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Cognitive Vehicular Networks: An Overview

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Abstract

Cognitive Radio (CR) is extending the applications of wireless communications worldwide. Cognitive radio verifies the electromagnetic spectrum availability and permits the modification of the transmission parameters using the interaction with the environment. The goal is to opportunistically occupy spectral bands with minimum interference to other users or applications. Cognitive radio for Vehicular Ad hoc Networks (CRVs or CR-VANETs) is a new trend in the automotive market. Recent and future vehicles will offer functionalities for the transmission of intra-vehicular commands and dynamic access to wireless services, while the car is in transit. This paper describes the cognitive radio technology and its signal processing perspectives for the automotive market.

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1. Introduction

The expansion of wireless applications and services is modifying daily lifes around the world. The advances of microelectronics and computing added portable devices everywhere. Besides, with the evolving of new wireless communications as WiMAX, 4G and cognitive radio, the available applications for customers multiply.

Vehicular market is facing a similar reality. With the merge of these technologies inside cars, new products and features must be implemented to offer communication in the vehicles'interior and among vehicles in transit. Recent applications on traffic monitoring and alerts, infotainment, collision avoidance, Internet access, WiFi or Bluetooth availability among others transformed the automobiles in an extension of the portable devices of the drivers and passengers.

Vehicle networks are a major research and development topic for automakers worldwide¹. In this context, this paper focus in the cognitive radio technology and how expansion of vehicular networks and new applications are related to wireless communications. The paper is organized as follows: Section 2 presents the concepts of cognitive radio and spectrum sensing; the definition and some main features of vehicular ad hoc networks (VANETs) and cognitive vehicular networks (CRVs) are detailed in Sections 3 and 4, respectively. Finally, the conclusions of this article are presented in Section 5.

2. Cognitive Radio

The electromagnetic spectrum is overloaded in some bands while it is sub-utilized in others². Government and international agencies use to grant operation licenses in specific frequency bands. As most part of the spectrum is already allocated, new licenses or the improvement of current services in operation face difficulties. On the opposite, some frequency bands experiment minimum spectrum usage in specific regions in the world³.

Cognitive radio extends the spectral efficiency, with opportunistic access, for the available frequency bands in a region. CR monitors the available spectrum and when a spectral opportunity is identified, adapts its transceivers to operate in that frequency channel (when temporarily not occupied by primary or licensed users or even when the interference levels do not harm other users)⁴.

Spectrum users are classified as Primary (or Licensed) Users (PU) or Secondary (or Cognitive) Users (SU). Licensed users are authorized to operate in a specific frequency band, while secondary users do not have a grant to transmit and receive in that frequency bands. Cognitive user should monitor the frequency spectrum to find out if there is any licensed user occupying the spectrum or if there is a spectral opportunity⁵.

Cognitive users verify the presence or absence of spectrum holes via spectrum sensing. Spectrum holes are defined as temporarily non-used spectrum bands that can be opportunistically accessed by cognitive users⁶. If a band is available, the cognitive user can opportunistically use that channel; although, when a priority user is present, the CR will not be allowed to benefit from that frequency band.

Spectrum Sensing (SS) is fundamental in a cognitive radio network. Higher bandwidth and lower error rates in the transmission can be observed with the monitoring of channel occupancy. Different spectrum sensing techniques can be adopted by cognitive networks⁷: Energy Detection; Matched Filtering detection; Cyclostationary (or Feature) Detection and other techniques help improve the spectral detection. Also, the combination of two or more spectrum sensing techniques (hybrid sensing) is a new approach in recent researches.

New applications in different scenarios are arising grace to cognitive radio. Some of the major applications of CR are:

- TV White Spaces and regulation⁸;
- Smart Grids⁹;
- Wireless Sensor Networks (WSN)⁴;
- Public safety and medical networks¹⁰;
- Power Line Communications¹¹;
- Vehicular networks¹².

