Automotive Ethernet: In-vehicle Networking and Smart Mobility

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Abstract — **This paper discusses novel communication network topologies and components and describes an evolutionary path of bringing Ethernet into automotive applications with focus on electric mobility. For next generation in-vehicle networking, the automotive industry identified Ethernet as a promising candidate besides CAN and FlexRay. Ethernet is an IEEE standard and is broadly used in consumer and industry domains. It will bring a number of changes for the design and management of in-vehicle networks and provides significant re-use of components, software, and tools. Ethernet is intended to connect inside the vehicle high-speed communication requiring sub-systems like Advanced Driver Assistant Systems (ADAS), navigation and positioning, multimedia, and connectivity systems. For hybrid (HEVs) or electric vehicles (EVs), Ethernet will be a powerful part of the communication architecture layer that enables the link between the vehicle electronics and the Internet where the vehicle is a part of a typical Internet of Things (IoT) application. Using Ethernet for vehicle connectivity will effectively manage the huge amount of data to be transferred between the outside world and the vehicle through vehicle-to-x (V2V and V2I or V2I+I) communication systems and cloud-based services for advanced energy management solutions. Ethernet is an enabling technology for introducing advanced features into the automotive domain and needs further optimizations in terms of scalability, cost, power, and electrical robustness in order to be adopted and widely used by the industry.**

Keywords— Ethernet; automotive; electric vehicle; smart grid; EV communication architecture; domain based commuication; in-vehicle networking; vehicle network topology

I. INTRODUCTION

Communication and bandwidth requirements increase as more new and complex applications appear in the vehicle, for example, enhanced safety and entertainment solutions. End users expect the same level of entertainment functions and data in the vehicle as known from home. Existing vehicle control networks, based on the LIN, CAN, and FlexRay standards, are not designed to cover these increasing demands in terms of bandwidth and scalability that we see with various kinds of ADAS.

The future networking technology should re-use as much as possible HW and SW components from consumer and non-automotive domains while adding automotive-specific requirements. Today, vehicle communication networks appear as heterogeneous systems as a result of its historically grown nature. New vehicle communication systems without legacy would most likely have an architecture like shown in Fig. 1. ECUs are composed in a clear hierarchical architecture where application domains are connected through a 'data highway'. Wired and wireless [1] interfaces allow communication between the vehicle and its environment.

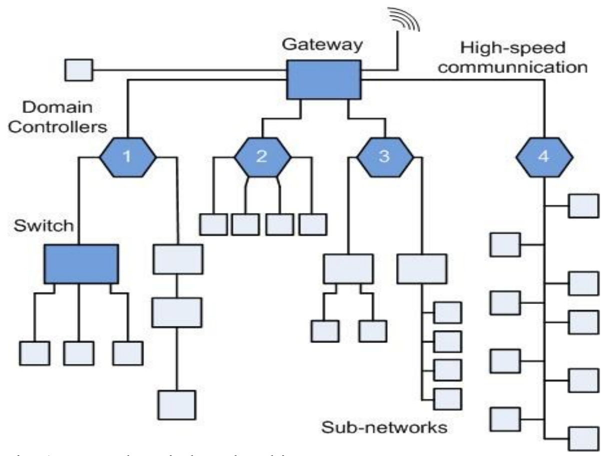

Fig. 1 Future domain based architecture

For in-vehicle networking, Ethernet provides all the pre-requisites for such a holistic approach, is suitable as backbone bus to connect the various application domains as well as within domains, when higher bandwidth is required. Today,

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switched Ethernet networks base on point-to-point communication and available bandwidth can more efficiently used compared to broadcast systems like CAN or FlexRay.

The usage of Ethernet in the vehicle means a paradigm shift in the design of next-generation in-vehicle networking systems when connecting application domains, transporting different kinds of data (control data, streaming, etc.), and fulfilling the stringent robustness demands in terms of extended temperature range and EMC performance.

In the automotive field, Ethernet has already been introduced for diagnostic access. Other use areas have been considered in the development of EV, due to the scalable bandwidth of Ethernet, flexibility, and connection to the V2V and V2I or V2I+I integration by using embedded software for e.g. the communication between charging stations and electric or hybrid vehicles as well as between ECUs within the vehicle. In the past a suitable and economical wiring technology was lacking for implementing the Ethernet modules into the EV.

The charging process for EVs is defined by ISO 15118. For instance, in the EV charge control module, a TCP/IP stack is used for communication with the charging station. It provides socket communication over IP (Internet Protocol) for TCP (Transmission Control Protocol) or UDP (User Datagram Protocol).

