Chair of Communication Networks
Department of Electrical and Computer Engineering
Technical University of Munich

QoS Provisioning in Industrial Wireless Sensor Networks

Samuele Zoppi, H. Murat Gürsu, Wolfgang Kellerer

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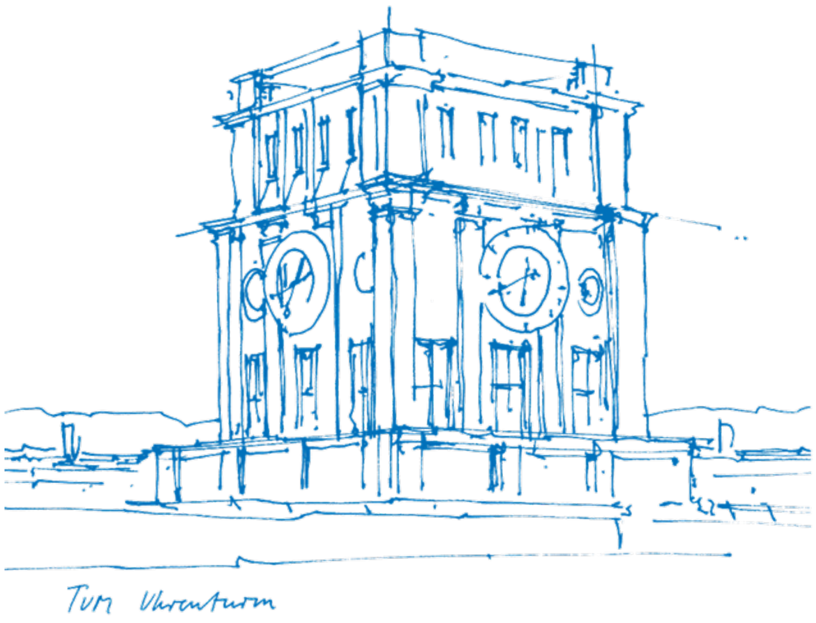
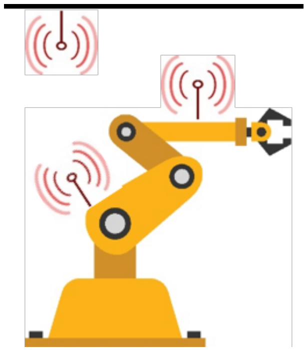
Munich, 1st December 2017



Background

Next-generation industrial automation systems will be **wirelessly** interconnected [HPO16].



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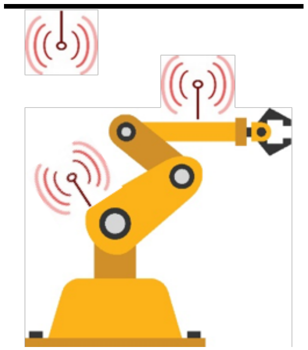

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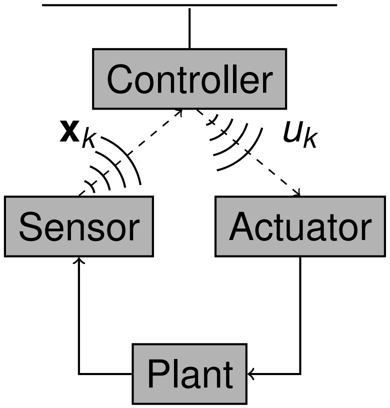

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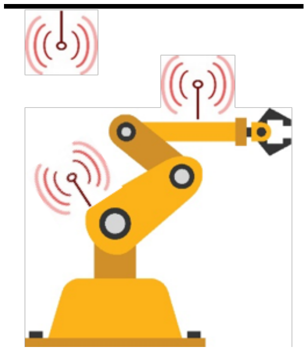
Stochastic LTI control system:

$$\mathbf{x}_{k+1} = \mathbf{A}\mathbf{x}_k + \mathbf{B}u_k + \mathbf{w}_k,$$
$$u_k = -\mathbf{K}\mathbf{x}_k,$$

$\mathbf{x}_k$ plant dynamic, u_k control law.



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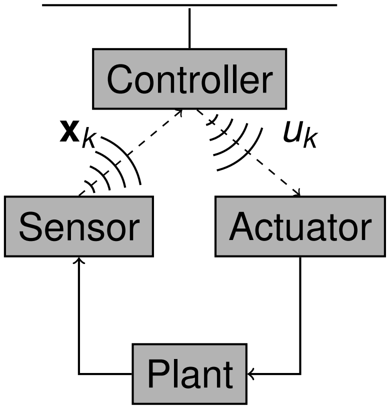

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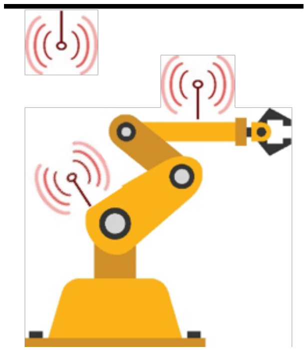
Sensor sends $\mathbf{x}_k$ to the Controller.

Controller computes and sends u_k to the Actuator.



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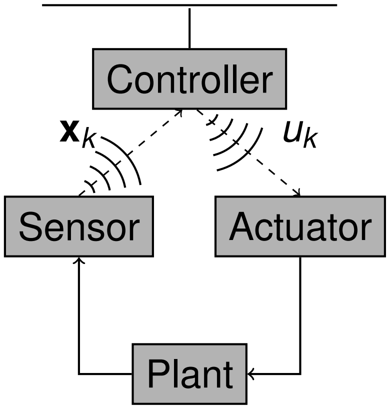

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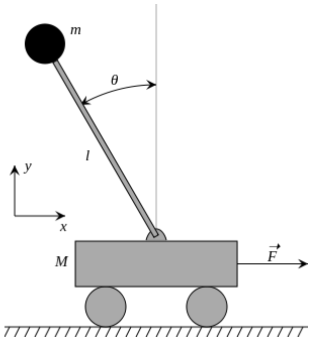
Inverted pendulum as benchmark NCS **application**.