Cognitive Radio Vehicular Ad Hoc Networks (CRVs or CR-VANETs) are one of the most promising applications of cognitive radio¹³. Each vehicle in a geographic area could communicate with other vehicles directly

or via some communication infrastructure⁷. Before defining CRVs, the concept of multihop ad hoc networking and vehicular ad hoc networking is described in the next section.

3. Vehicular Ad Hoc Networks (VANETs)

A MANET (Mobile Ad Hoc Network) refers to wireless network nodes that communicate with each other without no central control station or any infrastructure network to coordinate the communication. Nodes (or users) can receive data sent by others devices around the neighborhood via wireless transmission in ad hoc mode¹.

A MANET uses multihop strategies to improve the range of the data to be transmitted. The lack of a coordinator node or a specific infrastructure are desired features of specific networking strategies. Wireless Sensor Networks (WSNs) and Vehicular Ad hoc NETworks (VANETs) are the most common applications of MANETs¹, and can be adopted in multiple ways (traffic control, environmental monitoring, smart building deployments, military applications, between many others¹⁰).

VANETs are networks based on different sensors that can establish communication with the other nodes (or vehicles) in transit in a specific region. Fig.1 presents how vehicle-to-vehicle links via radio can enable a high capacity communication network⁷.



Fig. 1. Vehicular communication^{1,13}.

VANETs are motivated by the development of Intelligent Transportation Systems (ITS) and Wireless Access in Vehicle Environment (WAVE)¹⁴. ITS and WAVE aim to reduce traffic congestions and accidents by adding transceivers in the cockpits. Also, non-safety applications (as entertainment, Internet access or electronic messages) can be offered by these systems². The wireless transceivers will enable any vehicle to change real-time information (as road situations or weather conditions) and to warn others drivers to avoid collisions and accidents¹.

ITS is an important design issue for automakers today. Although, ITS is not restricted to automotive market; it refers to the interchange of information in several transportation systems as rail, water and air transport¹³. WAVE is an amendment to the IEEE 802.11 standard to support ITS applications in short-range communications^{14,15}.

3.1. V2V, V2I and V2P

ITS and WAVE are relevant design metrics for the automakers today. In this way, ITS technology will require two possibilities of communication possibilities to be implemented¹: V2V (Vehicle-to-vehicle) communications, in which automobiles will change information and data without a coordination infrastructure; and V2I (Vehicle-to-infrastructure), in which wireless technologies infrastructures (cellular base stations or routers and repeaters) along the roads will serve vehicles to gather specific traffic information from an access point or to establish a communication with other vehicles¹³.

Additionally, V2P (Vehicle-to-person or vehicle-to-pedestrian) is being developed to improve ITS and WAVE functionalities¹⁶. V2P intends to enhance the pedestrian's safety in roads by enabling its communication with

vehicles. The goal is to warn in-movement vehicles that pedestrians or byciclists are too close and an accident can happen.

In V2I the information is exchanged between the RSU (Roadside Unit) or a cellular network and the OBU (Onboard Unit). V2R (vehicle-to-roadside) is another variation of V2I: in V2R, information is transmitted between the RSU and the OBU units¹³. V2V and V2I evolution motivated an amendment to IEEE 802.11 standard. The IEEE 802.11p - also known as Dedicated Short-Range Communications (DSRC) standard or IEEE 1609^{14,15} - supports data exchange between high-speed vehicles and between automobiles and the fixed infrastructure in the licensed band of 5,9 GHz (5,85 - 5,925 GHz)^{1,13}. In USA, vehicular communication up to 200 km/h in the 5,9 GHz band are predicted¹³. DSRC spectrum is divided in seven channels, each one with a 10 MHz bandwidth¹. V2V and V2I communication are illustrated in Fig. 2.



Fig. 2. V2V and V2I communication^{1,13}.

3.2. Challenges in VANETs

The improvement of safety and traffic efficiency when in-movement vehicles dynamically self-organize via the available wireless communication interfaces is the main goal of a VANET. Driver assistance and infotainment are important features that can also be offered to drivers and passengers¹.

