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Delay-Sensitive Wireless Communication for Cooperative Driving Applications

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Abstract

Cooperative driving holds the potential to considerably improve the level of safety and efficiency on our roads. Recent advances in in-vehicle sensing and wireless communication technology have paved the way for the development of cooperative traffic safety applications based on the exchange of data between vehicles (or between vehicles and road side units) over a wireless link. The access to up-to-date status information from surrounding vehicles is vital to most cooperative driving applications. Other applications rely on the fast dissemination of warning messages in case a hazardous event or certain situation is detected. Both message types put high requirements on timeliness and reliability of the underlying communication protocols.

The recently adopted European profile of IEEE 802.11p defines two message types, periodic beacons for basic status exchange and event-triggered hazard warnings, both operating at pre-defined send rates and sharing a common control channel. The IEEE 802.11p Medium Access Control (MAC) scheme is a random access protocol that does not offer deterministic real-time support, i.e. no guarantee that a packet is granted access to the channel before its deadline can be given. It has been shown that a high number of channel access requests, either due to a high number of communicating vehicles or high data volumes produced by these vehicles, cannot be supported by the IEEE 802.11p MAC protocol, as it may result in dropped packets and unbounded delays.

The goal of the work presented in this thesis has therefore been to enhance IEEE 802.11p without altering the standard such that it better supports the timing and reliability requirements of traffic safety applications and provides context-aware and efficient use of the available communication resources in a vehicular network. The proposed solutions are mapped to the specific demands of a set of cooperative driving scenarios (featuring infrastructure-based and infrastructure-free use cases, densely and sparsely trafficked roads, very high and more relaxed timing requirements) and evaluated either analytically, by computer simulation or by measurements and compared to the results produced by the unaltered IEEE 802.11p standard.

As an alternative to the random MAC method of IEEE 802.11p, a centralized solution is proposed for application scenarios where either a road side unit or a suitable dedicated vehicle is present long enough to take the coordinating role. A random access phase for event-driven data traffic is interleaved with a collision-free phase where timely channel access of periodic delay-sensitive data is scheduled. The ratio of the two phases is dynamically adapted to the current data traffic load and specific application requirements. This centralized MAC solution is mapped on two cooperative driving applications: merge assistance at highway entrances and platooning of trucks. Further, the effect of a context-aware choice of parameters like send rate or priority settings based on a vehicle's position or role in the safety application is studied with the goal to reduce the overall number of packets in the network or, alternatively, use the available resources more efficiently. Examples include position-based priorities for the merge assistance use case, context-aware send rate adaptation of status updates in an overtaking warning application targeting sparsely-trafficked rural roads and an efficient dissemination strategy for warning messages within a platoon.

It can be concluded that IEEE 802.11p as is does not provide sufficient support for the specific timing and reliability requirements imposed by the exchange of safety-critical real-time data for cooperative driving applications. While the proper, context-aware choice of parameters, concerning send rate or priority level, within the limits of the standard, can lead to improved packet inter-arrival rates and reduced end-to-end delays, the added benefits from integrating MAC solutions with real-time support into the standard are obvious and needs to be investigated further.