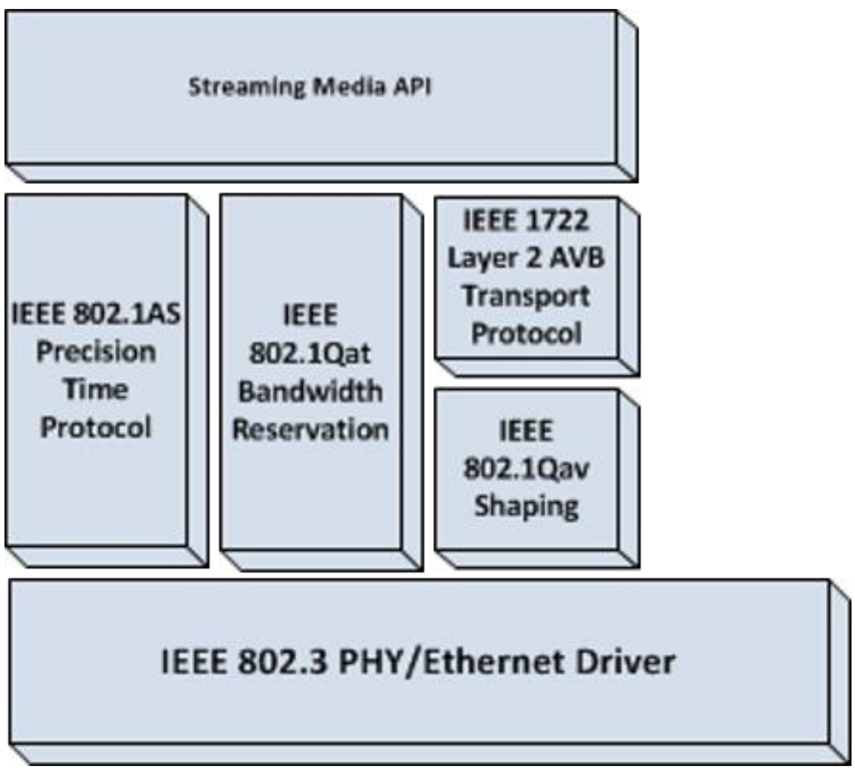
Audio Video Bridging (AVB) in an Automotive Ethernet Network



Project within: FFI Electronics, Software and Communication

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Content

1. **Executive summary 3**

2. **Background 3**

3. **Objective 4**

4. **Project realization 4**

5. **Results and deliverables 5**

5.1 Delivery to FFI-goals 5

5.2 Examples of Results 5

5.1.1. WP 1: Requirements and Use Cases 5

5.1.2. WP2: Test Bench TCN Part 6

5.1.3. WP2: Test Bench ArcCore Part 8

5.1.4. WP 3: Analysis & Validation 9

5.1.5. WP 4: Future Standards 10

6. **Dissemination and publications 11**

6.1 Knowledge and results dissemination 11

6.2 Publications 13

7. **Conclusions and future research 14**

8. **Participating parties and contact person 14**

9. **Annex 15**

9.1 References 15

9.2 Terminology 15

FFI in short

FFI is a partnership between the Swedish government and automotive industry for joint funding of research, innovation and development concentrating on Climate & Environment and Safety. FFI has R&D activities worth approx. €100 million per year, of which half is governmental funding. The background to the investment is that development within road transportation and Swedish automotive industry has big impact for growth. FFI will contribute to the following main goals: Reducing the environmental impact of transport, reducing the number killed and injured in traffic and Strengthening international competitiveness. Currently there are five collaboration programs: **Vehicle Development, Transport Efficiency, Vehicle and Traffic Safety, Energy & Environment and Sustainable Production Technology.**

For more information: www.vinnova.se/ffi

1. Executive summary

The AVB project commenced in January 2014 and terminated, according to plan, in December 2015. All project objectives defined in the application were fulfilled and the project will contribute to achieving overall FFI objectives from an automotive Ethernet perspective.

AVB has produced valuable results and knowledge in different automotive Ethernet areas, including: Identification of proper requirements and use cases, creation of a test bench and adaptation of tools for simulation, usage of simulator and test bench for studies of Ethernet AVB for different network configurations and traffic flows, and monitoring and participating in the future development of standards and platforms for Ethernet AVB.

