

Providing Guarantees in Wireless Cyber-Physical Systems

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Providing Guarantees in Wireless Cyber-Physical Systems

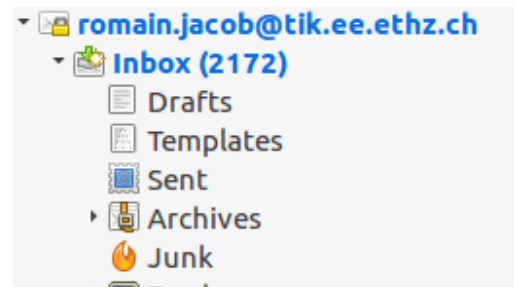


Romain Jacob

ETH Zurich

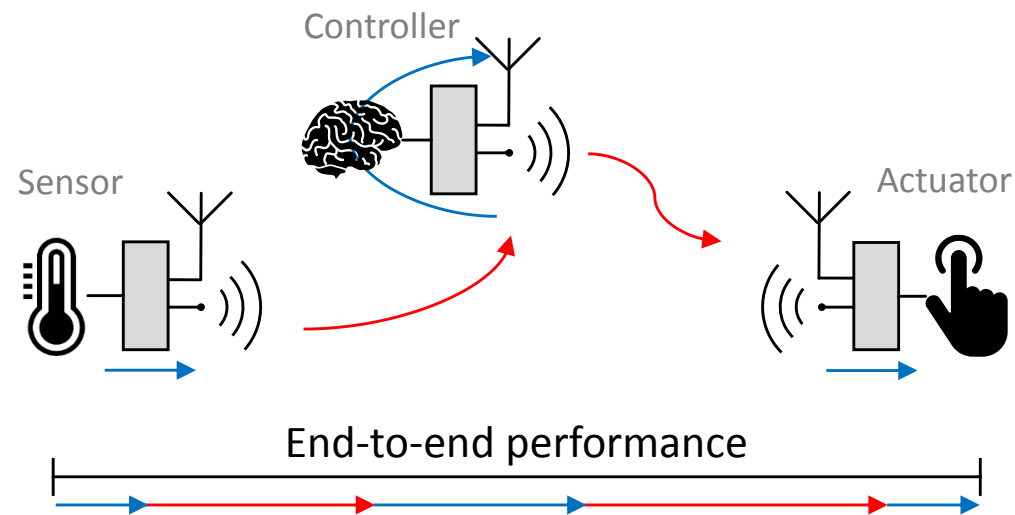
Prof. Langendoen Group's Seminar

January 31, 2018

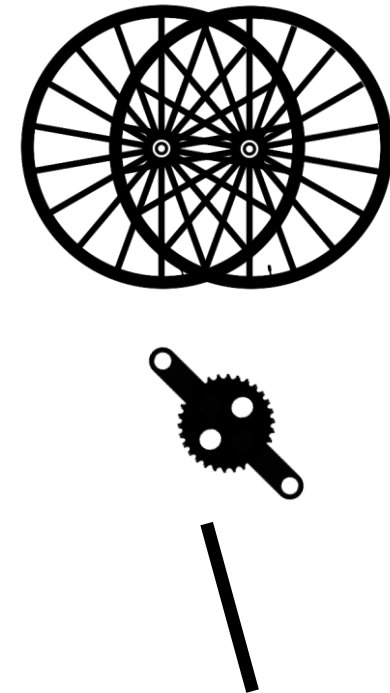
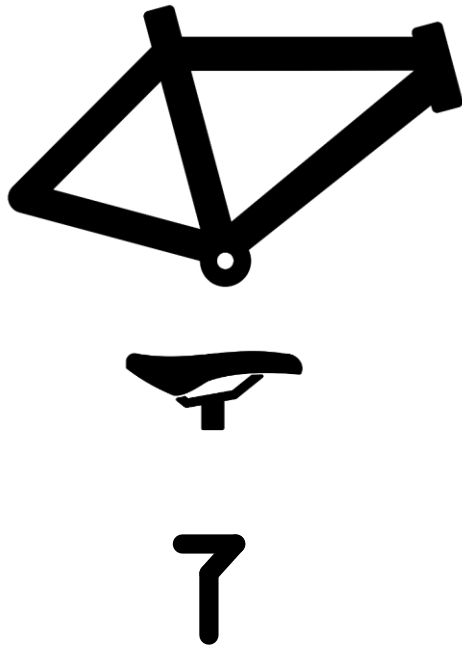


Romain, a researcher you cited is working on a project: Approximation
[URGENT] Feedback on SenSys paper draft (deadline next week!!!)
Ewd: Zürcher Silvesterlauf-Newsletter 11/2016: Jetzt aben!

Cyber-Physical Systems are made of distributed, heterogeneous components which *interact*



Performant systems require *performant parts*



Performant systems require *performant parts*
and a performant *system design*!



Something
went **wrong...**

Performant systems require *performant parts*
and a performant *system design*!

