Assay of White Space Technology Standards for Vehicular Cognitive Access

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Abstract

The provisioning of innovative connections between vehicles and backend information systems will enable new ways of vehicle management, traffic safety and efficiency. In this article we present Vehicular Cognitive Access, the concept of using TV white space access technology to support and facilitate end-to-end connectivity for certain types of automotive applications. We defined common requirements that an optimized radio system is expected to fulfill. An overview of different TV white space access standards is presented; motivations and open challenges of these standards as enabling technologies for vehicular communications are analyzed. It also provides an evaluation of the overall suitability of TV white space access for these applications and discusses research directions. TV white space access standards do show significant potential for vehicular cognitive access. However, some issues such as seamless handover schemes for high speed vehicles and the capability to support applications that have strict timeline and reliability requirements need to be further optimized before its full potential can be realized.

Keywords

White space standards, vehicular communications, automotive applications

1. Introduction

Intelligent Transportation Systems (ITS) need reliable and capable wireless connectivity supporting, infotainment (information and entertainment), road safety and traffic efficiency through vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications. It is anticipated that the level of automotive information exchanges enabled by wireless communications will significantly increase in the near future due to a growing number of wireless-enabled vehicles (Al-Hazmi et al. 2013). In addition vehicular communications have some unique features, in terms of generation patterns, delivery requirements, communication primitives, and spatial scope.

Current and upcoming wireless communication systems have been trying to exploit many techniques to provide seamless access solutions for automotive applications. Dedicated Short Range Communications (DSRC) is a type of wireless communications specially designed for vehicles. Standard IEEE 802.11p WAVE (Wireless access in Vehicular environments) was proposed to exchange data between high speed vehicles and between the vehicles and the roadside infrastructure (IEEE 2010). IEEE 802.11p supports vehicular applications in vehicular ad hoc networks. Easy deployment, low cost, mature technology, and the facility to natively support V2V communications in ad hoc mode are among its advantages. However this technology suffers from scalability issues, unbounded delays and lack of deterministic quality of service guarantee. Without a pervasive roadside communication infrastructure, it can only offer intermittent and short-lived V2I connectivity (Amadeo et al. 2012).

Among cellular systems Long Term Evolution (LTE) (3GPP 2010) is the most promising current wireless broadband technology that provides high data rate and low latency to mobile users. Like all cellular systems, it can benefit from a large coverage area, high penetration rate, and high-speed terminal support. Indeed, LTE particularly fits the high-bandwidth demands and QoS-sensitive requirements of a category of vehicular applications known as infotainment, which includes traditional and emerging Internet applications (e.g. content download, media streaming, VoIP, web browsing, social networking, blog uploading, gaming, cloud access). In any case, its capability to support applications specifically conceived for the vehicular environment to provide road safety and traffic efficiency services is still an open issue. The main concern comes from the centralized LTE architecture: even for localized V2V data exchange, communications always have to cross infrastructure nodes, with negative consequences on message latency for safety-critical applications (Araniti et al. 2013).

In addition, in dense traffic areas, the heavy load generated by periodic message transmissions from several vehicles strongly challenges current radio systems capacity and potentially penalizes the delivery of traditional applications. Furthermore due to growing demand of wireless communications for wide range of purposes, current radio systems may come to practical limits of frequency spectrum bands. To overcome bandwidth scarcity issue global interest in new solution is being fuelled. Use of the vacant frequencies at a given time in a given geographical area not being used by licensed services has been identified as an important spectrum resource. This spectrum has been termed as *white space.* The unused spectrum in UHF TV broadcast band (470-790 MHz) is one of these vacant frequencies and is referred as *TV white space*, providing excellent propagation characteristics and appears to be a relatively large amount of white space. In response to these observations, in this article we intend to make the following contributions:

- We present Vehicular Cognitive Access, the concept of using TV white space access technology to support and facilitate end-to-end connectivity for certain types of automotive applications.
- Realizing the future automotive environment: We defined common requirements that an optimized radio system is expected to fulfill in order to be aligned with vehicular cognitive access described in the present document.
- By analyzing three different TV WS access standards; we evaluate the overall suitability of TV WS access for vehicular communications and identify the research directions.

