Smart Vehicles, Technologies and Main Applications in Vehicular Ad hoc Networks

Anna Maria Vegni, Mauro Biagi and Roberto Cusani

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1. Introduction

Vehicular Ad hoc NETworks (VANETs) belong to a subcategory of traditional Mobile Ad hoc NETworks (MANETs). The main feature of VANETs is that mobile nodes are vehicles endowed with sophisticated "on-board" equipments, traveling on constrained paths (*i.e.*, roads and lanes), and communicating each other for message exchange via Vehicle-to-Vehicle (V2V) communication protocols, as well as between vehicles and fixed road-side Access Points (*i.e.*, wireless and cellular network infrastructure), in case of Vehicle-to-Infrastructure (V2I) communications [1].

Future networked vehicles represent the future convergence of *computers*, *communications infrastructure*, and *automobiles* [2]. Vehicular communication is considered as an enabler for driverless cars of the future. Presently, there is a strong need to enable vehicular communication for applications such as safety messaging, traffic and congestion monitoring and general purpose Internet access.

VANET is a term used to describe the spontaneous ad hoc network formed over vehicles moving on the roadway. Vehicular networks are fast emerging for developing and deploying new and traditional applications. More in detail, VANETs are characterized by high mobility, rapidly changing topology, and ephemeral, one-time interactions. Basically, both VANETs and MANETs are characterized by the movement and self-organization of the nodes (*i.e.*, vehicles in the case of VANETs). However, due to driver behavior, and high speeds, VANETs characteristics are fundamentally different from typical MANETs. VANETs are characterized by rapid but somewhat predictable topology changes, with frequent fragmentation, a small effective network diameter, and redundancy that is limited temporally and functionally.

VANETS are considered as one of the most prominent technologies for improving the efficiency and safety of modern transportation systems. For example, vehicles can communicate detour, traffic accident, and congestion information with nearby vehicles early to reduce traffic jam near the affected areas. VANETs applications enable vehicles to connect to the Internet to obtain real time news, traffic, and weather reports. VANETs also fuel the vast opportunities in online vehicle entertainments such as gaming and file sharing via the Internet or the local ad hoc networks.

Applications such as safety messaging are near-space applications, where vehicles in close proximity, typically of the order of few meters, exchange status information to increase safety awareness. The aim is to enhance safety by alerting of emergency conditions. Applications for VANETs are mainly oriented to safety issues (*e.g.*, traffic services, alarm and warning messaging, audio / video streaming and generalized infotainment, in order to improve the quality of transportation through time-critical safety and traffic management applications, [1]). At the same time, also entertainment applications are increasing (*e.g.*, video streaming and video-on-demand, web browsing and Internet access to passengers to enjoy the trip).

Applications of alarm messaging have strict latency constraints of the order of few milliseconds, and very high reliability requirements. In contrast, applications such as traffic and congestion monitoring require collecting information from vehicles that span multiple kilometers. The latency requirements for data delivery are relatively relaxed *i.e.*, they are "delay-tolerant", however, the physical scope of data exchange is much larger. In contrast, general purpose Internet access requires connectivity to the backbone network via infrastructure, such as Road-Side Units (RSUs).

Non-safety applications are expected to create new commercial opportunities by increasing market penetration of the technology and making it more cost effective. Moreover, comfort and infotainment applications aim to provide road travelers with needed information support and entertainment to make the journey more pleasant. They are so varied and ranges from traditional IP-based applications (*e.g.*, media streaming, voice over IP, web browsing, etc.) to applications unique to the vehicular environment (*e.g.*, point of interest advertisements, maps download, parking payments, automatic tolling services, etc.).

More in general, we can distinguish between *intra* and *inter*-vehicle communications. The first term is used to describe communications within a vehicle, while the second one represents communications between vehicles, or vehicles and sensors, placed in or on various locations, such as roadways, signs, parking areas, and so on. Inter-vehicle communications can be considered to be more technically challenging because vehicle communications need to be supported both when vehicles are stationary and when they are moving. As an instance, the use of a prepaid or automatic billing system when a vehicle slows down instead of stopping at a toll-booth is provided by using a small electronic transmitter. Another example is the integration of cameras and speed sensors to determine the speed of a vehicle (*i.e.*, the well-known autovelox).

Quality of service provided in a VANET is strongly affected by mobility of vehicles, and then dynamic changes of network topology. Different classes of vehicles can move in VANETs, depending on traffic conditions (*i.e.*, dense and sparse traffic), speed limits in particular roads (*i.e.*, highways, rural roads, urban neighborhoods), and also typology of vehicles (*i.e.*, trucks, cars, motorcycles, and bicycles). In general, compared to traditional mobile nodes in MANETs, vehicles in VANETs move at higher speeds (*i.e.*, from 0 to 40 m/s).

