Challenge of Ethernet Use in the Automobile
Flexible Interfaces and Software Tools Simplify ECU Development

Already this year, Ethernet will be used as a system network in the first production vehicles. Therefore, the next step is to integrate Ethernet with established technologies in the automotive industry: CAN, FlexRay, LIN and MOST. Functional development tools exist for them, which make it easy for developers to analyze heterogeneous networks. On the Ethernet side, however, only standard tools from office communications exist, but they do not support the special physical layers and IP protocols of the automotive world. Therefore, development and test tools are urgently needed that can be used to analyze and test existing bus systems together with Ethernet networks. But what would be the exact requirements of these tools?

It is already state-of-the-art technology to transmit camera images in vehicles at 100 MBit/s over a cost-effective, unshielded twisted pair connection. This technology is known as BroadR-Reach, which is standardized by the OPEN Alliance SIG consortium [1]. The next objective is to use Ethernet as a network for infotainment and driver assistance systems by 2015. Some OEMs predict that Ethernet will become a backbone technology starting as early as 2018 [2]. As described in a number of professional articles [3, 4], Ethernet offers flexibility, scalability and cost advantages in automotive use, especially in combination with certain Internet Protocols **(Figure 1, [1])**. Moreover, it offers the opportunity to enrich the proven automotive development process with methods from the IT world.

Challenges of an Automotive Ethernet Test Solution

The use of Ethernet in motor vehicles will require rethinking by developers and test engineers. First, efforts must address the issue of how to obtain a clear domain architecture **(Figure 2)**. In this architecture, the backbone is no longer a bus system, but rather it is implemented as a switched network with multiple full-duplex connections. When using it to implement real-time critical applications, synchronization technologies are required on higher protocol layers above the physical layer (OSI layer 1), e.g. AVB (Audio Video Bridging, **Figure 1**). Analysis requirements are also growing for the new architecture. For example, if the developer wishes to simultaneously analyze all data traffic on the backbone, access must be synchronized on all path branches **(Figure 2, a, b, c, d)**.

Use Case	Audio/Video Time Sync		Address Configuration	Service Discovery	Service Control	Flash Update	Helper Protocols
7 Application	API			API			
6 Presentation	API			API			
5 Session	IEEE 1722 (AVTP) AV-Transport	IEEE 802.1AS (gPTP) Time Sync	DHCP	SOME/IP		DoIP TFTP	
4 Transport			UDP/TCP				
3 Network			IPv6/ IPv4				ICMPv6, NDP ICMP, ARP
2 Data Link	Ethernet MAC + VLAN (802.1Q)						
1 Physical	Ethernet Physical Layer (Ethernet, OPEN Alliance BroadR-Reach, Reduced twisted-pair Gigabit Ethernet)						

□ = Audio Video Bridging (AVB)

Figure 1: Along with protocols familiar from the field of office communications such as UDP, TCP and IP, protocols specially optimized for automotive use are also used. They are described in ISO CD 17215-1.

Second, developers must utilize new, relevant filtering strategies to process the enormous quantities of data. The situation will be further intensified by transmission rates in the gigabit per second range, which are already on the wish lists of OEMs. A physical layer that is suitable for this, known as RTPGE (Reduced Twisted Pair Gigabit Ethernet), is already in development.

Minimizing Effects of the Interface on System Performance

Unlike in a bus system, special measures must be taken to avoid measurement effects on the system. On the one hand, developers must consider testability early in the system design (Design-to-Test). On the other hand, the tool producer must minimize the effects of the interface. Presented in the following are various measurement setups for analysis and testing purposes; their undesirable effects are explained, and it is shown how these effects can be minimized.

Limitations of Previous Solutions

A natural approach to analyzing an Ethernet network is to use an additional port (monitor port) at the implemented switches in the system (mirroring). All packets received from the switch are forwarded at this monitor port. This provides access to the arriving data packets, yet these data packets are not interrelated by a common time reference – there is no time stamp. Moreover, often only valid packets are forwarded to the monitor port, which makes error analysis difficult. Furthermore, for cost reasons no additional monitor port is provided at the switch for mirroring in the production system. [4].
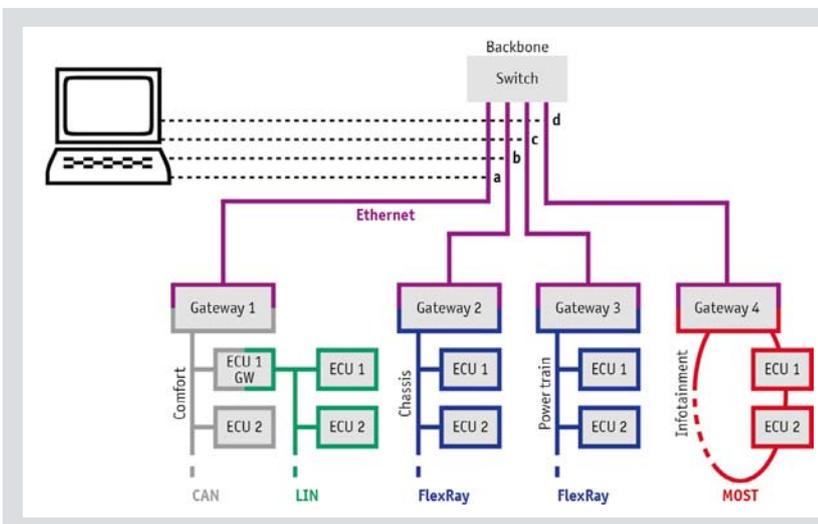
Figure 2: Potential domain architecture of future IP networks in the motor vehicle. To be able to analyze all Ethernet packets, the analysis software must access all Ethernet paths synchronously.

