Chapter 2
Vehicular Communications Standards

2.1 Goals

- To present all available and emerging standards related to V2V and V2I communications.
- To focus on emerging standards for V2V/V2I.
- To present concrete use cases so as to familiarize the reader with the V2V/V2I logic.
- To set the scene for gaining knowledge on the various standards' drawbacks, so as to work on new topics to eliminate them.

2.2 Introduction

As already mentioned, the main motivation for vehicular communication systems is safety and eliminating the excessive cost of traffic collisions. According to World Health Organization (WHO), road accidents annually cause approximately 1.2 million deaths worldwide,[13] one-fourth of all deaths caused by injury. Also about 50 million persons are injured in traffic accidents. If preventive measures are not taken road death is likely to become the third leading cause of death in 2020 from ninth place in 1990. A study from the American Automobile Association (AAA) concluded that car crashes cost the United States $300 billion per year.[14]

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[13] M. Peden; Richard Scurfield; D. Sleet; D. Mohan; et al. "World report on road traffic injury prevention" (PDF). World Health Organization. Retrieved April 15, 2016

[14] "Crashes Vs. Congestion—What's the Cost to Society?" (PDF). American Automobile Association. Retrieved April 15, 2016.

G. Dimitrakopoulos, *Current Technologies in Vehicular Communications*,
DOI 10.1007/978-3-319-47244-7_2

In general, V2I communications have been implemented based on numerous standards, such as IEEE 802.11n, DSRC, and Infrared techniques. They have been widely deployed for road charging applications but the infrastructure cost makes the cost/benefit calculation challenging, demanding significant investment overhead. Further, Wide Area Networking (WAN) technologies such as 2G/GPRS/EDGE, 3G/UMTS/HSPA/HSPA+, and 4G/LTE have also been used for vehicle to back office communication, but these suffer from location accuracy which could be improved by secondary mechanism such as GPS.

On the other hand, the concept of (mostly neighboring) vehicles communicating with each other has been the subject of research and development initiatives for many years. However, the level of adoption of V2V techniques in modern vehicles has only recently started to increase and it is still far below satisfactory levels.

Lately, through the connectivity available for vehicles, vehicles have started getting connected to the internet, giving birth to several applications that fall in the realm of V2B (Vehicle-to-Business) communications.

Last but not least, the increasingly rising utilization of smart devices has produced a new generation of mobile apps so that a driver can be connected to his/her vehicle remotely.

In this respect, this chapter aims at outlining the standards that are being used in V2X communications, emphasizing on the advantages and the drawbacks of each one of them.

2.3 Wireless Access for Vehicular Environments (WAVE) and Its Migration Towards IEEE 802.11p

Wireless Access for Vehicular Environments (WAVE) is an approved amendment to the IEEE 802.11 standard. WAVE is also known as IEEE 802.11p. WAVE is required to support the Intelligent Transportation Systems (ITS) applications in the short-range communications. The communication between vehicles (V2V) or between the vehicles and the roadside infrastructure (V2I) is relied on the band of 5.9 GHz (5.85–5.925 GHz).[15] With the equipment installed in the car and on the road, WAVE supplies the real-time traffic information, improves the safety of the transportation, and reduces the traffic congestion. It also benefits for the transport sustainability.

In 1992, United States started to research the Dedicated Short Range Communication (DSRC). It is the wireless communication protocol for the vehicles. United States, Europe, and Japan are the main countries of research and application for DSRC. From 2004, the concentration of DSRC has been migrating to the IEEE 802.11 standard group. At first DSRC is based on the IEEE 802.11a, which focus on the low overhead operations. DSRC standard is based on the Wireless

[15] Stephan Eichler, "Performance Evaluation of the IEEE 802.11p WAVE Communication Standard", in Proceedings of Vehicular Technology Conference, 2007, pp.2199–2203

Fidelity (Wi-Fi) architecture.[16] However, in order to support high-speed moving vehicle and simplify the mechanisms for communication group, IEEE working group dedicate more efforts on the WAVE, which is the core of the DSRC. WAVE ensures the traffic information collection and transmission immediate and stable, and keeps the information security.

Besides the IEEE 802.11p, WAVE also contains the standard of IEEE 1609, which is the upper layer standard. IEEE 1609 completes the WAVE by its sub-detail standards, for instance, IEEE 1609.2 standard is responsible for the communication security; IEEE 1609.3 standard covers the WAVE connection setup and management.[17] IEEE 1609.4 standard that is based on the IEEE 802.11p Physical (PHY) layer and Medium Access Control (MAC) layer supplies operation of high-level layers across multiple channels.

In general, standards-based vehicular networking for V2V communication has been so far implemented to a great extent, based on IEEE 802.11p,[18,19] which inherits several of the IEEE 802.x family characteristics, including simplicity and distributed medium access control mechanisms. It is at an early stage of adoption however and though it does meet the requirement for minimal infrastructure investment, it suffers from reliability, resilience to interference and stability problems, as well as faces the "fax machine problem"—it's only any good if you can communicate with a second party that has similar equipment.

Despite its limited applicability, several applications based on the IEEE 802.11p standard are on the market, but some projects are testing yet with few vehicles. A large number of companies, car manufacturers, and universities are involved in those projects, and we may see appearance in our cars the first applications in the next few years. The application can be separated into three aspects.

