Vehicular Communications Definition ~~and~~, Overview, and Challenges Prepared for the Task Force on Vehicular Communications (TF on VC)

This document provides an overview of definition, structure, ~~use-cases~~value, uses, and challenges for vehicular communications. ~~Addressing~~Achieving the potential benefits and challenges of vehicular communications requires a comprehensive approach that needs collaboration between industry stakeholders, researchers, and policymakers to protect such communications capabilities.

I. Vehicular Communications Definition

Vehicular communications ~~refer to~~is the exchange of information ~~and data~~ between vehicles, as well as between vehicles and their surroundings. In this document, the word 'information' includes data.

This information exchange involves the use of various wired and wireless communications technologies. Vehicles share information ~~and data~~ with other vehicles, road users, roadside units, traffic control and management systems, and other road transport infrastructure. Service providers also play a role in this interconnected network.

II. Vehicular Communications Structure

Vehicular communications can be broadly categorised into ~~w~~:

- Wired and wireless ~~types~~.
- One to one and one to many (broadcast).
- One way and both ways.

Current wired communications in vehicles primarily involves information ~~and data~~ exchange through the OBD port, USB ports, and the vehicle battery charging equipment. While these technologies currently utilise wired connections, they might also incorporate wireless approaches in the future.

Wireless communications technologies in vehicles, listed below in approximate range order, include, but are not limited to:

a. Proximity communications, such as access control technology using radio-frequency identification (RFID) and near-field communication (NFC) for short-range identification ~~and data~~ exchange.

b. Close-range communications, such as Bluetooth, ~~Ultra-Wide-Band~~ultra-wide-band (UWB), and infrared for connecting ~~devices~~equipment within a few meters.

c. Intermediate-range communications ~~Radio Local Area Networks~~radio local area networks (RLAN), such as Wireless LAN (802.11) for ~~data~~information transfer over a wider range than close-range communications technologies.

d. Direct, trusted short-range communications between vehicles, ~~smart~~ road transport infrastructure, and vulnerable road users (V2X). This includes vehicle-to-vehicle multi-hop, for example during emergencies when the mobile network is not available.

e. Cellular network intermediate range communications providing voice, text messages, and mobile internet access.

f. Radio broadcasting wide-range communications, such as digital audio broadcasting (DAB+).

g. Satellite ultra-wide-range communications, such as GNSS, satellite radio, and satellite internet.

III. Vehicular Communications Value

Vehicular communications has significant potential to improve road safety, reduce transport costs, enhance transport efficiency, elevate the overall transport experience, and minimise the environmental impact of transportation.

By enabling information exchange between vehicles, other road users, and road transport infrastructure components, vehicular communications ~~facilitate the~~facilitates sharing ~~of~~ critical ~~data~~information. This includes driver's condition, vehicle speed, location, acceleration, braking, signalling, road conditions, and information about other road users. Additionally, vehicles and drivers can receive valuable information from the road transport infrastructure and service providers.

IV. Vehicular Communications Uses

This section provides general information on common uses of vehicular communications. For clarity for diverse readers, some terms appear in multiple application descriptions below, as common terminology does not always have precise boundaries. Vehicular communications can be used for various applications, including but not limited to:

1. Safety and Emergency

a. *Safety information for vehicle operation*: Vehicular communications enables in-vehicle systems to provide timely notifications and warnings to drivers~~/~~ and vehicle occupants about potential hazards. These notifications can be based on information received from road users including other vehicles, road transport infrastructure (e.g., electronic signs), and service providers (e.g., weather services). Examples include warnings about wrong-way driving, traffic congestion, and road hazards.

b. *Safety information for road transport infrastructure operators and service providers:* Vehicular communications allows vehicles to transmit real-time ~~data to~~information to road transport infrastructure operators and service providers. This ~~data~~real-time information can include detection of wrong-way driving, traffic congestion, and road hazards, which can be used to improve drivers' response times, service operators' information, and overall traffic management.

c. *Emergency services:* Vehicular communications can enable faster emergency response by providing real-time information about crashes, road hazards, and other incidents. ~~Additionally, Accident Emergency Call Systems can further support improved responses.~~ In the future, vehicular communications could allow emergency services to remotely control ADS-equipped vehicles ~~with ADS products active~~ that do not have a fallback user.

d. *Automated Emergency Call*: In-vehicle eCall can support improved emergency responses.