All these unique features let VANETs well fit into the class of *opportunistic networks* that means the network behavior is changing and connectivity availability is not always satisfied. As a typical example, in order to maintain network connectivity in VANETs, it is a common technique to connect vehicles traveling on the roadway in opposite directions by means of opportunistic connectivity links. This situation is described as *bridging* technique [3]. However, link breakages strongly hinder stable and durable V2V communications, and as a result communications are dropped. On the other hand, the limited infrastructure coverage, because of sparse fixed access points settling, may cause short-lived and intermittent V2I connectivity. It follows that *interconnectivity* and *seamless connectivity* issues in vehicular ad hoc networks represent a challenge for many researchers. Solutions based on both horizontal and vertical *handover* procedures have been largely investigated in recent works [4], [5], [6].

To summarize, V2V communications have the following advantages: (*i*) to allow short and medium range communications, (*ii*) to present lower deployment costs, (*iii*) to support short messages delivery, and (*iv*) to minimize latency in the communication link. Nevertheless, V2V communications present the following shortcomings that can be solved with the integration with V2I, such as (*i*) frequent topology partitioning due to high mobility, (*ii*) problems in long range communications, (*iii*) problems using traditional routing protocols, and (*iv*) broadcast storm problems [7] in high density scenarios. On the other hand, the strong points of V2I, are the following: (*a*) information dissemination for VANETs, especially using advanced antennas [8], (*b*) VANET / Cellular interoperability [9], and (*c*) WiMAX (Worldwide Interoperability for Microwave Access) penetration in vehicular scenarios [10]. The integration of WiMAX and WiFi technologies seems to be a feasible option for better and cheaper wireless coverage extension in vehicular networks.

In this chapter we will introduce the state-of-the-art of recent technologies used in vehicular networks, specifically for *smart vehicles*, which require novel functionalities such as data communications, accurate positioning, control and decision monitoring.

This chapter is organized as follows. Section 2 describes the concept of *smart vehicles*, and introduces the main components, sensors and capabilities. Section 3 deals with the technologies for VANETs, such as IEEE 802.11*p*, 3GPP, CALM, and Cognitive Radio. Finally, an overview of main applications in VANETs will be provided in Section 4, while conclusions are drawn at the end of this chapter.

2. Smart vehicles

In the next years, vehicles will be equipped with multi interface cards, as well as sensors, both on board and externally. With an increasing number of vehicles equipped with on-board wireless devices (*e.g.*, UMTS, IEEE 802.11*p*, Bluetooth, etc.) and sensors (*e.g.*, radar, ladar, etc.), efficient transport and management applications are focusing on optimizing flows of vehicles by reducing the travel time ad avoiding any traffic congestions. As an instance, the on-board vehicle radar could be used to sense traffic congestions and automatically slow the vehicle. In other accident warning systems, sensors are used to determine that a crash occurred if air bags were deployed; this information is then relayed via V2V or V2I within the vehicular network.

Forgetting traditional vehicles, in the next few years we will drive *smart —intelligent— vehicles*, with a set of novel functionalities (*e.g.*, data communications and sharing, positioning information, sensor equipment, etc.). It is then necessary that for specific applications (*i.e.*, safety messages and alerts, gossip-based applications, etc.) the majority of mobile vehicles within a vehicular network be equipped with *on-board* wireless device, namely On-Board eqUipment (OBU).

A number of systems and sensors are used to provide different levels of functionality. Among the major systems and sensors exploited for intra-vehicle communications we cite: the braking system, crash sensors, the data recorder, the engine control unit, the electronic stability control, the electronic steering, the infotainment system, the integrated starter generator, the lighting system, the power distribution and connectivity, seat belt sensors, the tire pressure monitoring system, etc., [11]. Particularly, for the brake systems, there are also the parking brake and the antilock brake system. The parking brake, which is also referred to as an emergency brake, controls the rear brakes through a series of steel cables. This allows the vehicle to be stopped in the event of a total brake failure. Moreover, also vehicle-mounted cameras are largely used to display images on the vehicle console.

Commonly, a smart vehicle is equipped with the following devices and technologies: (*i*) a Central Processing Unit (CPU) that implements the applications and communication protocols; (*ii*) a wireless transceiver for data transmissions among vehicles (V2V) and from vehicles to RSUs (V2I); (*iii*) a Global Positioning Service (GPS) receiver for positioning and navigation services; (*iv*) different sensors laying inside and outside the vehicle to measure various parameters (*i.e.*, speed, acceleration, distance from neighboring vehicles, etc.); (*v*) an input/ output interface for human interaction with the system.

The basic idea of *smart vehicles* is addressed to safety issues, and then by a proper combination of functionalities like *control*, *communications*, and *computing* technologies, it will be possible to assist driver decisions, and also prevent wrong driver's behaviors [12]. The *control* functionality is added directly into smart vehicles to connect the vehicle's electronic equipment. The technology used for control should take into account the need of limit vehicle weight; as a matter, the added wiring increases vehicle weight, and weakens performance. It has been proven that for an average well-tuned vehicle, every extra 50 kilograms of wiring —or extra 100 W of power— increases fuel consumption by 0.2 liters for each 100 kilometers traveled.

