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Modeling and enhancing infotainment service access in vehicular networks with dual-radio devices

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ABSTRACT

A dedicated spectrum portion at 5 GHz is available to provide services in vehicular environments (e.g., road safety, traffic efficiency, comfort and infotainment services). The multitude of non-safety critical services offered by roadside and mobile providers can be accessed by vehicles under radio coverage if they listen to the advertisement messages announcing the service configuration parameters and tune to the announced frequency to access the service. Due to intermittent and short connectivity periods, timely and successful advertisements reception is crucial to enable a vehicle accessing available services while it is still connected to the provider.
In this paper, we design an analytical model of the service advertisement and access procedure for dual-radio vehicular devices. Moreover, we enhance the advertisement phase with a simple technique of message repetition and channel switching coordination, which helps in making vehicles aware of local services promptly coping with channel impairments and collisions. The model flexibly accounts for channel switching, message repetitions, access prioritization, and interference by contending traffic on the channel where service announcements are regularly transmitted.

1. Introduction

Vehicular Ad hoc NETworks (VANETs) play a crucial role in assisting Intelligent Transportation Systems (ITS) to improve road safety, enhance traffic and travel efficiency, and provide value-added comfort and convenience services [1].

A milestone for the VANETs deployment was the worldwide allocation of a dedicated spectrum in the 5.9 GHz band, with multiple 10 MHz-wide channels assigned to road safety and non-safety data traffic. One common control channel (CCH) and multiple service channels (SCHs) are allocated, Fig. 1.

In the Wireless Access in Vehicular Environments (WAVE) [2] protocol stack adopted in North America, multi-channel operations are regulated by the IEEE 1609.4 layer, on top of the IEEE 802.11 medium access control [3], Fig. 2.

Despite the availability of multiple channels, so far, most of the research has primarily focused on improving cooperative safety messages delivery. Mechanisms have been devised to boost the reliability and reduce the delay of broadcast safety transmissions, by mitigating channel congestion [4,5]. Some solutions proposed dynamic multi-channel access scheduling for single-radio devices to favor safety messages dissemination [6,7], others leverage the available multiple channels to offload the channel where safety messages are transmitted [8,9].

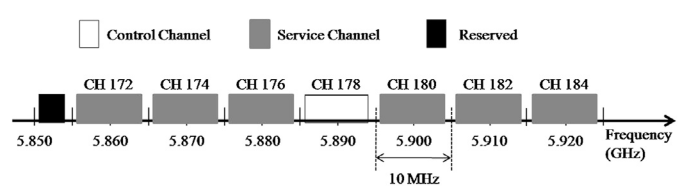

Fig. 1. FCC spectrum allocation in US.

Nonetheless, manifold ITS services for traveler comfort and infotainment are expected in VANETs, not only road safety services. Connectivity on the road can be used by a vehicle, for example to retrieve road maps, parking lot information, or points-of-interest notifications. Video streams captured by an in-vehicle camera [10] or pollution measurements collected from on-board and external sensors [11] can be uploaded from a vehicle to a remote data center for surveillance, analytics and monitoring purposes. In addition, access to traditional and emerging Internet applications (e.g., social

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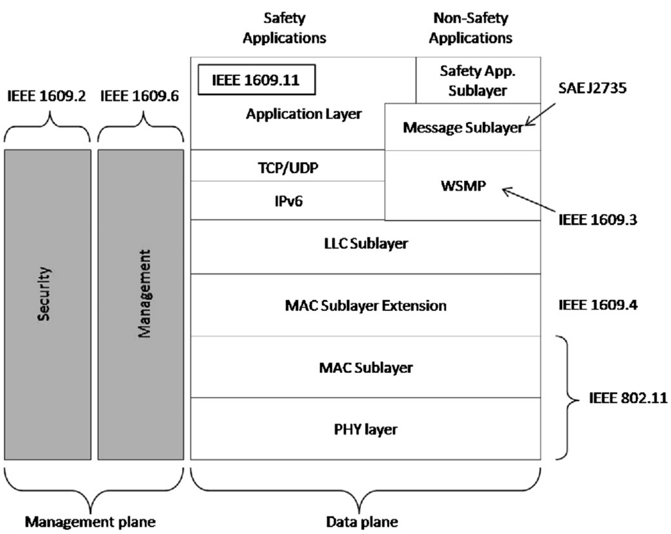

Fig. 2. WAVE protocol stack.

networking, web browsing, gaming, cloud computing) can be also enjoyed by users on board of connected vehicles.