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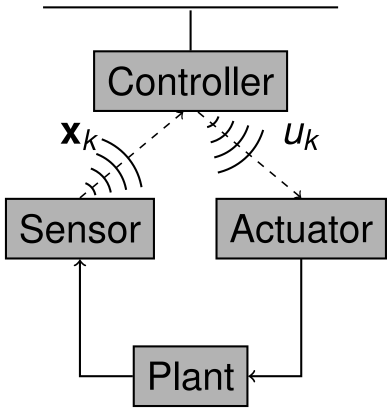

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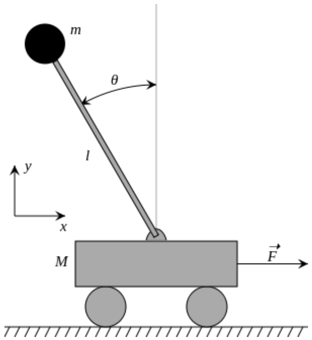

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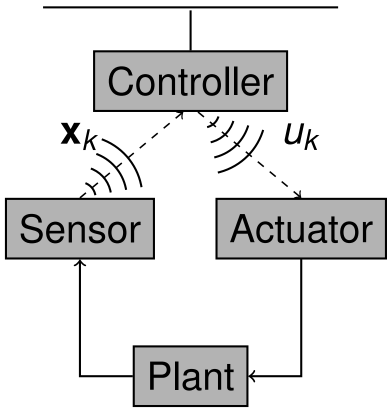

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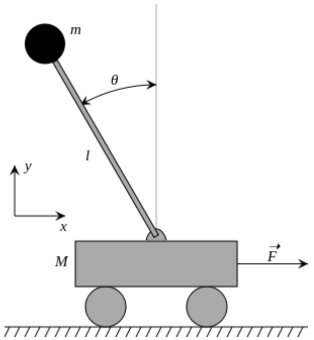
Uplink traffic:

$$\mathbf{x}_k = \begin{bmatrix} x_k \\ \dot{x}_k \\ \theta_k \\ \dot{\theta}_k \end{bmatrix} \rightarrow \text{256 bits @ 20Hz = 5 kbps.}$$



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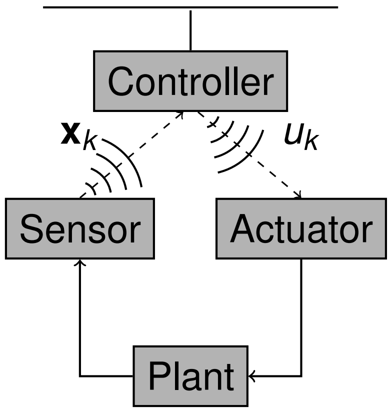

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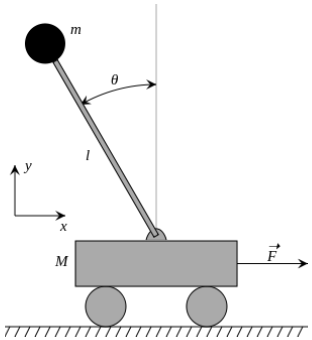

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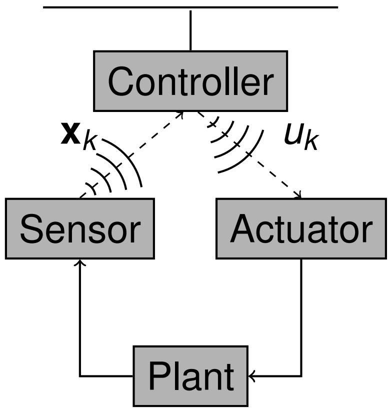

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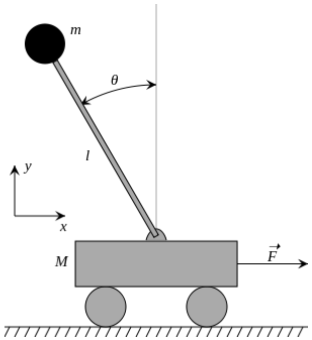
WSN (PHY IEEE 802.15.4) link $\rightarrow$ 250 kbps.



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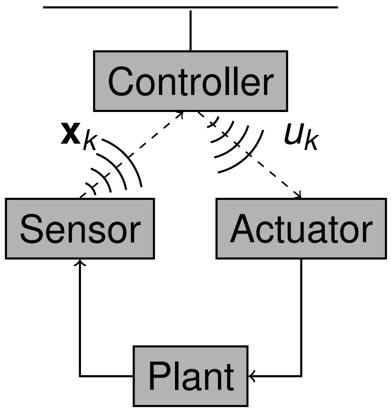

Motivation

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Problem: Current WSN lack dynamic real-time QoS provisioning.

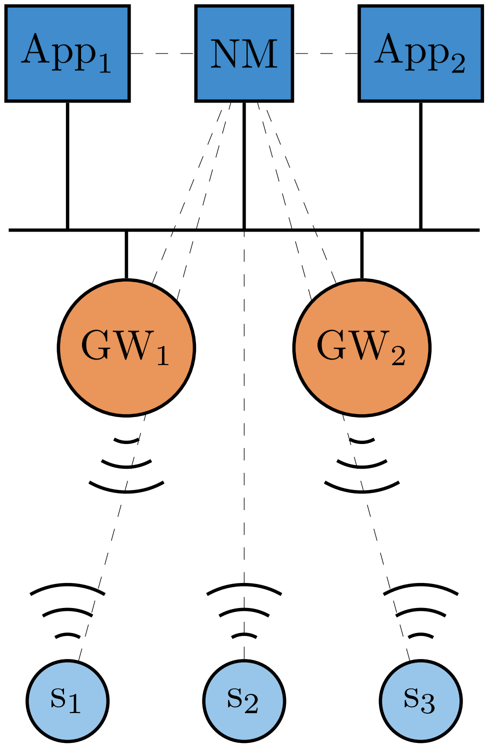
Approach:

1. Definition of a QoS provisioning framework for IWSN.
2. Implementation of the framework in a testbed.

Outline

Network Architecture

Centralized, star topology.



