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Co-operative traffic solutions for hybrid communication environments

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Abstract

Through communication between vehicles and infrastructure, vehicles can receive real-time warnings on incidents and dangerous situations, and can send own sensor data and observed incident information to other road users. Information between vehicles and infrastructures can be exchanged either using ITS-G5 or cellular communications. This paper describes how a fog vision sensor has been developed and deployed for warning drivers about adverse road weather conditions. A hardware-in-the-loop driving simulator has been utilized to test the transmission of vehicle data. Performance measurements of the communication between vehicles and infrastructure have been made for both ITS-G5 and LTE. LTE and the future 5G will provide lower latency, and hence may become the preferred solution especially for road side unit to vehicle communications. Providing seamless connectivity between different network technologies, a mobile IP based solution is utilized with Quality-of-Service (QoS) assisted handovers. Real-time QoS measurements with fast handovers enable the system to react rapidly to changing circumstances. Our solution can exploit multiple networks and prioritize them by quantities such as preference, signal strength and geotagged formerly measured link quality.

Peer-review under responsibility of Road and Bridge Research Institute (IBDiM)

Keywords: co-operative traffic services; hybrid communications; ITS-G5; sensors for reduced visibility

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1. Introduction

Through Infrastructure-to-Vehicle (I2V) communication, vehicles can receive real-time warnings on incidents and dangerous situations, and provide data to the traffic management centre. Work in Finland in I2V communications started with the Celtic-funded projects Carlink – Wireless Traffic Service Platform for Linking Cars and WiSafeCar – Wireless Traffic Safety Network Between Cars (Eloranta, 2013), and continued with the CoMoSeF project (2012-2015), which main aim was to create co-operative mobility solutions, including devices and applications, feasible for large scale deployment, that support the objectives of the European Commission's ITS Action Plan (European Commission, 2008) and national ITS strategies. The project brought existing and emerging sensor units, service platforms and communication technologies and solutions closer to market, introduced and created viable business models that promoted and accelerated the deployment. CoMoSeF has focused on the development and deployment of advanced vehicle and roadside data collection solutions to gather traffic, weather, and incident related information for road users.

Nomenclature

5G	5th generation mobile networks
DATEX II	Standard developed for information exchange between traffic management centres
DENM	Decentralised Environmental Notification Message
I2V	Infrastructure to Vehicle
ITS	Intelligent transportation systems
ITS-G5	Cooperative car to car/infrastructure communication standard operating in the 5.9 GHz band
LOS	Line Of Sight
LTE	Long Term Evolution
NIR	Near-infrared
OBD2	On-board diagnostics
QoS	Quality of Service
RDS/TMC	Radio Data System/Traffic Message Channel
RSU	Road Side Unit

2. State of the art

Changing winter weather conditions are a major challenge in road traffic in Nordic countries. Accurate information on road weather is important for both traffic management and road users (Leviäkangas & Hietajärvi, 2010). Several approaches have been developed for measuring road friction, both from road weather stations and directly from the vehicle (Pill-Sihvola & al., 2014). Jokela et al. (2009) have developed a road weather detection system, called IcOR, which is based on a stereo camera, and uses a lookup table to estimate the road friction.

Due to fog, visibility can suddenly be decreased, causing sudden and dramatic changes in driving conditions. Fog appears to play a major role in fatal multi-vehicle collisions, and are reported as a factor in nearly one-in-five such crashes involving 10 or more vehicles in the United States (Hamilton et al, 2014). Systems developed to increase visibility in fog are currently very expensive (Gschwendtner & Keicher, 2000). Viitanen et al. (2014) have developed a system using active infrared illumination for measuring visibility in fog conditions.

Information on dangerous road weather conditions should be transferred as soon as possible to road users. The fastest way to deliver this message is through I2V communications. Information between road side sensors and vehicles can be exchanged either using short range communications, based on IEEE 802.11p, or cellular communications. IEEE 802.11p is an amendment to the IEEE 802.11 standard, allowing adding wireless access in vehicular environments. In Europe, ITS-G5 protocols, which are standardized by ETSI, run on top of the IEEE 802.11p standard and support the GeoNetworking protocol for V2V and V2I communications. ITS-G5 can be considered as the most mature standard for short-range vehicular communications that require fast message exchange. Latencies over ITS-G5 are in the order of milliseconds. Major drawbacks for ITS-G5 are the limited range and infrastructure costs, making it problematic to cover large portions of the road network. Cellular networks do not necessarily require additional communication infrastructure. The use of cellular communications for provision of I2V messages has been investigated by e.g. the CoCarX project (ETSI TR 102 962, 2012).). In order to provide information with low latency only to the vehicles nearby, additional components are needed, such as a geolocation server, which keeps track of vehicle locations. (CONVERGE, 2015).

