Automotive communication protocols focused on the x-by-wire applications

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This paper presents an overview of automotive communication technologies, in particular, the wired communication protocols. Then, a review of the most widely and long-time used automotive networks is given. Next, the latest technology developments, which can be used in x-by-wire applications, are presented. X-by-wire systems are not functional without establishing a fast and reliable communication network between the electrical control units (ECUs). Finally, a case study is presented where redundant network topology is used for brake-by-wire in commercial vehicles.

Magyar absztrakt helye!

1 INTRODUCTION

Automotive technology is more and more involved by electronically controlled systems and subsystems. A today's luxurious passenger car has 60-70 electronic control units (ECUs). To establish the necessary communications, lines among the controllers of the subsystems would be practically impossible by point-to-point connections. A network of well-organised digital communication buses is built up to communicate the some thousands of signals. This complexity establishes strong requirements on the today's automotive communication.

2 COMMUNICATION REQUIREMENTS

The requirements on different communication channels are determined by the needs of the vehicle's components. The type of the component (if it is a central ECU of a subsystem, or an intelligent actuator, or a sensor) and its functional and safety requirements determine the type of communication channel used among the components.

In [1], five various requirements are discussed regarding performance and robustness of the communication, which includes fault tolerance, determinism, bandwidth, flexibility and security.

Fault tolerance: In safety-critical applications, fault tolerance is a key factor. The required safety integrity level [2] determines also the needed fault tolerance of the communication. A fault can be caused by external (electromagnetic) disturbance, loose contact, defective wire and defective circuit. With built in software and/or hardware redundancy, communication can be made tolerant against faults, or a communication failure caused by any fault can be detected and handled.

Determinism: A deterministic communication system provides guarantees in terms of timeliness, i.e., it makes it possible to know the transmission time of a message. Deterministic communication requires correct reception of messages. Many safety-critical automotive subsystems also have strong real-time requirements which need determinism, i.e. messages have to be sent at predefined time instants (or within precise time intervals) to fulfil the intended subsystem functionality.

Bandwidth: As the number and the complexity of the electronically controlled automotive subsystems increase, the need for higher and higher bandwidth increases as well. Naturally, there is a trade-off between the required bandwidth and the cost of providing such a bandwidth. In many cases, it is more desirable selecting a cheaper communication bus with lower bandwidth due to strong requirements on cost. Moreover, due to system architecture or security reason, the connection of components may also allow communication with lower bandwidth.

Flexibility: Flexibility can be seen as the possibility to cope with varying load and/or number of messages, scalability and extensibility of the network (without need of reconfiguration of the already configured communication).

Security: When the communication is reachable from outside the automotive system by, e.g., diagnostic tools, wireless connections and telematics, it is important to ensure that no unauthorized access to the system is possible. The currently used automotive communication protocols are generally not secured by their standards. Typically additional security handling is realised on application level for specific functions.

As it was seen, fault tolerance and security are features that basically require some redundancy over the pure information to communicate. Flexibility and determinism are often contradicting requirements. We can distinguish between the following two communication channel access methods used in automotive systems.

Time division multiple access (TDMA) is a channel access method for shared medium networks. It allows several users to share the same frequency channel by dividing the signal into different time slots. [3]

Carrier sense multiple access (CSMA) is a probabilistic Media Access Control (MAC) protocol, in which a node verifies the absence of other traffic before transmitting on a shared transmission medium. [4]

TDMA handles the messages time-triggered, thus it is deterministic, but all message transmissions must be predetermined off-line. CSMA results in an event triggered transmission, whose triggering depends on the actual load of the communication channel, thus it is not deterministic. But the networks message transmissions are resolved online, therefore it is considered more flexible than the former. The most advanced networking technologies – like FlexRay, which is going to be presented more detailed in this paper – relax in some way the fixed structure of TDMA message transmissions.

3 AUTOMOTIVE COMMUNICATION PROTOCOLS, WIRED TECHNOLOGIES

CAN (Controller Area Network) [5] [6] [7] is the most widely used network in the automotive industry. It was originally developed by Bosch in 1983. It is a multi master broadcast serial bus of CSMA type providing an up to 1 MBps bandwidth. Over the years, several different CAN standards have been developed and used in different applications. There are differences mainly in transmission speeds and higher layer protocols as well as the applications, in which they are used. Two-wire balanced signaling scheme in twisted pair format with a bandwidth of 250 KBps is used as the most common physical layer in automotive industry.

LIN (Local Interconnect Network) [8] is an inexpensive 19.2 KBps network with one-wire master-slave communication. It was initiated by a consortium of automotive companies together with Motorola in 1998. Its 2.0 version was standardised in 2003. It is typically used in non-safety-related body and comfort subsystems. But nowadays it appears as also backup communication lines in case of the main communication on CAN fails as well as safety-relevant sensor communication lines. It is often used together with CAN building up a common communication network in the vehicle using ECUs having (also) gateway roles.

