

Vehicular Communications Definition, Overview, Opportunities, and Considerations

Prepared for the Task Force on Vehicular Communications (TF on VC)

This document provides an overview of ~~the~~vehicular communications including its definition, ~~structure~~types, value, uses, opportunities, and considerations ~~for vehicular communications~~. Achieving the potential benefits of vehicular communications requires a comprehensive approach involving collaboration between industry stakeholders, researchers, and policymakers to deploy and protect such communications capabilities.

I. Vehicular Communications Definition

Vehicular communications ~~is~~concerns the exchange of information between vehicles, as well as between vehicles and their surroundings. In this document, the word ‘information’ includes data. In this document, references to ‘vehicle’ includes devices connected to vehicle systems by vehicle occupants, but not communications devices used in the vehicle by vehicle occupants, even if such devices are using the vehicle’s hot spot.

This information exchange involves the use of various wired and wireless communications technologies. Vehicles exchange information with other vehicles, road users, ~~and~~ road transport infrastructure components (roadside units, electronic signs, traffic control and management systems, ~~and other road transport infrastructure~~), and cloud-based operations. Service providers also play a role in this interconnected network.

II. Vehicular Communications Structure Types

Summary information about types of communications is provided in this section to provide a general background about possible vehicular communications. Vehicular communications can be broadly categorised into:

- Wired and wireless.
- ~~One to one~~Unicast, multicast, and one to many (broadcast).
- Unidirectional and bidirectional.

Current wired communications in vehicles primarily involves information 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 communications approaches in the future.

Wireless~~Individual vehicles only have a few, if any, wireless~~ communications technologies ~~in vehicles~~. The wireless communications technologies, listed below in approximate range order, which might appear in a vehicle now or in the future, 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 data exchange.
- b. Close-range communications, such as Bluetooth, ultra-wide-band (UWB), and infrared for connecting equipment within a few metres.
- c. Intermediate-range communications radio local area networks (RLAN), such as Wireless LAN (802.11) for information transfer over a wider range than close-range communications technologies.
- d. Direct, trusted short-range communications ~~(V2X)~~ between vehicles, ~~(V2V)~~, road transport infrastructure components, ~~(V2I)~~, and vulnerable road users (VRU) ~~(V2P)~~. This

~~includes communications technology mainly targets delay-sensitive (or time-critical) applications, using approaches such as 3GPP Cellular-V2X PC5 mode and IEEE 802.11p. This communications technology can be implemented by single hop and vehicle-to-vehicle multi-hop, both for dedicated applications and for example, during emergencies when the mobile data transmission.~~

- ~~d. Cellular network is unavailable.~~
- 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 / Opportunities

Vehicular communications has significant potential to:

- Improve road safety,
- Reduce road transport costs,
- Enhance road transport efficiency,
- Improve the overall road transport experience, and minimise.
- Reduce the environmental impact of road transport.

By enabling information exchange between vehicles, other road users, ~~and~~ road transport infrastructure components, and cloud-based operations, vehicular communications facilitates sharing critical information. This includes ~~driver's health condition, whether the driver is paying attention, driver's use of ADS,~~

- State of vehicle such as:
 - + Vehicle speed,
 - + Vehicle location,
 - + Vehicle acceleration and braking,
 - + Vehicle signalling,~~road.~~
- State of driver such as:
 - + Health condition.
 - + Paying attention.
 - + Use of ADS.
- Road conditions,~~and information.~~
- Information about detected weather conditions.
- Information about other road users.

In addition, vehicles and their occupants 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 elements appear in multiple use-case descriptions below, as common terminology does not always have precise boundaries. In an attempt to help understanding,

the use-case descriptions are grouped into sections according to the type of application. Vehicular communications ~~can be used for various~~has many use cases, including but not limited to:

