Vehicular Networking for Smart Cities

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Abstract—A city becomes smart when Information Communication Technologies (ICTs) effectively enhance the quality of life of citizens. Vehicular Networking is an ICT technology with the great potential of increasing driving safety and of reducing traffic and pollution, thus Vehicular Networking is forecasted to be one fundamental technology of Smart Cities in the near future. This paper introduce Vehicular Networking showing its possible applications, and also illustrates the main research challenges.

I. INTRODUCTION

Nobody wants to be involved in a car accident. However every year, over the world more than 1.2 million people die in car accidents and a number between 20 and 50 million people sustain non-fatal injuries [1]. Nobody wants to breath smog while walking as well. Unluckily, when driving our cars or waiting that some truck will deliver the last product we bought online, we are producing the 14% of the overall CO\textsubscript{2} emissions [2]. Road fatalities are not the only and tragic cost of our transportation system: in Germany and Italy, for example, every year 33 billion dollars (approximately the 3% of the national GDP) are spent by the healthcare system for the cure and rehabilitation of persons injured in a car accident. Moreover, delays and other problems due to traffic congestions generate costs for an amount of more than 167 billion dollars in the whole Europe, and this cost represents the 1% of the European GDP.

These extremely serious problems placed the need of technological advancements so to enhance driving safety and to reduce traffic and pollution. Many are the improvements in these directions of the last years: seat belts are mandatory in almost any country, helmets for motorcyclists as well, air-bags are installed on all sides of new cars, which are now designed to pass severe crash-tests. Moreover, car pooling services, electric or hybrid vehicles and more efficient car engines are becoming more and more popular counteracting the emission of CO\textsubscript{2} but, nevertheless, there is still the need to improve. To further reduce accidents and pollution, two are the new frontiers for research: self-driving vehicles (aka autonomous driving) and cooperative driving.

Self-driving vehicles attracted the attention of the public and are celebrated by mass media but, at present, are still an immature technology and also authoritative academic figures revealed their own scepticism [3,4]. In brief, the goal of implementing a truly self-driving car appears to be too much ambitious and consequently unfeasible. In fact, a driverless car should be able to both perceive and make-decisions as or better than a human. However, even the most recent sensors are not as accurate as humans and they are at the same time extremely expensive, furthermore, driving-software are able to grant safety only putting severe limits on car speed, making cars too slow to be useful. Cooperative driving is instead more feasible and, based on the concept of assisted-driving, promise to reduce risks at driving and to lower pollution too. The key idea of cooperative driving is to assist human drivers exploiting information that vehicles autonomously exchange among themselves and with the road or Smart City communication infrastructure. For example, collisions at traffic intersections can be automatically avoided if car are equipped with radios to communicate their presence to the other vehicles. Many more are the possible applications, all enabled by the cooperation of cars that communicate over a Vehicular Network.

In Sec. [V] we further outline and describe the applications of Vehicular Networking that will have an impact on the future of Smart Cities. In Sec. [III] we investigate the radio technologies necessary to implement inter-vehicle communication. Lastly, the research challenges that are attracting the interest of researchers and driving the market of car manufacturers are discussed in Sec. [IV].

II. APPLICATIONS OF VEHICULAR NETWORKING

Before introducing Vehicular Networking (VN) applications, it is worthwhile to mention that different kinds of vehicular networks do exist, targeting different expected communication patterns. For instance, if cars need to communicate among each other (Inter Vehicle Communication (IVC)) and, to do so, they do not rely on cellular technology but rather build their own ad hoc network, then we refer to Vehicular Ad Hoc Networks (VANETs). Conversely, if vehicles acquire and share information through a networking infrastructure deployed along the road, then this communication pattern is called Vehicle-to-Infrastructure (V2I). If the application requires a mix of ad hoc IVC and also communications with the road or cellular infrastructure, then the term Vehicle-to-X (V2X) is used. Fig. [I] illustrates a Smart City with vehicles communicating over all possible and different kinds of Vehicular Networks.

VN applications are generally divided into two categories: those enhancing safety, such as warning for blind spots or traffic lights violation, and those non-safety related, such as optimal speed advisory and pure entertainment for passengers. Fig. [I] proposes a taxonomy for V2X applications. The most important are applications that can enhance the safety while driving, which are further subdivided into two categories. First we have Situation Awareness applications, that exploit advanced sensors installed in cars to make them aware of obstacles or of other vehicles that can be non visible. One application of this kind is Blind Spot Warning. Then we have
applications able to timely generate Warning Messages, for example, in case of sudden brake the car can automatically activate Brake lights (Electronic Emergency Brake Light (EEBL)).

We present here a short list of selected VN applications, illustrated also by Figs. 3 and 4; more comprehensive surveys are available [6] [7].