Major drawbacks are the increased latency and the potential for network overload. In case Cooperative Awareness Messages (CAM), are sent according to ETSI specifications over cellular networks, the network may get overloaded for a relative small amount of vehicles (ETSI TR 102 962, 2012).

The use of Mobile Edge Computing (MEC) (He, 2015) adds intelligence to the base stations in LTE communication networks allowing very low latency transmissions (Ross, 2015), and to offload the transmission of CAM-messages to other networks. The forthcoming 5G standardization (LTE Release 14) will also include V2V functionalities (3GPP, 2015). Hence, cellular communications has the potential to become the preferred solution especially for I2V communications.

In the CoMoSeF project, VTT developed both data collection methods, middleware for the transmission and receipt of messages, design tools for testing the complete data transmission chain. Specifically, a sensor for improving visibility in fog was developed. Vehicle warnings related to poor visibility are transmitted utilizing either ITS-G5 or cellular means to vehicles. Performance measurements for I2V communications have been made for both ITS-G5 and LTE. A Mobile IP based solution is presented, that utilizes both communication systems with Quality--of-Service (QoS) assisted handovers for providing best available connectivity and performance.

3. Cooperative traffic pilots in Tampere

3.1. Pilot architecture

In the CoMoSeF project two co-operative traffic pilots are realized in Tampere, Finland. A business-oriented pilot aims to collect probe data from a large amount of vehicles and provide road hazard and road weather warnings. Three local companies work together in this pilot to develop and deploy cooperative safety related services, with as main target to develop concrete business opportunities between the partners. Two fleets are included in the pilot: taxis, which run software delivered by Mobisoft Oy, and commercial fleets, which have devices from Taipale Telematics. Vehicles collect data on location and speed and vehicle drivers report on events, e.g. accidents. The data is anonymously sent by the vehicles to the fleet's backend server, and forwarded to the Traffic Information Server from Infotripla, where the collected data are aggregated, analyzed, and warnings on identified events generated. The information from the Traffic Information Server is delivered in the DATEX II standard to authenticated users, including the fleets providing data. The fleet's backend server distributes the messages to the drivers.

This business oriented pilot is complemented with a research pilot, which investigates the integration of ITS-G5 I2V communications within this chain. The system consists of a road side unit with sensors for road weather and visibility. The roadside communicates directly with vehicles over short range ITS-G5, and sends the information for further processing and analysis to a backend server (Pyykönen et al., 2014). A test vehicle is equipped with ITS-G5 communications, using the Linkbird MX from NEC. An application unit has been developed in the vehicle for representing the messages transmitted.

3.2. Sensor for low visibility detection

Viitanen et al. (2013) have developed a system for the improvement of visibility for drivers in foggy weather conditions, using thermal emitters. A low visibility sensor was developed, using a XENICS Near-Infrared camera and Ibeo laser scanner (Fig. 1). The laser beam does not penetrate fog, but reflects from the fog droplets. The distance to the reflection point is measured continuously, and both the average and the maximum mean value over a short period are calculated. This mean value is then compared to a reference value without fog to get a visibility estimate. The sensor was tested during 6 months in winter near a motorway ramp at Tampere.

