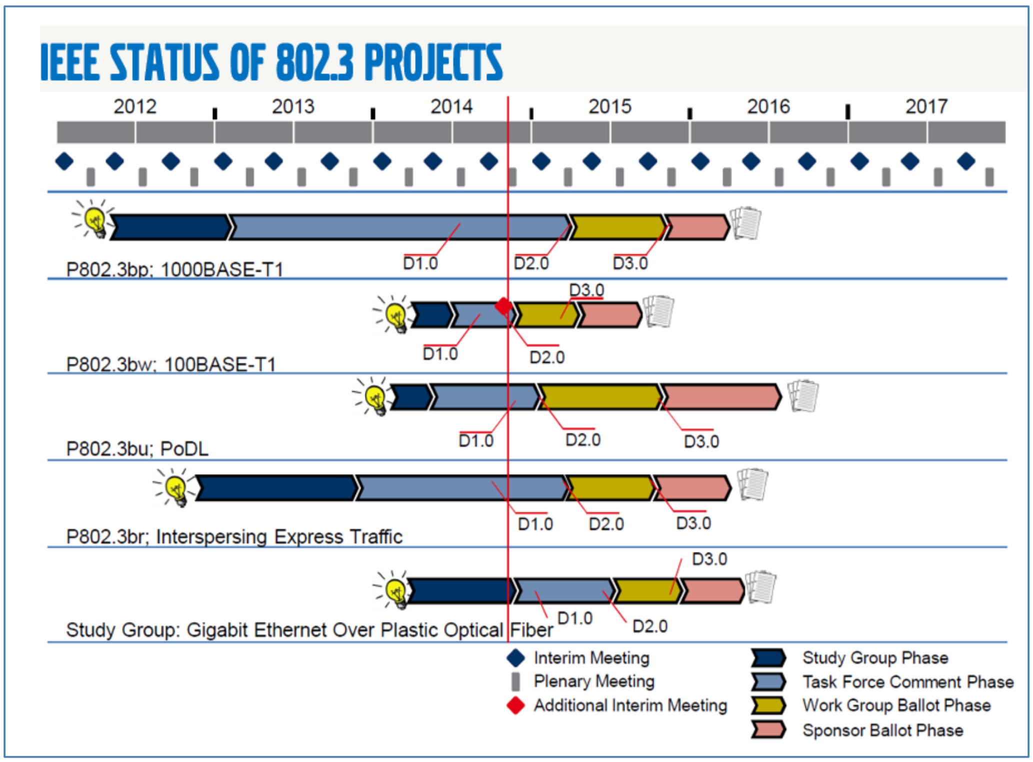
Ethernet Communication in Automotive Environment (ECAE)



IEEE Roadmap from ECAE/AVB seminar in February 2015

Project within: FFI Enabling Technologies

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FFI

Content

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 ECAE project commenced in the end of 2012 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.

ECAE has produced valuable results and knowledge in different automotive Ethernet areas, including: Ethernet (100 Mbit/s and 1 Gbit/s) based on unshielded twisted pair (UTP) cabling, electromagnetic compatibility (EMC), participation in further standardization of automotive Ethernet in IEEE and OPEN Alliance, development and use of a simulator and an test bench based on AUTOSAR for analysis of various Ethernet network topologies and traffic cases, and requirements on methods and tools for the automotive development process.

2. Background

When the FFI application was made, in 2012, the following was stated as background to the need for automotive Ethernet research [1]:

- Outside the automotive field Ethernet enjoys tremendous success in a variety of different commercial and industry applications. No other network technology in the market has shown such a continuous growth.
- In recent times, the OPEN Alliance (www.opensig.org), backed by a number of primary actors in the automotive world, has developed a physical interface that makes it possible to implement Ethernet communication on a simple unshielded twisted pair. This solution, fully compliant with the severe automotive requirements, is cost effective and makes Ethernet a good candidate for many vehicle applications.
- All this brings Ethernet to a position where it becomes a competitor to existing automotive communication standards, such as FlexRay, MOST, and to some extent CAN.
- To move from CAN, FlexRay, LIN and MOST of communication to a complete switched Ethernet network is a big step and will probably take considerable time. However, a number of domains will benefit from the higher bandwidth offered by Ethernet. Delays in a system can be reduced if gateways can be avoided or replaced with switches between the different IP domains.
- For Ethernet to become a major communication link in the vehicle there are a number of issues that needs to be solved. The wiring needs to be reduced, both weight and in the number of wires, compared to standard Ethernet. Ethernet is not inherently deterministic

or supports synchronisation, which is needed in an automotive environment. These issues will be addressed in this project.