2.3.1 Safety-Oriented

Most of applications are safety related, but these applications need real-time constraints that the IEEE 802.11p is not able to provide itself. So some extensions of the amendment are needed to allow the use of safety applications.[20]

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[16] D. Jiang, L. Delgrossi, "IEEE 802.11p: Towards an International Standard for Wireless Access in Vehicular Environments", in Proceedings of Vehicular Technology Conference, 2008, pp.2036–2040

[17] Task Group p, "IEEE 1609.3-2007 WAVE Networking Services", IEEE Computer Society, 2007

[18] F Bai, H Krishnan, Reliability analysis of DSRC wireless communication for vehicle safety applications, in Proceedings of the IEEE Intelligent Transportation Systems Conference (ITSC 2006), (Toronto). 17–20, September 2006

[19] A Vinel, 3GPP LTE versus IEEE 802.11p/WAVE: which technology is able to support cooperative vehicular safety applications? IEEE Wireless Commun. Lett. 1(2), 125–128 (2012)

[20] Bohm, A.Jonsson, "Position-Based Data Traffic Prioritization in Safety-Critical, Real-Time Vehicle-to-Infrastructure Communication", CERES (Centre for Res. on Embedded Syst.), Halmstad Univ, Halmstad, Sweden,

The communication could be based on the point to point or multipoint. It also demands the low latency requested by the real-time communication. Car-to-car communication (C2C) can be used to provide a global view of the traffic that the driver could not be able to have by himself. For example, by exchanging of information such as position and speed, a driver can see on a screen in his car all vehicles around. This is very useful if the weather prevents a good visibility, like fog or rain, and in a turn or at an intersection. A driver can also be advertised of a traffic jam or a traffic collision. This is also very useful especially if the driver have a bad visibility. For an emergency vehicle, because it has to arrive at the destination without delay, it can broadcast a message to the cars around it and make a place for itself.

Car-to-infrastructure communication (C2I) can be used, for example, to allow an emergency vehicle to preempt a red light on its way, and then have green light all along its path, or at the intersection, the traffic light sends the light information to the cars that are in its communication scope. It assists drivers better know about the conditions of the intersection to avoid traffic collision.

2.3.2 Traffic Control-Oriented

Some other applications are not related to the safety, but by exchanging information about position we can have a global view about the density of the traffic and used it to regulate the traffic. For example, the traffic jam advertiser, enumerated for safety purpose, is also a traffic control-oriented application in a way that the user knows about a traffic jam further and then can choose an other way.

We can also imagine a "smart red light" that could collect information about number of cars waiting and how long time they have been waiting, and then change its status based on that.

The infrastructure can also supply the localization map for the drivers and make a suggestion of appropriate path to the destination and avoid traffic jam. The Electronic Toll Collection (ETC) has been applied in some Europe countries. ETC charges the road price for reducing the congestion. The system can recognize the car by car's identification by the equipment based on the WAVE technology without stopping the cars. The antenna installed on the car can communicate with the on-board equipment, which is on the car.

2.3.3 User Comfort-Oriented

Some previous applications could be also in this section, such as the traffic jam advertiser or the smart red light, because they can avoid the driver to wait too long time in a traffic jam or at a red light. But the comfort-oriented applications are more service that the users could enjoy themselves in their cars like download movies or music or upload some documents to their friends. Actually having access to the Internet can summarize comfort applications.

Some research initiatives are in-going for that, but for some obvious reasons the IEEE 802.11p is not design for that. First of all having always a path to an access point for the Internet is almost impossible, because of the high mobility of vehicles, which should be routers. There is also a big problem of security in a way that it is not possible to trust any routers on the path. So having the Internet now in our vehicles by using the IEEE 802.11p amendment is not a really good solution and using other technology like the 3G is still better.

2.4 IEEE 1609

The IEEE 1609 family of standards defines the following parts:

- Architecture
- Communication model
- Management structure
- Security mechanisms

Physical access for high-speed (<27 Mb/s), short-range (<1000 m), and low latency wireless communications in the vehicular environment.

The primary architectural components defined by these standards are the On Board Unit (OBU), Roadside Unit (RSU), and WAVE interface.

The IEEE 1609.3 standard covers the WAVE connection setup and management. The IEEE 1609.4 standard sits right on top of the IEEE 802.11p and enables operation of upper layers across multiple channels, without requiring knowledge of PHY parameters. The standards also define how applications that utilize WAVE will function in WAVE environment. They provide extensions to the physical channel access defined in WAVE.

This is shown in Fig. 2.7.

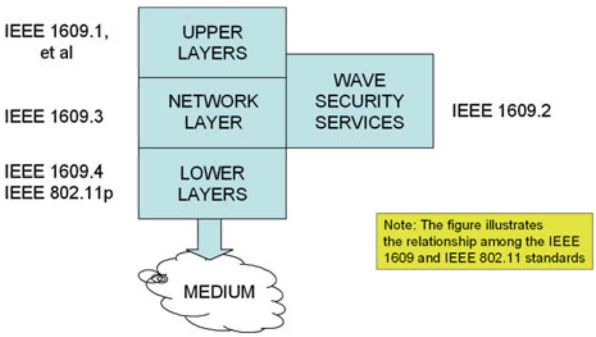

Fig. 2.7 IEEE 1609

2.5 SAE J2735

Another standard that is commonly used in vehicular communications and, in particular, V2V communications is the J2735, Dedicated Short Range Communications (DSRC) Message Set Dictionary, maintained by the Society of Automotive Engineers (http://www.sae.org). This SAE Standard specifies a message set, its data frames, and data elements specifically for use by applications intended to utilize the (DSRC/WAVE) communications systems.

Although the scope of this Standard is focused on the message set and data frames of DSRC, it specifies the definitive message structure and provides sufficient background information for the proper interpretation of the message definitions from the point of view of an application developer implementing the messages according to the DSRC standards.

It supports interoperability among DSRC applications through the use of standardized message sets, data frames, and data elements. The message sets specified in J2735 define the message content delivered by the communication system at the application layer and thus defines the message payload at the physical layer. The J2735 message sets depend on the lower layers of the DSRC protocol stack to deliver the messages from applications at one end of the communication system (OBU of the vehicle) to the other end (a roadside unit). The lower layers are addressed by IEEE 802.11p, and the upper layer protocols are covered in the IEEE 1609.x series of standards.

The message set dictionary contains:

15 Messages
72 Data Frames
146 Data Elements
11 External Data Entries

The most important message type is the basic safety message (often informally called "heartbeat" message because it is constantly being exchanged with nearby vehicles). Frequent transmission of "heartbeat" messages extends the vehicle's information about the nearby vehicles complementing autonomous vehicle sensors. Its major attributes are the following:

- Temporary ID
- Time
- Latitude
- Longitude
- Elevation
- Positional Accuracy
- Speed and Transmission
- Heading
- Acceleration
- Steering Wheel Angle
- Brake System Status
- Vehicle Size

The other kinds of messages are the following:

A la carte message—composed entirely of message elements determined by the sender, allowing for flexible data exchange.