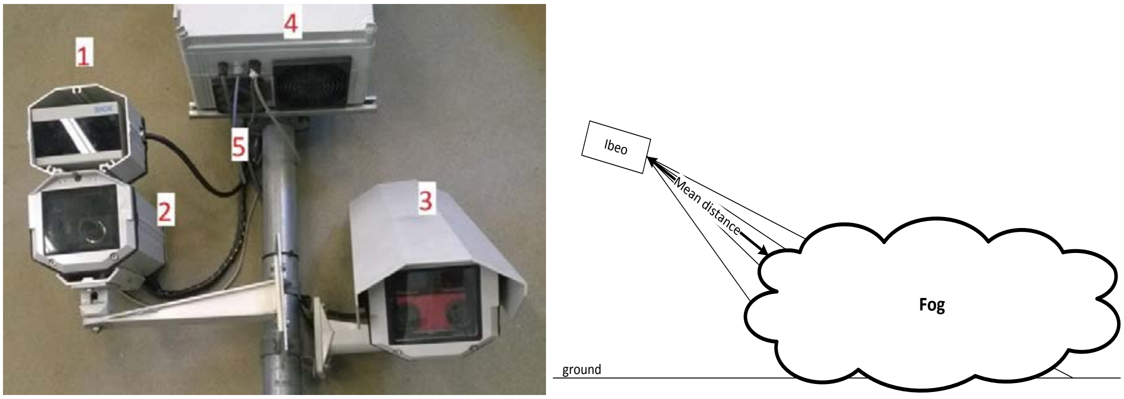

Fig. 1. Road Side Unit Road side ITS station sensor system. From left to right: Laser scanner (1), NIR camera (2), IcOR stereo camera system (3), road side unit PU (4) and air temperature sensor (5). The figure on the right shows the operation principle of the fog sensor.

Rain does not affect to the visibility range measured, but dense snow at low temperatures (-10…-15 °C) can affect. In case of snow fall, dense snow drizzles affect especially the measured average of the distance, as individual laser beams can still further penetrate the snow drizzle, whereas for fog the average and maximum value are similar.

The Road Side Unit (RSU), which is also equipped with the IcOR system for detection of the road weather type (Jokela et al., 2009), was installed at the motorway ramp on the Tampere ring road. Data on incidents, which was provided by the Traffic Information Server of the Tampere business oriented pilot, is also sent to the RSU. The RSU is able to send warnings to vehicles as DENM (Distributed Environmental Notification Message) messages through ITS-G5 communication and to send measurements on road condition, friction value and GPS location, to a database using 3G/UMTS mobile connections.

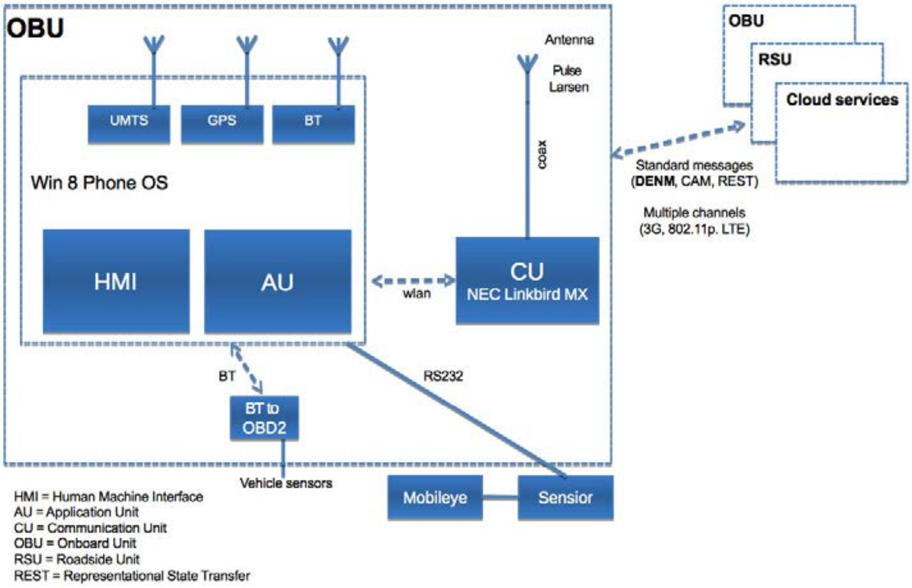

Fig. 2. Hardware components of the Smartphone-centric Vehicle station.

Fig. 3. City model and hardware in the loop simulator for DENM delivery.

3.3. Vehicle ITS station

Fig. 2 presents the main components of the CoMoSeF smartphone-centric Vehicle ITS station. The Vehicle ITS station consists of an Application Unit, which is a Windows 8 –based nomadic device (mobile phone or tablet), and communication unit, which is a LinkBird MX from NEC. The communication unit is connected over WLAN to both the Application Unit and a GPS receiver. Information of the vehicle's in-vehicle network can be accessed by the application unit from the vehicle's OBD2-interface over a Bluetooth connection. The Vehicle ITS station communicates with the Road Side unit over ITS-G5 using DENM messages. Both Road Side Unit and the application unit of the vehicle ITS station use the Windows 8 operating system, which eases the development of software for transmission and receipt of DENM messages.

