Schedule Management Framework for Cloud-based Future Automotive Software Systems

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Overview

- **Problem**
  - Schedule synthesis for Ethernet-based time-triggered system
  - Online schedule generation and management for Plug-and-Play scenario

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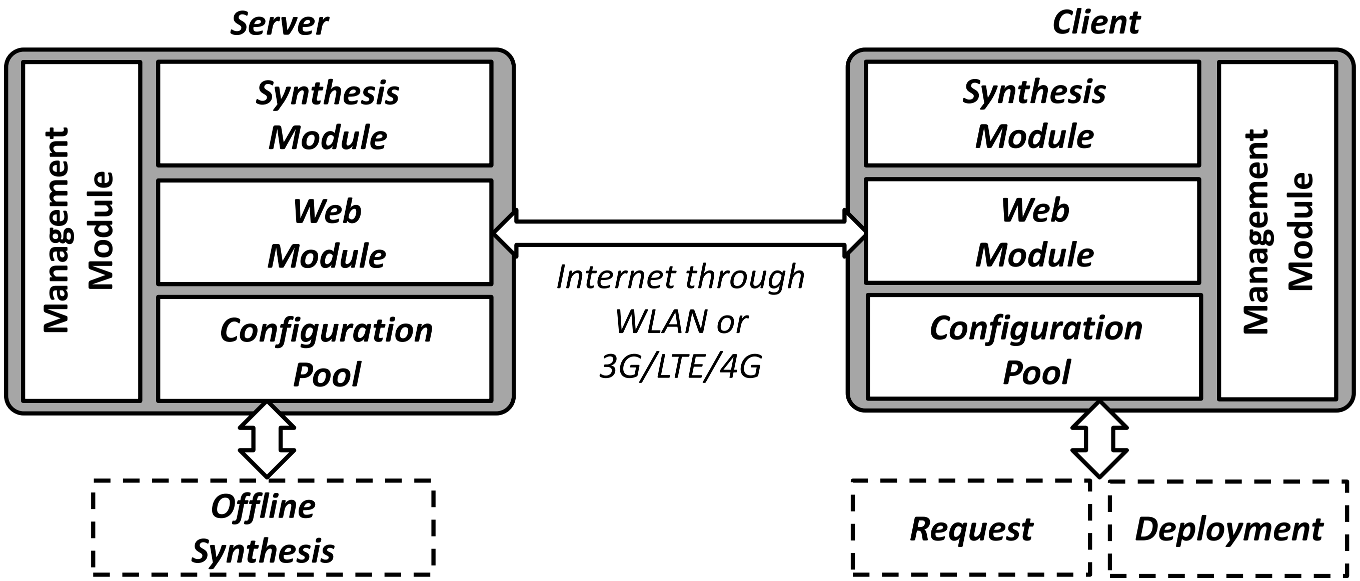
  - Online schedule generation and management for Plug-and-Play scenario

- **Approach**
  - Software framework for schedule management
  - Utilization of both local computation and cloud-computing
  - Four-stage scheduling strategy, online schedule synthesis, configuration pool

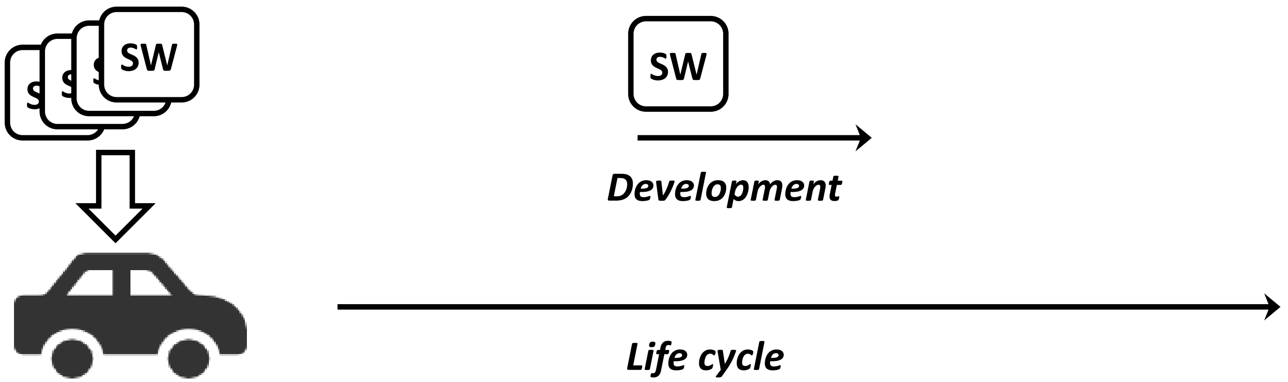


Outline

- Motivation
- Background
- Problem Formulation
- Proposed Framework
- Experimental Results
- Concluding Remarks

Motivation

- **Software update and installation after sales**
  - Shift of innovation in automotive domain to Electrical/Electronics systems and software
  - Development cycle of electronic system and software is much shorter than vehicle life cycle
  - Increasingly more new software functions, e.g., in driver assistance, autonomous driving and infotainment domain



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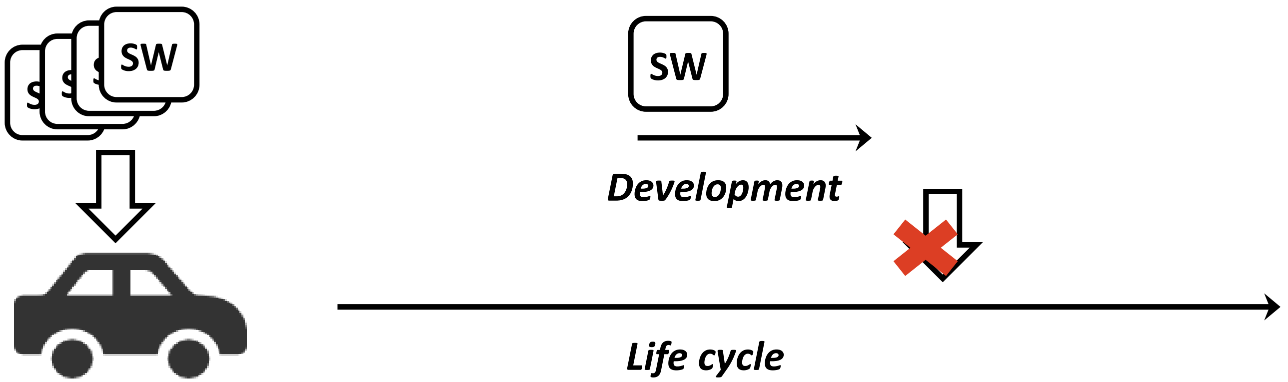

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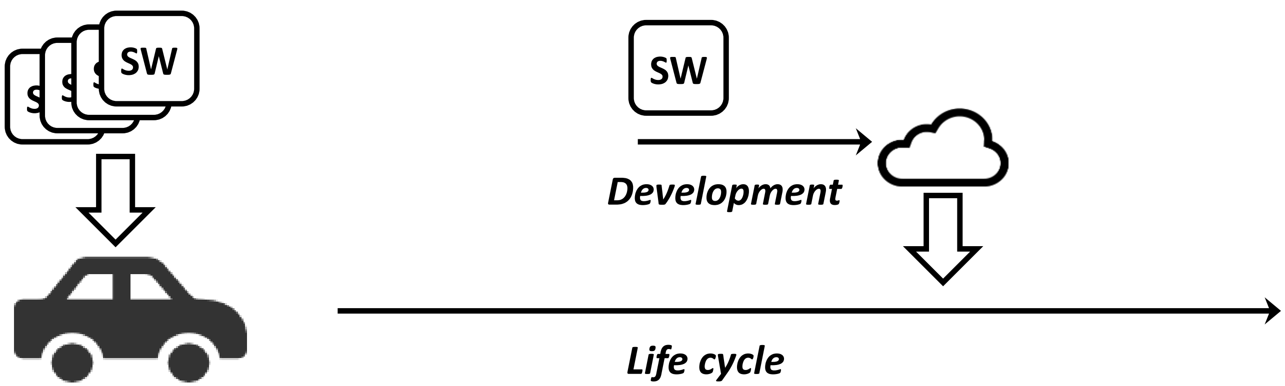

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- **Cloud-based future automotive software systems**
  - Internet connection for cars
  - Vehicle is becoming increasingly autonomous

  ➢ Autonomous detection of driving condition and download software applications on demand

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  - Supply chain – ECU with single independent function
  - ➢ ECU consolidation – ECUs are becoming computing platforms and multiple applications can be mapped on a single ECU

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  - Reallocation of communication and computation resources
  - ➢ The problem to be addressed in this work

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  - Change of configuration for processor scheduling and network scheduling
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  - Task and network transmission are triggered according to pre-calculated schedules
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- **Requirements**
  - Obtain schedules online in relatively short time
  - As many as possible new applications can be accommodated
  - Facilitation of schedule reuse and minimization of disturbance to existing schedules

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- **Related Works**
  - Schedule synthesis problem for Ethernet-based time-triggered systems [10,11,13,15,16]
  - Incremental scheduling [11,12]
  - Configuration and reconfiguration of time-triggered Ethernet networks [18,19]
  - Plug-and-Play in the automotive setting [2,3,5,6]

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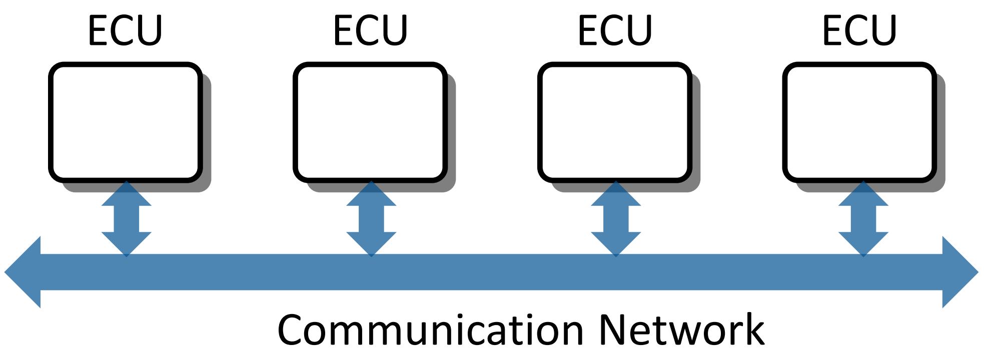
  - Configuration and reconfiguration of time-triggered Ethernet networks [18,19]
  - Plug-and-Play in the automotive setting [2,3,5,6]

- **Contributions**
  - Software framework for schedule generation and management for Plug-and-Play
  - Online schedule synthesis based on a mixture of embedded and cloud computing
  - Configuration pool for schedule reuse
  - A four-stage scheduling strategy offering trade-off between chance of accommodating new applications and synthesis time and disturbance to existing schedules

Background

- **Distributed embedded systems**
  - Hardware architecture



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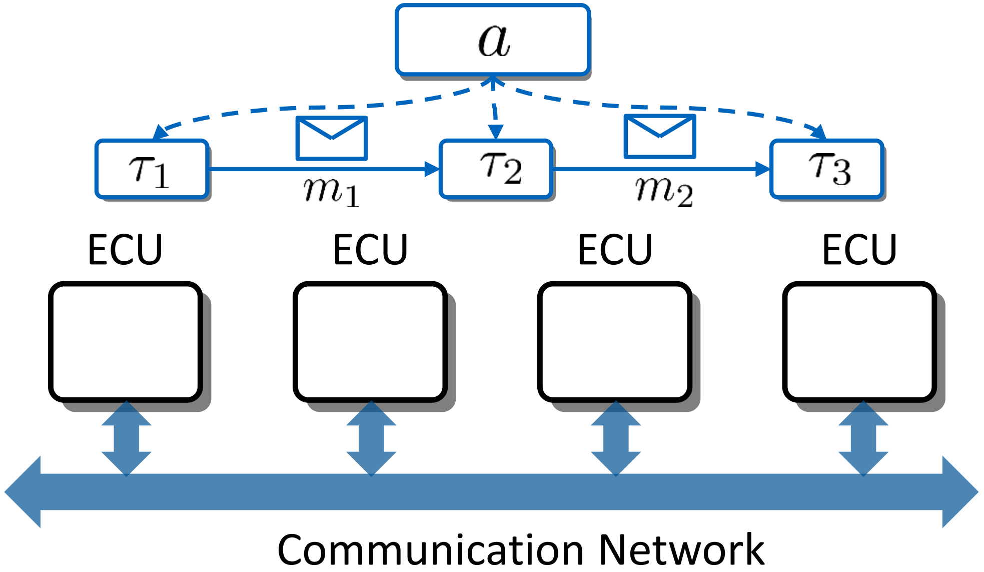