Emergency vehicle alert message—used for broadcasting warnings to surrounding vehicles that an emergency vehicle is operating in the vicinity.

Generic transfer message—provides a basic means to exchange data across the vehicle-to-roadside interface.

Probe vehicle data message—contains status information about the vehicle to enable applications that examine traveling conditions on road segments.

Common safety request message—used when a vehicle participating in the exchange of the basic safety message can make specific requests to other vehicles for additional information required by safety applications.

2.6 LED-Enabled Visible Light Communications (IEEE TG 802.15.7)

Light emitting diodes (LEDs) constitute a well-established choice for light sources in display and illumination applications. LEDs combine the advantages of high brightness and low power as well as low heat dissipation and longer life span compared to conventional incandescent lamps. Moreover, LED lamps are an important candidate for road illumination, traffic signs, and vehicle head lights.

However, according to medium to long-term research EU roadmaps, technology will enable the enhancement of any real-world object (such as traffic signs, road lights, and vehicle head lights), even the simplest, with ICT capabilities. These smart objects will be equipped with sensors, actuators, and embedded processors and will need to adopt an open networked architecture. In this respect, considering that LEDs can also be modulated at relatively high speeds, this offers the intriguing possibility of realizing the illumination or display functionality and at the same time of transmitting data. This concept is usually referred to as VLC,[21,22] and provides to the overlying applications increased reliability, significantly reduced energy footprint, interference-free transmission, cost efficiency (LED lights already installed for various applications), as well as easy integration and interoperability.

However, since almost all vehicles dispose LED lights, it would be very easy and cost-efficient to utilize those LEDs for additional purposes, such as for offering fast,

[21] O. Bouchet et al, “Visible-light communication system enabling 73 Mb/s data streaming 2010 IEEE Globecom Workshops”, GC’10, art. no. 5700092, pp. 1042–1046.

[22] T.Komine et al, “Basic Study on Visible-Light Communication using Light Emitting Diode Illumination,” Proc. of the 11th Int. Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC 2000), London, US, pp. 1325–1329, 2000.

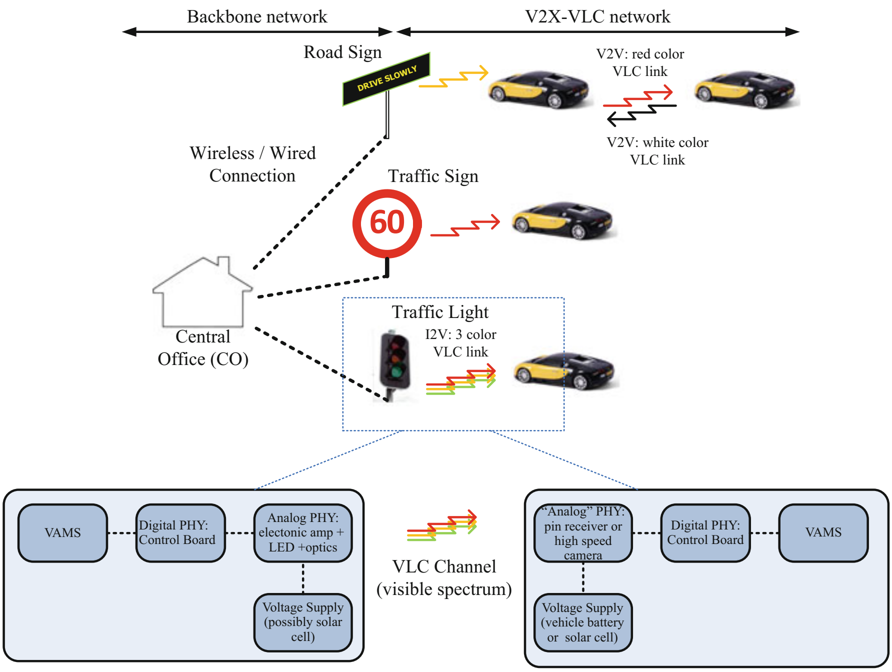

Fig. 2.8 VLC as a standard for V2X communications

reliable, and energy-efficient information to the driver, complementing and cooperating with other available solutions, as will be explained in the sequel. As such, LED-VLC seems a natural candidate for realizing V2X communications.[23]

Figure 2.8 illustrates the basic concepts associated with a system relying on VLC. The system is decomposed into a backbone network connecting the central office (CO) to the various access points of the network (traffic lights, road signs, etc.). The CO is responsible for coordinating and managing the information exchange between the vehicles and the infrastructure. The backbone network can be implemented using existing wire-line or wireless technologies (fiber-to-the-x, ADSL, RF links, etc.). The second part of the network is based on VLC technology and consists of the various V2I and V2V connections.

The VLC links can be used for:

- Downstream connection from the traffic lights to the vehicles using the LEDs of the lights as a means of transmitting data. All three LED colors must be used here (red, green, yellow).
- Downstream connection from road and traffic signs to the vehicles. The connections are realized through the sign's single color LED.

[23] Binti Che Wook et al, "Visible light communication with LED-based traffic lights using 2-dimensional image sensor", CCNC 2006, 1, art. no. 1593024, pp. 243–247 (2006).

- Upstream connection between the vehicle and the various access points. This can be realized using the vehicle's white LED lights.
- Upstream and downstream connection between the vehicles. These are supported with the LED front and break lights. During daytime it may be interesting to consider IR LEDs embedded in the vehicle lights.
- Upstream connection from the vehicle to the access point through either visible or IR LEDs.
- Supporting decision-making in the "Vehicle Autonomic Management System" (VAMS).

Overall, VLC is a valid candidate for complementing current solutions in the world of transportation, through offering (1) high reliability, (2) low infrastructure cost, (3) very low carbon emissions, and (4) resilience to interference.