SENT (Single Edge Nibble Transmission) [9] aims to define a new low cost implementation of the digital pulse scheme for reporting sensor information. It was first standardised in 2007 and most recently in 2010. It intended for use in applications where high-resolution data need to be communicated from a sensor to an ECU. It is intended as a replacement for the lower-resolution methods of 10 bit A/D's and PWM. In this manner, it is a low cost alternative to CAN or even LIN. It is a unidirectional communications scheme from sensor to receiving ECU without a coordination signal from the ECU. The sensor signal is transmitted as a series of pulses with data encoded as falling to falling edge periods with an up to ca. 64 KBps bandwidth. The way of coding and the only 4 bit CRC checksum provides only a low tolerance against faults. Therefore, SENT is targeted at systems that can tolerate undetected faulted messages. In case additional robustness is needed, application level diagnostics should be used.

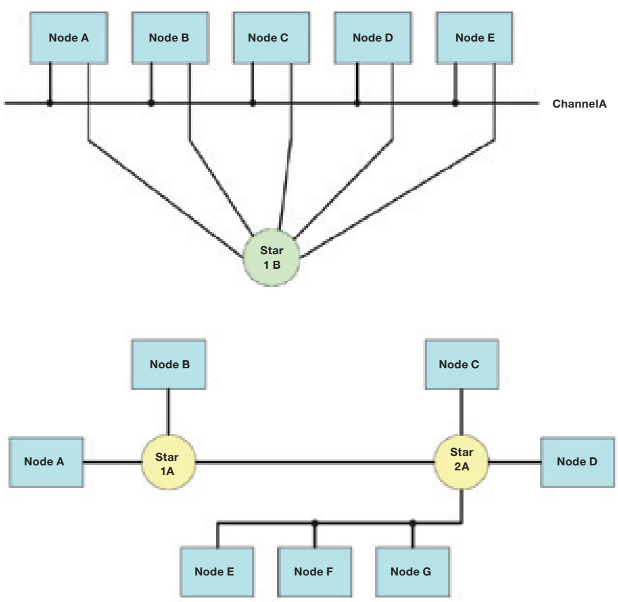

Figure 1: Single- and dual-channel hybrid topology example [12, pp. 20-21]

PLC (Power line communication or power line carrier) are common names for systems for carrying data on a conductor primarily used for electric power transmission. The data are transmitted by modulating an additional signal with low amplitude on top of it. Since considerable noises may appear on the electric power transmission lines, this type of data transmission is not suitable for safety-critical communication (or only as backup). However, there are examples for the realization of LIN and even CAN communication protocols over PLC [10].

FlexRay communication protocol: FlexRay [12] is a high-speed, deterministic and failure-tolerant bus system, which was developed especially for the automotive industry. In 2000, the FlexRay consortium was formed by BMW, Daimler-Chrysler, Motorola (Freescale) and Philips (NXP) to develop a new protocol as the de-facto industry standard to meet the more and more increasing requirements and future needs on communication systems of the vehicles. Among other things, the demand on the bandwidth, the number of the safety-critical applications are increasing, which requires real-time and reliable behaviour of the new protocol. This new protocol should be the solution for the introduction of x-by-wire and advanced systems. In the middle of 2004, the FlexRay protocol specification was made public. The first mass-production vehicle, which used FlexRay network for adaptive damping system, was the BMW X5. This FlexRay network based on the 1.1 revision of the protocol. The today's latest specification is 2.1.

The FlexRay protocol can be realised on either single channel or dual channel. The bandwidth of each channel is 10Mbit/s. The channels can be used either independently or redundantly in order to increase the reliability of the communication. FlexRay is a time-triggered communication protocol but it offers the choice of two media access schemes within one communication cycle. These are a static TDMA scheme, and a dynamic mini-slotting (flexible TDMA) based scheme. These two access schemes make e.g. the multimedia data transmission in dynamic segment without disturbance of the data transmission of the safety-critical systems in the static segment possible.

FlexRay network topology: The FlexRay network topology can be very varied. The architecture can be either bus or star network. Each combination of the channels and architectures can be applied: passive bus, active star and hybrid topology (shown in **Figure 1**). A FlexRay network usually contains two channels: Channel A and Channel B. Each FlexRay network node can connect to one or both channels. In case of star topology, each network channel must be free of closed rings, and there can be no more than two star couplers on a network channel.