3. Objective

The project objectives as defined in the FFI application [1] were divided into the two highest-level work packages (WPs) and they remained unchanged during the course of the project:

WP 1

- Investigate further development of Ethernet to make it better fit into the automotive world.
- This includes investigating the possibilities of communicating on Ethernet via an unshielded twisted wire pair, without jeopardising other functions in the vehicle by excessive EMC problems.
- Conduct a pre-study to evaluate the need of support on the physical layer and data link layer for synchronisation protocols like AVB (Audio & Video Bridging).

WP 2

- Investigate the issue of using a network of switched Ethernet links to build an IP network for in-vehicle communication. This will be done development of tools for simulations and creation of a test bench for studies of appropriate network topologies and traffic flows (use cases).
- Demonstrate the usability of the theory by analysing the communication in an existing vehicle communication architecture and apply this communication on an Ethernet/IP network.

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 at the two highest levels:

- WP 0: Project Management
- WP 1: Automotive Ethernet
    - WP 1.1: Requirement for Ethernet UTP and Power over Ethernet (PoE)
    - WP 1.2: Pre-study examining when AVB is feasible
- WP 2: Ethernet Backbone Architecture
    - WP 2.1: Define different aspects to consider when defining an automotive Ethernet electrical architecture
    - WP 2.2: Modelling and optimisation of one or several different architectures, considering aspects and requirements from WP 2.1
    - WP 2.3: Identify requirements for Tools and Methods in the development process

- WP 2.5: Gigabit Ethernet study

The actual work was done in work packages at the third level, totally 18 work packages at the start of the project [1].

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]:

a. CO_2 emissions are reduced as the use of unshielded standard automotive wiring reduces the vehicle weight compared to the use of standard shielded Ethernet wiring. We expect that other communication links, using shielded wires today, may change to Ethernet UTP.
b. Safety is enhanced by Ethernet enabling the development of active driver support systems.
c. Small innovation companies, with close ties to the academic world, offering cutting edge technology are promoted by the cooperation with automotive manufacturers.
d. The competitiveness of all companies in the project is strengthened as advanced and cost saving technology is being developed and introduced in industrial applications, and the 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. Ethernet in Automotive Environment at VCC (WP 1.1.1)

VCC carried out this work package and the work was done as an internal Advanced Engineering project. The major part of the work was done in 2013 and 2014. Some of the major activities and results are described below.

Start-up times, End2end Delay and synchronization measurements
Start-up times were measured. System delay for a system containing cameras, a switch and a computer were measured and analysed, as well as synchronization between four cameras. Tests were done on two different set of cameras.

The results from these tests showed a delay in the system between 100 – 200 ms from camera imager to the display. Synchronization between the cameras were within a few ms. The Start-up time was measured to be less than 700 ms. A conclusion from this test was that delay and synchronization are within limits for 100BASE-T1 to be feasible for a surround view camera system

EMC
EMC bench tests were performed with an evaluation kit provided by Broadcom as well as with a switch together with cameras from Valeo.

Figure 1: EMC Test Setup

EMC tests were also performed in a V60 test vehicle with the following results

- Emissions: Surprisingly low emissions but few peaks over VCC requirements
- RF Immunity: No Issues between 80 MHz – 1000 MHz at 100 V/m
- BCI: Issues found in frequencies around 30 MHz

Signal quality
Ground offset and cable length measurements were performed to make sure that the BroadR-Reach technology fulfilled the applicable requirements. For the ground offset measurements +/- 3.0 volts were tested and for the cable length measurements up to 15 meters was tested.

The signal quality tests showed that the BroadR-Reach technology is feasible regarding signal quality when it comes to ground offset and cable length.