2.7 Bluetooth

Bluetooth technology is a wireless communications technology that is simple, secure, and can be found almost everywhere. You can find it in billions of devices ranging from mobile phones and computers to medical devices and home entertainment products. It is intended to replace the cables connecting devices, while maintaining high levels of security. Automotive applications of Bluetooth technology began with implementing the Hands-Free Profile for mobile phones in cars. The development is coordinated by the Car Working Group (CWG) and is ongoing ever since 2000 by implementing different profiles and new features. The key features of Bluetooth technology are ubiquitousness, low power, and low cost. The Bluetooth Specification defines a uniform structure for a wide range of devices to connect and communicate with each other.

When two Bluetooth-enabled devices connect to each other, is the so-called pairing. The structure and the global acceptance of Bluetooth technology means any Bluetooth-enabled device, almost everywhere in the world, can connect to other Bluetooth-enabled devices located in proximity to one another.

Connections between Bluetooth-enabled electronic devices allow these devices to communicate wirelessly through short range, creating ad hoc networks commonly known as piconets. Piconets are established dynamically and automatically as Bluetooth-enabled devices enter and leave radio proximity, meaning that you can easily connect whenever and wherever it's convenient for you. Each device in a piconet can also simultaneously communicate with up to seven other devices within that single piconet and each device can also belong to several piconets simultaneously. This means the ways in which you can connect your Bluetooth devices is almost limitless. There are applications that even do not require a connection establishment. It may be enough if the Bluetooth device's wireless option is set to "visible" and "shown to all," because fixed positioned Bluetooth access points may detect the movement of the Bluetooth device from one AP to another AP. This technology can easily be used for measuring the traffic flow.

A fundamental strength of Bluetooth wireless technology is the ability to simultaneously handle data and voice transmissions, which provides users with a variety of innovative solutions such as hands-free sets for voice calls, printing and fax capabilities, and synchronization for PCs and mobile phones, just to name a few.

The range of Bluetooth technology is application specific. The Core Specification mandates a minimum range of 10 m or 30 ft, but there is no set limit and manufacturers can tune their implementations to provide the range needed to support the use cases for their solutions.

Range may vary depending on class of radio used in an implementation:

– Class 3 radios—have a range of up to 1 m or 3 ft
– Class 2 radios—most commonly found in mobile devices—have a range of 10 m or 33 ft
– Class 1 radios—used primarily in industrial use cases—have a range of 100 m or 300 ft

Bluetooth technology operates in the open and unlicensed industrial, scientific, and medical (ISM) band at 2.4–2.485 GHz, using a spread spectrum, frequency hopping, full-duplex signal at a nominal rate of 1600 hops/s. The 2.4 GHz ISM band is available and unlicensed in most countries. The most commonly used radio is Class 2 and uses 2.5 mW of power. Bluetooth technology is designed to have very low power consumption. This is reinforced in the specification by allowing radios to be powered down when inactive.

Bluetooth technology's adaptive frequency hopping (AFH) capability was designed to reduce interference between wireless technologies (such as WLAN) sharing the 2.4 GHz spectrum. AFH works within the spectrum to take advantage of the available frequency. This is done by the technology detecting other devices in the spectrum and avoiding the frequencies they are using. This adaptive hopping among 79 frequencies at 1 MHz intervals gives a high degree of interference immunity and also allows for more efficient transmission within the spectrum. For users of Bluetooth technology this hopping provides greater performance even when other technologies are being used along with Bluetooth technology.

The newest Bluetooth Technology is Bluetooth 4.0 called Bluetooth Smart (Low Energy) Technology. While the power efficiency of Bluetooth Smart makes it perfect for devices needing to run off a tiny battery for long periods, the most important attribute of Bluetooth Smart is its ability to work with an application on the smartphone or tablet you already own. Bluetooth Smart wireless technology features:

– Ultra-low peak, average and idle mode power consumption
– Ability to run for years on standard coin-cell batteries
– Low cost
– Multi-vendor interoperability
– Enhanced range

In automotive industry the primary usage of Bluetooth connects hands-free car systems which help drivers focus on the road. Another special usage is health monitoring, e.g., people with diabetes can monitor their blood glucose levels by using a

Bluetooth glucose-monitoring device paired with the car. Also in-vehicle intelligent interfaces may provide, e.g., vehicle-related technical information to the driver via a Bluetooth channel.

In V2I systems Bluetooth can be used to provide communication channel between the car and the traffic signal systems. Nowadays several manufacturers offer Bluetooth capable traffic control devices. It is capable for privileging the public transport at the intersections or measuring the traffic and pedestrian flows with the help of the electronic devices installed with Bluetooth radio (such as smartphones, tablets, and navigation units). These systems detect anonymous Bluetooth signals transmitted by visible Bluetooth devices located inside vehicles and carried by pedestrians. This data is then used to calculate traffic journey times and movements. It reads the unique MAC address of Bluetooth devices that are passing the system. By matching the MAC addresses of Bluetooth devices at two different locations, not only the accurate journey time is measured, privacy concerns typically associated with probe systems are minimized.

2.8 2G and 3G Mobile Communication Infrastructures

The most wide-spread mobile (cellular) network technology is GSM (Global System for Mobile communication). GSM was designed principally for voice telephony, but a range of bearer services was defined (a subset of those available for fixed line Integrated Services Digital Networks, ISDN), allowing circuit-switched data connections at up to 9600 bits/s. The technology behind the Global System for Mobile communication (GSMTM) uses Gaussian Minimum Shift Keying (GMSK) modulation, a variant of Phase Shift Keying (PSK) with Time Division Multiple Access (TDMA) signaling over Frequency Division Duplex (FDD) carriers. Although originally designed for operation in the 900 MHz band, it was soon adapted also for 1800 MHz. The introduction of GSM into North America meant further adaptation to the 800 and 1900 MHz bands. Over the years, the versatility of GSM has resulted in the specifications being adapted to many more frequency bands to meet niche markets.

At the time of the original system design, this rate compared favorably to those available over fixed connections. However, with the passage of time, fixed connection data rates increased dramatically. The GSM channel structure and modulation technique did not permit faster rates, and thus the High Speed Circuit-Switched Data (HSCSD) service was introduced in the GSM Phase 2+.