2. Background

When the FFI application was made, in 2013, the following was stated as background to the need for Ethernet AVB research [1]:

- The FFI project Ethernet AVB (diary number 2013-04722) was the result of a pre-study performed in 2013 as part the FFI project ECAE (Ethernet Communication in Automotive Environment). More general background and other information related to automotive Ethernet can be found in the project description and final reports for the ECAE project (diary number 2012-03676).
- Regular Ethernet does no fully provide functionality to be able to use in in automotive systems. It is not inherently deterministic which is problematic when sending time sensitive data, such as collision avoidance camera or synchronized audio and video. It does not provide any time guarantees when data will be delivered which makes it hard to synchronize received data.
- Ethernet AVB is an extension to regular Ethernet and has its roots in professional audio and video applications. It makes several changes and additions to Ethernet, both in software and hardware, to make it possible to use Ethernet in audio and video applications. It for example states upper timing limits and provides precise synchronization and prioritization of participants.

3. Objective

The project objectives as defined in the FFI application [1] remained unchanged during the course of the project:

1. Gain more in-depth knowledge of the AVB standard and how it can be used within the Swedish automotive industry,
2. Develop and evaluate model based techniques for designing automotive communication networks, in particular AVB networks, and
3. Investigate (and try to impact, if needed) future standardization in accordance with our findings.

The fulfilment of project objectives is analyzed and commented on in detail in a separate final report related to goal fulfilment [2]. To summarize: All project objectives were fulfilled.

4. Project realization

The project was structured into the following WPs:

- WP 0: Project Management
- WP 1: Requirements and Use Cases
    - Specify requirements and use cases for Ethernet AVB. Specify and maintain verification and validation requirements.
- WP 2: Test Bench
    - WP 2.1: Test Bench Analysis
        - Analyse the requirements from WP1. Compile a list of components needed in the test bench.
    - WP 2.2: Test Bench Implementation
        - Implement the test bench. Incrementally build to allow parallel work with WP3.
- WP 3: Analysis & Validation
    - Optimisation by using TCN tools, both for modelling as well as test and measurements of real-time physical architecture
- WP 4: Future Standards & Autosar
    - WP 4.1: Pre-study of next generation Ethernet AVB
        - Follow the standardization of future generation of Ethernet AVB.
    - WP 4.2: Pre-study of Ethernet AVB & Autosar
        - Investigate how Ethernet AVB and Autosar can cooperate.

Project Management was based on monthly reports and meetings in the project team, meetings with the steering group at least before each reporting to VINNOVA, meetings within each WP, workshops and project seminars.

5. Results and deliverables

5.1 Delivery to FFI-goals

The project's contribution to FFI over-arching and sub-program targets/goals were defined as follows in the FFI application [1]:

- Safety is enhanced by Ethernet enabling the development of active driver support systems.
- Small innovation companies, with close ties to the academic world, offering cutting edge technology are promoted by the cooperation with automotive manufacturers.
- The competitiveness of all companies in the project is strengthened as advanced and cost saving technology is being developed and introduced in industrial applications.
- Competence is strengthened within the participating companies as information and technology is shared among project participants in the respective work packages.

The project's contribution to achievement of these goals/targets is analyzed and commented on in detail in a separate final report related to goal fulfilment [2].
To summarize: The project has contributed to achievement of these goals/targets as appropriate.

5.2 Examples of Results

5.1.1. WP 1: Requirements and Use Cases

This WP was led by VCG but done in cooperation mostly with AB Volvo. It concludes the use cases foreseen within both companies, which translates in to initial high level requirements that can be used by all involved parties. For the requirements a set of verification and validation requirements was defined to clarify how to test and verify the functionality.