If no additional port is available at a given switch, an additional switch can be inserted in an existing connection. This additional hop is not transparent, however, and it causes a delay over the total transmission path. In networks that are synchronized by the AVB protocol this dynamic delay may disturb the time synchronization under certain circumstances. For this measurement setup, it is possible to utilize tools and switches commonly used in the IT field. However, in the BroadR-Reach networks that are generally used in the automotive industry it is necessary to perform a media conversion to standard Ethernet (IEEE 802.3). Moreover, from the perspective of automotive network development these tools are usually insular solutions, and they have no reference to bus systems that are still important and commonly used.

Transparent Ethernet Analysis

Instead of using a classic switch as an interface, it is desirable to monitor the network by a method that is as transparent as possible. The primary objective here is to avoid having the system affected by increased latency time or filtering of faulty packets. This can be done by a so-called TAP (Test Access Point) **(Figure 3)**, which acquires and routes the data passively on the physical layer **(path 1 in Figure 4)**. In this process, the latency time is not only very short, but constant as well, which is especially advantageous in the analysis of AVB systems. Another method of transparent monitoring involves using a switch with AVB time synchronization support. The AVB protocol then compensates for the latency time that occurs when the packets are routed.

Regardless of which method is chosen, to accurately analyze the packet data precise time stamps are needed which are acquired as close to the physical layer as possible. These time stamps must be synchronized with other interfaces, because the network analysis often focuses on more than just one Ethernet path **(Figure 2)**.

For an inactive interface a transparent behavior is also important. If the interface hardware is installed in the vehicle for a test drive, for example, the interface must autonomously assume a preconfigured stand-alone mode even if the measurement application is inactive. Otherwise, certain Ethernet paths would be interrupted during the drive.

TAP with Stimulation

Along with pure data analysis, the network must often be tested by intentionally sending certain packets. Here – as in pure monitoring – the connections between any two nodes should be affected as little as possible. However, these supplemental packets cannot be sent on the physical layer, because an additional flow control is necessary, which is not available until layer 2. Here too, dynamic latency times occur, which could be compensated by protocol support directly at the interface, e.g. by AVB.

One use is to send supplemental faulty data for test purposes while the normal communication between the two nodes is running **(path 3 in Figure 4)**. This data is either supplied directly by a test application, e.g. Vector CANoe .Ethernet, or by a packet generator which generates a defined bus load directly at the interface **(path 2 in Figure 4)**.

Remaining Bus Simulation

Particularly when developing individual ECUs, the remaining bus simulation [6] is a flexible way to test any types of scenarios before the ECUs are integrated in a real network. First, hardware is needed that permits unrestricted and high-performance network access. Second, the application must be able to forward logged or self-generated data to the hardware **(path 4 in Figure 4)**. And third, the combination of hardware and software must be able to receive packets, corrupt them and then send the corrupted packets. This provides a way to test ECU behavior in response to specific error cases such as protocol errors.
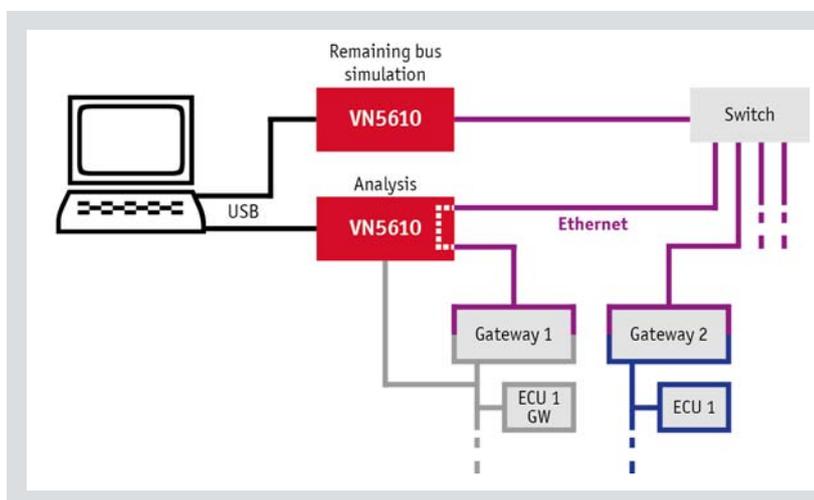
Figure 3: Possible wiring of Ethernet interfaces for analysis or for a remaining bus simulation. Synchronism with familiar automotive bus systems is also required.