Based on such considerations, today *control* and *communications* in a vehicular ad hoc network counter the problems of large amounts of discrete wiring. In the following Figure 1 we show the sheer number of systems and applications contained in a modern vehicle's network architecture.

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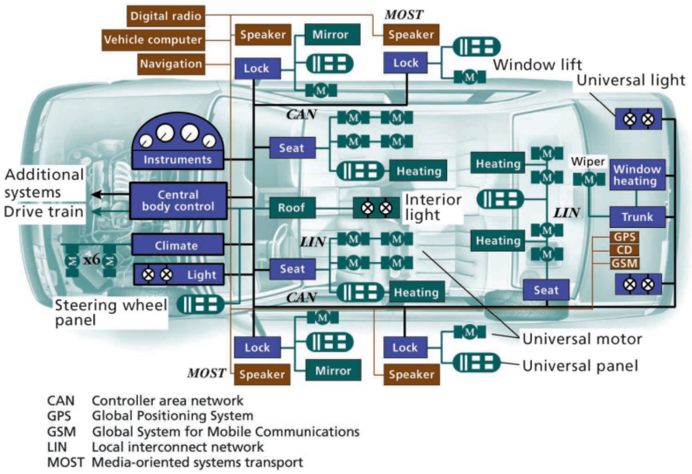

Figure 1. Design of a modern vehicle's network architecture, [13].

In the mid-1980s, Bosch developed the Controller Area Network (CAN), one of the first and most enduring automotive control networks, and now being used in many other industrial automation and control applications. CAN (ISO 11898) is currently the most widely used vehicular network, with more than 100 million CAN nodes sold in 2000.

CAN is a high-integrity serial data communications bus for real-time applications, operating at data rates of up to 1 Mbit/s and having excellent error detection and confinement capabilities. A typical vehicle can contain two or three separate CANs operating at different transmission rates. A low-speed CAN running at less than 125 Kbps usually manages a car's "comfort electronics," like seat and window movement controls and other user interfaces. Generally, control applications that are not real-time critical use this low-speed network segment. Low-speed CANs have an energy-saving sleep mode in which nodes stop their oscillators until a CAN message awakens them. Sleep mode prevents the battery from running down when the ignition is turned off. A higher-speed CAN runs more real-time critical functions such as engine management, antilock brakes, and cruise control. Although capable of a maximum baud rate of 1 Mbps, the electromagnetic radiation on twisted-pair cables that results from a CAN's high-speed operation makes providing electromagnetic shielding in excess of 500 Kb/s too expensive.

CAN is a robust, cost-effective general control network, but certain niche applications demand more specialized control networks. For example, X-by-wire systems use electronics, rather than mechanical or hydraulic means, to control a system. These systems require highly reliable networks.

In 2011 a novel enhanced version of CAN, called *CAN with Flexible Data-Rate* (CAN FD), supports payloads higher than 8 byte per frame. CAN FD protocol controllers are also able to perform standard CAN communication: this allows the use of CAN FD in specific operation modes, like software download at end-of-line programming, while other controllers that do not support CAN FD are kept in standby. In automotive electronics, engine control units, sensors, anti-skid-systems, etc. are connected using CAN. At the same time, CAN is cost effective to build into vehicle body electronics, *e.g.* lamp clusters, electric windows etc. to replace the wiring harness otherwise required.

Another component as shown in Figure 1 is the *LIN-Bus* (Local Interconnect Network), such as a vehicle bus standard −a computer networking bus-system− used within current automotive network architectures. The LIN specification is enforced by the LIN-consortium, with the first exploited version 1.1, released in 1999. The LIN bus is a small and slow network system that is used as a cheap sub-network of a CAN bus to integrate intelligent sensor devices or actuators. Recently LIN is also used over the vehicle's battery power-line with a special DC-LIN transceiver.

A well-known communication system designed for automotive applications is the *FlexRay Communications System i.e.*, a robust, scalable, deterministic, and fault-tolerant digital serial bus system. The core concept of the FlexRay protocol is a time-triggered approach to network communications. This is a different approach to some earlier successful networking schemes. Indeed, FlexRay is an option for upgrading existing network systems using CAN in the automotive industry.

It could be useful for applications, where safety and reliability in a work environment is of most importance due to its deterministic approach and two channel topologies. Due to its high data rate of 10Mb/s over each of its two channels, this protocol suits as the basis of a network backbone. The FlexRay protocol developed by the FlexRay consortium has already found applications in the automotive industry and looks set to become the network scheme favoured especially in x-by-wire applications and other safety critical systems. There is on-going research into the migration from CAN based systems to FlexRay based systems and as such the protocol could find itself being used in many areas outside the automotive industry. With its deterministic time-triggered approach and the high data rates achievable it is also suitable for safety and control applications.

