Ad Hoc Networks 25 (2015) 197–212

Contents lists available at ScienceDirect

Ad Hoc Networks

journal homepage: www.elsevier.com/locate/adhoc

An infrastructure-aided cooperative spectrum sensing scheme for vehicular ad hoc networks

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ARTICLE INFO

Article history:
Received 29 January 2014
Received in revised form 16 October 2014
Accepted 18 October 2014
Available online 24 October 2014

Keywords:
Spectrum sensing
ISM channels
WAVE
DSRC
Cognitive radio networks
Blind detectors

ABSTRACT

The Wireless Access in Vehicular Environments (WAVE) protocol stack has been recently defined to enable vehicular communication on the Dedicated Short Range Communication (DSRC) frequencies. Recent studies have demonstrated that the Control Channel (CCH) of the DSRC protocol on which all vehicular safety messages are sent might not provide sufficient spectrum for reliable exchange of safety information over congested urban scenarios. In this paper, we develop a scheme that calls for collecting spectrum sensing measurements by cars and then aggregating these measurements by Road Side Units (RSUs) to assess the state of the spectrum on road segments. We propose to opportunistically use the white spaces in the spectrum as an extension of the crowded Control Channel (CCH) for the next passing cars. A blind detector is applied and tested on the cars level, which takes advantage of their mobility to span a large area of the roads and deliver more accurate decisions in dynamic vehicular environments. To ensure homogeneity in the sensing samples among cars, we make the sensing rate of the cars dependent on their traveling speed. A fusion and decision algorithm is employed by Road Side Units (RSUs) to aggregate the individual sensing data and decide on the vacancy of the sensed frequency bands. The performance of the sensing and decision algorithms are evaluated and tested in various vehicular scenarios using the network simulator ns2. The obtained results prove the effectiveness of the system in detecting available ISM channels.

1. Introduction

Vehicular Ad Hoc Networks (VANETs) are distributed networks that allow car-to-car as well as car-to-infrastructure communication. Nodes in a VANET can share a whole range of information, from safety messages to application data, like multimedia file sharing. Modern cars are being equipped with a computing unit having a built-in transceiver, called On-Board Unit or OBU. On the infrastructure side, possible infrastructures include Road Side Units (RSUs), which are interconnected via a wired network or through the Internet by the use of high-bandwidth links. They are used to facilitate and control information sharing among the nodes. In 1999, 75 MHz of spectrum bandwidth was reserved for vehicular communication and now forms what is known as the Dedicated Short Range Communications (DSRCs) Spectrum at a center frequency of 5.9 GHz. Progressive attempts to standardize the communication along the whole protocol stack gave rise to several standards [18]. IEEE 802.11p was developed at the physical and lower MAC layers as an amendment to the preexisting IEEE 802.11 standard. It divides the spectrum into 7 channels of 10 MHz each, one of which (the center one) is the Control Channel (CCH), while the other six are Service Channels. Another protocol named Wireless Access in Vehicular Environments (WAVE) protocol covers all layers

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http://dx.doi.org/10.1016/j.adhoc.2014.10.012
1570-8705/

from the network till the application layers. Nodes in WAVE are synchronized to alternate between an SCH slot during which communication on one of the service channels is performed, and a CCH slot, during which all nodes switch to the common control channel.