3.4. Hardware-in-the-Loop simulator for message delivery

A 3D simulator was utilized for testing the complete message delivery chain of DENM messages using I2V ITS-G5 communications, from the Road Side Unit or the central ITS server to the vehicle (Fig. 3). The simulator contains a model of the town district, where the VTT premises are located. The same data on incidents, provided by the Traffic Information Server, is injected to the simulator model. The data was provided by the Traffic Information Server, which also provided the warnings for another CoMoSeF pilot within the Tampere area. In addition the messages from the road side unit were included. This procedure speeded up the development process greatly, since it allows testing the whole message delivery chain in laboratory before performing the field tests. The simulator is a hardware-in-the-loop development tool, which contains a city model and the operator can drive a car inside the model, and can receive the same information to the on-board tablet as he would get when driving in the town district.

4. Performance measurements of ITS-G5 and LTE communications

IEEE 802.11p and LTE measurements were performed using the Qosmet tool, developed by VTT (Prokkola et al. 2007) for monitoring the network quality of service (QoS) metrics, such as delay, jitter, packet loss, throughput and number of sent/received packets. Qosmet is a light-weight software running in both VRU and vehicle terminals to be able to perform bi-directional measurements in the IEEE 802.11p radio link.

Measurements were made for IEEE 802.11p devices from two manufacturers: NEC (LinkBird MX) and Componentality (FlexRoad) on both an airfield strip with various speeds and a public road (Valta et al. 2015). The tests were made with five different speeds (60, 80, 100, 120 and 140 km/h), with three repetitions for each speed. When starting the test measurement, the vehicle was first inside the radio range and then driven out of the coverage area. The driving speed does not notably affect to the packet loss rates and the range. With each driving speed, the packet loss is almost zero at distance of 0 to 900 meters and then goes quickly to 100% at the edge of the coverage area in distance of 900 to 1100 meters. There are no notable differences between the two tested devices regarding packet loss. The Componentality device, which is a more recent device than the LinkBird MX, has a lower delay of about 0.85 milliseconds.

Table 1 shows the IEEE 802.11p results with the speed of 60 km/h measured in the airfield having LOS connectivity and in a public road. As seen from the table, the range drops to one third of the LOS range with packet loss being less than 30%, when having obstacles in the link path in a normal urban road environment.

Table 1. IEEE 802.11p performance.

		NEC Linkbird MX	Componentality
Line-of-sight (60 km/h)	Reliable link range (packet loss < 0.3)	1030 m	990 m
	Delay at 300 m	5.88 ms	0.85 ms
Public road (speed varies, max 60 km/h)	Reliable link range (packet loss < 0.3)	331 m	not measured
	Delay at 300 m	6.00 ms	not measured

The newest ITS-G5 devices have good performance in terms of delay and line-of-sight range. However, due to the high operational frequency of 5.9 GHz, physical obstacles on the link path can be problematic for the signal propagation that effect to the operational range. Jutila et al. (2015) studied the effect of obstacles in the link path for ITS applications targeted to Vulnerable Road Users. These tests were performed in scenarios, which were identified as critical for VRU safety (Scholliers et al., 2014), including scenarios where the VRU is situated behind a vehicle, behind a queue of vehicles, between vehicles, behind trees/bushes or behind the corner of a building. The network requirements of the time-critical cooperative services that were monitored and measured relate to latency, range, positioning accuracy and packet loss rates using the ITS-G5 technology. As a criterion for sufficient range, the exchange of messages at a time-to-conflict (TTC) of 5 seconds is set. This results in 100 meters for pedestrians and cyclists in urban scenarios (vehicle speed maximum 50 km/h) and 160 meters in extra-urban (vehicle speed maximum 90 km/h) scenarios.

Table 2. Test results for ITS-G5 with different obstacles in the link path.

Test case where VRU is situated:	Distance from VRU to roadside	Range [m] for transmission power		
		20 dBm	10 dBm	0 dBm
line-of-sight (LOS)	1 m	1002	327	121
behind a vehicle	1 m	>200	152	60.4
between two vans	1 m	>200	123	53.7
between vehicle + van	1 m	>200	157	53.5
behind bushes/trees	5 m	>200	101	0
behind the corner of a building	8.4 m	>200	85	61.4
	59.5 m	90.4	10.6	1
	111.9 m	17.8	2.7	-
behind a queue of vehicles	-	203	84	37.6

The results give valuable in-sight about the performance limitations that have to be considered in the development of different service applications. The tests, shown in Table 2, were performed at 3 different power levels, corresponding to the type of equipment of the VRU: 20 dBm corresponds the normal vehicle transmission level, 10 dBm the smartphone transmission power, and 0 dBm the transmission level of a smartphone with body absorption (e.g. smartphone in a pocket close to body). The results indicate that with 0 dBm the TTC is less than 3 seconds, which is not sufficient for the safety critical applications. With 10 dBm the TTC is more than 5 seconds which is enough for urban scenarios.