Development of Requirement specifications
Based on the results from the tests described above and other evaluations physical and data link layer specifications were developed.

5.1.2. Hardware Investigation of Ethernet BroadR-Reach Technology (WP 1.1.2)

A prototype ECU called *FlexECU-III* was developed, as a physical layer test bench, to test the BroadR-Reach technology. BroadR-Reach is promoted by OPEN Alliance and standardized within IEEE 802.3.

To develop the FlexECU-III, the following tasks have been performed.

- Use case collections
- Design specification creation
- ECU hardware design and implementation, as well as mechanical housing construction
- Verification of the ECU functionalities

The FlexECU-III was used as test bench where signal integrity and EMC tests were performed. Signal integrity tests aim at checking the communication signal quality and how it is affected by connectors and cables. EMC tests aim at checking how immune the equipment is to outside radiation (immunity tests) and how much radiation it emits itself (emission tests).

Figure 2: Photo of FlexECU-III printed circuit board

The results of these tests showed that Ethernet BroadR-Reach is a promising technology but care must be taken when designing the ECU and when choosing cables and connectors.

5.1.3. Standardization Activities (WP 1.1.6)

The aim of this work package, Standardization activities, was to follow and participate in standardization in IEEE and OPEN Alliance.

IEEE
Through the engagement in OPEN Alliance (see below) VCC was indirectly active in a technical committee (C5) within IEEE. Figure 3 gives an overview of IEEE standardization efforts related to automotive Ethernet.

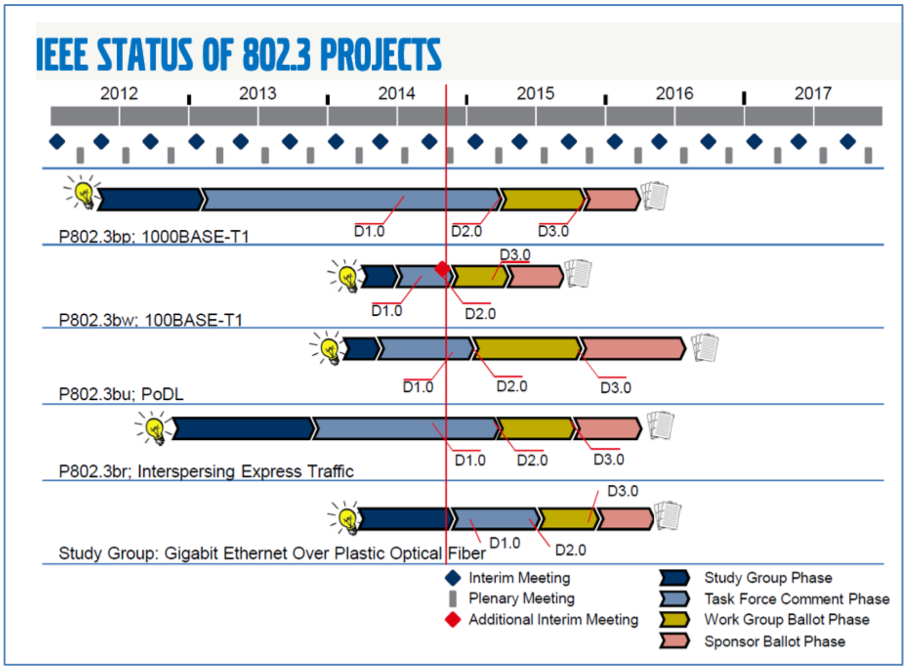

Figure 3: IEEE Roadmap from ECAE/AVB seminar in February 2015

OPEN Alliance

From the beginning of 2015, VCC holds the position as Secretary in OPEN. This has meant more involvement and possibility to actively influence standardization work in industry alliance.

One main result from OPEN that has evolved is the promotion of 100BASE-T1 or BroadR-Reach which has resulted in four semiconductor vendors that offer, or very soon will offer, components that are compliant with the 100BASE-T1 standard. At the OPEN Alliance "All members meeting" in Yokohama 2015 an interoperability demo was shown with components from Broadcom, NXP and Realtek.

5.1.4. Tools for Simulation and Analysis of Automotive Networks (WP 2.2.1)

TCN defined proper input (network topologies and traffic flows) in close cooperation with AB Volvo and VCC respectively.