- **Intersection Movement Assist (IMA)**: IMA warns drivers when it is not safe to enter an intersection as there is an high collision probability with other detected vehicles which are approaching the intersections.
- **Electronic Emergency Brake Light (EEBL)**: When a car breaks suddenly, this event is detected by the intelligent computation system on board that automatically enables back lights that will blink to warn other drivers.
- **Forward Collision Warning (FCW)**: FCW warns of an impending collision with another vehicle ahead in traffic, in the same lane and moving in the same direction.
- **Blind Spot Warning (BSW) and Lane Change Warning (LCW)**: BSW and LCW features warn drivers if the blind-spot zone into which the vehicle intends to switch will be soon occupied by another vehicle travelling in the same direction.
- **Do Not Pass Warning (DNPW)**: DNPW warns drivers during a passing manoeuvrer attempt when a slower-moving vehicle ahead cannot be passed safely because vehicles moving in the opposite direction are approaching.
- **Left Turn Assist (LTA)**: LTA warns drivers during a left turn attempt when it is not safe to enter an intersection or continue in the left turn attempt, due to a car approaching the same path with no intent of stopping.
- **Curve Speed Warning (CSW)**: With CSW vehicles receive information from the road infrastructure when approaching a curve: this information are required for the automatic computation of the safe speed.
- **Reduced Speed Zone Warning (RSZW)**: Well before moving into a workzone, the user receives lane closure information.
- **Red Light Violation Warning (RLVW)**: RLVW provides information about the signal phase and timing of the traffic light intersection.

### III. COMMUNICATIONS LAYER OF VEHICULAR NETWORKS

Different radio technologies have been developed to support the plethora of applications presented in Sec. II. VN requires, in fact, new radio technologies to meet the specific requirements placed by radio communications that involve moving vehicles. These requirements vary depending on the application’s category, as shown in Tab. I. For instance, safety applications rely on a robust and timely communication. For this reason, transmitted packets are usually few and small, and transmission coding techniques are robust so to never misreceive a piece of information. However, to be extremely reactive and robust comes at a precise cost: data rate is slow and communication range short. Conversely, non-safety
Curve Speed Warning (CSW)

Reduced Speed Zone Warning (RSZW)

Red Light Violation Warning (RLVW)

Fig. 4. A selection of V2I applications (source: www.savari.net/technology/applications)

TABLE I

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<tr>
<th>Networking Requirements Depending on the Kind of Application</th>
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<tr>
<td>Safety</td>
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<tr>
<td>Few messages</td>
</tr>
<tr>
<td>Small packet size</td>
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<tr>
<td>Low latency</td>
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<tr>
<td>High reliability demands</td>
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<tr>
<td>Short range</td>
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applications privilege data rate and communication range over reliability, thus are characterized by more and larger packets, transmitted as fast as possible over longer-range radio links.

Other crucial factors for the selection of the best VN communication technology are i) the road environment and ii) the presence of a communication infrastructure.

A. Road Environment

Vehicles exhibit very different mobility patterns if they are travelling at high speed on a freeway rather than slowly in an urban environment. On a freeway, vehicles need to communicate only on the road’s direction, as they move only forward. Moreover, they establish stable or short-timed connections with vehicles travelling respectively on the same or the opposite direction. Conversely, in an urban environments cars travels on roads with many intersections, thus communication can happen not only on the direction of travel. Furthermore, compared to a freeway, most of the communicating entities are not moving, but are fixed road-side-units such as traffic lights. An additional difference is that in an urban environment there are buildings that obstacle radio propagation deteriorating the quality of communications.

B. Presence of Infrastructure

The technology used by vehicles to communicate with each other is much different than the one used to communicate with a road infrastructure or via the cellular network. Without a dedicated infrastructure, vehicles needs to setup their own communication network, thus need to implement all the components of a typical network. For example, channel access and authentication protocols are installed on board on each car, so that vehicles can self organize and maintain a Vehicular Network while travelling. Cars typically own a basic radio-equipment, used to form short-range and low data-rate links with neighbouring vehicles.

When an infrastructure is available a core network manager can provide fundamental services such as security and resource managements. However the latency is higher, as the traffic of information needs to go through a remote core network and is not kept local among the vehicles on the road. Moreover, consider that traffic generated by all travelling vehicles is sent trough this core network, that may get overloaded and congested.

C. Fundamental Radio technologies for Vehicular Networking

We have seen that Vehicular Networks place peculiar communication requirements, that require specific engineering solutions. We discussed the typical networking requirements that depend on the kind of applications, road environment and availability of infrastructure. Without going into technical details, Tab. [1] reports the main protocols used to support the applications explored so far. A taxonomy for them is illustrated by Fig. [5] The reader interested in a more deep study of these protocols is invited to read [6].

IV. RESEARCH CHALLENGES

Technologies for Vehicular Networks are still young and research efforts are required at many layers. We highlight here the research challenges of VN focusing on 4 main layers: Communication, Networking, Mobility and Security.

