

Towards Real-time Wireless Cyber-physical Systems

ETH zürich Towards Real-time Wireless Cyber-physical Systems **TECHNISCHE UNIVERSITÄT DRESDEN**

Romain Jacob¹, Marco Zimmerling², Pengcheng Huang¹, Jan Beutel¹ and Lothar Thiele²
¹ETH Zurich (Switzerland), ²TU Dresden (Germany)

Wired industrial installations are costly, bulky, and restricted. **BUT** Resource usage is too high.

Developing effective wireless Cyber-physical Systems is challenging. Design goals: **Real-time guarantees** (End-to-end deadlines are met), **Resource reservation** (No buffer overflows).

We address this challenge by **Distributing global responsibilities to local components**.

Our solution is based on three building blocks:

- Node level:** Dual-processor architecture, Based on a processor interconnect, Decouples Application and Communication tasks.
- Network level:** Wireless real-time protocol, Reliability, Adaptiveness, Real-time guarantees.
- System level:** DRP - Distributed Real-time Protocol, Enforces global guarantees, End-to-end deadlines are met, Buffer overflows are prevented.

Applications exchange packets via flows. Flow $F = (\text{source}, \text{destination}, T, D)$. Bolt decouples processors in time, power and clock domain, while supporting predictable inter-communication.

DRP distributes the end-to-end deadline among the different components.

DRP defines the responsibility of each component using "contracts".

- AP: "I will not receive more than D_{AP} packets every T_{AP} ".
- CP: "I can guarantee network deadline D_{CP} of all packets".
- Network: "I prevent local overflow and satisfy end-to-end deadline D of all packets".
- AP: "I can with the network and prevent local memory overflow".
- CP: "I can with the network and prevent local memory overflow".

Packets can be sent on a **represen flow**, To regulate a new flow, all contracts must be locally overreed on. Satisfaction of contracts is for all the components. Admisson tests for AP and CP are defined via a global overhead flow and buffer analysis.

The simulated system correlates closely with the worst-case analysis.

