# Reconfigurable Communication Middleware for FlexRay-based Distributed Embedded Systems

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IIT Guwahati

Technische Universität München

# Overview

- **Motivation**
  - Automotive E/E architecture increases rapidly in scale and complexity
  - Increasingly more and complex software and data
  - Constrained communication resources
  - Static design and development of safety-critical buses (e.g., FlexRay)
  - Multi-mode, Plug-and-Play applications and software installation/update after sales

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  - Online communication reconfiguration of FlexRay-based ECU network
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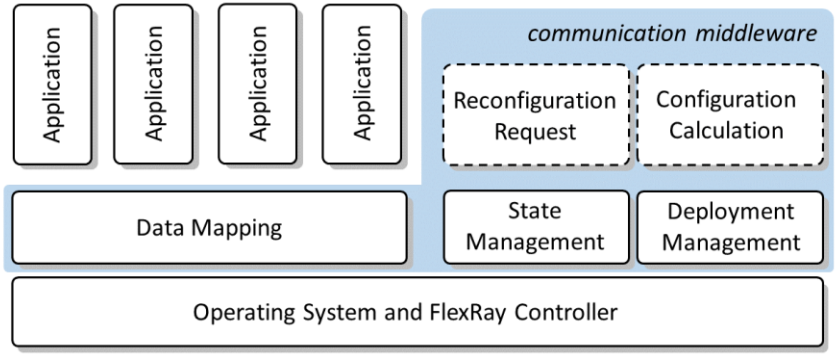
  - Online communication reconfiguration of FlexRay-based ECU network
  - Communication resource re-allocation for
    - multi-mode applications
    - newly activated applications
- **Approach**
  - Insertion of a middleware layer
  - Reconfigurable data-to-schedule mapping
  - Online configuration calculation and deployment



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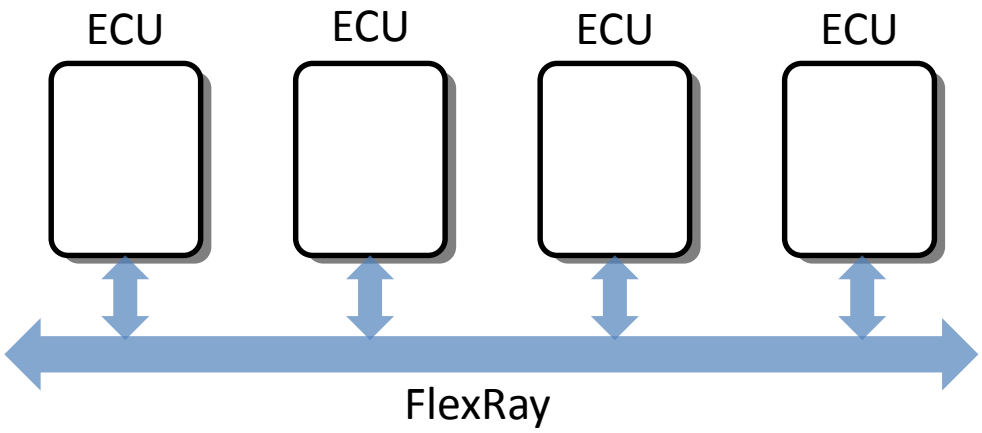
- **FlexRay-based ECU networks**
  - Hardware architecture



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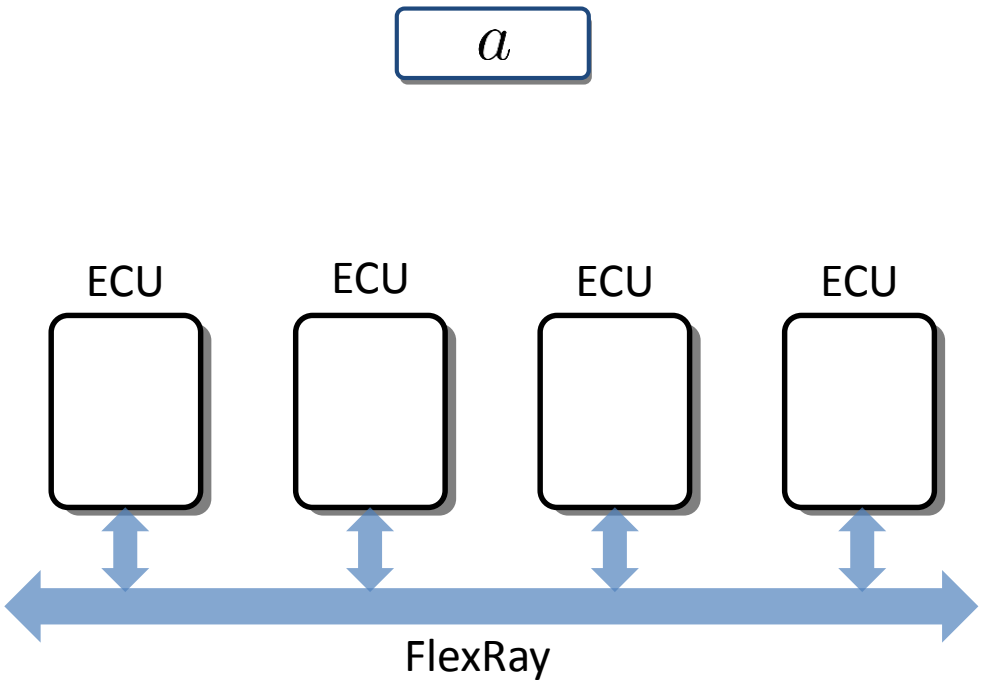

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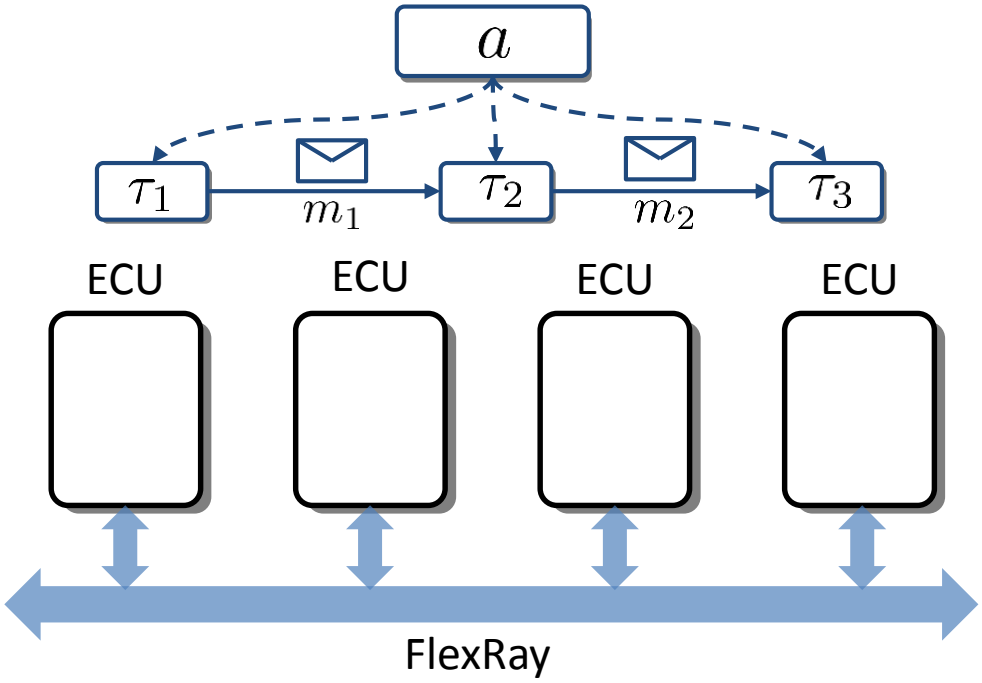

