Dynamic Channel Partition and Reservation for Structured Channel Access in Vehicular Networks

Ray K. Lam
Dept. of CS and Coordinated Science Lab.
University of Illinois at Urbana-Champaign
Urbana, IL, USA
konglam2@illinois.edu

P. R. Kumar
Dept. of ECE and Coordinated Science Lab.
University of Illinois at Urbana-Champaign
Urbana, IL, USA
prkumar@illinois.edu

ABSTRACT

A large portion of vehicular safety applications require reliable broadcasting. IEEE 802.11p has been shown to have doubtful performance in this aspect [2]. In [1] we have proposed a Dynamic Channel Reservation (DCR) protocol to provide low packet loss probability for vehicular communication by exploiting the unique *structure* of vehicular networks (VANET), and employing a dynamic TDMA mechanism. In this work, we address the situation when there is asymmetric traffic demands from vehicles on the two sides of a roadway, under which condition the throughput performance of unmodified DCR would be significantly degraded, due to its *static* partition and allocation of TDMA channels to each side of the road. We therefore augment DCR by designing a protocol to *dynamically* allocate channels to the two sides of the road according to their *time-varying* traffic demands. Our design replaces the need for vehicles on the two sides to contend for *each* TDMA channel with a mechanism for them to contend for the *boundary* between the contiguous sets of channels allocated to the two sides. Preliminary ns-2 simulations show that our design enhances DCR and delivers low packet loss rate and higher throughput regardless of the level of asymmetry of the traffic demand.

Categories and Subject Descriptors: C.2.1 [**Computer-Communication Networks**]: Network Architecture and Design—*wireless communication*

General Terms: Design

1. INTRODUCTION

A major goal of the development of vehicular networks is to support vehicular safety applications, a large portion of which rely on the periodic *broadcasting* of driving data by each vehicle. However, IEEE 802.11p, the current MAC standard for VANET, has been shown to have doubtful performance in broadcasting under saturation condition, due to its high packet loss probability and low throughput [2]. This calls for improving the *reliability* and *efficiency* of the MAC layer of VANET, so as to adequately support the development of *reliable* safety applications.

To achieve this goal, we have suggested in [1] to thoroughly exploit the *distinct characteristics* of VANETs and specifically design its MAC protocol. We exploited the one-dimensional, group mobility of vehicles on an extended roadway, as well as the periodic broadcast communication pattern of safety applications, to design, based on dynamic TDMA, a Dynamic Channel Reservation protocol for the MAC layer of VANET.

In this paper we continue this design process and enhance DCR to perform well in situations where the vehicular traffic on the two sides of a roadway is *imbalanced*. Under DCR, each vehicle reserves a TDMA channel (time slot) and uses it for broadcasting. The protocol ensures that, on each side of the road, the TDMA channels are reserved by vehicles in a way that channels are reused at proper distances, so as to avoid packet collisions. The spatial separation of vehicles sharing the same channel is preserved in each direction by their group mobility. However, this does not apply to vehicles on different directions, as they move against each other. A default possibility is to divide the TDMA channels *statically* into *two halves*, and allocate one half to each side of the road, forming two logically separated systems. This mitigates packet collisions between vehicles on opposite sides, but, in saturation condition, it results in *channel misallocation*, and hence reduced throughput, when the traffic demands on the two sides of the road are asymmetric.

The contribution of this work is the design of an algorithm and protocol which *dynamically* allocates the TDMA channels in DCR to the two sides of the road, according to the *time-varying* communication demands of the two directions. We call the resulting enhanced design of DCR as the Dynamic Channel Partition and Reservation (DCPR) protocol. Our design attains this goal efficiently by replacing the contention for each TDMA channel by vehicles on the two directions with a simple contention for just the *boundary* separating the sets of contiguous channels allocated to the two directions. The channel boundary cuts the *indexed* set of TDMA channels into two partitions: Channels with indices smaller than the boundary are allocated to one side of the road, and channels with larger indices to the other side. In our preliminary ns-2 simulations, DCPR delivers low packet loss rate and high throughput regardless of the level of asymmetry of the traffic. DCPR also outperforms the unenhanced DCR in all scenarios with asymmetric traffic and IEEE 802.11p in all scenarios.

2. BACKGROUND

Here, we first explain the portion of the DCR protocol which is necessary for understanding the design of DCPR. DCR builds on a dynamic TDMA mechanism. The media air time is divided into frames, each of which is subdivided into indexed time slots called "channels." To transmit data

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in the media, each vehicle must first reserve a channel by transmitting a "probe" packet on the channel. The reservation succeeds if the using of the channel by the probing vehicle will cause no packet collisions in its vicinity, and fails otherwise, due to the design of the reservation mechanism. When the reservation attempt fails, the probing vehicle continues to probe other channels, until a reservation succeeds. Once a channel is reserved, the vehicle subsequently uses it to transmit its periodic broadcasts. If collisions are later detected on the reserved channel, the vehicle drops the channel, and repeats the channel reservation process. Readers are referred to [1] for a full account of the DCR protocol.

