Note by the secretariat

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Vehicular Communications Definition, Types, Value, Uses, and Considerations
Prepared for the Task Force on Vehicular Communications (TF on VC)

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

I. VC Definition

VC concerns the information exchange between vehicles and their surroundings. In this document, the wording:

- 'Information' includes data and commands.
- 'VC' includes mobile communications devices connected to vehicle systems by vehicle occupants. Mobile communications devices that are not connected to vehicle systems are not included, even if the vehicle serves as the connection to mobile networks (e.g., by an in-vehicle Wi-Fi hotspot).
- 'Surroundings' includes drivers/vehicle owners outside their vehicle, household elements, other vehicles, other road users including VRUs in the future, road transport infrastructure components (roadside units, electronic signs, traffic control and management systems, and other road transport infrastructure), service providers, cloud-based operations, etc.

This information exchange involves the use of various wired and wireless communications technologies.

II. VC Types

This section provides general background about types of VC.

VC include the following broad categories:

a. Wired and wireless.

b. One to one (unicast), one to a group (multicast), and one to many (broadcast).

c. Unidirectional and bidirectional.

Current wired communications in vehicles primarily involves:

a. The OBD port.

b. USB ports.

c. The electrical vehicle (EV) charging equipment.

While these technologies often utilise wired connections, they might also incorporate wireless communications approaches.

Individual vehicles only have a few wireless communications technologies. 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. Very-short range communications, such as access control technology using radio-frequency identification (RFID) and near-field communication (NFC) for short-range identification data exchange in the range of centimetres.

b. Close-range communications, such as Bluetooth, ultra-wide-band (UWB), and infrared for communications in the range of a few metres.

c. Radio local area networks (RLAN), such as Wireless LAN (IEEE 802.11 family) for information exchange over tens or hundreds of metres or as an in-vehicle wireless communication link between a vehicle internet router and vehicle occupants' devices, often referred to as a hotspot.

d. Direct short-range communications between vehicles (V2V), road transport infrastructure components (V2I), and vulnerable road users (VRU) (V2P).

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

f. Radio, such as AM, FM, shortwave, and DAB.

g. Satellite, such as GNSS, satellite radio, and satellite internet.

III. VC Value

VC has significant potential to:

- Improve safety in road transport (including vehicle and VRU safety).
- Reduce the environmental impact of road transport.
- Enhance the road transport efficiency.
- Improve the road transport experience.
- Reduce the road transport costs.

VC enables vehicles and their occupants to receive information from their surroundings.

VC enables vehicles to provide their surroundings with information including:

- State of the vehicle such as:
  + Vehicle location, speed, and direction.
  + Vehicle acceleration and braking.
  + Vehicle signalling (audio and visual).
  + Use of features such as driver control assistance systems (DCAS) and automated driving systems (ADS).
- The state of driver engagement (including sudden health issues).
- Identified road conditions.
- Identified weather and environmental conditions.
- Identified other road users, including VRUs.

IV. VC Uses

This section provides general information on common uses of VC. 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. VC has many use cases, including but not limited to:

1. Safety and Emergency

a. *Safety information for vehicle operations*: VC enable in-vehicle systems to provide timely notifications and warnings to drivers and vehicle occupants about potential hazards. These notifications are based on information collected from their surroundings. Examples include warnings about wrong-way driving, traffic congestion, VRU presence, slippery roads, and other road hazards.

b. *Safety information for road-transport operations:* VC enables vehicles to transmit real-time information to their surroundings, allowing road transport infrastructure operators to improve their traffic management operations. This real-time information can lead to the detection of wrong-way driving, traffic congestion, slippery roads, and road hazards, which can be used to improve drivers' response times, service operators' information, and overall traffic management.

c. *Emergency services:* VC can enable first responders and emergency services to accelerate their response by providing real-time information about crashes, road hazards, and other incidents. In the future, emergency services could remotely control ADS-equipped vehicles that do not have a fallback user. Also, see the *Optimised traffic signal systems* use case below.

d. *Automated emergency call systems (eCall/AECS)*: VC enables in-vehicle eCall/AECS systems that can 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. Also, see the *Emergency services* use case above.

e. *Collision warning and avoidance:* VC 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), complementing the in-vehicle sensors, further enhancing collision prevention capabilities.

