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Mitigating adjacent channel interference in vehicular communication systems

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ABSTRACT

In the last few decades, dedicated wireless channels were specifically allocated to enable the development and implementation of vehicular communication systems. The two main protocol stacks, the WAVE standards proposed by the IEEE in the United States and the ETSI ITS-G5 in Europe, reserved 10 MHz wide channels in the 5.9 GHz spectrum band. Despite the exclusive use of these frequencies for vehicular communication purposes, there are still cross channel interference problems that have been widely reported in the literature. In order to mitigate these issues, this paper presents the design of a two-stage FIR low-pass filter, targeting the integration with a digital baseband receiver chain of a custom vehicular communications platform. The filter was tested, evaluated and optimized, with the simulation results proving the effectiveness of the proposed method and the low delay introduced in the overall operation of the receiver chain.

1. Introduction

Vehicular communications play a key role in the development of Intelligent Transportation Systems (ITS), whose main goal is the improvement of road safety and traffic efficiency. By extending the driver's field of view, vehicular networks can increase the time available to make decisions or to react in the case of traffic hazards. This way for instance, collisions in low visibility intersections and chain reaction crashes can be drastically reduced. In addition to this, value-added infotainment services can also be provided by vehicular communication systems, such as broadband internet connection or prices and locations of parking slots or gas stations.

There are two main protocol stacks for vehicular communications systems [1], enabling exchange of data among vehicles (V2V communications) and between vehicles and the road-side infrastructure (V2I/I2V). These two families of standards correspond to the IEEE Wireless Access in Vehicular Environments (WAVE), adopted in the United States, and the ETSI ITS-G5 in Europe. At the physical and medium access control layers, both protocol stacks rely on the IEEE 802.11p standard, an amendment to the IEEE 802.11 Wi-Fi reference [2]. In comparison with the typical Wi-Fi operation, there are just a number of modifications that are introduced to enhance the behavior of the communicating nodes under such dynamic scenarios. For instance, the channel bandwidth is reduced from 20 MHz to 10 MHz, in order to mitigate the effects of multi-path propagation and Doppler shift. As a consequence, the data rate is half of what can be obtained with standard Wi-Fi, i.e., from 3 Mbit/s to 27 Mbit/s instead of 6–54 Mbit/s. Another example is the introduction of non-IP messages that are broadcast outside the context of a Basic Service Set (BSS), avoiding the overhead introduced by the registration and authentication procedures, commonly present in wireless local area networks.

In order to guarantee that vehicular communications do not suffer from any type of interference from unlicensed devices, the Federal Communications Commission (FCC) in the United States and the European Conference of Postal and Telecommunications Administrations (CEPT) in Europe, allocated a dedicated spectrum band at 5.9 GHz (Fig. 1). In America, a bandwidth of 75 MHz was reserved, while in Europe only 50 MHz were assigned. This spectrum was divided into smaller 10 MHz wide channels and in the American case, a 5 MHz guard band at the low end was also included. As a result, there are 7 different channels for IEEE WAVE operation and 5 for the case of ETSI ITS-G5. In Europe, 30 MHz (3 channels) are reserved for road safety in the ITS-G5A band and 20 MHz are assigned for general purpose ITS services in the

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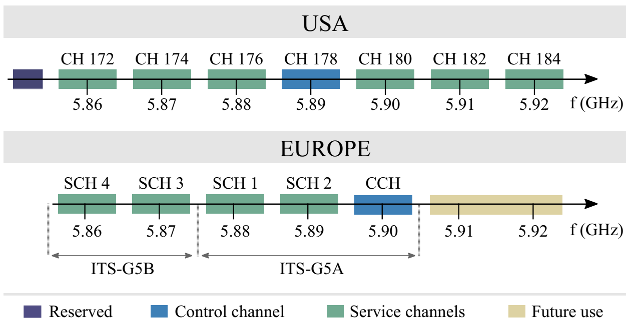

Fig. 1. Spectrum allocation for vehicular communications (adapted from [1]).

ITS-G5B band. As a general rule, a control channel (CCH 178 in the USA and CCH 180 in Europe) is exclusively used for cooperative road safety and control information. The remaining channels are designated as Service Channels (SCH). In the United States, concerns about the reduced capacity for road safety messages led to the decision to allocate SCH 172 specifically for applications regarding public safety of life and property [3]. Moreover, it is mandatory in Europe to have two radios in each vehicular communication platform, in order to guarantee at least one radio always tuned in the dedicated safety channel [4].