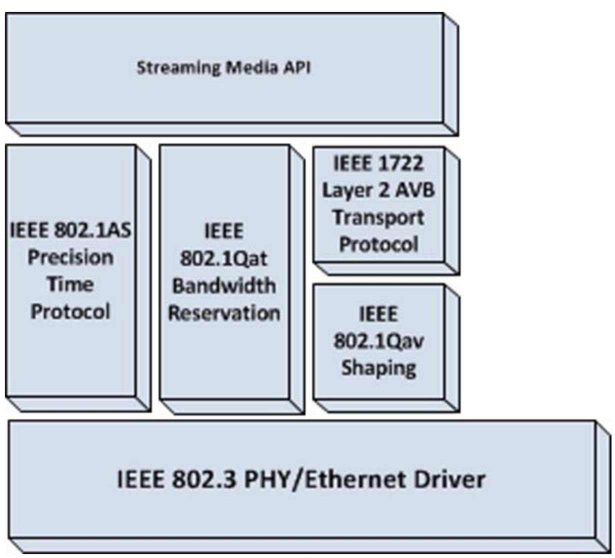

Figure 1: AVB Protocols Overview

Initially, much time went into studying AVB in order grasp the technology in more depth. Meetings were held with all partner companies with the aim to exchange knowledge and getting the same understanding of the goal ahead.

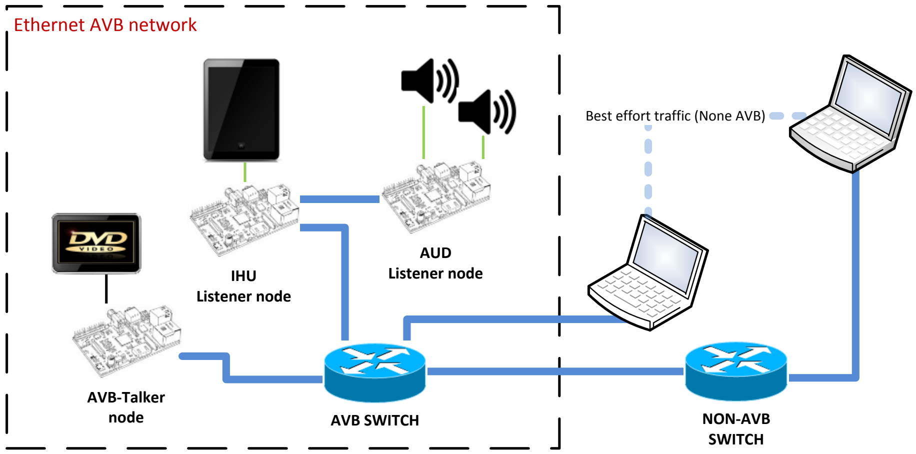

Figure 2: An example AVB network showing an infotainment domain use case

The results were documented in a technical report [3]. The report includes the two deliverables required for WP1, namely L1.1 Requirements and Use cases followed by L1.2 detailed verification and validation requirements.

5.1.2. WP2: Test Bench TCN Part

In close cooperation with the other project partners Time Critical Networks (TCN) identified demands and requirements on test bench components. Thereafter, appropriate components from different vendors were selected and evaluated and the test bench was assembled. Three different versions of the test bench were configured and used during the project (illustrated in the figures below):

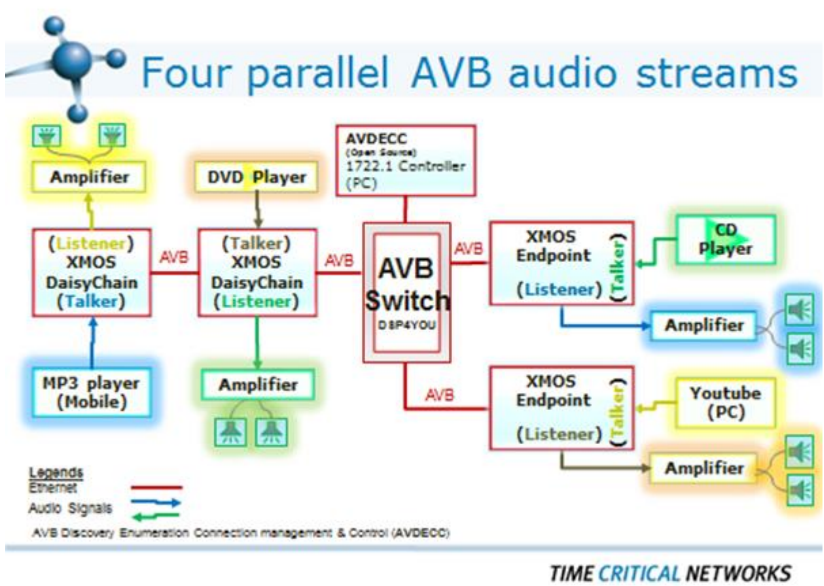

Figure 3: AVB Sound only (1st version of test bench)