In other words

Combining components
must be done **carefully**

—————
*Relying on
well-defined
interfaces*

To be trusted, the system design
must provide guarantees on its behavior

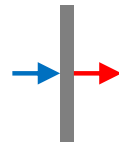


System design methodology

- Like user guide
- Must guarantee to work!



Performant Components



Well-defined Interfaces



Trusted system design

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Providing **Guarantees** in Wireless Cyber-Physical Systems

Providing **Guarantees** in Wireless Cyber-Physical Systems

Predictability



Execution
Timing

Providing **Guarantees** in Wireless Cyber-Physical Systems

Predictability

Reliability

Fault-tolerant

Providing **Guarantees** in Wireless Cyber-Physical Systems

Predictability

Reliability

Adaptability

Reactive to events

Providing **Guarantees** in Wireless Cyber-Physical Systems

Predictability

Reliability

Adaptability

Performance

Latency

Bandwidth

Energy

Relevant guarantees can be provided
for Cyber-Physical Systems
built *on low-power wireless* networks

Providing Guarantees in Wireless Cyber-Physical Systems



Using well-defined interfaces

Glossy and Bolt

Implementing complex functions

Real-time scheduler

Providing guarantees in Wireless CPS

DRP – The loose coupling approach

Providing Guarantees in Wireless Cyber-Physical Systems



Using well-defined interfaces

Glossy and Bolt

Implementing complex functions

Real-time scheduler

Providing guarantees in Wireless CPS

DRP – The loose coupling approach

Luckily, some very good interfaces
for Wireless CPS are available

Glossy

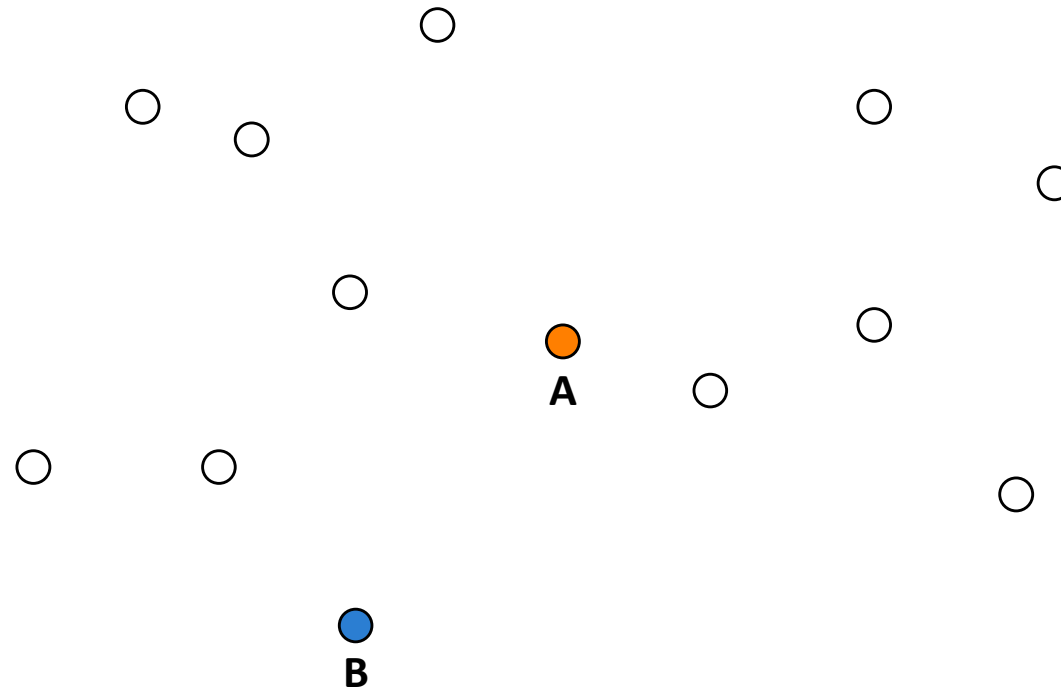
Network interface
between all devices



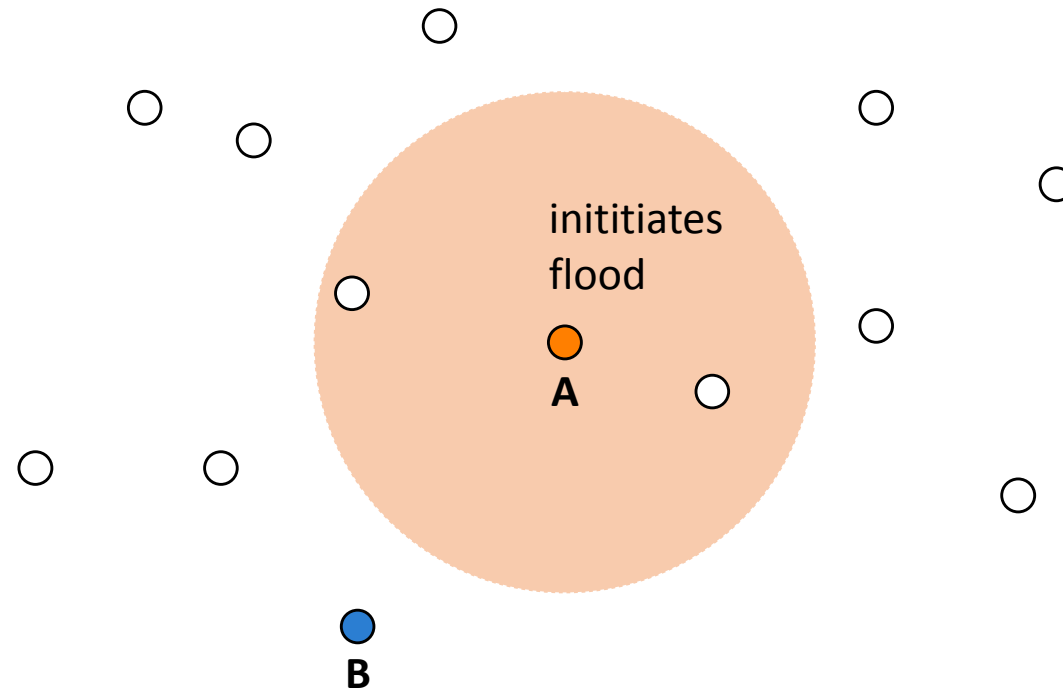
Local interface between
application and communication