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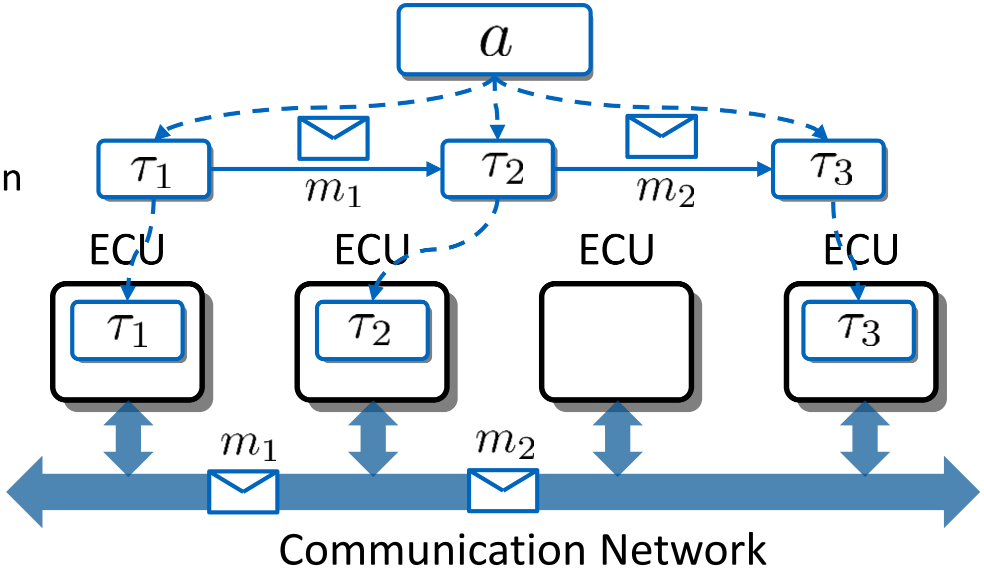

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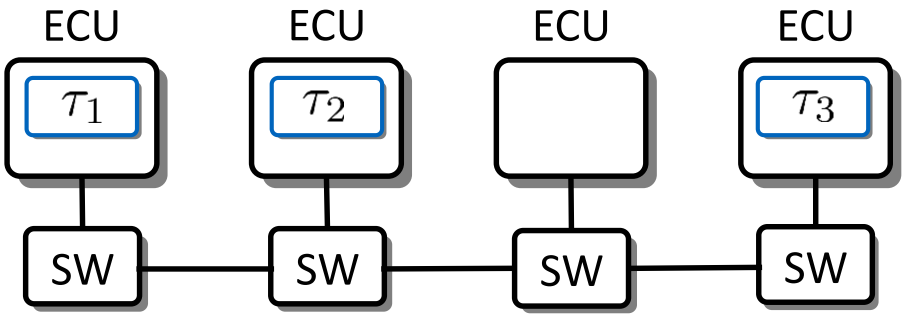

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  - Commonly with full-duplex links

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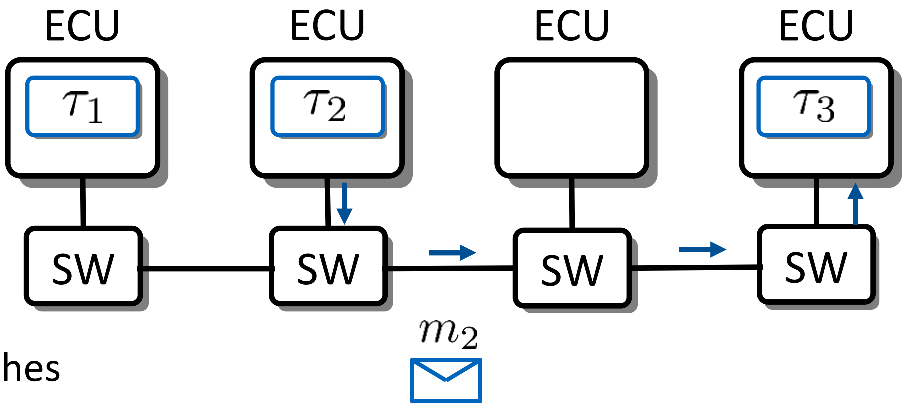

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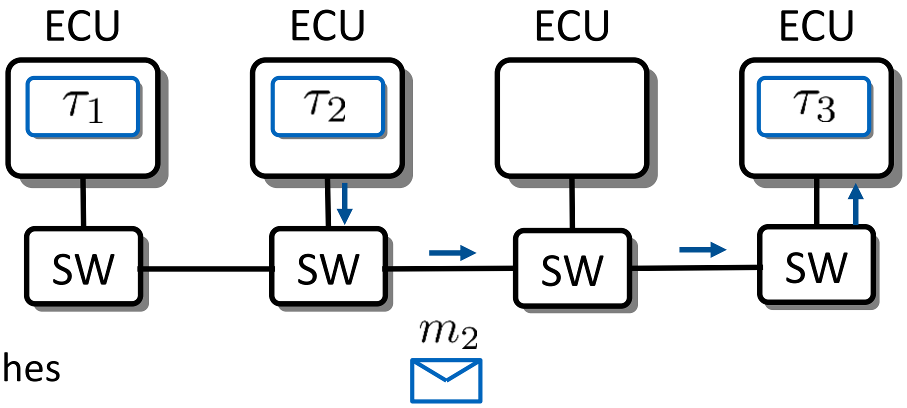

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➢ Queueing delay at each switch
  - Not deterministic
  - Can be relatively large

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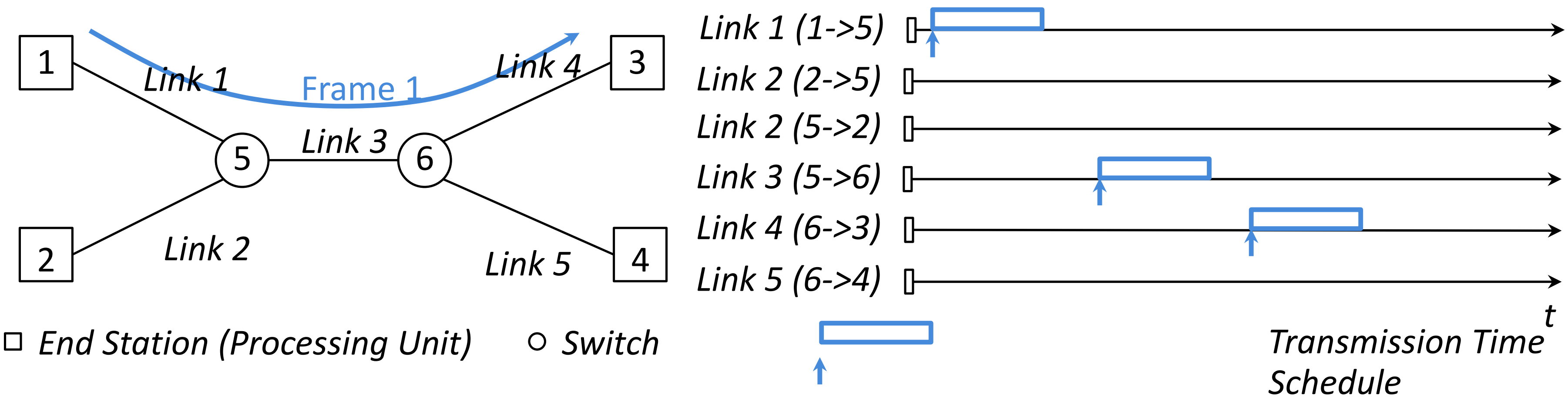
  - Frames are scheduled to avoid queueing delay
  - Frames transmission on each link according to static schedule



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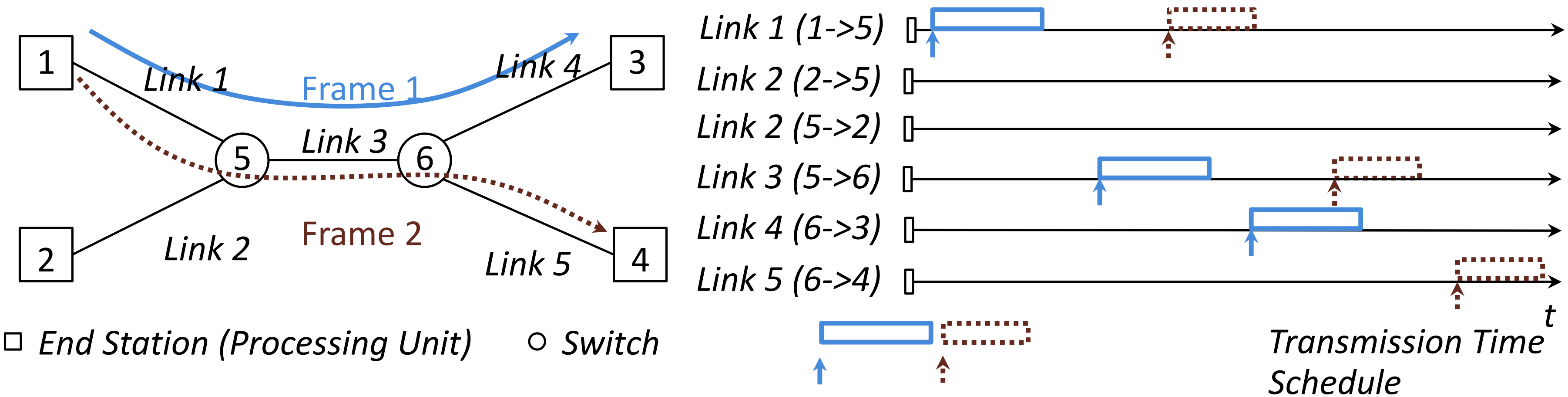

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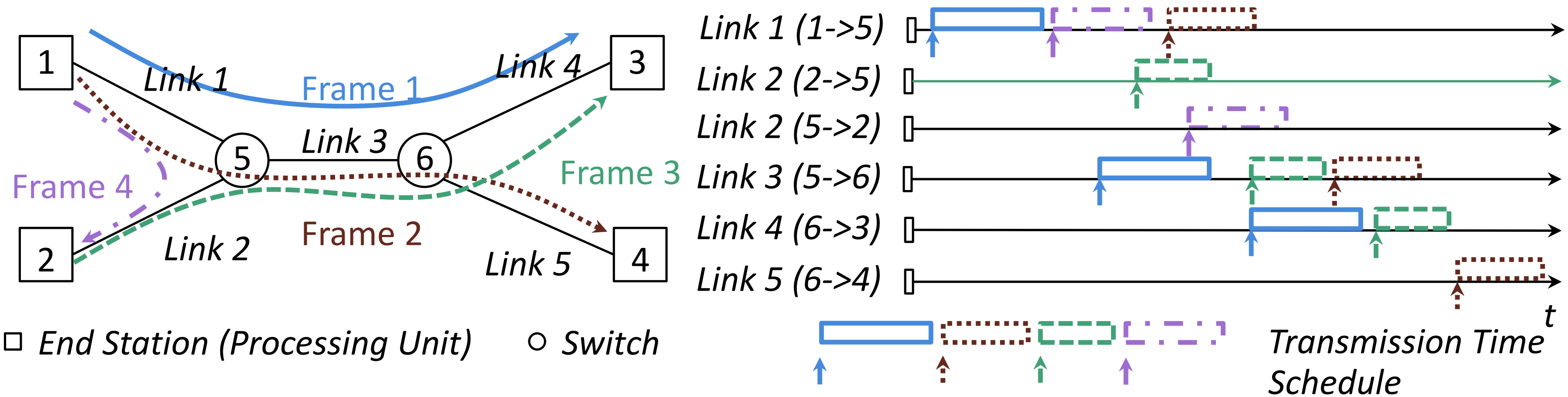

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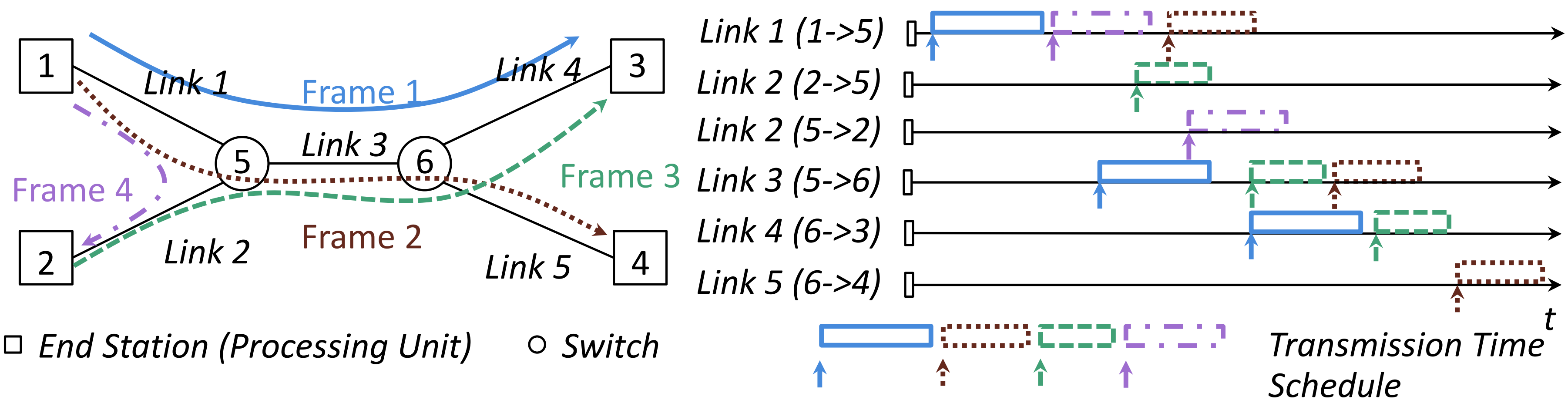


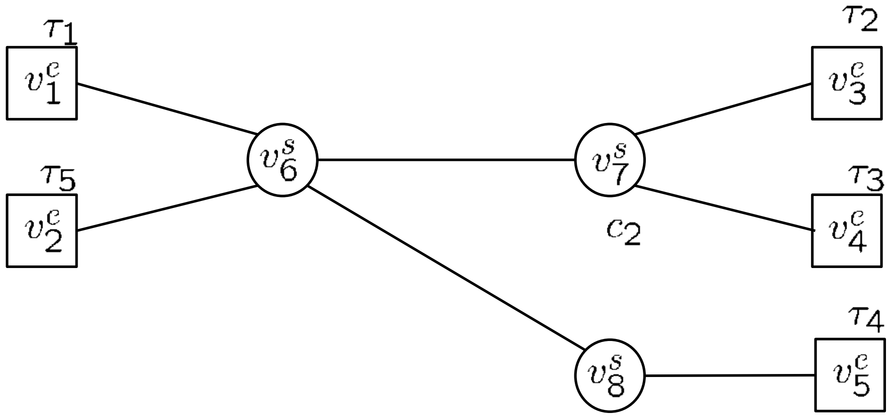
- **Ethernet-based time-triggered systems**
  - Processor: time-triggered non-preemptive task scheduling
  - Network: time-triggered Ethernet communication