Cellular communications (3G/4G/LTE) are an interesting solution for vehicular networks in case when being out of the IEEE 802.11p range, and when the application requirements are not that time-sensitive. LTE has an extensive mobility support and wide deployment of infrastructure already built in many countries. LTE provides advanced services over cellular networks and is attractive for vehicular communications due to high data rates and rather low latency. LTE’s planned support for V2X communication in Release 14 (3GPP, 2015) will add proximity and broadcasting services into cellular networks.

For the comparison we made LTE measurements in the same part of the public road as for ITS-G5 in Table 2 (Valta et al., 2015). The LTE performance on the other hand provides a wide reliable link range (see Table 3) being more than 4 km when driving inwards to the range and more than 6 km for the outward range. However, the delay is around 11 milliseconds for downlink and 20 milliseconds for uplink for outward and inward directions, respectively.

Table 3. LTE performance.

	Reliable link range (packet loss < 0.3)	Delay at 300 m
Driving Outward (downlink)	6102 m	11.02 ms
Driving Outward (uplink)	6132 m	20.21 ms
Driving Inward (downlink)	4414 m	11.08 ms
Driving Inward (uplink)	4395 m	19.95 ms

5. Automatic handover between different communication networks

In order to utilize available networks the most efficient way, and to deliver accurate real-time co-operative ITS (C-ITS) messages, networks need to be monitored, performance indicators measured and mobility being controlled. The growing amount of data traffic in vehicle communications can cause large variations in the perceived QoS in heterogeneous network environment. Traffic loads in networks and individual Road Side Units and base stations vary, which can cause increased transmission delays and packet losses. Moreover, the average cell size is anticipated

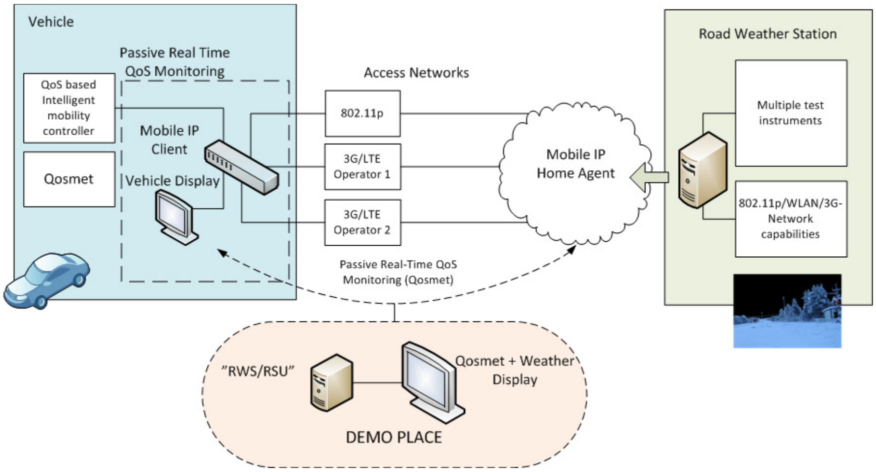

Fig. 4. Test pilot for handover between different communication networks.

to decrease in the future in order to better cope with the increasing amount of data and users. This poses great challenges especially for high-speed vehicular mobility, as the number of handovers can increase significantly, when the traditional cell selection scheme, which is based on the strongest signal criterion, is utilized (Piri, 2014). Fig. 4 shows the test setup for handover testing in the pilot case from the CoMoSeF project.

In the test pilot case, a Road Weather Station from FMI (Finnish Meteorological Institute) (Sukuvaara et al., 2015) delivers up-to-date road weather information to bypassing vehicles with compatible radio communication systems, including IEEE 802.11p and 3G/LTE. The measurement data provided to vehicle consists of friction, temperature, wind and visibility information. The communication was prioritized to utilize the primary local area network with IEEE 802.11p, but whenever the measured signal strength and QoS dropped, a smooth handover connection to commercial cellular 3G/LTE communication, offered by two operators, was made. Our system was utilizing Mobile IP for doing the vertical handover between IEEE 802.11p and 3G/LTE based on the passive real-time QoS monitoring with Qosmet (Prokkola et al., 2007) and measuring RSSI (Received Signal Strength Indication) values. This test pilot showed that by providing status information of the networks and managing the traffic in a dynamic way enhances the performance, reliability and capacity of traffic networks that provides better ground to build the C-ITS services.