During the next few years, the General Packet Radio Service (GPRS) was developed to allow aggregation of several carriers for higher speed, packet-switched applications such as always-on internet access. The first commercial GPRS offerings were introduced in the early 2000s. Meanwhile, investigations had been continuing with a view to increasing the intrinsic bit rate of the GSM technology via novel modulation techniques. This resulted in Enhanced Data-rates for Global Evolution (EDGE), which offers an almost threefold data rate increase in the same bandwidth. The combination of GPRS and EDGE brings system capabilities into the range covered by the International Telecommunication Unions IMT-2000 (third generation) concept, and some manufacturers and network operators consider the EDGE networks to offer third generation services.

In 1998, the ETSI (European Telecommunications Standards Institute) General Assembly took the decision on the radio access technology for the third generation cellular technology: wideband code-division multiple access, W-CDMA, would be employed. A dramatic innovation was attempted: a partnership project was formed with other interested regional standards bodies, allowing a common system to be developed for Europe, Asia, and North America. The Third Generation Partnership Project (3GPP) was born.

The Third Generation mobile cellular technology developed by 3GPP—known variously as Universal Mobile Telecommunications System (UMTS), Freedom of Mobile Multimedia Access (FOMA), 3GSM, etc., is based on wideband code division multiple access (W-CDMA) radio technology offering greater spectral efficiency and higher bandwidth than GSM. UMTS was originally specified for operation in several bands in the 2 GHz range. Subsequently, UMTS has been extended to operate in a number of other bands, including those originally reserved for Second Generation (2G) services. The UMTS radio technology is direct-sequence CDMA, each 10 ms radio frame is divided into 15 slots.

As a development of the original radio scheme, a high-speed download packet access (HSDPA, offering download speeds potentially in excess of 10 Mbit/s) and an uplink equivalent (HSUPA, also sometimes referred to as EDCH) were developed. Collectively the pair are tagged HSPA, and permit the reception of multimedia broadcast/multicast, interactive gaming and business applications, and large file download challenging traditional terrestrial or satellite digital broadcast services and fixed-line broadband internet access. The radio frames are divided into 2 ms subframes of 3 slots, and gross channel transmission rates are around 14 Mbit/s.

3GPP's radio access undergoes continuous development and the "long-term evolution" (LTE) exercise aims to extend the radio technology

2.9 4G/5G-D2D

2.9.1 Concept Overview

Given the diverse performance requirements of a wide spectrum of vehicular networking applications and the huge cost of deployment of specialized road infrastructure, research has been currently moving towards the investigation of the benefits of exploiting the existing/emerging mobile communication standards (LTE—X2 interface, and most importantly 5G Device-to-Device—D2D) as suitable mechanisms for delivering automotive applications, with a focus on autonomous driving (AD). It is envisaged that next generation mobile technologies (4G/4G+, 5G), including D2D networking and very low latency communications, will constitute alternative technology solutions to 802.11p.

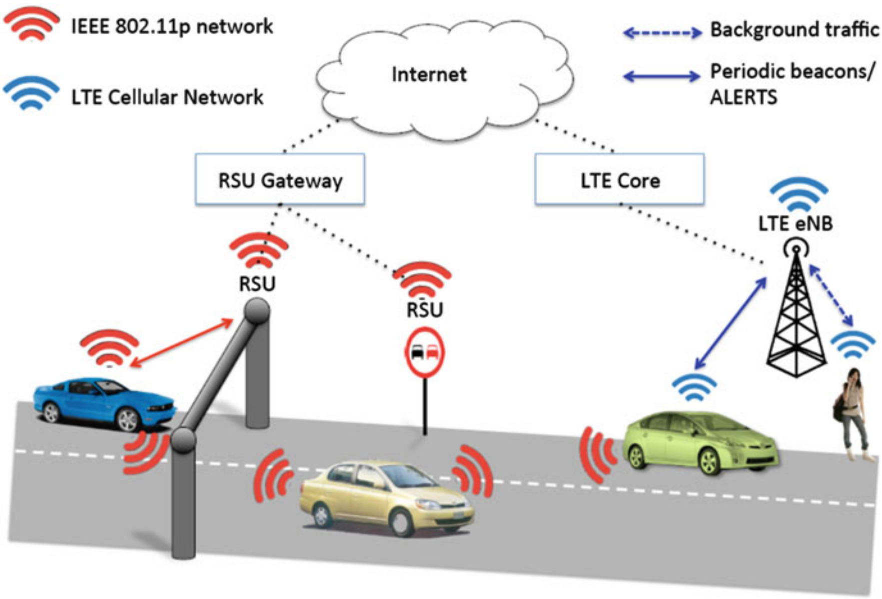

Fig. 2.9 Exploitation of 4G/5G mobile communication infrastructures in V2V and V2I

The main idea of this trend is to exploit emerging wireless standards to leverage Mobile Network Operators (MNOs) existing telecommunication infrastructures and (network) data, to enhance intelligence on the move for providing novel Advanced Driver Assistance Systems solutions.

In this respect, the framework depicted on Fig. 2.9 can exploit 4G/5G MNO infrastructure/date for V2V/V2I communications as an alternative to conventional approaches based on the utilization of costly Roadside Infrastructure/Units (RSU) and IEEE 802.11p. This solution might be able to promise multidimensional advantages since it promises (a) reduced latency, (b) increased reliability, (c) a more efficient and pervasive market penetration model, and (d) cost-efficiency.

A 2nd illustration of this framework, more detailed one, is presented in the following figure (Fig. 2.10). As shown, the framework should utilize various data "sources," aggregates the collected information through a Data Acquisition, Pre-processing and Fusion (DAPF) module, processes it on the basis of Cognitive Decision-Making (CDM) functionality, and provides as output directives to drivers to support them in accident avoidance and to mitigate the consequences of collisions.

Yet, ALL message transmissions foreseen to take place can be realized FULLY through the existing MNO telecom infrastructures instead of needing to build costly roadside infrastructures. The latter can of course be additionally exploited when and where available, for further enhancing road safety, but it is not a necessary condition for the success of such solutions.

The following subsections present, in detail, the information sources that such solutions use, the information itself, as well as some example operational scenarios that showcase its effectiveness.