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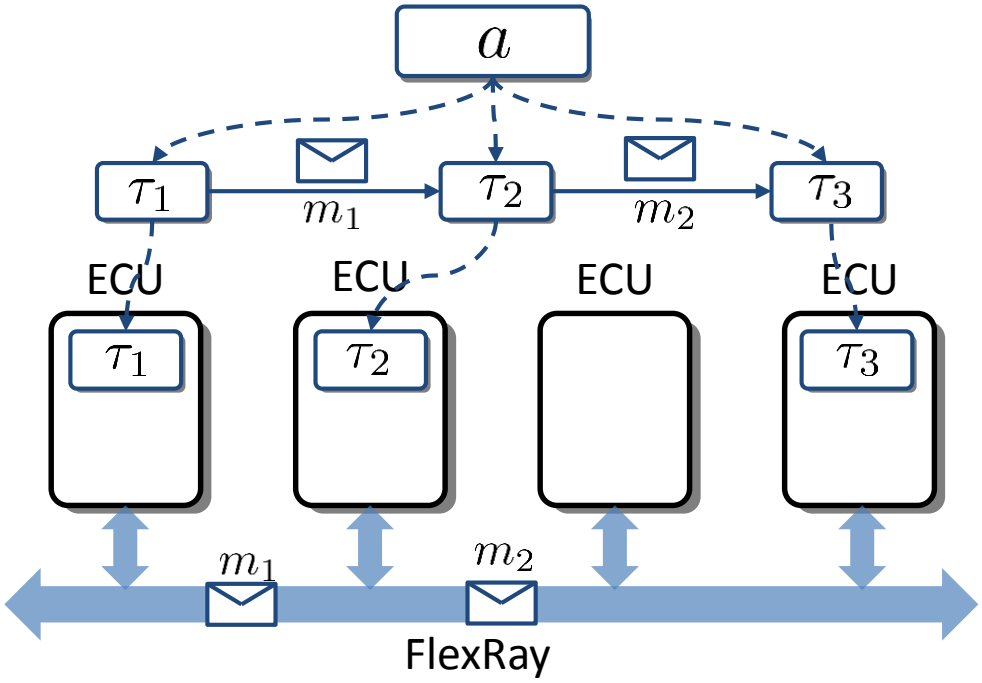
  - Task mapping / bus communication



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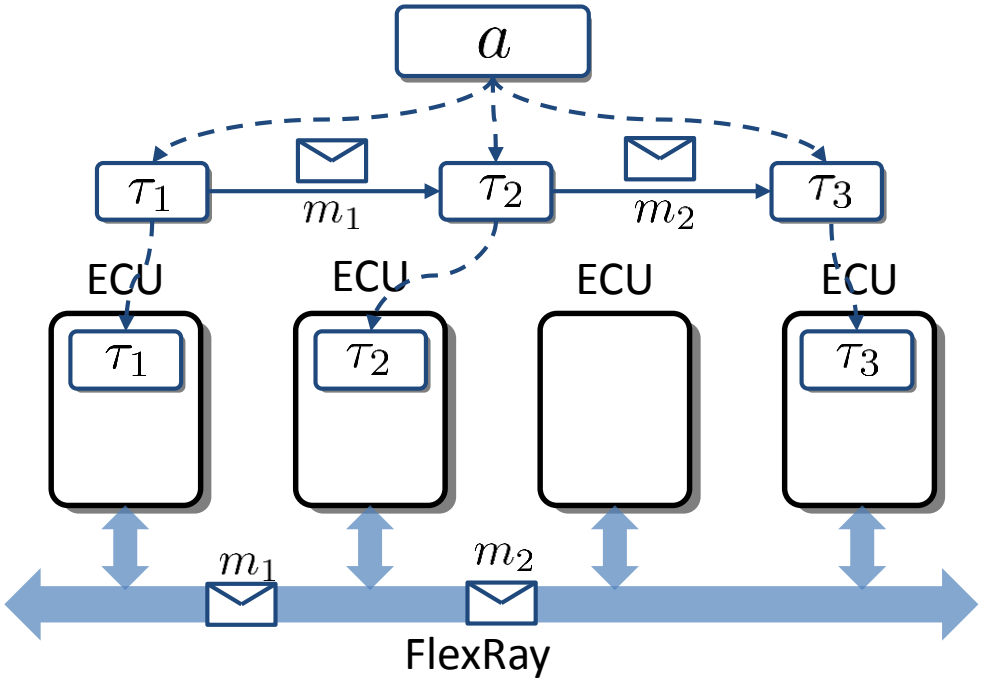
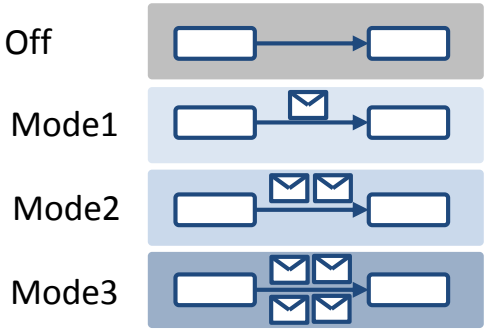
  - Multi-mode application




| Mode | Resource | Performance |
|---|---|---|
| 1 | high | high |
| 2 | medium | medium |
| 3 | low | low |
| Off | none | none |



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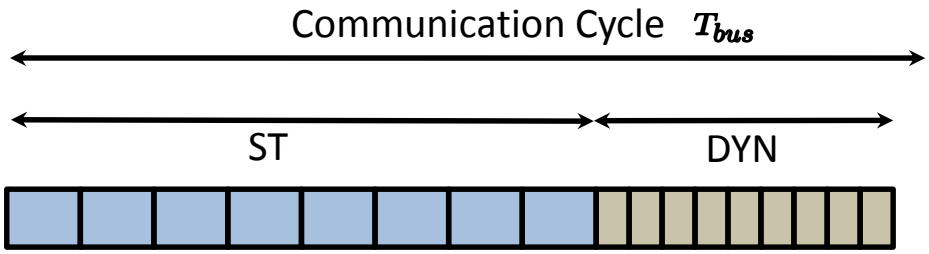
  - Hybrid protocol: mixed time-triggered and event-triggered paradigm
  - Communication cycle, static segment (ST) and dynamic segment (DYN)



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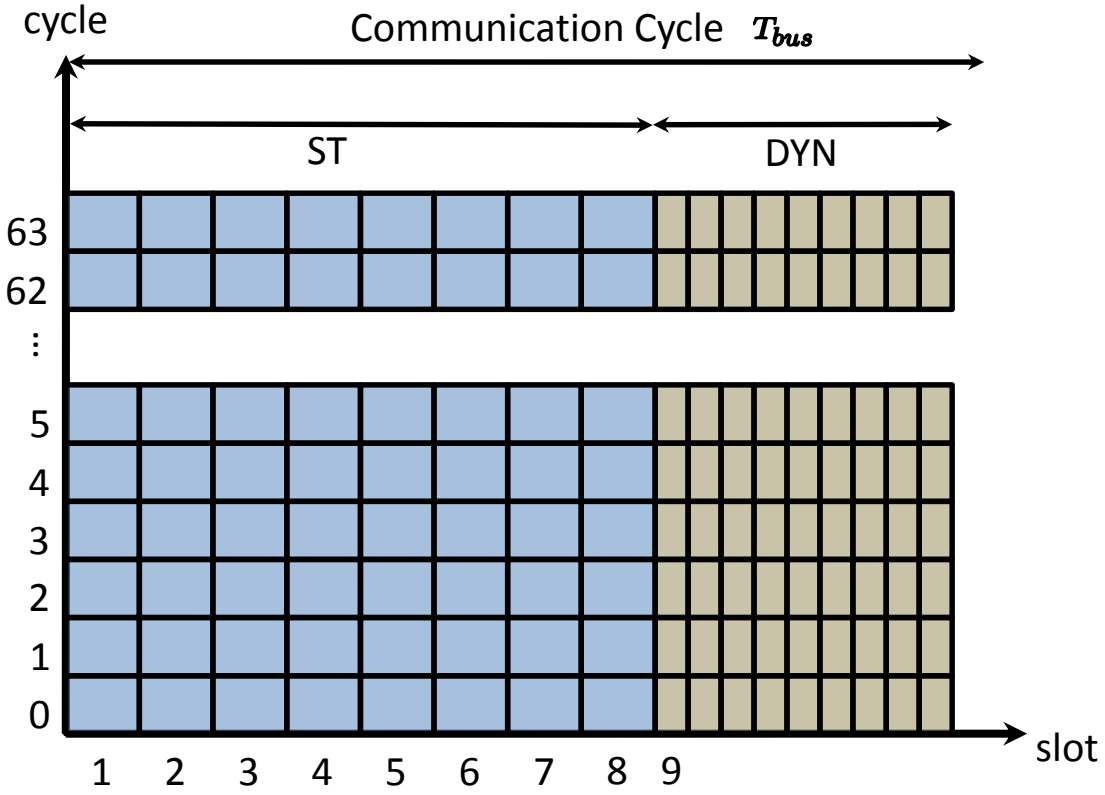