Although, specific design issues still challenge researchers and automakers. Security and privacy are fundamental for the consolidation of the VANETs. Privacy of the messages interchanged between two vehicles or through the roadside infrastructure must be guaranteed. Additionally, vehicular networks must provide liability for warning or alert messages broadcasted; if this not happens, false informations would harm and confuse the drivers¹.

Also, the high-speed characteristic of a VANET and the changeable topology (with vehicles moving to different directions in distinct environments) provoke multipath fading, delays and other undesirable effects that penalyze the communication². In order to deal with these challenges, cognitive radio concept was introduced in vehicular applications.

4. Cognitive Radio Vehicular Ad Hoc Networks (CRVs)

Recently, almost all automakers are investing to provide infotainment solutions and new alternatives to drivers and passengers². Features and services tend to overload the available spectrum in the automotive context. Internet access or Bluetooth connections inside cars are already suffering interferences in heavy-traffic roads.

Cognitive radio can be inserted to vehicular communication. Opportunistic and dynamic access strategies derived from CR are a new trend in automotive market. Cognitive radio for vehicular Ad hoc Networks (CRVs or CR-VANETs) lead cars to monitor the available frequency bands and to opportunistically operate in these frequencies^{1,13}.

CRVs can improve the throughput; also, CR-VANETs enable more users to operate in high user density scenarios¹². Transceivers with reconfigurable software defined radio (SDR) devices are being added to vehicles. The

operating parameters can be dynamically modified via software, which optimizes flexibility and operation in different bands¹³. Consequently, hardware limitations are reduced in the development of new devices.

Spectrum sensing is fundamental in cognitive networks – as well as in cognitive vehicular networks². Spectrum sensing intends to properly detect the presence or absence of PUs or SUs in a specific frequency band; this optimizes the usage of spectrum holes opportunistically. Spectrum sensing schemes are classified as¹:

- Per-vehicle sensing;
- Spectrum database techniques;
- Cooperation.

In per-vehicle sensing, each car performs the spectrum sensing independently and autonomously from the others. The spectrum sensing is performed with traditional SS strategies as energy detection, matched filter, cyclostationary detection and others¹.

However, despite the fact that each car can perform it own sensing with no need of any infrastructure support, the accuracy of the sensing decreases in scenarios with tunnels, mountains or other obstructions¹. Fig.3 presents the scenario of an opportunistic communication in a vehicular network.



Fig. 3. Opportunistic Communication in a Vehicular Network^{1,13}.

Spectrum database techniques are employed to establish a centralized database with information collected from all PUs operating in a geographic region. This centralized database can reduce the limitations observed in the per-vehicle sensing, however the control of this database is complex and expensive¹.

Based on the CR concept of cooperation, the data gathered from all vehicles are forwarded to a fusion center to be processed and transmitted to all users in the range of the central node¹⁷.

4.1. CRV Network Architecture

The network architecture of a CRV is based on vehicles with onboard units (OBUs) and infrastructure facilities (as RSUs and base stations of cellular networks)¹³. The following network architectures for a cognitive vehicular radio are defined¹:

- Without infrastructure support (non-centric architecture);
- Limited infrastructure support;
- Complete infrastructure support.

When vehicles operate to transmit data only as V2V or V2P, the architecture is defined as without infrastructure support or non-centric architecture; communication is established only between the vehicles (which have CR devices to perform the spectrum sensing). The sensing can be shared among them. Infrastructure support absence reduces the geographical coverage of the communication performed^{1,2}. Fig.4 illustrates a non-centric architecture.



Fig. 4. Non-centric CRV architecture¹³.

With limited infrastructure support, low complexity base stations and other facilities as repeaters and routers are installed through the highways. The range of the data is limited by this minimum infrastructure, consequently the data is transmitted only to the vehicles in the range of the facilities installed (few kilometers)^{1,13}. Fig.5 represents this architecture.



Fig. 5. Limited Infrastructure CRV architecture¹³

The best scenario would be based in a complete and centralized infrastructure support: a base station enables the connection with (and between) vehicles¹³. Although, if there is not enough base stations alongside the highways and streets, the communication will be penalyzed. Fig.6 summarizes a complete infrastructure support architecture.