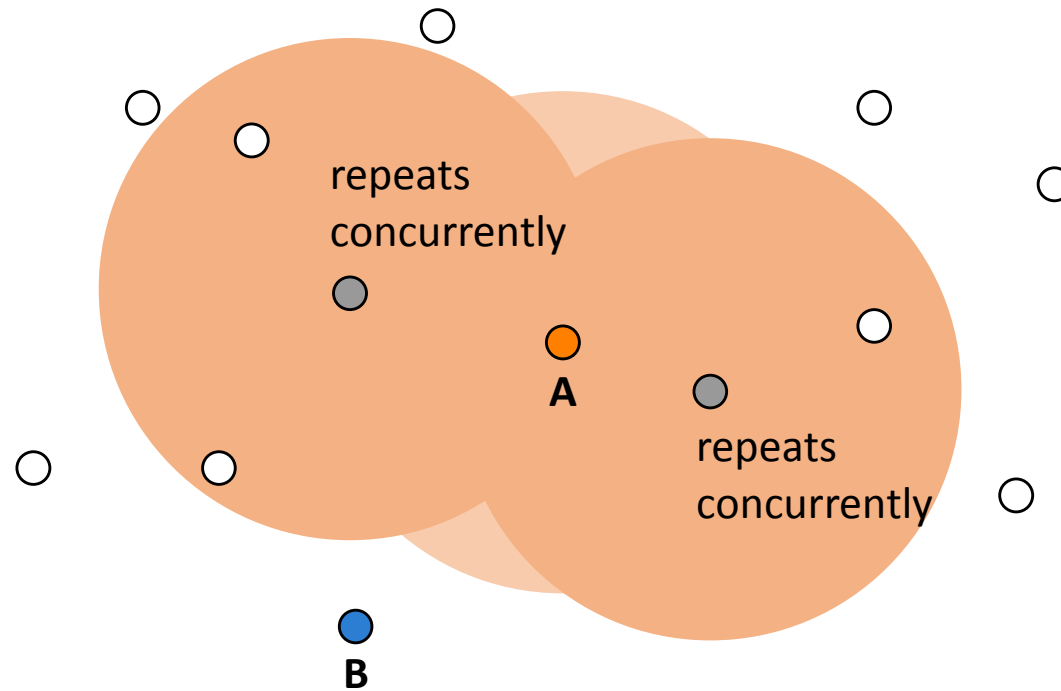
Glossy, in short

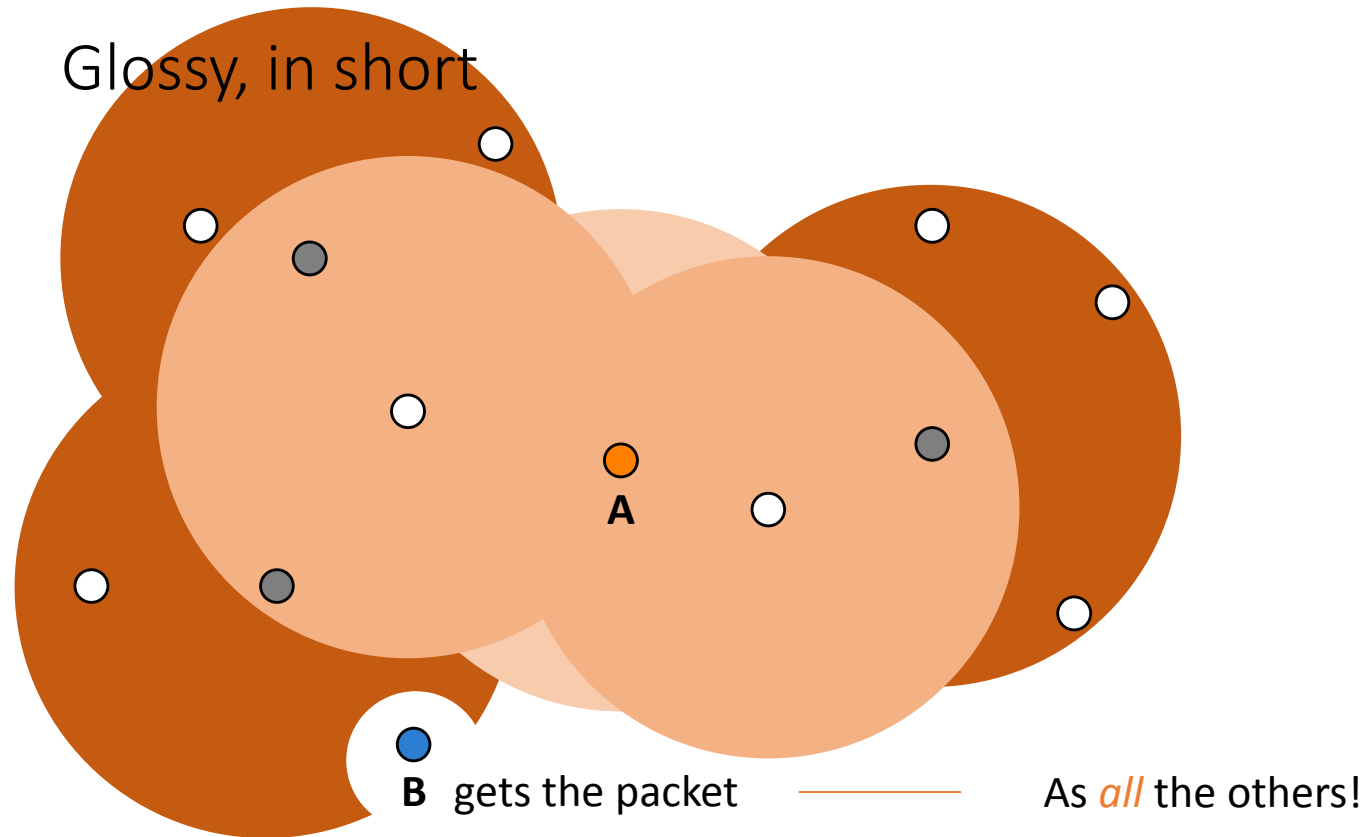


Glossy, in short



Glossy, in short





Glossy, in short

- *Stateless*
- Virtual *single-hop* network
- Unicast/broadcast/multicast
- $T_{comm} = f(\text{payload, diameter})$
- Fully *synchronous*

B gets the packet — As *all* the others!

The wireless network can be scheduled like a shared bus

Low-power
Wireless Bus



Round structure

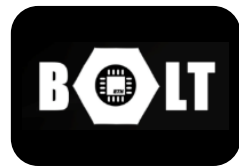


- Round-based design
- A central node (*host*) computes the schedules
- Dynamic traffic and round intervals
- Time triggered