Overlaid on this protocol are several applications and protocols such as: DNS (Domain Name System) for name resolution; TLS (Transport Layer Security) for encrypting the data on the transport level and V2GTP (Vehicle to Grid Transport Protocol), a new protocol for connection monitoring and data transfer. Intelligent charging of EVs has its base in the framework of ISO 15118. The ISO 15118 standard will further expand its range of application, which includes extensions of the AUTOSAR-based basic software.

II. Evolution towards Automotive Ethernet

A. *Generation 1: Diagnostics over IP*

The first Ethernet applications for the automotive industry are On-Board Diagnostics (OBD) and the update of ECU flash memories. For the reading of diagnostics data and updating of software within a given time frame, Ethernet 100BASE-TX with CAT 5 has been chosen to connect vehicle and diagnostics test (service) equipment. The higher bandwidth of Ethernet saves time and costs in service and production. ISO 13400 and ISO 14229 utilize existing industry standards and define a long-term stable state-of-the-art diagnostics standard.

B. *Generation 2: Driver Assistance Systems and Infotainment*

In the 2nd generation of automotive Ethernet, infotainment and camera systems for e.g. surround view applications are addressed. Future vehicles will consist of more cameras fused with sensor data e.g. from short/long-range radar. The demand for higher bandwidth and lower latency is obvious. Multiple high-resolution cameras for the usage of e.g. object detection require uncompressed data transfers to avoid, for example, compression artefacts for obstacle detection and are strong requestor of high-speed communication due to safety aspects.

C. *Generation 3: Ethernet as network backbone*

While previous generations focus on a certain application domain, generation 3 of automotive Ethernet will introduce the backbone of the in-vehicle network. A typical backbone is illustrated in Fig. 2. Such network architecture introduces a new concept how communication is organised between the ECUs and the network management. Needless to say that software content increases while communication is in a hierarchical way with domain controllers connected via Ethernet backbone and switches.

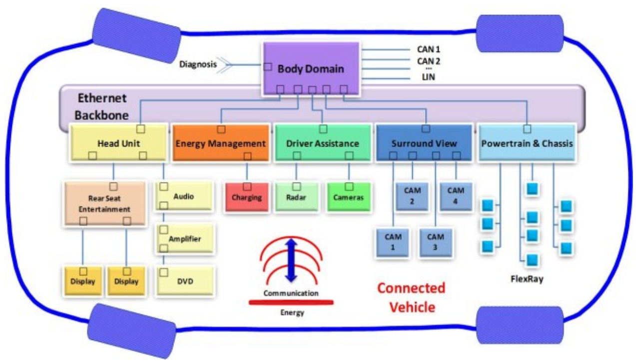

Fig.2 Ethernet backbone in domain architecture

This structure represents a scalable solution as each port of a switch can be implemented as 10Mbps, 100Mbps, or 1Gbps without any change in higher protocol layers. The paradigm shift is also visible in how a message is transported via domain boundaries to its destination. While in a vehicle network today complex and network-dependent gateways realise the data transport, existing and matured IP-based routing concepts within switches and routers are proposed for the backbone network. As advantage, the IP-based routing does not depend on the underlying network implementation, thus allows a unified addressing concept for the whole in-vehicle network. Moreover, the IP-based routing enables the straightforward connection of the vehicle to the Internet [2], a trend which is mainly driven by end users who expect the same access to services as in office and home environments.

A further characteristic of the new style of architectures is the usage of one and only backbone network technology, namely Ethernet, which has to accommodate different data communication classes like diagnostics, video/audio streaming, and highly dependable control data.

While AVB [3] Ethernet and TTEthernet [4] can already provide different levels of Quality of Service (QoS) in combination with real-time performance, further work is needed to validate the ensure coexistence of different data classes on the same communication structure. In addition, encryption of data is required to secure communication with the infrastructure.

Fig. 3 gives an example for a data flow through different layers of the Ethernet stack. Data packets pass 100BASE-TX and Unshielded Twisted Single Pair (UTSP) Ethernet networks, and, finally, the wireless link to the infrastructure (grid).

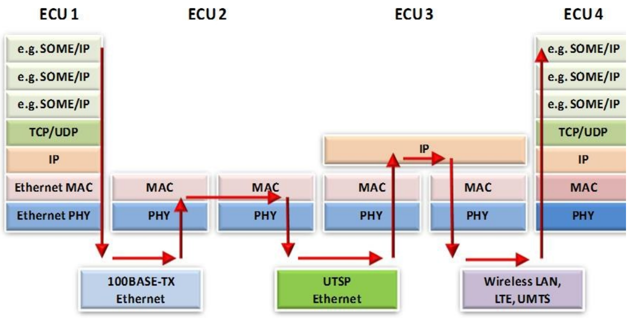

Fig.3 Data flow through layered architecture

III. BroadR-Reach – A 100Mbps Automotive Ethernet Solution

It took almost 20 years to attract interest of the automotive industry in Ethernet as next generation networking standard. This was partly caused by the lack of a physical layer suitable for the usage in vehicles.

