Ethernet Oriented E/E Architecture with CAN Virtualization for Automated Driving Vehicles

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Agenda

1. E/E architecture for automated driving vehicles

2. Technical challenges for data exchange between Ethernet and CAN
   1. Address assignment
   2. Data sharing
   3. Time synchronization

3. Evaluation result with an actual vehicle
1-1. Motivation for Applying Ethernet

• To implement automated driving applications, it is necessary to use outside information such as
  ✓ outside recognition information from camera and radar ECUs
  ✓ high accuracy road map
  ✓ information from near vehicles or infrastructure (C2X)

To apply wider bandwidth communication technology to the in-vehicle network, we apply Ethernet to the in-vehicle network
1-2. Roadmap for Applying Ethernet to the In-Vehicle Network

Target Scope

CAN network | Applied to local connection | Applied to network | Connected to center through gateway
---|---|---|---
ECU | ECU | ECU | ECU
ECU | ECU | ECU | ECU
ECU (Camera) | ECU | ECU | ECU

CAN | Ethernet

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1-3. Our E/E Architecture for Automated Driving

- Ethernet connects ECUs that use vehicle-outside information, and CAN transmits vehicle information
- A central gateway provides access between CAN and Ethernet
  - CAN messages and IP packets are exchanged via an Ethernet switch and a CAN Gateway

Central gateway

*Ethernet connects ECUs that use vehicle-outside information, and CAN transmits vehicle information*
*A central gateway provides access between CAN and Ethernet*

CAN Gateway

Ethernet switch

ECU

ECU

ECU

ECU

ADAS ECU

Stereo Camera ECU

View Camera ECU

MPU

CAN1

CAN2

ADAS: Automated Driving Assist System

MPU: Map Positioning Unit
1-3. Our E/E Architecture for Automated Driving

- Ethernet connects ECUs that use vehicle-outside information, and CAN transmits vehicle information
- A central gateway provides access between CAN and Ethernet
  - CAN messages and IP packets are exchanged via an Ethernet switch and a CAN Gateway

- Outside recognition info.
- Map for automated driving
- Vehicle positioning info.

• Ethernet connects ECUs that use vehicle-outside information, and CAN transmits vehicle information
• A central gateway provides access between CAN and Ethernet
  - CAN messages and IP packets are exchanged via an Ethernet switch and a CAN Gateway

Vehicle motion control signals

Vehicle info. (speed, steering angle, etc.)

Several Mbps

Ethernet switch

CAN Gateway

ADAS ECU

Stereo Camera ECU

View Camera ECU

MPU

CAN

Ethernet

CAN1 CAN2

Central gateway

ADAS: Automated Driving Assist System

MPU: Map Positioning Unit
Agenda

1. E/E architecture for automated driving vehicles

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3. Evaluation result with an actual vehicle
How to exchange data seamlessly between CAN and Ethernet?

The following items are our challenges:
1. Address assignment to send data from Ethernet to CAN
2. Data sharing for efficient data exchanges among multiple ECUs
3. Time synchronization between Ethernet and CAN for data fusion
2-1-1. Challenge 1: Address Assignment

- **Problem**
  
  If an IP address is assigned to the CAN gateway, the CAN gateway has to lookup a CAN ID of all messages from Ethernet to CAN. Therefore the load on the CAN gateway increases.

  **Lookup table becomes Big!**

  ![Diagram](image)

<table>
<thead>
<tr>
<th>CAN ID</th>
<th>Bus</th>
</tr>
</thead>
<tbody>
<tr>
<td>0001</td>
<td>CAN2</td>
</tr>
<tr>
<td>0010</td>
<td>CAN1</td>
</tr>
<tr>
<td>1111</td>
<td>CAN1</td>
</tr>
</tbody>
</table>

  **Central gateway**

  **Ethernet switch**

  **CAN Gateway**

  **ECUs**

  **CAN IDs**

  **Address Assignment**

<table>
<thead>
<tr>
<th>CAN ID</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>192.168.1.1</td>
<td>CAN Gateway</td>
</tr>
<tr>
<td>192.168.0.1</td>
<td>ADAS ECU</td>
</tr>
<tr>
<td>192.168.0.2</td>
<td>Stereo Camera ECU</td>
</tr>
<tr>
<td>192.168.0.3</td>
<td>View Camera ECU</td>
</tr>
<tr>
<td>192.168.0.4</td>
<td>MPU</td>
</tr>
</tbody>
</table>

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2-1-2. CAN Virtualization

- **Solution**
  - Assign a virtual IP address to each CAN bus
  - It is possible to reduce the size of forwarding table
  - The load on the CAN gateway is decreased