Luckily, some very good interfaces
for Wireless CPS are available

Glossy

Network interface
between all devices

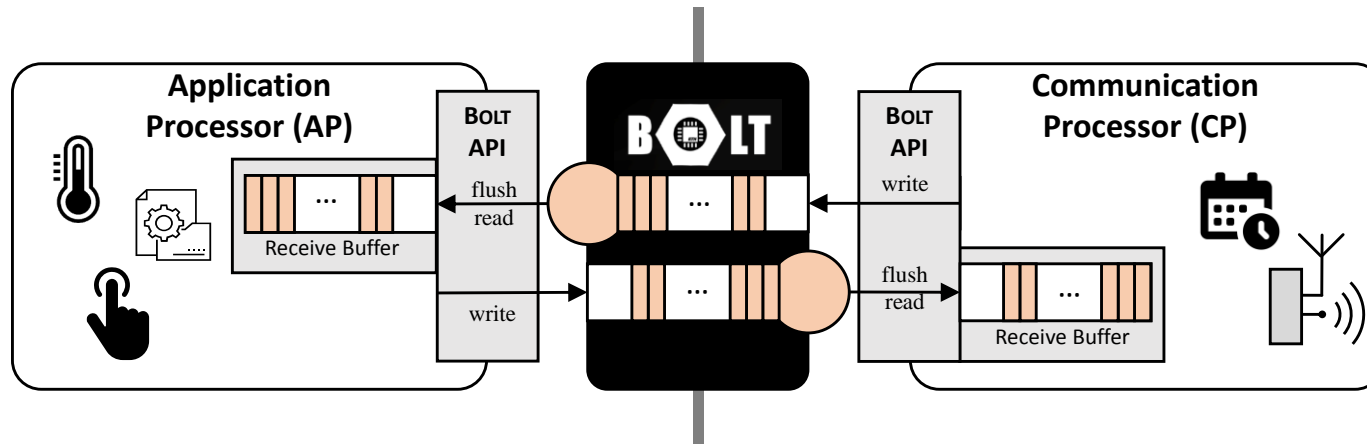


Local interface between
application and communication

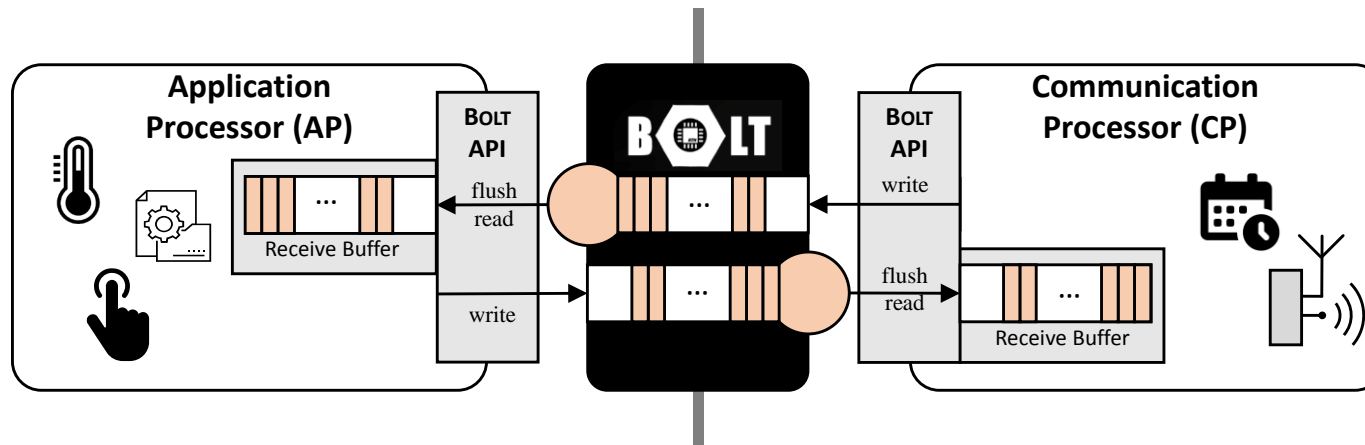




Bolt, in short



Bolt, in short



Predictability

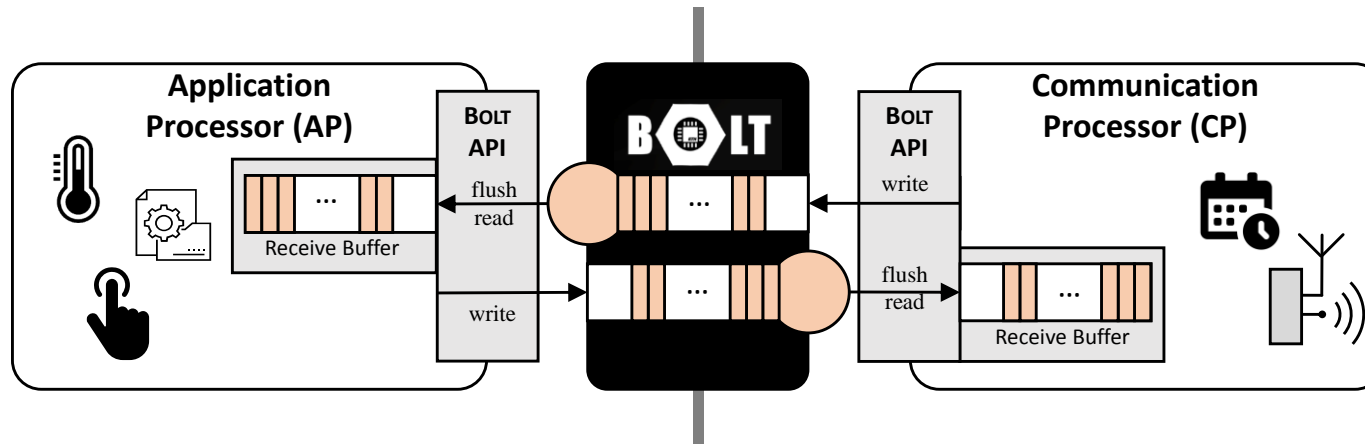
Reliability