$S_i$ slot number

$B_i$ base cycle

$R_i$ repetition rate

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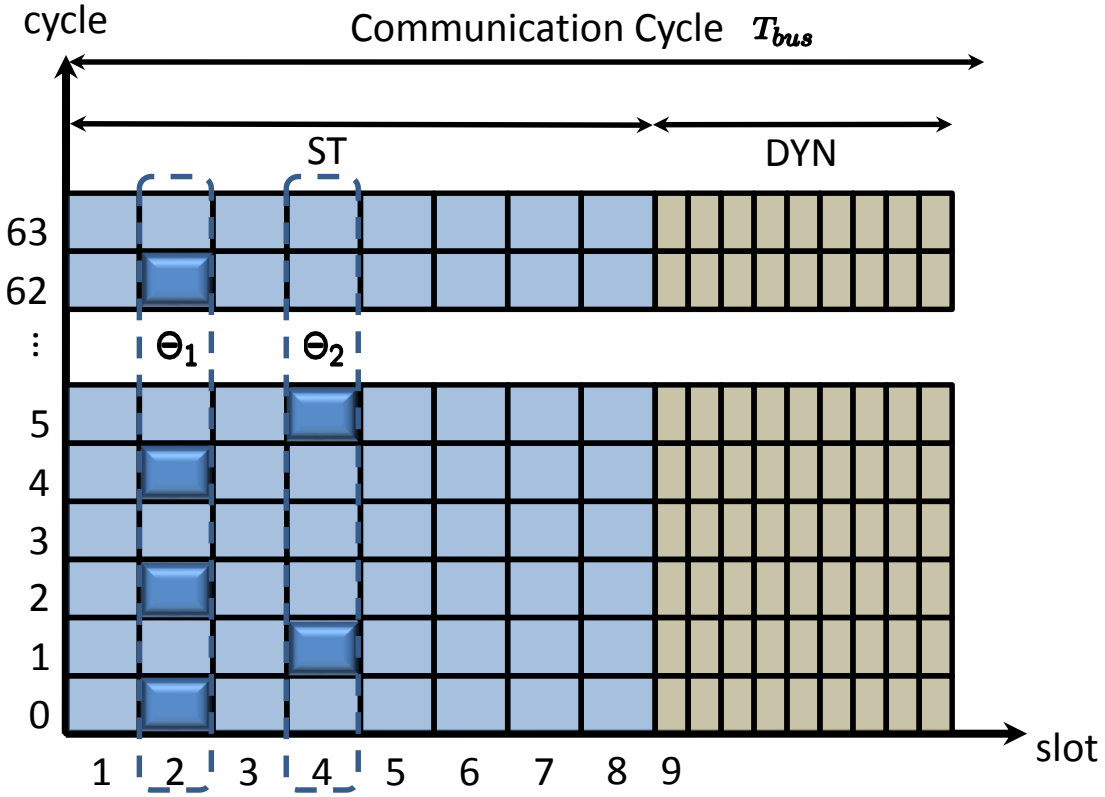


$S_i$ slot number

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$\Theta_1 = (2, 0, 2)$

$\Theta_2 = (4, 1, 4)$

# Motivational Example

- **Applications**

| $a_1$ | | | |
|---|---|---|---|
| $\alpha$ | $w$ | $p$ | $J$ |
| 1 | 8 | $T_{bus}$ | 100 |
| 2 | 4 | $T_{bus}$ | 80 |
| 3 | 4 | $2\,T_{bus}$ | 50 |

| $a_2$ | | | |
|---|---|---|---|
| $\alpha$ | $w$ | $p$ | $J$ |
| 1 | 4 | $2\,T_{bus}$ | 100 |
| 2 | 4 | $4\,T_{bus}$ | 80 |
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| $a_3$ | | | |
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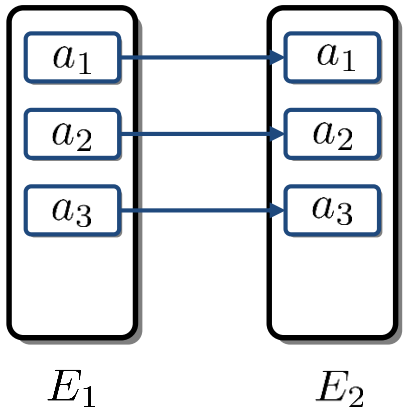
$\alpha$ mode $w$ data size $p$ period $J$ performance

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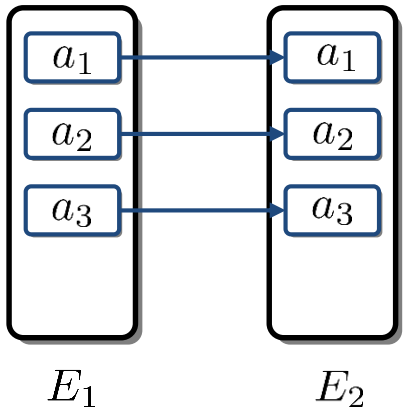


2 static slots of 8 bytes payload

Possible mode combinations

| | $a_1$ | $a_2$ | $a_3$ | $J$ |
|---|---|---|---|---|
| *1* | 1 | 1 | 2 | 280 |
| *2* | 2 | 1 | 1 | 280 |
| *3* | 1 | 2 | 2 | 260 |
| *4* | 2 | 2 | 1 | 260 |

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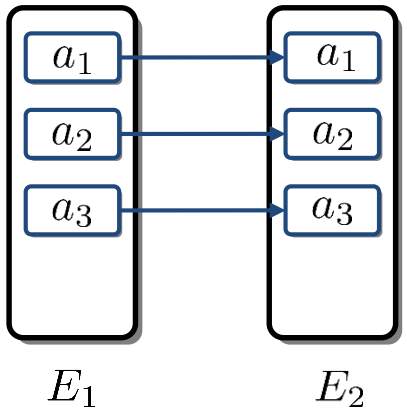


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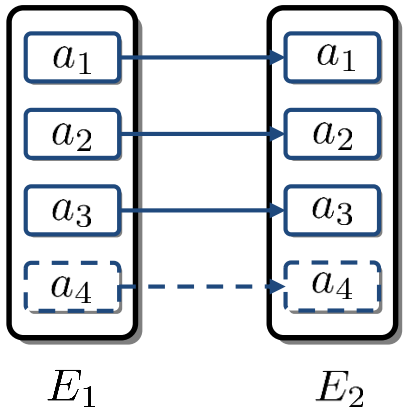


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**online switch not possible**

Newly installed application

| $a_4$ | | | |
|---|---|---|---|
| $\alpha$ | $w$ | $p$ | $J$ |
| 1 | 4 | $2\,T_{bus}$ | 100 |

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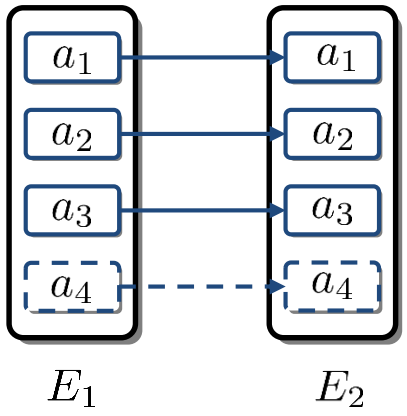


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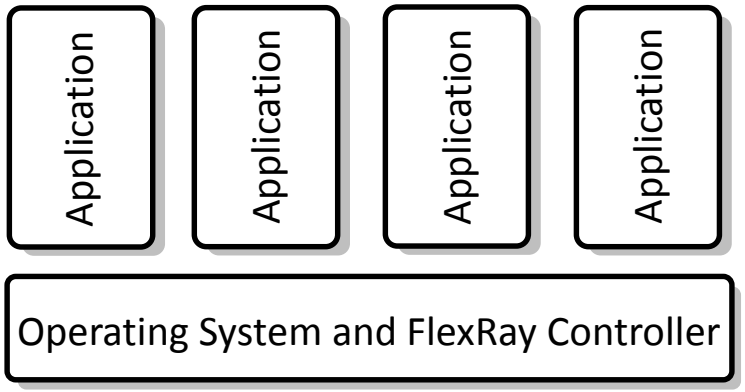
**online activation not possible**

although enough resource to map it on combination *1*

# Middleware

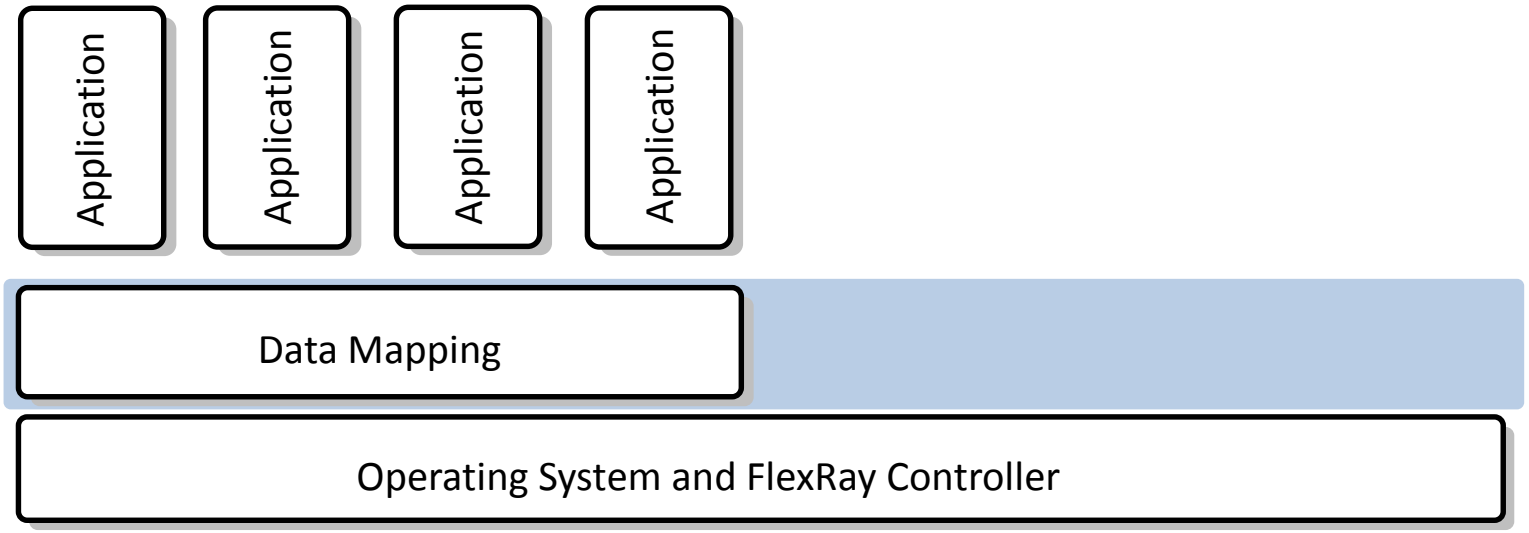
- **Software architecture**
  - Simple software architecture




