OUTLINE

1. Introduction and Scope
   - Motivation
   - Vision and Challenges for the future In-Car network
   - Ethernet in a Vehicle
   - Reverse Engineering of current bus systems: CAN and FlexRay
   - Methodology

2. Solutions 1/2: Standard Switched Ethernet
   - Influence of the Topologies
   - Non Prioritized (1) vs. Prioritized Network (2)

3. Solution 3: IEEE 802.1 Ethernet AVB
   - Background Information
   - Evaluation of an Ethernet AVB based In-Car Network
   - Summary

4. Future Work
   - Publications
MOTIVATION

(-) heterogenous network
- different protocols, used complex centralized application gateway
- complex cable harness
  ⇒ Costs
- slow down innovations

VISION AND CHALLENGES

Internet Protocol (IP)-based In-Car Network
- Replacement of current specific In-Car protocols by standard IP

- Suitable technology to transport IP for the automotive use
  ⇒ Future applications have higher bandwidth demand due to the increasing number of advanced driver assistance (ADADS) systems and ECUs

- Which of the existent In-Car technologies are capable to transport IP and can fulfill the high bandwidth demand of future applications?
**LEGACY ETHERNET**

<table>
<thead>
<tr>
<th></th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>7: Application</td>
<td>?</td>
</tr>
<tr>
<td>6: Presentation</td>
<td>?</td>
</tr>
<tr>
<td>5: Session</td>
<td>?</td>
</tr>
<tr>
<td>4: Transport</td>
<td>TCP / UDP</td>
</tr>
<tr>
<td>3: Network</td>
<td>IP</td>
</tr>
<tr>
<td>2: Data Link</td>
<td>Ethernet MAC</td>
</tr>
<tr>
<td>1: Physical</td>
<td>Ethernet Phy</td>
</tr>
</tbody>
</table>

(+): Mature Technology  
(+): Fast, easy to use  
(+): Two-wire unshielded available for automotive use  
(+): No single source  
(-): Real-time data transmission is not supported  
(-): Frames can be delayed or lost (Switch)  
(-): Efficiency problems with small packets

Ethernet is currently used only for two areas:
- Diagnosis and flashing (OBD)
- Remote disc access (CIC ⇔ RSE)

Currently: no real-time applications; Ethernet without any QoS mechanisms

**Research Questions**

Can Ethernet also be used for Real-Time in the car??

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**REVERSE ENGINEERING OF CAN, FLEXRAY [*]**

- Trace Analysis:  
  Analysis of control messages based on real In-Car CAN and FlexRay data derived from a BMW vehicle

  (1) Message length and their distribution  
  (2) Cycle Times – Time between two consecutive messages for cycle based messages

![CDF: Probability of used message length (CAN)](image)

Most of the in-car control messages have a message length less than 8 Byte. A single UDP packet with a minimum payload size of 20 bytes will cover 95% of the in-car control message length.

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[*] Work was presented at the Nets4Cars 2011 Conference, Überpfaffenhofen, Germany
(2) Cycle Times – Time between two consecutive messages for cycle based messages

ECUs using cycle messages with low cycle times are preferred by FlexRay, while high cycle times are mainly used by the CAN bus.

In case of event based messages, CAN bus system are preferred to use.

RESEARCH WORK AND METHODOLOGY

Three essential aspects are considered in our work:

<table>
<thead>
<tr>
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<tr>
<td></td>
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<td>Simulation based</td>
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<tr>
<td></td>
<td></td>
<td>Evaluation</td>
</tr>
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<td>1</td>
<td>Switched Ethernet without Prio. ('Legacy')</td>
<td>Finished</td>
</tr>
<tr>
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<td>Switched Ethernet with Prio</td>
<td>Finished</td>
</tr>
<tr>
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Do the different Ethernet types support real-time communications and fulfill QoS-requirements in terms of bandwidth and end-to-end delay by a given topology and applications?
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INTRODUCTION: OMNET++

- Network Simulation Tool
- component-based, modular and open-architecture discrete event network simulator.
- Specific application areas are implemented by various simulation models and frameworks, most of them open source.