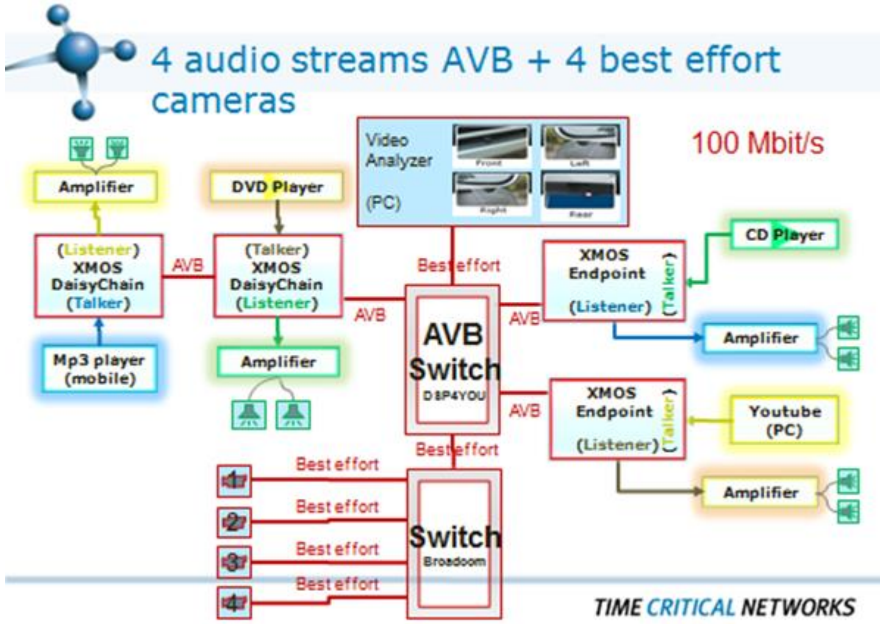

Figure 4: AVB Sound and regular video (2nd version of test bench)

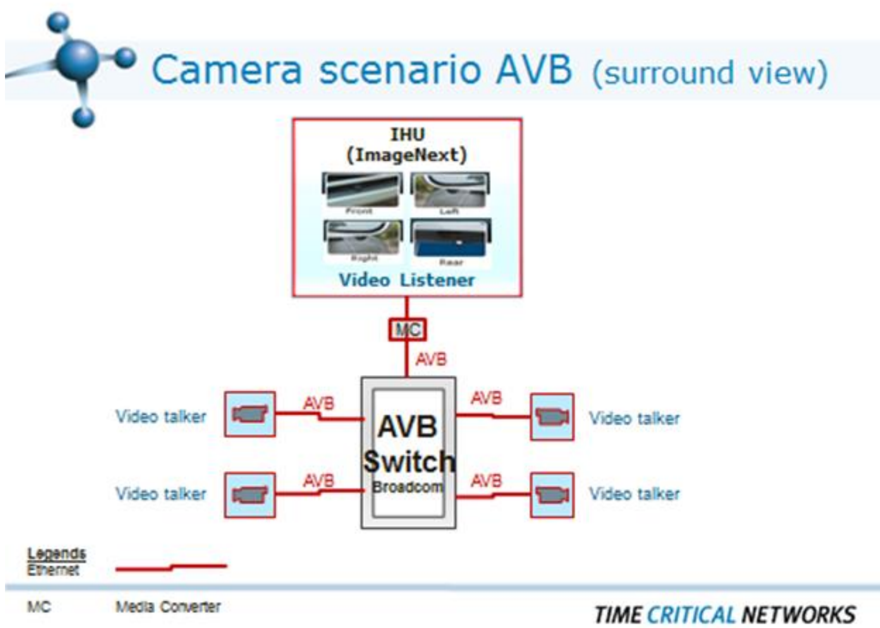

Figure 5: AVB Video only (3rd version of test bench)

5.1.3. WP2: Test Bench ArcCore Part

The purpose of this part of the work package was to add control signalling to the test bench. This made it possible to see how the control signalling would be affected when e.g. video traffic is added to the Ethernet backbone network. In this type of systems it is important for the ECU: s to detect, in real-time, if the timing constraints fails and if so take actions to compensate for this delay or in worst case switch mode to limp home.