Problem Formulation

- **The scheduling problem**
  - Application task

$$\tau_i = \{\tau_i.p, \quad \tau_i.o, \quad \tau_i.e\}$$

↓ *period* ↓ *offset* ↓ *WCET*



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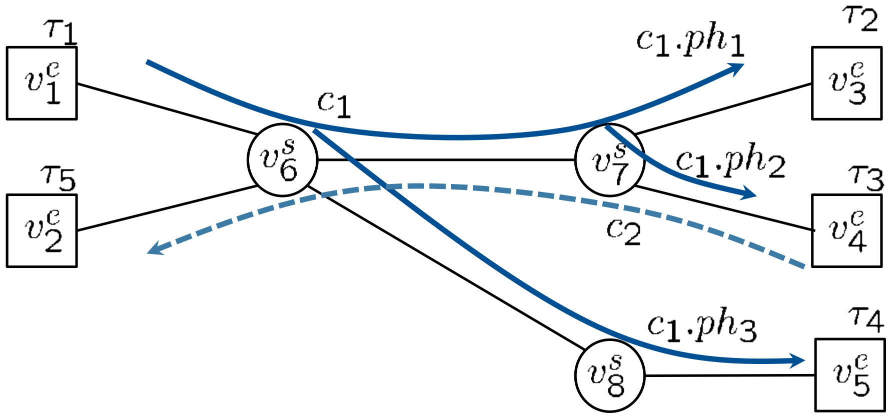
  - Communication task

$$c_i = \{f_i, \quad c_i.tr, \quad c_i.o, \quad c_i.p\}$$

↓ *frame length* ↓ *path tree* ↓ *offsets* ↓ *period*



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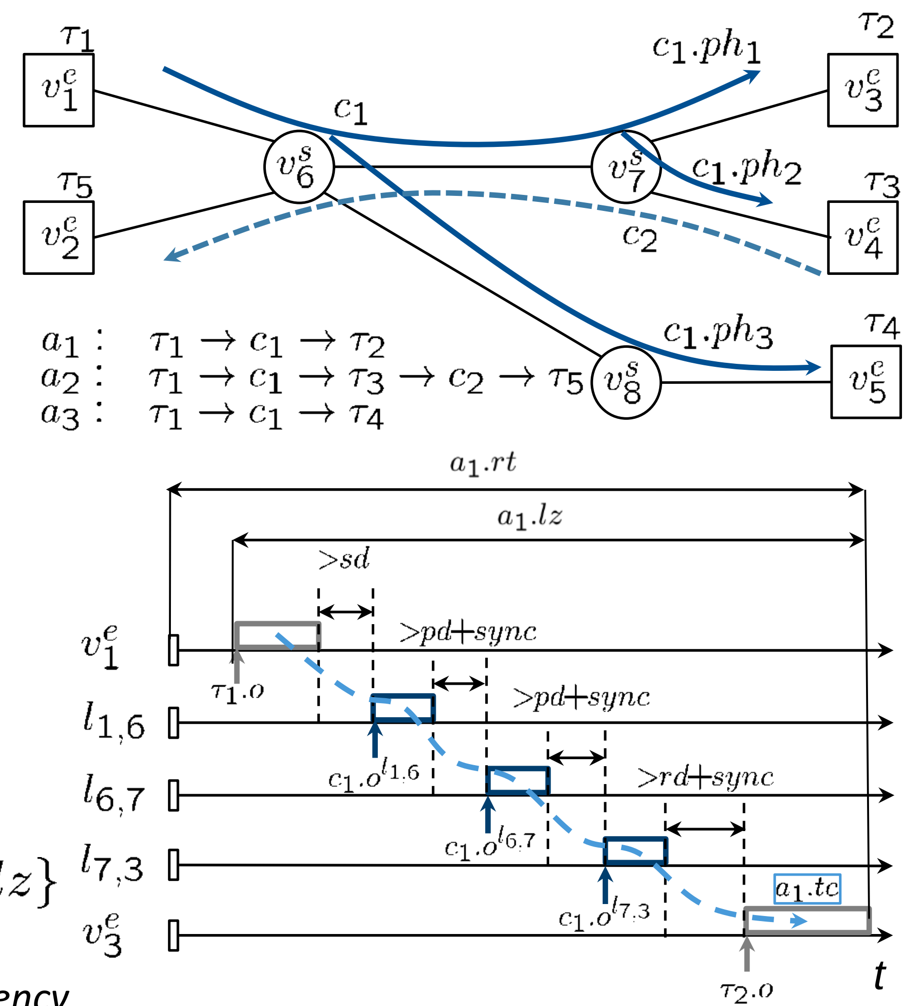
  - Application

$$a_i = \{a_i.tc, \quad a_i.p, \quad a_i.rt, \quad a_i.lz\}$$

period *task chain* *response time* *latency*



Problem Formulation

- **The scheduling problem**
  - Hardware specific parameters $hw.\omega$
    - System topology
    - Timing parameters including network bandwidth, synchronization precision, etc.
  - Application parameters $\mathcal{A}.\omega$
    - Task mapping, period, WCET
    - Communication frame length, path tree, latency and response time constraints
  - Application schedules $\mathcal{A}.\mathbf{o}$
    - Task schedules and frame transmission schedules on each link

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- **Approach**
  - Formulation of the problem in SMT or MIP problem and use solvers to obtain the schedules, as in [10,11,13,15,16]

Problem Formulation

- **The schedule management problem**
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  - Synthesize schedules offline for a specific application -> conflicts with existing schedules
  - Synthesize all possible schedule sets offline -> possibly a huge number combinations
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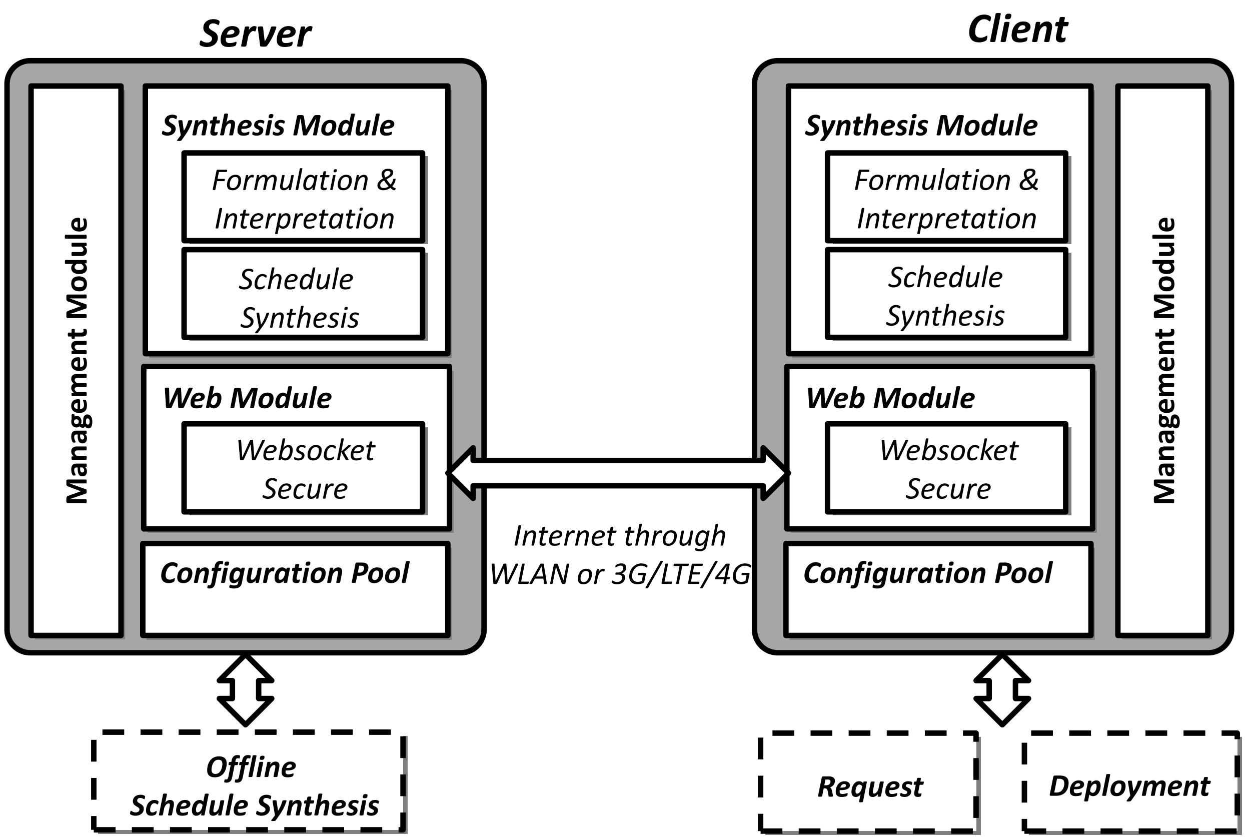
➢ **Need of an online schedule management framework**

Schedule Management Framework

- **Overview**
  - Client-server architecture
  - Utilization of both onboard processor and cloud-computing
  - Components: Synthesis Module, Web Module, Configuration Pool, Management Module



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- **Configuration and request**
  - TTCON
    - An XML format containing $hw.\omega$, $\mathcal{A}.\omega$ and $\mathcal{A}.\mathbf{o}$
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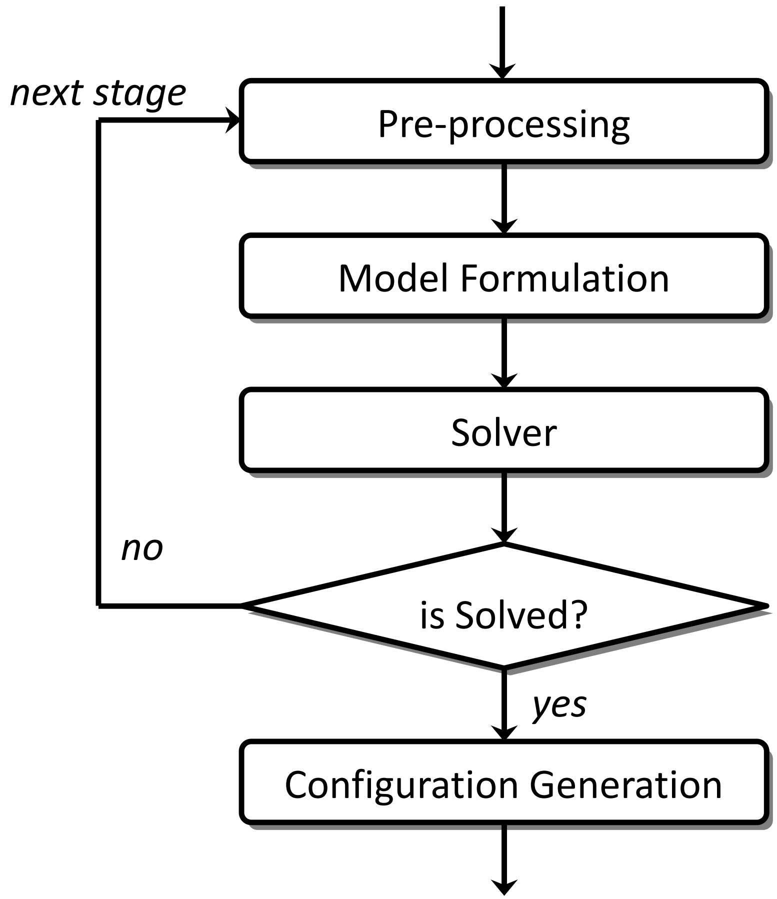
- **Configuration Pool**
  - Can be managed through different metrics like frequency of reuse
  - Retrieve a configuration
    - If the application set of request matches exactly or is a subset of a configuration in pool, the configuration can be retrieved
    - In the case of a subset, schedules of other applications are removed
  - Update the configuration pool
    - Add a configuration if it is not in pool
    - If the new configuration is a superset of an existing one, it replaces the existing one
  - It facilitates schedule reuse for a single vehicle or between vehicles of the same variant and request based configuration management