1. Safety and Emergency

- a. *Safety information for vehicle operation:* Vehicular communications enable 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 vehicles, road transport infrastructure components, service providers (e.g., weather services), and potentially from road users in the future. Examples include warnings about wrong-way driving, traffic congestion, and road hazards.
- b. *Safety information for other road-transport operations:* Vehicular communications enables vehicles to transmit real-time information to road transport infrastructure operators and service providers. This 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 a faster response of emergency response vehicles by providing real-time information about crashes, road hazards, and other incidents. In the future, ~~vehicular communications could enable~~ emergency ~~vehicles to services~~ could remotely control automated driving systems (ADS)-equipped vehicles that do not have a fallback user to clear a route for emergency vehicles. Also, see Optimised traffic signal systems use case below.
- d. *Automated emergency call:* ~~In systems (eCall/AECS): Vehicular communications enables~~ in-vehicle eCall/AECS systems that can support improved automatically detect the occurrence of a crash to initiate a call to emergency services, providing vital information such as location, crash severity, and vehicle data. This process can significantly reduce the emergency response times and improve the effectiveness of the emergency response.
- e. *Collision warning and avoidance:* Vehicular communications can help drivers and vehicles systems detect and avoid potential collisions by sharing reliable, highly accurate, real-time information about their locations, speeds, and trajectories. This information can be used as additional input for advanced emergency braking systems (AEBS), further enhancing collision prevention capabilities.

Vehicular communications can also report various types of potential hazards, allowing for a more comprehensive risk assessment. Safety is further improved when road transport infrastructure components detect unconnected vehicles and send the information to surrounding traffic participants in real time and with high accuracy.

- f. *VRU protection:* Vehicular communications enables vehicles equipped with VRU detection ~~capabilities~~systems to share the information that they identify with surrounding vehicles and road transport infrastructure components. This information can then be used to implement VRU protection strategies. ~~Communications~~Additionally, communications equipment in the possession of pedestrians, cyclists, and motorcyclists can alert drivers and vehicles system about their presence.

Similar to the collision warning and avoidance use case, this information – if reliable, relevantly relevant, reasonably accurate, and real-time – can be used as an additional input for AEBS and other safety systems. Safety is further improved when road transport infrastructure components detect VRUs ~~as well as unconnected vehicles~~ and send the information to surrounding traffic participants in real time and with high accuracy.

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

In situations where the primary communications infrastructure is disrupted, future vehicle-to-vehicle communications ~~can~~will be able to relay information across the road network using a multi-hop approach, ~~enabling~~. This will allow for comprehensive warnings to reach vehicle occupants even in areas where there are communications infrastructure outages. Similarly, vehicles in areas where there are communications infrastructure outages can use such a multi-hop approach to deliver critical information to road transport operators.

- h. *In-vehicle alerts*: Vehicular communications can enable road transport infrastructure components and other vehicles to send alerts to vehicles ~~for their~~, informing drivers and ADS-equipped vehicles ~~to be informed~~ of special situations ahead on the road. Such situations include road closures and rerouting, materials spills, and accidents.

2. Traffic Management

- a. *Road transport infrastructure management*: Vehicular communications can assist road transport operators to optimise traffic flow, reduce congestion, and improve overall road transport efficiency. Vehicles can provide real-time information on their location, movement, and intended manoeuvres (e.g., lane changes, upcoming turns). In addition, vehicles can report local hazards such as road surface issues and areas with frequent braking or electronic stability control activation. This information can identify areas for targeted maintenance and repair of the road transport infrastructure.
- b. *Road works*: Vehicular communications can inform drivers and ADS-equipped vehicles about road works, including detours, lane changes, revised speed limits, and potential delays. Timely, real-time warnings can reduce accidents and improve safety for both vehicle occupants and road workers.
- c. *Optimised traffic signal systems*: Vehicular communications enables traffic signal controllers to transmit their signal phase and timing (SPaT) information, along with intersection topology, to vehicles. This information can enable vehicle systems to optimise speed for energy efficiency and to achieve green-light-optimal speeds. Additionally, vehicles can provide anonymous traffic information for dynamic signal timing adjustments. In the future, vehicular communications could replace inductive-loop detectors and support red-light violation prevention, further reducing accidents and improving safety. 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*: Vehicular communications enables 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 route changes during special traffic situations such as sporting events, parades, protests, and VIP travel. This can help drivers and ADS-equipped vehicles plan their routes and avoid congested areas.

3. Automated Driving Support

- a. *Automated driving support*: Vehicular communications can significantly support, and potentially accelerate, the deployment of ADS. By utilising 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 supplementary information, ~~explicit and supplementary~~complementary to the vehicles' own sensor interpretations, allows for earlier and smoother automated actions.

Road transport infrastructure components 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, ADS-equipped vehicles can announce their status, enabling remote human control and automated guidance from road transport infrastructure components.