In recent past, more number of multimedia and telematics applications has been integrated into premium class vehicles. These include Sound system, CD player, navigation systems, video players, voice input. High bandwidth requirement of all these applications has led to the development of infotainment communication system, *i.e. MOST* (Media Oriented Systems Transport). MOST is the de-facto standard for *multimedia* and *infotainment* networking in the automotive industry. The technology was designed from the ground up to provide an efficient and cost-effective fabric to transmit audio, video, data and control information between any devices attached even to the harsh environment of an automobile.

MOST technology is the result of the collaboration between car makers and suppliers, working to establish and refine a common standard within the MOST cooperation. MOST Cooperation was founded in partnership by BMW, Daimler Benz, Becker and OASIS silicon system.

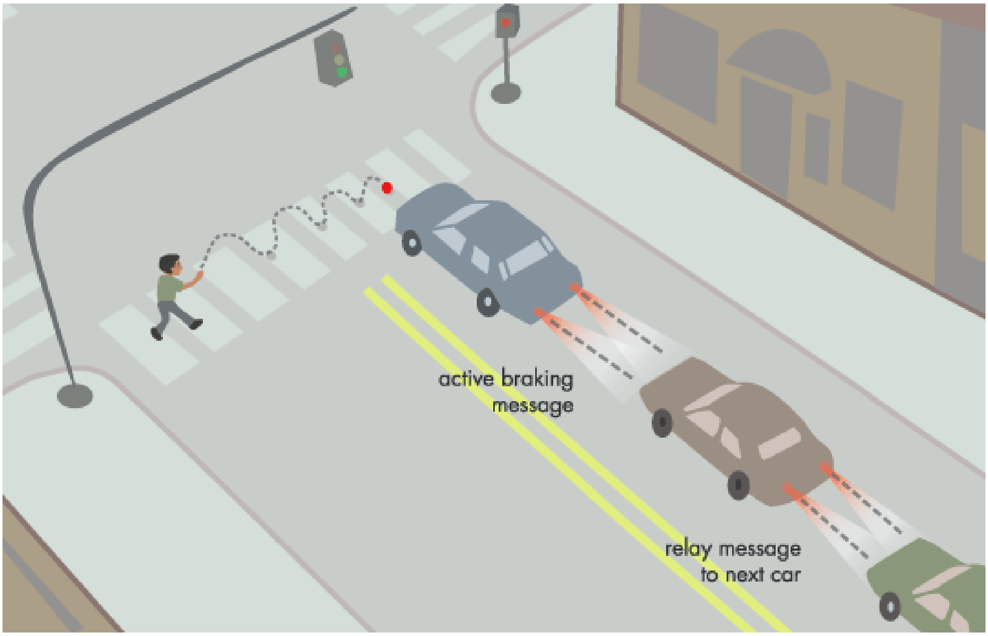

Figure 2. Safety application (*i.e.*, brake messaging) by using VLC devices.

Now SMSC is a leading provider of MOST, the de-facto standard for high bandwidth automotive multimedia networking.

Finally, our attention will be focused on the use of Visible Lighting Communications (VLC) can provide a valid technology for communication purposes in VANETs. The use of the visible spectrum provides service in densities exceeding femtocells for wireless access. It represents a viable alternative that can achieve high data rates, while also providing illumination. This configuration minimizes packet collisions due to Line Of Sight (LOS) property of light and promises to alleviate the wireless bottleneck that exists when there is a high density of rich-media devices seeking to receive data from the wired network.

Possible applications of VLC impact the quality of life, including control of auto / traffic signaling for safety and enabling communications where high noise interferes with WiFi. However, the main issues are related to medium-range LED-based communication derived from outdoor lighting (*i.e.*, sunlight and interference illuminations) that is common in public and private infrastructure (*e.g.*, street, building, and signage illumination).

It is also common on vehicles and in traffic infrastructure including car, rail and air transportation. Specific scenarios include V2V, V2I, as well as V2X communications [14], all of them supporting goals of improved safety, reduced carbon emissions, energy conservation, enhanced connectivity and network performance.

Although LEDs are commonly used in automotive and infrastructure lighting (*i.e.*, brake and traffic lights, as depicted in Figure 2), there remain key challenges to achieving effective modulation and communication between devices, especially while they are moving or in the presence of sunlight. Enabling communications in mobile outdoor systems, particularly in dense, fast moving safety-critical automotive environments is one of the main benefits of VLC for VANETs. In vehicular applications, mobile communications are particularly suitable for adoption of directional communications using LOS links. Applications such as safety and emergency messaging require very high reliability, and this can be provided through short-range inter-vehicular communications. As an instance, vehicles can be equipped with optical transceivers, such that they can communicate with other similarly equipped vehicles.

As a practical example, it is easy to understand how through the use of electronic or light pulse or radar, it is possible to measure the round-trip delay when pulses bounce off an object. For decreasing delays, the distance between the vehicle and any obstruction in the roadway decreases as well. This information can be used to automatically adjust the speed of the vehicle and inform the driver of the potential occurrence of a frontal collision condition (see Figure 2).