Adaptability

Performance

Tight bounds on the
API execution time

Bolt, in short



Predictability

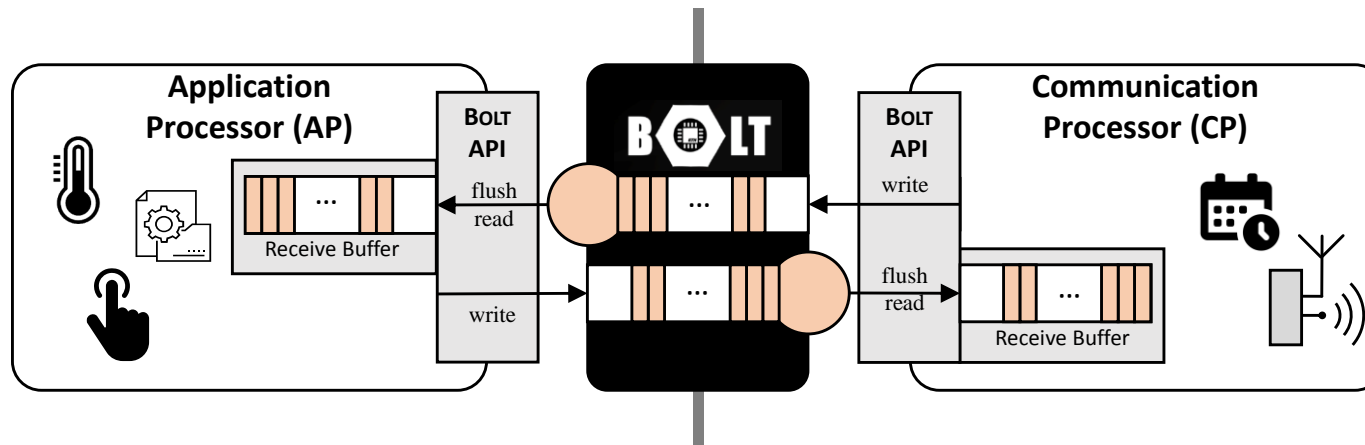
Reliability

Adaptability

Performance

Non-volatile memory

Bolt, in short



Predictability

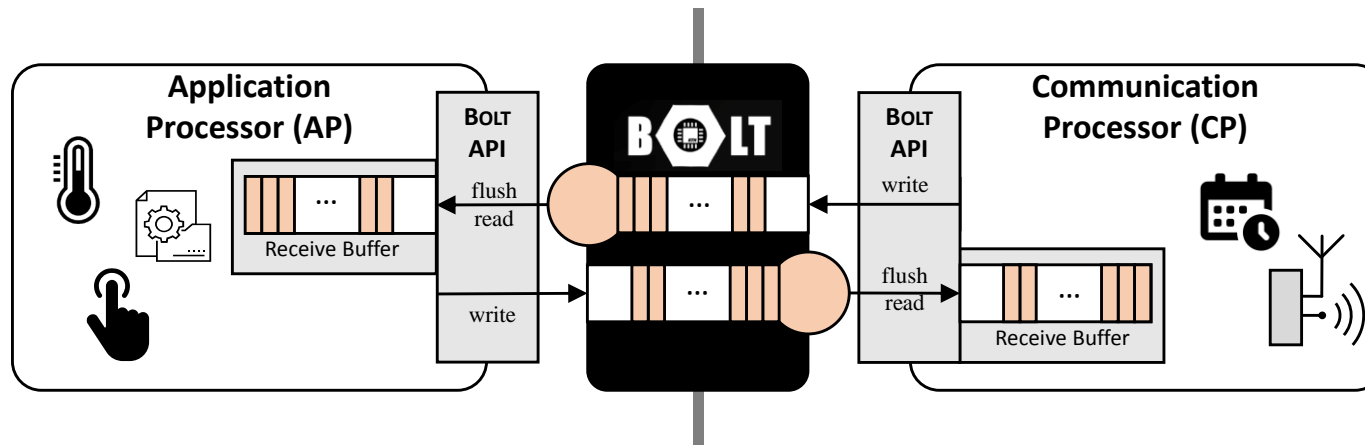
Reliability

Adaptability

Performance

Supports interrupt-driven