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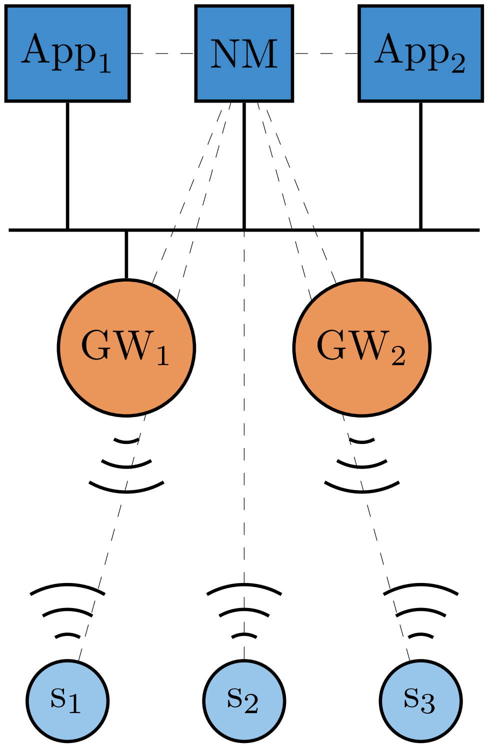
Network elements:

1. **Application (App)**: industrial NCS application
2. **Network Manager (NM)**: manager of the Network Resources of the entire WSN
3. **Gateway (GW)**: interface btw the WSN devices, the NM and Apps
4. **Sensor (s)**: WSN device



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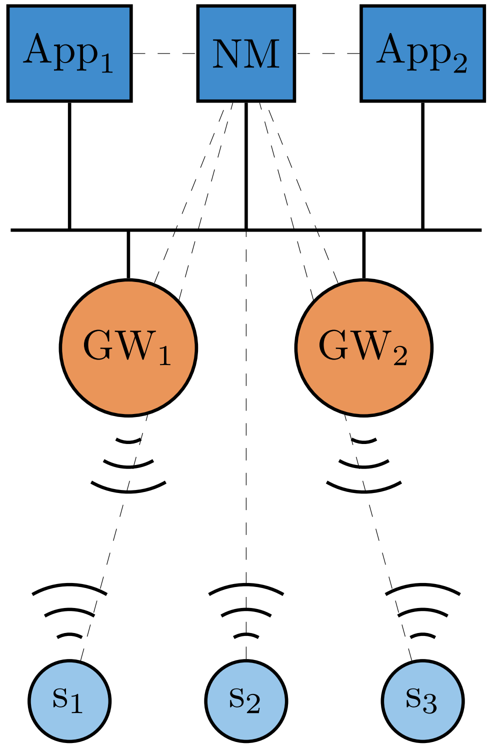
Data links btw NM and WSN devices through the GW.

Control links btw App and WSN devices through the GW.



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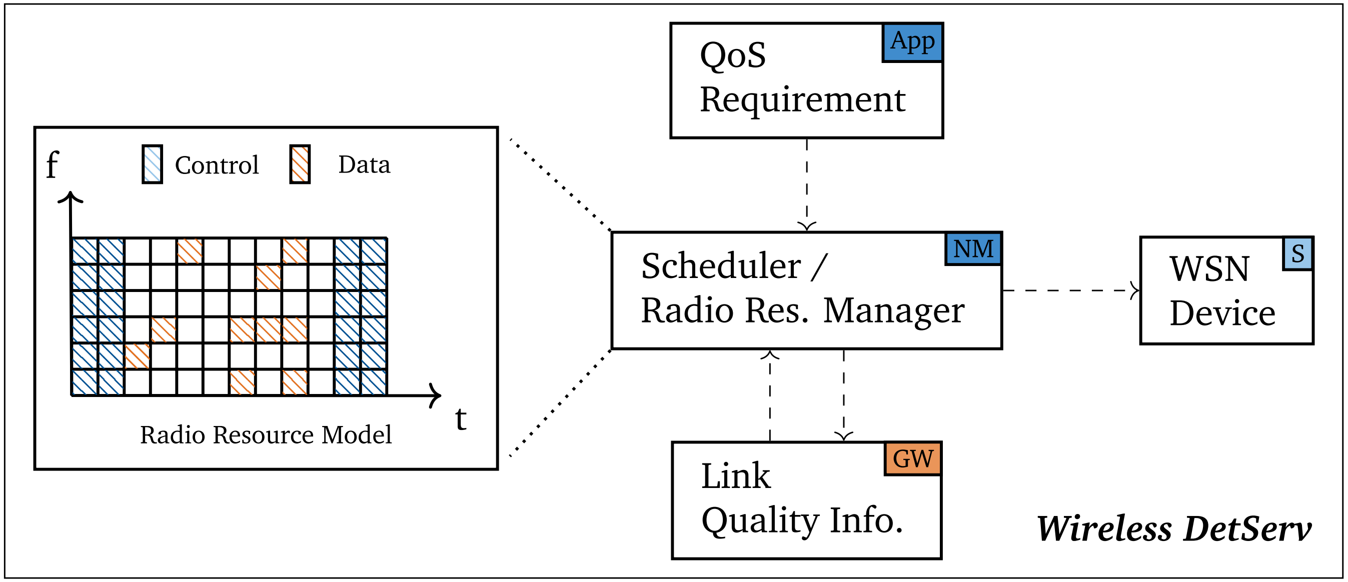