Schedule Management Framework

- **Synthesis module**



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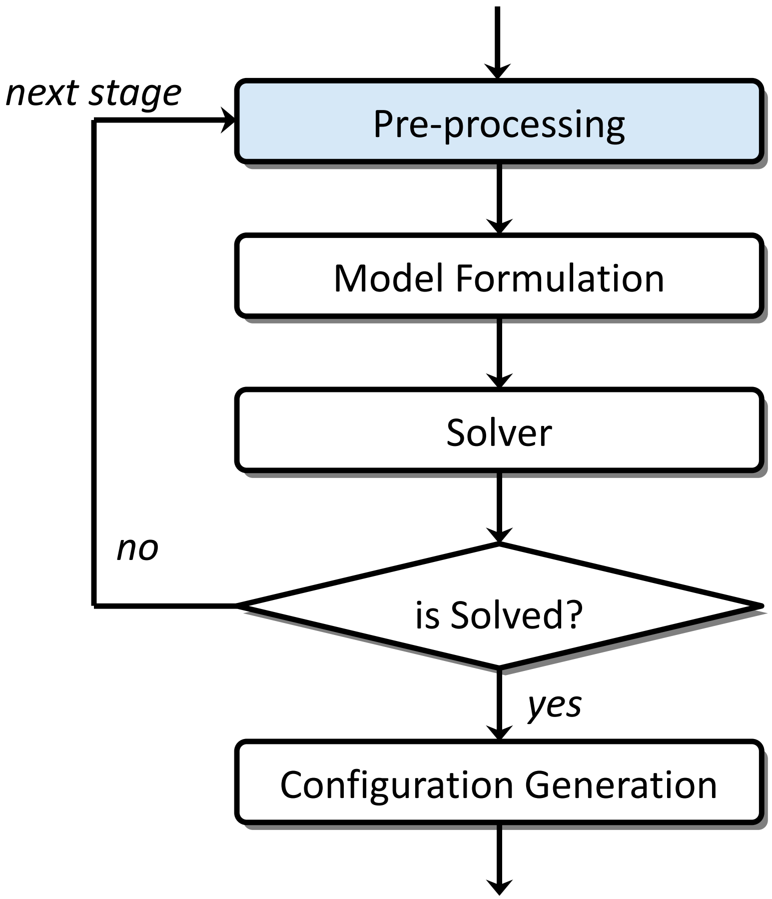

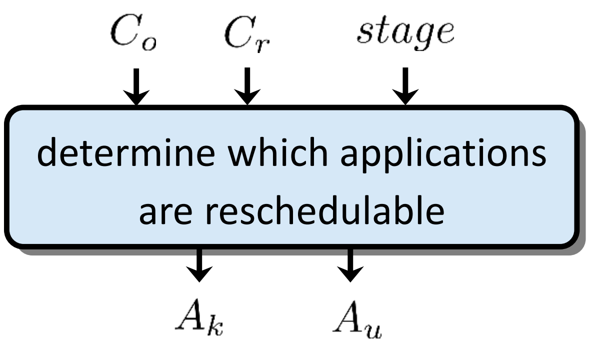

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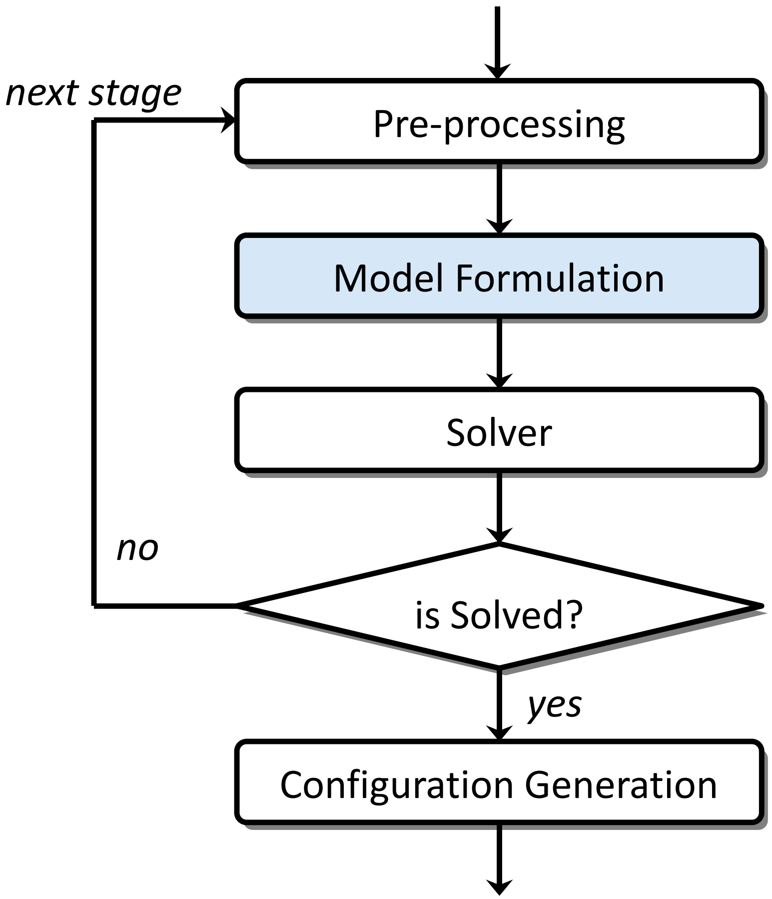

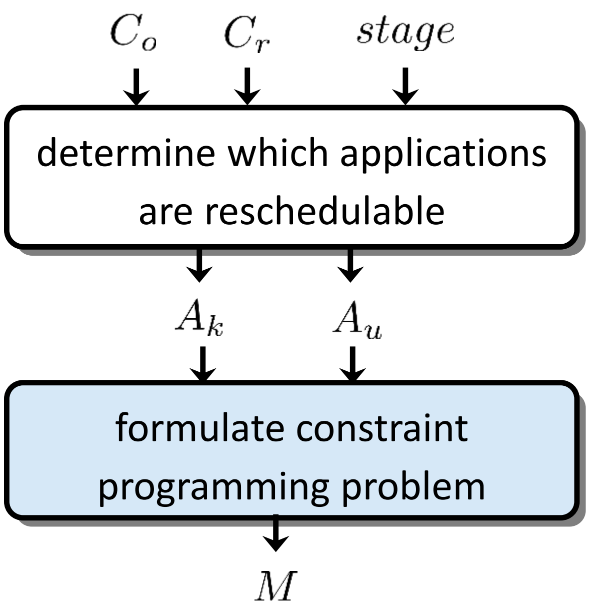

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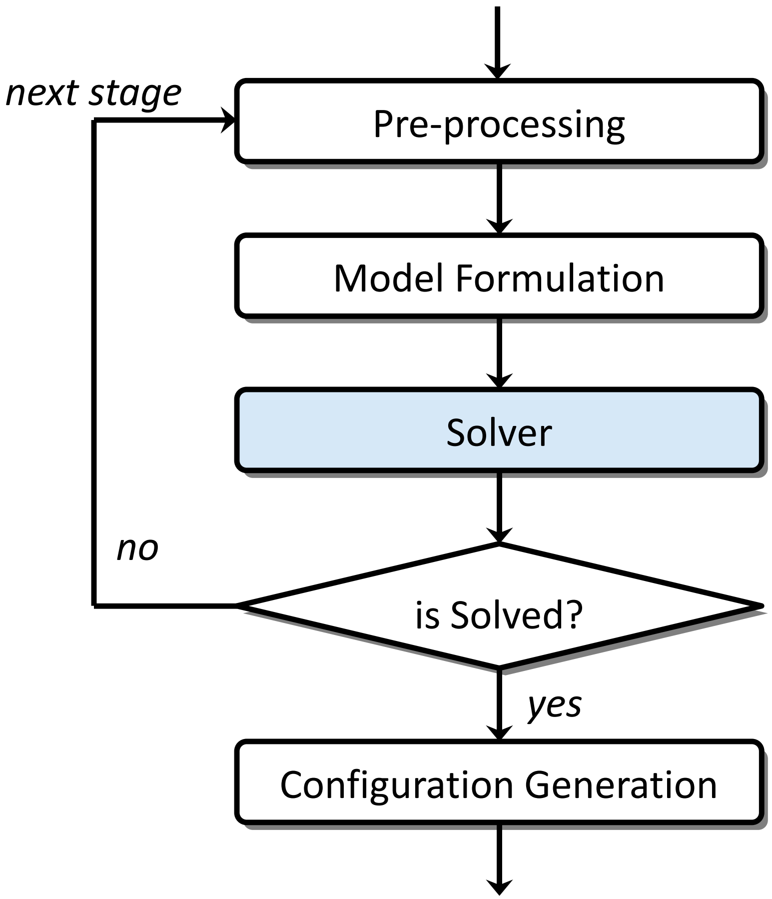

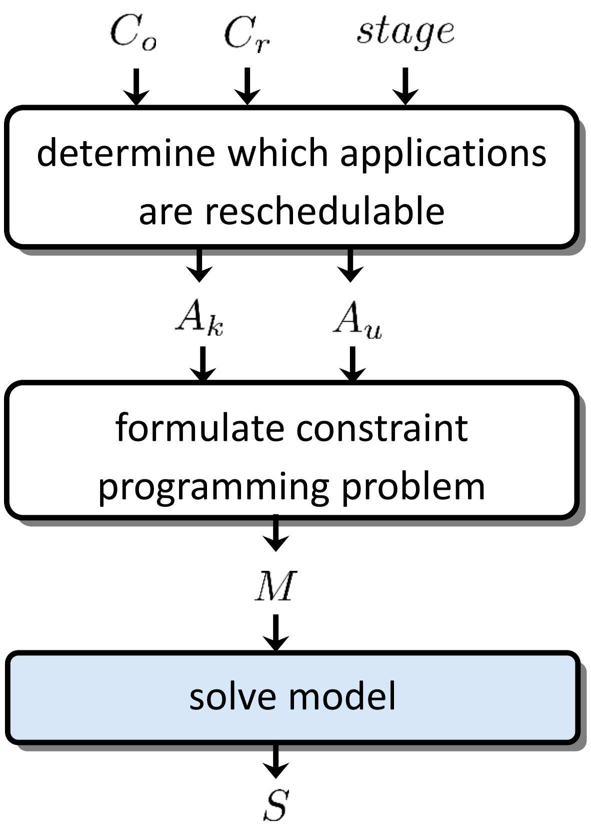

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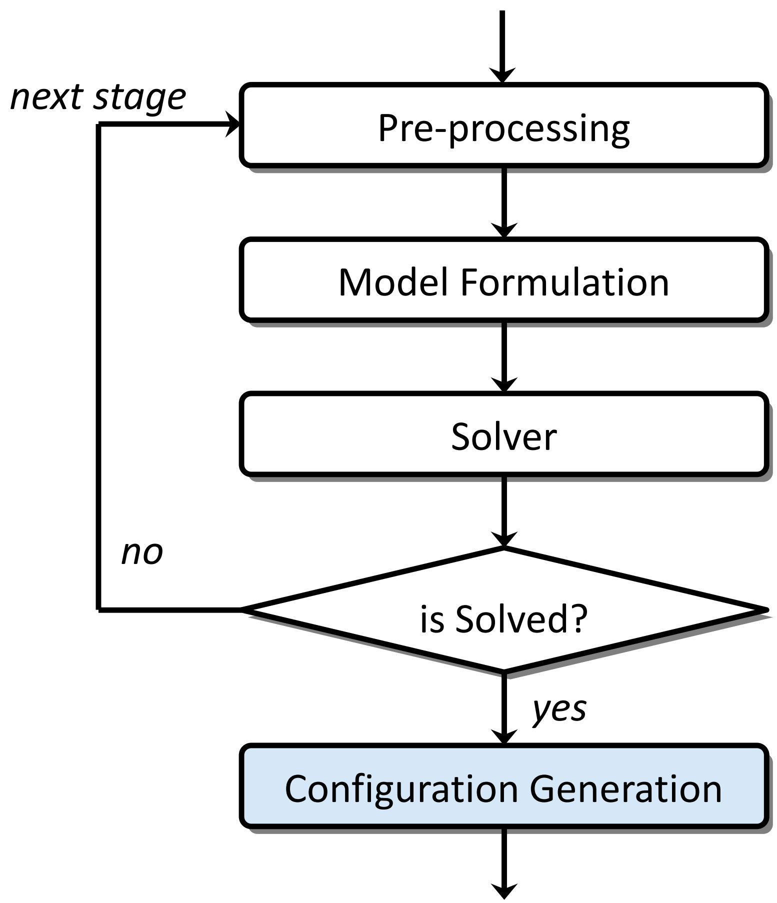

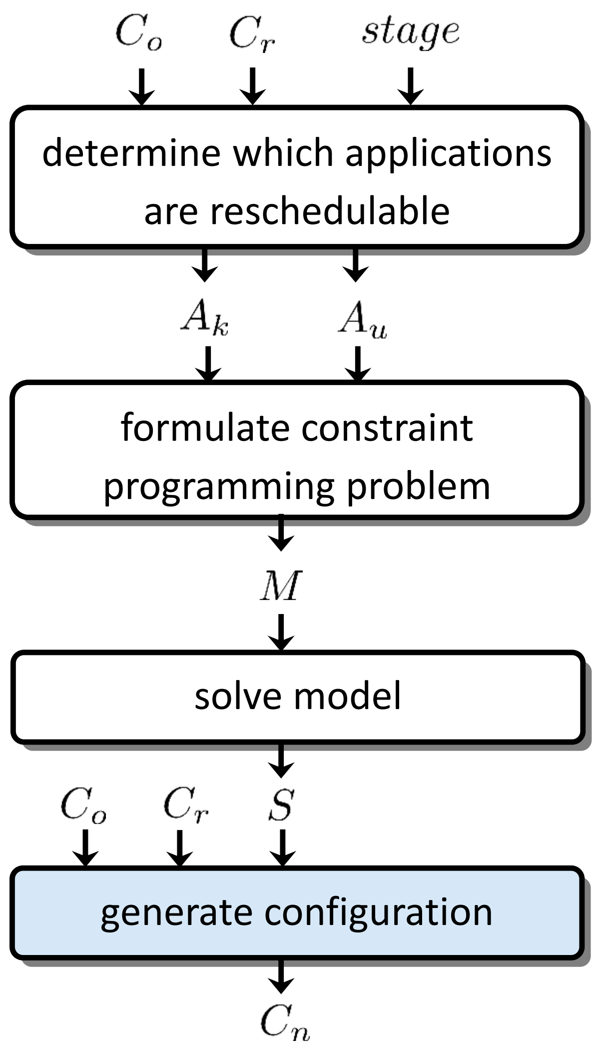

Schedule Management Framework

- **Four-stage scheduling strategy**
  - Stage 1 – Incremental scheduling
    - None of the existing applications are rescheduled

      $$\mathcal{A}_k = \mathcal{A}_o \cap \mathcal{A}_n, \mathcal{A}_u = \mathcal{A}_n \backslash \mathcal{A}_k$$