Simulation studies were been performed in which the FlexRay backbone of SPA (VCC) and two backbone CAN buses in TEA2+ (AB Volvo) were replaced with a switched Ethernet backbone network.

Simulations of video streams were also performed by TCN and compared to measurements in test bench (with same simplified network topology and traffic flows) built up by partner ArcCore (in another WP, see next section below).

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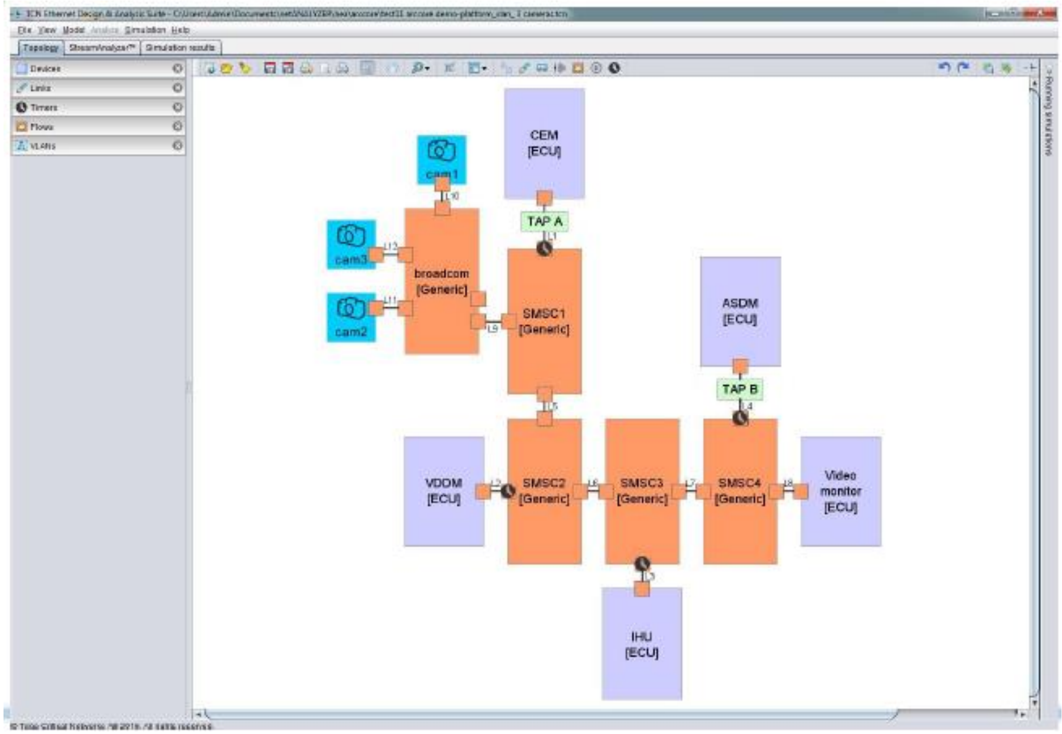

Figure 4: Example Input to Simulation – Video streams from cameras

Based on these tests (simulator and test bench) the following was concluded:

- Similar results found from both
  - Latency distribution
  - Bandwidth utilization
  - Memory utilization –no packet drop
- But simulation is easier
  - Much easier to test different traffic scenarios
  - Easy to set test probes for latency distributions
  - Much easier to change configuration parameters
    - Priorities, VLANs, traffic shaping, etc.