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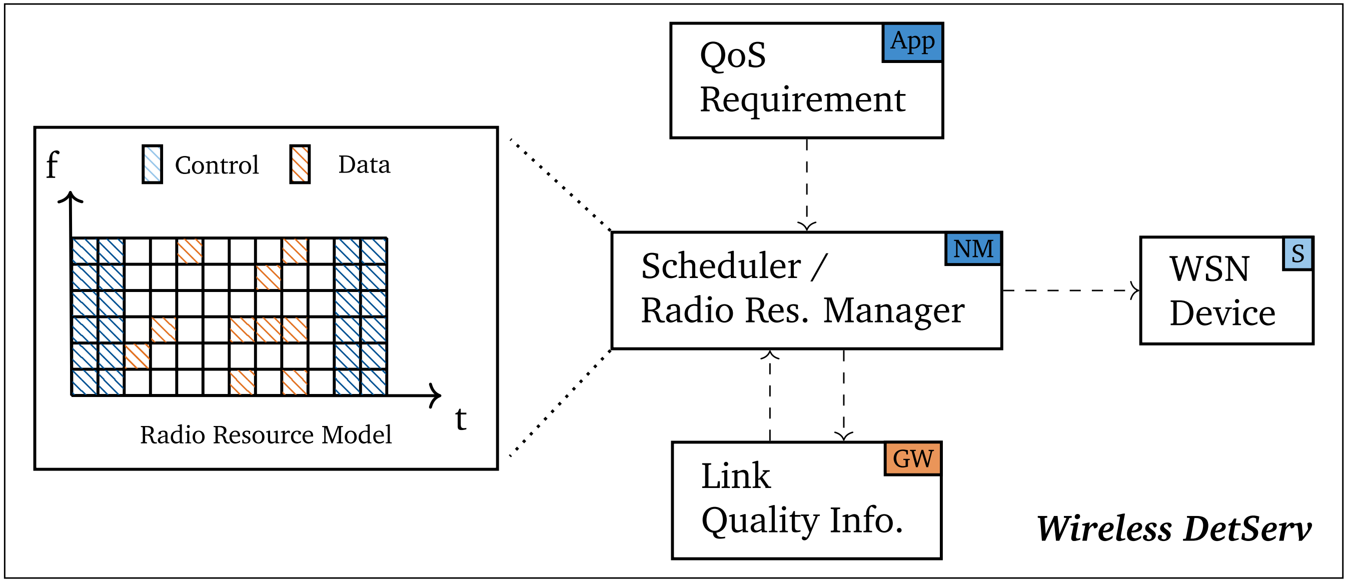

Radio Resource Manager **inputs**:

1. QoS requirements from the application.
2. QoS Model of the MAC radio resources.
3. Link Quality Information of the radio resources.

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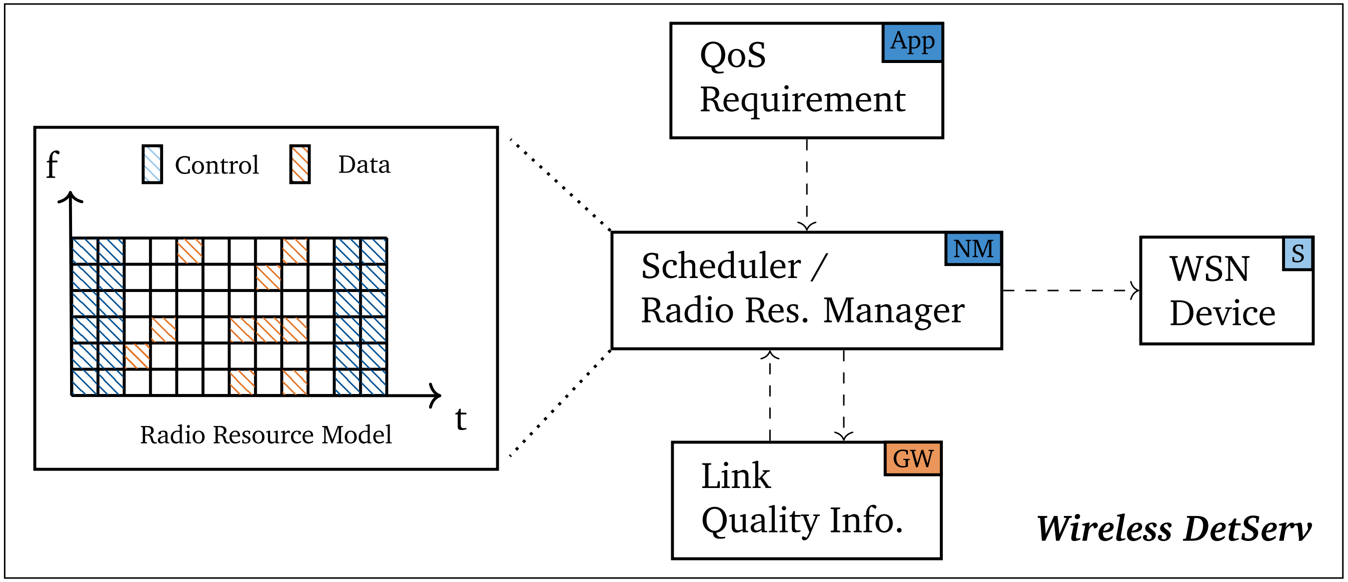

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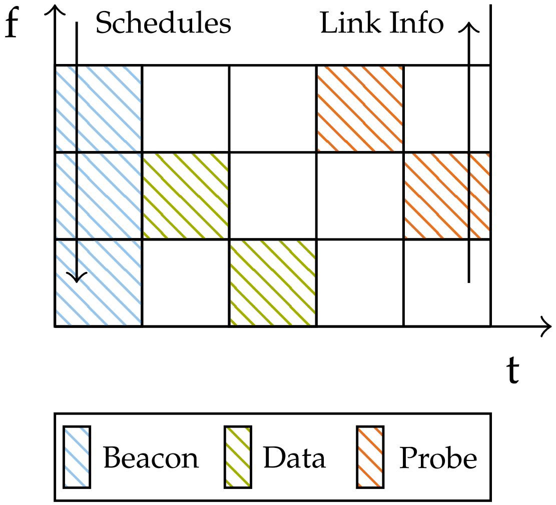
Radio Resource Manager **outputs**:

1. Radio resources for Data packets (application).
2. Radio resources for Control packets (schedules, LQI probes, ...).

QoS Framework (2)

Dynamic scheduling is possible in a TDMA-FDMA radio resource grid model.



