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Cognitive multicast with partially overlapped channels in vehicular ad hoc networks

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ABSTRACT

Vehicle to many vehicles (V2MV) multicast is an attractive application to provide vehicle safety and traffic control information, urban sensing and multimedia content sharing in vehicular ad hoc networks. Due to the limitation of DSRC channels, Wi-Fi channels can be alternative to realize the multicast in the vehicular networks. However, the deployment using the Wi-Fi in ISM bands is challenging due to the interference from increasing residential Wi-Fi users as well as inter-vehicle interference. In this study, we propose a cognitive multi-channel, multi-radio multicast protocol, *CoCast*, borrowing concept of recently developed cognitive radio techniques, which can help overcome such interference, with spectrum sensing and multi-channel assignment. Unfortunately, number of orthogonal channels is very limited in the ISM band to avoid interference in urban Wi-Fi cloud. Therefore, we apply two additional features to use partially overlapped channels: parallel frame transmission over OFDM subchannels to exploit spectral diversity, and network coding for the subchannel frames. Our evaluation results show that the reliability of multicast communication among vehicles in a dense urban environment can be significantly improved with these protocol extensions.

1. Introduction

Vehicular ad hoc network (VANET) has been popular researched to support vehicle to vehicle (V2V) communication in which vehicles exchange mainly safety and traffic information. However, VANET multicast, vehicle to many vehicles (V2MV) had not been exploited much even if it were probably useful to provide group communication of video conferencing, contents sharing and broadcasting. In this paper, we focus on deploying the VANET multicast using Wi-Fi channels rather than licensed DSRC channels for safety purpose.

On-Demand Multicast Routing Protocol (ODMRP) [1] is one of the most popular multicast protocols due to its robustness in highly mobile wireless networks like the VANET. The ODMRP establishes a forward mesh structure for a multicast flow, which increases receiving opportunity. However, the ODMRP is unscalable as a trade-off that the mesh structure increases interference exponentially from multiple multicast flows. Channel diversity assigning multiple Wi-Fi channels to the multicast flows can be a key to reduce the intra and inter flow interference.

Not only the internal interference, but vehicles can suffer heavy interference from external users like residential Wi-Fi access points (APs). Here cognitive radio is an attractive technology providing an opportunistic use of empty spectrum avoiding interference from the both internal and external users (i.e., incumbent (*primary*) nodes). More precisely, cognitive radio periodically senses Wi-Fi channels and adapts to the changing usage of wireless medium, selecting the least congested channel among them, which is different to the conventional cognitive radio networks utilizing white spaces in licensed bands like TV bands.

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We propose a new cognitive multicast routing protocol called *CoCast* [2] for the urban VANET. *CoCast* extends the ODMRP to overcome the scalability and interference problems with cognitive radio technology. All of the nodes in VANET sense cooperatively Wi-Fi channels to estimate channel workload and occupy least congested channels in a distributed fashion. The channel information is piggybacked on Join Query and Join Reply messages, which travel on a common control channel (CCH).

However, *CoCast* can still have limitation in the potential due to a few Wi-Fi channels in ISM bands. For instance, in IEEE 802.11b/g in the 2.4-GHz ISM band are only three orthogonal channels among total 11 channels, which are not enough to avoid interference in the urban Wi-Fi AP cloud. If all 11 channels were in use simultaneously, transmission in each channel would suffer from *Adjacent Channel Interference* (ACI). Recent advances in channel allocation [3] have shown that ACI can be mitigated if the nodes that share adjacent channels are sufficiently apart geographically.

The picture, however, is complicated when nodes are mobile, where nodes dynamically change location and the channel orthogonality is quickly invalidated by motion. To aggravate the situation, external random interference from primary users can also disturbs wireless communications. To cope with these problems, we propose a subchannel allocation scheme utilizing spectral diversity within a single Wi-Fi channel that exploits Orthogonal Frequency-Division Multiple Access (OFDMA) style channel division. Subchannel level network coding leverages the gain from subchannel diversity and simplifies subchannel assignment to data blocks. Thus *CoCast* can be more robust to ACI and deep fading while still coexisting with primary users.

