Automotive Ethernet for Mobile Machines

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The CAN bus is the predominant communication technology in the mobile sector, from the car to the fully automated harvester. The continuously growing demand for bandwidth as a consequence of ever further-reaching automation cause the by now numerous CAN buses in the vehicle to increasingly become a bottleneck in communication between the individual subsystems. The increasing level of automation even of safety-relevant functions brings other necessities such as functional safety, hard real-time behaviour and expanded diagnostic capabilities further into the foreground.

In the area of mobile machines it is attempted to solve these limitations by technology transfers from industrial automation and the automotive industry. In this article, the suitability of automotive Ethernet for the area of mobile work machines is to be illuminated.

The central parameters of this investigation are the degree of standardization, technological maturity, achievable data throughput, real-time behavior and functional safety in mixed criticality networks. With regard to their potential and their options the most important technological innovations such as OABR, Time-Sensitive Networking (TSN) and Deterministic Ethernet are compared with alternative approaches from industrial automation such as EtherCAT or POWERLINK, as well as with a further development from the automotive industry, CAN-FD.

Furthermore, existing limitations and possible effects of automotive Ethernet in the agricultural sector are analyzed: which adjustments are necessary to the currently used network topologies, how can automotive Ethernet be integrated into existing architectures and how can typical functions of agricultural machines benefit from the new standards?

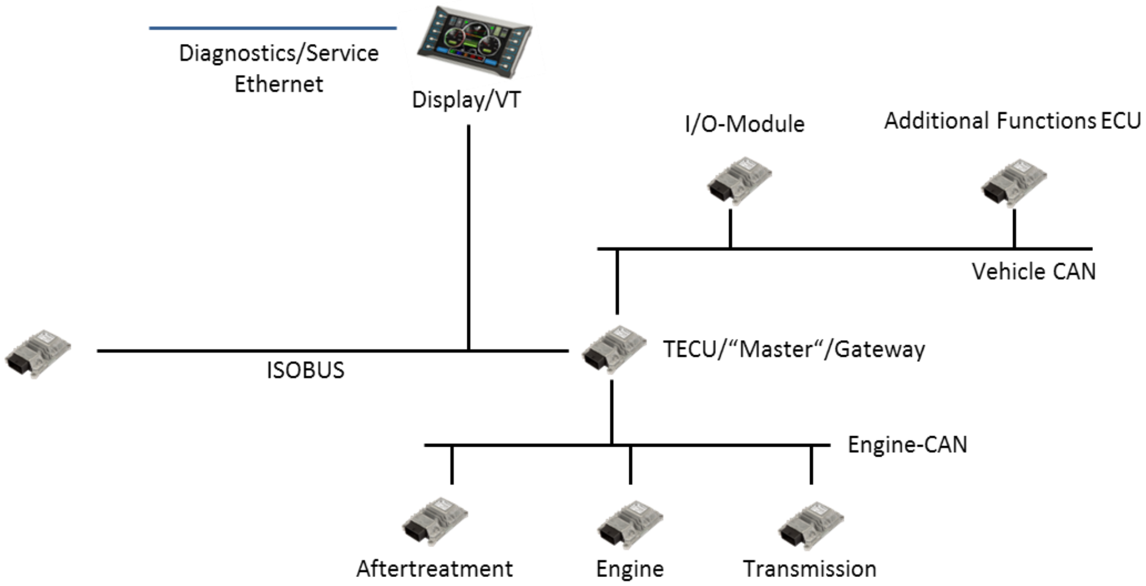
Finally, a migration scenario based on a CAN/OABR/Ethernet gateway is also illustrated.

Growing Demands on Modern Bus Systems

In modern agricultural machines, such as tractors or fully automated harvesters, numerous CAN buses, such as an engine CAN or vehicle CAN, are used in order to enable communication within the control system. For this – depending on use – the CAN-based ISOBUS (ISO 11783) is additionally used in order to allow communication with implements such as trailers. Often SAE J1939 is used as a basic protocol for these CAN buses, which specifies a bit rate of 250 kBit/s.

In communication with HMIs as well as fleet management and diagnostic systems Ethernet is already used today, often with the classic physical layer 100BASE-TX.

The bandwidth requirement of new technologies, such as every higher resolution displays, IP cameras (in some cases with Surround View functionality), sophisticated fleet management systems, which use the technologies from the IoT/Industry 4.0 world and greater automation of machine functions exceed the available bandwidth by orders of magnitude. Just a single IP camera causes a data throughput in the range of 10 MBit/s.



Picture 1: Schematic network of a tractor

Consequently a modern CAN-based system often including complex gateways has an overall bandwidth of approx. 1-2 MBit/s, whilst future technologies will cause a data volume that is up to three orders of magnitude greater than currently available.