Additionally, vehicular communications can facilitate valet (remote) parking systems.

- b. Cooperative automated driving:* Vehicular communications fosters collaboration between vehicles to improve safety and efficiency. This includes functionalities such as platooning and coordinating intersection entry for ADS-equipped vehicles. Vehicular communications also facilitates ADS-equipped vehicles to safely and reliably complete challenging manoeuvres such as lane changing and merging. Vehicular communications can provide earlier awareness of emergency and other prioritised vehicles ~~(. Also, see the traffic management use case above).~~

4. In-Vehicle Experience and Convenience

- a. Infotainment and convenience:* Vehicular communications can enhance ~~vehicle occupants' the~~ in-vehicle experience for drivers and vehicle occupants 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 initiation of vehicle actions such as door locking and unlocking, activating the climate-control, managing battery charging, opening the trunk for delivery and ~~pick-up~~pickup, and controlling home and destination devices such as home appliances and garage doors. Vehicular communications can support vehicle sharing ~~and~~, vehicle rental services, and automated transport services.
- c. Charging support:* Vehicular communications can provide information from the grid to control battery charging times and facilitate bidirectional 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 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 enables updating vehicle software, firmware, and map data; accessing real-time information on the health and performance of vehicle

components; and transmitting the maintenance status of vehicle 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.

d. *Vehicle emissions information*: The actual vehicle emissions can be reported to authorities to determine the real-world emissions performance of vehicles.

6. Other Services

- a. *Police authorities*: Vehicular communications can enable 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 appropriate legal authorisation.

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

- d. *Public transport*: Vehicular communications can provide waiting passengers with information about public transport arrival times and service variations. ~~Vehicular communications can, as well as~~ assist public transport fleet operations and management ~~(e.g., including prioritisation of public vehicles at traffic signals).~~

- e. *Fleet management*: Vehicular communications can enable fleet operators to collect information from their managed vehicles and control their operations.

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

~~d.g. *Vehicle emissions information*: The actual vehicle emissions can be reported to authorities to determine the real-world emissions performance of vehicles.~~

V. Vehicular Communications Considerations

Although there are many benefits from vehicular communications, it is important to be aware of potential considerations of using vehicular communications. These considerations and the required countermeasures vary across uses, countries, and regions. Many of the considerations will lead to requirements to be met in developing vehicular communications applications. The considerations include, but are not limited to

- a. *Cybersecurity*: Communications are sensitive to cybersecurity threats, including hacking attempts and unauthorised access. Malicious actors ~~will~~might attempt to exploit vulnerabilities in the communications protocols and compromise the integrity of information exchanged between vehicles and external systems. There is a risk of a terrorist group could take remote control of connected vehicles including ADS-equipped vehicles.

Malicious entities will attempt to disseminate false information. This misinformation might confuse drivers and vehicle systems and might pose a risk to road safety. Verifying the authenticity of 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.

Vehicle manufacturers have implemented a Cybersecurity Management Systems (CSMS) to secure vehicles and ~~the vehicle's~~their data. Similarly, road transport infrastructure operators have implemented an Information Security Management Systems (ISMS) to secure their components and data.

b. *Privacy*: Exchange of information among vehicles and road transport infrastructure components ~~can~~could raise privacy issues, especially with regard to the personally identifiable information (PII) of vehicle occupants. Concerns have been raised ~~regarding~~about the potential risk of unauthorised tracking and profiling of individuals. Authentication to access vehicle information, including anonymisation and pseudonymisations of the information, are mitigations to reduce the risks involved. In general, access and processing of personal information is allowed (1) with the driver's consent, (2) when necessary to protect vital interests of the driver or another person, ~~and/or~~ (3) based on public interest or compliance with legal obligations.

c. *Communications interference*: ~~Communications~~Vehicular communications could be disrupted by interference, either within the same frequency range (in-band) and from outside that range (out-of-band,~~can)~~. Such interference could disrupt or limit information transfer between vehicles, road transport infrastructure components, and the communications infrastructure. International (ITU-R) regulations on radio spectrum use mitigate the risk of communications interference.

~~d. *False information propagation*: Vehicle service lifetimes, backward compatibility, and futureproofing: Continuity of communication services should be maintained for the service life of the vehicle. The core issue lies in balancing backward compatibility with futureproofing to ensure that all safety-of-life vehicular communication capabilities are maintained.~~

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~~*Vehicle service lifetimes*~~: In many countries, vehicle service lifetimes exceed 20 years. In some countries, the average age of vehicles routinely operating on its roads is up to 15 years. Development of vehicular-communications equipment has to take into account the long service lifetimes of vehicles.