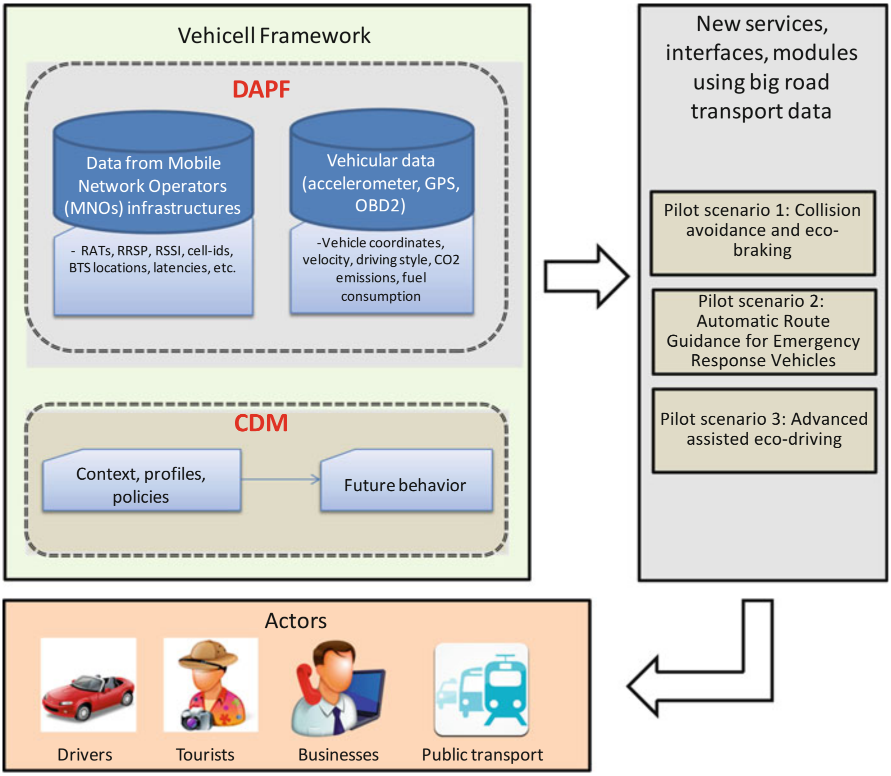

Fig. 2.10 Exploitation of mobile communication infrastructures in detail

2.9.2 Information Sources

As already mentioned, the fundamental novelty of this approach lies in the utilization of the MNOs telecom infrastructures, for any "message" transmission, instead of any other costly V2I technologies (requiring roadside infrastructures) and/or unreliable V2V technologies. To do so, the following data "sources" are utilized:

- A mobile smartphone (inside the vehicle) and/or an on-board device (if available)
- The vehicle itself (via an OBD-II device)
- MNO-related data

These 3 data sources can provide significantly useful information for drivers, with minimum costs, reduced latency, and high reliability, as will be shown in the sequel.

2.9.3 Example Data to Be Aggregated

Example data that will be collected from the abovementioned data sources are the following:

Smartphone/Tablet and/or On-Board Device (ADAS)

- MNO-related info, such as (a) Cell-id, LAC, and Radio Access Technology (RAT) currently utilized, (b) Received Signal Strength Indicator (RSSI) and/or Reference Signal Received Power (RSRP) from the serving Base Stations and/or from the neighboring ones, etc.
- Information from motion sensors, environmental sensors, and position sensors, such as accelerometers, gravity sensors, gyroscopes and rotational vector sensors, barometers, photometers, and thermometers, orientation, and magnetometers sensors.
- Location information (from GPS) such as latitude and longitude.

Vehicle/OBD-II

- Current and average speed, acceleration, throttle/boost, coolant temperature
- Timings (0–60 Km/h, 0–100 Km/h, 0–1000 m, etc.)
- Current and average CO_2 emissions (trip, overall)
- Current and average consumption (trip, overall)
- Tank level, etc.

MNO Data

- Location of Base Stations (i.e., GPS coordinates)
- RAT supported per Base Station (GSM, UMTS, HSPA, HSPA+, 4G)

2.9.4 Processing and Outcomes

The processing of the aforementioned information is made on the basis of smartphone applications that constantly provide the RSSI/RSRP level of the phone from the x-nearest BTSs, where $x > 3$ (often $x \approx 10$). This information is extremely useful if combined with additional data provided by the MNO, such as the location of BTS/Node-Bs, the RAT (GSM, UMTS, LTE, etc.), as with the help of triangular and multi-angular calculations and GPS data (if and whenever available-considering users reluctance to utilize an always-GPS ON application due to high battery consumption), it can result in the specification of coordinates of the cell phone with very high accuracy, its velocity, etc.

Moreover, this information can pave the way for significant improvements in the provision of fast, tailor-made information which the driver is capable of processing in changing conditions, in the sense that the efficiency of this and therefore its level of "automation" depends on the RAT that is locally and currently provided by the MNO. This "progressive" procedure is further justified in the scenarios presented below.

Cell phone accelerators can act complementarily to the above information, if we consider that the acceleration/deceleration of a vehicle can exploit cognitive principles and machine learning techniques, in order to result in extracting the driver's profile and proactively identifying a forthcoming emergency, judging from the driver's reactions, which will be provided through the cell phone accelerator. The driver's profile can be used in adding further enhancements to the directives provided.

Finally, specific data extracted from the vehicle through OBD2 and sent to the cell phone or on board device can also be exploited in providing innovative nature assistance to drivers.