In [26] and other publications, like [5], it has been proven that the control channel can suffer from severe contention under certain road scenarios. This problem has led researchers to search for innovative ways to solve this problem. Their primary aim was to improve the packet delivery ratio, along with other parameters crucial to the functioning of the VANET under contention, especially when important safety information is transmitted. The works in [19,10] exploited the use of TV channels to extend the spectrum used by network users. However, in practice, this solution is not practical when applied to vehicles in a highly mobile environment since it would require using a large and separate antenna (TV bands are in the MHz, as opposed to GHz for 802.11p). For this reason, we have proposed in our previous work [14] to apply cognitive radio concepts to VANET safety applications by exploiting the IEEE 802.11a outdoor channels centered around 5.8 GHz. Note that the extension of the licensed spectrum to bands outside the 5.9 GHz allocated spectrum but not directly adjacent to it was made possible through the use of Non-Contiguous Orthogonal Frequency-Division Multiplexing (NC-OFDM). The proposed system aimed at providing passing cars with spectrum availability information for the 802.11a channels. The RSU advised the cars about the free bands so they can cognitively use them when contention is inferred in the network [14]. It is therefore of crucial importance that the spectrum availability information be accurate to a certain extent so that cognitive users (also called secondary users) do not interfere with users who are initially intended to use this part of the spectrum (also called primary users). Examples of primary users of the ISM channels include passengers in cars who may be communicating with other passengers in WiFi ad hoc mode (i.e., without infrastructure), or trying to connect to the Internet via hotspots provided by shops and residences on sidewalks (although such a scenario is unlikely). In the simulations (Section 4), we model such scenarios using nodes (cars) of the vehicular network by supposing that a percentage of such nodes are primary users. Moreover, we assume that the probability of users located in cafes and restaurants along sidewalks interfering with WiFi communications on roads where cars are driven (especially major roads and highways) should be very low, which is why we did not consider such users in our experimental scenarios.

This brings us to the focus of the current paper, where the aim is to develop a robust sensing scheme that would: (1) allow the creation of accurate maps of the unlicensed ISM spectrum across the roads, (2) identify vacancies (also called white spaces) in those spectrum maps and (3) allow passing cars to use white spaces as cognitive extensions of the CCH. We propose a system where:

- The cognitive cars themselves are sensing nodes that use a blind detector. By doing so, we are taking advantage of their mobility so as to span a large area of the roads.
- The RSUs perform fusion and decision on the free ISM channels.
- The decision information is conveyed to the passing cars, enabling them to cognitively use the white spaces in the spectrum as extensions for the contended CCH.
- The approach is cooperative in nature since cars and RSUs work together to keep updated information on the state of the unlicensed spectrum on the roads, and to provide a viable extensions of the CCH.

We use the network simulator ns2 to show testing and evaluation of the performance of both sensing and decision algorithms, as well as the overhead incurred. Moreover, the performance of the blind detector is compared to that of the energy detector on a vehicle.

2. Related work

Several schemes have been proposed to perform sensing and manage the unlicensed spectrum for cognitive users in a Cognitive radio (CR) network [30,32]. The authors of [1] distinguish between different spectrum management functions: spectrum sensing, spectrum decision, spectrum sharing and finally spectrum mobility. In this paper, we focus mainly on the first two. Spectrum sensing can be either stand-alone or cooperative. The latter is of course much more effective in terms of accuracy since it combines information from several nodes to arrive to a decision, but such a scheme naturally incurs higher overhead. In [25], a cooperative spectrum sensing framework is described, where a coordination node (CN), normally an RSU or an elected car, performs the sensing on a continuous basis using energy detection. The CN receives requests on a predefined channel from regular cars that wish to communicate (secondary nodes: SNs), and sends them coordination instructions, specifying the free channels to use on a secondary-user basis. An SN that receives such instructions transmits pilot signals on the suggested channel C_i and sends a management signal to the intended recipient which must check if C_i is free in its area. If the channel is free, the two cars can communicate. The authors report that their proposed architecture is autonomous in the sense that cars, after receiving instructions from the CN, decide on the channel autonomously. However, and as was described above, the use of a free channel is still subject to the receiver finding it free on its end. In other words, the lack of coordination between the sender and the receiver in the initial selection of the free channel could result in scenarios where the channel selected by the sender may not be free in the intended receiver's area.

Obviously, a robust detector that delivers accurate decision in complicated vehicular scenarios will enhance the sensing performance. Accordingly, we replace the traditional energy detector (ED), which decides on the amount of energy collected, by a more sophisticated blind detector. Cognitive radio researchers proposed several spectrum sensing algorithms in the last decade. Some of those methods require a priori knowledge of noise and/or signal power information. Those include matched filter-based