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QoS and robustness of priority-based MAC protocols for the in-car power line communication

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ABSTRACT

Communication demands of electronic devices are rising in almost every area of life including modern vehicles. In the past, growing in-car communication demands were countered with an increasing number of deployed bus systems, thus increasing complexity and weight of the wiring harness. A promising technology to counteract these effects is Power Line Communication (PLC). With PLC the cabling is reduced to the minimum as existing power lines are used for communication. Besides the physical layer, the Medium Access Control (MAC) layer has to meet automotive requirements, too. As a result of our previous research, a priority-based MAC for in-car PLC is considered most promising. Unique message IDs are used as priorities, thus collisions are avoided. The priority ordering is crucial for guaranteeing worst case response times for functions and applications with strict Quality of Service (QoS) requirements. In this paper, a worst case response time calculation for the analysis of our priority-based PLC MAC protocol is given. The analysis builds upon available Controller Area Network (CAN) schedulability analyses. In addition, we introduce a new definition of robustness and provide an extended algorithm determining the priority ordering with highest robustness. The reservation and assignment of priorities is discussed, having flexibility for future changes in the traffic mix in mind.

1. Introduction

Today's vehicles incorporate a high and still increasing number of ECUs (Electronic Control Units). Each ECU fulfills various functions depending on the application domain. Typical domains are powertrain, body and comfort, chassis, safety and infotainment. With an increasing number of functions, the demand for a communication between ECUs and other devices like sensors and actuators rises. In order to meet the requirements of different application domains, various communication systems have been developed. Nowadays, in a car a huge number of communication systems are deployed in parallel.

Widely spread communication systems in today's vehicles are CAN (Controller Area Network) [1], LIN (Local Interconnect Network) [2] and FlexRay [3]. For infotainment applications often MOST (Media Oriented Systems Transport) [4] is used. The first widely deployed in-car communication system is the CAN bus, which has been designed and released in the 1980s. It is used for many different applications. With an increasing number of functions in the body and comfort domain, the LIN bus has been developed in the beginning of the 21st century as a cheap and simple alternative to CAN. In parallel, especially for applications in the safety domain, FlexRay has been designed. Multiple of these communication buses are deployed in an up-to-date vehicle. Depending on model and brand, in an upper class vehicle up to 40–50 bus segments can be found. The high number of wires that have to be placed in the car leads to a huge effort in planning, deployment and maintenance of the harness. Gateways interconnecting multiple buses have to be used in order to enable cross domain communication. On the other hand, the weight of the wiring harness increases with rising number of wires placed in the car. For an upper class vehicle the weight is already comparable to the weight of a passenger. However, when considering the fuel or energy consumption, the weight of a car should be minimized.

In order to cope with future increasing demands, new solutions for the in-car communication are needed. Regarding weight and flexibility of the harness, wireless communication is an option as no dedicated wires for the data transmission are needed. But as a lot of antennas have to be placed in the car and due to unpredictable interference from other devices or even jamming transmitters, wireless communication is not suitable for the major-

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ity of applications. Measurements [5] show a high effective area of influence.

A wired candidate for future in-car networking is Ethernet. Some vehicles already make use of Ethernet for example in the infotainment domain. With BroadR-Reach [6] a physical layer standard for automotive Ethernet on an unshielded two-wire twisted pair cable is available. Nevertheless, dedicated wires for the communication have to be installed.

In contrast to Ethernet, PLC (Power Line Communication) is a promising technology when the number of wires is to be decreased. With PLC the cabling is reduced to a minimum – the already existing power supply. The physical transmission of PLC signals on a vehicle's energy backbone is feasible as measurements [7] show. Besides the feasibility, the EMC (electromagnetic compatibility) has to comply with automotive regulations. Additionally the MAC (Medium Access Control) layer has to meet automotive requirements. As costs are crucial in automotive engineering, usage of off-the-shelf components is preferred. In our previous research [8] we found HomePlug AV [9] and IEEE 1901 [10] providing a promising basis. In particular, there is a simpler and cheaper subset of HomePlug AV, namely HomePlug Green PHY [11] available, which allows for reduced costs. With modifications to the firmware and/or hardware, our priority-based MAC (PR MAC) [8] is considered most suitable for the in-car power line communication providing proper support for event based traffic.