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  - Stage 2 – Rescheduling based on task conflict
    - ➢ Reschedule existing applications with common tasks with new ones

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  - Stage 3 – Rescheduling based on computation resource conflict
    - Reschedule existing applications with tasks mapped on common ECU with new ones

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  - Stage 4 – Complete rescheduling
    - All existing applications are considered reschedulable

      $$\mathcal{A}_k = \mathcal{A}^b, \mathcal{A}_n = \mathcal{A}_n^a$$

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  - Stage 1 – Incremental scheduling
    - ➢ None of the existing applications are rescheduled

      $\mathcal{A}_k = \mathcal{A}_o \cap \mathcal{A}_n, \mathcal{A}_u = \mathcal{A}_n \backslash \mathcal{A}_k$
  - Stage 2 – Rescheduling based on task conflict
    - ➢ Reschedule existing applications with common tasks with new ones

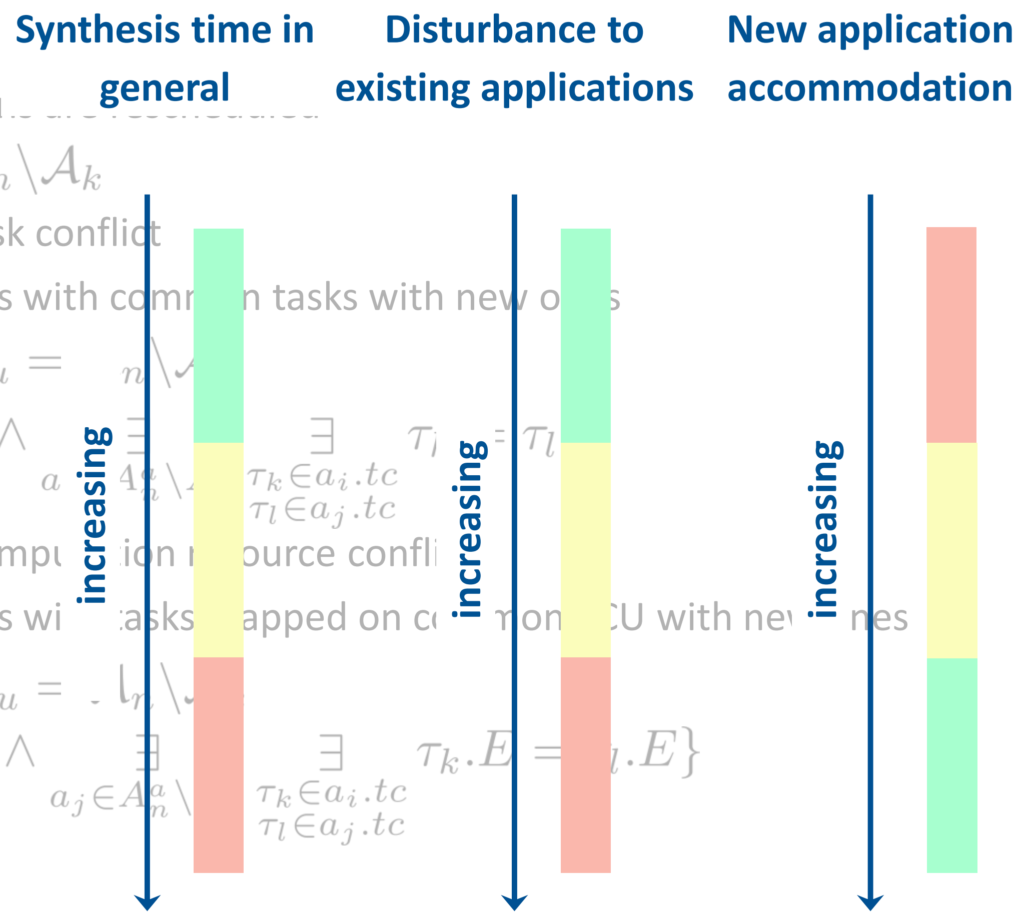
      $\mathcal{A}_k = (\mathcal{A}_o \cap \mathcal{A}_n) \backslash \mathcal{A}_\tau, \mathcal{A}_u = \mathcal{A}_n \backslash \mathcal{A}_k$

      $\mathcal{A}_\tau = \{a_i | a_i \in \mathcal{A}_o^a \cap \mathcal{A}_n^a \wedge \exists_{a_j \in \mathcal{A}_n^a \backslash \mathcal{A}_o^a} \exists_{\tau_k \in a_i.tc, \tau_l \in a_j.tc} \tau_k = \tau_l\}$
  - Stage 3 – Rescheduling based on computation resource conflict
    - ➢ Reschedule existing applications with tasks mapped on common ECU with new ones

      $\mathcal{A}_k = (\mathcal{A}_o \cap \mathcal{A}_n) \backslash \mathcal{A}_E, \mathcal{A}_u = \mathcal{A}_n \backslash \mathcal{A}_k$

      $\mathcal{A}_E = \{a_i | a_i \in \mathcal{A}_o^a \cap \mathcal{A}_n^a \wedge \exists_{a_j \in \mathcal{A}_n^a \backslash \mathcal{A}_o^a} \exists_{\tau_k \in a_i.tc, \tau_l \in a_j.tc} \tau_k.E = \tau_l.E\}$
  - Stage 4 – Complete rescheduling
    - ➢ All existing applications are considered reschedulable

      $\mathcal{A}_k = \mathcal{A}^b, \mathcal{A}_n = \mathcal{A}_n^a$



Schedule Management Framework

- **Web module**
  - Utilizes the Websocket Secure
    - Full-duplex communication between client and server
    - SSL/TLS layer for secure communication

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  - Methods for client-server communication
    - Request
    - ➢ Client sends request file to server

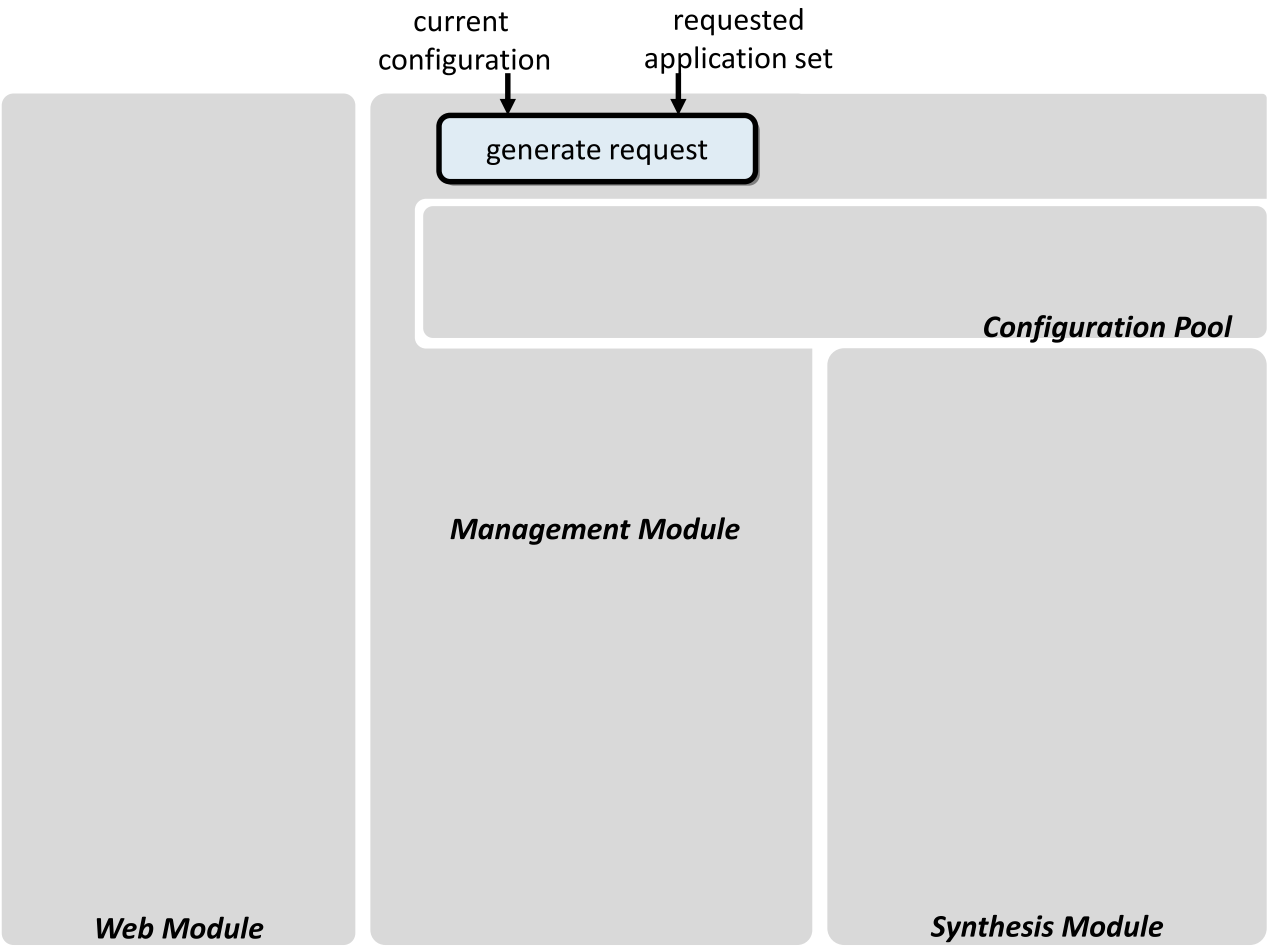
    - Response
    - ➢ Server sends response to client: either a valid configuration or a request denial

    - Abort
    - ➢ Client informs the server to abort operation, when a local result is obtained first

    - Update
    - ➢ Client sends the new configuration to the server to update the configuration pool

Schedule Management Framework

- **Management module – client side**



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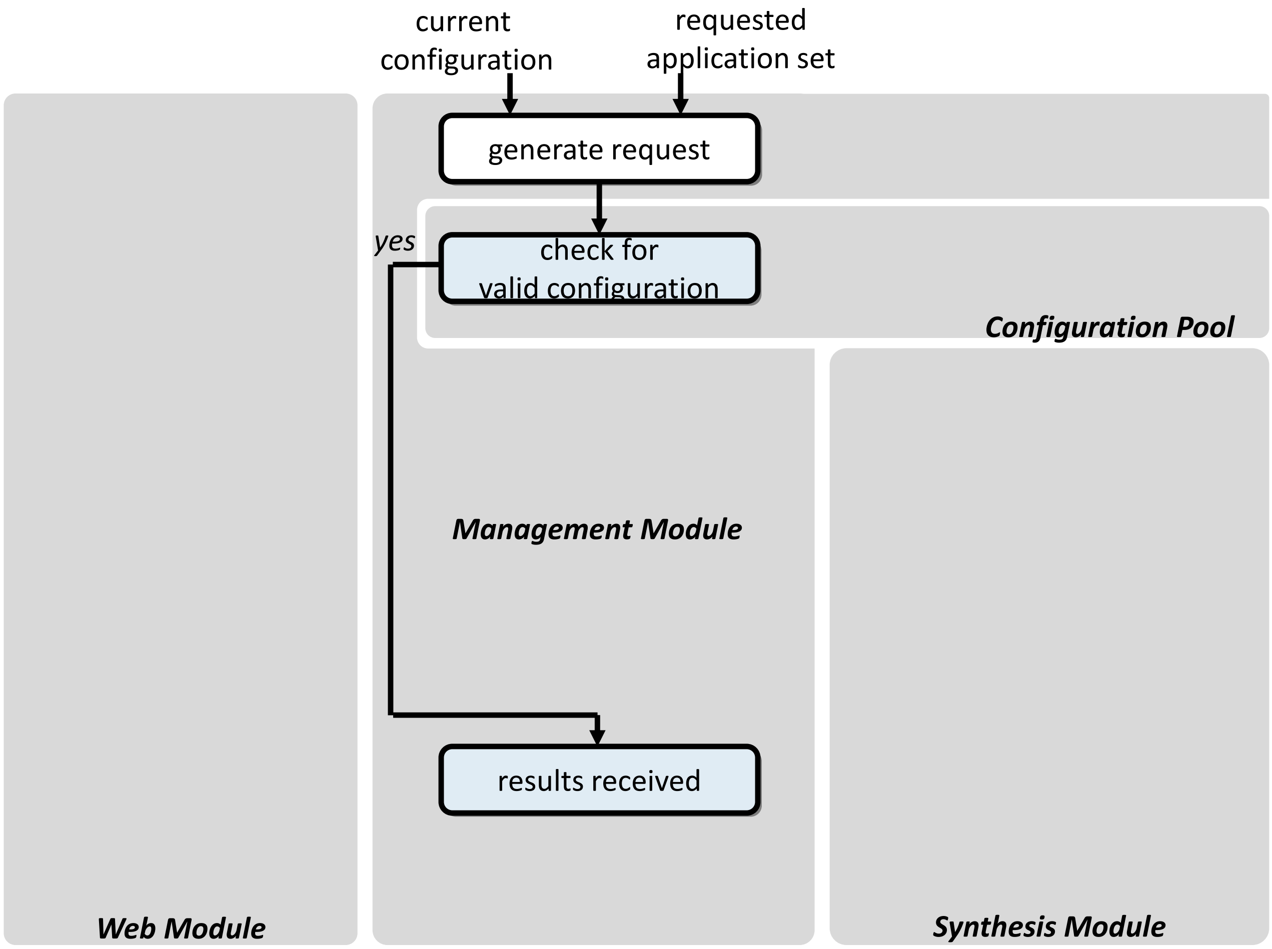