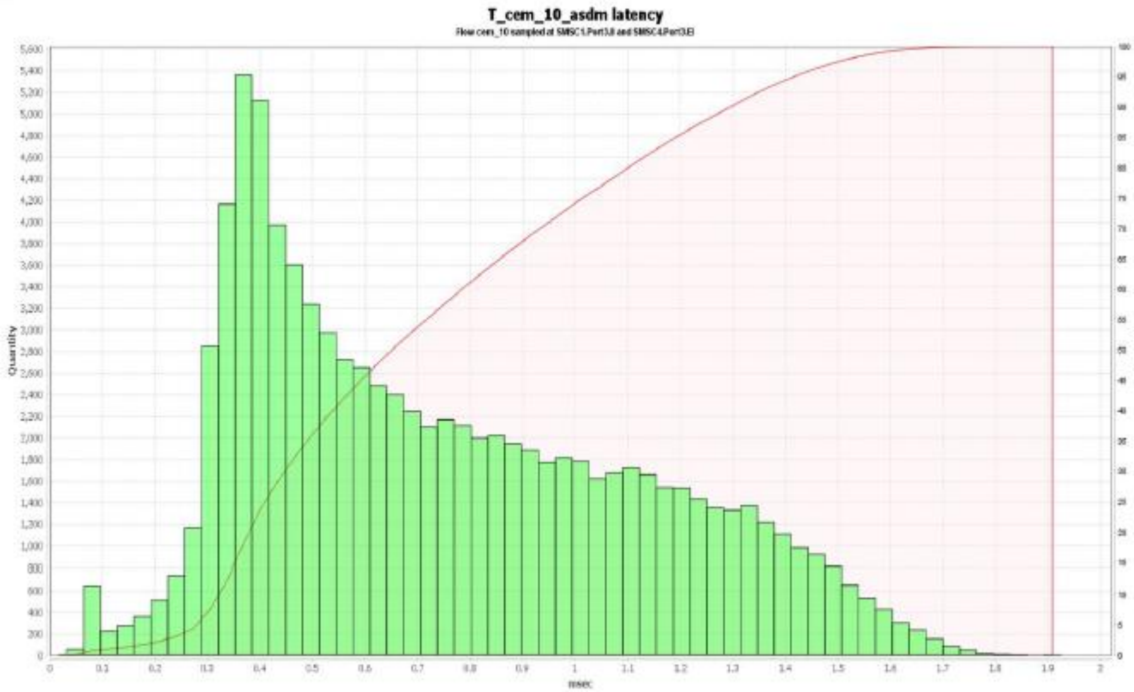

Figure 5: Example Simulation result – Latency distribution

5.1.5. Building a Laboratory Test Bench (WP 2.2.3)

In this WP, a laboratory test bench was created by ArcCore together with the other project partners, mainly TCN.

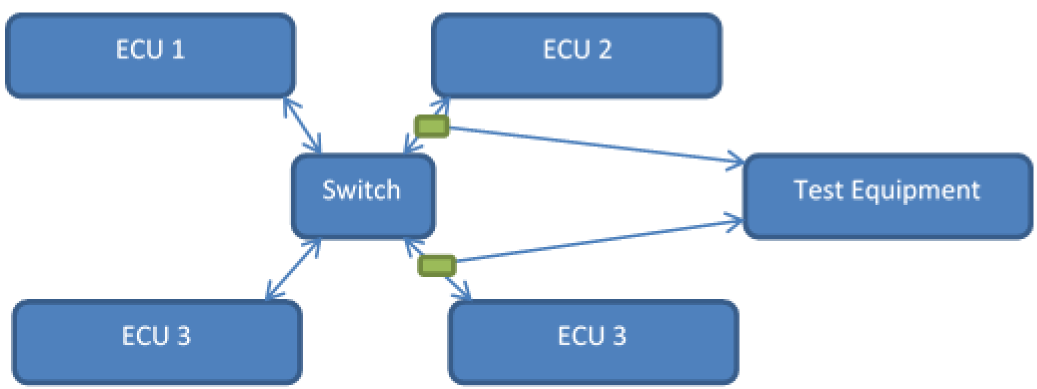

Figure 6: Example test bench topology

The test bench was based on ArcCore's AUTOSAR platform, Ethernet switches, the *FlexECU-III* prototype from AB Volvo (developed in WP 1.1.1) and SPA ECUs from VCC. The test bench could be configured for measurements of different AB Volvo and VCC topologies and traffic flows.