Several of these functions, especially the automation functions in the area of drive, steering and working functions, also set strict requirements of functional safety, security and real-time capability. These three points particularly come to the fore if automation functions have to share the physical communication medium with other services, such as a steer-by-wire system that shares the same network with the diagnosis system with Cloud access. In this case it must be ensured that in the event of problems in the diagnosis system the automation function continues to have guaranteed bandwidth and latencies, so that the steering continues to reliably and safely work despite an unwanted network load created by the diagnosis system.

Possible Solutions

Each possible solution has to ideally increase the bandwidth by an order of magnitude, i.e. make bandwidths of at least 10 ideally to 1,000 MBit/s available.

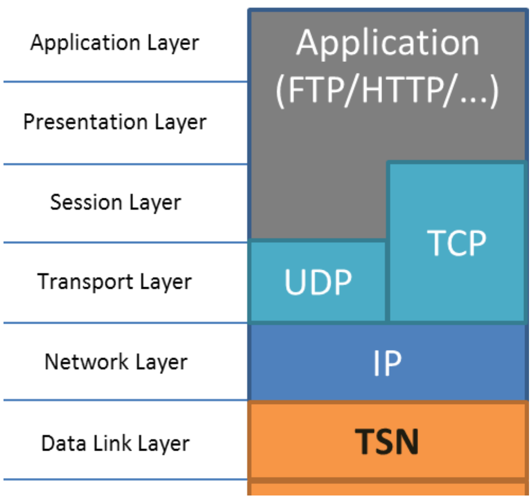
CAN-FD, a further development of the classic CAN bus, that with a dynamic, time-limited bandwidth increase significantly increases the throughput of CAN by up to 12 MBit/s and a larger payload, offers a clear migration path from existing systems to higher bandwidths thanks to the technology relationship to the classic CAN, however, with an achievable average bandwidth of approx. 3-4 MBit/s is not suitable for IoT/Industry 4.0 or image-based applications such as Surround View.

A further option is the integration of an established industry field bus such as EtherCAT, ProfiNET, POWERLINK or EtherNet/IP. Each of these communication media has its own application-specific advantages and disadvantages and is bound to the respective manufacturer that has developed this communication technology to varying degrees. These are based on Ethernet and depending on the protocol, they access the Ethernet stack at various levels. EtherCAT for example, already accesses from layer 2 (data link layer) in the Ethernet protocol, whilst on the other hand, POWERLINK, for example, only accesses from layer 3 (network layer). All of these protocols support at least a data rate of 100 MBit/s.

A further solution could be completely based on Ethernet-standardized mechanisms of the IEEE. There are many advantages of Ethernet-based solutions available. Ethernet is widespread, excellently standardized and there are already many products, technologies and tools by many suppliers that base on Ethernet. However, there are also challenges to implementing a solution originally developed for use in an office in the area of mobile machines: these range from cabling and plug technology, to functional safety, determinism to integration into existing systems. In these areas there are several current core developments such as new physical layers suitable for automotive or Deterministic Ethernet expansions that solve these problems in the long term. The combination of these technologies is described in this article as "automotive Ethernet" and is to be presented in the following layers.

Physical Layer – Layer 1

100Base-T1 (formerly OABR – Open Alliance BroadR-Reach®) is a PHY, which achieves a bandwidth of 100 MBit/s via a simple UTP (unshielded twisted pair) cable and which was primarily developed for the automotive market. This development originally came from BroadCom, was later made a de-facto standard for automotive Ethernet by the Open Alliance BroadR-Reach® as an interest group and finally standardized directly by IEEE as 100Base-T1.



Picture 2: Automotive Ethernet (in orange) in the ISO OSI model

This PHY is already used in the production programs of cars and is also considered a favorite for future Ethernet uses for a variety of applications in the mobile sector, such as the "high-speed ISOBUS".

Data link layer – layer 2

IEEE is working on the expansion of the IEEE 802 standard in order to offer real-time capability for applications in the automation and automotive sector. These activities are based on significant preparations for AVB (Audio Video Bridging) and predominantly access in layer 2. The group of Time-Sensitive Networking-Standards (TSN) offers features such as traffic shaping, bandwidth guarantees, deterministic messages with guaranteed latency and redundancy mechanisms. These new Ethernet features can, in principle, access various protocols on a higher level, such as UDP, but also be combined with established industry protocols that only access from layer 3 (network layer). With TSN, automation applications that require hard real-time and functional safety, video signals that require guaranteed bandwidth and service or diagnosis data that can create a very inter-deterministic network load can be converged on one single Ethernet network.