3. THE DYNAMIC CHANNEL PARTITION AND RESERVATION PROTOCOL

The goal of this work is to enhance DCR with the necessary component of dynamically allocating TDMA channels to the two sides of traffic on a roadway, so that it is proportional to the asymmetric communication demands.

The core of our design is a mechanism for vehicles on the two directions to *contend for the settlement of the channel boundary through advertising their "presence."* The basic idea is that the presence of a vehicle manifests itself in the transmission of data from that vehicle in the communication domain, and the accumulation of such evidence from the two sides can help determine where the channel boundary is to be set. Under DCR, a vehicle is allowed to transmit data only *after a channel is reserved*. Vehicles which have reserved a channel are thus capable of *indicating their presence* by transmitting their periodic broadcasts. We will hereafter call such vehicles as "*visible* vehicles." Other vehicles, on the contrary, are not able to indicate their presence before they successfully reserve a channel, and hence are called "*hidden* vehicles." Our design provides a separate mechanism for the hidden vehicles to advertise their presence.

Since visible vehicles can advertise their presence, the only problem left unsolved is how to generate and use information *purely in the communication domain* to differentiate between vehicles on the two sides. To attain this goal, DCPR exploits the unique *structure* of VANET, and ultimately accomplishes the task with ease. First, vehicles on one side of the roadway follow the same direction, and on the other side, the opposite direction. (This is known as *one-dimensional group mobility*.) Second, each vehicle is equipped with GPS, which can easily determine the direction of the vehicle based on its trajectory. DCPR thus attaches this direction information to every packet a vehicle sends, thereby clearly indicating the side of the road a visible vehicle belongs to.

For the hidden vehicles, DCPR sets aside the last TDMA channel in the frame as the special "*presence indication (PI) channel*" for them to advertise their presence. As this channel is shared among an arbitrary number of hidden vehicles, DCPR requires a hidden vehicle to send a packet, called the PI packet, on this channel with a low probability in each TDMA frame. The PI packet sent is an indicator of the presence of the hidden vehicle, and it includes the vehicle's direction. By listening to the PI channel, one can estimate the *total* number of hidden vehicles present, based on the empirical probability that the channel is idle, or successfully delivers a PI packet. The number of hidden vehicles on *each side* can then be determined from the ratio of PI packets received from each side.

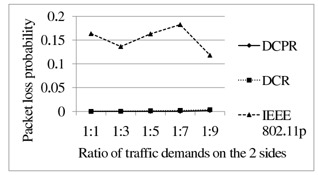

Figure 1: Comparison w.r.t. packet loss probability.

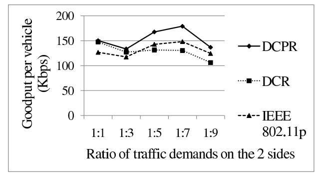

Figure 2: Comparison w.r.t. goodput per vehicle.

By employing the above mechanisms, all vehicles can advertise their presence, and each vehicle can determine the number of vehicles present on each side of the road within its reception range. Each vehicle then sets the channel boundary by dividing the indexed set of TDMA channels (not counting the PI channel) with the measured ratio of vehicles present on the two sides. Vehicles keep monitoring the number of vehicles present in their vicinity as they move, and update the channel boundary in each TDMA frame. Any vehicle not having a reserved channel is mandated to probe only the channels allocated to its side, with respect to the channel boundary calculated by the DCPR algorithm.

4. PRELIMINARY EVALUATION

We have conducted preliminary simulations to compare the performance of DCPR, (the unenhanced) DCR, and IEEE 802.11p under traffic demands of different levels of asymmetry. Using ns-2.33 and VanetMobiSim-1.1, we simulate 38 vehicles moving at a constant speed of 100km/h on a highway of 3000m, each periodically broadcasting an application payload of 200 bytes every 10ms. The total traffic demand is kept constant, and we vary the ratio of traffic volumes on the two sides from 1:1 to 1:9. Results in Fig. 1 show that DCPR and DCR achieve near-zero packet loss probabilities, while those of 802.11p range from 12% to 18%. Fig. 2 shows that in scenarios with highly asymmetric traffic demands, DCR has degraded performance in goodput, and performs even worse than 802.11p. In contrast, DCPR outperforms 802.11p and DCR across all levels of asymmetry in traffic demands.

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6. REFERENCES

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