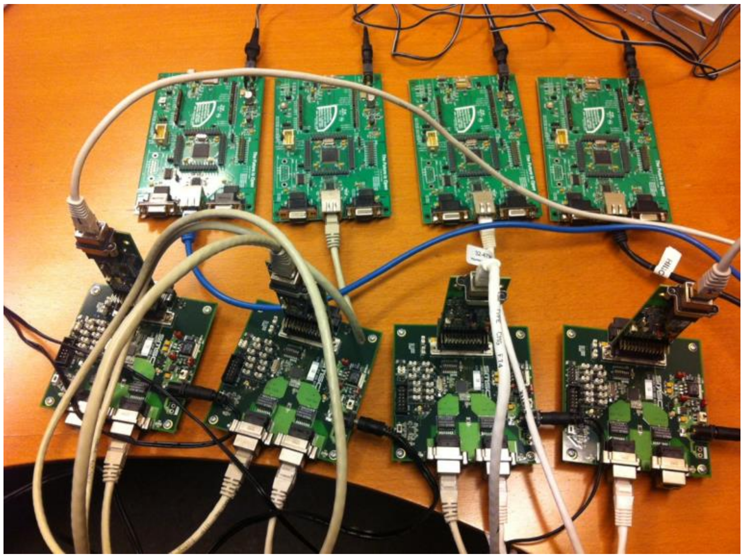

Figure 7: Example of test setup with prototype ECUs

Results from this WP included:

- The developed drivers enabled further use and evaluation of Ethernet concepts for AB Volvo and the *FlexECU-III* was made available to other parties within the project. The Flex ECU III will most likely be used in future research and advanced engineering projects.
- A prototype network with four ECUs based on Volvo Cars SPA architecture was successfully brought up to verify the simulator and further build confidence of the accuracy of the simulations. Each one of the four ECUs was based on a domain master in the SPA architecture where a FlexRay backbone network is used for communication between the masters. The FlexRay network was replaced by an Ethernet network and the ECUs were configured to send Ethernet messages at the same rate as the corresponding FlexRay messages.
- The network description provided by Volvo Cars was used together with the importer (created in WP 2.3.3). The time spent on configuration decreased significantly due to the importer. The usage of network description and an automated import ensured that relevant properties were transferred to the Ethernet configuration to achieve valid prototype of the replacement of the backbone network.

5.1.6. Gigabit Links (WP 2.5)

This work package started in the beginning of 2015 with the aim to start evaluating possible TCP/IP links when bandwidths higher than 100 Mbit/s is requested. There are a number of TCP/IP capable technologies that could be relevant in the automotive industry and the following technologies were part of the evaluation. Results from this WP are to be found in a VCC-internal technical report.

IEEE 1000BASE-T1

This is an Ethernet solution with the aim to pass EMC requirements and other automotive requirements using a cost efficient and low weight unshielded single twisted pair physical layer. The bandwidth is 1000 Mbit and the communication is full duplex.

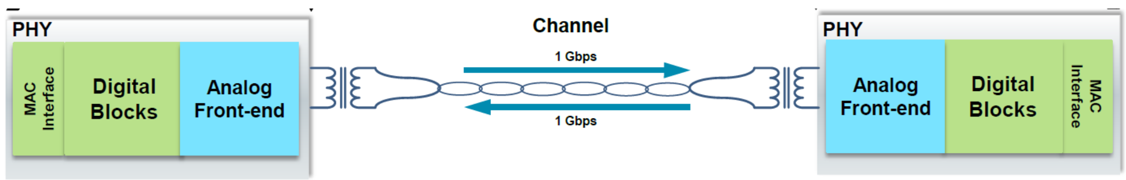

Figure 8: IEEE 1000BASE-T1

GEPOF

Gigabit Ethernet over Plastic Optical Fiber also have a bandwidth of 1000Mbit/s. Advantages are low weight and that the optical fiber is immune to electromagnetic interference. Emission and immunity tests are relevant anyway since the silicon and PCB layouts still needs to fulfill all automotive requirements. This technology is also standardized in IEEE 802.3bv.