3. Technologies in Vehicular Ad hoc Networks

Several technologies are involved in Vehicular Ad hoc Networks, especially as enablers of Intelligent Transportation Systems (ITS). These are GSM, UMTS, Wi-MAX limited Wi-Fi and a new and specific technology thought for this kind of applications, namely Wireless Access in Vehicular Environments (WAVE), also known as IEEE 802.11/*p* [11]. This implicitly suggests that a car should have on board different radio interfaces (and/or network card). About WAVE, it is member of the IEEE 802.11 family, this implicitly suggests that this solution (currently at the stage of draft) is borrowed from IEEE 802.11 and adapted for the vehicular context.

Recent advances in the area of ITS have developed the novel Dedicated Short Range Communication (DSRC) protocol, which is designed to support high speed, low latency V2V, and V2I communications, using the IEEE 802.11*p* and WAVE standards. In 1999, the Federal Communication Commission (FCC) allocated a frequency spectrum for V2BV and V2I wireless communication. DSRC is a communication service that uses the 5.850-5.925 GHz band for the use of public safety and private applications [11].

The allocated frequency and newly developed services enable vehicles and roadside beacons to form VANETs in which the nodes can communicate wirelessly with each other without central access point. Specifically, the communication is in the bandwidth 5.850 GHz—5.925 GHz, so allowing a band of 70 MHz with some guard bands. This band is partitioned in 7 different sub-bands presenting a bandwidth of 10 MHz. The first channel is for V2V communication with public safety purposes while the second and third channels are private channels and used for public safety too in a medium range environment. The fourth is a control channel while the fifth and sixth channels are for public safety services with short range. The seventh channel is dedicated to manage public safety intersections.

Data-rates offered by VANET strictly depend on the kind of service and its own specifications. As an example the smaller data rate is for toll and payment services (highways) where the transmission ate is of the order of few Mb/s at tens of meters. The same distance range is for the Internet access even if the required rate can rise till to 54 Mb/s. Safety message service should allow proactive actions so the range is much higher, of the order of hundreds of meters and the required rate is below 20 Mb/s, down to 6 Mb/s. Finally, services regarding emergency vehicles require rate of the order of 5 Mb/s at a very high distance with respect to previous ones (*e.g.*, 3000 m).

The worldwide ISO TC204 / WG16 has produced a series of draft standards, known as CALM (Continuous Air-Interface, Long and Medium Range). The main goal of CALM is to develop a standardized networking terminal, able to seamless connect vehicles and roadside systems, avoiding disconnections. This can be well accomplished through the use of a wide range of communication devices and networks, such as mobile terminals, wireless local area networks, and the short-range microwave (DSRC) or infrared (IR).

The CALM architecture separates service provision from medium provision via an IPv6 networking layer, with media handover, and will support services using 2G, 3G, 5 GHz, 60 GHz, IEEE 802.16*e*, IEEE 802.20, etc. A standardized set of air interface protocol is provided for the best use of resources available for short, medium and long-range, safety critical communications, using one or more of several media, with multipoint (mesh) transfer.

The CALM concept is now at the core of several major EU sixth framework research and development projects. In the United States, the Vehicle Infrastructure Integration (VII) initiative will be operating using IEEE 802.11*p* / 1609 standards at 5.9 GHz, which are expected to be aligned with CALM 5.9-GHz standards, although the IEEE standards do not have media handover.

Due to the recent strides made in VANETs, a new class of in-car entertainment systems and enabling emergency services using opportunistic spectrum has increased by means of Cognitive Radio (CR) technology [15]. These CR-enabled Vehicles (CRVs) have the ability to use additional spectrum opportunities outside the IEEE 802.11*p* specified standard band.

The growing spectrum-scarcity problem, due to the request of high-bandwidth multimedia applications (*e.g.*, video streaming) for in-car entertainment, and for driver-support services, such as multimedia-enabled assistance, has driven researchers to use the CR technology, for opportunistic spectrum use, which directly benefits various forms of vehicular communication. In such a network, each CRV implements spectrum management functionalities to (*i*) detect spectrum opportunities over digital television frequency bands in the Ultra-High Frequency (UHF) range, (*ii*) decide the channel to use based on the QoS requests of the applications, and (*iii*) transmit on it, but without causing any harmful interference to the licensed owners of the spectrum.

CRVs have many unique characteristics that involve additional considerations than merely placing a CR within a vehicle. As an example, unlike static CR systems, the spectrum availability perceived by each moving vehicle changes dynamically over time, as a function not only of the activities of the licensed or Primary Users (PUs) but also based on the relative motion between them. Spectrum measurements need to be undertaken over the general movement path of the vehicles, leading to a path-specific distribution, instead of focusing on the temporal axis alone.

The CRV network can also leverage the constrained nature of motion, *i.e.* along linear and predecided paths corresponding to streets and freeways. At busy hours or in urban areas, spectrum information can be exchanged over multiple cooperating vehicles, leading to know more about the spectrum availability.