~~d.~~e. *Collision warning and avoidance:* Vehicular communications can help vehicles and drivers detect and avoid potential collisions by sharing information about their locations, speeds, and trajectories. This information can be used as an additional input for Advanced Emergency Braking Systems (AEBS), further enhancing collision prevention capabilities. Vehicular communications can also report various types of potential risks, allowing for a more comprehensive risk assessment.

f. *Protecting vulnerable road users (VRU):* ~~Vehicles~~ Vehicular communications allows vehicles equipped with VRU detection ~~can~~ capabilities to share th~~is~~e information that they identify with surrounding vehicles and the road transport infrastructure to implement VRU protection strategies. Communications equipment, carried by pedestrians, cyclists, and motorcyclists can alert vehicles to their presence.

Similar to the collision warning and avoidance application, this information can be used as an additional input for AEBS and other safety ~~functions. Devices, carried by pedestrians, cyclists,~~

~~and motorcyclists can alert vehicles to their presence and vice versa~~features. Safety is improved when the road transport infrastructure detects VRUs as well as unconnected vehicles and sends the information to surrounding traffic participants in real time.

~~e.~~g. *Emergency alerts:* Vehicular communications can deliver alerts about various emergencies, including tsunamis, typhoons, and fires. This information can be crucial for supporting evacuations, including for ADS-equipped vehicles~~ with ADS~~ that do not have a fallback user.

In situations where the primary communications infrastructure is disrupted, vehicle-to-vehicle communications can relay information through a multi-hop approach across the road network, enabling comprehensive warnings to reach vehicle occupants in areas with communications infrastructure outages. Similarly, vehicles ~~with connectivity~~in areas with communications infrastructure outages can use this multi-hop approach to deliver critical information to ~~those in areas with communications outages~~road transport operators.

h. In-*vehicle alerts*: Vehicular communications can allow road transport infrastructure and other vehicles to send alerts to vehicles for their drivers to be informed about special situations.

2. Traffic Management

a. *Road transport infrastructure management:* Vehicular communications can assist road operators to optimise traffic flow, reduce congestion, and improve overall transport efficiency. Vehicles can provide real-time ~~data~~information on their location, movement, and intended manoeuvres (e.g., lane changes, upcoming turns) to support road transport infrastructure improvements. Additionally, vehicles can report local hazards such as road surface issues and areas with frequent braking~~/~~ or electronic stability control activation, enabling targeted maintenance and repair of the road transport infrastructure.

b. *Road works:* Vehicular communications can inform drivers about road works, including detours, revised speed limits, and potential delays. Timely warnings can reduce accidents and improve safety for both drivers and road workers.

c. *Optimised Traffic signal Systems:* ~~Traffic~~Vehicular communications allows traffic signal controllers ~~can~~to transmit their signal phase and timing (SPaT) ~~data~~information, along with intersection topology, to vehicles. This ~~allows~~information can enable vehicles to optimise speed for energy efficiency and achieve green-light-optimal speeds. Additionally, vehicles can provide anonymous traffic ~~data~~information for dynamic signal timing adjustments. In the future, vehicular communications could replace inductive-loop detectors and support red-light violation prevention. Vehicular communications can enable emergency and public transport vehicles to request priority at traffic signals, facilitating a swift change to green.

d. *Real-time Traffic Updates:* ~~Drivers can~~Vehicular communications allows drivers to receive information on road network status from road transport infrastructure operators, service providers, and other vehicles.

e. *Event management*: Vehicular communications can provide information about road closures, detours, and other routing changes during special traffic situations such as sporting events, parades, protests, and VIP travel. This can help drivers plan their routes and avoid congested areas.

3. Automated Driving Support

a. *Automated driving support:* Vehicular communications can support, and potentially accelerate, the deployment of automated driving systems (ADS). By utilising ~~data~~information received as an additional input, ADS ~~products~~features might improve their performance within their operational design domain (ODD) and even extend their ODD. This ~~data~~information, explicit and supplementary to the vehicles' own sensor interpretations, allows for earlier and smoother automated actions.

