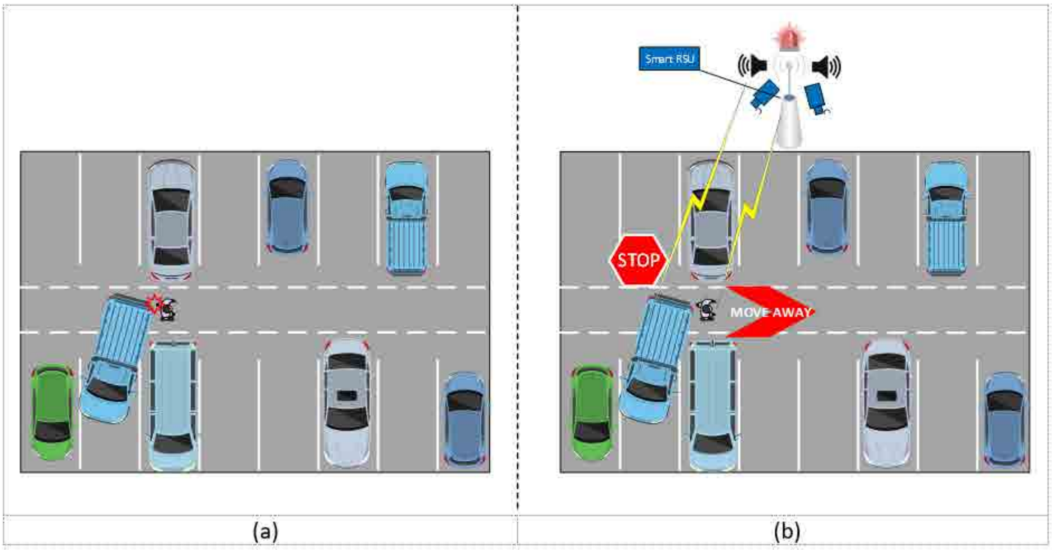


Figure A.9: (a) Backing car colliding with a VRU passing by (b) RSU-assisted 'emergency brake' notification sent to vehicle leading to braking of the car and 'move-away' message and/or siren/flashing lights resulting in VRU moving away in time to avoid contact.

On average, more than 50,000 crashes occur in parking lots and garages annually, resulting in 500 or more deaths and more than 60,000 injuries[5]. In a parking lot, pedestrians may be distracted by their smartphones thus unaware if a car with a distracted driver suddenly pulls out from parking lot, leading to a collision, as shown in Figure A.9 (a). In another situation, this time in an indoor carpark or garage, pedestrians may also be blocked from view by walls and pillars, which exacerbates the usual risk to VRUs in compact carparks.

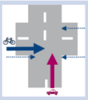
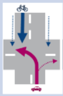
One potential solution to avoid a collision in the above situation is to devise a notification mechanism for the approaching vehicles and dangerous situation. For the example shown in Figure A.9 (b), in the parking lot an RSU may be deployed as a message exchange (i.e. when VRUs are equipped with a comms device) or non-message-based notification (when not carrying a device) to avoid a potential collision, thus helping the VRU move away from the approaching vehicle's path. Also, the vehicle may receive notification from the RSU which triggers its emergency brakes.

[5] https://www.ehstoday.com/safety/article/21917821/black-friday-alert-driving-through-a-parking-lot-is-still-driving

UC Category 3.2 and 3.3: Cyclist/Motorist collision alert including option to send alerts to smartphone mounted on eBike

As mentioned in the introduction, cyclist fatalities in traffic accidents are still numerous. Analysis of accident statistics reveals that intersections are the most dangerous situations.