This also allows the vehicles that follow to adapt their operations and undertake a proactive response, which is infeasible in both static and non-stationary scenarios with random motion. The CRV networks fall under three broad classes, such as (*i*) V2V only, (*ii*) V2I only, and (*iii*) centralized V2I. More in detail, in the first class, a network can be formed between vehicles only that rely on cooperation for increasing accuracy. The second class deals with periodic interactions between vehicles and roadside BSs, where the latter acts as a repository of data that is subsequently used by passing vehicles. Finally, a completely centralized network is possible, in which the BS autonomously decides the channels to be used by the CRVs, without relying on information from the vehicles.

The access problem can be solved on two different layers. The first access problem is the selection of the network providing the service. The second one is the access within the selected network. This is mainly true for the V2I environment. Once specified the network quality metric, the vehicle should select the best network (this is the principle of *vertical handover*). Regarding the V2V communications, requiring network synchronization appears complicated so static access procedure x-DMA usage is by fact discouraged. Dynamic access best suit the typical channel features of the multi-hop network so Carrier Sensing Multiple Access – Collision Avoidance may be used. In this context the lack of synchronization at network level is not dramatic and requires only a node-by-node synchronization.

About routing procedures, these are a key point since, especially in the V2V scenario, each kind of message generated after a sensing action should be forwarded, in principle, to all the interested vehicles. In the V2I environment, the routing is not so critical even if vertical handover procedures should be considered.

Regarding V2V connections some routing *philosophies* can be considered. These are Geo-Broadcast, when a node send to all its neighbors an update about a region, Geo-anycast when a vehicle interrogates other nodes about road status and Fleetnet Routing, when a Greedy approach is used, that is, each node tries to forward the information according to a metric (variation of flooding) and it can be implemented via a beacon-based scheme that requires to each node to periodically transmit its position. It this last the positioning is really important and it can be derived or via an absolute service —like GPS— or by triangulation, so requiring more signaling.

The use of GPS (and, more in general, the GNSS) unit within the vehicles allows knowing the vehicles' positions. The awareness of precise locations is very important to every vehicle in VANET so that it can provide accurate data to its neighbors. Currently, typical localization techniques integrate GPS (GNSS) receiver data and measurements of the vehicle's motion.

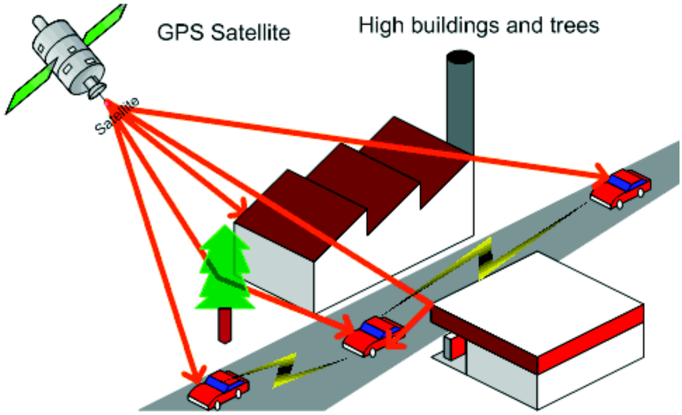

Figure 3. The use of satellite (GPS system) for outdoor localization. However, multipath effect affects the accuracy, [16].

GPS is a positioning system developed and operated by the U.S. Department of Defence. A GPS system is formed from a network of satellites that transmit continuous coded information, which makes it possible to identify locations on Earth by measuring distances from the satellites. At the same time, the receiver has the ability to obtain information about its velocity and direction.

With respect to VANET, many techniques have been proposed to the use of GPS as a localization technique, as shown in Figure 3. However, in many applications a simple GPS receiver is not a satisfactory tool for location estimation (*e.g.*, to discriminate vehicles between those vehicles on a particular highway and others outside the highway), also due to the multipath effect, specially affecting urban areas. Such a system requires highly accurate location estimation. Solutions integrating a GPS with an Inertial Navigation System (INS) can increase the accuracy of the localization application. Also augmented GPS solutions like Differential GPS are largely used for increasing accuracy.

Finally, hybrid approaches comprising of both V2V and V2I mode are largely used in order to improve network performance, while limiting the packet forwarding delay. For example, the ubiquitous integration of existing high-speed WLANs with wide-range 3GPP Long Term Evolution (LTE) results in the service extension of the backbone cellular network, [17]. LTE is the upcoming 4G cellular network with high data rate support for multimedia services, and robustness to high speed. The use of small cells will be massively deployed for increasing coverage areas; as a result they can be good candidates for V2I communications due to their reduced cost.

Novel solutions exploit the use of LTE technology in VANETs. In [18], the authors propose LTE4V2X approach, for the framework of a centralized vehicular network, whose effectiveness has been proven with respect to decentralized protocols. LTE4V2X uses both the IEEE 802.11*p* and 3GPP, LTE to provide an efficient way to periodically collect messages from vehicles and send them to a central server. As a result, the use of heterogeneous wireless network architectures achieves seamless data connectivity among separated vehicular clusters.