An AUTOSAR 4.2 stack was developed and an overview of the Ethernet stack in AUTOSAR 4.2 is described in the figure below with focus on the time synchronization.

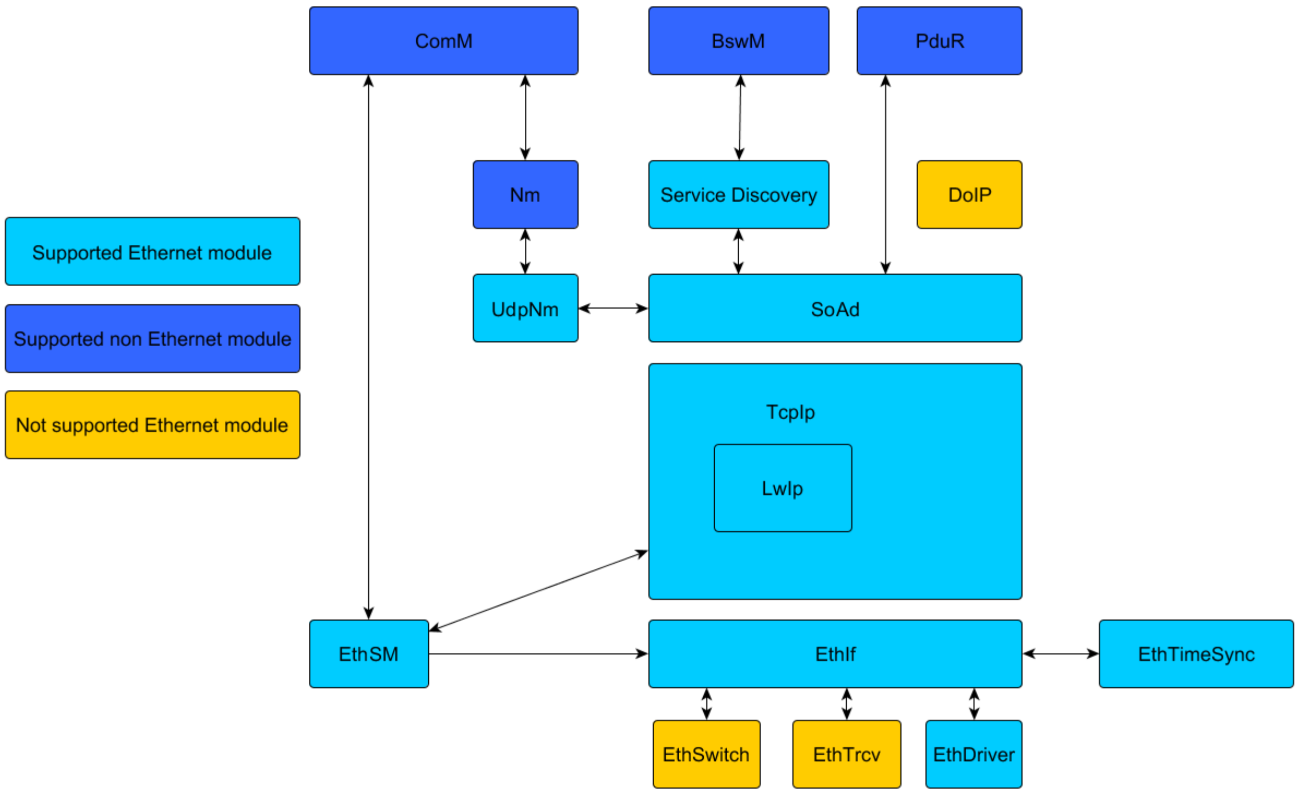

Figure 6: AUTOSAR 4.2 Ethernet stack overview

The AUTOSAR standard has evolved since the FFI application was written and the complete Ethernet stack was revised with major changes to all Ethernet related modules in AUTOSAR 4.2.2. Several new Ethernet related modules were introduced and one of them was the EthTSync module.

The Ethernet mechanism is based on existing PTP mechanisms that are described in standards like IEEE1588 (IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems) and IEEE802.1AS (Timing and Synchronization for Time-Sensitive Applications in Bridged Local Area Networks).However, neither IEEE1588 nor IEEE802.1AS has been developed considering automotive requirements. Currently an AVnu subgroup is working on an automotive profile of IEEE802.1AS.