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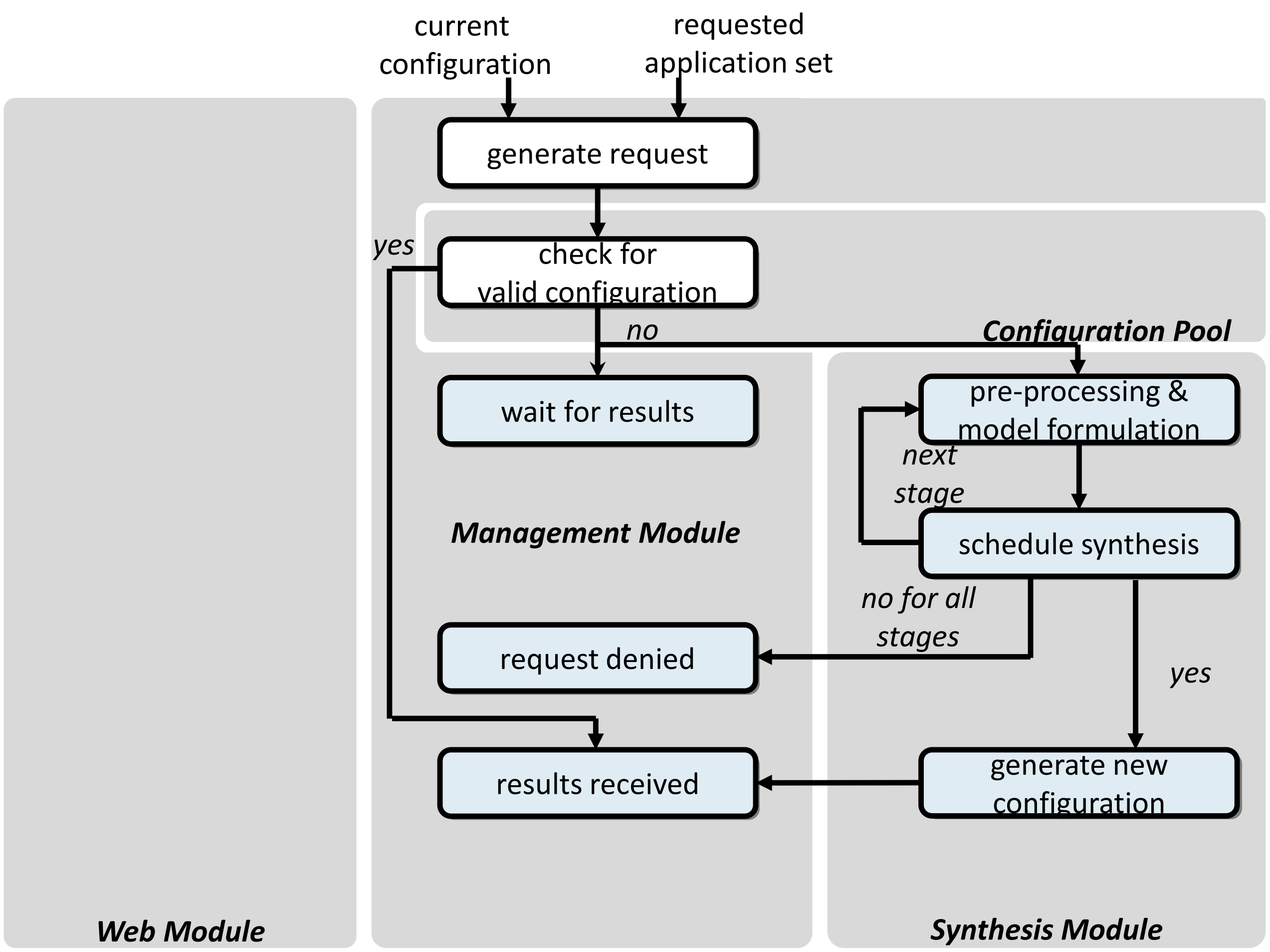

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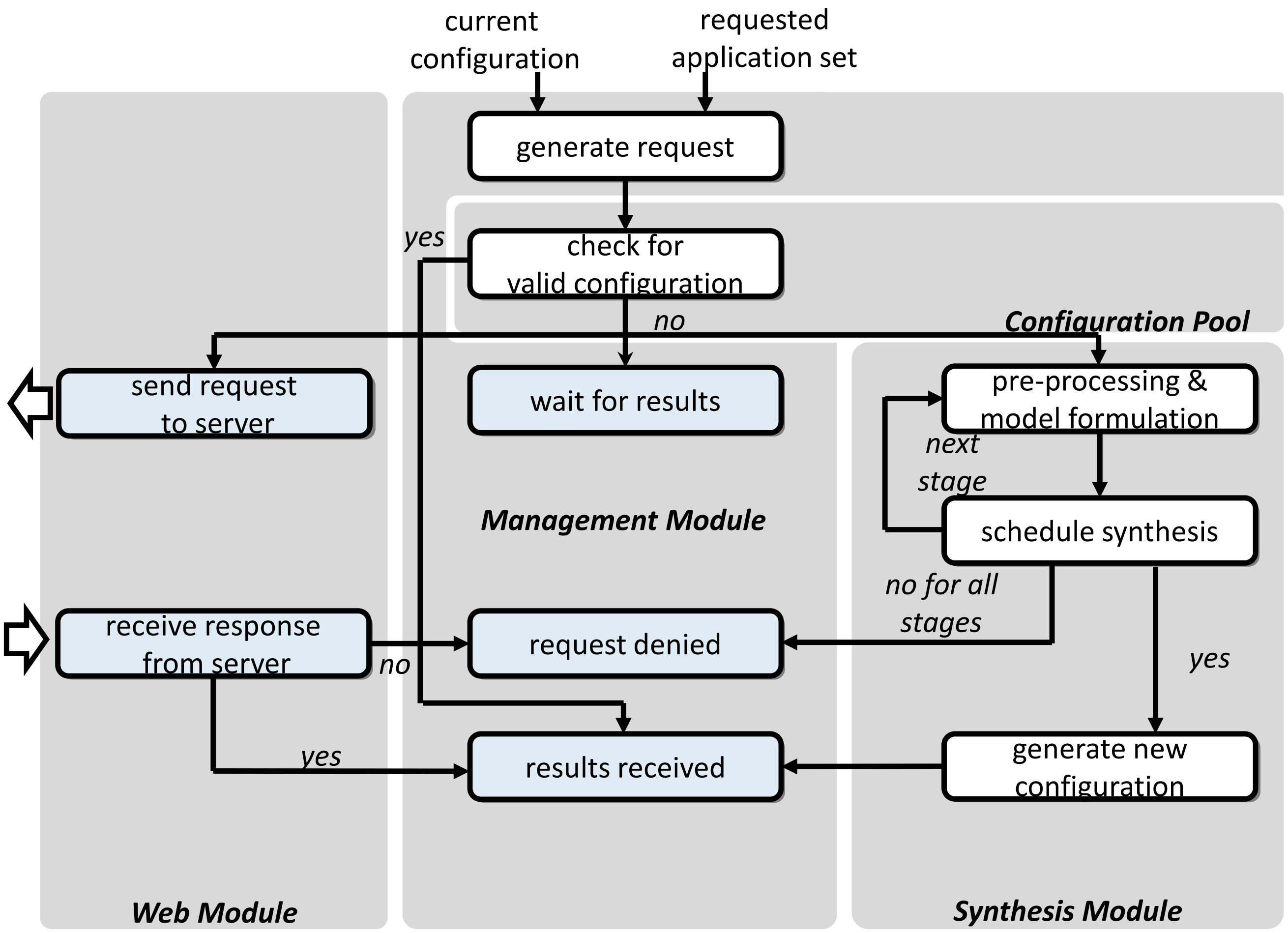

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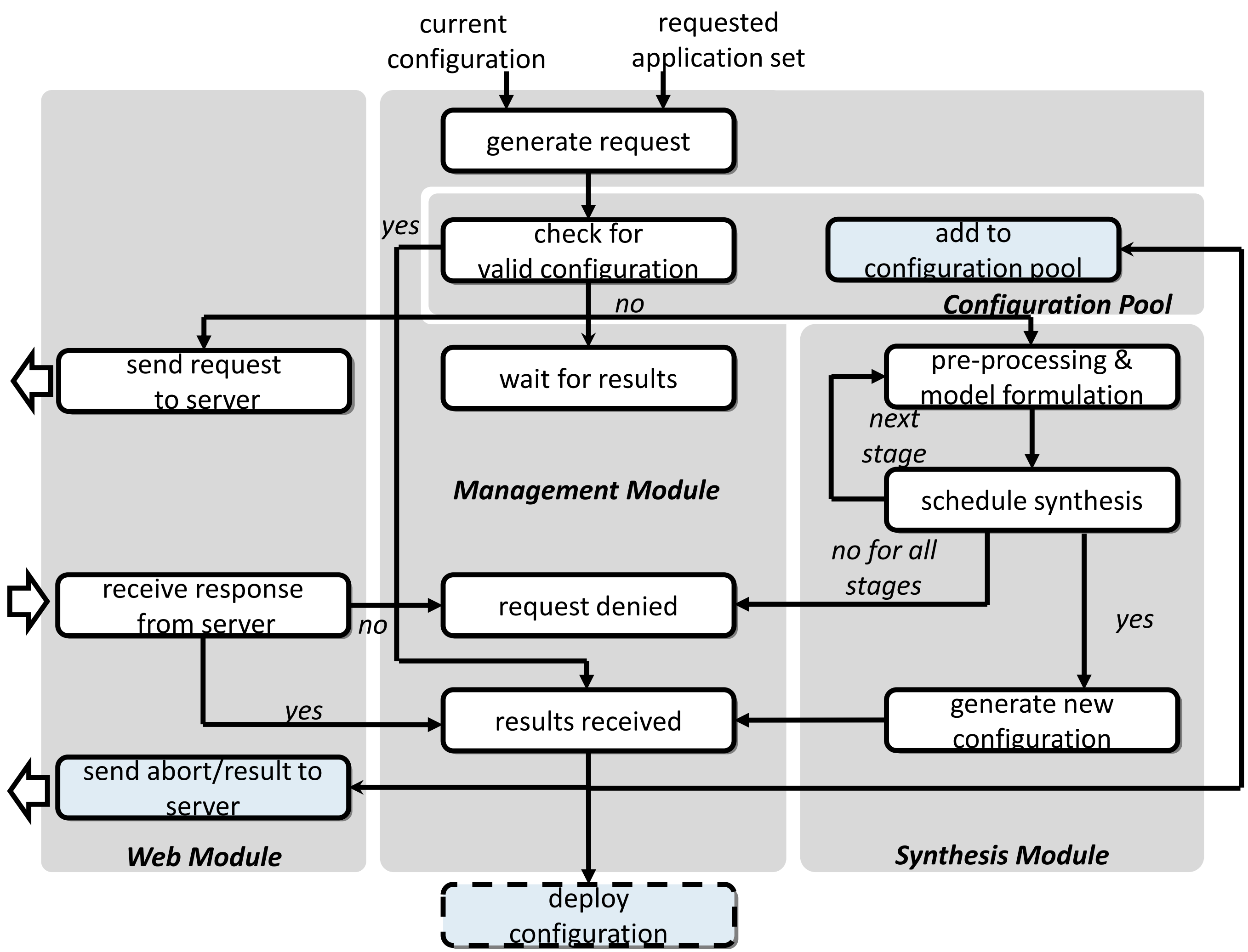
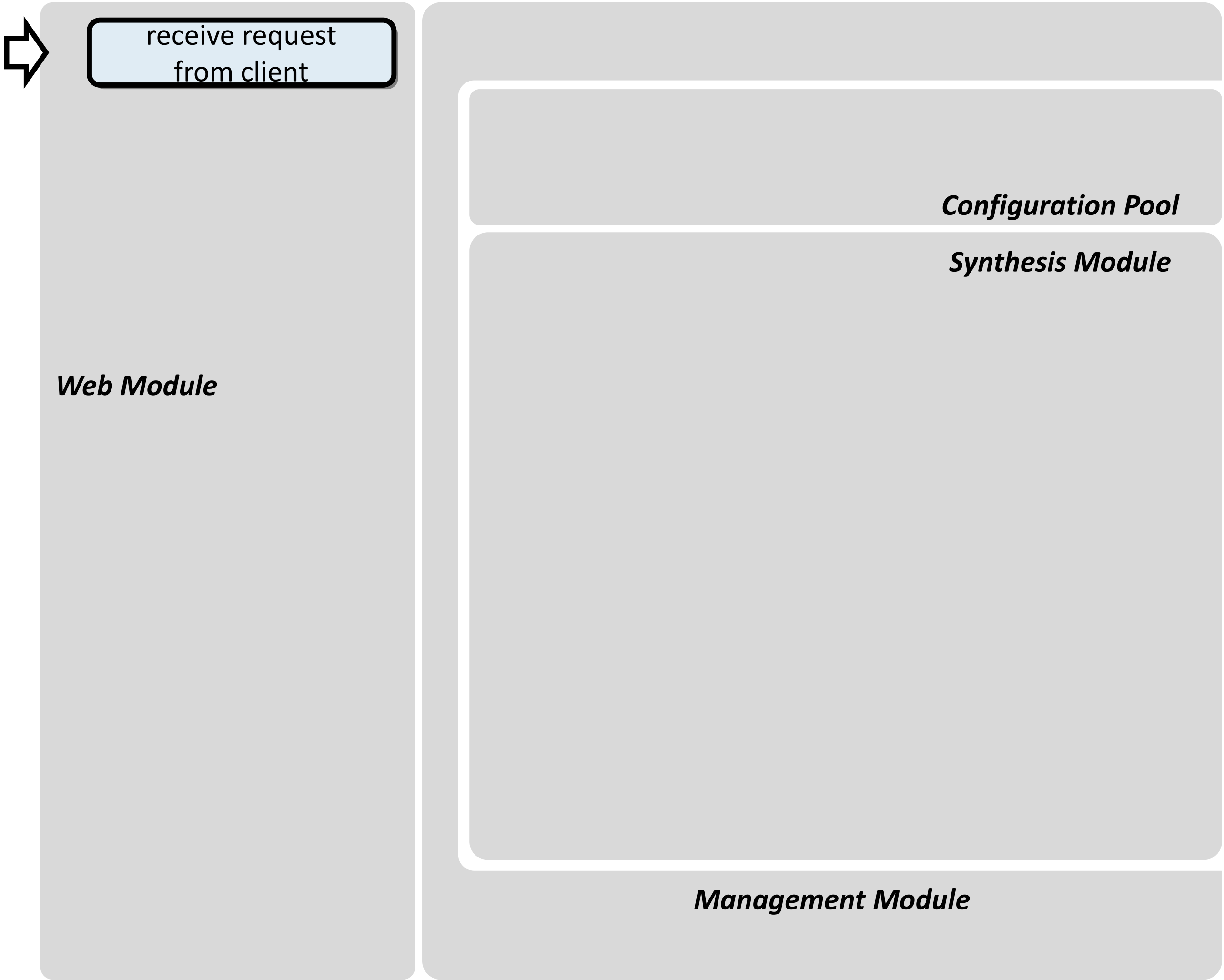