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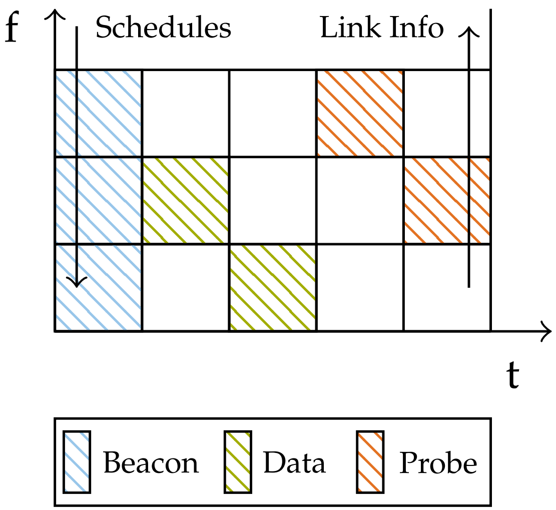

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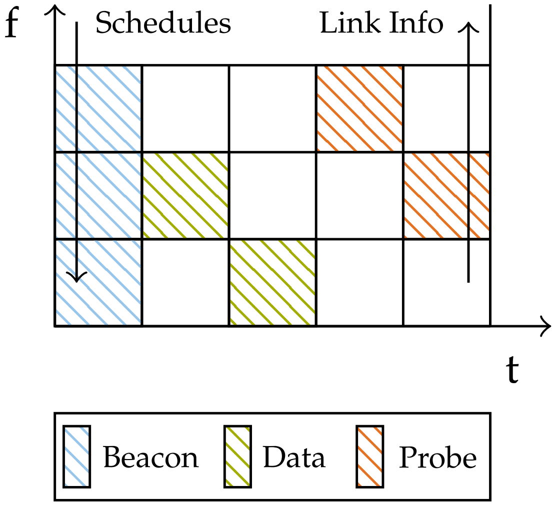

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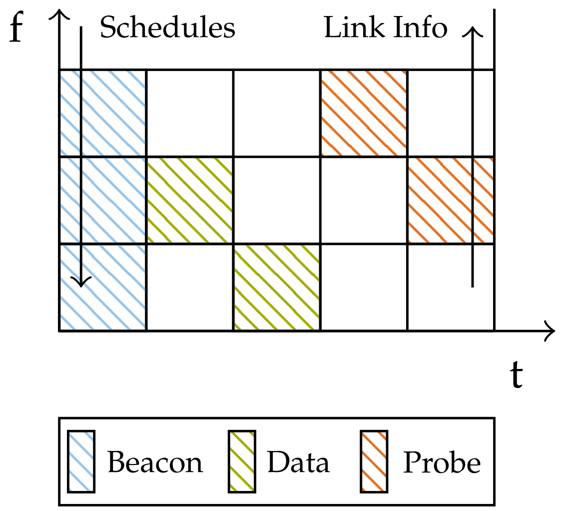
3. Distribution of new schedules (**output**)
   → sequence of radio resources (time-freq. pairs)
   → distributed using the beacon
   → calculated with a **reliability-based scheduler**



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- Nodes represent time instants before/after time slots.
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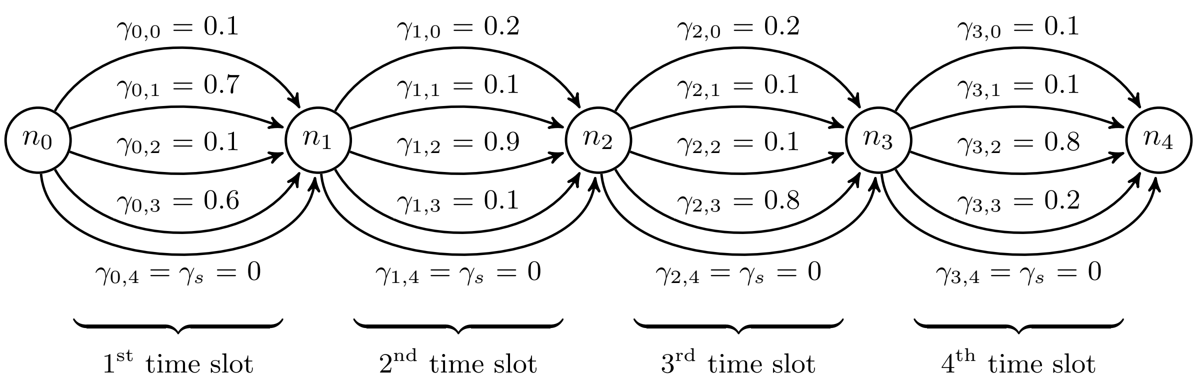