The rest of this article is organized as follows. In Section 2, we identify automotive communication scenarios and define common requirements for vehicular cognitive access. Key characteristics of different TV WS access standards and important aspects of their suitability in vehicular environment are discussed in section 3. We evaluate the overall applicability of TV WS technology standards for the purpose and discuss research directions. We conclude the article in Section 4.

2. Communication Aspects of Centralized ITS Applications

2.1. Floating Car Data

In this paper, applications based on a floating car data (FCD) service are considered. The FCD requires periodic collection of information by vehicles, from internal and external sensors (e.g. CAN bus, in-vehicle camera, environmental monitoring sensors) and transmission of this information to a centralized backend information system on the network side. The backend system collects data from vehicles for further processing and analysis. This real-time data is combined with other existing quality traffic information sources such as traffic management centers, Automated Vehicle Location systems, mobile devices, and Connected Vehicle equipments, resulting in the most complete and reliable traffic information and provided back to vehicles. Based on the underlying application this system could be further connected with service delivery platforms, enterprise applications or service providers. Figure 1 shows a conceptual view of end to end wireless communications and innovative ITS applications of FCD class considered in this contribution.

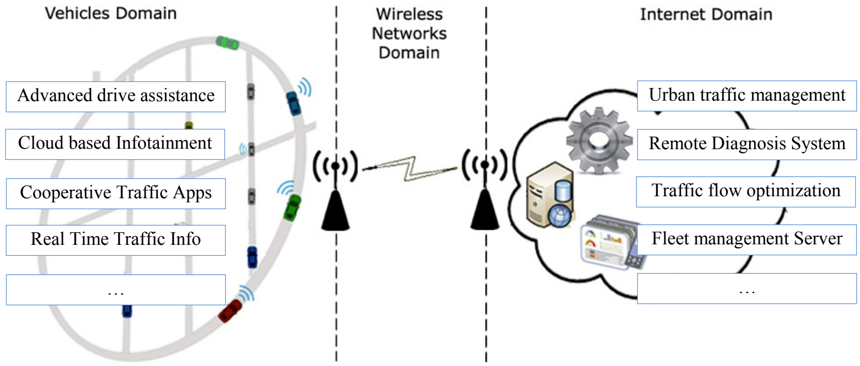

Figure 1: conceptual view of wireless communications for ITS applications

2.2. Vehicular Cognitive Access

Vehicular communication for Intelligent Transportation Systems (ITS) based on short-range wireless communications (IEEE 802.11p/ITS G5), ad hoc networking and cellular mobile networks has been extensively studied and for road safety application is being tested in major field trials. An opinion is raised that cognitive radio technology should be involved as a building block when designing a general purpose wireless communication system for future vehicles. In this paper the acronym VCA is used for vehicular connectivity using TV white space wireless technologies that should fulfill following functional requirements:

- Ability to obtain knowledge of its current geographical and operational radio environment (available resources, target applications, number of vehicles), established policies and its internal state.
- Dynamically and autonomously adjust its operational parameters and protocols
- Operate in an uncertain environment where the frequency availability is not guaranteed and may change from location to location and time to time.
- Operate in an unlicensed environment where the interference caused by other unlicensed terminals cannot be predicted and must be avoided or overcome.
- Cause no interference to licensed users or causing unnecessary interference or blocking.

Following is a summary of the performance requirements for considered applications that an optimized radio system is expected to fulfill, in order to be aligned with vehicular cognitive access described in the present document:

Support of large number of vehicles: With growing number of connected vehicles it is anticipated that a single cell may need to serve very large number of connected vehicles (Boswarthick et al. 2012). Therefore appropriate network should provide a mechanism to reduce peaks in signalling and the data traffic resulting from large numbers of vehicles, almost simultaneously attempting data and/or signalling interactions. When the network is in overload, it should be capable to provide a mechanism to restrict downlink data and signalling as well as access towards a specific access point name (APN).