  - FlexRay parameters, FlexRay schedules and data-to-frame mapping statically configured offline

# Middleware

- **Software architecture**
  - Proposed software architecture




  - Middleware between application and OS layers
    - Data mapping
      - Data-to-frame mapping based on a configuration

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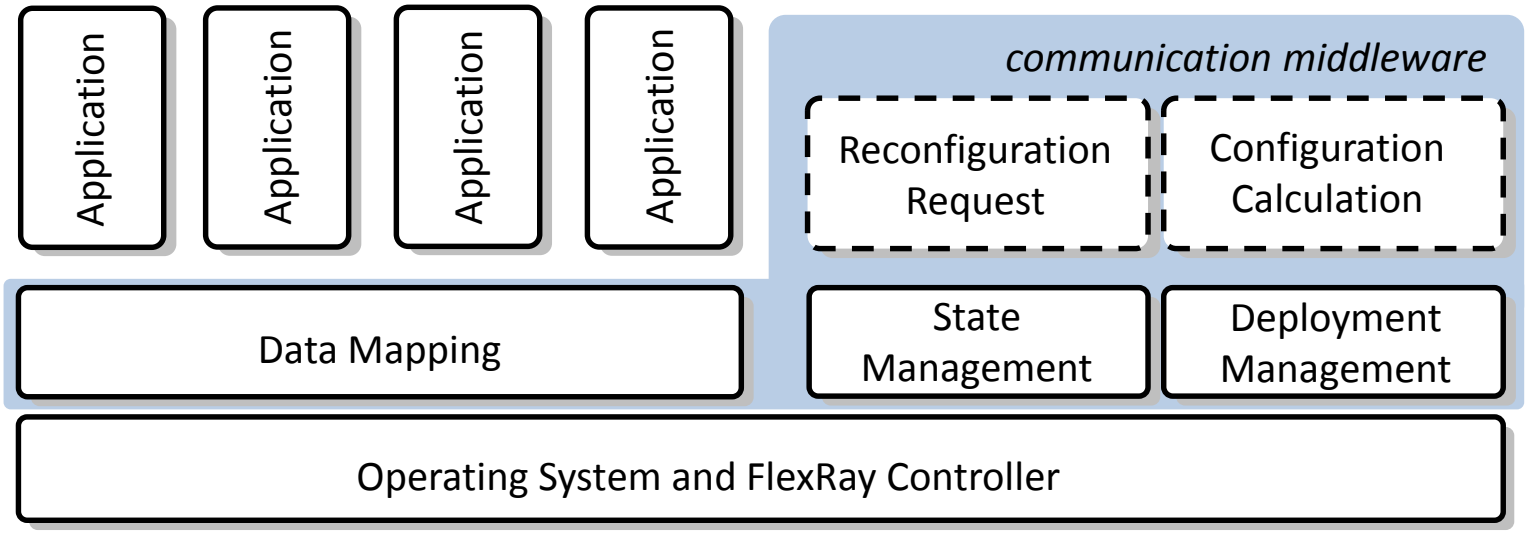


  - Middleware between application and OS layers
    - Data mapping
    - Reconfiguration request
    - Configuration calculator
    - State management
    - Deployment management

# Middleware

- **Application, task, message, mode and manifest**
  - Application $a_i(\alpha_i) = (\mathcal{T}_i(\alpha_i), \mathcal{M}_i(\alpha_i), \mathcal{J}_i(\alpha_i))$
  - Task $\tau_j \in \mathcal{T}_i$ , message $m_j \in \mathcal{M}_i$ , performance $J_i \in \mathcal{J}_i$ , mode $\alpha_i$
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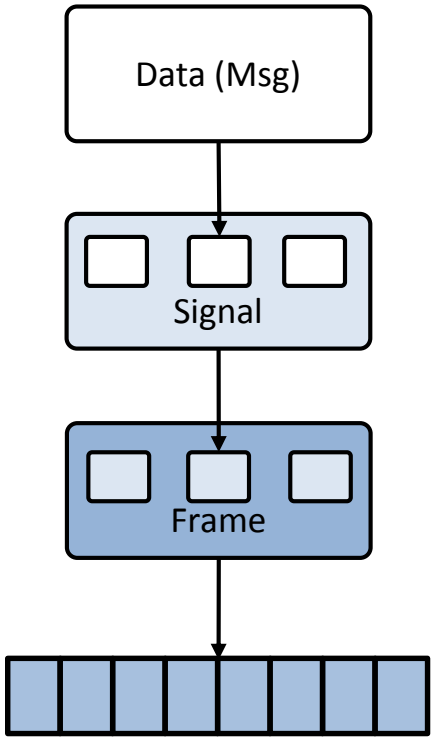
- **Configuration**
  - Application configuration $C_a = \{\alpha_i | a_i \in \mathcal{A}\}$
  - Communication configuration $C_c = \{\mathcal{M}_i | a_i \in \mathcal{A}\}$
  - $C_c$ contains the mapping of messages to FlexRay schedule $m_j \rightarrow \Theta_j$

# Middleware

- **Data mapping**



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- **Data mapping**
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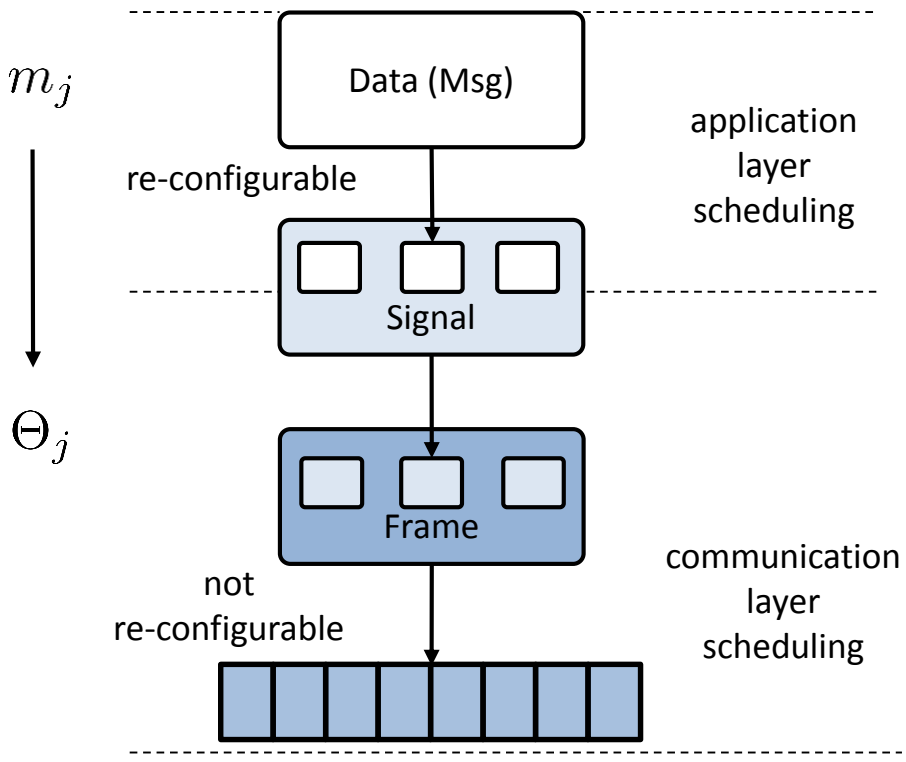