2.9.5 Benefits of Framework

This approach can bring about significant advantages, with respect to safe and connected automation in road transport, compared to existing solutions, for all stakeholder involved (drivers, citizens, public authorities, and businesses). These advantages can be summarized as follows:

- *>50 % reduced latency*. This approach operates with significantly lower latencies (from 10 to 20 ms) compared to existing vehicle connectivity solutions (e.g., IEEE 802.11p— >60 ms) and thus can guarantee for faster decision-making and, in return, increased active safety for drivers[24]
- *20–30 % increased reliability and robustness*. The framework will bring a revolution to current road transport automation solutions since it will be able to provide a support for accurate, stable, reliable, and proactive tailor-made directives (assistance) to drivers. Reliability is higher than that of existing approaches (e.g., IEEE 802.11p,[25,26])
- *30–40 % increased cost-efficiency.* The framework is inherently cost-efficient since its main idea from its conception was to use existing infrastructures (namely telecommunication infrastructure), whilst exploiting their benefits (reduced latency, increased reliability), in order to provide innovative ADAS to drivers without the costs for road infrastructure
- *10–20 % resulting reduced energy footprint*. The CDM along with its decision-making support process can constitute a seminal move towards enhancing Green Driving Support Systems, through providing "greener" directives that will result in lower CO_2 emissions by at least 10 % compared to current conditions, which will positively impact the European society as a whole

[24] Hameed Mir and Filali, "LTE and IEEE 802.11p for vehicular networking: a performance evaluation", EURASIP Journal on Wireless Communications and Networking 2014, 2014:89

[25] KA Hafeez, L Zhao, Z Liao, BN Ma, Performance analysis of broadcast messages in VANETs safety applications, in Proceedings of the IEEE Global Telecommunications Conf. GLOBECOM 2010, Miami, FL, 6–10 December 2010

[26] F Bai, H Krishnan, Reliability analysis of DSRC wireless communication for vehicle safety applications, in Proceedings of the IEEE Intelligent Transportation Systems Conference (ITSC 2006), (Toronto). 17–20, September 2006

- *30 % increased security, privacy and confidentiality.* The solution is protected against jamming and tapping through the utilization of the mobile communication infrastructure mechanisms, compared to current vehicular networking approaches (e.g., IEEE 802.11p,[27,28,29])
- *Easy integration (availability).* With such a solution, drivers, businesses, and public service providers will have the possibility to communicate with each other and share useful information. One of the major challenges of public service providers and local authorities is the need to manage the multiple interfaces to the different legacy and newly introduced systems. This solution will overcome this by introducing a unified frontend to the system having a built in capability to support and integrate legacy deployed solutions and thus introduce the real added value for the operators and decision makers in adoption of the solution from the business perspective. This is particularly easy due to the utilization of existing user equipment (smartphones)

2.9.6 Operational Scenarios

This subsection describes some indicative scenarios that showcase the efficiency of the solutions that exploit mobile communication infrastructures in providing novel ADAS solutions.

2.9.6.1 Scenario 1: Collision Avoidance

Scenario 1 envisages a faster, more reliable, and more secure collision avoidance use case compared to today's solutions, as illustrated in Fig. 2.11.

A cell phone inside a vehicle (blue vehicle) is currently located within an LTE service area, and a potential emergency incident (e.g., sudden brake) takes place close to it. The vehicle involved in the incident (white vehicle) can notify the nearest eNB and the eNB can inform the blue vehicle accordingly, with the communication taking place through the X2-AP protocol, over the X2 interface designed for LTE. The overall required latency is <20 ms, this being appropriate for most of today's available as well as future vehicular applications.

The resulting advantages of such low latency are obvious since even emergency braking can be activated. The emergency messages will have a structure compliant with the ETSI standards Decentralized Environmental Notification Message

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[27] G Araniti et al, "LTE for vehicular networking: a survey", IEEE Commun. Mag. 51(5), 148–157 (2013)

[28] HY Kim, DM Kang, JH Lee, TM Chung, A performance evaluation of cellular network suitability for VANET. World Academy of Science, Engineering and Technology, International Science Index 64, 6(4), 1023–1026 (2012)

[29] A Vinel, 3GPP LTE versus IEEE 802.11p/WAVE: which technology is able to support cooperative vehicular safety applications? IEEE Wireless Commun. Lett. 1(2), 125–128 (2012)

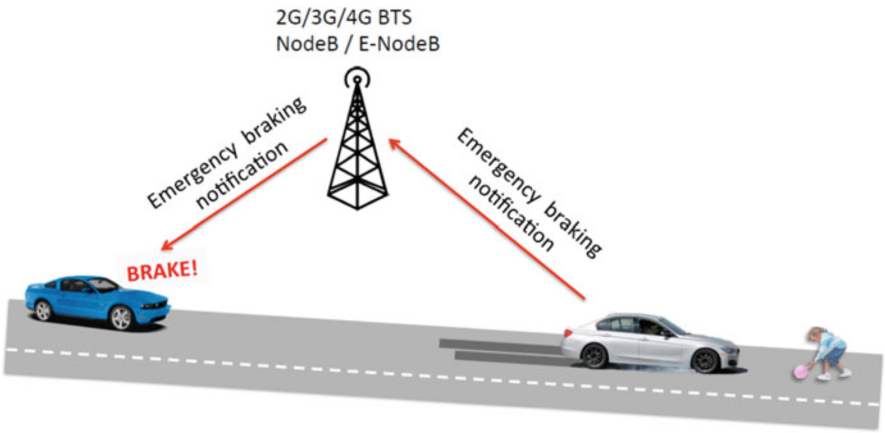

Fig. 2.11 Scenario 1—collision avoidance and eco-braking

(DENM)[30] and Cooperative Awareness Message (CAM).[31] Therefore the applications layers for the emergency braking functions will be identical, whether the messages are transmitted only through mobile communication systems (i.e., LTE). Moreover, the absence of roadside infrastructure costs renders this solution attractive.

The aforementioned scenario is even more challenging in the case of a 5G service area, where the potential D2D communication (without even the communication through any base station) will support even lower latencies (<10 ms), paving the way for progressively autonomous driving applications. On the other hand, in the case that the cell phones in vehicle A and vehicle B are located in a UMTS (3G) service area, latency drops down to >60 ms. This can be acceptable for some fundamental vehicular applications. Moreover, considering the existence of a GSM service area, the required latency would be >600 ms on average. This latency is calculated stressing the necessity of data (re)transmission within the same cell, which is needed for minimizing the required Round Trip Time (RTT). However, such high latencies are inappropriate for most of the vehicular applications since they prohibit any substantial real-time emergency management.

In general, such solutions also explore all the potential combinations among the current RATs (e.g., GSM–UMTS, and LTE-UMTS) since neighboring vehicles may be served through versatile RATs.