Scenario	Max. delay (ns)
Best	85
Worst	96

Romain Jacob
 Pengcheng Huang
 Lothar Thiele

Marco Zimmerling
 Jan Beutel

ECRTS 16 – WiP Session
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200

Installation cost (\$)
per meter of cable

Sensors
Actuators
Controllers



<http://cat5-wiring-hq.com>

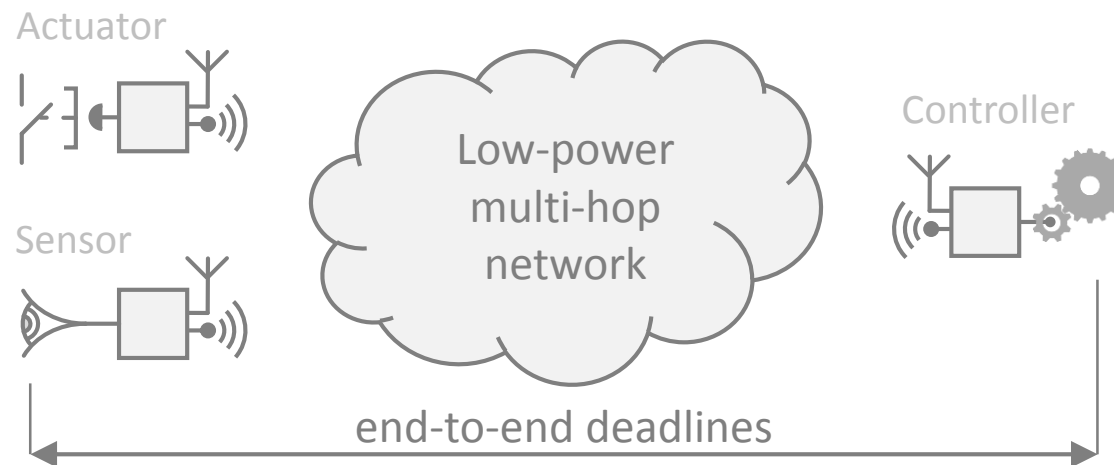
*Let's try to
go wireless!*

Developing effective wireless Cyber-physical Systems is challenging

Design
goals

Real-time guarantees > *End-to-end deadlines
are met*

Resource reservation > *No buffer overflow*



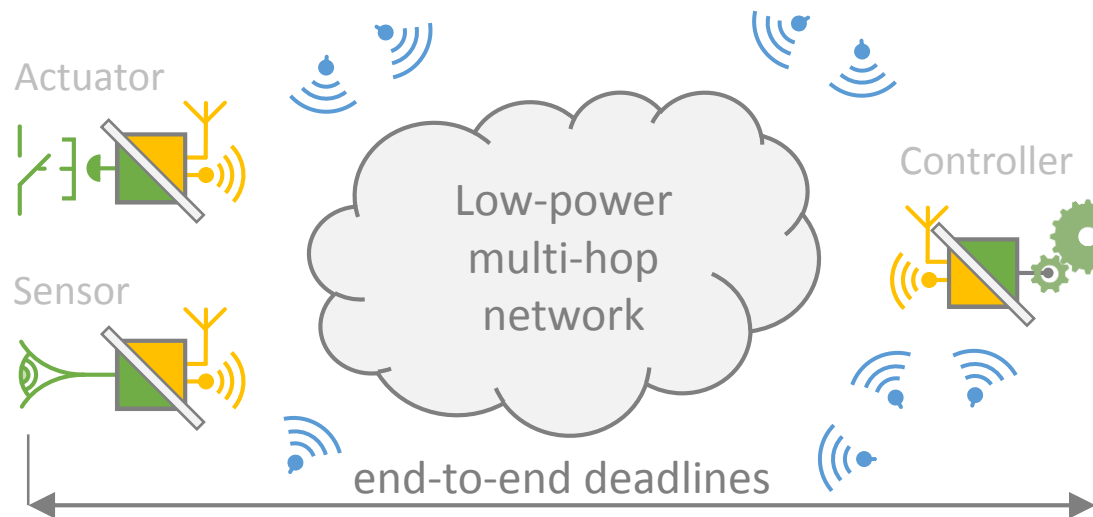
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Real-time guarantees > *End-to-end deadlines are met*

Resource reservation > *No buffer overflow*

Require *Reliability*



Subject to

External interference



Local interference



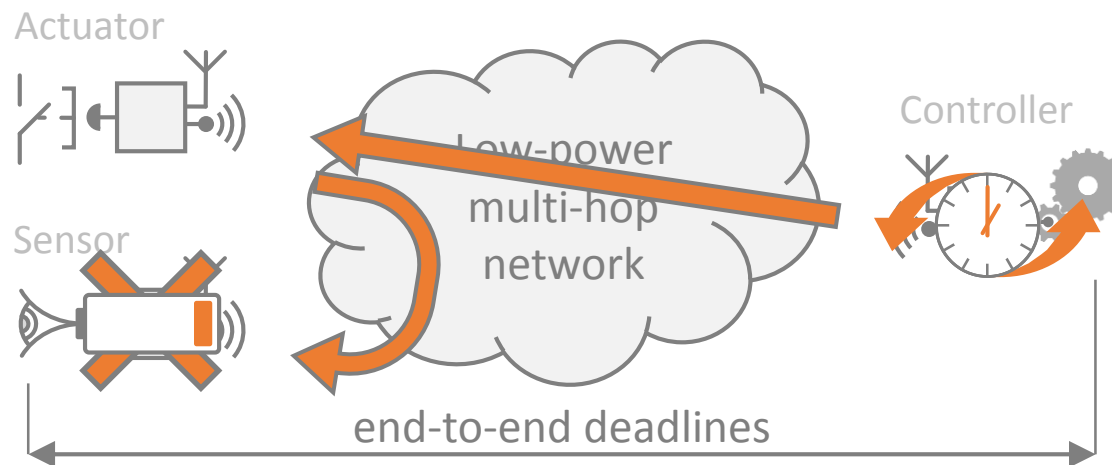
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Adaptiveness



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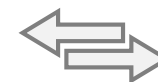
Local interference



Power failure



Changes in traffic demand



Scheduling update



There is **hope** for
Real-Time Wireless
Cyber-Physical Systems!

We tackle the wireless CPS challenge by combining...

Wireless real-time protocol

[1]

Reliable
Adaptive
Real-Time

Communication

Dual-processor architecture

[2]

Decouples

Application
Communication

Distributed real-time protocol (DRP)

Ensures deadlines
Prevents overflows

[1] Zimmerling M. et al., *Adaptive Real-time Communication for Wireless Cyber-physical Systems* Tech. Rep., ETH Zurich, **2016**

[2] Sutton F. et al., *Bolt: A Stateful Processor Interconnect*, SenSys'15, **2015**