Road transport infrastructure can provide ADS-equipped vehicles with crucial, real-time updates, including:

i) Changed road conditions such as special traffic situations, roadworks, and accident locations.

ii) Information about challenging topological situations such as tunnel entries, highway entries and exits, and complex intersections.

Emergency vehicles can use vehicular communications to transmit their location, speed, and trajectory, ensuring earlier awareness by ADS ~~products~~features of these emergency vehicles and facilitating safe interaction with them.

When approaching their ODD limits, vehicles can announce their status, enabling remote human control and automated guidance from the road transport infrastructure.

Additionally, vehic~~e~~ular communications can facilitate valet parking services.

b. *Cooperative automated driving:* Vehicular communications fosters collaboration between vehicles to enhance safety and efficiency. This includes functionalities such as platooning and coordinating intersection entry for ADS-equipped vehicles. Vehicular communications also facilitates challenging manoeuvres such as lane changing and merging. Vehicular communications can provide earlier awareness of emergency and other prioritised vehicles (see the Traffic Management section above).

4. In-vehicle Experience and Convenience

a. *Infotainment and convenience:* Vehicular communications can enhance ~~the~~driver and occupants in~~-~~-vehicle experience by delivering multimedia content, internet access, and personalised services. This includes providing real-time information such as location of rest areas for passenger vehicles; availability of overnight parking for lorries; status of facilities for campers; location, availability, and pricing of battery charge points and petrol stations; and availability of parking spaces. Additionally, reservations can be made for parking, battery charging, and other services such as dining and lodging.

b. *Remote activations*: Vehicular communications can be used for remote control of vehicle actions such as door locking~~/~~ and unlocking, ~~starting~~ climate control settings, managing battery charging, opening the trunk for delivery~~/~~ and pick, and controlling home and destination devices such as home appliances and garage doors. Vehicular communications can support vehicle sharing and vehicle rental services.

c. *Charging support:* Vehicular communications can provide information from the grid to control battery charging times and facilitate two-way ~~energy~~electricity flows, enabling electric vehicles to power the grid or a user's home and devices. Such communications could play a role in supporting electrical energy storage and electric grid balancing activities.

d. *Payment services*: Vehicular communications can be used for in~~-~~-vehicle purchases and payments for tolls, road pricing, parking, fuelling, battery charging, and drive-thru ~~services~~purchases.

5. Vehicle Management and Maintenance

a. *Geofencing*: Vehicular communications can alert vehicle owners and managers when a vehicle exceeds pre-set geographic limits and speed. Vehicular communications can transmit information relevant to vehicle operations within those limits, such as ADS ODDs and traffic rules.

b. *Vehicle maintenance*: Vehicular communications allows updating vehicle software, firmware, and map data; accessing real-time ~~data~~information on the health and performance of vehicle components; and transmitting the maintenance ~~issues detected by~~status of vehicle ~~systems~~components to vehicle owners and vehicle manufacturers.

c. *ISMR:* Vehicular communications will enable vehicle manufacturers to provide in~~-~~-service monitoring and reporting (ISMR) to vehicle-regulatory authorities about their vehicles.

6. Other Services

a. *Police authorities*: Vehicular communications can allow police officers to retrieve information from vehicles, including whether an ADS ~~product~~feature is active.

b. *Remote authority vehicle control*: Vehicular communications can remotely slow, stop, and disable a vehicle with authorisation of police authorities.

c. *Stolen vehicle tracking*: Vehicular communications can allow police authorities to track a stolen vehicle.

~~b.~~d. *Public transport*: Vehicular communications can provide waiting passengers with information about public transport vehicle arrival times and service variations~~, as well as~~. Vehicular communications can assist ~~with~~ public ~~service~~transport fleet operations and management.

~~c.~~e. *Fleet management*: ~~Fleet operators can use vehicular~~Vehicular communications can allow fleet operators to collect information from their managed vehicles and control their managed vehicles' operations.

~~d.~~f. *Freight movement*: Vehicular communications can track freight movement, improve freight transport efficiency, and enable lorries to transmit weight and electronic manifests to relevant authorities, such as traffic management centres and customs authorities.