Fig. 4 illustrates technical principles in more detail and explains why consumer-oriented physical layers of Fast and Gigabit Ethernet were not accepted.

Fast Ethernet bases on the MLT-3 signaling scheme (contains levels +1/0/-1) and features simplex communication on two twisted pairs of cable. Gigabit achieves 10x higher data rate by introducing duplex communication on four twisted pairs of cable and a PAM-5-based signaling scheme.

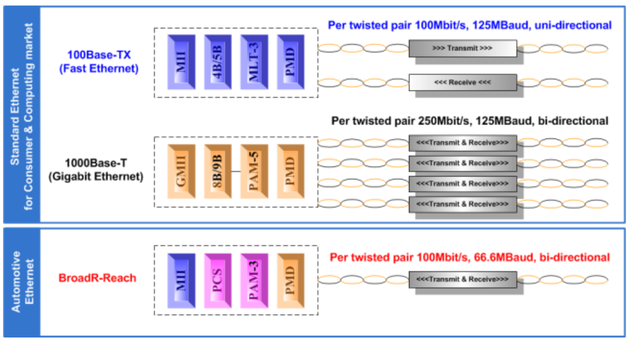

Fig. 4 Coding schemes of standard Ethernet and BroadR-Reach

The high symbol rate of 125 MBaud for both Fast and Gigabit Ethernet contributes to a significant electromagnetic emission profile in e.g. the critical FM radio band and, thus, rules out the usage of cheap unshielded twisted pair cable in the automotive environment.

The BroadR-Reach technology [5] has managed to nearly half the symbol rate to 66.6 MBaud and allowed with this the usage of unshielded twisted-pair cable.

IV. Networking in Electric Vehicles

Electric and hybrid vehicles are entering the automotive market. Its presence on the roads is expected to rapidly grow over the next decade. In-vehicle networking and infrastructure (grid) communication are important aspects of EV functions. EV applications impose considerably higher requirements on electronic systems and its components in terms of EMC [ISO11452] and environmental conditions.

First investigations show that BroadR-Reach is suitable for its usage in the automotive environment. However, to achieve the necessary robustness for a next-generation vehicle networking standard, new optimized components have to be developed. The system diagram in Fig. 5 reveals the main components of the automotive BroadR-Reach link. Compared to 100BASE-TX (Fast Ethernet), the bill of material is significantly reduced.

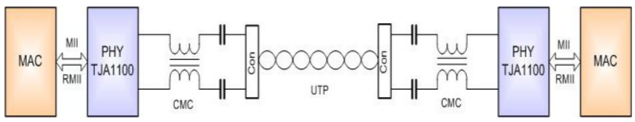

Fig. 5 BroadR-Reach system diagram

A physical layer component, e.g. TJA1100, NXP [6], as the interface between the analogue transmission medium and the digital MAC controller, largely determines the robustness and emission performance of the link. While a consumer physical layer is optimized to support a cable length of more than 100 meters, automotive solutions have typically to deal with a link length of less than 10 meters.

Challenge is the definition of a pulse shape and a receiver equalizer implementation optimized for such cable length that meets the stringent automotive emission and immunity requirements. Fig. 6 shows the signal spectrum for unshielded twisted pair communication with optimized pulse shape.

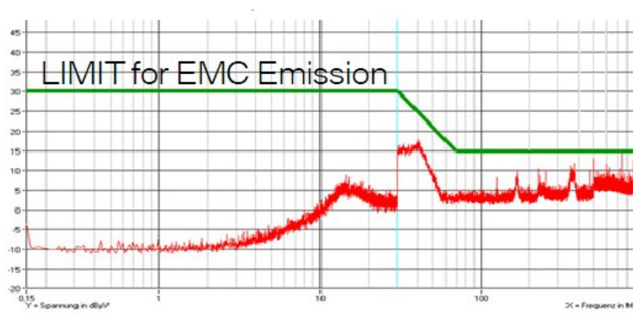

Fig. 6 Signal spectrum for unshielded twisted pair communication

Using a backbone in a domain based architecture with high-speed communication results in less ECUs and less cables. For all vehicles, especially the EV, the benefit of smaller cable harness is cost, weight, and energy consumption.

The BroadR-Reach technology allowing the usage of unshielded twisted-pair cable and makes Ethernet cost-competitive for automotive applications.

V. Internet of Energy – Connecting Smart Mobility in the Cloud

The introduction of Smart Grid, Internet of Energy (IoE) and IoT pave the way for new and exciting communication possibilities. While connected to the grid, e.g. during charging, the electric vehicle has almost unlimited network access. It can be used to communicate the current condition of the vehicle to the infrastructure, update software, run system checks, retrieval of data for infotainment, etc.