<table>
<thead>
<tr>
<th>Address</th>
<th>Bus</th>
</tr>
</thead>
<tbody>
<tr>
<td>192.168.1.1</td>
<td>CAN1</td>
</tr>
<tr>
<td>192.168.1.2</td>
<td>CAN2</td>
</tr>
</tbody>
</table>
### In the case of sending data to multiple ECUs

<table>
<thead>
<tr>
<th>Overview</th>
<th>Initial design</th>
<th>Load</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Sender</td>
</tr>
<tr>
<td><strong>Broadcast</strong></td>
<td>Distribute to all ECUs</td>
<td>++ simple</td>
</tr>
<tr>
<td><strong>Multicast</strong></td>
<td>Distributed to specific ECUs</td>
<td>- complex</td>
</tr>
<tr>
<td><strong>Unicast</strong></td>
<td>Distribute Individually</td>
<td>+</td>
</tr>
</tbody>
</table>

- We have adopted multicast from the viewpoint of load
- We have assigned a multicast address to each data type based on design experiences for automated driving
### 2-2-2. Example of Data Addressing (1/2)

<table>
<thead>
<tr>
<th>Data Type</th>
<th>Multicast Address</th>
<th>Destination ECU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outside recognition info.</td>
<td>224.0.0.1</td>
<td>ADAS, MPU</td>
</tr>
<tr>
<td>Map, Position</td>
<td>224.0.0.2</td>
<td>ADAS, SC, View</td>
</tr>
<tr>
<td>Vehicle info. (vehicle speed, steering angle, etc.)</td>
<td>224.0.0.3</td>
<td>ADAS, MPU, SC</td>
</tr>
<tr>
<td>Time info.</td>
<td>224.0.0.4</td>
<td>SC, View, MPU, CGW</td>
</tr>
</tbody>
</table>

By assigning a multicast address to each data type, a new ECU can be added without making changes to an existing ECU.

Example data forwarding with the proposed multicast
2-2-3. Example of Data Addressing (2/2)

Example data forwarding with the proposed multicast

Add a multicast address to a CAN message
In Ethernet, time synchronization can be realized by sharing time information among ECUs.

**How to synchronize between Ethernet and CAN?**
2-3-2. Time Synchronization between Ethernet and CAN

- CAN gateway shares time information with ECUs on Ethernet
- CAN gateway adds the time information to a CAN message and sends it to Ethernet
Agenda

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   3. Time synchronization

3. Evaluation result with an actual vehicle
3-1. Estimation of CAN Gateway Load

- We estimated the effectiveness of the proposed address assignment.
- As a result of the estimation, the proposed address assignment enables:
  - Size of table to 1/7
  - Table lookup time to 1/2

<table>
<thead>
<tr>
<th></th>
<th>Conventional</th>
<th>Proposed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size of table (byte)</td>
<td>230</td>
<td>30</td>
</tr>
<tr>
<td>Table lookup time (μsec)</td>
<td>10</td>
<td>5</td>
</tr>
</tbody>
</table>

**Estimation result**

**Conventional:** Assignment of an IP address to a CAN gateway

**Proposed:** Assignment of an IP address to each CAN bus

**Estimation condition**
- # of CAN buses: 6
- # of CAN IDs: 46
3-2. Central Gateway Prototype

- We have developed a central gateway prototype with the proposed architecture.
- The central gateway prototype has been incorporated in an actual automated driving vehicle.

- Features
  - Interface
    - CAN 6ch
    - Ethernet (BroadR-Reach) 6ch
  - CAN <->CAN, CAN <->Ethernet: software on a microcomputer (120 MHz)
  - Ethernet <-> Ethernet: switching hardware
3-3. Experiment Environment

We measured data-exchange delays between Ethernet and CAN

- CAN messages and IP packets are captured at PC
- A performance of the central gateway is evaluated by calculating time differences between CAN messages and IP packets
3-4. Evaluation Result by the actual vehicle

The data-exchange delay between Ethernet and CAN does not affect automated driving performance.
We have proposed E/E architecture with Ethernet for automated driving vehicles.

For seamless data exchange between Ethernet and CAN,

- We assigned a virtual IP address to each CAN bus.
- We assigned an IP multicast address for each data type.
- CAN gateway adds a timestamp to CAN messages for time synchronization with Ethernet.

We have developed a central gateway prototype with the proposed architecture.

- We measured that the data-exchange delay: CAN -> Ethernet 120 μsec, Ethernet -> CAN 110 μsec.

We have successfully demonstrated automated driving with the developed gateway.
Thank you for your attention
Any questions?