These types of comfort and infotainment services can boost market penetration for connected vehicles, provided that effective service management procedures are designed in the multichannel vehicular environment to fully support them without penalizing safety services. To this purpose, the usage of dual-radio devices is advocated by involved stakeholders to simultaneously access safety and non-safety services [12,13]. Specifically, one of the radio transceivers is continuously tuned to the channel dedicated to safety messages, while the second radio switches between the channel where services are announced and the channel where service are offered.

Based on the WAVE specifications, a roadside unit (RSU) or a special vehicle (e.g., a bus, a police car), operating as a service *provider*, *regularly* announces the offered services by broadcasting *WAVE Service Advertisement* (WSA) frames [14] on a common channel (i.e., the CCH). The successful WSA reception permits a vehicle to detect a nearby provider and become *aware* of the offered services, and then, if interested, to access them on the channel frequency (SCH) and with the parameter settings advertised by the provider.

It is desirable that a vehicle becomes timely aware of the services offered by a nearby provider, so to make the most of the short time it may stay under the provider's coverage range. Although the success of service announcement can dramatically affect the performance of connected vehicles, the WAVE standards [2,14] only provide high-level indications for service advertisement and multi-channel operation and leave many details unspecified.

In this paper, we develop a novel analytical framework, which gives some insight into the WAVE standard performance, and we propose a simple technique for WSA repetitions and channel switching coordination boosting the effectiveness of the service advertisement procedure in order to improve service awareness and channel usage. Specifically, the model in this paper contributes to:

- assess the performance of standard WSA broadcasting in spreading *service awareness* among vehicles under a provider's coverage, in presence of *interfering traffic* and by accounting for *prioritized channel access*;
- understand to which extent letting a provider *repeat the WSA transmission* can improve the message delivery and affect other traffic simultaneously transmitted on the same channel;
- delve into the impact of WSA periodicity and repetitions onto the service access performance, accounting for *channel switching* schemes on *dual-radio transceivers*.

Some efforts to improve the reliability of WSA delivery can be found in preliminary works [15,16]. In general, transmitting replicas of a given message has been shown to be effective in counteracting collisions and channel errors [17,18]. Multi-channel operation is considered in [19] and [20] to study advertisements, but the channel dynamics that may affect service announcements are not fully investigated. To the best of our knowledge, this is the first work addressing the complex phenomena that may affect the *service awareness* in WAVE networks, with the aim to give some practical rules for service advertisement in order to increase the communication opportunities of vehicles and enlarge the providers' user basin while meeting the service demands.

The remainder of the paper is organized as follows. Section 2 describes the WAVE multi-channel architecture and the basics of the standard service announcements and trade-offs. Section 3 presents the proposed WSA repetition and switching coordination scheme. Model assumptions are provided in Section 4. The analytical framework is described in Section 5. Model validation and performance analysis are presented in Section 6. Section 7 summarizes the main findings and provides some best practices for parameter settings. Section 8 concludes the paper.

2. Service access in WAVE networks

2.1. The WAVE protocol stack

The WAVE architecture specifies the protocol stack for vehicular communications. At the physical (PHY) and medium access control (MAC) layers the IEEE 802.11 access technology [3] is considered. Multi-channel operation is supported on top of the 802.11p MAC layer, then at upper layers the stack is split into two branches: on the one hand, traditional Internet protocols (IPv6, TCP, UDP) support non-safety applications, on the other hand, the WAVE Short Message Protocol (WSMP) supports fast single-hop non-routed traffic, like Basic Safety Messages (BSMs) and other types of WAVE Short Messages (WSMs).

2.2. Multi-channel and dual-radio transceivers operation

According to the Federal Communication Commission (FCC), among the six available SCHs, Channel 172 (CH 172) in Fig. 1 is exclusively allocated for public safety applications, including safety of life and property, vehicle-to-vehicle (V2V) collision avoidance and mitigation messages [12]. Channel 178 (CH 178), known as the CCH, is intended for the exchange of WSAs, WSMs, and other management information; no IP packets are allowed on the CCH. WSMs may carry short public utility messages and other messages of common interest for many vehicles (e.g., concerning charging station fees for electric cars, parking lots availability, city maps) delivered in broadcast in the one-hop neighborhood [13].

In order to benefit from both safety and non-safety services, a dual-radio device has one radio continuously tuned onto CH 172 for broadcasting of BSMs, while the second radio is for control and service transactions in a different channel [12,13]. In particular, the second radio switches between the CCH, where non-safety services are announced by means of WSAs, and the advertised SCH where services can be accessed.

The switching schemes are defined in the IEEE 1609.4 standard [2], as illustrated in Fig. 3, and rely on node synchronization to the Coordinated Universal Time. In the *alternating* access mode, devices tune to CCH on a regular basis; CCH and SCH intervals alternate