OMNeT++ with the INET-Framework
- Framework for wired and wireless TCP/IP based simulations
- (contains most of the standard protocols from OSI-Layer L1 – L7)
- some limitations for my purposes

1. **No Prioritization mechanism:**
   - data traffic is not classified by different priorities.
   - all applications are considered as best effort
   - the switches use only a single output queue and a First-In-First-Out (FIFO) scheduler

2. **Data Traffic based on statistical models:**
   - packet size and sending rate are set by statistical distribution functions

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[*] Work was realized in cooperation with the BMW development part
SWITCHED ETHERNET-BASED IN-CAR NETWORK [*]

Goal of the analysis: 
Influence of the 

1. Topology 
2. Prioritization mechanisms 
3. Linkload

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IN-CAR APPLICATIONS: TRAFFIC CHARACTERISTICS

<table>
<thead>
<tr>
<th>Traffic Type</th>
<th>UDP Packet Length [Byte]</th>
<th>Sending Rate [ms]</th>
<th>Bandwidth [Mbit/s]</th>
<th>Prio</th>
<th>Max. End-to-End Delay [ms]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>18</td>
<td>uniform (10,100)</td>
<td>&lt;1</td>
<td>3</td>
<td>10 [1,2]</td>
</tr>
<tr>
<td>Driver Assistance CAM</td>
<td>1472</td>
<td>0.5</td>
<td>24</td>
<td>2</td>
<td>45 [2]</td>
</tr>
<tr>
<td>Navigation</td>
<td>1400 0.7</td>
<td>16</td>
<td>1</td>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td>MM Video</td>
<td>1400 0.28</td>
<td>40</td>
<td>0</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>MM Audio</td>
<td>1400 1.4</td>
<td>8</td>
<td>0</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>TV Video</td>
<td>1400 uniform (0.56,1.12)</td>
<td>10 – 20</td>
<td>0</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>TV Audio</td>
<td>1400 2.33</td>
<td>4.8</td>
<td>0</td>
<td>150</td>
<td></td>
</tr>
</tbody>
</table>

PERFORMANCE EVALUATION [*]

System Model

- **Assumptions**
  1) Ethernet Link Bandwidth: 100Mbit/s
     - Ethernet is based on the 100Base-TX standard
  2) Quality-of-Service (QoS) with Prioritization mechanism as specified in IEEE 802.1Q (VLAN-tag)
     - 4 Queues per output Port:
       - Prio3 (highest Priority): Strict Priority Scheduler
       - Prio2 .. Prio1: Weighted Fair Queuing (WFQ)
  3) MAC Transmission Queue Size: 100 Frames
  4) Switch Processing Time: 3µs [1]

- **Metrics**

  - End-to-End delay


RESULT: PERFORMANCE ANALYSIS

(1) **CDF: End-to-End delay**

- Service constraints:
  - CTRL: Delay ≤ 10 ms
  - CAM: Delay ≤ 45 ms

Independent of the used Topology, Prioritization reduces the end-to-end delay of driver assistance camera data to approx. less than 10%

Prioritization reduces the end-to-end delay of the highest data class to approx. 40%
SUMMARY: PERFORMANCE ANALYSIS

- Prioritization mechanism at a MAC-Layer as defined in the IEEE 802.1p/q standard can considerably improve the performance in terms of the end-to-end delay
  ⇒ Application constraints of the in-car applications are fulfilled

- The star-based topology has the best performance in terms of the minimum end-to-end delay.

- Are there any mechanisms at Layer-2 to support a deterministic behavior of applications in a switched Ethernet network?
  - frames should arrived at the destination within a certain time
  - high synchronization accuracy
  - low jitter

⇒ IEEE 802.1 Audio/Video Bridging (AVB) standard

IEEE 802.1 ETHERNET AUDIO/VIDEO BRIDGING (AVB)

- IEEE 802.1 AVB:
  - Specifications that will allow time-synchronized low latency streaming services and QoS through 802 networks (Switched Ethernet, WLAN)
  - Mechanisms on Layer2 (MAC-Layer)
  - The Standard guarantees
    • Maximum latency of 2ms over 7 Hops (Class A) or 50ms (Class B)
    • Synchronization accuracy of less than 1us over 7 Hops