TABLE II

<table>
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<th>Potential Wireless Communication Technologies for VN Applications (Source: [6]).</th>
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<td>Functionality</td>
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<td>----------------</td>
</tr>
<tr>
<td>Safety</td>
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<tr>
<td>Road sign notifications</td>
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<td>Incident management</td>
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<td>Efficiency</td>
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<td>Road monitoring</td>
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<td>Comfort</td>
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<td>Contextual information</td>
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a) Communication: The main problem of IVC is to establish and maintain well working communication channels with neighbouring vehicles and with the fixed infrastructure. In fact, while travelling, the channel conditions vary continuously as the distances with base-stations and other vehicles necessarily keeps changing, as well as the environments (weather conditions, type of roads etc.). Moreover, on the same road many vehicles attempt to use the same radio frequencies to perform their communication, thus interferences are common. Furthermore, in case of high traffic the network can be overloaded. One last consideration about the radio equipment of cars: it must be necessarily cheap not to make cars unaffordable, hence provides only limited performances at most in terms of capacity. In brief, these are the main challenges at the communication layer:

- Highly varying channel conditions
- High congestion, contention, interference
- Tightly limited channel capacity

b) Networking: To build a network putting together links of very different kinds is an extreme challenge. Many radio technologies (see Fig. 3) lead to the establishment of very diverse links, that can be stable and at long-range or completely different and thus short-timed and short-ranged. Nevertheless, information must be routed and forwarded passing through cars produced by different manufacturers (therefore with different radio equipments) and different telco operators. Cooperation becomes crucial to jointly build a well working Vehicular Network. Summing up, here are the main networking challenges:

- Multi-Radio/Multi-Network Networking
- Heterogeneous equipment

c) Mobility: The greatest and obvious difference between traditional and Vehicular Networks is mobility. In traditional networks, once the topology is set and known, many optimizations can be put in place assuming the network will remain static. This advantage is lost when dealing with Vehicular Network, that exhibit very dynamic topologies which ask ultra-fast reconfiguration techniques. To the rescue of researchers in this area, vehicles’ mobility is predictable: consider for instance cars that are driving only forward for hours on a freeway. As mobility is predictable also network topology becomes to some extent predictable, enabling network resources management in a planned and more optimal manner. The aforementioned considerations about the challenges placed by the mobile nature of Vehicular Networks are summarised here:

- Highly dynamic topology
- Highly dynamic (but predictable) mobility
- Heterogeneous environment

d) Security: Vehicular Networks are not immune to attacks like all other communication networks. A peculiar complication of VN is that traffic encryption may be unfeasible, as it adds delays to communication and these delays may be not tolerable for a typical safety applications. Moreover, while travelling cars may exit from an area served by their telco operator and be forced to be transferred to an untrusted service providers, this to keep connectivity. The main security challenges of VN are therefore:

- Ensuring privacy
- No (or non reliable) uplink to central infrastructure

A. Research effort in Trento: Platooning

Automated car following, better known as platooning, is a vehicular networking application where a group of vehicles autonomously follow a common leader at close gap. In other terms, vehicles form a road-train (aka platoon, as the one shown in Fig. 6), automatically following each other. Only the leader vehicle requires a human constantly driving, the intervention of the drivers of the following vehicles is required only for emergencies or special manoeuvrers. The advantages of platooning are many. First of all, drivers of non-leader vehicles can relax or, if commuting on their way to the office, can start working. In general the driving experience is enhanced. Platooning improves also safety: in fact, the probability of a human error is greater than the failure probability of the control systems that enable platooning. These control systems are also more reactive than humans, thus the safe distance between vehicles can be reduced. As the safe distances are reduced, more vehicles can drive together on the same road, achieving an increased road capacity. Lastly, as vehicles follow each other at a relative shorter distance, they can exploit the “wake effect” and the consequent air drag reduction to save fuel. The air drag reduction phenomena for a vehicle in the slipstream of a leading one is illustrated in Fig. 7.

The Advanced Networking System research group of the University of Trento, in particular with the works conducted by Michele Segata, is advancing the Vehicular Networking technology. Among the outcomes of the recent research efforts in this area, we mention the main ones starting from PLEXE [8], an open-source platooning simulation tool that models both network and vehicles dynamics with high realism, taking

\[ \text{www.en.wikipedia.org/wiki/Wake} \]
into account state-of-the-art IEEE 802.11p models, as well as detailed engine models and real world control systems for vehicles. Particular interest is then placed on implementing platooning manoeuvres designing ad hoc distributed protocols \[9,11\], and on developing better models, methodologies and experimentation tools for the research community \[12-15\].

V. CONCLUSIONS

In the near future the great majority of the world population will live in always larger cities \[16\]. The cities’ road infrastructure will grow as well, and people will spend more and more time commuting. While travelling, people will be exposed to all dangers of driving, such as car accidents, and will increase traffic and pollution too. To improve the safety of driving and counteract traffic and pollution, a practical solution is Cooperative Driving. For example, cars automatically exchange information to avoid collisions or to build driving formations like platoons, hence saving on fuel and reducing traffic and pollution at the same time. Many more are the potential applications of cooperative driving explored in this paper, all enabled by Vehicular Networks, that allow the communication among vehicles and the fixed telecommunication infrastructure. This paper introduced the fundamental technologies of Vehicular Networking, showing that they will play a key role in the development of the future Smart Cities.

ACKNOWLEDGMENT

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REFERENCES