4. Applications

Vehicular applications are typically classified in (*i*) active road *safety* applications, (*ii*) traffic efficiency and *management* applications, and (*iii*) *comfort* and *infotainment* applications [11]. The first category aims to avoid the risk of car accidents and make safer driving by distributing information about hazards and obstacles. The basic idea is to broaden the driver's range of perception, allowing him/her to react much quicker, thanks to alerts reception through wireless communications. The second category focus on optimizing flows of vehicles by reducing travel time and avoiding traffic jam situations. Applications like enhanced route guidance/navigation, traffic light optimal scheduling, and lane merging assistance, are intended to optimize routes, while also providing a reduction of gas emissions and fuel consumption.

Finally, although the primary purpose of VANETs is to enable safety applications, non-safety applications are expected to create commercial opportunities by increasing the number of vehicles equipped with *on-board* wireless devices. Comfort and infotainment applications aim to provide the road traveler with information support and entertainment to make the journey more pleasant. In the next subsections we will describe the main aspects of *safety* and *entertainment* applications for VANETs.

The applications regarding *safety* are strictly tied to the main purpose of vehicles: moving from a point till to destination. Car collisions are currently one of the most frequent dead causes and it is expected that till 2020 they will become the third cause. This leads to a great business opportunity for infotainment, traffic advisory service, and car assistance.

Safety applications are always paramount to significantly reduce the number of accidents, the main focus of which is to avoid accidents from happening in the first place. For example, TrafficView [15] and StreetSmart [18] inform drivers through vehicular communications of the traffic conditions in their close proximity and farther down the road. Vehicle platooning is another way to improve road safety. By eliminating the hassle of changing lane and/or adjusting speed, platooning allows vehicles to travel closely yet safely together [20]. Fuel economy can also benefit from reduced aerodynamic as a vehicle headway is tightened (*e.g.*, the spacing can be less than 2 m [21]). Together with adaptive cruise control assisted by V2V communications, the problem of vehicle crashes due to human error can be alleviated.

Some of the most requested applications by polls, currently under investigation by several car manufacturers are Post Crash Notification (PCN), Congestion Road Notification (CRN), Lane Change Assistance (LCA) and Cooperative Collision Warning (CCW). In the following, a brief overview of the above-cited applications is provided.

In PCN, a vehicle involved in an accident would broadcast warning messages about its position to trailing vehicles so that it can take decision with time in hand as well as to the highway patrol for asking away support. The PCN application may be implemented both on V2V and V2I network configurations. In fact the V2V presents the advantage of giving quickly the information through a *discover-and-share* policy. Through the use of specific sensors, it consists in measuring possible changes in the rational behavior of the driver (*e.g.*, quick brake use, rapid direction changes, and so on), which are then communicated back via directional antennas to the other vehicles along the same direction. Once received, the closest vehicle can share this information with the other nodes with a flooding routing. In the particular case of false alarm by the first vehicle experiencing the irrational behavior of the driver, this information floods on the VANET. It is then important to fix the issue of false alarms.

Let us suppose a driver has been distracted by something on the panorama and moves the steering wheel, so that the vehicle direction changes accidentally. Once recognized the error, the driver will react by quickly changing direction or with a quick and strong use of breaks. This behavior is not rational since there is no danger for the VANET community, but only the behavior of a single is irrational. This represents a false indication of alarm. If the first following driver does not experience some accidents, then the vehicle does not forward this information, and false alarm probability is reduced, otherwise if it discovers the same problem, it shares such information with the other vehicles.

Dealing with the use of V2I architecture, the access points should gather information (*e.g.*, alarms for quick speed changes), coming from different vehicles, and merging the data so reducing the signaling from the vehicles. The V2V has the drawback of not allowing a quick communication if the vehicles are far away from each other (*e.g.*, in low traffic density scenarios), while the V2I is more energy consuming since it should be on all the time.

The LCA application constantly monitors the area behind the car when passing or changing lanes, and warns the driver about vehicles approaching from the rear or in the next lane over. This application has two different modalities, the first one is the so called passive mode, while the other one is the active mode. In the passive mode the vehicle simply measures distances, by means of detection and ranging procedures, while in the active mode it communicates to the other vehicles that they are too close, so they should change their direction / behavior.

Traffic monitoring and management are essential to maximize road capacity and avoid traffic congestion. Crossing intersections in city streets can be tricky and dangerous at times. Traffic light scheduling can facilitate drivers to cross intersections. Allowing a smooth flow of traffic can greatly increase vehicle throughput and reduce travel time [22]. A token-based intersection traffic management scheme is presented in [23], in which each vehicle waits for a token before entering an intersection. On the other hand, with knowledge of traffic conditions, drivers can optimize their driving routes, whereby the problem of (highway) traffic congestion can be lessened [24].

