Demo: Real-time Ethernet In-Car Backbones: First Insights into an Automotive Prototype

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***Abstract*—The communication infrastructure of today's automobiles forms a complex composition of heterogeneously interconnected components. At the same time, demands for higher bandwidth and low-latency communication are emerging from chassis control, camera based driver assistance and infotainment that cannot be accommodated by established technologies. A new approach towards a flexible highly scalable network is real-time Ethernet. The RECBAR research project develops and evaluates concepts and technologies for next-generation in-car backbones.**

In this demo we show a prototype based on a 2014 Volkswagen Golf 7 series car additionally equipped with high-bandwidth sensors, such as HD cameras and 3D laser scanners. The car uses a backbone network utilising time-triggered real-time Ethernet for the deterministic transmission of messages with hard real-time as well as rate-limiting and best-effort frames for messages with relaxed timing requirements. On the physical layer the setup utilises the OPEN Alliance 100Mbit/s BroadR-Reach (OABR or 100 BASE-T1) in addition to 100 BASE-TX.

I. Introduction & Motivation

Real-time Ethernet is expected to become the favoured technology to satisfy the requirements of upcoming communication architectures in cars. With its huge bandwidth, Ethernet provides the potential to consolidate the communication of the different automotive domains – e.g. chassis, powertrain or info- and entertainment – on a single shared physical infrastructure. Today, different technologies, such as CAN, FlexRay and MOST, are required to satisfy the heterogeneous temporal demands of these domains. Real-time extensions, such as Ethernet AVBs credit based shaping (CBS) or time-triggered Ethernet allow for a high degree of determinism and enable the introduction of different traffic classes, each with unique temporal attributes.

In the presented prototype car (see figure 1), we install a real-time Ethernet based backbone network. Gateways between the legacy fieldbusses (CAN) and the Ethernet network transparently translate messages, allowing communication to cross the borders of both technologies. By adding high bandwidth sensors, in particular HD cameras and 3D laser scanners we fully utilise the bandwidth limits of the automotive certified OPEN Alliance 100 Mbit/s BroadR-Reach (OABR) [1] physical layer. By running challenging applications, such as sensor fusion, we add rigid temporal demands. During the test, a dedicated control unit in the network logs every aspect of the communication. This allows us to offline analyse the backbones behaviour and feed simulation models to gain a deeper understanding of effects that are usually hidden.

Fig. 1. Prototype car equipped with real-time Ethernet backbone and high-bandwidth sensors

II. Background

In the prototype backbone we use the traffic classes of TTEthernet, standardised by the Society of Automotive Engineers in AS6802 [2]: For *time-triggered (TT)* communication, pre-configured schedules assign dedicated transmission slots to each participant. This coordinated time-division-multiple-access (TDMA) multiplexing strategy allows deterministic transmission with predictable delay. *Rate-constrained (RC)* traffic, intended for the transmission of messages with moderate timing requirements, limits the streams bandwidth and prioritises according to the strategy of the ARINC-664 (AFDX) protocol. *Best-effort (BE)* traffic conforms to standard Ethernet messages transmitted with the lowest priority.

On the physical layer the OPEN Alliance 100 Mbit/s BroadR-Reach (OABR) [1] is used for robust links. It allows the bi-directional communication with 100 Mbit/s on a single unshielded twisted pair of wires to reduce costs for cabling and weight. OABR was designed for environments with harsh EMC and noise conditions and is currently being standardised by the IEEE (802.3bw).

III. In-Car Backbone Prototype

The in-car backbone network (see figure 2) is based on a flat network using 3 switches. With the star topology, the switches can be located in close proximity to the ECUs. In the prototype we use one switch in the front and two switches in the rear. Due to the OABR physical layer, we require only one unshielded twisted pair to connect both locations. The front switch connects the laser scanners and camera in the bumper, while the switches in the back are connected to the