V. ~~Potential Challenges for~~ Vehicular Communications Challenges

Although there are many advantages to vehicular communications, it is important to be aware of potential challenges with~~en~~ using vehicular communications. ~~Interpretation of these~~These challenges and the required countermeasures vary across uses, countries, and regions.

a. *Cybersecurity ~~Risks~~*: Communications are sensitive to cybersecurity threats, including hacking attempts and unauthorised access. Malicious actors will attempt to exploit vulnerabilities in the communications protocols and compromise the integrity of ~~data~~information exchanged between vehicles and external systems. ~~The automotive industry has~~There is risk of a terrorist group taking remote control of ~~-~~connected vehicles including ADS vehicles. Vehicle manufacturers have implemented Cybersecurity Management Systems (CSMS) to secure vehicles and the vehicle's data.

b. *Privacy ~~Concerns~~*: Exchange of information among vehicles and road transport infrastructure can raise privacy ~~concerns~~issues, especially with relation to the personally identifiable information (PII) of ~~the~~ vehicle occupants. Concerns have been raised regarding the potential risk of unauthorised tracking and profiling of individuals. Authentication to access ~~the data~~vehicle information, including anonymisation and pseudonymi~~z~~sation of the ~~data~~information, are mitigations to reduce the risks involved. In general, access and processing of personal ~~data~~information is allowed with the driver´s consent, when necessity to protect the driver´s or another person´s vital interests, and base~~s~~d on public interest or compliance with legal obligations.

c. ~~*Interference*: Interference~~*Communications interference*: Communications interference, direct or out of band, can disrupt or limit ~~communications~~ information transfer between vehicles and between vehicles and the communications infrastructure. International (ITU) regulations on ~~Radio Spectrum~~radio spectrum use mitigate the risk of communications interference.

d. *False Information Propagation*: Malicious entities will attempt to disseminate false information~~ within communications networks.~~. This misinformation might confuse drivers~~/~~ and vehicles and might pose risks to road safety. Verifying the authenticity of ~~data~~information is crucial to prevent the spread of false information. A critical element for some communications technologies, particularly direct communications and cellular networks, is sender verification.

e. *Vehicle life*: In many countries, vehicle service life is more than 20 years. Vehicular-communications life and in-vehicle communications equipment life must be made to match vehicle service life so that vehicular communications is not lost as older vehicles move to less-advantaged owners.

f. *Damage to Communications Infrastructure*: ~~Damage to communications infrastructure caused by physical~~Physical attacks or environmental effects might cause roadside units and base stations to malfunction and disrupt the communications ~~network.~~ infrastructure.

g. *Damage to in-vehicle communications equipment*: Physical or remote damage to in-vehicle communications equipment might cause safety issue. In addition, compromised in-vehicle communications equipment might cause erroneous transmissions that impact the communications infrastructure.

h. *Delays*: All communications is subject to delays from equipment processing time, protocol set-up time, spectrum bandwidth for information, etc. Vehicular communications applications must ensure that the delays for the selected communications method match the acceptable data-transmission delays for the application, taking into account the maximum driving speed that is supported.

i. *Timeliness*: Safety-related vehicular communications should have priority in the communications infrastructure.

j. *Coverage*: Communications infrastructure can have areas of no coverage (dead spots). Vehicular communications needs to avoid coverage limitations.

k. *Availability*: Communications infrastructure can have service outages. Vehicular communications needs to avoid interruptions by communications infrastructure outages, both local and wide area.

l. *Backup*: Vehicles must be built to properly handle all possible communications issues.

m. *Costs*: Communications infrastructure and in-vehicle communication equipment might be expensive. Cost for vehicular communications must be controlled. Safety-related vehicular communications should not incur usage costs to vehicle owners, vehicle occupants, and road users.

n. *Penetration*. Many vehicular communications applications only work well if there is a significant number of vehicles with the vehicular communications equipment. Ways must be found to create substantial, fast rollouts of in-vehicle communications capabilities.

~~e.~~o. *VRU communications*. The communications capabilities of VRUs are not controlled by vehicle communications equipment manufacturers. Ways must be found to equip VRUs with equipment capable of reliably communicating to equipped vehicles.