CRN detects and notifies about road congestions, which can be used for route and trip planning. This kind of application is partially implemented in current GPS-based applications where a new route is evaluated when heavy congestion has been detected on a route or in a portion of it. Up till now several commercial tools are available for smart-phones and special purpose devices. These are currently based on GPS coordinates and local resident software able to indicate the shortest or fastest routes from a starting point till to a destination by considering one ways streets and so forth. A new generation of this kind of software integrates some control messages coming from the so-called Radio Data System-Traffic Message Channel (RDS-TMC) that gathers information about unavailable routes or congested streets. TMC messages contain a considerable amount of information:

- *Identification*: what is causing the traffic problem and its seriousness;
- *Location*: the area, road or specific location affected;
- *Direction*: the traffic directions affected;
- *Extent*: how far the problem stretches back in each direction;
- *Duration*: how long the problem is expected to affect traffic flow;
- *Diversion advice*: alternative routes to avoid the congestion.

The service provider encodes the message and sends it to FM radio broadcasters, who transmit it as an RDS (Radio Data System) signal within normal FM radio transmissions. There's usually only about 30 seconds between the first report of an incident to the traffic information centre and the RDS-TMC receiver getting the message.

Also this application may be implemented according to a V2V configuration or a V2I one. In fact, it is possible to encapsulate information about the position, the direction, and the average speed, which are then communicated back to the vehicle following on the street the information. As it appears clear, this solution suffers for a large amount of data to be processed by the vehicles themselves. What is worth in this environment is the use of V2I since the access points can process information coming and communicate to the incoming vehicles the new route after request information about their destination. So, with a software that implements what is current available on the market (with a special purpose processor in this case and without strict bounds on energy consumption for processing) it is possible to develop an instance of ITS.

Finally, the CCW system works with a cutout revealing a stopped car, or a stopped or slow-moving car before arrival at the curve or downhill. All these applications require radio transceivers for message exchange, GPS and sensor on board car and road infrastructure units. Even in this case the dualism between V2V and V2I is renovated. Not so different from PCN, the behavior of the driver must be *understood* by the vehicles and then forwarded to the following cars and the vehicles coming with an opposite direction. This can be set up in a V2V modality since once recognized (*i.e.*, just happened) it is important to spread and flood this information. In the second phase, about 30 seconds or one minute, depending on traffic level, the information should be managed by the access point so to advice upcoming vehicles in time.

For what concerns *non-safety* applications, they have very different communication requirements, from no special real-time requirements of traveller information support applications, to guaranteed Quality-of-Service needs for multimedia and interactive entertainment applications. In general, this class of applications is motivated by the desire of the passengers to communicate either with other vehicles or with ground-based destinations (*e.g.*, Internet hosts or the Public Service Telephone Network (PSTN)). Also, various traveler information applications belong to this category. As an instance, the driver could receive local information regarding restaurants, hotels and, in general, Point of Interest, whenever the vehicle is approaching there (*i.e.*, *context aware* applications).

The aim of *infotainment* applications is to offer convenience and comfort to drivers and/or passengers. For example, Fleetnet [25] provides a platform for peer-to-peer file transfer and gaming on the road.

A real-time parking navigation system is proposed in [26] to inform drivers of any available parking space. Digital billboards for vehicular networks are proposed in [27] for advertisement. Internet access can be provided through V2I communications; therefore, business activities can be performed as usual in a vehicular environment, realizing the notion of mobile office [7]. On-the-road media streaming between vehicles also can be available [7], [8], making long travel more pleasant. An envisioned goal is to embed *human-vehicle-interfaces*, such as color reconfigurable head-up and head-down displays, and large touch screen active matrix Liquid Crystal Displays (LCDs), for high-quality video-streaming services. Passengers can enjoy their traveling time by means of real-time applications *e.g.*, video streaming and online gaming, using individual terminals next to their seats [28]. Figure 4 (a) and (b) depict the use of LCD devices for entertainment applications.

(a) (b)

Figure 4. Video-streaming applications for passengers in a smart vehicle, [28].

5. Conclusions

In this chapter we have presented the main technologies used in vehicular networks for *smart vehicles*. Different technologies can be exploited to provide communication, control and safety capability to vehicles, as well as comfort and entertainment applications are well supported.

We investigated main aspects of vehicular ad hoc networks (*i.e.*, the communication protocols V2V and V2I, differences from MANETs, main applications), and the main technologies, and sensors, used to support emerging inter and intra-vehicle communications. We also envisaged the vehicle of tomorrow *i.e.*, *smart* vehicle, which will be considerably different from the vehicle of today, due to the use of short distance transmitters and receivers that operate similarly to Doppler radar, and the increase in a vehicle's ability to control and take decisions.

Author details

Anna Maria Vegni[1], Mauro Biagi[2] and Roberto Cusani[2]

1 University of Roma Tre, Department of Applied Electronics, Rome, Italy

2 University of Rome Sapienza, Department of Information Engineering, Electronics and Telecommunications, Rome, Italy

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