Tomorrow’s In-Car Interconnect?
A Competitive Evaluation of IEEE 802.1 AVB
and Time-Triggered Ethernet (AS6802)

Till Steinbach¹
Thomas C. Schmidt¹

Hyung-Taek Lim²
Daniel Herrscher²

Franz Korf¹
Adam Wolisz³

¹Hamburg University of Applied Sciences
{till.steinbach, korf, schmidt}@informatik.haw-hamburg.de

²BMW Group Research and Technology
{hyung-taek.lim, daniel.herrscher}@bmw.de

³Technische Universität Berlin and University of California, Berkeley
wolisz@ieee.org

IEEE 76th Vehicular Technology Conference
4 September 2012, Québec City, Canada
1 Problem Statement & Motivation
2 Background & Related Work
3 Evaluation & Comparison
4 Conclusion & Outlook
Problem Statement
The heterogeneity of in-car networking

- The in-car network grew over the past decades
- Increasing demand continuously required introduction of new technologies
- Today, extremely heterogeneous network formed of domain specific systems
  - CAN, FlexRay, MOST …
- Abstraction layers (e.g. AUTOSAR) introduced interface to applications
- On the transport layer still very high complexity
Motivation
Why should we consider Ethernet?

- Ethernet offers:
  - Mature technology
  - High transmission bandwidth
  - Low prices for components
  - Many development/diagnostic tools and expert developers

- Ethernet considered for (or already used):
  - On-Board Diagnosis (OBD)
  - Multimedia
  - Image transmission (Camera)

- But: Ethernet as additional transport technology cannot reduce complexity
Motivation

What if Ethernet could be used as the medium for a uniform homogeneous in-car backbone?
IEEE 802.1 AVB
Time-synchronized low latency streaming through IEEE 802 networks

IEEE 802.1 Audio Video Bridging Protocol suite

- **Stream Reservation Protocol**
  - Online signaling protocol for traffic flows
  - reserves required bandwidth for a specific stream

- **Queuing and Forwarding Rules**
  - Based on IEEE 802.1Q, Mapping of priority values to AVB classes
  - Strict Priority Algorithm for Legacy Ethernet
  - Credit Based Shaper Algorithm for AVB
  - Maximum latency of 2ms over 7 Hops (Class A) or 50ms (Class B)
Time-triggered Ethernet (AS6802)
Mixed critical applications through IEEE 802 networks

Extension to standard switched Ethernet
SAE standardized in 2011 (AS6802)
3 traffic classes:

1. **Time-triggered (TT)**
   highest priority, time-triggered, cyclic, offline
   planned, requires synchronised time

2. **Rate-constrained (RC)**
   event-triggered, bandwidth-based (AFDX)

3. **Best-effort (BE)**
   lowest priority, standard Ethernet
Time-triggered Ethernet (AS6802)
Ethernet for mixed critical applications

Problem Statement & Motivation
Background & Related Work
IEEE 802.1 AVB
Time-triggered Ethernet
Evaluation & Comparison
Conclusion & Outlook

Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences
Evaluation

- Discrete event based simulation
  - OMNeT++ Network Simulation Framework
  - Models for TTEthernet\(^1\) and Ethernet AVB\(^2\)
- Simulation of realistic traffic-flows derived from configuration of BMW series car
- Tree based topology

---


Traffic Model

<table>
<thead>
<tr>
<th>Type</th>
<th>Bandwidth [MBit/s]</th>
<th>IEEE 802.1 AVB Class (Priority)</th>
<th>TTEthernet Class (Priority)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TV</td>
<td>10...20</td>
<td>B (Prio 4)</td>
<td>RC (Prio 7)</td>
</tr>
<tr>
<td>Media Audio</td>
<td>8</td>
<td>B (Prio 4)</td>
<td>RC (Prio 7)</td>
</tr>
<tr>
<td>Media Video</td>
<td>40</td>
<td>B (Prio 4)</td>
<td>RC (Prio 7)</td>
</tr>
<tr>
<td>Camera</td>
<td>25</td>
<td>A (Prio 5)</td>
<td>RC (Prio 6)</td>
</tr>
<tr>
<td>Control</td>
<td>(3.68...736) · 10^{-4}</td>
<td>A (Prio 5)</td>
<td>TT + RC (Prio 0...5)</td>
</tr>
</tbody>
</table>

- High bandwidth multimedia traffic flows with low timing requirements
- High bandwidth driver assistance camera traffic flows with medium timing requirements
- Low bandwidth control traffic flows with high timing requirements
22 Nodes, 7 Switches, 21 Links
Tree structure with one root switch
Domain specific regions in the network
Multimedia Traffic
Cumulative Distribution

Tomorrow’s In-Car Interconnect?
T. Steinbach

Problem Statement & Motivation
Background & Related Work
Evaluation & Comparison
Evaluation & Toolchain
Scenario
Results

Conclusion & Outlook
### Multimedia Traffic

Results in Detail

<table>
<thead>
<tr>
<th>Type of Stream</th>
<th>IEEE 802.1 AVB</th>
<th></th>
<th>TTEthernet</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Camera</td>
<td>115.40</td>
<td>6.69</td>
<td>209.77</td>
<td>90.98</td>
</tr>
<tr>
<td>TV</td>
<td>674.32</td>
<td>135.80</td>
<td>485.18</td>
<td>117.27</td>
</tr>
<tr>
<td>Media Audio</td>
<td>497.67</td>
<td>6.11</td>
<td>610.49</td>
<td>117.28</td>
</tr>
<tr>
<td>Media Video</td>
<td>503.68</td>
<td>130.70</td>
<td>725.37</td>
<td>232.15</td>
</tr>
</tbody>
</table>
Tomorrow’s In-Car Interconnect?
T. Steinbach

Problem Statement & Motivation
Background & Related Work
Evaluation & Comparison
Evaluation & Toolchain
Scenario
Results
Conclusion & Outlook

Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences
### Control Traffic

#### Results in Detail

<table>
<thead>
<tr>
<th>Hops</th>
<th>Type</th>
<th>IEEE 802.1</th>
<th>AVB</th>
<th>TTEthernet</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>sync.</td>
<td>75.69</td>
<td>6.58</td>
<td>71.53</td>
</tr>
<tr>
<td></td>
<td>async.</td>
<td>75.07</td>
<td>39.19</td>
<td>84.79</td>
</tr>
<tr>
<td>2</td>
<td>sync.</td>
<td>31.90</td>
<td>5.50</td>
<td>31.37</td>
</tr>
<tr>
<td></td>
<td>async.</td>
<td>32.83</td>
<td>6.19</td>
<td>30.31</td>
</tr>
</tbody>
</table>

- Both protocols have almost equally low latency (Latency <100 µs)
- Synchronous traffic in TTE is most precise (Jitter <4 µs)
Conclusion

- Both technologies are able to fulfill the requirements
  - for camera and multimedia traffic
  - for control traffic
- With the tree-based topology and today’s amount of traffic flows the protocols perform almost equally well
- Light advantages for Ethernet AVB for multimedia and camera streams
- Light advantages for TTEthernet for control traffic
In our ongoing and future work we will …

- …analyse how cross-traffic will influence the performance of the backbone network
- …analyse whether a backbone with coexistence of both concepts can improve performance and flexibility
  - Time-triggered traffic class and strict priority scheduling for control traffic
  - Credit based shaping and online stream reservation for multimedia streams

Outlook
Thank you for your attention!

- Website of CoRE research group: http://www.haw-hamburg.de/core
- Website of TTEthernet simulation model: http://tte4inet.realmv6.org