Schedule Management Framework

- **Management module –server side**



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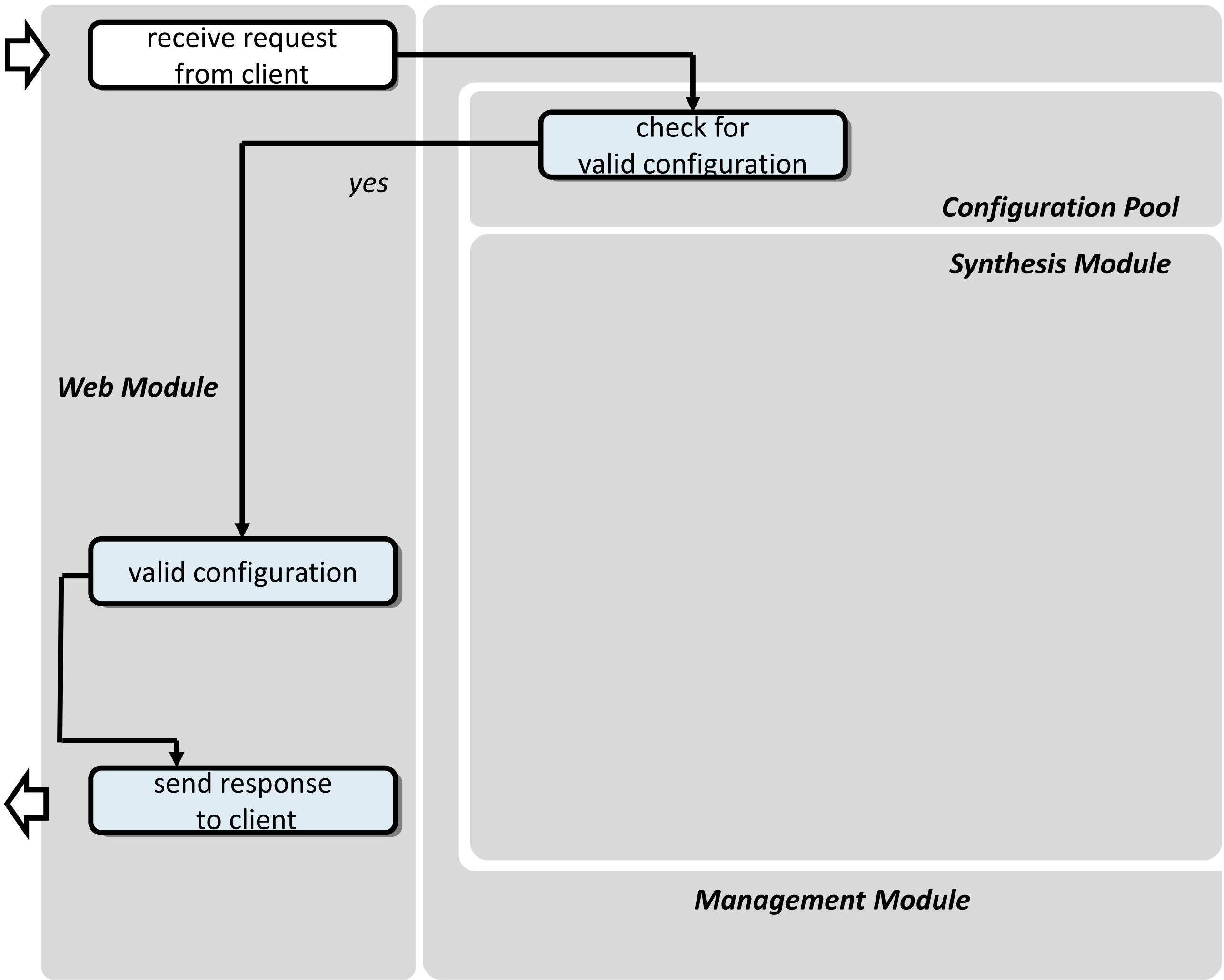

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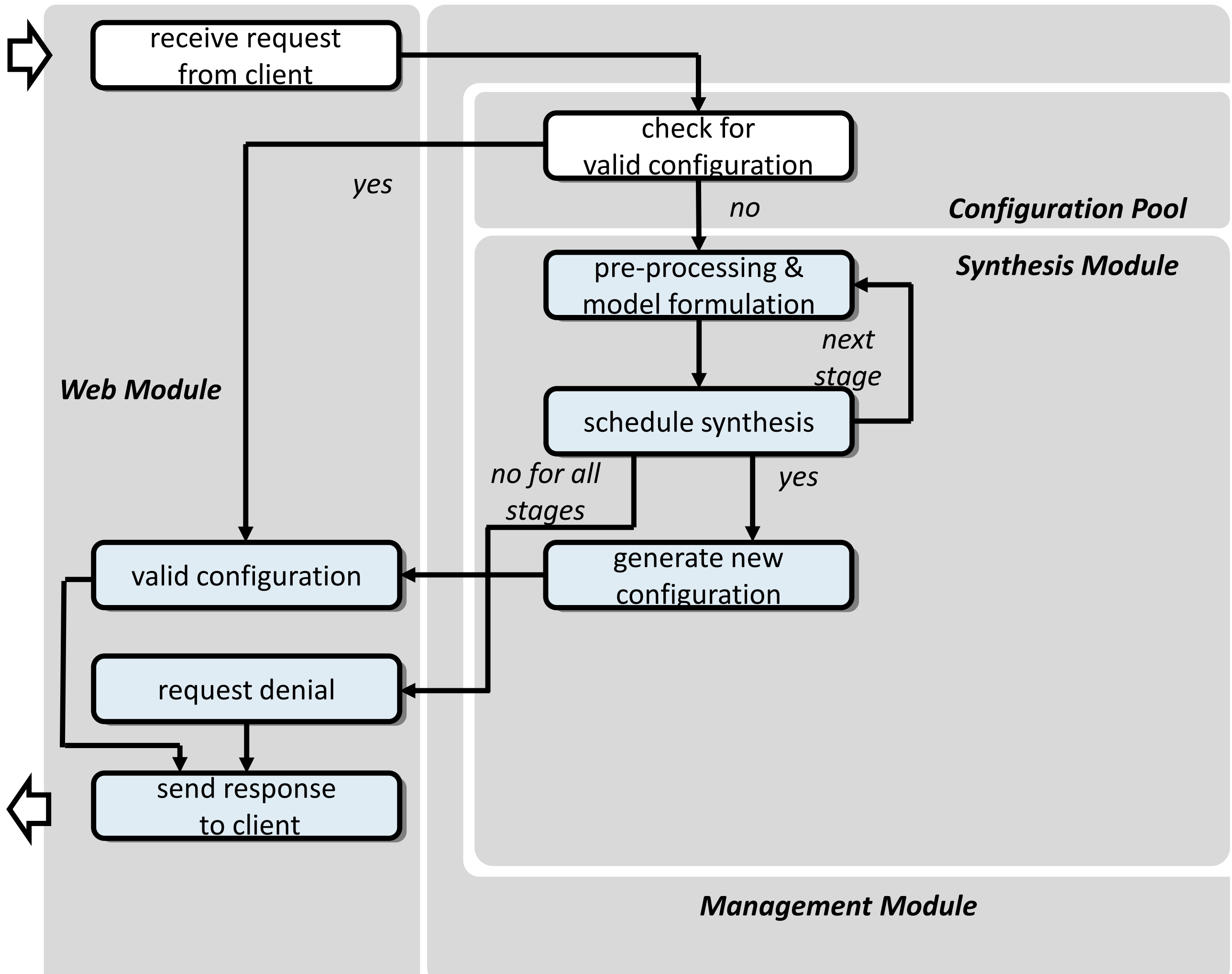
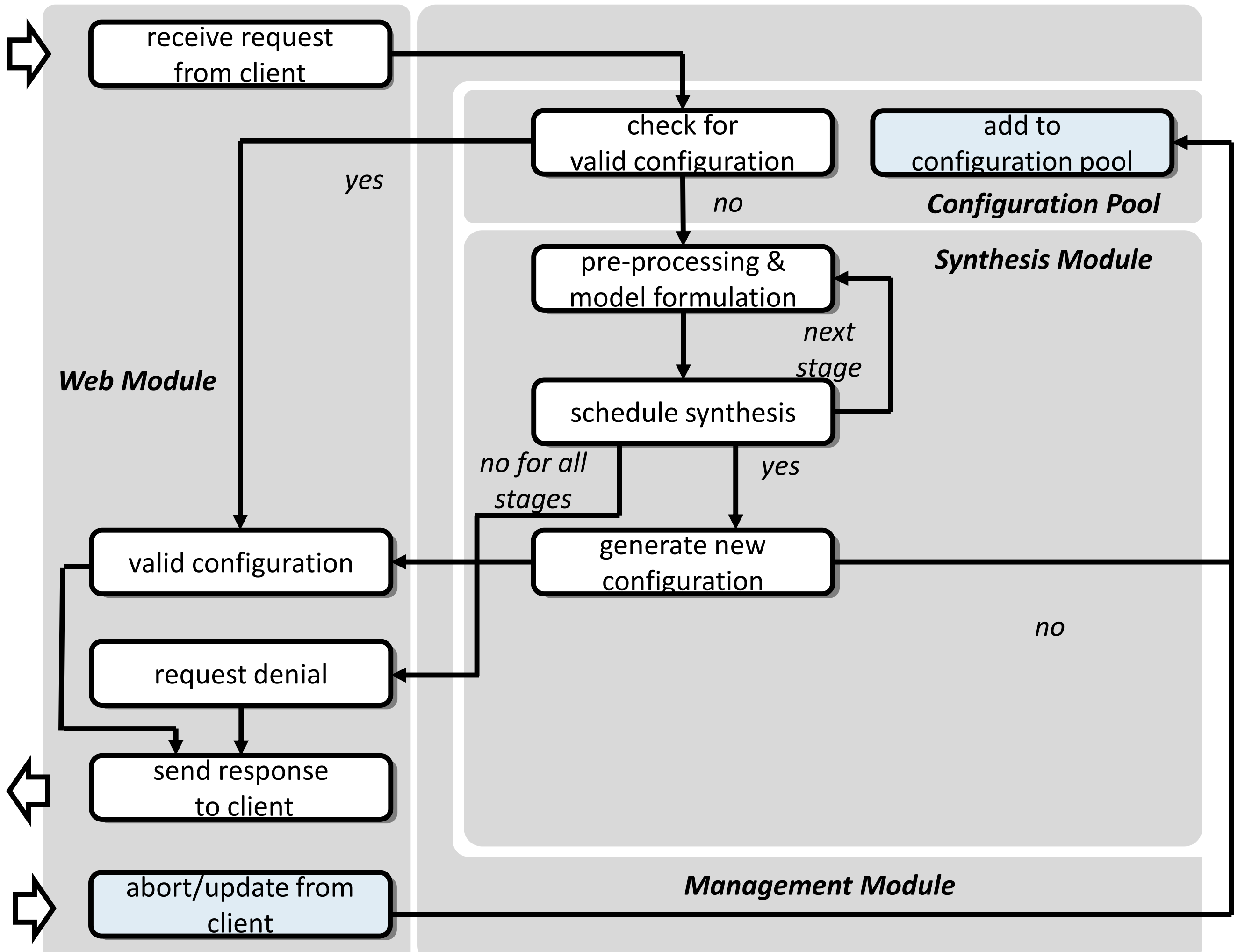
- **Management module –server side**