Therefore, major features of *CoCast* are:

- the utilization of nodes' cognitive ability to sense the channel and select a least congested channel from primary and secondary nodes,
- the use of OFDM to divide a channel into subchannels and to mitigate the effect of ACI and narrowband interference,
- the use of frequency level network coding to reduce duplicate packet reception and enhance reliability.

Contribution of this paper is threefold: first, state-of-the-art communication technologies, i.e., cognitive radio, OFDM, and network coding, are integrated into the multicast protocol to enhance the robustness of vehicular communications. Next, the new scheme is shown to provide reliable multicast communications in an urban area. Last, a simulation study shows performance gains in terms of packet delivery ratio and end-to-end delay in the Wi-Fi band, e.g., 2.4-GHz.

The remainder of this paper is structured as follows. Section 2 introduces our cognitive multicast protocol, *CoCast*. Section 3 discusses the *CoCast* with real channel models in ISM bands where channels are partially overlapped, and also describes the *CoCast* extension using OFDM subchannels and network coding. Evaluation results are shown in Section 4. We introduce some related works in Section 5 and conclude in Section 6.

2. *CoCast* architecture

CoCast consists of vehicles and Wi-Fi access points as primary nodes (PNs) which potentially interfere with each other in an urban environment as shown in Fig. 1. *CoCast* attempts to provide adequate throughput performance to vehicles by selecting and using least congested channels. Each vehicle is equipped with two radio interfaces (i.e. R1 and R2) that are tuned to different channels to exploit spectral diversity and used to receive and transmit packets simultaneously. Here channels of each interface R1 and R2 are assigned by hybrid channel assignment algorithm [4] in which a channel for the receiving interface R1 does not change for a long time (e.g. every 30 min) but a channel for the transmitting interface R2 is able to be changed dynamically among the channels used by neighboring vehicles for their receiving. So there is no extra overhead required for channel rendezvous mechanism between intended sender and receiver since a receiving interface is semi permanently tuned to its preferred idle channel.

2.1. Spectrum sensing and workload estimation

In order to achieve an optimal channel assignment for the receiving radio interface R1, vehicles sense spectrum periodically on both interfaces and estimate PN traffic workload. Following radio resource measurements (e.g., 802.11k) based on channel occupancy and/or interference [5], vehicles then estimate PN traffic workload on each channel. The *PN traffic workload* can be calculated by an equation $\omega = \frac{\textit{busy-samples}}{\textit{total-samples}}$, where channel status (busy or idle) for each sample is determined by energy level (i.e., Clear Channel Assesment (CCA)) during a given sensing window that vehicles are not allowed to send any traffic in order to identify external PN traffic. Synchronization for the sensing window among the vehicles could be realized using the GPS in which timing error is less than a μs [6]. The longer the sensing window, the better the workload estimation, but the more overhead the sensing will take. Collaborative sensing that exchanges measured channel information among the vehicles helps reducing the overhead.

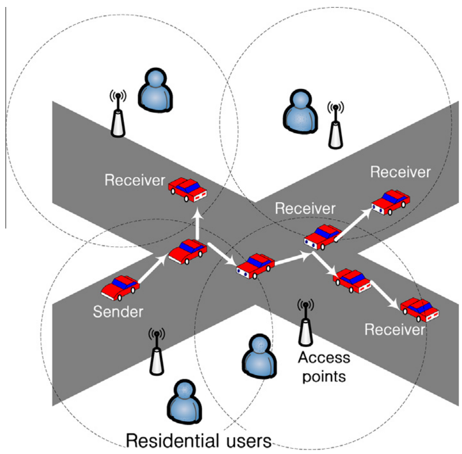

Fig. 1. *CoCast*: cognitive multicast using ISM bands in urban vehicular ad hoc networks.