- consists of several sub-standards which are currently ratified and published

AVB Protocols

- Max. 75% of Bandwidth for AVB
- Min. 25% of Bandwidth for legacy
IEEE 802.1AS – Time Synchronization Protocol

- Synchronization of distributed nodes in a switched Ethernet network to achieve two goals:
  1. Common Time Basis/Reference Clock
     - Synchronization of distributed, networked ECUs (Audio/Video: Lip Sync)
     - Coordination multiple ECUs
  2. Meets jitter requirements
     - Guarantees timely execution
     - Administration free protocol

- Sync Process is executed by two steps:
  1. Selection of the best master clock (BMC) in a network
  2. Start of the synchronization by the BMC (grandmaster)
     - Measurement only between two adjacent systems
     - Clock drifts between AVB systems and the grandmaster are determined

IEEE 802.1Qat – Stream Reservation Protocol

- Signaling protocol to reserve the required bandwidth for a specific stream (AVB-Stream) over the network

- Signaling process is executed by three steps:
  1. Stream Announcement by a source node (‘Talker’)
  2. Stream Registration by a sink node (‘Listener’)
  3. Stream Deregistration
     - Initiation by a source node
     - Initiation by a sink node
IEEE 802.1Qav – Queuing and Forwarding Rules

- Mechanisms for switches to guarantee time-sensitive data transmission in terms of delay, jitter and frame loss requirements

- Based on the IEEE 802.1Q standard which allows a separation of the network traffic into different classes by prioritization mechanisms

- Following two mechanisms are specified:

  1) Mapping of the IEEE 802.1Q priority values to AVB

     - AVB frames have always the highest priority value

     ![Priority Mapping Table]

     | Priority | Class 1A | Class 1B | Class 2 | Class 3 | Class 4 | Class 5 | Class 6 | Class 7 | Class 8 |
     |----------|----------|----------|---------|---------|---------|---------|---------|---------|---------|
     | 0 (Default) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
     | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
     | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
     | 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
     | 4 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
     | 5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
     | 6 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
     | 7 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

     AVB Frames (Class-A; Class-B)

  2) Queuing Algorithms for AVB- and non AVB-frame

     - Two different scheduling algorithms to transmit AVB and non AVB (legacy Ethernet) frames in a network

     a) **Strict Priority Algorithm** for Legacy Ethernet

     b) **Credit Based Shaper Algorithm** for AVB

        • Each AVB-Class (A or B) has certain credits
        • A Transmission is only allowed when a credit is >=0
        • For each transmission the credit is decreased at a rate of sendSlope

        Otherwise: - credit is increased at a rate of idleSlope

        $\Rightarrow$ Transmission of legacy Ethernet frames
RESEARCH WORK

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<td>Simulation based Evaluation: Ongoing, Prototyping Evaluation: Ongoing</td>
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</tbody>
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EVALUATION OF ETHERNET AVB [*]

Research Questions:
1. Is the IEEE 802.1 Ethernet AVB standard able to guarantee the latency, jitter and synchronization requirement of streaming data even in high load situations?
2. Do control data transmitted with legacy Ethernet frames meet the application constraints in terms of the maximum latency and frame loss rate?

System Model
- Topology: daisy-chain with 3 switches in a network
- Applications
  1) Driver Assistance Camera Data (AVB: Class A)
  2) TV Streaming Data (AVB: Class B)
  3) MM Streaming Data (AVB: Class B)
  4) Control Data
  5) Navigation Data
  6) Bulk Data
- Metrics:
  - Maximum Latency
  - Jitter
  - Frame Loss Rate
EVALUATION OF ETHERNET AVB – SYSTEM MODEL

Assumptions

- Ethernet Link: 100Mbit/s
- Static clock drifts of the ECUs without BMCA
  - Grandmaster (node with best clock): HeadUnit
  - Each nodes have static clock drifts
- Six Different Traffic Classes
  - Six Queues per output port (2 AVB + 4 Legacy Ethernet)