   VC, combined with good vehicle positioning, can improve both the vehicle's detection capability of the 360° surrounding conditions as well as improving the likelihood that the vehicle is detected by other vehicles. This capability is especially useful in challenging scenarios such as non-line-of-sight and bad weather, where visual recognition by on-board sensors (e.g. radar, camera, lidar) is compromised.

   VC 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. Also, see the *Safety information for vehicle operations* use case above.

f. *VRU protection:* VC enables communications equipment in the possession of pedestrians, cyclists, and motorcyclists can alert drivers and vehicles system about their presence. In additional, vehicles equipped with VRU detection systems can 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.

   This information – if reliable, 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 and send the information to surrounding traffic participants in real time and with high accuracy. See the *Collision warning and avoidance* use case above.

g. *Natural disaster and crisis management:* VC can enable vehicles and their occupants to receive alerts about various disasters or crisis, including tsunamis, typhoons, and wildfires as well as unrest, strikes, shootings, and terrorist attacks VC can support 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 will be able to relay information across the road network using a multi-hop approach. 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*: VC can enable vehicles to receive alerts from their surroundings of special situations ahead on the road. Such situations include road closures and rerouting, materials spills, and crashes. Also, see the *Safety information for vehicle operations* use case above.

2. Traffic Management

a. *Road transport infrastructure management:* VC 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 additional, 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:* VC 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 crashes and improve safety for both vehicle occupants and road workers.

c. *Optimised traffic signal systems:* enables vehicles to receive intersections signal phase and timing (SPaT) information, along with intersection topology, from traffic signal controllers. Additionally, vehicles can provide anonymous traffic information for dynamic signal timing adjustments. With this information, vehicle systems can optimise speed for energy efficiency to achieve green-light-optimal speeds. Additionally, traffic signal controllers can dynamically adjust their signal timing. Also, traffic signal controllers can provide red-light violation warnings to both the violating driver as well as others approaching the intersection.

   In the future, VC could replace inductive-loop detectors and support red-light violation prevention, further reducing crashes and improving safety. Also, see the *Safety information for vehicle operations* use case above.

d. *Traffic light pre-emption,* VC can enable emergency and public transport vehicles to request priority at traffic signals, facilitating a swift change to green.

e. *Real-time traffic updates:* VC enables drivers to receive information on road network status from their surroundings.

f. *Event management*: VC 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:* VC can significantly support, and potentially accelerate, the deployment of ADS. By utilising information received as an additional input, ADS features might improve their performance within their operational design domain (ODD) and even extend their ODD. This supplementary information, 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 crash locations.

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

When approaching their ODD limits, ADS-equipped vehicles can announce their status, enabling remote human control (possibly remote driving) or automated guidance from road transport infrastructure components.

b. *Automated parking*: VC can facilitate valet (remote) parking.

c. *Merging*: VC facilitates ADS-equipped vehicles to safely and reliably complete challenging manoeuvres such as lane changing and merging.

d. *Emergency vehicle support*: VC enables emergency vehicles to transmit their location, speed, and trajectory, ensuring earlier awareness by ADS features of these emergency vehicles and facilitating safe interaction with them.

e. *Cooperative automated driving*: VC fosters collaboration between vehicles to improve safety and efficiency. This includes functionalities such as platooning and coordinating intersection entry for ADS-equipped vehicles. Also, see the *Collision warning and avoidance* use case above.

f. *Remote driving*: VC enables remote driving.

