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MCB – A multi-channel beaconing protocol

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ABSTRACT

We present Multi-Channel Beacon (MCB), a novel approach for efficient wide area data dissemination in vehicular networks using all the DSRC/WAVE channels. Current standardization efforts towards beaconing (i.e., one-hop broadcasting) protocols in vehicular networks focus on the use of a single radio channel only. This is a major bottleneck at high vehicle densities, leading to high delays or packet loss. Instead, the main focus has been to use adaptive transmit rates in order to not overload the wireless channel. Based on our previous work towards multi-channel operation, we developed a novel approach, MCB, which provides adaptivity not only in time, i.e., congestion control, but also in space by selecting appropriate channels for upcoming data transmissions. We evaluated our approach in simulations, comparing our solution to state of the art beaconing protocols, most importantly to the current ETSI Decentralized Congestion Control (DCC) standard. Our results clearly demonstrate the feasibility of our multi-channel approach, showing that it successfully reduces channel utilization and observed packet collisions without sacrificing goodput.

1. Introduction

Intelligent Transportation Systems (ITS) primarily rely on efficient communication concepts [1]. In the last few years, much progress has been made in the field of Inter-Vehicle Communication (IVC), leading to industry standards that define both the physical and the access layer for Dedicated Short Range Communication (DSRC) like IEEE 802.11p and IEEE 1609.4 [2,3] or ETSI ITS-G5 [4]. Based on this radio access technology, different concepts for information dissemination have been explored. This started with simple messages to be broadcast periodically. Such one-hop broadcasts have been termed *beacons*, were later standardized as Cooperative Awareness Messages (CAMs) [5] and Basic Safety Messages (BSMs) [6], and are now thought to be the main communication primitive for a wide range of IVC applications.

In order to enable CAMs/BSMs in all possible scenarios, e.g., during rush hour or in traffic jams with hundreds of cars in communication range but also in very sparse scenarios at night time, the inter-packet interval has been identified as the most critical parameter to adapt [4,7–10]. The main objective of such adaptive beaconing is to minimize the communication delay while keeping the wireless channel use well below its capacity to avoid packet collisions. The presented concepts rely on a single wireless channel making use of either the DSRC Control Channel (CCH) or one of the Service Channels (SCHs).

In this paper, we study the feasibility of using multiple channels at the same time in a Single-Radio Multi-Channel (SR-MC) fashion. In particular, we created a novel multi-channel beaconing approach, called the Multi-Channel Beacon (MCB) protocol. The presented work has evolved from our previous work presented in [11], now employing a novel concept for channel scheduling that exploits emergent behavior. This approach substantially reduces the channel

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utilization and observed packet collisions without sacrificing goodput, while at the same time increasing reliability. Furthermore, we show that MCB also reduces the inter beaconing interval, together with a lower channel utilization, compared to single-channel approaches. Although we take a traffic efficiency application as example, the presented approach can be applied to any other application requiring information dissemination in vehicular networks. Our evaluation shows that the use of multiple channels is not only feasible but also leads to substantial performance improvements.

Our main contributions can be summarized as follows:

- We present a novel Single-Radio Multi-Channel (SR-MC) beacon scheduling system for vehicular networks that follows a split phase approach.
- We show how MCB can keep channel coordination overhead low by relying on a careful selection of when to send coordination information.
- Using a traffic information system as an example, we clearly show that the use of multiple channels not only reduces the load of the wireless channel(s) but also lowers the information dissemination delay as required for safety applications.

2. Related work

We classify related work on this topic into two categories, namely Traffic Information System (TIS) protocols for IVC using beaconing and approaches to multi-channel scheduling systems for both single-radio and multi-radio environments.

Regarding TIS protocols, the usage of CAMs [5] and BSMs [6] represents the simplest form of information dissemination via beacons. Here, to improve situational awareness, these beacons contain information about the current speed and driving direction of vehicles.

SOTIS [12] goes one step further: at its core are knowledge bases (one is being maintained on each vehicle) which integrate any received traffic information items; selected parts of these knowledge bases are periodically assembled into beacons and broadcast to neighboring vehicles.

It was found that static periodic beaconing is not suitable for every road traffic scenario, since the wireless channels easily get overloaded in case of traffic congestions with many vehicles simultaneously distributing their information. At the same time, in very sparse scenarios, the beacon interval might be too large to exploit the few communication opportunities and disseminate information in a timely manner.

REACT [13], to best of our knowledge, is the first protocol which proposes a dynamic beaconing approach, where the interval between two consecutive beacons is adapted to the density of the road network.

Adaptive Traffic Beaconing (ATB) [7] extends this approach by proposing a novel prioritization scheme, where the inter-packet interval depends on the channel quality and the priority of the traffic information. The goal of ATB is to send as much information as possible, but avoid overloading the wireless channel at any time. Similar concepts have also been investigated in [8,9] as well as in the ETSI ITS-G5 standardization group [4].

FairDD [14] considers another topic on information dissemination. Most of the protocols for IVC rate information based on sender side metrics which in fact does not represent a realistic road network, where a receiver maybe is interested in information which is near irrelevant for a sender. To maximize the overall message utility (i.e., transmitting only the information which is most interesting for receivers) is a key challenge in vehicular networks, where FairDD provides an algorithm using Nash Bargaining.

FairAD [15,16] successfully combines the two approaches for fair and efficient information dissemination of FairDD and ATB, respectively, while retaining the advantages of both. However, it still operates on a single channel only, leaving room for further improvements.

In the context of multi-channel scheduling approaches, the problems and pitfalls of wireless communication both for SR-MC and Multi-Radio Multi-Channel (MR-MC) systems have been described in [17]. The authors in [18] study the complexity of channel scheduling for MR-MC in a theoretical way and prove that it is NP-hard under different interference models. The question of how the capacity of such a network scales with an increasing number of nodes has been studied in [19].

In [20] the authors study dynamic channel intervals instead of fixed ones for the use in IEEE 1609.4. They divide the CCH interval into three phases to support service announcements, status beacons and peer to peer communication resource reservation, but they do not provide channel selection algorithms.

In [21] a multi-channel MAC protocol is proposed which uses two phases in the CCH interval to provide a time window for time slot reservation on an SCH and the CCH, as well as collision free access for messages in their reserved time slots. Their channel negotiation scheme consists of several packets to be exchanged by each vehicle to perform one negotiation step which adds additional channel load.

The authors in [22] study dynamic channel intervals using an analytical model. They divide the CCH interval into a safety and a service announcement interval which are dynamic according to the traffic density. They do not focus on the SCH selection scheme.

In [23] an asynchronous multi-channel approach for DSRC is proposed which employs a channel negotiation scheme which uses a well-known SCH (instead of the CCH) to announce specific services, investigating the additional time needed for rendezvous in such a scheme.

In contrast to the presented multi-channel approaches, our protocol follows the beaconing principle, which lowers the complexity of channel negotiation – at no cost to the speed of information dissemination, as we will demonstrate.

3. Preliminaries

In this section, we briefly introduce IEEE 1609 WAVE and the Adaptive Traffic Beaconing (ATB) protocol that we used to manage the load on a single wireless channel.

3.1. IEEE 1609 WAVE

In most countries that are envisioned to operate IVC services, more than one channel is available to participating vehicles. For example, in the U.S., up to seven channels are