6. Delay in complete message chains when using cellular networks

The latency measured in the tests relay to a single link in the whole data transmission chain (i.e. from V2V or I2V). Current cellular communications between vehicles require that the message is always relayed through the network, hence involving at least two links as well as processing the message at least in one server.

Very small latencies, less than 100 milliseconds are required for time critical applications, when the time to conflict at (first) message arrival is small, e.g. less than 5 seconds, and hence requiring immediate attention of the driver or automatic activation of braking and/or steering. However, for services aiming at raising the awareness of the driver near conflicts, e.g. when approaching roadworks, longer latencies can be allowed, if it is assured that the driver is warned in advance when entering the hazard area.

The Finnish government assesses the use of cellular networks to provide safety related traffic information in real-time in highway environments in the NordicWay pilot. Safety Related Traffic Information should be provided to road users free of charge, according to priority action of the European Commission directive 2010/40/EU. The main purpose of the pilot is to deliver this information to relevant vehicle drivers with low delay using commercial LTE mobile network. In the pilot, coordinated by HERE, drivers can also inform about hazardous events on the road by clicking on their smartphone application. Warnings, issued by the drivers, are sent as DENM messages over the mobile network to a C-ITS cloud, which forwards it to other road users having this application in the neighborhood and to the Road Authority’s Traffic Information System. The Traffic Information System sends warnings as DATEX II messages to registered parties, such as the C-ITS cloud, which transmit them to other road users approaching the hazardous area. Technical feasibility tests were performed at and analyzed by VTT in August 2015. The messages were distributed to smart phones in the area of relevance in two ways: by immediate transmission of the message to other smartphones at receipt of the message at the C-ITS cloud in the area (short loop) and by forwarding the messages to the Traffic Information Centre, which sends the message back via the C-ITS cloud to vehicles in the area of interest (long loop). The short loop aims to warn vehicles near the impact area as soon as possible. The long loop allows for validation of the message and aggregation with other data in order to assure the validity of the event.

Based on these tests in a commercial LTE network, the delay of the chain vehicle-C-ITS cloud-vehicle was about 1.4 second, and of the chain vehicle-C-ITS cloud-Traffic Information System-C-ITS cloud-vehicle about 3.8 seconds (Kauvo and Koskinen, 2015). Although this delay is much larger than the latencies required for time critical applications, the message can be derived in time to drivers entering the hazardous area in a much faster way than through traditional channels, such as RDS/TMC, and is within the limits set for similar cooperative applications, such as informing conceptual speeds to drivers (ISO/TS 17426). It also fulfills the requirements set by EIP (European ITS Platform) for traffic information services (Lohoff et al., 2015).

7. Conclusions and next steps

Communication between vehicles and infrastructure allows providing drivers with real-time information on road hazards and dangerous weather conditions. This paper describes a system to provide warnings to drivers either using short-range ITS-G5 communications or through cellular communications.

ITS-G5 communications allow distributing information using very low latencies. In line-of-sight applications ITS-G5 can have a range of up to 1 km, but obstacles in the line of sight reduce the range substantially. Modern ITS-G5 has latencies of 1 millisecond or less. The technology is hence the preferred solution for Vehicle-to-Vehicle safety related scenarios, such as emergency braking and collision avoidance. The technology involves no additional service costs during the lifetime of the vehicle.

The latencies of cellular communications are higher than for ITS-G5. Future 5G solutions (LTE Release 14) will have very short latencies for V2V solutions and can become a competitor for ITS-G5.

For I2V applications, the main advantage of cellular communications is that they do not need any additional infrastructure. Hence, they are the preferred solutions for situationswhere larger latencies are acceptable. A major application of interest is the provisioning of Safety Related Traffic Information, which should, according to the directive of the European Commission, be provided free of charge to vehicle users. Safety Related Traffic Information can be provided by a Traffic Information Server through DATEX II, and then distributed to a fleet of vehicles. The latency of this approach depends on the transmission frequency of the DATEX II feed. In order to efficiently distribute messages to road users, the service provider needs a geolocation server, which keeps track of the users. This approach has been demonstrated in Finland in real-life scenarios involving a central server and communication with the national Traffic Information System, and shows delays of less than 2 seconds for transmission between vehicles and of less than 4 seconds when messages are routed via the Traffic Information Server, which is within the limits set by relevant specifications.

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