communication AP <-> CP

Bolt, in short



Predictability

Reliability

Adaptability

Performance

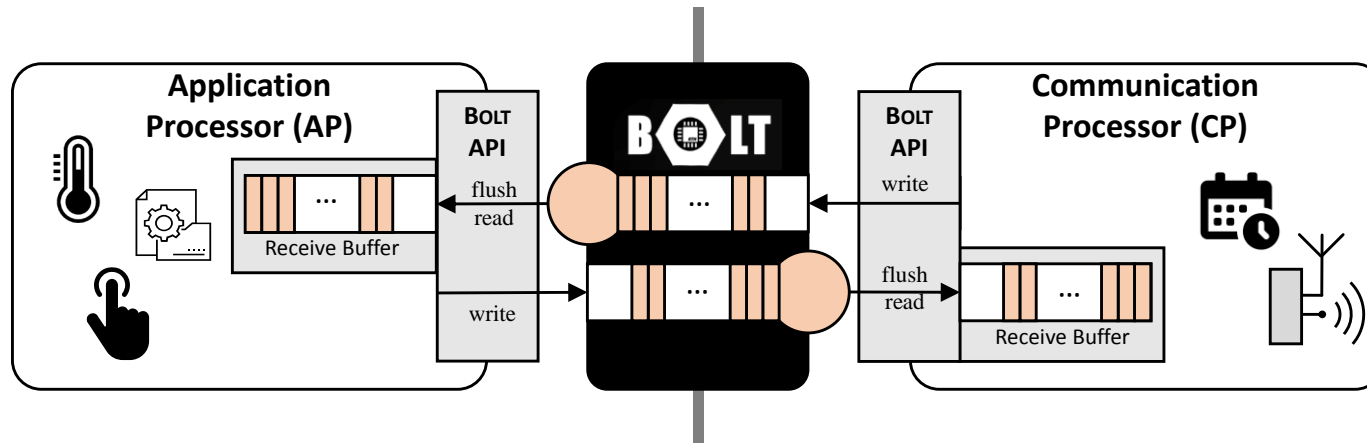
Fast

Low-power

Mbps

μW to mW

Bolt, in short



Sutton et al.

Bolt: A stateful processor interconnect

Proc. of ACM SenSys, 2015

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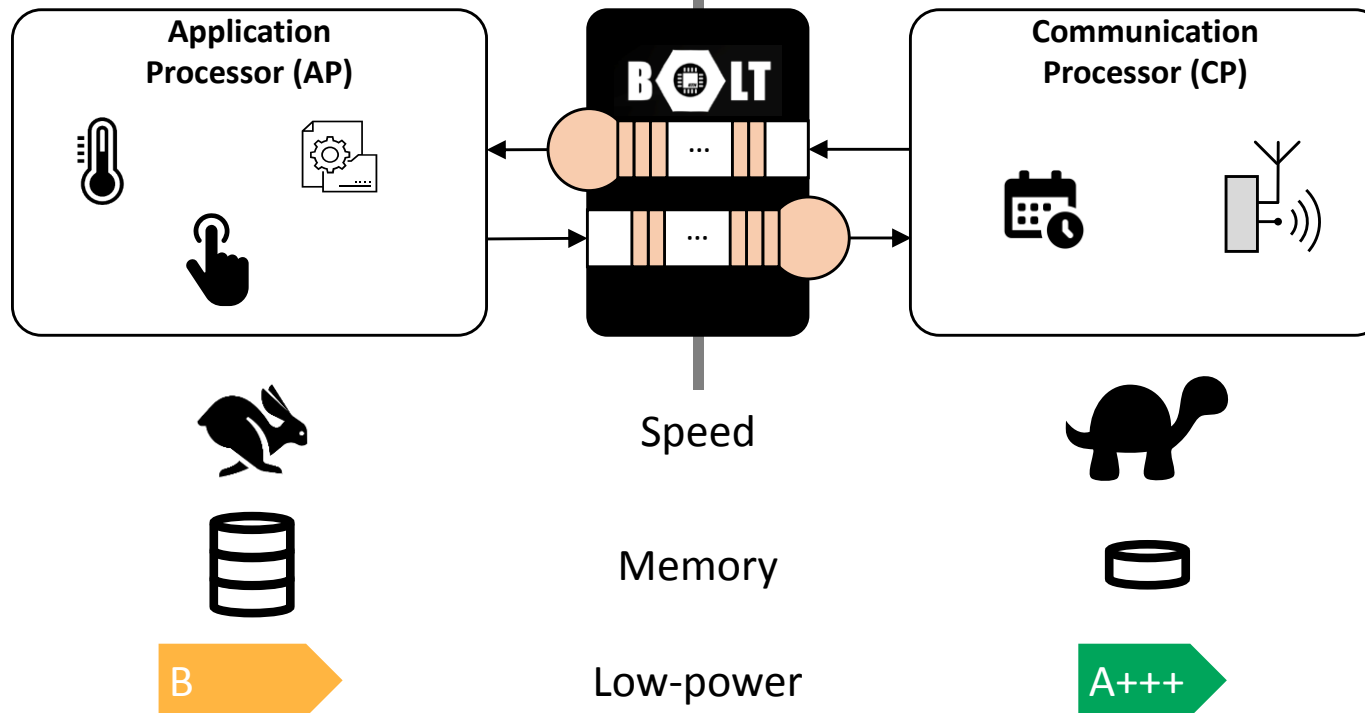