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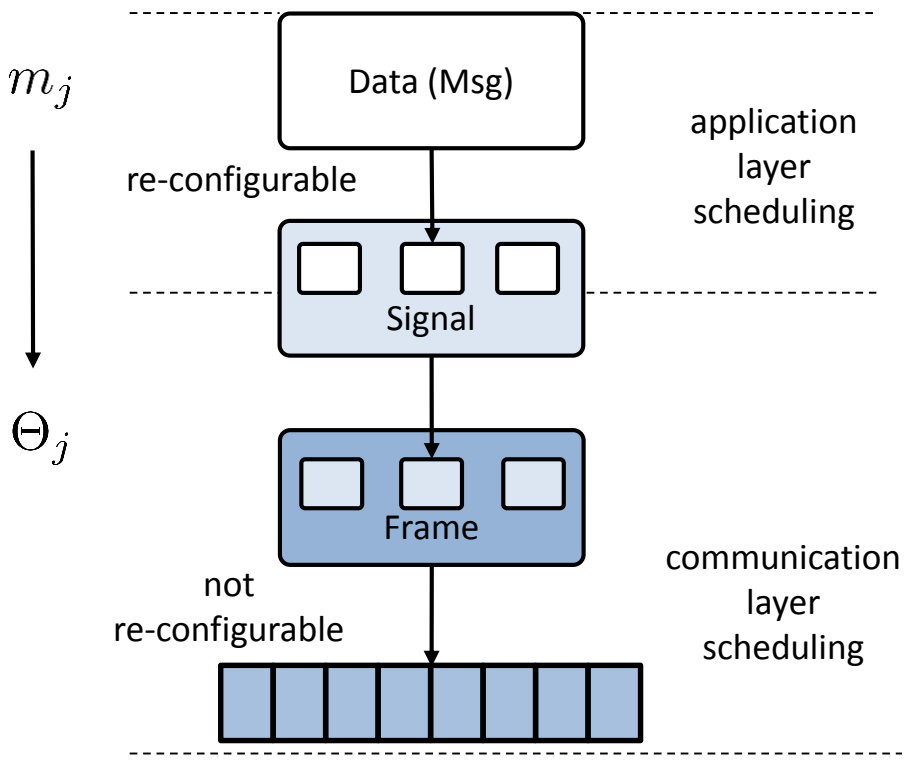


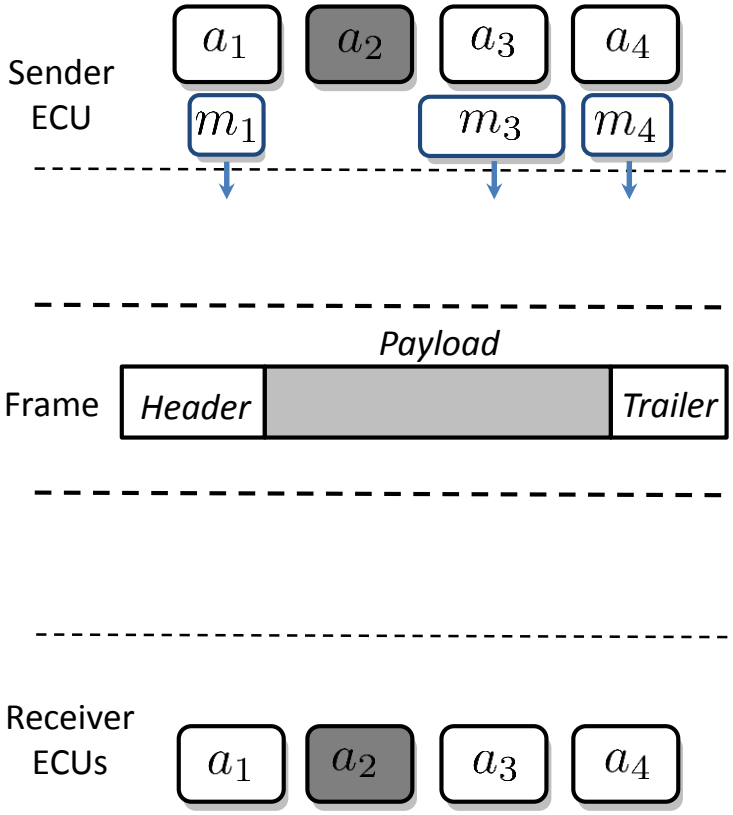

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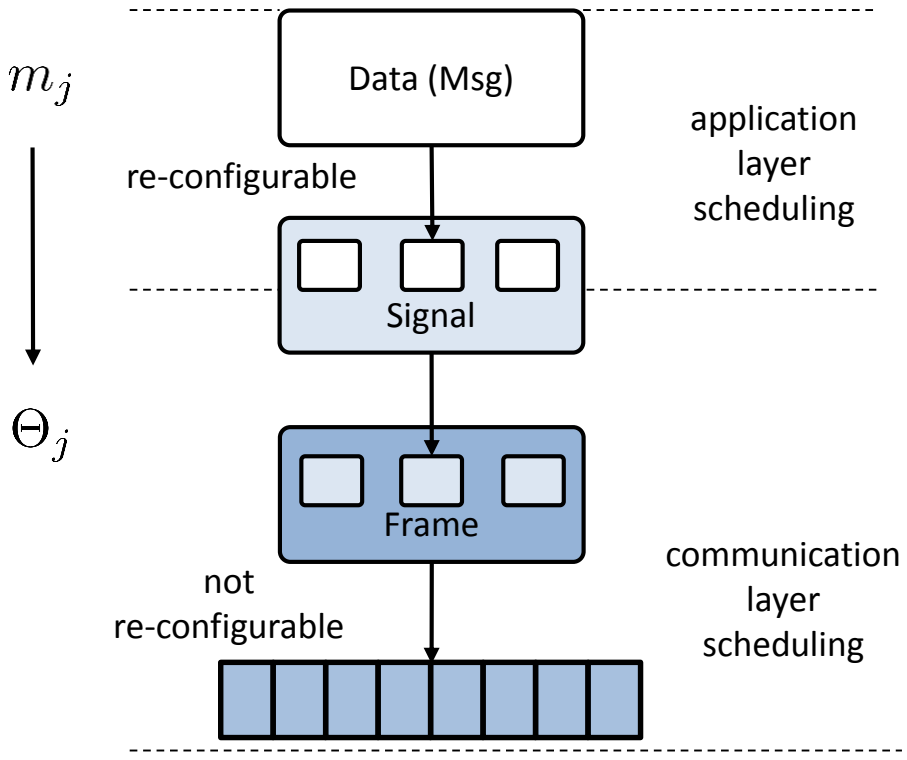