Based on German accident research data, most accidents with physical injury between cars and bicycles happen in the following scenarios:

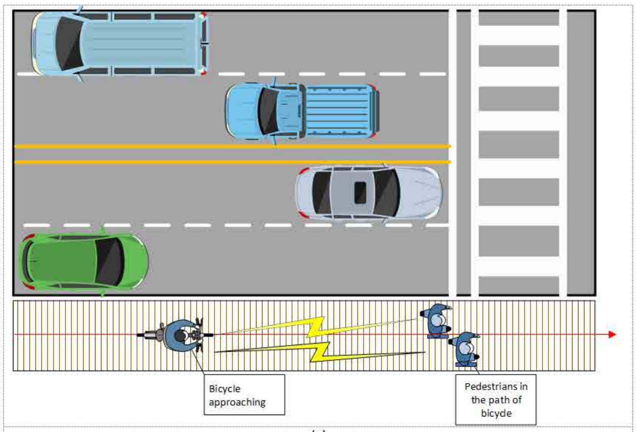
Name	Crossing cyclist	Oncoming cyclist	Lateral riding cyclist	Upfront riding cyclist
Description				
Actors	• Cyclist • Driver • Visual obstructions (e.g. buildings) • Other traffic participants	• Cyclist • Driver • Other traffic participants	• Cyclist • Driver • Visual obstructions (e.g. vehicle design) • Other traffic participants	• Cyclist • Driver
Includes	• Cross road	• Turning	• Start of cycling	• Blind spot for cyclists • Lane change • Start of cycling • Sudden braking by cyclist
Accident frequency*	↑ (36%)	↖ (10%)	↖ (6%)	↓ (1%)
Cyclist fears**	-	Top 1 (88%)		Top 2 (83%)
Further use-cases (w/ minor accident frequency)	• Parking: Vehicle exists parking lot alongside the road • Dooring: Vehicle driver opens door after parking alongside the road (Top 3 of cyclist fears rated with 69%)			

Sources: *Traffic accidents with injured participants weighted for Germany based on GIDAS in 2016 ‖ ** Forsa survey by CosmosDirekt in 2017

Both bicycle-to-car communication and infrastructure-based communication are expected to have the potential to massively decrease the occurrence or severity of these kinds of accidents, by increasing visibility (in bad weather conditions or when obscured by obstacles) and by communicating additional information, such as VRU position, type, rider intention/path prediction, stability, and reaction.

Alerts are considered helpful in both directions, to the motorist and to the cyclist (e.g. to his/her smartphone mounted on the bike).

UC Category 3.4: VRU cCollision aAlert



(a)

Figure A.10 (a): Pedestrian VRUs in the path of cyclist VRUs may be unaware of the approaching bicycle but may be directly able to exchange VAM.

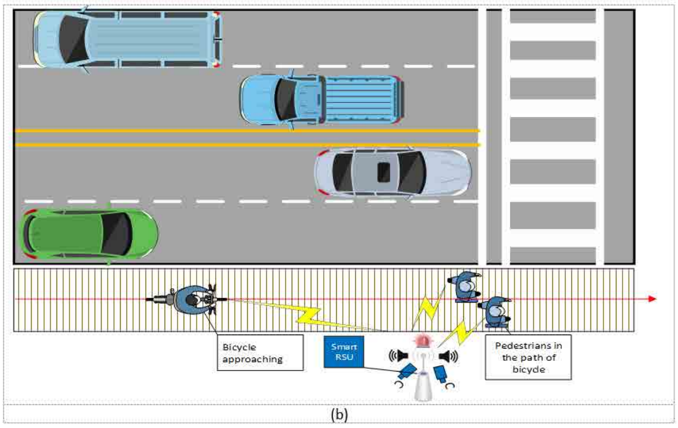


Figure A.10 (b): Pedestrian VRUs in the path of cyclist VRUs may be unaware of the approaching bicycle but may receive messages from RSU.