Extended coverage: Since vehicles have to travel across different regions and thus given applications require widespread coverage.

Reliable: One essential requirement is that the message or data delivery must be reliable.

Secure: With the growing threat of hacking and unauthorized compromising of systems, security is an issue high on the agenda of many users.

Broadcast message capability: There could be instances where broadcast messages may be needed. The system must be able to accommodate this type of message

Small data bursts: As many vehicles would send amounts of data at a time, the system must be able to efficiently handle packets of around 50 bytes

Mobility Support: Automotive applications are those that need to communicate wherever they are and as vehicles move around different regions. This requires mechanisms to provide mobility support for roaming scenarios and efficient seamless handoff schemes to enhance Quality of Service (QoS) and provide flawless mobility. There must be an optimized frequency of mobility management procedures.

3. Wireless Standards for TV White Space

Three standards are considered that provide the ability for exchanging data using radio transmissions in unoccupied TV transmission channel. Their key characteristics are summarized in Table 1 and their suitability for ITS applications is discussed in the next sections.

Feature	**802.22**	**802.11af**	**Weightless**
Frequency bands	54-862 MHz	300-710 MHz	470-790 MHz
Channel width	6, 7 or 8 MHz	6, 7 or 8 MHz	6 or 8 MHz
Max data rate	22.69 Mb/s	54 Mb/s	16 Mb/s
Range	Up to 100Km	Up to 5Km	Up to 5Km
Capacity	Potentially high	Medium	High (M2M)
multicast support / MIMO	No	Yes	Yes
Modulation Method	QPSK, 16-QAM & 64-QAM	BPSK, QPSK & 16-QAM	16-QAM, pi/4 QPSK, pi/2 BPSK
PHY Transport (Multiple Access Method)	OFDMA	CSMA/CA & TDMA	TDMA

Table 1: System parameters of TV WS access Standards

3.1. IEEE 802.22

The standard IEEE 802.22 belongs to the class of wireless regional area networks (WRAN). It defines cellular topology with control system composed of a base station (BS) and zero or more customer premises equipment (CPEs) associated to a cell. The coverage area of the cell extends up to the point where the signal received from the BS is sufficient to allow CPEs to associate and maintain communication with the BS.

The reference architecture for IEEE 802.22 systems as shown in figure 2 incorporates all communication related components as well as the interactions between the individual entities. The reference architecture indicates PHY and MAC levels and the interface between station management entity (SME) through PHY and MAC layer management entities (MLMEs). The higher layers such as IP layer, PHY and MAC levels interact with each other through the service access points (SAPs), which give modularity to the system. A spectrum management entity (SME) in its turn communicates with PHY level by the PHY layer management entity (PLME) and its SAPs (Stevenson 2009).

On the PHY level, there are three particularly important features: the main data communications, the spectrum sensing function (SSF), and the geolocation function. PHY communications specification is based on orthogonal frequency division multiple access (OFDMA) for both Upstream (US) and Downstream (DS). The standard optionally employs the duo-binary Convolutional Turbo Code (CTC), low density parity check codes (LDPC) and shortened block turbo codes (SBTC) coding. On MAC layer the 802.22 standard uses Time Division Multiplex (TDM) based access. The MAC also uses a synchronous timing structure, where frames are grouped into a superframe structure.

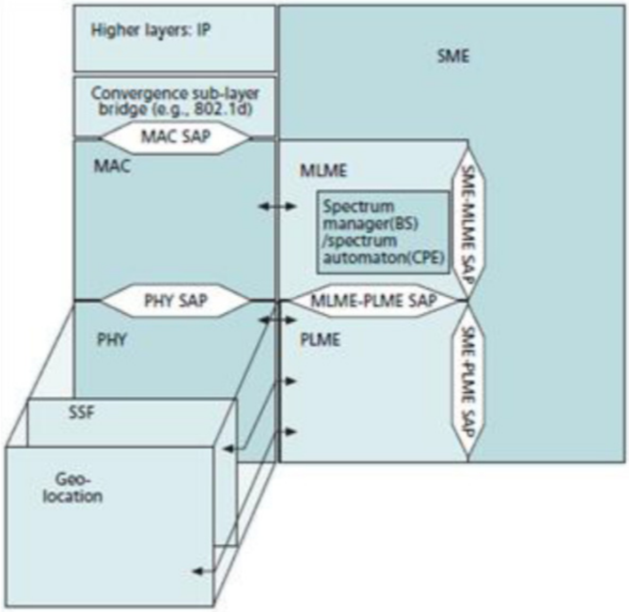

Figure 2: Reference architecture of IEEE 802.22 (Stevenson 2009)

