Automotive Ethernet for mobile machines

The increasing level of automation, even of safety-relevant functions, highlights other necessities such as functional safety, hard real-time behavior, and expanded diagnostic capabilities. In the area of mobile machines, these limitations are overcome by technology transfers from industrial automation and the automotive industry.

In this article, we look at the suitability of automotive Ethernet for the area of mobile work machines. The essential 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 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 to the currently used network topologies are necessary, how can automotive Ethernet be integrated into existing architectures as an extension of CAN networks, and how can typical functions of agricultural machines benefit from the new standards?

Growing demands on modern bus systems

In modern agricultural machines like tractors or fully automated harvesters, numerous CAN networks, such as an engine CAN or vehicle CAN, are used in order to enable communication within the control system. For this purpose – depending on the application – the CAN-based Isobus (ISO 11783) is additionally used in order to allow communication with implements such as trailers. SAE J1939 is often used as a basic protocol for these CAN networks, which specifies a bit-rate of 250 kbit/s. In communication with HMI’s as well as fleet management and diagnostic systems, Ethernet is already used today, often with the classic physical layer 100 Base-TX.

The bandwidth requirements of new technologies, such as the continuously increasing resolution of displays, IP cameras (in some cases with surround view functionality), sophisticated fleet management systems using technologies from the IoT/Industry 4.0 world, as well as increasing automation of machine functions, exceed the available bandwidth by orders of magnitude. A single IP camera causes a data throughput in the range of 10 Mbit/s. A modern CAN-based system which includes complex gateways often has an overall bandwidth of approximately 1 Mbit/s to 2 Mbit/s, whilst future technologies will cause a data volume that is up to three orders of magnitude bigger 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, for example a steer-by-wire system that shares a network with the diagnosis system having 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 work reliably and safely, despite an unwanted network load created by the diagnosis system.

Possible solutions

Each possible solution has to increase the bandwidth by an order of magnitude, i.e. make bandwidths of at least 10 Mbit/s to ideally 1000 Mbit/s available. With a dynamic, time-limited bandwidth increase, CAN FD, significantly improves the throughput of Classical CAN by up to 12 Mbit/s (with currently available CAN transceivers) and a larger payload. It also offers a clear migration path from existing systems to higher bandwidths thanks to the technology relating to Classical CAN. However, with the achievable average bandwidth of 5 Mbit/s, CAN FD is not always suitable for IoT/Industry 4.0 or image-based applications such as surround view.

A further option is the integration of an established industrial Ethernet variant such as Ethercat, Profinet, Powerlink or Ethernet/IP. Each of these 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 layer 2 (data link layer) in the Ethernet protocol, whilst on the other hand, Powerlink, only accesses layer 3 (network layer). All of these protocols support a data rate of at least 100 Mbit/s.

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

**Physical layer – layer 1**

100Base-T1 (formerly OABR – Open Alliance BroadR-Reach) is a PHY primarily developed for the automotive market that achieves a bandwidth of 100 Mbit/s via a simple UTP (unshielded twisted pair) cable. This development originally came from Broad Com, 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. This PHY is already used in car production programs 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 capabilities for applications in the automation and automotive sector. These activities are based on significant preparations for AVB (Audio Video Bridging) and predominantly intervene in layer 2. The group of Time-Sensitive Networking standards (TSN) offers features such as traffic shaping, bandwidth guarantees, and deterministic messages with guaranteed latency and redundancy mechanisms. These Ethernet features can access various protocols on a higher level, such as UDP, but also be combined with established industry protocols that only access layer 3 (network layer). With TSN, automation applications that require hard real-time and functional safety, video signals that require a guaranteed bandwidth, and service or diagnosis data that can create a very interdeterministic network load can be converged on one single Ethernet network.

As TSN is very broadly defined 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 safety-critical controllers a full deterministic Ethernet with an error-tolerant time synchronization and redundant paths is preferable. It could even be expanded with further extensions such as SAE AS6802 or similar mechanisms with microsecond-jitter. TSN describes a collection of standards that are prepared by the IEEE Standards Association in the LAN/MAN Standards Committee in the Working Group IEEE802.1 TSN. Figure 3 shows the status of standardization.

**Limitations and future expansions**

Even though 100Base-T1 and the TSN standards offer a solid basis to complement CAN in future communication architectures of mobile machinery, several improvements are still possible. It can be predicted today, for example, that 100 Mbit/s will not be sufficient for all applications, especially those with environment recognition and image processing. With 1000 Base-T1, a gigabit variant of the Single-Pair Unshielded Twisted Pair-PHY was already signed off by IEEE on June 20, 2016 [1].

The limitation of the cabling length to 15 m at USP is also relevant for 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): sensors, cameras, or controls consuming little power can be directly supplied via the UTP communication cabling. This standard is to be signed off by the IEEE at the beginning of 2017 and can lead to further optimization in the cabling of sensors and cameras.

100(0)Base-T1 and TSN offers a solid foundation (layer 1-2) for 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 happen with simple UDP-based proprietary protocols for smaller machines or by borrowing from industrial automation such as the integration of existing fieldbus protocols or concepts such as OPC UA. The automotive sector will also offer options for major manufacturers with Autosar, DoIP, or Some IP.

Integration into existing architectures

The integration of automotive Ethernet is likely to 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, parts of local networks in a machine can be gradually converted to Ethernet. Due to the large bandwidth, CAN/Ethernet gateways, like the ones offered by TTControl, 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 that also offers numerous CAN channels can take over 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.

References


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