Automotive Ethernet networks deviate from commercial Ethernet networks in terms of the following items:

- Role and functions of ECUs is known and defined a priori
- The network is static, i.e. components like ECUs, switches and characteristics like cable length don't change during 'operation' or even after switching off and switching on the vehicle. Components of course may be unavailable (due to failure situations or by purpose) but mostly only change when the vehicle is at a service facility.

Therefore, dynamic mechanisms like determining the Global Time Master (denoted as grandmaster in IEEE802.1AS) by the best master clock algorithm (BMCA) during operation are not required. It is also possible to omit the cyclic measurement of link delays on Ethernet links due to the static nature of the automotive network and restrict mechanisms that belonging to dynamic network topology. Removing the dynamic behaviours means that the implementation becomes simpler but it will also require less CPU resources which are important in an automotive context.

5.1.4. WP 3: Analysis & Validation

Activities performed in this WP included:

- Measurements on the individual network components such as switches and cameras
- Modelling of network components for simulation
- Simulation of Ethernet best-effort and AVB traffic to predict system and network resource utilization, identify worst case situations, etc.
- Used measurements on the Valeo cameras to construct a statistical model on how packet bursts are generated by a typical camera
- Analysis of the fragmentation of large video-frames in IP-stack since large frames will be defragmented when passing through gateway ECUs and when received by end hosts
- Implementation of AVB credit-based shaper-algorithm
- Implementation of fragmentation and defragmentation of large UDP frames carrying video frames
- Implementation of limited switch memory buffers; tracking the current bit fill level of all switch ports and registering of worst case buffer utilization

The results from measurements and analysis on the three test bench configurations described in WP 2 (see section 5.1.2 above) included:

- AVB Sound only (1st version of test bench)
    - Testing in the AVB Audio Network showed that once the connection between a talker and a listener had been established by the AVDECC, the sound stream was very good without any interferences.
    - Beside the four AVB audio streams, best effort internet data was simultaneously transmitted over the network to the connected PC without any quality loss of the audio streams. However, the required bandwidth for each 2 channel audio stream was well within the available 100 Mbit/s so no disturbance was to be expected.

- AVB Sound and regular video (2nd version of test bench)
    - Video streams distorted
    - 100 Mbit/s Ethernet
        - Mixture of standard (best effort) + Ethernet AVB
    - 29 Mbit/s per camera best effort
    - 7,168 Mbit/s per audio stream Ethernet AVB
        - 2 channels (stereo) class A traffic
    - Disconnected one camera
        - Significantly improved video output
    - Audio went through okay during all scenarios
- AVB Video only (3rd version of test bench)
    - An ImageNext automotive AVB camera system was used.
    - The test results are described in detail in a TCN technical report [4].

5.1.5. WP 4: Future Standards

Pelagicore AB was responsible for this WP and activities during the project period included: Participation in standards organisations (AVnu, GENIVI), multiple Ethernet-AVB related projects with silicon vendors, proof-of-concepts demos, studies of published and draft AVB/TSN standards, analysis of ongoing work in standards organizations and discussions regarding the future of AVB with key players in the industry (OEMs, silicon vendors, AVB product developers).

The results from this WP included the following regarding the future generation of AVB, which is TSN (Time Sensitive Network):

- While Ethernet AVB was originally designed to transport audio over standard Ethernet networks, it's becoming apparent that the very high degree of time precision, low latency requirement and precise synchronization need is also applicable to critical control applications within industrial and automotive. The next generation of AVB is therefore called TSN and allows Ethernet to move into the area of hard real-time and reliable communication.
- TSN can be described as "AVB 2.0" and backwards compatible with the AVB standards. Targeted application is converged networks with real time Audio/Video Streaming and real-time control streams as used in automotive or industrial control facilities. TSN has tighter requirements on latency and synchronization and addresses the transmission of very low transmission latency and high availability. It also adds redundancy and other important features.
- IEEE AVB/TSN specs in development:
    - 802.1ASbt - Timing and Synchronization: Enhancements and Performance Improvements
        - This standard adds support for new media types such as IEEE Std 1901 and WiFi Direct to the existing 802.11AS standard. It also adds support for redundant paths, improved performance and additional parameter sets for non-Audio/Video applications.