Traffic Characteristics

<table>
<thead>
<tr>
<th>Traffic Type</th>
<th>Ethernet Payload [Byte]</th>
<th>Sending Rate [ms]</th>
<th>Bandwidth [Mbit/s]</th>
<th>Prio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driver Assistance CAM</td>
<td>390</td>
<td>0.125</td>
<td>27.6</td>
<td>Class A (Prio5)</td>
</tr>
<tr>
<td>TV Streaming</td>
<td>700</td>
<td>0.250</td>
<td>23.7</td>
<td>Class B (Prio4)</td>
</tr>
<tr>
<td>MM Streaming</td>
<td>700</td>
<td>0.125</td>
<td>47.5</td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>46</td>
<td>uniform (10,100)</td>
<td>70 e-3 .. 700e-3</td>
<td>3</td>
</tr>
<tr>
<td>Bulk</td>
<td>1428</td>
<td>0 .. 0.168</td>
<td>[0,25,50,70]</td>
<td>1</td>
</tr>
<tr>
<td>Navigation</td>
<td>1000</td>
<td>5</td>
<td>1.667</td>
<td>2</td>
</tr>
</tbody>
</table>

Hyung-Taek Lim, BMW Forschung und Technik, 30.11.2011

EVALUATION OF ETHERNET AVB – RESULT

Control and AVB data depending on the background Load

<table>
<thead>
<tr>
<th>Metric</th>
<th>Control Data (Control → CTRL_PU)</th>
<th>AVB Class-A (DA_CAM → HU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Add. Load (%)</td>
<td>0% 25% 50% 70%</td>
<td>0% 25% 50% 70%</td>
</tr>
<tr>
<td>Max Latency [ms]</td>
<td>0.095 0.434 0.391 22.40</td>
<td>2.0003 2.0004 2.0003 2.0003</td>
</tr>
<tr>
<td>Max Jitter [ms]</td>
<td>0.059 0.372 0.285 12.39</td>
<td>0.0003 0.0004 0.0003 0.0004</td>
</tr>
<tr>
<td>Frame Loss Rate</td>
<td>0 0 0 0.584</td>
<td>0 0 0 0</td>
</tr>
</tbody>
</table>

Max. Latency of AVB Data

Max. Latency of Control Data

58 % for our requirement
Requirement given by Toyota
100us [*]

[*] Requirements for Automotive AVB System Profiles, White Paper, Toyota, 2011

Hyung-Taek Lim, BMW Forschung und Technik, 30.11.2011
EVALUATION OF ETHERNET AVB – SUMMARY

The simulation based performance evaluation of the AVB protocols shows:

(1) The latency and frame loss of AVB streaming data are independent of the network load.

- All applications modeled as AVB Class-A/AVB frames have the latency less or equal than specified values (2ms for Class-A; 50ms for Class-B)

(2) The performance of control data in an AVB-network depends strongly on the network load.

- In order to guarantee the hard latency requirement of 100us, the additional background load should be less or equal than 15%.

- The IEEE 802.1 Ethernet AVB standard improves definitely the performances of multimedia and applications for driver assistance purposes. A deterministic behavior of these applications are achieved.

- In order to fulfill the hard real-time requirements of control data additional scheduling and prioritization mechanisms are required.

PUBLICATIONS – 2011 –


- Kay Weckemann, **Hyung-Taek Lim**, Daniel Herrscher: Practical Experiences on a Communication Middleware for IP-based In-Car Networks. Proc. of the Fifth International Conference on COMmunication System softWare and middleware (COMSWARE), July 2011, Verona, Italy.


Questions?
Any Comments?

thank you.

Research and Technology.

Hyung-Taek Lim, BMW Forschung und Technik, 30.11.2011

INNOVATIONEN GESTALTEN - STEIGEN SIE EIN

• Möglichkeiten zur Mitarbeit bei BMW Forschung und Technik
• Praktikum (nach Bedarf)
• Diplom-/Masterarbeit (6 Monate)
• Dissertation (3 Jahre)
• Arbeit vor Ort bei BMW, wissenschaftliche Betreuung durch Uni
• Bevorzugt Informatiker, Elektrotechniker oder verwandte Studiengänge
E-Mail: hyung-taek.lim@bmw.de
Thank You

Research and Technology.

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