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Leveraging



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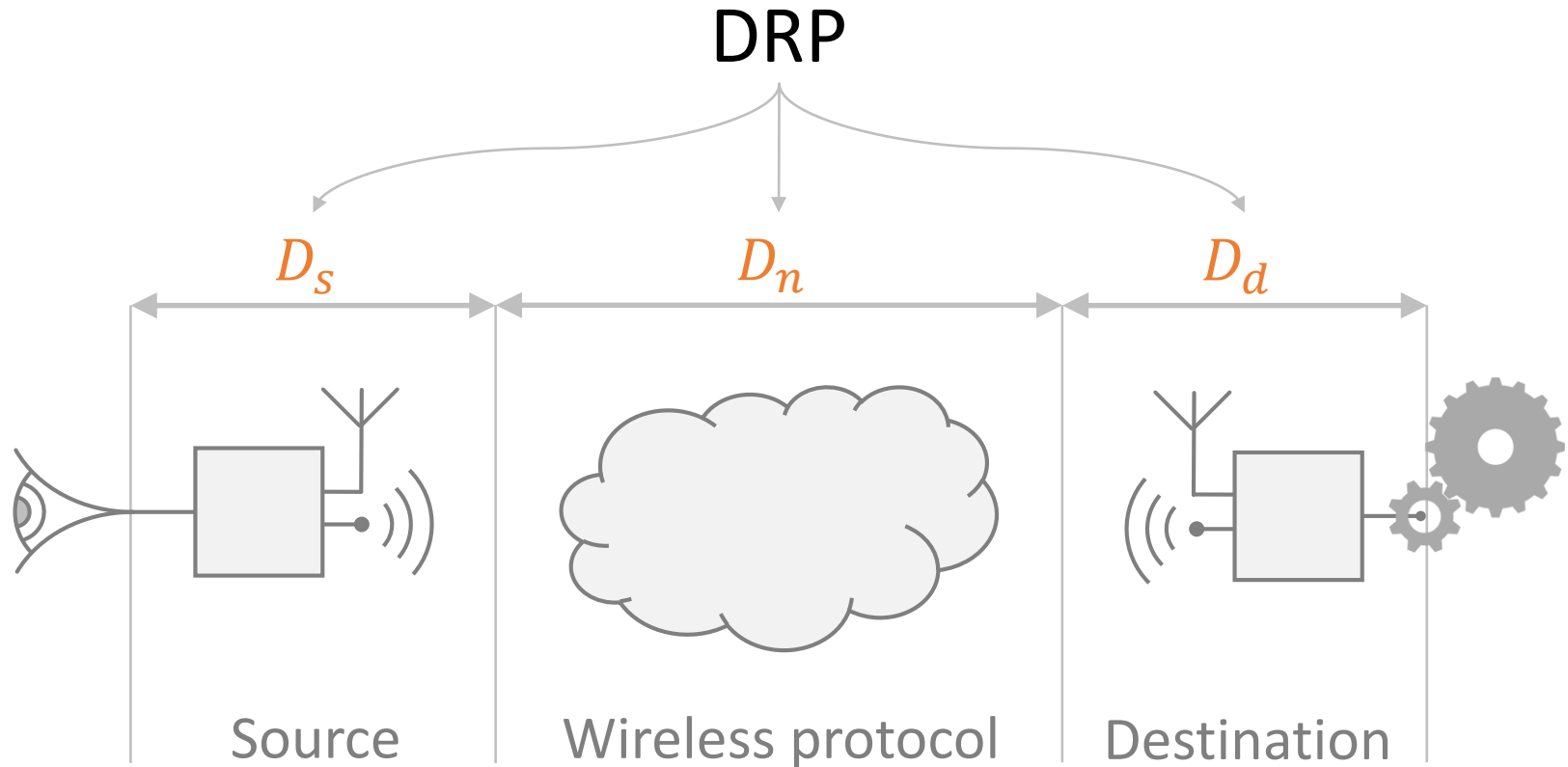
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DRP is based on *contracts*, which distribute responsibilities between components