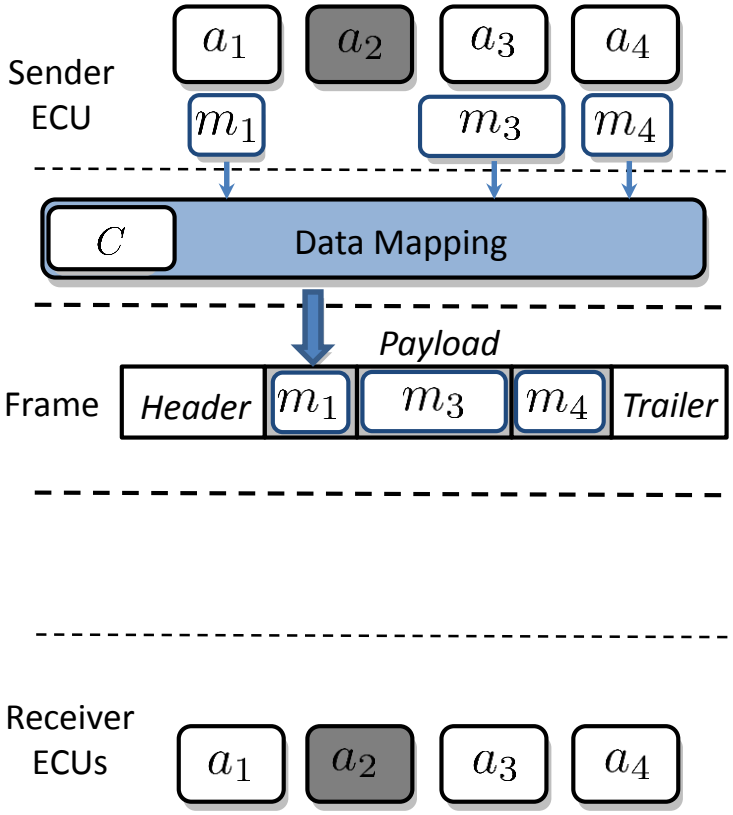

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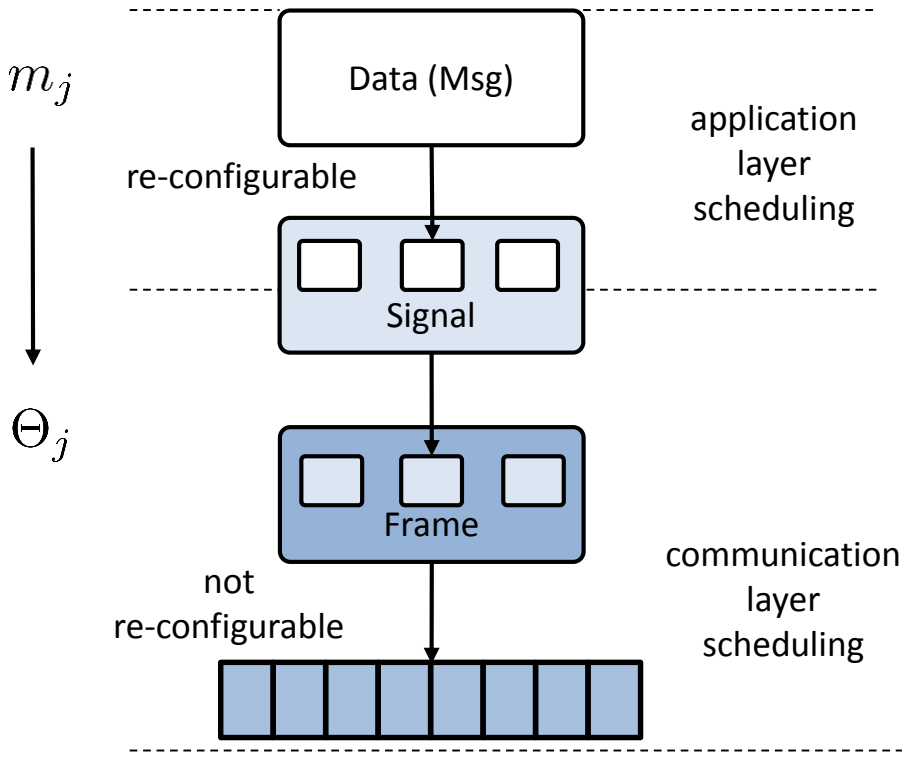


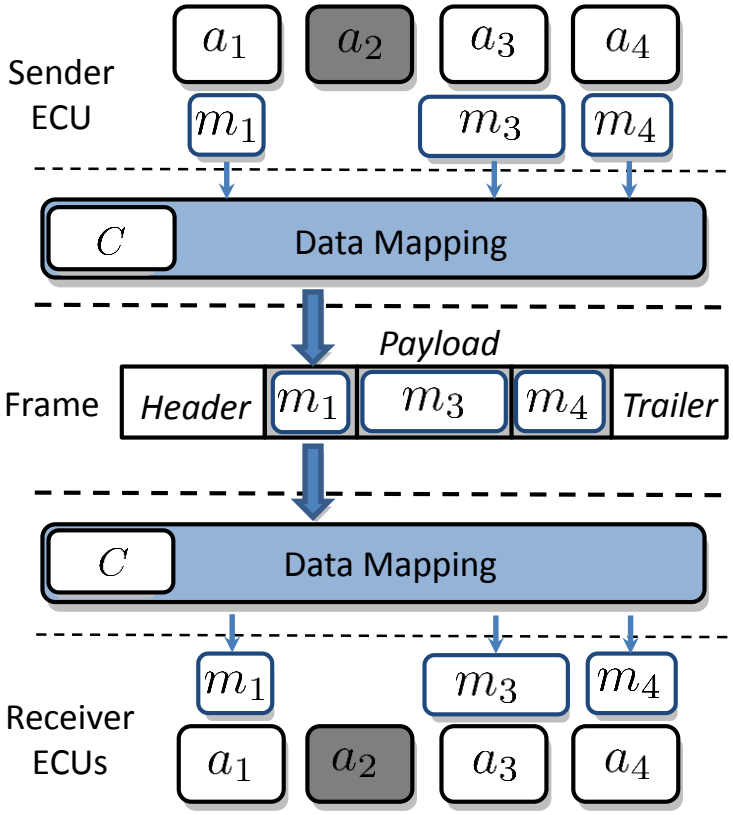

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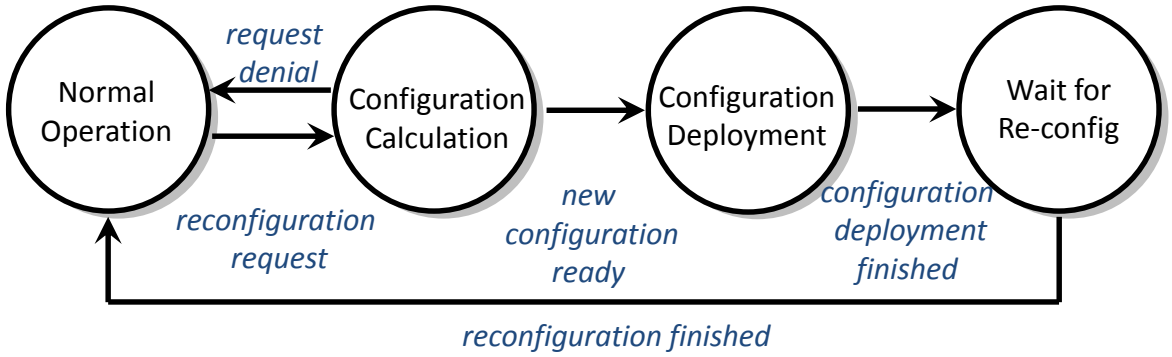
- **Configuration calculation**
  - To synthesize configuration $C_a = \{\alpha_i | a_i \in \mathcal{A}\}$ and $C_c = \{\mathcal{M}_i | a_i \in \mathcal{A}\}$, where the request and constraints are satisfied and overall performance maximized
  - Can be divided into a two layer problem
    - Layer one: all possible combinations of application modes are traversed
    - Layer two: to determine a feasible $C_c$
      - An exhaustive search
      - A classical bin packing ILP formulation for FlexRay slot packing [8]

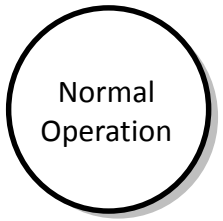
# Middleware

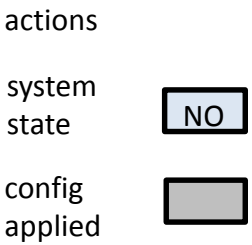
- **Configuration deployment and state management**



# Middleware

- **Configuration deployment and state management**



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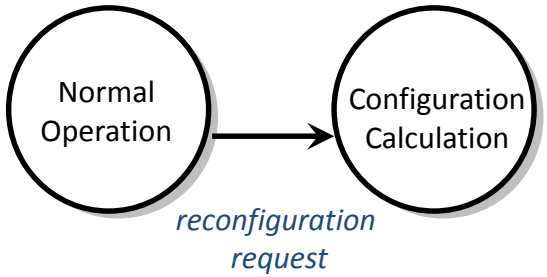


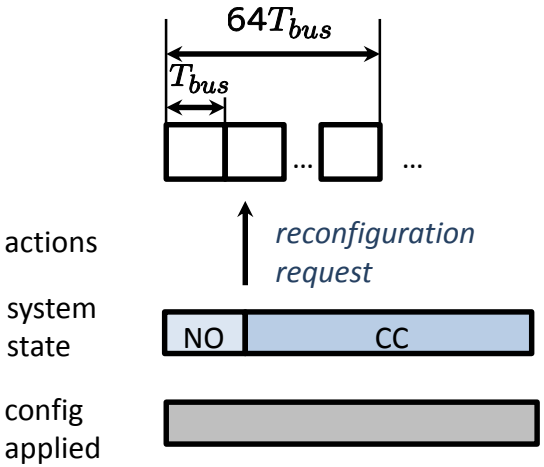

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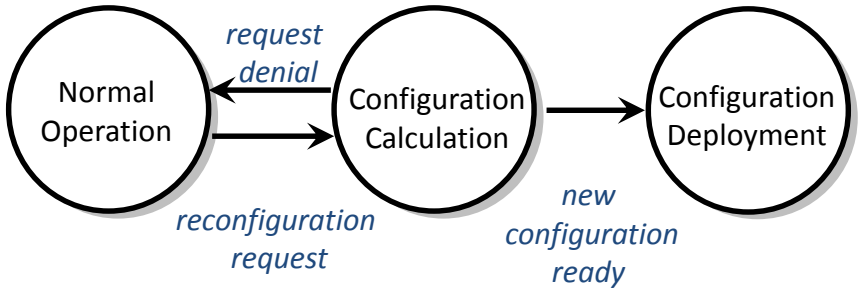