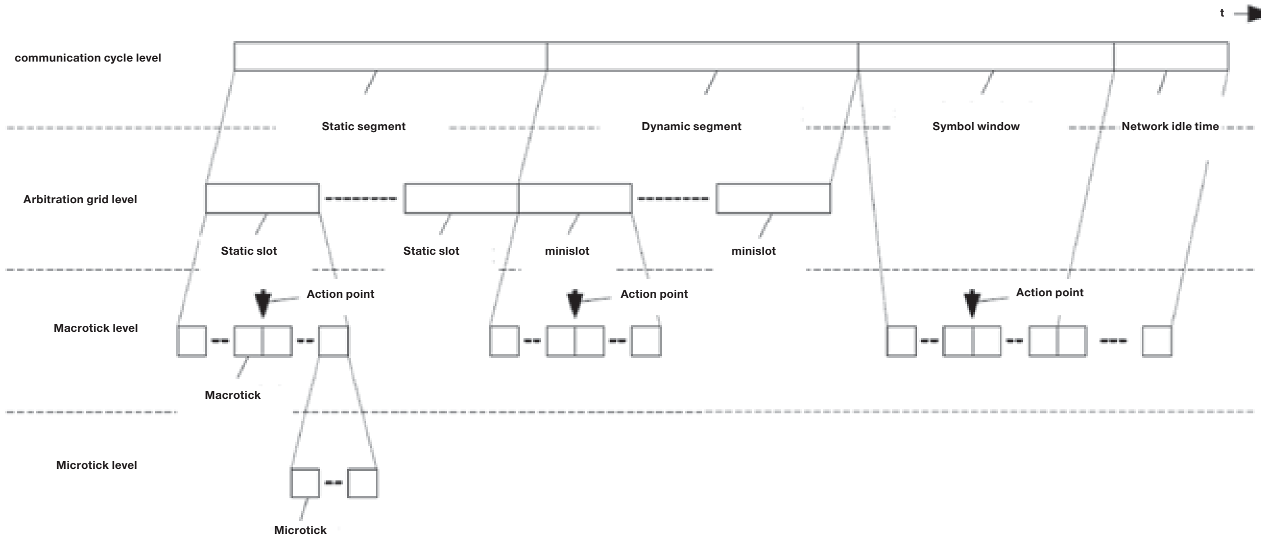

Figure 2: FlexRay communication cycle

FlexRay node architecture: One communication controller, one host, one power supply unit, two bus guardians (optional) and two bus drivers are built in one FlexRay node. Each communication channel has one bus driver to connect the node to the channel. The host provides control and configuration information to the communication controller and provides payload data that is transmitted during the communication cycle. The communication controller provides status information to the host and delivers payload data received from communication frames. There are some microcontrollers on the market, where the host and the communication controller is integrated together.

FlexRay communication cycle (Figure 2): The highest level of the timing hierarchy of the FlexRay protocol is the communication cycle level. It contains the static segment, the dynamic segment, the symbol window and the network idle time slot. The arbitration grid level contains the arbitration grid that forms the backbone of FlexRay media arbitration.

In the static segment, all communication slots are of equal, statically configured duration and all frames are of equal, statically configured length. In the dynamic segment, the duration of communication slots may vary in order to accommodate frames of varying length.

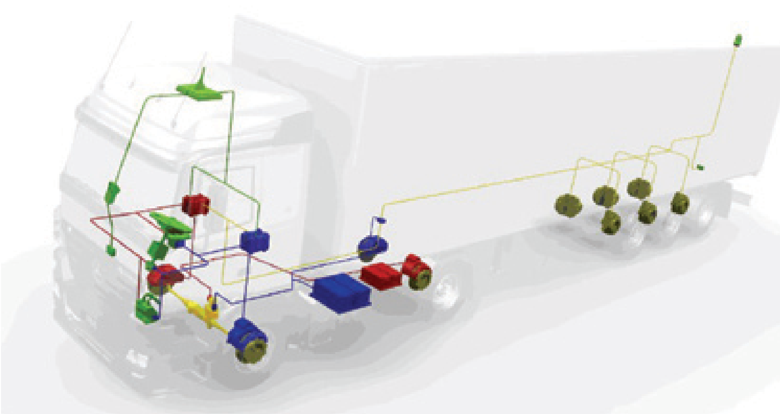

Figure 3: SPARC vehicle combination

4. CASE STUDY: REDUNDANT COMMUNICATION TOPOLOGY FOR BRAKE-BY-WIRE IN COMMERCIAL VEHICLES

In this section, a short overview is given about an EU-funded project, SPARC (Secure Propulsion Using Advanced Redundant Control), where a redundant communication topology was used to provide a reliable control of a whole vehicle.

The goal of SPARC is to substantially improve traffic safety and efficiency for heavy goods vehicles using intelligent x-by-wire technologies in the powertrain. To prove this standardised concept a SW/HW platform was developed that is scalable down to small passenger cars (sPC) and is integrated therein.

