

Internet Protocol over Ethernet in Powertrain - Comparison with Current Applications and Future Trends

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ABSTRACT

The increasing number of *electronic control units* (ECUs) in vehicles leads to more and more complex systems with a steadily growing demand for data exchange. This growth includes the number of bus participants, the amount of data and hence the data transfer rates. In addition, the trend towards car-to-x connectivity reinforces the need for new in-vehicle communication solutions.

Since the early 1990s *Controller Area Network* (CAN) is the most widely used powertrain bus system. Since 2000 FlexRay is used in addition to CAN in the premium segment. For classic powertrain applications, the data transfer rates of these bus systems are sufficient; however the utilization is sometimes difficult and gateways are often required. For new applications like hybrid and electric vehicles and the next generation of external communication applications (e.g. telematics services) new concepts based on the existing bus systems or completely new solutions are needed. Looking outside of automotive business, *Internet Protocol over Ethernet* (IPoE) is the current standard technology for consumer and industry applications. IPoE has, compared to the currently used systems in powertrain area, very high data transfer rates and has the potential for further system cost reduction using standardized solutions. A first automotive application of IPoE was introduced in the market in 2008 for external communication. So far, IPoE is expensive compared to CAN and FlexRay due to higher hardware costs. Since a new transceiver technology enables the introduction of Ethernet in vehicles and Ethernet communication controller integrated into the microcontroller will be available for future powertrain ECUs, both evolutions together can be the enabler for Ethernet sub-bus systems in vehicles. Major technical challenges for the introduction of Ethernet in powertrain are the achievement of the necessary robustness under automotive conditions (*electromagnetic compatibility* (EMC), temperature range, mechanical vibrations) and the fulfillment of automotive real time, security and safety requirements. In addition, the capability of fast and easy adaptation to different vehicle configurations is mandatory. At the same time, the cooperation between *original equipment manufacturer* (OEM) and supplier needs to be considered to ensure an efficient integration and development.

This paper analyses applications and the communication extend in current powertrain systems. A forecast for the future demand of communication capacity is calculated. Based on this, requirements are extracted and applied to Ethernet as well as IPoE. The result is an uncompromising approach to migrate in-vehicle powertrain communication to Ethernet and IPoE. Technical and process related requirements are considered to obtain a coherent picture.

CITATION: Schneider, S., Dang, L., Schlottmann, E., Baque, S. et al., "Internet Protocol over Ethernet in Powertrain - Comparison with Current Applications and Future Trends," *SAE Int. J. Passeng. Cars - Electron. Electr. Syst.* 5(1):2012, doi: 10.4271/2012-01-0195.

INTRODUCTION

In today's in-vehicle networks different bus technologies are used to fulfill the specific demands of the *electric/electronic* (E/E) architecture domains. In premium class vehicles several CAN sub-networks exist and depending on the special characteristics of the respective domains FlexRay, *Media Oriented System Transport* (MOST) and *Low Voltage Differential Signaling* (LVDS) are used. In addition, an increasing number of sensors and actuators are

interconnected with the vehicle's ECUs using *Local Interconnect Network* (LIN), *Single Edge Nibble Transmission* (SENT) and in future *Peripheral Sensor Interface 5* (PSI5). Bandwidth, functionality, cost-and weight-reduction and safety are the main criteria for the assignment of a specific communication technology to the vehicle domain. Looking at the history of in-vehicle networking, a clear trend from local to global communication emerges ([figure 1](#)).

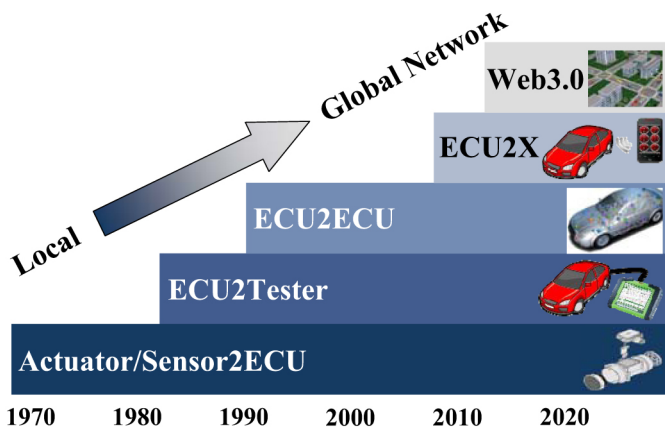


Figure 1. Evolution and future trend of in-vehicle communication.