The European experience with eCall is a sample of the possible problems.

~~d.e.~~ *Damage to communications infrastructure*: Physical attacks ~~or~~, accidents, and environmental effects might cause roadside units and base stations to malfunction ~~and disrupt~~disrupting communications. See Also, see the cybersecurity consideration above.

~~e.f.~~ *Damage to in-vehicle communications equipment*: Physical damage to in-vehicle communications equipment ~~might cause issues, such as antennas and onboard units, might compromise functions reliant on real-time information exchange. Warning information about such issues can be provided to the vehicle occupants.~~

~~g.~~ *Delays (latency)*: All communications ~~are~~is subject to delays due to equipment processing time, protocol ~~set-up~~setup time, radio-spectrum bandwidth for information, transmission rate, transmission throughput, etc. Additionally, delays can come from ~~the~~ communications infrastructure- limitations.

Vehicular communications applications should be designed so that the delays for the selected communications technology match the acceptable data-transmission delays for the application, ~~taking into account elements. This requires considering factors~~ such as the maximum number of communications participants at any time, the coverage of the communications networks used, selected, and the supported vehicle speed ~~that is supported, etc.~~

~~f.h.~~ *Timeliness*: Safety-related vehicular communications should be given priority in the radio spectrum used and for transmissions across communications infrastructure.

~~g.i.~~ *Limited Coverage*: Communications infrastructure can have areas of limited or no coveragesignal (dead spots). Such limits might disrupt information transmission.

~~h.j. Unavailability: Communications Service Outages: Communication infrastructure can have experience service outages due to various reasons, such as technical failures (e.g., power cuts) or maintenance activities. Vehicular communications needs to avoid interruptions by communications infrastructure outages, both local and wide area.~~

~~i.k. Costs: Communications infrastructure, road transport infrastructure components, and in-vehicle communications equipment as well as licenses for communications technologies might be expensive. How costs are handled can be policy issues.~~

~~j.l. Radio spectrum misuse: Some radio spectrum has been allocated, and will be allocated, for safety-of-life vehicular communications. ~~It~~There is ~~tempting~~a risk of safety-of-life radio spectrum being used for ~~developers and operators of vehicular communications systems~~applications that are not safety of life to use safety-of-life radio spectrum, possibly because it is 'free'.~~

~~k.m. Market Penetration. Some vehicular communications applications work well only when require a substantial number of devices are be deployed. Ways should be found to function effectively. Policies and strategies to achieve substantial and rapid the desired deployment of communications devices in the road transport infrastructure or vehicles must be developed.~~

~~n. VRU awareness: VRUs can be detected, by (1) roadside;~~

- ~~• Roadside sensors (and possibly forwarded by a collective perception service), 2) vehicle,~~
- ~~• Vehicle sensors (and possibly forwarded by a collective perception service), and (3),~~
- ~~• Communications devices carried by VRUs.~~

~~l. Awareness of the VRU communications devices.~~

~~Thereafter, awareness about VRUs can be communicated to all traffic participants-, including by a collective perception service.~~

The detection and integration components of systems protecting VRUs should take into account the position accuracy, reliability, availability of data (independent of whether a mobile device is charged or switched on), etc. The information received from communications should supplement the vehicle's safety systems for protecting VRUs.

~~m.o. Interoperability: Vehicles and road transport infrastructure components should be able to successful seamlessly exchange data and share information and knowledge for to support common services such as collision avoidance and cooperative adaptive cruise control. A unified approach is required to ensure that vehicles and road transport infrastructure communicate effectively.~~

~~n. Backward compatibility: As services and communications technologies evolve, they should remain compatible with previously deployed vehicles and road transport infrastructure components using the same service.~~

~~o.p. Harmonised services: Triggering conditions and minimum key performance indicators (KPI) for senders and receivers of vehicular communications should be harmonised to provide effective communications-based services.~~

~~p.q. Compliance assessment: The minimum performance of communications systems and communicated information should be validated so that using recognized standard procedures. It is necessary to achieve the required quality and timeliness of transmitted data is achieved for the communications services offered.~~