3.2 Weightless Standard

Weightless is a standard designed specifically for machine-type communications within white space. The Weightless core network consists of service providers that communicate with base station networks. A base station networks operates one or more base stations. A base station is the grouping of a base station controller and a base station modem. The base station is intended to be kept as simple as possible to reflect the light-weight nature of the protocols used within the standard and to maximize the flexibility that arises from making key scheduling and assignment decisions in a central location. All of the MAC layer processing takes place within the base station controller within the network (Weightless SIG 2012), thus as far as possible the base station is sent complete frames of information which it passes to the physical layer. Hence, the message flow on the base station to network (BSN) interface is relatively limited.

The Weightless air interface has the flexibility to use either phase shift keying or quadrature amplitude modulation together with a scheme of Whitening to spread the signal and make it look more like white noise to reduce any levels of interference that may be caused. In addition to this the system uses time division duplex, TDD to enable both uplink and downlink transmissions to use the same channel. Physical layer design facilitate wide range of trade-offs between data throughput and available signal to noise ratio (SNR). The Weightless physical layer use frequency hopping, applied at the frame rate to mitigate interference as well as for propagation characteristics where some frequencies may experience deep fades as a result of multiple transmission paths. Whitening and interleaving is applied to the uplink and downlink transmissions in an identical manner. Continuous phase modulation (CPM) mode is supported for the uplink. There are two modes of downlink support, a high rate mode and a standard rate mode. Both modes are single carrier and are based on the same underlying signal bandwidth, pulse shaping and multiple access method. The spectral characteristics of the transmissions are the same for the high rate and standard rate modes, and the single carrier nature of the transmissions ensures low peak to average power ratio.

Weightless uses trade off data rate against range, this technology involves spreading the data to be transmitted. Spreading multiplies the data by a pre-defined codeword so that one bit of transmitted data becomes multiple bits of codeword. The receiver can then use correlation to recover the codeword at lower signal levels than would otherwise be possible. Spreading allows an extra gain on the link budget. Variable spreading factors are a core part of the Weightless specification, ensuring deep coverage. In cases where limited white space is available then Weightless can operate a mix of licensed and unlicensed Weightless technology using a few channels in the 900MHz (Weightless 2013).

3.2. IEEE 802.11af

The standard 802.11af is also called Super Wi-Fi or White-Fi because of its cognitive properties. The requirements specification of 802.11af system is formed, the standardization process is not yet finished and expected date of completion this work is Mar 2014 (IEEE 2014).

The 802.11af system is composed of three different station (STA) types: fixed, enabling, and dependent STA. Figure 3 shows two infrastructure BSSs where AP1 and AP2 are enabling STAs and the other STAs are dependent STAs. Fixed and enabling STAs are registered station that broadcast its registered location. The enabling STA is permitted to enable operation of unregistered STAs, i.e. dependent STAs. The enabling STA gets the available channel information from the TV WS database and transmits the contact verification signal (CVS). The CVS is used to determine that the dependent STAs are still within the range of enabling STAs, as well as for checking the list of available channels.