The development of a new Ethernet technology, using *Unshielded Twisted Single Pair* (UTSP) wiring [1], is the technical enabler to bring Ethernet and IPoE into the vehicle. The first camera application is already equipped with this technology and it is feasible that UTSP Ethernet will replace MOST and LVDS due to the possibility to use a simple and low-priced UTSP wire combined with the high bandwidth capability of up to 100 MBit/s in the domains infotainment and driver assistance. Another already foreseeable application for this technology is the communication between *Domain Control Units* (DCUs), presented by Stolz et al. [11].

Until now, the networking evolution in the powertrain domain was mainly driven by bandwidth, costs and legislative requirements. From today's point of view, the data rates of CAN and FlexRay seem to be sufficient for classical powertrain systems. In addition, a recently published further development of the CAN frame-format [10] will significantly increase the data transfer rates of this bus system. Looking at future powertrain systems the higher bandwidth of Ethernet can support the introduction of new E/E architectures. In addition, the complexity of the in-vehicle bus systems can be reduced.

This paper will focus on the specific powertrain requirements for a communication network. Not only technical aspects will be considered. The OEM to supplier relation and its impact on the development process of a vehicle's networking software will be discussed as well. An assessment of Ethernet and IPoE on the requirements will be done. CAN and FlexRay will also be assessed, showing their advantages and drawbacks. This will give additional input, in order to define a suitable concept to introduce Ethernet in the powertrain domain.

RELATED WORK

Plankensteiner [8] proposes a time-triggered Ethernet protocol as solution to fulfill the real-time requirements of the in-vehicle communication. In parallel to the time-triggered communication presented by TTA-Group [15], their protocol

is also capable to integrate a rate-constrained and best-effort communication seamlessly into the transmission. Lim et al. [7] made a major finding by evaluating and clustering different communication traffic types into four categories based on their bandwidth and end-to-end delay requirements. Their study reveals the need for *Quality-of-Service* (QoS) mechanisms, such as prioritization in order to fulfill latency requirements. The most time critical category is defined with a maximum end-to-end delay of 10 ms according to Rahmani et al. [9]. However, Takeuchi et al. [13], who evaluate the use of IEEE 802.1 Audio/Video Bridging (AVB) standards in automotive applications, state a much stricter ultra-low latency requirement of 100 μ s. Lim et al. [6] further provided the evidence that Ethernet can serve as communication media in an inter-domain network. Their research is based on recorded data traffic from a premium segment car. The IEEE802.1p/q VLAN tag prioritization mechanism is applied to the four traffic data categories defined in [7]. None of their stated constraints was violated, however, the 100 μ s latency requirement of [13] could not be guaranteed. In difference to the cited publications that focus on the application of Ethernet as backbone between DCUs, Kern et al. [5] investigate on migration concepts from CAN to Ethernet in the body domain. Using only cyclic transmission and unicast addressing, a one-to-one mapping of CAN messages to Ethernet packets, as well as two optimization variants for grouping of the data are evaluated.

Summing up, an increasing number of research studies targeting the use of Ethernet within vehicles have been published recently. Mainly they are focused on video data transmission. It seems to be common sense that certain applications in the vehicle will use Ethernet as transport media in future. However, there are different points of view on the required data rates and latency times, as well as the QoS mechanisms to be used to guarantee the real-time behavior.

REQUIREMENTS IN POWERTRAIN DOMAIN

There are general requirements that need to be considered for any deployed bus system in the powertrain domain. Even if the focus is not towards these aspects, a short explanation is given. In this paper, Ethernet and IPoE will be assessed against the requirements that are identified by evaluating the development process and analyzing the communication dependencies of different cars.

GENERAL ASPECTS

The physical requirements of any communication bus system, which is used in the powertrain domain, are more stringent compared to typical Ethernet applications. EMC and robustness against other environmental impacts are requested. Especially for ECUs mounted in the engine compartment, the requirements are very high (table 1).