Schedule Management Framework

- **Management module –server side**



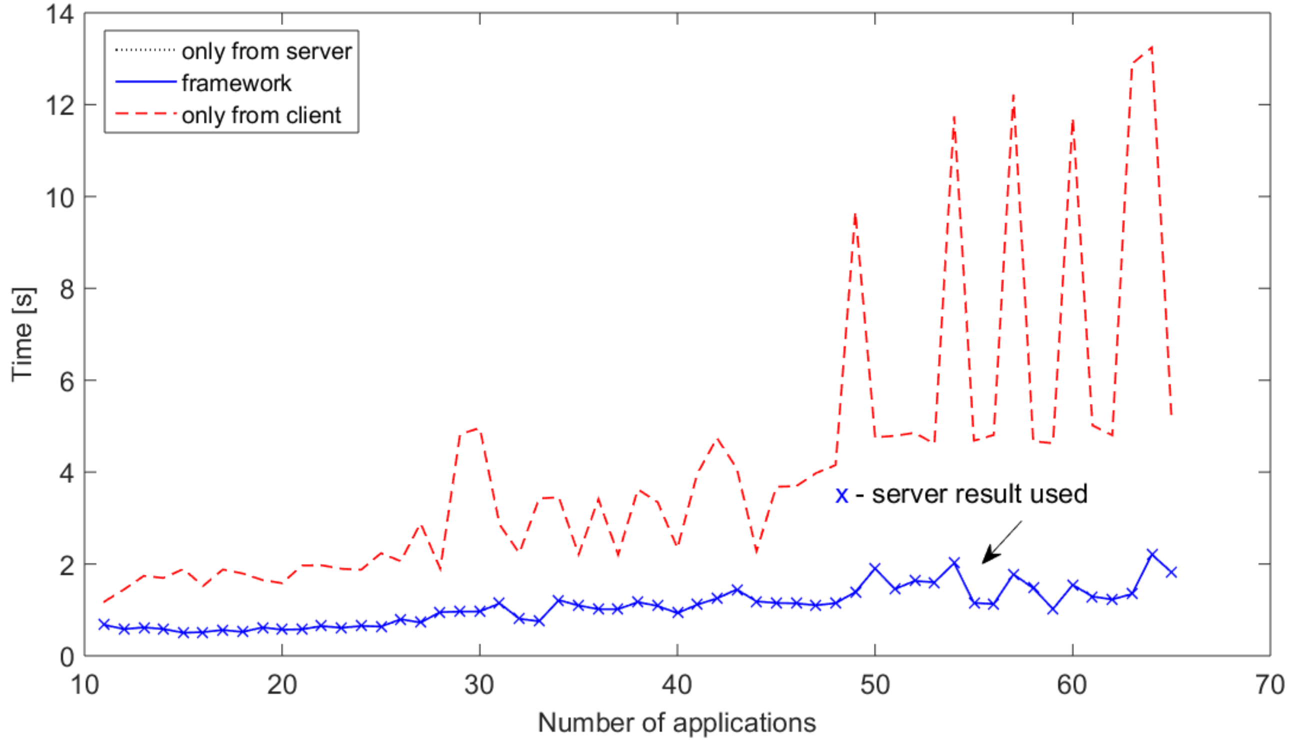
Results

- **Implementation**
  - Client on a Raspberry PI 2 Model B
  - Server on a PC
  - Connection through WLAN

- **Case study**
  - Hardware architecture: 10 ECUs connected by 4 switches
  - 100 applications are randomly generated (10 basic applications, 90 plug-in applications)
  - 20 request series of incrementally adding applications
  - Different overhead provision for possible authentication and security process on server

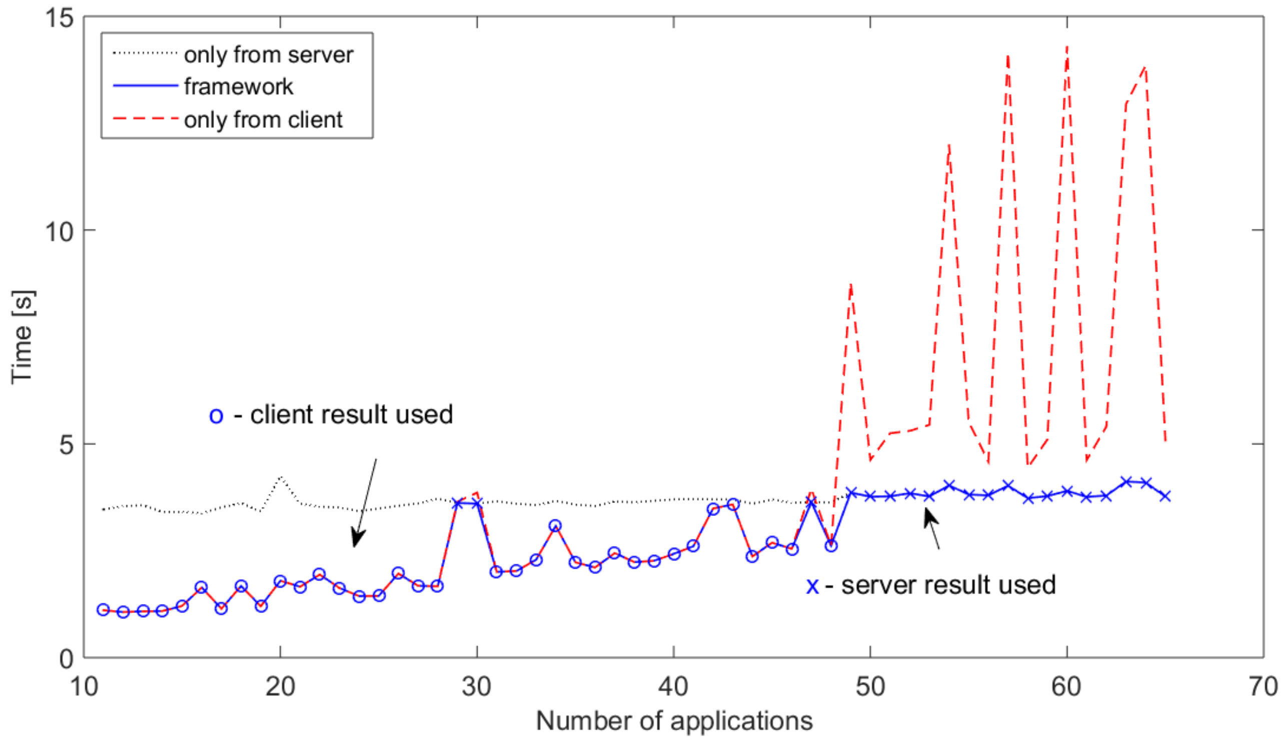
Results

- **Synthesis time**
  - Case 0 s overhead provision for server



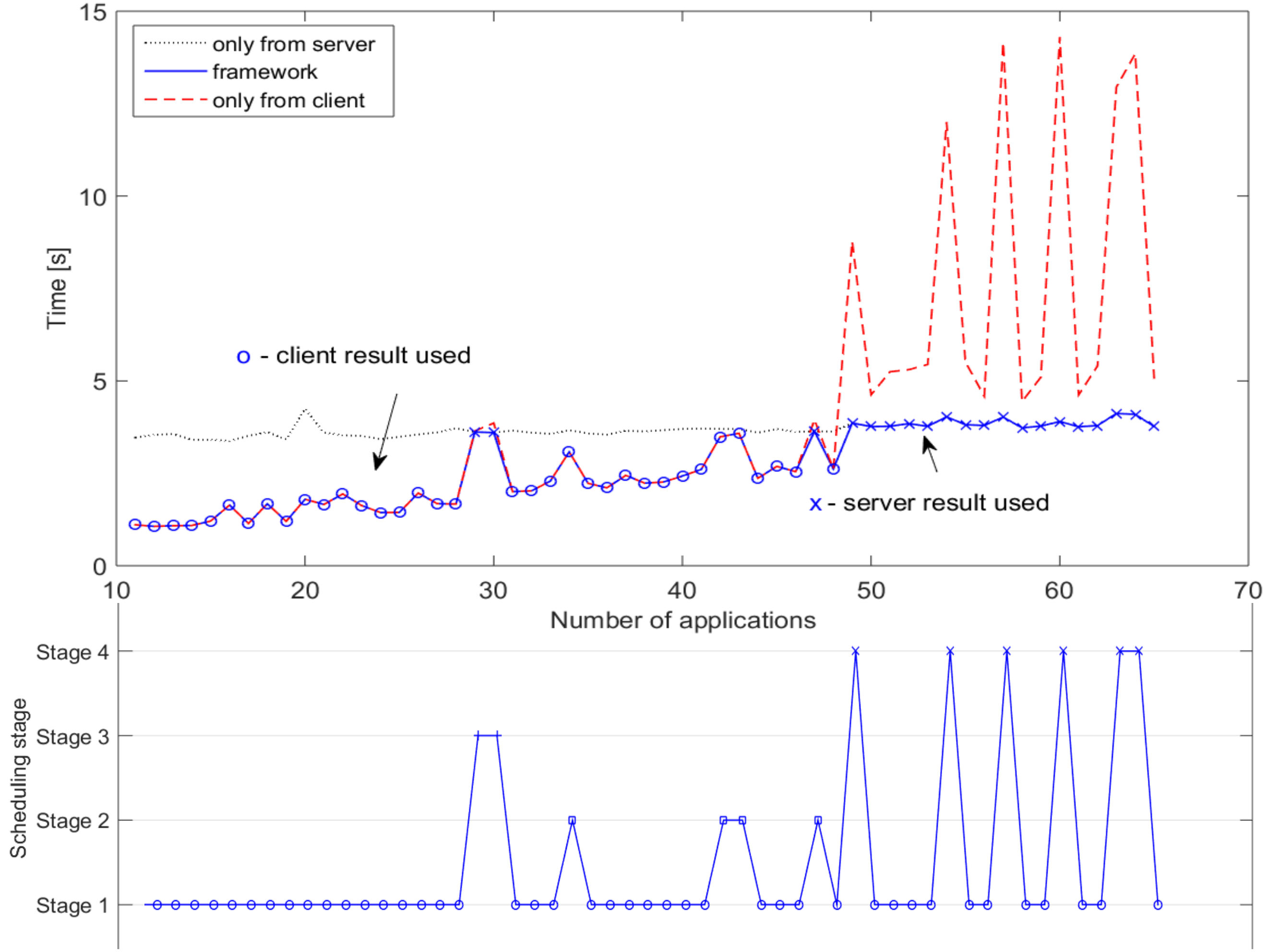
Results

- **Synthesis time**
  - Case 3 s overhead provision for server



Results

- **Scheduling stages**



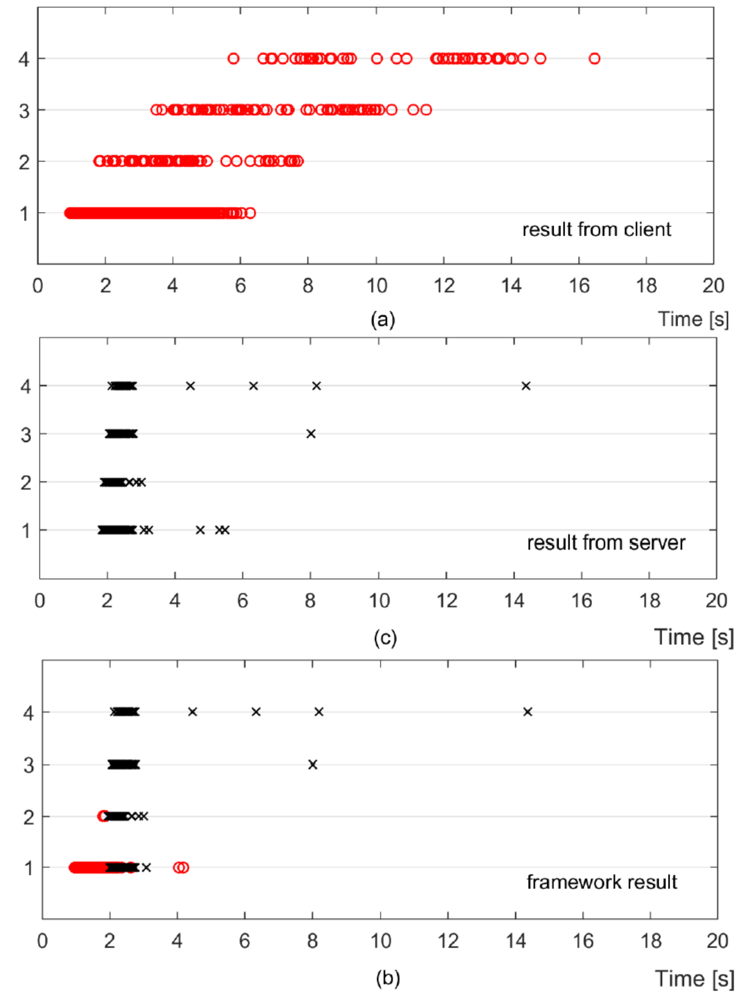
Results

- **Comparison of synthesis time for client, server and proposed framework**
  - Case 1.5 s overhead provision for server

client

server

framework



Concluding Remarks

- **Problem**
  - Ethernet-based time-triggered automotive system
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- **Approach**
  - Client-server based software framework for schedule management
  - Use of local computation and cloud-computing for online schedule synthesis and management
  - Four-stage scheduling strategy for trade-off between synthesis time, disturbance to existing applications and the chances of accommodating new ones

Concluding Remarks

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  - Four-stage scheduling strategy for trade-off between synthesis time, disturbance to existing applications and the chances of accommodating new ones
- **Future work**
  - Utilize the multi-core architecture to parallelize synthesis methods to reduce synthesis time
  - Explore extensibility-aware scheduling to provision resources for future applications so more applications can be accommodated using incremental design

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Thanks for your attention!

Q/A