Improving Multi-Channel Beaconing in Vehicular Networks

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I. Introduction

One-hop broadcasts, termed beacons, are nowadays the main communication primitive for a wide range of Inter-Vehicle Communication (IVC) applications. They have been standardized as Cooperative Awareness Messages (CAMs) and Basic Safety Messages (BSMs).

Adapting the beacon interval has been identified as the most critical parameter to allow CAMs/BSMs to be exchanged in all possible scenarios, e.g., traffic jams with hundreds of cars within communication range or very sparse scenarios. The main reason is to not overload the wireless channel and thus avoid packet collisions while at the same time minimizing the communication delay. Presented adaptive beaconing concepts rely on a single wireless channel, and thus have the limiting factor of channel capacity.

This is in contrast to current standardization, which reserves multiple wireless channels for vehicular networking. Initially, seven channels were allocated in the U.S., later five channels in Europe as well – and there is a clear trend towards the availability of even more channels: More recently, the European ITS standard ETSI ITS-G5 moved to define up to seven channels, with optional use of IEEE channel 94 to 145 in traditional WiFi bands as well [1].

We study the feasibility of multi-channel beaconing and show how this improves message dissemination performance. Our approach builds on our previous work presented in [2], adding a novel concept for channel scheduling for different message priorities. First results show that the use of multiple channels leads to substantial performance improvements, while at the same time lowering the channel utilization per individual channel.

II. Related Work

SOTIS [3] pioneered the exchange of information for traffic efficiency applications: knowledge bases (one being maintained on each vehicle) integrate received traffic information items; a subset of a vehicle's local knowledge base is periodically assembled into beacons and broadcast to neighboring vehicles. Yet, as discussed earlier, it was found that static periodic beaconing is not suitable for every road traffic scenario.

To the best of our knowledge, REACT [4] is the first protocol which proposed a dynamic beaconing approach. The interval between two consecutive beacons is adapted according to the density of the road network.

Adaptive Traffic Beacon (ATB) [5] extends this approach. It proposes a novel prioritization scheme. Its overarching goal is to exchange as much information as possible, but avoid overloading the wireless channel at any time. Each knowledge base entry includes a priority based on the entries' information, and the beacon interval is based on this priority and the channel quality. In [6], [7] similar concepts have been investigated, as well as in the ETSI ITS-G5 standardization group [8].

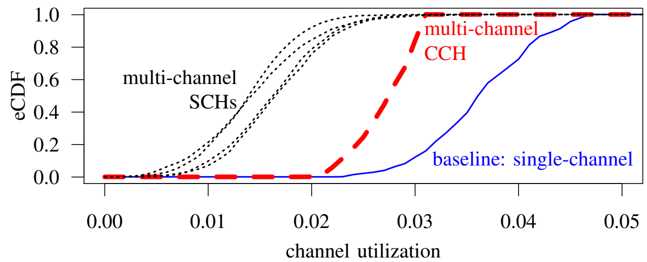
The IEEE 1609 DSRC/WAVE series of standards [9] describes how to operate a single-radio multi-channel system using a dedicated Control Channel (CCH), but leaves scheduling decisions to applications. Our work fills this gap and proposes channel scheduling algorithms to provide multi-channel operation for IVC.

III. Multi Channel Beaconing

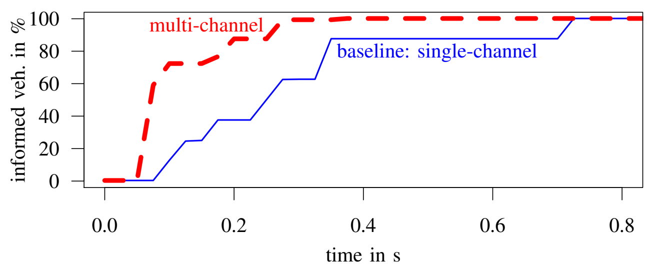
We are working on a multi-channel beaconing extension to ATB, which is specifically designed to take advantage of the additional Service Channels (SCHs) available in the DSRC band. We evaluated our multi-channel approach in a Single-Radio Multi-Channel (SR-MC) split phase scenario, but the presented concept can easily be extended to Multi-Radio Multi-Channel (MR-MC) environments without using split phase channel switching.