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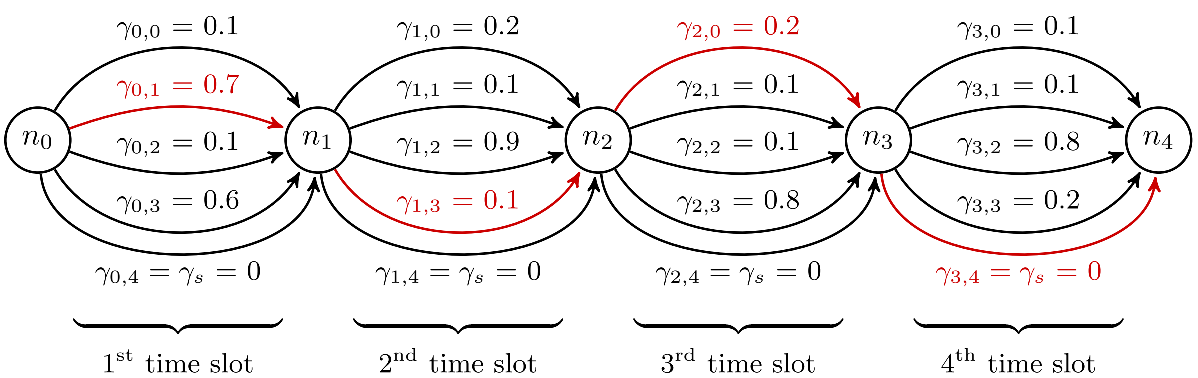
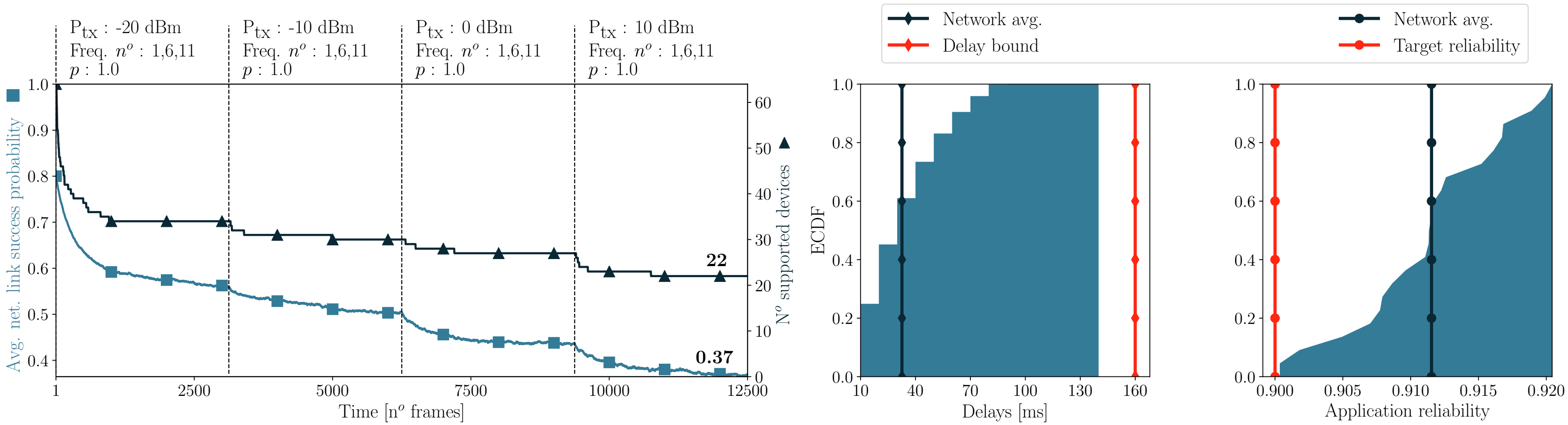
A Constrained Shortest Path scheduling algorithm finds the **schedule** (path) fulfilling the **target reliability**. $\rightarrow \{(0,1),(1,3),(2,0)\}$



QoS Framework (4) - Results

Simulation results of dynamic scheduling with latency and reliability constraints.



Reliability-based scheduling [eaED].

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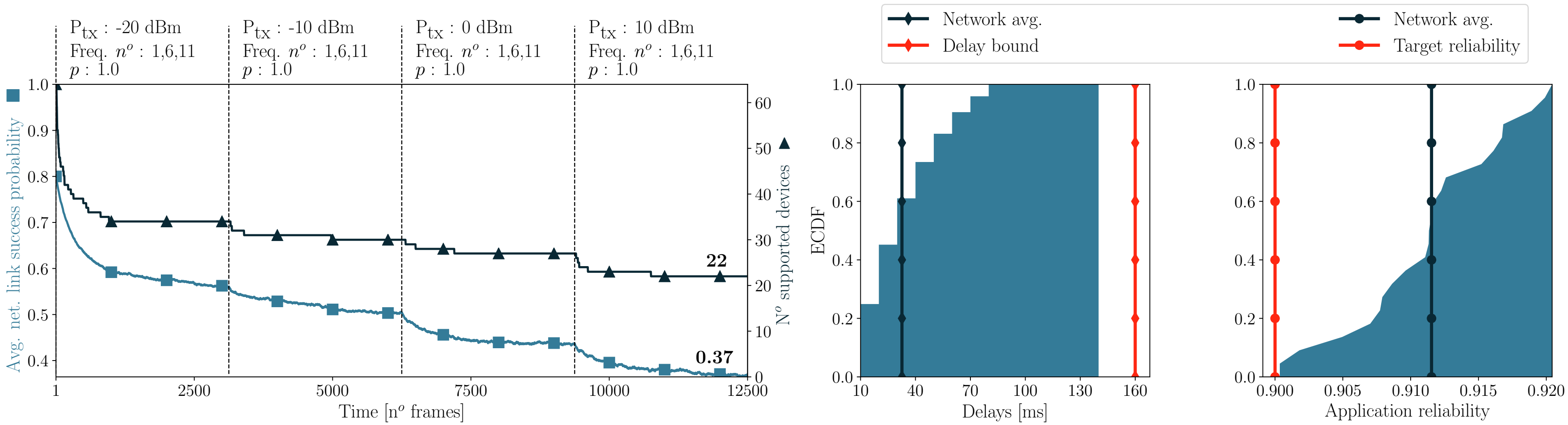
WSN operating in a dynamic interference scenario (Wi-Fi APs, @2.4GHz).