Depending on the application domain, requirements regarding Quality of Service (QoS) highly differ. A key property of mechanisms like PR MAC or the CAN medium access (called arbitration) is that higher priority traffic is always transmitted first. The delay of lower priority traffic strongly depends on the actual composition of higher priority traffic. A detailed analysis has to be performed for functions with different priorities but strict delay deadlines. With the knowledge of task periods and queuing jitter, worst case response times can be calculated and the schedulability of each function can be determined. This paper focuses on schedulability analysis and robust priority ordering of PR MAC on the one hand and rules for assigning and reserving IDs from the ID space on the other hand.

1.1. Related work

In our previous research [8] we proposed different MAC protocols optimized for the in-car communication. As a conclusion, PR MAC turns out to be most promising. In [12] we presented modifications to PR MAC in order to reduce the energy consumption which is assumed to be comparatively high when using PLC.

PR MAC and also the CAN arbitration behave like fixed priority single processor systems with non-preemptive task execution. In previous research, CAN schedulability analysis builds upon schedulability analysis of real-time systems with a single processor. In [13] research on periodic tasks with arbitrary deadlines is given. Deadlines are called arbitrary if the task's deadline is greater than its period. To analyze such tasks, Lehoczky introduces the concept of a busy period [13]. To find the worst case response time of a task, all instances of a task within the busy period have to be analyzed. Non-preemptive scheduling with fixed priorities can also be seen as a special case of preemptive scheduling with varying priorities, when the priority of a task is shifted to the highest priority as soon as the task is being executed. As shown in [14], again multiple instances of a task in a busy period have to be analyzed when deadlines are less or equal to task periods.

Tindell et al. [15] improve on previous research by providing an analysis of arbitrary deadlines for real-time systems using a recurrence relation. CAN real-time communication analysis and the calculation of CAN message response times have been presented by Tindell and Burns in [16] and Tindell et al. in [17] and [18]. In [16] and [17] an analysis of specific CAN controllers is provided. An extended analysis taking transmission errors into consideration is presented in [18]. Algorithms for determining the ordering of priorities are not given.

Based on this previous research, George et al. [19] provide a comprehensive schedulability analysis for both, preemptive and non-preemptive single processor systems. In 2006, Bril [20] showed available analysis of worst case response times of fixed-priority scheduling with deferred preemption to be optimistic. The schedulability analyses of CAN messages given in [16,17] and [18] suffer from the very same flaw.

In [21] this flaw of previous contributions is highlighted and a revised schedulability analysis eliminating the possibility of calculating optimistic response times is presented. In this paper we present an adapted analysis in order to calculate worst case response times for PR MAC. Modifications are needed to incorporate for periodic beacon transmissions on the one hand and for fixed access slots on the other hand. Furthermore, the given equations depend on the number of subsystems used. In addition, Audsley's priority ordering algorithm [22] used in [21] is extended in order to determine the priority ordering with highest newly defined robustness.

1.2. Contribution of this paper

The main contribution of this paper, building on a complete description of PR MAC, is summarized as follows: we present a novel method for analytically determining worst case response times of messages for PR MAC depending on the number of subsystems. Furthermore, a new definition of robustness is given. Additionally we present a novel algorithm for determining the priority ordering with highest robustness. A priority ordering is robust when a high number of messages can be added in the future without having present messages violating their deadline. Our algorithm is an improvement to the priority ordering algorithm presented in [21] which is able to find a schedulable priority ordering if one exists. When more schedulable orderings exist, the original algorithm in [21] will just find one of them. With our new algorithm, the robustness regarding future extensions of the schedule is maximized. An in-depth definition of robust priority ordering is given in Section 4. At last, we give rules for message ID reservation and ID to priority mapping. By following the rules, the flexibility for future changes in the traffic mix is maximized. The presented algorithm and rules aim to be applied to PR MAC but can be applied to similar systems as well.

In order to highlight our new ideas and the contribution of this paper, the most important points are summarized as follows:

- Method for analytically determining worst case message response times for PR MAC
- New definition of robust priority ordering
- Novel algorithm determining the priority ordering with highest robustness
- Rules for message ID reservation and ID to priority mapping

The paper is structured as follows: in Section 2 an overview of in-car PLC communication and its requirements is given and MAC protocols are discussed. The priority-based MAC protocol is presented in detail, as it is the basis for our analysis. In Section 3 the system model for our schedulability analysis is presented. In addition we give equations for determining worst case response times of messages when using PR MAC. A new definition of robustness and the algorithm identifying the robust priority ordering are given in Section 4. Finally, in Section 5 the mapping of the priority ordering to the ID space is discussed and the reservation of IDs having flexibility in mind is addressed.