As in WAVE, time is divided into CCH and SCH intervals, each with a duration of 50 ms and having a small guard interval in front to minimize the probability of lost messages during channel switching. WAVE follows the principle to broadcast data announcements on the CCH, advertising that SCH where data will be transmitted during the following SCH interval. Channel switching is only performed during guard intervals.

Our protocol's operation is divided into four distinct steps: First, we regulate the beaconing rate by adapting the number of intervals to elapse before sending a data announcement. Second, when we selected an interval, we carefully determine the time within the interval to broadcast the announcement. This time t within the CCH interval is based on the priority of the payload information such that more important messages are sent earlier in the interval. Third, at t, a node selects the SCH to transmit the payload information by taking into account all received announcements up until this point, and sends the announcement. In a fourth step, during the guard interval the node tunes its radio to the announced SCH and broadcasts the data in that way to avoid synchronized collisions.



(a) Channel Utilization



(b) Fraction of informed vehicles

Fig. 1. Channel utilization and fraction of informed vehicles for a medium density freeway scenario.

IV. First results

We show the performance of our multi-channel approach by using a medium utilized freeway scenario having two lanes in each direction, consisting of 90 % cars and 10 % trucks. Each vehicle periodically generates low priority dummy messages and fills its local knowledge base with it. After protocol execution has reached a steady state, we select a random vehicle in the middle of the freeway to generate a high priority message. We will track its dissemination in our evaluation. Each simulation is repeatedly executed for different random number seeds to get good confidence in the results. Data is recorded within a region of interest of 1 km to minimize border effects, and only after a steady state of the protocol has been reached. We compare our multi-channel approach to the baseline single-channel ATB protocol and focus on two different metrics, namely channel utilization as low level performance, and relative message dissemination speed to measure application level performance.

To investigate channel conditions we select the channel utilization experienced by each individual vehicle. This metric is calculated as the fraction of simulation time for which physical Clear Channel Assessment (CCA) of that vehicle would have considered the channel busy. Figure 1a shows the results split by channel. Both beaconing schemes, single-channel and multi-channel, keep the channel utilization at a very low level, following their aim of not overloading the channel. In particular, the CCH is lower utilized by the multi-channel protocol, because it uses the channel only for much shorter announcement beacons. This means that the multi-channel variant even would be able to send substantially more frames on the CCH than its single-channel counterpart. Payload transmissions across all SCHs can also be seen to be evenly distributed.

Looking at application layer performance, the second metric we select is the fraction of informed vehicles. We track how fast a single piece of information spreads through the network, by generating such a high priority item in the middle of a highway and feeding it to the vehicle's local knowledge base like described before. For each time step in the simulation we then track the fraction of all vehicles that already received this particular piece of information. The results are shown in Figure 1b, where we plot the mean fraction of informed vehicles in all simulation repetitions, normalized to $t = 0$. This metric is influenced by all previous mentioned factors, e.g., channel utilization and packet collisions. As can be seen, the multi-channel variant of the protocol is able to propagate the information through the network substantially faster than the single-channel variant. The results are even more interesting, since the multi-channel approach can only use 46 ms of each 50 ms channel interval to send and receive beacons, which is caused by the 4 ms guard interval in front of each slot.

V. Conclusion and Future Work

We presented an improved version of our previous work for multi-channel beaconing, which is able to lower the channel utilization and thus observed packet collisions while at the same time increasing the relative message dissemination speed. First simulation results performed using a single-radio split phase multi-channel approach show the feasibility of multi-channel beaconing in vehicular networks. Since our approach is not limited to a single-radio system, we will extend our proposed protocol to work towards a multi-radio system using all available channel space specified by ETSI ITS-G5.

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