4. In-Vehicle Experience and Convenience

a. *Infotainment and convenience:* VC can enhance 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 EV charge points and petrol stations; and availability of parking spaces. Additionally, reservations can be made for parking, EV charging, and other services such as dining and lodging.

b. *Remote activations*: VC can be used for remote initiation of vehicle actions such as door locking and unlocking, activating the climate-control, managing EV charging, opening the trunk for delivery and pickup, and controlling home and destination devices such as home appliances and garage doors. VC can support vehicle sharing, vehicle rental services, and automated transport services.

c. *EV Charging support:* VC can provide information from the grid to control EV charging times and facilitate bidirectional electricity flows, enabling EVs 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*: VC can be used for in-vehicle purchases and payments for tolls, road pricing, parking, fuelling, EV charging, and drive-thru purchases.

e. *Traditional Radio*: VC is in vehicles as FM, AM, shortwave, etc. This can provide general information to vehicle occupants.

5. Vehicle Management and Maintenance

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

b. *Vehicle maintenance*: VC 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:* VC 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 of vehicles.

6. Other Services

a. *Police authorities*: VC can enable police officers to retrieve information from vehicles, including whether an ADS feature is active.

b. *Remote authority vehicle control*: VC can remotely slow, stop, and disable a vehicle with appropriate legal authorisation.

c. *Stolen vehicle tracking*: VC can enable police authorities to track a stolen vehicle.

d. *Public transport*: VC can provide waiting passengers with information about public transport arrival times and service variations, as well as assist public transport fleet operations and management, including prioritisation of public vehicles at traffic signals.

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

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

V. VC Considerations

Although there are many benefits from VC, it is important to be aware of potential considerations of using VC. 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 VC 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 might attempt to exploit vulnerabilities in the communications protocols and compromise the integrity of information exchanged between vehicles and external systems. If not addressed properly, there might be a risk of a terrorist group taking 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 communications, is sender verification.

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

b. *Privacy*: Exchange of information among vehicles and road transport infrastructure components could raise privacy issues, especially with regard to the personally identifiable information (PII) of vehicle occupants. Concerns have been raised 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, or (3) based on public interest or compliance with legal obligations.

c. *Communications interference*: VC could be disrupted by interference, either within the same frequency range (in-band) and from outside that range (out-of-band). Such interference could disrupt or limit information exchange 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. *Vehicle service lifetimes, backward compatibility, and futureproofing*: Continuity of communications 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 VC capabilities are maintained.

   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 VC equipment has to take into account the long service lifetimes of vehicles.

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

e. *Damage to communications infrastructure*: Physical attacks, mishaps, and environmental effects might cause roadside units and base stations to malfunction disrupting communications. Also, see the *Cybersecurity* consideration above.

f. *Damage to in-vehicle communications equipment*: Physical damage to in-vehicle communications equipment, 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 is subject to delays due to equipment processing time, protocol setup time, radio-spectrum bandwidth for information, transmission rate, transmission throughput, etc. Additionally, delays can come from communications infrastructure limitations.

   VC applications should be designed so that the delays for the selected communications technology match the acceptable data-transmission delays for the application. This requires considering factors such as the maximum number of communications participants at any time, the coverage of the communications approaches selected, and the supported vehicle speed.

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

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

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

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.

l. *Radio spectrum misuse*: Some radio spectrum has been allocated, and will be allocated, for safety-of-life VC. There is a risk of safety-of-life radio spectrum being used for applications that are not safety of life to use safety-of-life, possibly because it is ‘free’.

m. *Market Penetration*. Some VC applications require a substantial number of devices be deployed to function effectively. Policies and strategies to achieve the desired deployment must be developed.

n. *VRU awareness:* VRUs can be detected by:

- Roadside sensors.
- Vehicle sensors.
- Communications devices carried by VRUs.

Awareness of the VRU 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.

o. *Interoperability:* Vehicles and road transport infrastructure components should be able to seamlessly exchange information 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.

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

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