The architectural design of the system is driven by the requirement that even with the occurrence of one major failure, the system shall perform in a safe way i.e. it shall not produce any unsafe situation for the driver or the surrounding environment. Anyway, a functional degradation will be accepted. In order to meet these central requirements, events such as communication failure or power failure shall not lead to the loss of safe-state motion of the vehicle. The proper functioning of safety-related subsystems like steering and braking and also the central control-platform shall exhibit a fail-operational/fail-passive behaviour.

On tractor, a duo-duplex FlexRay network is used to ensure the reliable, failure-tolerant communication channels between the ECUs. On semi-trailer, different protocols are applied on two separate lines to maintain fault tolerant communication (ISO11992, which is the current standard of electronic trailer communication and PLC). See [11] for demonstrating CAN over PLC in truck-trailer communication **(Figure 3.)**.

Brake-by-wire system of the tractor: An EBS (Electronically Controlled Brake System) was developed for project SPARC. The main objective was to integrate the brake system in the vehicle redundant electric architecture. The main EBS function is integrated in the PTC (Powertrain Controller), which is responsible for the execution of motion vector from a decision control algorithm. The brake actuators (wheel ends) are modular components; either electro-pneumatic or electro-mechanic actuators can be connected via the same interface.

The brake system of SPARC vehicle combination has to provide all functions of a today's 2p1e (2 pneumatic and 1 electric)

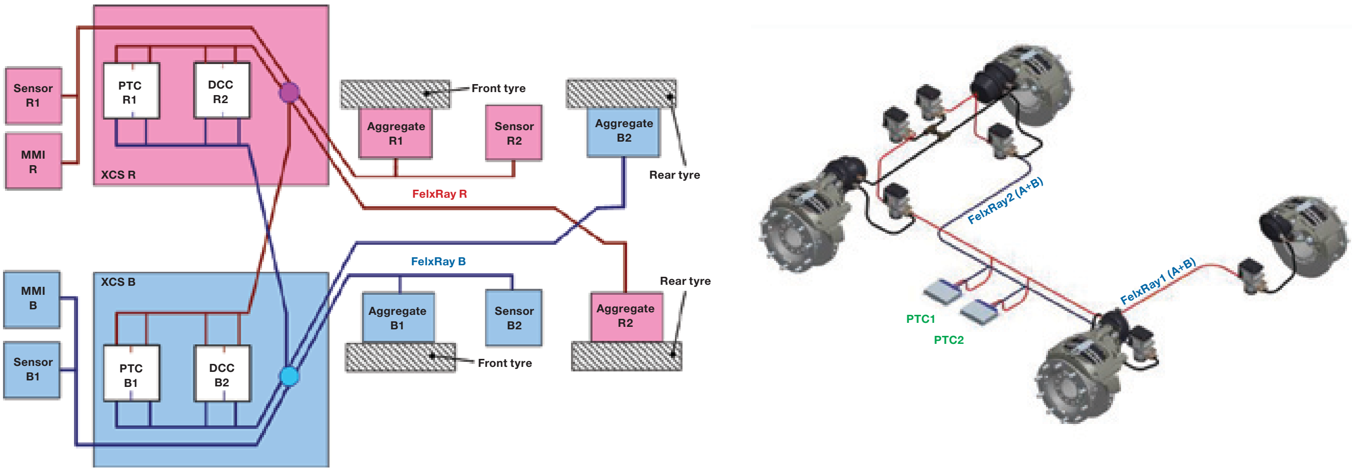

Figure 4: SPARC 4x2 tractor brake system with electro-pneumatic brake actuation

circuit EBS, but here, the control is electronically redundant (2e) and there is no pneumatic back-up. The main control of the vehicle consists of two physically separated FlexRay communication lines (see **Figure 4**). Half of the brake actuators are connected to one of the FlexRay lines; the other half is connected to the other. In case of serious failure in one of the communication lines, one half of the actuators are still available **(Figure 4.)**.

The EBS application software runs in the PTC. There are two PTCs operating on the vehicle, thus the same EBS applications run parallel in the following way: Either PTC is passive, which means that it gets all inputs, the calculations run, but it does not make any intervention. The output signals of active PTC are transmitted to the aggregates, which are the wheel ends in case of EBS system.

Both PTC have access to both FlexRay communication lines, which means that both have direct access to the wheel ends. In case of any failure the PTCs can reconfigure themselves and provide a redundant control.

5 CONCLUSIONS

An overview of the requirements on the automotive communication and an introduction of the most commonly used communication protocols were provided. As a case study, a redundant communication topology is presented for brake-by-wire control system for commercial vehicles. The latest developed communication protocols are suitable for providing safe-redundant communication in a complex system, but to introduce a full x-by-wire for serial production gives still some challenges to the developers of the automotive industry.

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