DRP

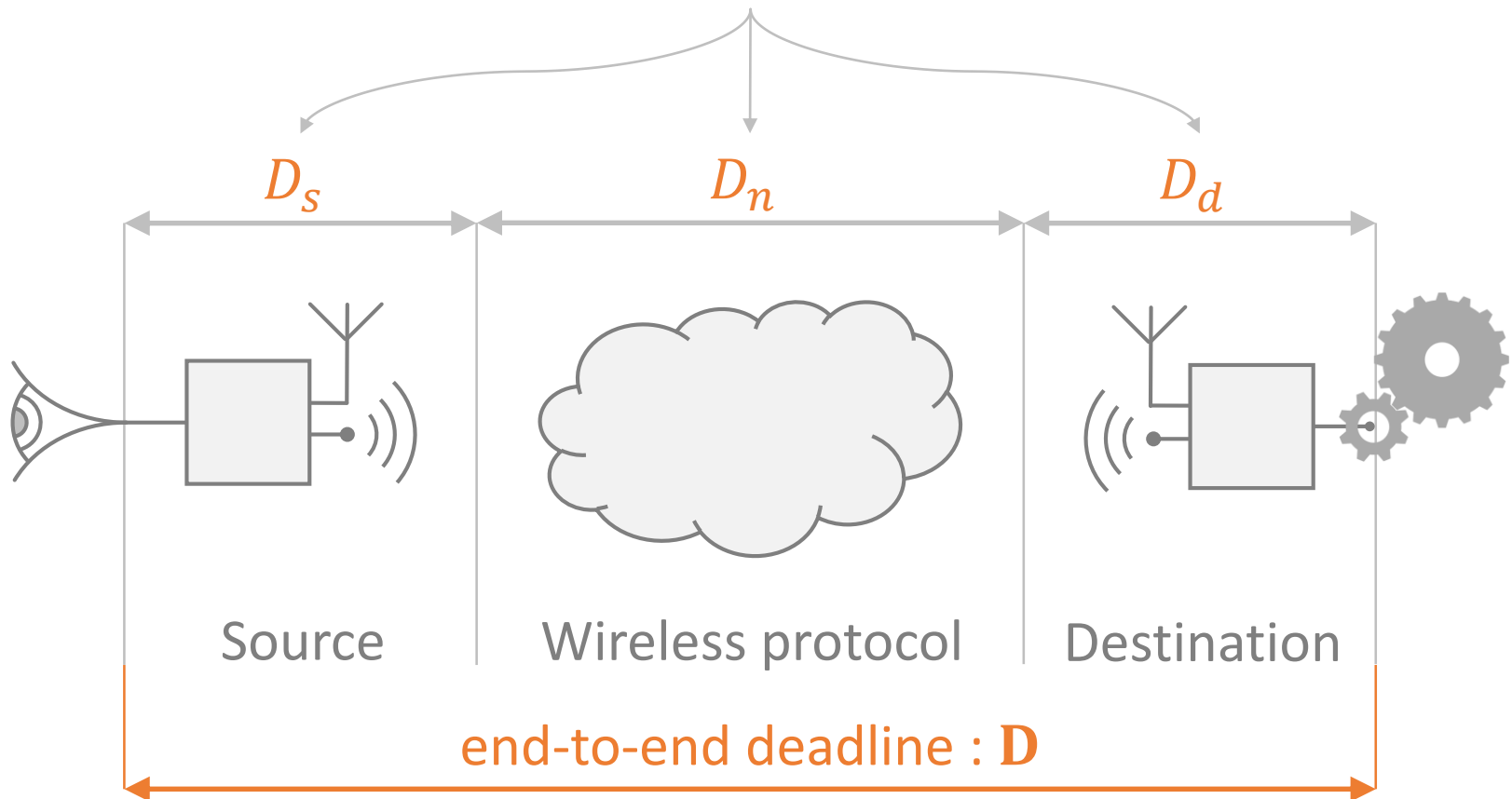


DRP is based on *contracts*, which distribute responsibilities between components



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$$\text{DRP} : D_s + D_n + D_d = \mathbf{D}$$



The simulated system correlates closely with the analysis

Simulated end-to-end delay
compared to the analytic bound

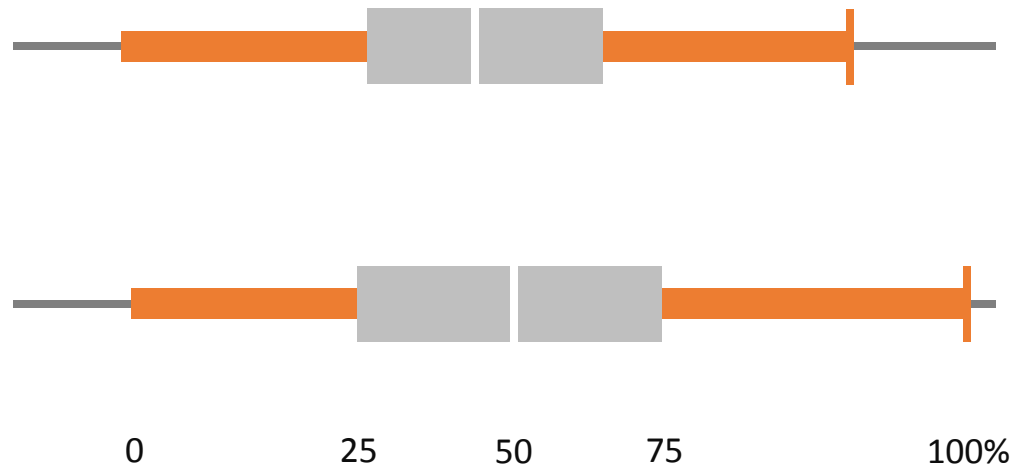
[%]

Basic
load

85

Medium
load

96



There is still work to be done before convincing both industry and academia

Physical implementation of the protocol

Extensive testing on Flocklab *public WSN testbed*

Dependability evaluation and optimization

Probability of failure
Retransmission scheme

Reaching meaningful performances

Very low rate few *bps*
Very small deadlines from 10ms
 to 0.5s

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