IoE provides an innovative concept for power distribution, energy storage, grid monitoring and communication. It will allow units of energy to be transferred when and where it is needed.

Power consumption monitoring will be performed on all levels, from local individual devices up to national and international level.

In this context the new smart electric mobility vehicles will be integrated, creating new mobile ecosystems based on trust, security, and convenience to mobile/contactless services [7]. Transportation applications will ensure security, mobility and convenience to consumer-centric transactions and services.

Introducing an intelligent electrical grid (Smart Grid) and by using intelligent charging, overload and grid failure can be avoided, while data is exchanged about power requirements, and the electrical grid can be optimized accordingly.

The power needed for charging operation lies between 3kW and 20kW, or even over 100kW depending on the available power connection and charging profile.

EVs require communication between battery and external EV charging station system (EV Supply Equipment - EVSE) for battery power monitoring/management, billing/payment information, identification, and security purposes. Fig 7 shows recent ISO and SAE standards for charging communications.

Definition of vehicle to grid communication interface		
ISO/OSI Layer	**Europe**	**Content**
7 Application	ISO/IEC 15118 Part 1	General information and use case definition
7 Application 6 Presentation 5 Session 4 Transport 3 Network	ISO/IEC 15118 Part 2	Technical protocol description and Open Systems Interconnections (OSI) layer requirements
2 Data Link 1 Physical	ISO/IEC 15118 Part 3	Wired physical and data link layer requirements

Fig. 7 Charging communication defined in ISO and SAE standards

Communication modules have integrated Ethernet interfaces that can be used as communication and diagnostic ports for the Ethernet in-vehicle backbone. Ethernet-based networks operate via switches and the available bandwidth per network sub-system is not necessarily shared beyond the sub-system and can have different speed (scalability). Adding or changing electronic units will, therefore, not affect the entire network, but primarily the unit(s) they directly connect to. This means that Ethernet-based communication supports fundamental concepts for in-vehicle networks for electric vehicle. In this context an evaluation of automotive qualified Ethernet parts (ICs, connectors, cables), and the emission and immunity profile for the Ethernet-based communication networking over UTSP cabling solution was investigated in the ARTEMIS JU POLLUX project. The QoS has to be considered taking into account the IEEE AVB (audio video bridging) standard(s), while security by considering the IEEE 802.1Q VLANs (virtual local area networks) standard.

The EV has to negotiate with the charging station for the details of the requested charging service. The choice of transmission medium and protocol will be flexible when Ethernet is used as a backbone for in-vehicle communication. In addition, charging station and vehicle need to communicate with various servers in the Internet by usage of conventional protocols of IP-based networking. PLC (Power Line Communication) technology and IP-over-power line is intended to be used for this purpose.

The next generation of EVs will request novel automotive network architectures. The shift from proprietary solutions to a communication network architecture based on established standard technology will allow to shorten the development phases of design and analysis of network transmission schedule, better quality, and performance assessments.

Adopting common communication network architectures would simplify the task of the ECU suppliers and would allow the component reuse across different vehicle manufacturers. This will definitely shorten time to market and reduce the overall time to provide an efficient implementing of an energy management solution and the real time communication with the infrastructure and the Smart Grid

VI. Summary

Ethernet and IP-based routing are very important technologies for future communication networks in EVs. Ethernet meets the demand for powerful data transmission, while being less expensive and more flexible than comparable network technologies. EV communication architectures that are based on Ethernet will help to accelerate activities to create standards in order to promote the technology in the automotive industry at large. This will assure low development outlay and wide range of Ethernet compatible products on the market.

The usage of Ethernet as backbone in EVs will enable V2V and V2I communication, where the communicating nodes are vehicles, charging stations or base stations that can exchange information. This enables the integration of the vehicular communications and networks, Dedicated Short

Range Communications (DSRC) and Wireless Accessing Vehicular Environments (WAVE) (based on IEEE 802.11p), with the charging stations and infrastructure information network.

Automotive Ethernet will bring in itself a number of fundamental benefits while, for sure, over the next decades, CAN and FlexRay will remain for body domain and safety-critical communications:

- Increasing communication bandwidth for advanced driver assistance and infotainment systems
- Network topologies change from decentralized domain-specific architectures to hierarchical with backbone
- Provides scalability and flexibility for next-generation in-vehicle networking architectures

Further work is needed:

- to validate secure coexistence of different data classes on the same Ethernet network
- to develop new automotive-optimized components affecting Ethernet switches and PHYs – first promising step has been made with BroadR-Reach technology
- OPEN Alliance and AUTOSAR are driving further standardization on the hardware and software levels.

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