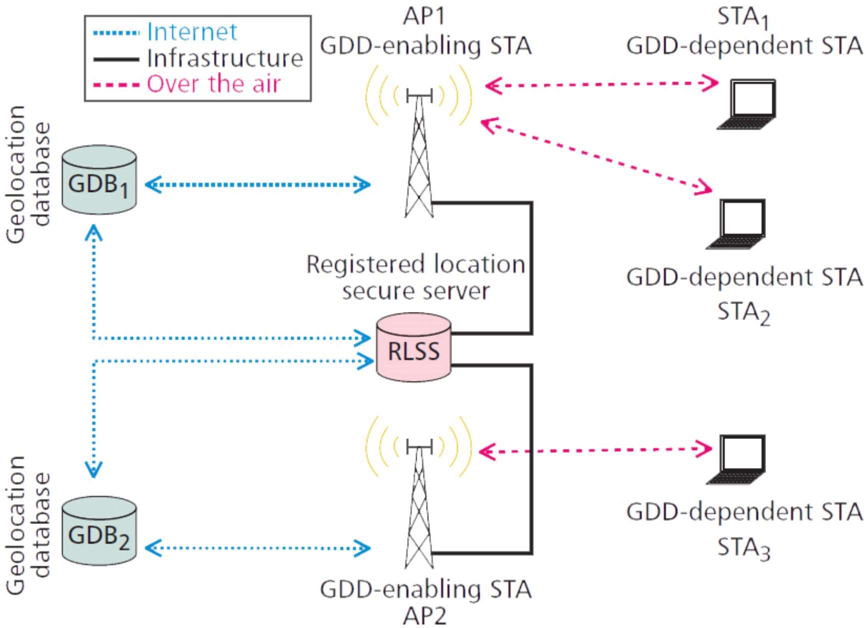

Figure 3: IEEE 802.11af Network Infrastructure (IEEE 2013)

The standards use the Orthogonal Frequency Division Multiplexing (OFDM) technology and Binary Phase-Shift Keying (BPSK), Quadrature Phase-Shift Keying (QPSK), 16-QAM (Quadrature Amplitude Modulation), 64-QAM payload modulations schemes at PHY layer. The standardization is ongoing in IEEE 802.11 TG (Task Group) as a major enhancement IEEE 802.11af (D5.0) introduced multi-channel support MIMO (Multiple-Input Multiple-Output) with aggregation (contiguous and non-contiguous mode) up to 4 channels to increase transmission data rate.

4. Analysis of TV WS standards for vehicular access

The important aspects for TV white space applicability in vehicular environments are discussed in the following.

Architecture: The network *architectures* of these standards are relatively simple. In Weightless standard unlike cellular systems there are no defined interfaces within the network. All MAC layer processing takes place within the base station controller within the network and base station is sent complete frames of information which it passes to the physical layer. Since nearly all automotive applications of our interest follow a client-server paradigm so making key scheduling and assignment decision in a central location maximize the flexibility and suitability for V2I communications.

The IEEE 802.11af standard provides a common architecture, a communication scheme, and a control structure that adapts to the different operating parameters and regulatory domains around the world.

Capacity and date rate: IEEE 802.22 standard offers moderate uplink and downlink capacity, the maximum available data rate of 22.69 MB/s is calculated with quadrature amplitude modulation and at the coding rate of ¾ (Lekomtcev and Marsalek 2012). The Weightless provide up to 16 Mb/s downlink and 500 Kb/s uplink which is configurable to meet requirements. Weightless MAC enables Multicast with ability to handle large numbers of vehicles connected to a single base station. The weightless system provides mechanisms to efficiently maintain connectivity for a large number of vehicles by reducing peaks in the data and signalling traffic and restrict access towards a specific APN when the network is overloaded. It also supports multiple vehicles to transmit simultaneously, using FDMA, which increases uplink system capacity. The Weightless specification defines various RF parameters that minimum level must be to ensure that the capacity of the network is not degraded. IEEE 802.11af standard uses MIMO and channel aggregation mechanisms to meet the demand for ever-higher data rates, and offers up to 54 Mb/s download rate which are good enough for considered automotive applications.