As TSN is very broad and offers differing mechanisms, users should create a "profile" suitable to them, in which they only use those features that they actually need in order to keep the complexity to a minimum. For a simple video signal, time stamping and VLANs are sufficient, for high availability, safety-critical controllers a full Deterministic Ethernet with an error-tolerant time synchronization and redundant paths is preferable, which could even be expanded with further extensions such as SAE AS6802 or similar mechanisms with microsecond-jitter.

Standardization

TSN describes a collection of standards that are processed by the IEEE Standards Association in the LAN/MAN Standards Committee in the Working Group IEEE802.1 TSN. Picture 3 shows the status of standardization.

Picture 3: Status of TSN standardization (as of March 2016)

Limitations and Future Expansions

Even though 100BASE-T1 and the TSN standards offer a solid basis for a future communication architecture, several improvements are still possible. It can be predicted today, for example, that 100 MBit/s will not be sufficient for many applications, especially those with environment recognition and image processing. With 1000BASE-T1, a gigabit variant of the Single-Pair Unshielded Twisted Pair-PHY was already signed off on by IEEE on 20 June 2016 [1]. The limitation of cabling length to 15 m at USP is also relevant to mobile machines. Whilst this does not present a serious limitation in a car, it can cause problems in large mobile machines or networks that are operated between a tractor and trailer, for example. Currently, it is only possible to work with extra switches or STP (up to 40 m) [2] in order to overcome these limitations.

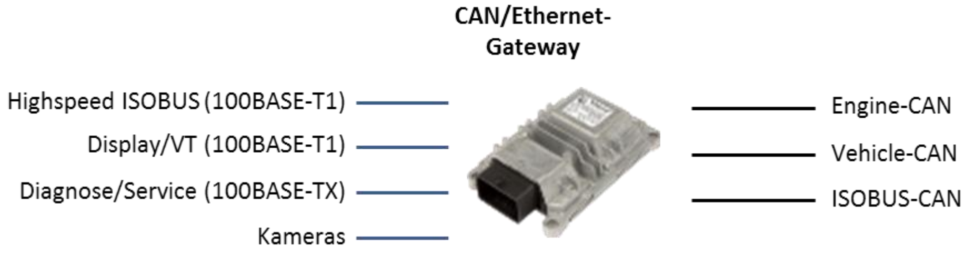
A further development that may be of interest to the mobile machinery sector is offered by IEEE P802.3bu (1-Pair Power over Data Lines – PoDL), with which sensors, cameras or sufficient control can be directly supplied via the UTP communication cabling. This standard is to be signed off by the IEEE at the start of 2017 and can lead to further optimisation in the cabling of sensors and cameras.

100(0)BASE-T1 and TSN offers a solid foundation (layer 1-2) for an Ethernet-based communication, however, over the next few months and years it has to be decided sector-specifically how the higher layers can be designed. In the area of mobile machines this can occur with simple UDP-based proprietary protocols for smaller machines or by borrowing from industrial automation such as the integration of existing field bus protocols or concepts such as OPC-UA. The automotive sector will also offer options for major manufacturers with AUTOSAR, DoIP or SOMEIP.

After all, in the switch from CAN to Ethernet, network topology also has to be thought about, as a bus-based protocol has to be converted to a "switched Ethernet" in star topology. Here actual switches can be used as physical devices (see the integration scenario below) or the switch ICs can – with a corresponding redesign, of course – be directly integrated into the controllers and therefore form a bus-like "daisy chain" via multihops.

Integration into Existing Architectures

The integration of automotive Ethernet will likely happen via various channels. On the one hand, there are corresponding activities in groups, such as the "High-Speed ISOBUS" project team in the AEF [3], in which cross-manufacturer interfaces are being defined, on the other hand, local networks in a machine can be gradually converted to Ethernet. Due to the large bandwidth, CAN/Ethernet gateways can be more easily realized and even become an advantage for diagnosis and maintenance, as the entire CAN traffic can be accessed with a single Ethernet-based diagnostic connector and safety mechanisms (in terms of security) can be integrated at a central point. This means a corresponding 100BASE-TX/TSN Deterministic Ethernet switch, which also offers numerous CAN channels, which include the necessary Ethernet switch role in the network, but can also be a 100BASE-TX/100-BASE-T1 media converter and realize CAN/Ethernet gateway functions in order to integrate existing CAN and new Ethernet networks.



Picture 4: CAN/Ethernet gateway as an integration element in existing architectures

[1] http://www.ieee802.org/3/bp/

[2] https://standards.ieee.org/events/automotive/2015/01_IEEE_Standards_for_Automotive_Networking.pdf

[3] http://www.aef-online.org/en/aef-projects/the-project-teams.html