Table 1. Typical requirements for ECUs mounted in the engine compartment of passenger cars.

lifetime requirements	
service life	15 years
hours of operation	8000 h
mileage	300 000 km
days of operation per year	365 days
EMC requirements	
ESD (contact discharge)	± 8 kV (330 Ω ; 150 pF)
ESD (air discharge)	± 15 kV (2 k Ω ; 330 pF)
EMC (radiated emission)	12 dB μ V (VHF; antenna; average)
EMC (radiated interference)	200 V/m (antenna; different modulations)
mechanical & electrical requirements	
ambient temperature	-40...105 °C
acceleration (engine hard mounted)	181 m/s ² (noise, effective)
overvoltage (defect generator)	18 V (1 hour)
overvoltage (jump start)	27 V (2 min)

Related to the aftermarket service requirements it is important to keep the repair costs low. An easy method to detect failures on either any defect node or any problem with the wiring harness itself is required. A faulty node should not influence the normal operation of the communication between all other nodes on the network. In a worst-case scenario, a faulty node would jam the normal bus traffic by continuously sending a high amount of data. Hence appropriate fault confinement mechanisms are required.

Data transmission always provides the possibility to a not authorized party to gain access to confidential data within the network. Tempering and manipulating vehicles today mainly focuses on disabling the immobilizer in order to steal the vehicle or to gain an increased vehicle performance by modifying the internal settings of an ECU, the so called “tuning”. The engine ECU plays a major role for both targets and OEMs are spending high efforts to prevent any access to internal data. The use of proprietary local communication bus systems help in terms of making it more difficult for attackers requiring more specific expertise and tools, but does not completely eliminate the threat. The introduction of an internet link using IPoE technology opens up the possibility to get direct access to a high number of cars in parallel. Also with the installation of commonly used operating systems, there is the potential that malware such as viruses will find their way into vehicles. Therefore, it is a requirement to filter and secure the powertrain network from the network, which is connected to the outside world, in order to cope with any remote attacks. In addition, data securing using appropriate encryption methods is required.

Legislative requirements on diagnosis of exhaust emissions have always been a driving force in terms of standardization of the used bus technologies within a vehicle. With the introduction of the *On Board Diagnosis-II* (OBD-II), the use of K-Line as communication media became mandatory. Actual model year requirements of the OBD specifications make CAN as vehicle communication interface compulsory. As the ECUs within the powertrain domain mainly fall into the category of OBD relevant ECUs, the specified bus technologies have been applied in the powertrain domain. The latest legislative standard, the *World Wide Harmonized OBD* (WWHOBD), which is currently deployed in commercial vehicles, will be first set up using CAN. However, the specification already foresees the use of Ethernet as communication media by referencing the *ISO13400 Diagnostic communication over Internet Protocol* (DoIP) [4]. In addition, the standardized SAE J1962 diagnostic connector for the diagnostic communication has been extended for the use of Ethernet within the ISO13400. For future model years, it is very likely that Ethernet has to be supported.

DEVELOPMENT PROCESS

The development process in the automotive industry follows the V-model. According to *Burgdorf* [2] the OEMs develop vehicles by breaking down the specification of the complete system into sub-systems and components such as a single ECU. Most of the single component development is ordered from suppliers based on component specifications. Validation and verification of the component is done by the suppliers. The tested components are in the end again integrated by the OEMs into sub-systems and the entire system. Additionally, the validation of the system is within the responsibility of the OEMs. The communication dependencies within the vehicle network are always either part of the system or at least of the sub-system. A supplier can therefore only contribute partly to the complete network. Within the single nodes, the communication dependencies are configured statically. This simplifies the evolutionary development, avoiding re-validation efforts and providing a possibility for seamless integration in the system as well as a deterministic data exchange. In the powertrain domain low latency, real-time requirements and available data transfer rate need to be considered by the OEMs.

Another aspect in the development process is the partitioning of a vehicle family into vehicle variants. The specific variants of a vehicle distinguish themselves via different features. Depending on the feature extra information needs to be exchanged within the network. By this, an additional network node, an intelligent sensor or actuator or a complete ECU, needs to be integrateable without any changes to the existing communication. Therefore, different car variants use scalable communication dependencies depending on their level of equipment.

Looking at the development lifecycle of a vehicle, changes to the communication dependencies are therefore