Notwithstanding the decision to allocate specific wireless channels for vehicular communication purposes, there are still issues with the operation of these systems, caused by the cross channel interference in the IEEE-WAVE/ETSI-ITS-G5 band and with the European tolling systems operating in the 5.8 GHz frequency band. The interference risks in the latter case were early identified by CEPT in 2007 [5] and several studies [6–8], simulation and experimental tests [9] were then conducted in order to evaluate the impact of ITS-G5 communications in a coexistence scenario with Electronic Toll Collection (ETC) systems. In these tests [9] organized by ETSI, the results have shown that under certain conditions, the ITS-G5 signals can harmfully interfere with ETC systems, causing a loss or non-completion of ETC transactions and/or a disruption of the stand-by mode of ETC On-Board Units (OBUs), i.e. the devices placed inside the vehicles.

Based on these findings, it was clear that the simultaneous operation of both systems at toll plazas could be seriously disturbed. This could lead to safety and congestion problems in these areas and cause substantial loss of revenues for road operators. It was also concluded that this interference is inevitable, unless ITS-G5 will adapt the transmitted power within a certain range around the tolling station or reduce the duty cycle of the message transmission. As a result, ETSI has introduced mandatory requirements for ITS-G5 stations to switch to a “protected mode” [7]. This shall be done when receiving information from any other ITS station containing the location of a tolling station. The ITS station that sends out the information about the tolling station location may either be a fixed located transmitter – Road-Side Unit (RSU) – in the vicinity of the tolling station, or it may also be an OBU in any vehicle that, in addition, is equipped with a 5.8 GHz toll detector.

Furthermore, there is also a perspective to use IEEE 802.11p for ETC communications, but studies [10] have shown it is possible that 802.11a based on-board devices operating in the 5 GHz band could degrade the performance of ETC systems based on vehicular communications. Simulation and real-world experiments [10] demonstrated an increase in the Packet Error Rate (PER) of the ETC 802.11p based system, when both technologies were working simultaneously. It was also shown that this effect cannot be removed by simply increasing the power transmitted by the 802.11p ETC units. In general, one can conclude that wireless communication systems operating near the 5.9 GHz frequency band pose serious problems to the performance of vehicular networks.

Nevertheless, the major source of interference in vehicular communications systems is the cross channel interference, generated by nodes communicating in the adjacent channels [11]. This Adjacent Channel Interference (ACI) can severely compromise the integrity of the messages received by a radio unit, whenever simultaneous communications occur in the nearby channels. Therefore, in order to reduce the effect of ACI in vehicular communication radio links, this paper presents the design of a two-stage Finite Impulse Response (FIR) filter, which guarantees an efficient suppression of the unwanted components of the received signal. At the same time, it is also ensured that few digital hardware resources are utilized and only a small delay is introduced in the receiver chain of the ITS-G5 station. The rest of the paper is organized as follows. Section 2 presents some related work and background on the topic of ACI in vehicular networks. Section 3 shows the effects of cross channel interference in the received signal of a custom vehicular communication platform, while Section 4 describes the design of the proposed digital filter and presents the obtained simulation results. Finally, Section 5 summarizes the concluding remarks and discusses some future work.

2. Related work and background

The IEEE WAVE and ETSI ITS-G5 protocol stacks establish a multi-channel architecture for vehicular communications, where different vehicles in the same geographical area can simultaneously transmit over the multiple channels presented in Fig. 1. This design decision produces obvious throughput improvements, however, since the parallel usage of adjacent channels can occur when vehicles are in the radio range of each other, interference between different nodes' transmissions may arise. This adjacent channel interference (ACI) can cause two main negative effects in the network communications [11]: an increased PER and a reduced transmission opportunity. In the former case, the Signal-to-Interference-plus-Noise-Ratio (SINR) of a packet being received by a node can be increased by another unit communicating in an adjacent channel, which may lead to the impossibility of correctly processing and decoding the frame. This will cause the loss of the packet and, if the situation is not momentary, it can result in large values of PER. The second mentioned effect occurs when a node wants to transmit a frame, but it perceives the channel as occupied due to a packet transmission in an adjacent channel. This channel busy indication is given by the Clear Channel Assessment (CCA) mechanism, being triggered by the power level sensed in the wireless medium, raised by the interferer in the nearby channel. In this situation, the potential transmitter will follow the back-off procedure specified by the CSMA method of IEEE 802.11 standard and thus the access to the wireless medium and the transmission of the intended message will be deferred. Moreover, it can happen that the packet decoding process in the potential receivers is not affected by the interferer, but the transmitter is still wrongly prevented to send its message. The ACI problem could be amplified in dual-radio units, as the ones in Europe, with antennas simultaneously operating on nearby channels and located in the same place, either in the same vehicle or road-side site.

In order to limit cross channel interference, the standard [2] specifies a spectrum emission mask that defines the out-of-band energy allowed for a transmitting device. This spectral mask is defined up to 15 MHz far from the center frequency and it becomes more stringent and difficult to comply with higher transmission power classes (A–D) [12]. On the receiver side, the standardization rules also establish a minimum Adjacent Channel Rejection (ACR) ratio for each modulation, measured by the power difference between the interfering signal and the signal in the desired channel. These masks are sufficient to avoid the most