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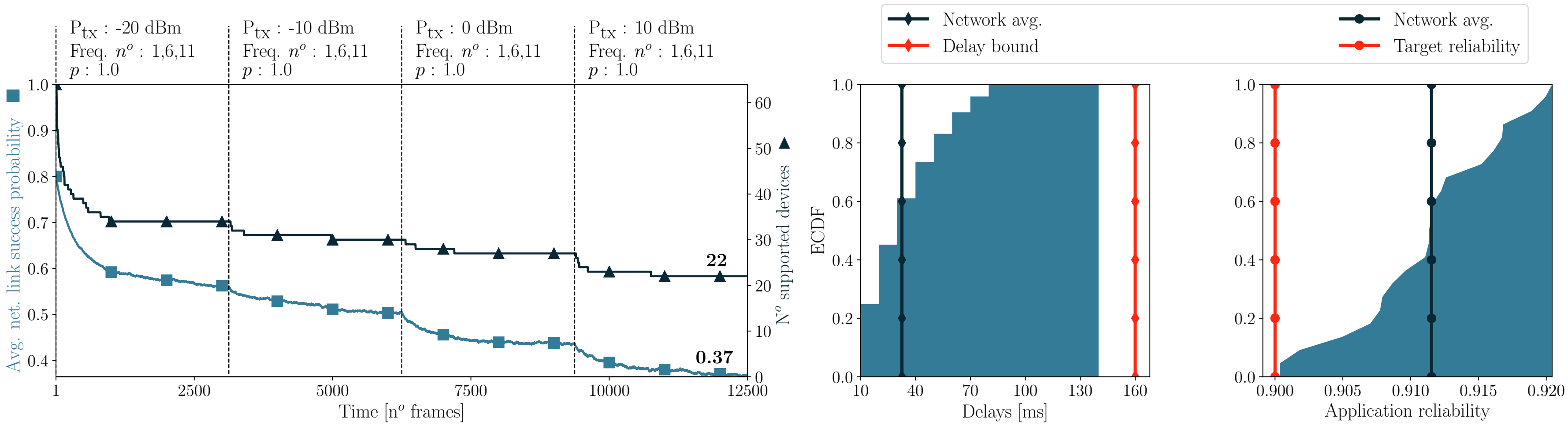

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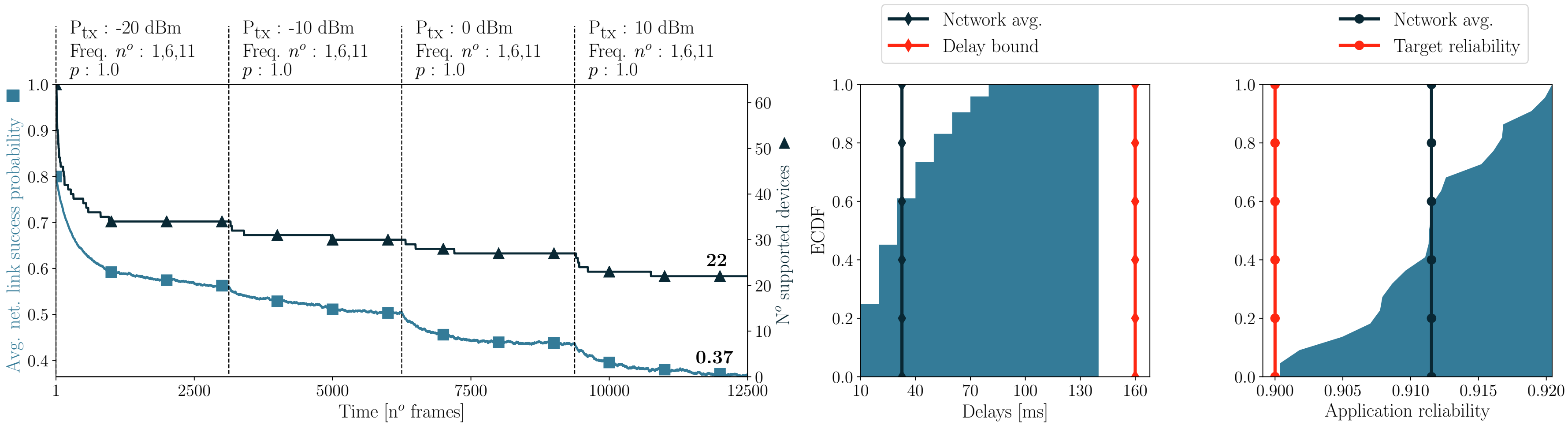


Reliability-based scheduling [eaED].

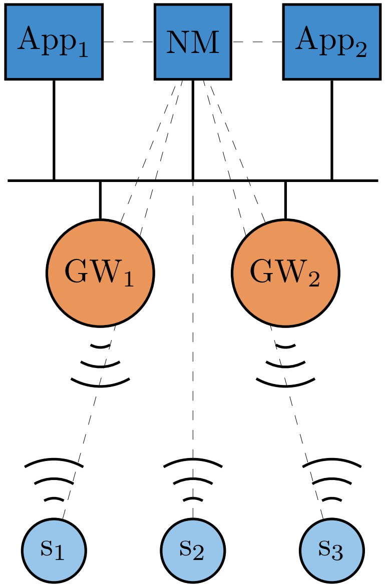
WDetServ guarantees reliability and delay bounds reacting against interference.

Outline

Implementation (1)

Deployment of an WDetServ NCS testbed:

1. Control logic (Controller) in the Cloud.
2. Sensing and Actuation in the WSN devices.
3. Gateway acts as forwarding entity.
4. Inverted Pendulum as benchmark control application.