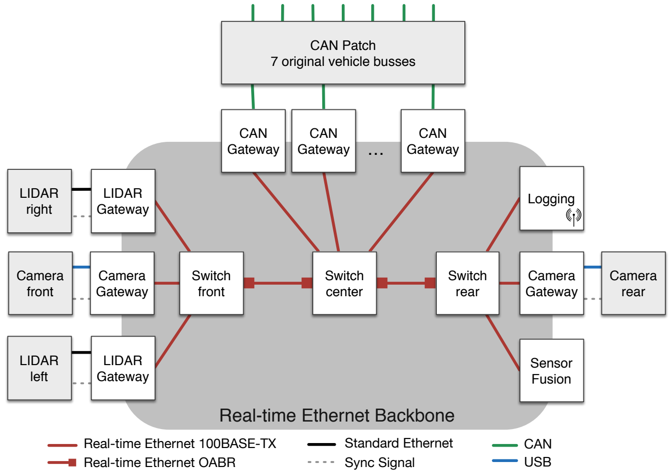

Fig. 2. Simplified architecture of the prototype car

CAN-bus gateways, the rear camera, and the industrial PCs for logging and sensor fusion. As the car is already equipped with many electronic components the limited space is challenging. Most electronic control units (ECUs) are located in the glove compartment or under the trunk.

Standard components, such as cameras and laser scanners, do not implement the real-time Ethernet protocols used in the backbone. Therefore, one challenge is to implement gateways that transparently integrate those components without corrupting the temporal attributes. Further, local regulations for road safety require us to be able to recover the original in-car network at any time. Thus, the in-car backbone was installed in addition to the legacy cable harness to build a shadow network. This further allows to compare the timing of the original busses and the prototype network.

Architecture

The legacy in-car traffic, which consists of messages transmitted over the original vehicle busses (such as chassis, drivetrain, or infotainment), is handled by the backbone through CAN gateways. These gateways are configurable for different strategies to aggregate several CAN frames into real-time Ethernet messages. These aggregation strategies allow for a more efficient utilisation of the bandwidth as the minimal Ethernet payload size of 46 byte can carry multiple CAN frames. At the same time this frame aggregation has significant impact on the end-to-end latency and therefore must be carefully evaluated.

The laser scanners (LIDAR) in the bumper, each covering 110° are combined to cover 180°. Thanks to the overlap in the front of the vehicle the precision of the distance measurement is improved. This sensor fusion requires the network to forward the raw sensor data instead of only transferring detected objects. At the same time the network allows to add more sensors, such as the HD cameras, to the fusion process. The multicast approach of the network enables to flexibly deliver sensor data to a group of receivers.

The LIDAR also uses gateways, which encapsulate the TCP streams of raw data into the real-time traffic class to allow for a transparent forwarding over the Ethernet backbone with sub millisecond delay. The gateway further synchronises the triggering of the scans using a globally synchronised clock. Further, the scan process is synchronised with the cameras to allow the fusion of laser scanners and camera in the future. Due to the synchronisation process any raw data is related to the global time, which simplifies the algorithms running at the sensor fusion unit.

All gateways collect the timing information of incoming packets and transfer these timestamps along with the raw-data. The logging unit constantly records the timing collected during the forwarding in the network to a relational database. This allows for a detailed offline analysis of the network behaviour.

The CAN and LIDAR gateways are based on hardware using a system-on-chip design. The modular platform consists of an ARM926EJ CPU running at 200 MHz and four independently configurable communication channels. Based on firmware programs each channel works like a DMA controller, which supports different communication technologies like Ethernet or CAN. The real-time Ethernet stack and scheduler were developed and carefully evaluated in previous work [3].

IV. Conclusion & Outlook

First trial runs of the prototype have proven the feasibility of our approach. The backbone network transparently tunnels the messages of the legacy CAN busses while providing enough bandwidth to transfer the raw sensor data of the laser scanners as well as high definition video. The real-time Ethernet allows for a deterministic transmission with low latency and ultra low jitter. The access of the sensors used for fusion can be precisely triggered without further equipment using a globally synchronised network clock.

During the upcoming two years the prototype will be used for our research on in-car backbone architectures. We will work on real-time protocols and evaluate future trends currently in discussion in the Time-Sensitive Networking (TSN) Task Group. The prototype will be used as a platform to test implementations of real-time communication stacks and hardware, such as approaches to hardware/software co-design. Further, we will evaluate new strategies for the consolidation of legacy busses, like new gateway designs and scheduling strategies.

Acknowledgements

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