[30] ETSI TS 102 637-3—Decentralized Environmental Notification Message, (http://www.etsi.org/deliver/etsi_ts/102600_102699/10263703/01.01.01_60/ts_10263703v010101p.pdf), accessed February 2015.

[31] ETSI TS 102 637-2—Cooperative Awareness Message (http://www.etsi.org/deliver/etsi_ts/102600_102699/10263702/01.02.01_60/ts_10263702v010201p.pdf), accessed February 2015.

2.9.6.2 Scenario 2: Automated Route Guidance for Emergency Response Vehicles

From data regarding traffic speed of individual vehicles and traffic concentration, it will be possible to generate a real-time traffic map, with a high degree of accuracy. Compared to current mobile apps (e.g., www.waze.com), solutions of this kind usually promise higher reliability, since it will guarantee service provision without necessitating a community participation). Using intelligent algorithms, it is possible to determine the fastest route to a destination, utilizing actual times, rather than estimates that ignore delays caused by irregular traffic (a frequent occurrence) or unforeseeable events (accidents). By plotting the processed data onto a map, it is possible to display:

- Real-time Average speed of traffic on a road, including (a) on an individual segment of road, (b) at an intersection, and (c) on individual road lanes.
- Predict changes in those traffic speeds, based on traffic in the broader area
- The fastest route to a destination based on current traffic speeds and precise estimations of future traffic speeds. The time to destination will be calculated based on the driver's "driving profile."

Furthermore, the software is able to identify which vehicle in a fleet can reach a destination in the shortest time, taking into consideration actual situational awareness, rather than broad, inaccurate estimations. Such route guidance can one day lead to fully automated response services and can be utilized by unmanned taxiing companies for efficient passenger transport, with a profound impact on eco-driving, by providing significant improvements in fuel economy.

2.9.6.3 Scenario 3: Advanced Assisted Eco-Driving

The 3rd scenario envisages the utilization of the accelerometer and of the in-vehicle *OBD-II*, so as to devise eco-driving directives. In particular, the accelerometer and the *OBD-II* can provide several data on the current fuel consumption, the CO_2 emissions, the road vehicle condition, and the driver profile (driving style). This information is usually aggregated by a software module that is able to aggregate large amounts of heterogeneous data and provides a twofold outcome:

- Extract the most appropriate (re)route for the vehicle dynamically, depending on the traffic (real-time estimation through RSSI/RSRP/GPS) and the expected CO_2 emissions and fuel consumption.
- Gather long-term statistical data leading to knowledge and experience in order to extract an overall eco-driving profile of the driver and provide information to insurance companies.

2.10 ETSI and CEN Standards for V2X Communications

Two EU organizations (ETSI and CEN) have been performing research towards identifying and specifying new standards for vehicular communications. In this respect, they have recently announced[32] connected car standards that pave the way for V2V (vehicle to vehicle) and V2I (vehicle to infrastructure) throughout Europe. More and more connectivity is being added to vehicles and as a result their attack surface is increasing, as is the list of potential implications of cyber attack against vehicles.

The standards are: the specification of Cooperative Awareness Basic Service—EN 302 637-2, and the specification of Decentralized Environmental Notification Basic Service—EN 302 637-3. They define the message sets needed for running Cooperative ITS safety critical applications. Published as Technical Specifications in Release 1 of ETSI ITS, the ENs have been prepared taking into account feedback from Plugtests interoperability testing workshops organized by ETSI for the industry, as well as feedback from implementation. They were developed under Mandate 453 of the European Commission.

The Cooperative Awareness Service enables the exchange of information between road users and roadside infrastructure, providing each other's position, dynamics, and attributes. Road users may be cars, trucks, motorcycles, bicycles, or even pedestrians, while roadside infrastructure equipment includes road signs, traffic lights, or barriers and gates. Awareness of each other is the basis for several road safety and traffic efficiency applications. This is achieved by regular exchange of information from vehicle to vehicle (V2V), and between vehicles and roadside infrastructure (V2I and V2I) based on wireless networks. EN 302 637-2 specifies the syntax and semantics of the Cooperative Awareness Message (CAM) and provides detailed specifications on the message handling.

EN 302 637-3 defines the Decentralized Environmental Notification (DEN) Basic Service that supports road hazard warning. The Decentralized Environmental Notification Message (DENM) contains information related to a road hazard or an abnormal traffic condition, including its type and position. Typically for an ITS application, a message is disseminated to ITS stations that are located within a geographic area through direct vehicle-to-vehicle or vehicle-to-infrastructure communications in order to alert road users of a detected and potentially dangerous event. At the receiving side, the message is processed and the application may present the information to the driver if it is assessed to be relevant. The driver is then able to take appropriate action to react to the situation accordingly.

[32] europa.eu/rapid/press-release_IP-14-141_en.htm

2.11 Conclusions

This chapter has gone through the available standards for vehicular communications. Let it also be noted it was intentionally avoided to distinguish between V2V standards and V2I standards because many of them, especially the newest ones, have been designed so as to serve both types of communication.

Overall, from an implementation point of view, the problem with V2V communications so far is that they suffer from the fax-machine problem, i.e., all vehicles on route should have the technology implemented. Imagine, e.g., an incident where 3 cars are involved, where 2 of them are enabled with any of the technologies that support V2V communications, whereas the 3rd one is not. The accident would not be avoided.

On the other hand, the problem with V2I communications is that usually they require high installation costs. As a result, only a few cities can afford to have everywhere sensors and/or internet-enabled objects of the transportation infrastructure.

In conclusion, researchers are now trying to put into effect hybrid standards, in that they should enable both V2V and V2I communications.

2.12 Review Questions

Question 2.1:
What are the most commonly utilized standards for V2V communications?

Question 2.2:
What are the most commonly utilized standards for V2I communications?

Question 2.3:
What are the barriers for the adoption of V2V standards and what for V2I standards?

Question 2.4:
Why and how mobile communication infrastructures can be a candidate for V2X communications?

Question 2.5:
How does 5G-D2D promise low latencies in vehicular communications?

Question 2.6:
Is LED-VLC a better standard than IEEE 802.11p?

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