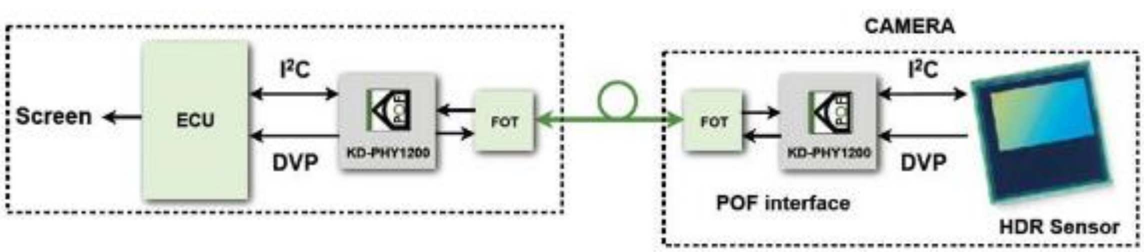

Figure 9: IEEE GEPOF

MOST NG

Media Oriented System Transport – Next Generation is a new generation with higher speed grade that is under consideration within the MOST Cooperation. Bandwidth is 5 Gbit/s or higher and the physical layer could be glass fiber or coax cabling.

GMSL

Both Inova with APIX and Maxim with LVDS are looking at new versions of their technologies with significantly higher bandwidths to support channels with video streaming of 4K resolution. These links will also be capable of transporting TCP/IP in separate channels.

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.

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 10: Agenda ECAE/AVB Seminar 2015-02-26

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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 11: 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 ECAE, 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 in the electrical architecture, the importance of implementing Ethernet UTP the right way in order to achieve robustness and avoid problems with EMC and other technical issues, the possibilities and limitations of automotive Ethernet compared to other network technologies, and the importance of adapting the tool chain to automotive Ethernet. 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 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, simulation and analysis tools) to match the further development of automotive Ethernet.

Since the project started, late 2012, Ethernet has become more and more popular in the automotive industry. For example, VCC use regular Ethernet (100BASE-TX) between a few ECUs in the first car based on the new SPA platform, the new XC90, launched in 2015. BMW is strongly promoting automotive Ethernet and use UTP in the new 7 series, launched in 2015 [3].

However, Ethernet for in-vehicle use is a complex area that is still being developed and standardized with a high pace, e.g. IEEE standards for 100 Mbit/s and 1 Gbit/s over UTP will be ready in 2016. It is important to continue the participation in the two standard organizations IEEE and OPEN, which was part of ECAE. The Swedish automotive industry and its partners also need to better understand where automotive Ethernet is optimal in the electrical architecture. What are the pros and cons of automotive Ethernet compared to replace legacy network technologies like CAN, FlexRay and MOST? For high bandwidth communication, mainly video streams from in-vehicle cameras, Ethernet has to compete with other technologies such as LVDS and APIX, which offer higher bandwidth for point-to-point links where Ethernet has to use video codecs meaning higher latency.

To study these 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
- Mecel AB, Anders Eliasson
- Time Critical Networks AB, Lars Bröhne
- Volvo Personvagnar AB, Per-Anders Jörgner

9. Annex

9.1 References

[1] FFI Project Description – Application within Ethernet Communication in Automotive Environment, Lennart Casparsson, VCC, 2012-12-19.
[2] Måluppfyllelse – ECAE, VCC 94141, P-A Jörgner, 2015.
[3] Automotive Ethernet, Kirsten Matheus & Thomas Königseder, Cambridge University Press, 2015.

9.2 Terminology

AE	Advanced Engineering
APIX	Automotive PIXel link
AUTOSAR	AUTomotive Open System Architecture
AVB	Audio Video Bridging
CAN	Controller Area Network
ECAE	Ethernet Communication in Automotive Environment
ECU	Electronic Control Unit
EMC	Electro-Magnetic Compatibility
FFI	Fordonsstrategisk Forskning & Innovation
GEPOF	Gigabit Ethernet over Plastic Optical Fiber
GMSL	Gigabit Multimedia Serial Link
IEEE	Institute of Electrical and Electronics Engineers
IP	Internet Protocol
Gbit	Gigabits
LVDS	Low-Voltage Differential Signalling
Mbit	Megabits
MOST	Media Oriented Systems Transport

OEM	Original Equipment Manufacturer (here automaker)
OPEN	One-Pair Ether-Net
PoE	Power over Ethernet
SPA	Scalable Platform Architecture
TC	Technical Committee
TCN	Time Critical Networks
TCP	Transmission Control Protocol
UTP	Unshielded Twisted Pair
VCC	Volvo Car Corporation
WP	Work Package