4.2. Open Issues and Challenges in CRVs

Cognitive radio was originally conceived for opportunistically access for TV bands, then this solution would not be directly applied to CRVs. The elevated mobility of the vehicles and the demand for vehicular communication would impact in the usual rigorous quality of service (QoS) requirements in automotive market^{1,13}.

Despite these restrictions, the evolving of cognitive vehicular networks is motivated by bandwidth scarcity and congestion (new technologies made available inside cars demand high bandwidth and reliable wireless connections – as Internet access, traffic and weather announcements)². Cognitive vehicular networks can benefit from the spectrum sensing to temporarily and opportunistically use available spectrum, which combats bandwidth scarcity and congestion in the main frequency bands¹.

The flexibility of SDR devices makes cognitive radios very useful in safety and emergency ITS and WAVE applications. Additionally, when compared to fixed cognitive radio applications, vehicles can benefit from the mobility to detect spectrum holes in highways and roads. With the variation of the propagation characteristics and spectrum occupancy alongside highways and streets, more transmission opportunities can be detected by SDR inside cars¹².

Another important requirements are space and power supply issues. Vehicles have enough space in the chassis to insert new devices and components. Besides, battery and alternator supply the energetic consumption need by wireless transceivers, eliminating extra batteries and minimizing dead battery restrictions^{2,13}. However, some issues

for CRVs applications still challenge automakers: interference; mobility of the vehicles and security and privacy are the main pending issues in cognitive vehicular networks evolution.



Fig. 6.Complete Infrastructure Support CRV architecture¹³.

Interference is a remarkable issue in cognitive radio, consequently it is also a challenge in CR-VANETs. Two main interference issues are being investigated lately: the interference to primary users in a CRV; and the interference from other networks in an operating CRV¹³.

Due to vehicles' unpredictable tracks, SDR inside cars will face different environments and spectrum occupancies as well as specific infrastructure conditions. Minimum coverage must be guaranteed for the transceivers when in transit^{1,13}.

In the same way, privacy and security policies must be adopted as a vehicle should not access unauthorized messages and data from other drivers in the same region. An important investigation line focus on routing algorithms to minimize the risks of capturing in-transit messages and data^{1,13}.

4.3. Applications

Recent applications devoted to VANETs and CR-VANETs are under development to be deployed in nextgeneration vehicles. Main objectives are public safety; V2V and V2P communication; and vehicle entertainment and information systems^{1,2}.

VANETs and CRVs primary concern is the improvement of safety for drivers and passengers by means of the optimization of the communication between vehicles¹⁷. Driving Safety Support Systems (DSSS) are under development to reduce traffic accidents and to increase drivers' awareness. Vehicles communicate with each other and with the infrastructure alongside the highways and roads. Global automakers as Toyota and Nissan are developing solutions for new vehicles¹⁸.

Vehicle-to-Person applications aim to extend the security to pedestrians, bicycles and motorcycles. To eliminate V2P collisions, the pedestrian DSRC-enabled smartphone sends an audible warning and a navigation screen alert to the vehicle that is approaching¹⁹. On the other side, when the under development system detects a vehicle close to the person (or bicyle or motorcycle), a high-volume warn and a visual alert are forwarded to the walker. Honda also develops similar solutions for the named Vehicle-to-Motorcycle (V2M) safety²⁰.

Volvo is in field tests of a vehicle prototype that moves in Sweden autonomously without human intervention²¹. Google is also testing an autonomous car. Test vehicle already traveled more than 700.000 miles in the United States until 2014²². Other companies as Audi, Mercedes, General Motors and Nissan work and invest on similar projects²¹.

5. Conclusions

Cognitive radio is an evolving wireless communication technology that can extend the vehicular communication networks features and applications. Cognitive radio motivates the expansion and development of vehicle-to-vehicle,

vehicle-to-infrastructure and vehicle-to-pedestrian communications. However, there are still relevant design issues to be solved and to consolidate the CRVs. In the continuation of this work, the open issues and challenges in CRVs will be investigated as well as more recent applications in the automotive market.

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