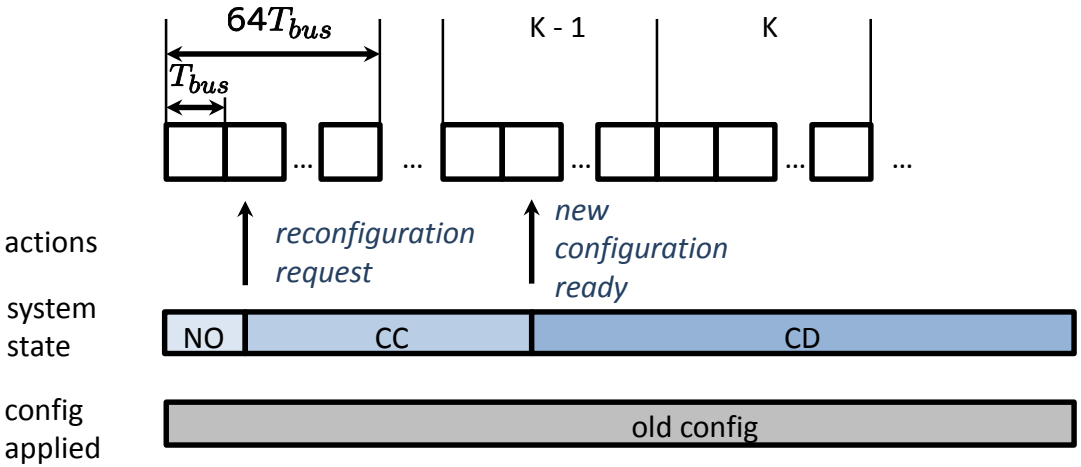

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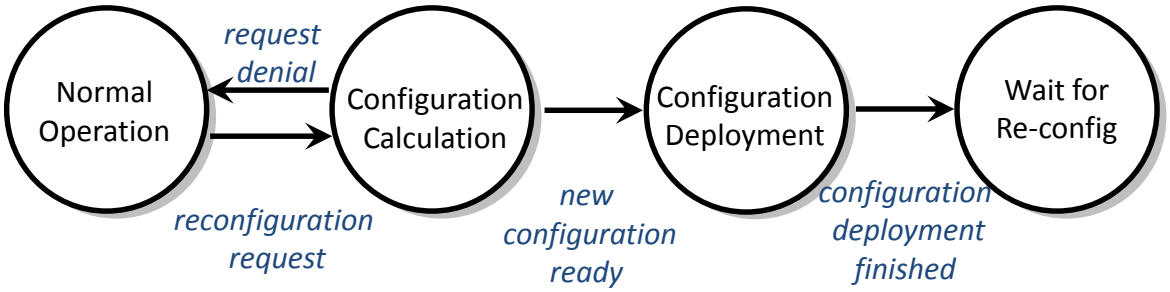


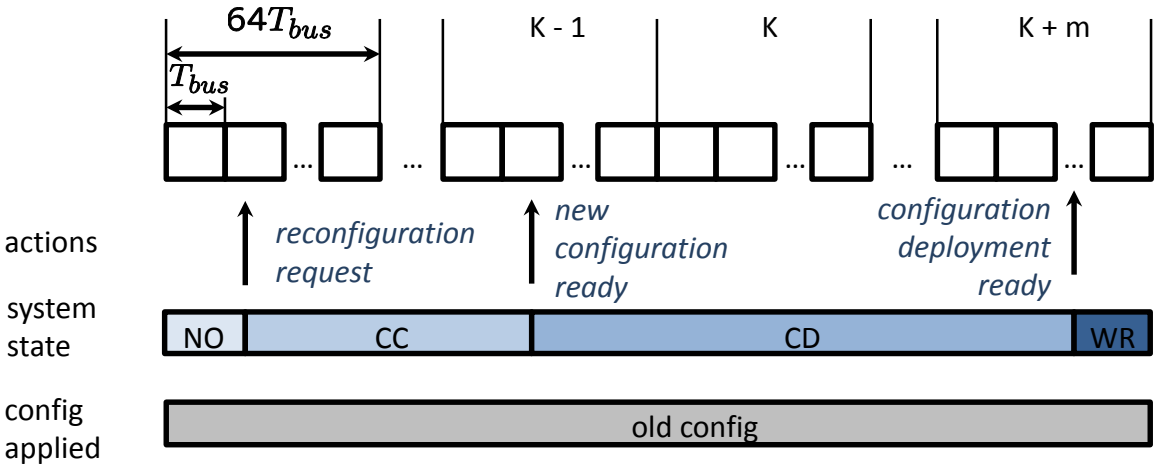

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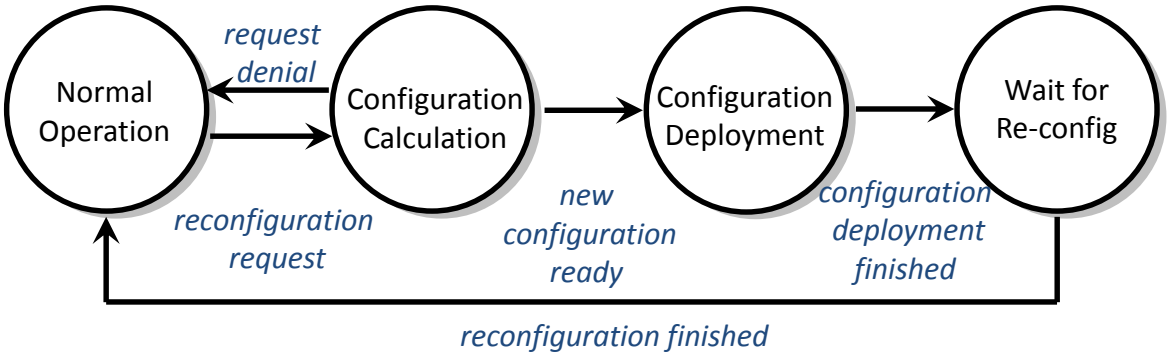


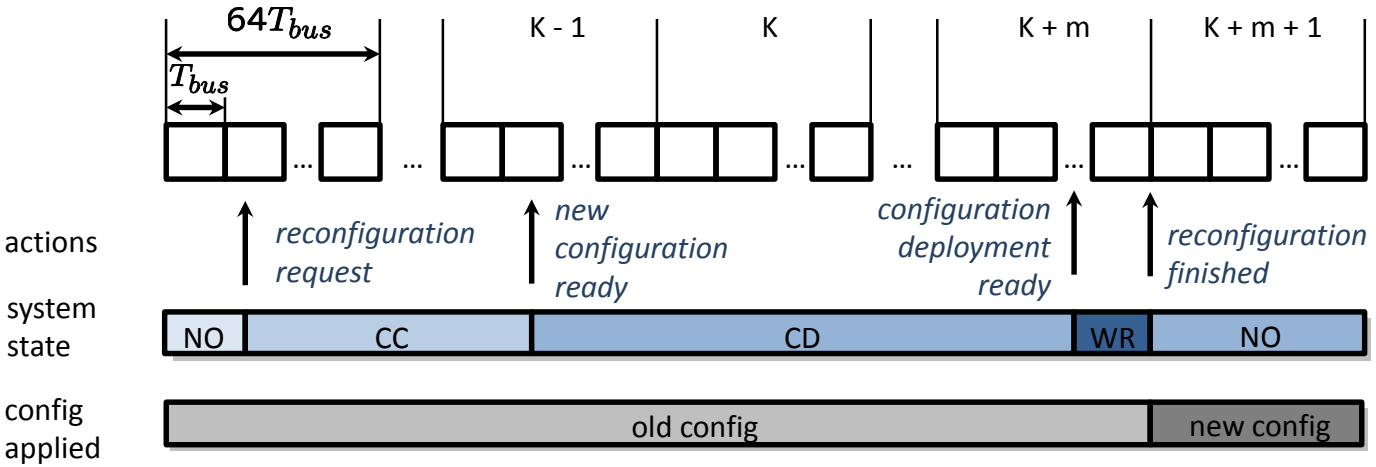

# Case Study

- **System Description**
  - 2 ECUs, 4 applications

| $a_1$ | | | |
|---|---|---|---|
| $\alpha$ | $w$ | $p$ | $J$ |
| 1 | 16 | $T_{bus}$ | 100 |
| 2 | 16 | $2\,T_{bus}$ | 50 |
| 3 | 8 | $2\,T_{bus}$ | 25 |

| $a_2$ | | | |
|---|---|---|---|
| $\alpha$ | $w$ | $p$ | $J$ |
| 1 | 8 | $T_{bus}$ | 100 |
| 2 | 8 | $2\,T_{bus}$ | 56 |
| 3 | 8 | $4\,T_{bus}$ | 34 |

| $a_3$ | | | |
|---|---|---|---|
| $\alpha$ | $w$ | $p$ | $J$ |
| 1 | 16 | $T_{bus}$ | 100 |
| 2 | 8 | $T_{bus}$ | 50 |
| 3 | 4 | $T_{bus}$ | 25 |

| $a_4$ | | | |
|---|---|---|---|
| $\alpha$ | $w$ | $p$ | $J$ |
| 1 | 8 | $T_{bus}$ | 100 |
| 2 | 4 | $2\,T_{bus}$ | 56 |
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| 1 | 8 | $T_{bus}$ | 100 |
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- **Reconfiguration requests**

| **step** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| **request** | $a_1 \rightarrow \text{on}$ | $a_2 \rightarrow \text{on}$ | $a_3 \rightarrow \text{on}$ | $\alpha_3 \rightarrow 1$ | $a_4 \rightarrow \text{on}$ | $\alpha_4 \rightarrow 1$ | $a_3 \rightarrow \text{off}$ | $a_3 \rightarrow \text{on}$ |