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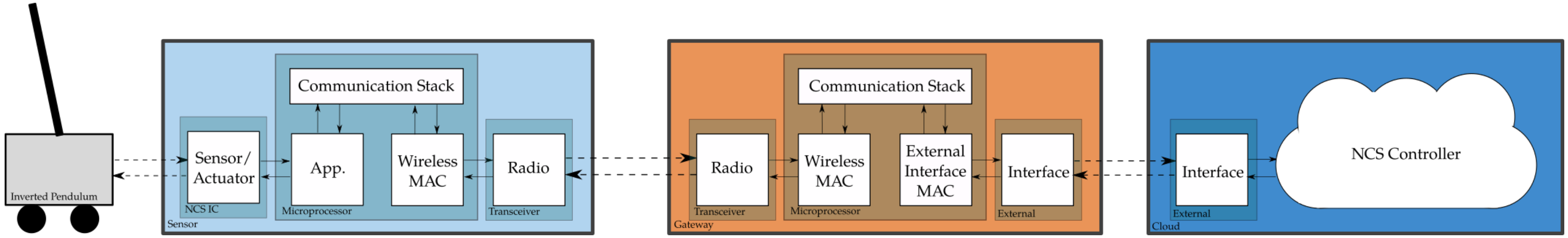

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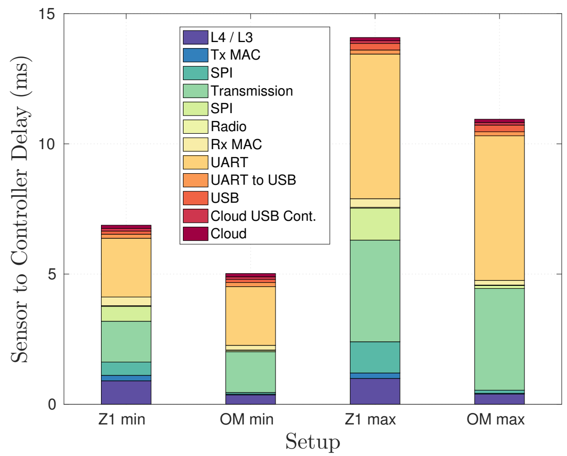
Problem: several HW and SW latency bottlenecks.



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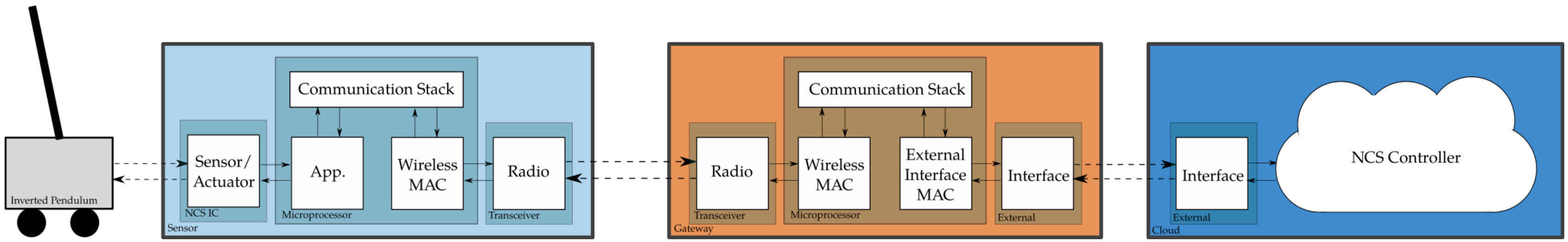

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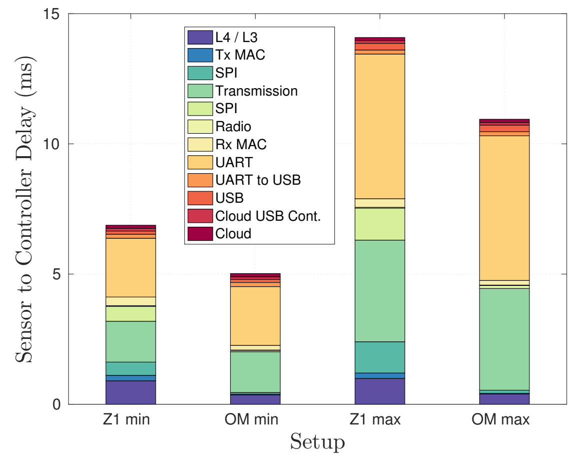
Problem: several HW and SW latency bottlenecks.

Solution: ad-hoc HW solutions for GW and WSN:

- Gateway
  high perf., multi-radio, multi-processor
  ⟶ low-latency, multi-channel SDR
- Sensor
  limited perf., single antenna, single processor
  ⟶ Zolertia Z1/RE-Mote, TI SimpleLink



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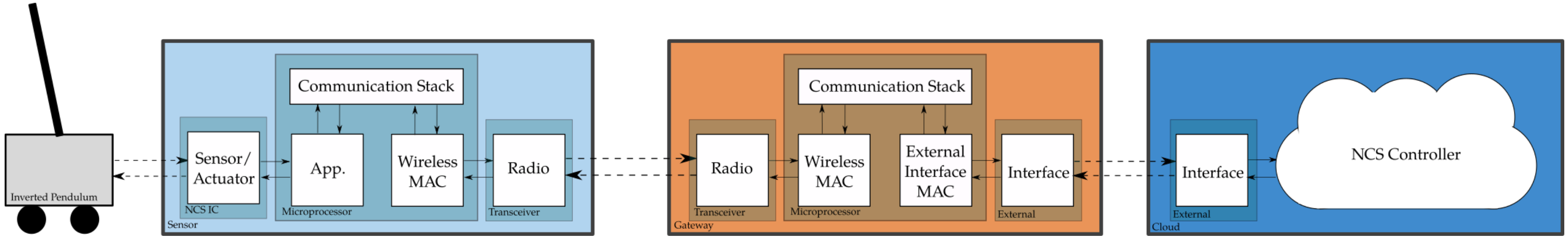

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The implemented reliability-based scheduler is able to react to changes in the wireless environment.

Latency is the major issue for HW implementation (radio, processing, ext. interface).

Further Work

Measurements of NCS Inverted Pendulum operating over the testbed will be performed.

NCS cross-layer scheduling algorithms will be developed.

Different Link Quality Estimators will be evaluated in the testbed.

Multi-radio, multi-processor, high-speed interface solutions will be implemented.

References

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