Important Properties of a Flexible Interface/Software Combination

The described measurement setups illustrate how the analysis of Ethernet networks places different requirements on the hardware and software. To avoid having to change interfaces for the different measurement setups, it must be possible to use the interface flexibly as a TAP, converter or as a switch with supplemental functionality. The following properties are desirable here:

> In the simplest case, when the interface is used as a TAP, the TAP itself must only cause minimal and precisely specifiable latency times.
> The interface must be able to convert between all commonly used media such as BroadR-Reach, Fast Ethernet, Gigabit Ethernet and in the future RTPGE as well. This eliminates the need to use external media converters, which has been necessary so far.
> For test drives, it must be possible to install the interface in the vehicle, and while it is not being used it must not disturb the network (stand-alone mode).
> Packet generators are important on the software or hardware level, because along with analysis the automotive development process also requires controlled stimulation.
> In conjunction with the simulation software the hardware interface must allow real media access for one or even several virtual network nodes (remaining bus simulation).

> It must be possible to use the analysis and simulation tool to analyze and manipulate data on all OSI layers of interest and over all protocol levels.
> To support heterogeneous networks, it must be possible to synchronize the interface with all commonly used bus systems.

The use of high-performance analysis tools from the field of office communications together with external media converters is often overly simplified. The noted requirements can only be implemented by specialized hardware that is closely intermeshed with the analysis and simulation software. One combination already used in practice is the VN5610 Ethernet/CAN interface from Vector together with the CANoe .Ethernet development tool. This solution is already being used by some automotive OEMs and suppliers.

Outlook

Over the next five to ten years, heterogeneous network structures will continue to be found as clusters of established bus systems in the vehicle. After the camera application, Ethernet will be used in other system domains and will to some extent replace other bus systems. After being used as a backbone, Ethernet and IP technologies will penetrate into other automotive application areas.

For developers of vehicle networks, multibus capability, remaining bus simulation and low-level time stamps for all data packets will continue to gain in importance. At Vector, the next development steps in the Ethernet and IP area will be to support users in signal representation over all IP protocol layers **(Figure 1)** and to comprehensively check real-time and service-oriented communication, e.g. via AVB and SOME/IP.

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Image rights:
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Literature References:
[1] OPEN Alliance SIG, http://www.opensig.org/
[2] Das IP-basierte Bordnetz kommt ["The IP-based on-board electrical system is coming"], Elmar Frickenstein, BMW AG, SEIS Status seminar, 2011-20-09, http://www.strategiekreis-elektromobilitaet.de
[3] Ethernet und IP im Kraftfahrzeug: Neue Anforderungen an das Entwicklungswerkzeug durch den Ethernet- und IP-Einsatz ["Ethernet and IP in motor vehicles: New development tool requirements for the use of Ethernet and IP"], Hans-Werner.Schaal, Elektronik automotive, April 2012
[4] Herausforderungen von Ethernet-Debugging ["Challenges of Ethernet debugging"], Helge Zinner, www.elektroniknet.de, October 2012
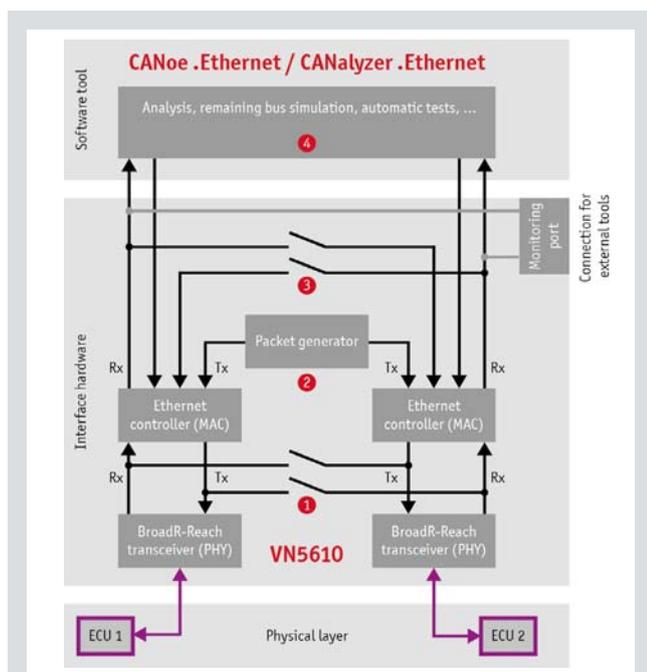
Figure 4: The VN5610 Ethernet/CAN interface passively and actively participates in communication in Ethernet networks together with CANoe .Ethernet/CANalyzer .Ethernet. A flexible configuration supports different measurement setups for analysis and test purposes.

[5] ISO CD 17215-1 (E) of 2012-07-02

[6] Schnelle Wege zur Restbussimulation: Virtuelle Netzwerke ohne Programmier-Know-how erstellen ["Quick paths to remaining bus simulation: Creating virtual networks without requiring programming know-how"], Stefan Albrecht and Peter Decker, Automobil Elektronik, March 2012

Links:

Vector: www.vector.com

Vector Solutions for IP and Ethernet:
www.vector.com/vi_automotive_ethernet_solutions_en.html

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