# Case Study

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  - 2 ECUs, 4 applications

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| $\alpha$ | $w$ | $p$ | $J$ |
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|---|---|---|---|
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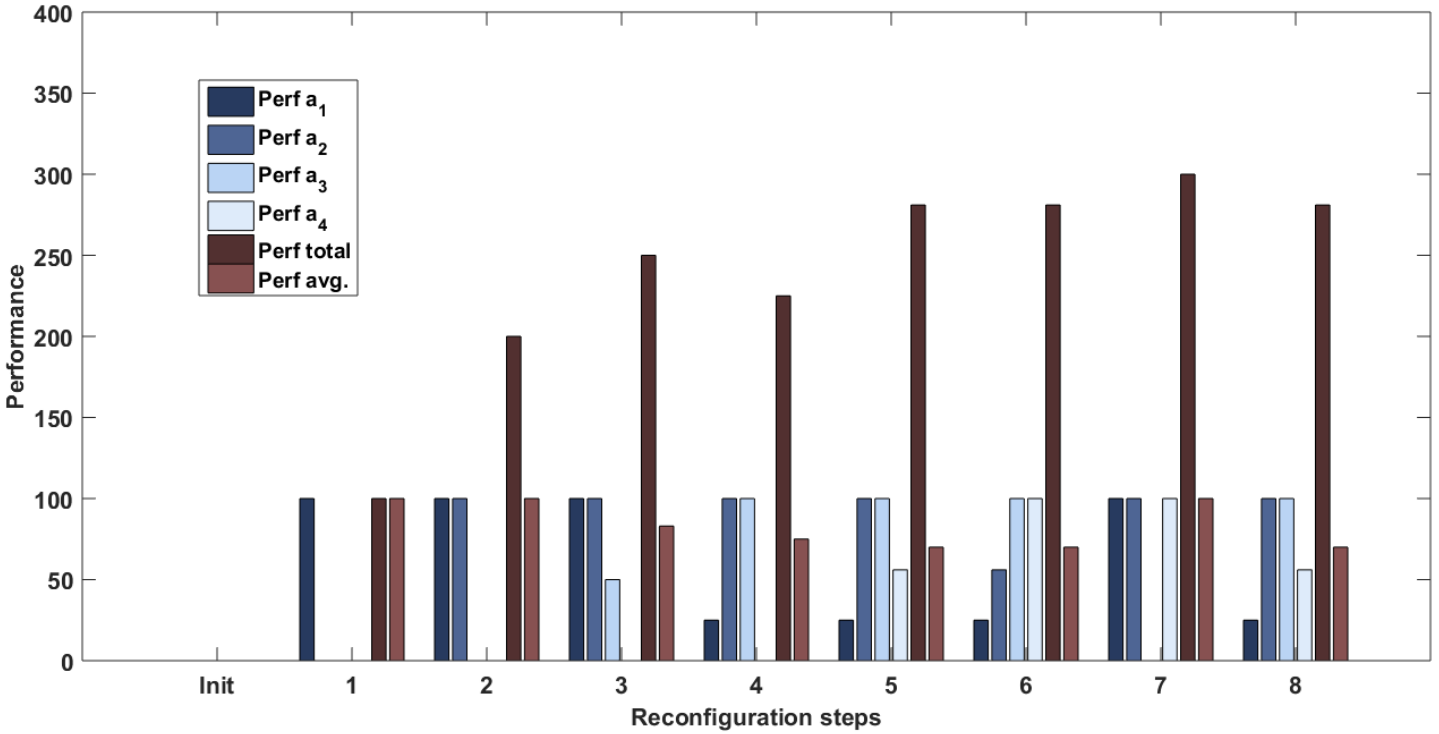
- **Reconfiguration requests**

| **step** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| **request** | $a_1 \rightarrow$ on | $a_2 \rightarrow$ on | $a_3 \rightarrow$ on | $\alpha_3 \rightarrow 1$ | $a_4 \rightarrow$ on | $\alpha_4 \rightarrow 1$ | $a_3 \rightarrow$ off | $a_3 \rightarrow$ on |

- **Implementation**
  - EB6120 [11] as ECUs
  - Software developed with Simulink and SIMTOOLS/SIMTARGET [12]
  - Middleware implemented with Simulink
  - Configuration calculation mapped on a dedicated ECU

# Experimental Results

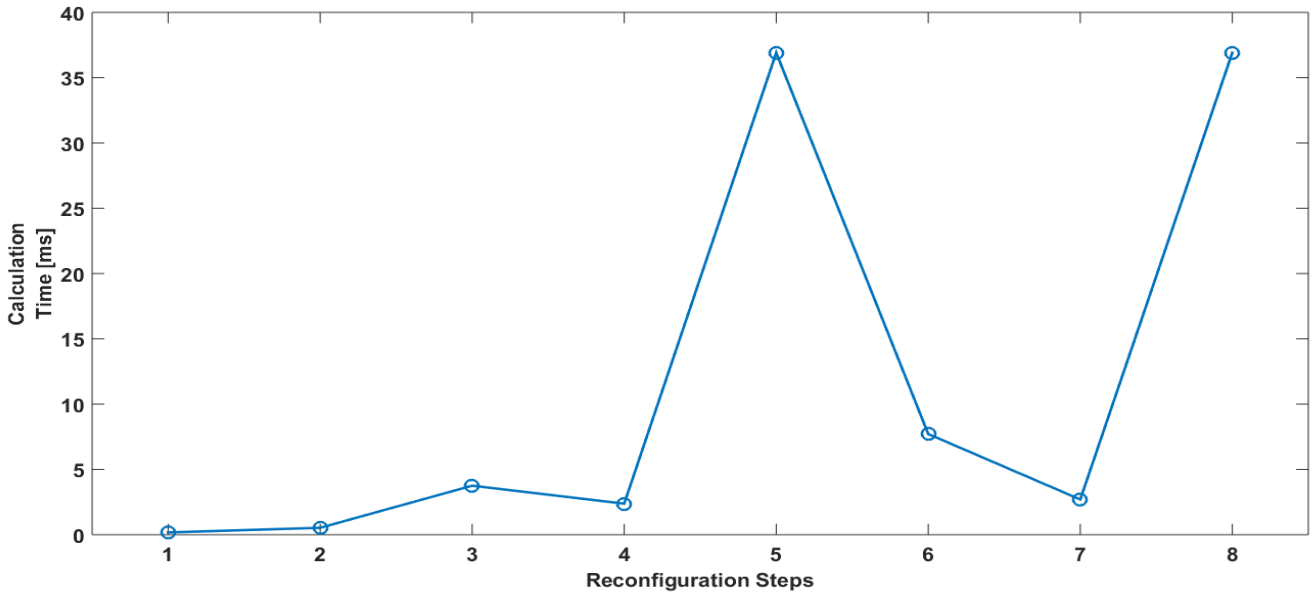
- **Re-configuration according to request sequence**
  - Application and overall performance




| step | request |
|---|---|
| 0 | |
| 1 | $a_1 \rightarrow \text{on}$ |
| 2 | $a_2 \rightarrow \text{on}$ |
| 3 | $a_3 \rightarrow \text{on}$ |
| 4 | $\alpha_3 \rightarrow 1$ |
| 5 | $a_4 \rightarrow \text{on}$ |
| 6 | $\alpha_4 \rightarrow 1$ |
| 7 | $a_3 \rightarrow \text{off}$ |
| 8 | $a_3 \rightarrow \text{on}$ |

# Experimental Results

- **Online configuration synthesis time**
  - EB6120 as ECU
  - Software implementation with Simulink Matlab-embedded functions




| step | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| No. apps | 1 | 2 | 3 | 3* | 4 | 4* | 3 | 4 |

**one application has a fixed mode*

# Concluding Remarks

- **Problem**
  - Online communication reconfiguration of FlexRay-based ECU network
  - Communication resource re-allocation for multi-mode applications and newly activated applications

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  - A middleware layer with
    - Reconfigurable data-to-schedule mapping
    - Online configuration calculation and deployment
  - Achieves online re-allocation of communication resources with an ECU

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- **Outlook**
  - Extension to support other communication protocols
  - Extension to allow features like re-routing of messages
  - More efficient configuration calculation algorithms

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[11] Elektrobit. www.elektrobit.com.

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# The End

**Many thanks**

**Q/A**