  - 802.1Qbv/ 802.1Qbu - Enhancements for Scheduled Traffic and Frame Pre-emption
    - This standard introduces the concept of a time-aware shaper, a way to define a time-triggered paradigm on a per class level (opposed to on a per-flow level). This allows blocking of non-control traffic during particular windows of time to ensure that the egress port for a control stream is idle when the control traffic is expected and enables arbitrary networks (i.e., non-engineered) and scheduled transmissions are able to be consolidated into a single network, with a significant cost reduction to the user.
  - 802.1Qca/ 802.1CB
    - These two standards introduce as a set of protocols and mechanisms to set up and manage redundant communication paths in the network and add resiliency control mechanisms.
- Ongoing development in the IEEE1722 Working Group:
  - The IEEE1722 working group is currently drafting a revision to IEEE1722-2011 that adds support for encapsulation and transport of control frames (LIN/CAN/FlexRay) in 1722 transport streams.

6. Dissemination and publications

6.1 Knowledge and results dissemination

The main mechanism for dissemination with the project partner organizations were the Project Seminars arranged towards the end of the project in cooperation between the FFI projects ECAE and AVB. Apart from project team and steering group members, key individuals from the partner organizations participated in these seminars, and VINNOVA representatives were invited.

The figures below shows the agenda for these seminars. The presentations were, like other results from the project, stored on the Project SharePoint site, administered by VCC and accessible for the other project partners.

FFI

ECAE & AVB Seminar – Agenda 2015-02-26

Time 09.30-15.00, Place: AB Volvo, Götaverksgatan 10, Lundbystrand, Göteborg, Room: M1.103
(First go to: Reception on floor 7)

09.30 Registration and Coffee/Tea

09.50 Welcome and Introduction – P-A Jörgner, Volvo Car Corporation (VCC)

10.00 Automotive Ethernet - Background, motivation and market outlook
Lars Bröhne, Time Critical Networks

10.20 Standardization activities of Ethernet in OPEN and IEEE for Automotive
Samuel Sigfridsson, VCC

10.40 FlexECUIII – A Prototype ECU to investigate Ethernet BroadR-Reach Technology
Oscar Ljungkrantz, AB Volvo

11.00 Break (Coffee/Tea)

11.20 Simulation results of replacing Flexray with Ethernet backbone
Jonas Lext, Time Critical Networks

11.40 Achieving deterministic transmission behavior in Ethernet
Ieroklis Symeonidis, ArcCore

12.00 Audio Video Bridging (AVB) in an Automotive Ethernet Network
Mohammad Mirzraei, VCC

12.20 Lunch

13.20 AVB Test bench set-up and test results
Lars Bröhne/Jonas Lext, Time Critical Networks

13.40 Implementation of Ethernet in Autosar 4.2.x – Kostas Beretis, ArcCore

14.00 Break (Coffee/Tea)

14.20 Ethernet as part of Architecture for Autonomous Driving
Kent Melin, VCC

14.40 Ethernet AVB Future Developments – Mikael Söderberg, Pelagicore

15.00 (The End)

Figure 7: Agenda ECAE/AVB Seminar 2015-02-26

FFI

ECAE & AVB Seminar – Agenda 2015-12-03

Time 09.30-14.00, Place: Volvo Car Corporation (VCC), Volvo Jakobs väg, Torslanda, Göteborg
Room: PVH5 "Hörsal B"
(External participants, first go to: PVH Reception, see attached map in Outlook Invitation)

09.30 Registration and Coffee/Tea

09.50 Welcome and Introduction
P-A Jörgner, Volvo Car Corporation (VCC) (10 min)

10.00 Hardware investigation of Ethernet BroadR-Reach Technology and AVB
Oscar Ljungkrantz, AB Volvo (30 min)

10.30 Ethernet in Automotive Environment at VCC
Samuel Sigfridsson, VCC (30 min)

11.00 Break (Coffee/Tea) (30 min)

11.30 AUTOSAR compliant Ethernet test bench configuration
Ieroklis Symeonidis, ArcCore (20 min)

11.50 Build and optimize Ethernet systems with latency, jitter and no packet drops in mind (30 min)
a. Network Performance Simulation vs measurements in test bench, Jonas Lext/Lars Bröhne, TCN (10 min)
b. Infotainment performance simulation, Jan Svensson, AB Volvo (10 min)
c. Ethernet AVB findings, pros and cons, Shahin Ghazinouri , Pelagicore (10 min)

12.20 Lunch (60 min)

13.20 Methods/Tools Challenges when introducing Automotive Ethernet
Lennart Casparsson, VCC (20 min)

13.40 Ethernet AVB Future Standardization and Trends
Shahin Ghazinouri, Pelagicore (20 min)

14.00 Thank You and End of Seminar
P-A Jörgner

Figure 8: Agenda ECAE/AVB Seminar 2015-12-03

Regarding drivers of change we can mention that there is a number of internal projects at each project partner which, based on results and gained knowledge from Ethernet, will lead to new and improved products.