A potential VRU-to-VRU collision is shown here when a pedestrian VRU is in the path of an approaching cyclist VRU. In these cases, the cyclist can ring the bike's bell but it may not be audible enough. Moreover, in the event that the cyclist is distracted, the chance of the bicycle hitting the pedestrian is higher. This could be avoided:

i. If the VRUs are equipped with communications devices, they can directly communicate with each other, as shown in Figure A.10 (a)

ii. If the VRUs are equipped with communications devices but cannot directly communicate, the RSU may still be able to send notification messages to both the bicyclists and pedestrians, to alert them of a potential collision, as shown in Figure A.10 (b)

iii. If the VRUs are not equipped with communications devices, they may still be alerted by the smart RSU siren and/or flashing lights (not shown in the figure)

UC Category 3.5: High-density VRUs in urban crosswalk

Figure A.10 (b): Pedestrian VRUs in the path of cyclist VRUs may be unaware of the approaching bicycle but may receive messages from RSU.

Figure A.11 (a): High-density VRU in urban intersection[6].

In densely populated cities, the number of VRUs circulating in a given area can become very high, as shown in Figure A.11 (a). In such cases, there will be extremely high messaging overhead (VRU-related PSMs or VAMs) thus leading to network congestion and message loss at the access layer. To alleviate the challenge, grouping VRUs into clusters managed by the cluster-leader – which could be, for example, an RSU, as shown in Figure A.11 (b) – and then exchanging PSMs or VAMs only via the cluster leader, could be done. This may result in a significant reduction of network congestion and message loss. In addition, to reduce message congestion, pre-defined VRU common areas (e.g. zebra crossing in Fig. A.11(a)) could be treated as a single warning area, rather than as a collection of VRUs sending messages, and messages sent only from VRUs not in those areas.

[6] www.cnn.com

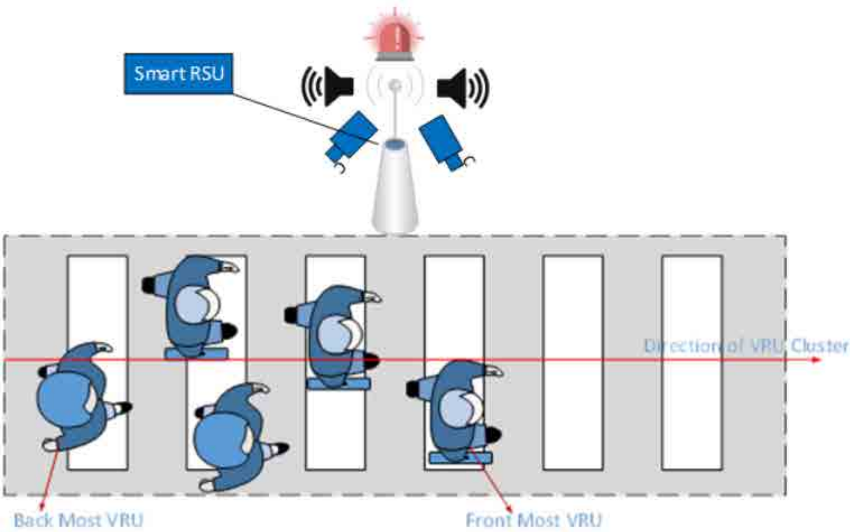


Figure A.11 (b): Example VRU cluster showing 'front-most' and 'back-most' VRU locations with respect to direction of the VRU cluster movement. Such cluster formation and management is done by RSU.

Annex B: Acronyms

AI	Artificial Intelligence
AV	Automated Vehicle
BSM	Basic Safety Message
CAM	Cooperative Awareness Message
CPM	Collective Perception Message
DENM	Decentralised Environmental Notification Message
ETSI	European Telecommunications Standards Institute
GNSS	Global Navigation Satellite Service
MEC	Mobile Edge Computing
MCM	Manoeuvre Coordination Message
MNO	Mobile Network Operator
OEM	Original Equipment Manufacturer
PSM	Personal Safety Message
RSU	Roadside Unit
RTK	Real-time Kinematic
SAE	Society of Automotive Engineers
SDO	Standards Developing Organization
VAM	VRU Awareness Message
VRU	Vulnerable Road User
V2I	Vehicle-to-Infrastructure
V2N	Vehicle-to-Network
V2P	Vehicle-to-Pedestrian

5GAA Automotive Association