Quality of Service and Security: The IEEE 802.22 QoS service model includes Service flow QoS scheduling: A service flow is a unidirectional flow of packets provided a particular QoS support level, which is specified by a set of QoS parameters such as latency, jitter, and throughput guarantees. Weightless scheduling techniques specifically accommodate the requirements of machine-type communications also applicable to vehicular applications. In weightless to protect integrity of payload, data is transferred to the service layers with no data loss (in acknowledged mode), unless the link is lost irrecoverably during data transfer. Data transported using unacknowledged mode is transferred to the service layers, but may be subject to drop-outs with error indication. Encryption and integrity protection of Control messages using keys provided by Higher Layer Network Management or Security entities. Encryption and integrity protection of User and Network Management messages using keys provided by Higher Layer Network Management or Security entities. IEEE 802.11af packet schedulers satisfy the objectives of high spectrum efficiency, throughput, and fairness.

Coverage and Mobility: TV white space bands are towards lower frequency, propagate long way and achieve greater distances, their infrastructure require around one third as many base stations as a traditional cellular network to offer ubiquitous wireless connectivity to vehicles in near future. In IEEE 802.22 standard the coverage area of a cell is generally 17–100 km and typically every CPE is considered as fixed user device that allows portability (nomadic use). For this reason, this standard is not suitable for adapting to mobile user devices. The Weightless standard support mobility, it deals with stationary and moving devices differently. As PHY transport is based on TDMA that is less expensive and much suitable for implementation of soft handovers, Moving terminals log onto a new cell as in WiFi, There are parameters to prevent excessive log-ons for fast moving terminals. To gain additional range the spreading process within the Weightless physical layer multiplies the data by a code-word to create a longer data sequence. It is used where there is insufficient signal level to support communications via an un-spread signal. IEEE 802.11af is designed for both mobile and fixed terminals with ~5 km outdoor radio range.

The evaluation of TV white space access for vehicular communications especially the coexistence with other wireless networks in mobility scenario is difficult to realize in feasibility study. Moderate coverage and capacity makes these standards adequate for considered vehicular scenarios. But as vehicles operating environment is highly mobile, supported mobility can encounter bad channel condition, high connection drop rate, signaling congestion and excessive power consumption with longer latency than cellular systems. These standards are initially designed for applications that are assumed not to require seamless handovers (i.e. a short break in transmission while a terminal moves to a different cell is acceptable). They are trying to tackle the problem with ability to reduce the frequency of mobility management procedures but support for special mobility pattern, the varying vehicle density, and interference with other types of networks need to be optimized. The standardization is ongoing, as a major enhancement of IEEE 802.11af in terms of bit rate, capacity, and spectral efficiency through the support of MIMO techniques. With IEEE 802.11af still in an early stage, the focus of the related work reported in this article is on Weightless standard, but IEEE 802.11af potentialities are discussed.

5. Conclusions

In this article we presented an assay of TV white space access technology in the view of assessing its suitability to automotive applications. The conducted analysis qualitatively describes the main features, strengths, and open challenges of TV white space access standards and solutions under development. We conclude that TV white space technology could be involved in designing a general-purpose (in contrast to traffic efficiency applications) wireless communication system for future vehicles.

Discussed standards strikes a balance between coverage and capacity and can potentially support several thousand vehicles per cell. In the initial deployment phase of vehicular networks, with widespread transmission range TV white space access can particularly helpful to extend vehicular connectivity in those scenarios where DSRC ad hoc networks suffers from limited radio range and pervasive roadside communication infrastructure. In addition TV white space access expected to play a critical role in overcoming situations where cellular communications cannot be supported due to challenging propagation conditions (e.g., corner effect due to building obstructions at road intersections). These standards meet many of the common communication requirements of our target applications however some issues are still open such as seamless handover schemes for high speed vehicles, the capability to support natively V2I communications and QoS for application that have timeliness and reliability as the major requirements.

Since TV white space technology infrastructure exploitation also represent a viable solution to maximize the use of bandwidth resources, Studies should not only analyze the capacity of white space access in supporting vehicular applications, but also their potential impact on overall need for more spectrum to satisfy the growing demand. The introduction of TV white space as an additional candidate access technology would require some changes in the specification of automotive use cases, some amendments are necessary to the current standard documents and architectures. For example, TV white space access technology role in ITS reference architecture

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