6.2 Publications

As no research institute or academia was part of this project, no academic papers and similar publications were produced.

7. Conclusions and future research

The OEMs (AB Volvo and VCC) have gained deeper understanding about the possible roles of automotive Ethernet AVB in the electrical architecture, the importance of implementing Ethernet AVB the right way in order to achieve robustness and avoid unnecessary protocol complexity, the possibilities and limitations of automotive Ethernet AVB compared to other network technologies, and the importance of efficient tools for simulation and analysis. The competence level regarding automotive Ethernet among the employees has of course also increased, which is valuable for other projects.

The other project partners (ArcCore, Pelagicore and TCN) have gained increased knowledge about demands and requirements in the automotive industry. They have also been able to further to prepare and develop their respective product portfolios (AUTOSAR platform, open platforms for Infotainment, simulation and analysis tools) to match the further development of automotive Ethernet, including AVB/TSN.

However, AVB is still a bit immature for automotive use. Not all AVB protocols are necessarily needed for automotive use-cases. The upcoming TSN standards bring the positives of AVB to control/sensor protocols and adds extra reliability and redundancy. By utilizing AVB/TSN into the network, solutions can take advantage of an open, interoperable standard with independent testing available (through AVnu). Protocol tunnelling of automotive specific protocols (CAN/LIN/FlexRay) can provide gateways to legacy nodes for smooth migration towards automotive Ethernet with AVB/TSN.

Traditionally, automotive car network architectures have been heterogeneous and historically grown by building on existing architecture and adding more and more additional nodes. Ethernet can clear up the network topology and enable more hierarchal and simpler network structures – reducing the number of nodes and the costs and complexity of wiring.

To study the upcoming challenges and opportunities further research is needed. For example, new FFI applications in the area of automotive Ethernet have therefore been submitted late 2015.

8. Participating parties and contact person

The following organizations were part of this project (listed below in alphabetical order with main contact person):

- AB Volvo, Oscar Ljungkrantz
- ArcCore AB, Michael Lundell
- Pelagicore AB, Mikael Söderberg
- Time Critical Networks AB, Lars Bröhne
- Volvo Personvagnar AB, Per-Anders Jörgner

9. Annex

9.1 References

[1] FFI Project Description – Audio Video Bridging (AVB) in an Automotive Ethernet Network, AnnSofie Ruuth, VCC, 2013-10-15.
[2] Måluppfyllelse – AVB, VCC 94141, P-A Jörgner, 2015.
[3] FFI Ethernet AVB - WP1 - v1.docx, Report, Mohammad Mirzaei Volvo Cars, Atul Yadav AB Volvo, 2015-06-11.
[4] TCN report 20150709:1, Jonas Lext, Time Critical Networks AB.

9.2 Terminology

AE	Advanced Engineering
AUTOSAR	AUTomotive Open System Architecture
AVB	Audio Video Bridging
AVDECC	AVB Discovery, Enumeration, Connection management and Control
CAN	Controller Area Network
ECAE	Ethernet Communication in Automotive Environment
ECU	Electronic Control Unit
EMC	Electro-Magnetic Compatibility
FFI	Fordonsstrategisk Forskning & Innovation
IEEE	Institute of Electrical and Electronics Engineers
IP	Internet Protocol
Mbit	Megabits
MOST	Media Oriented Systems Transport
OEM	Original Equipment Manufacturer (here automaker)
OPEN	One-Pair Ether-Net
TCN	Time Critical Networks
TCP	Transmission Control Protocol
TSN	Time Sensitive Network
UDP	User Datagram Protocol
VCC	Volvo Car Corporation
VCG	Volvo Car Group
WP	Work Package