Using well-defined interfaces
Glossy and Bolt

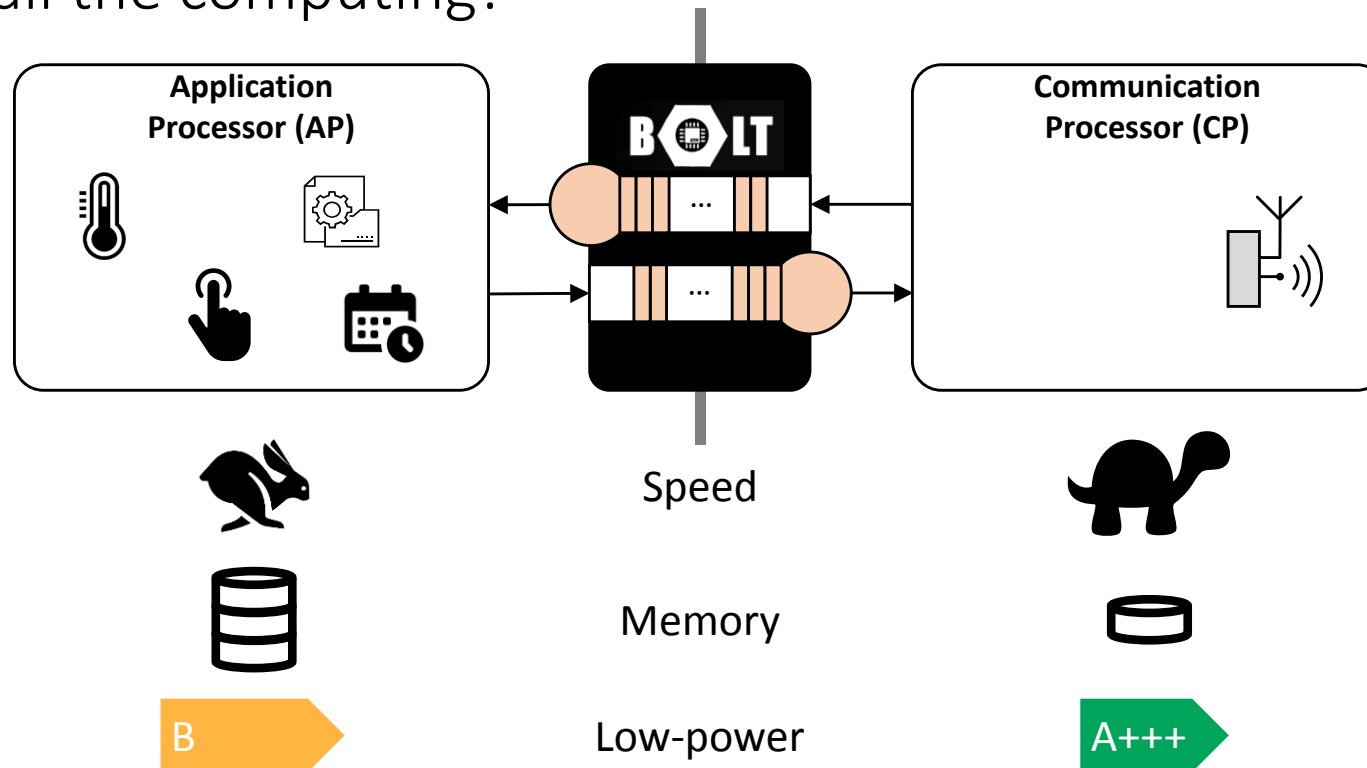
Implementing complex functions
Real-time scheduler

Providing guarantees in Wireless CPS
DRP – The loose coupling approach

Having two independent processors
allows hardware specialization



Then let's the powerful processor
do all the computing!



Single Proc.



Single Proc.



Dual Proc.

CP



AP

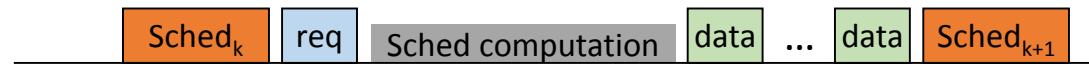


Single Proc.



Dual Proc.

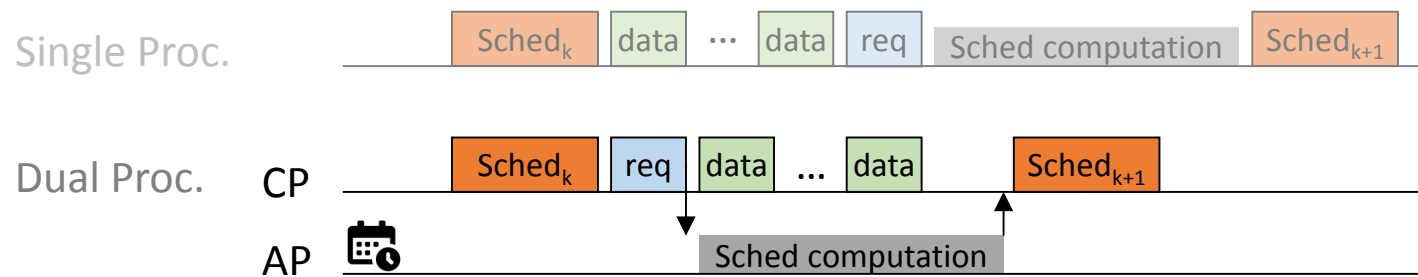
CP



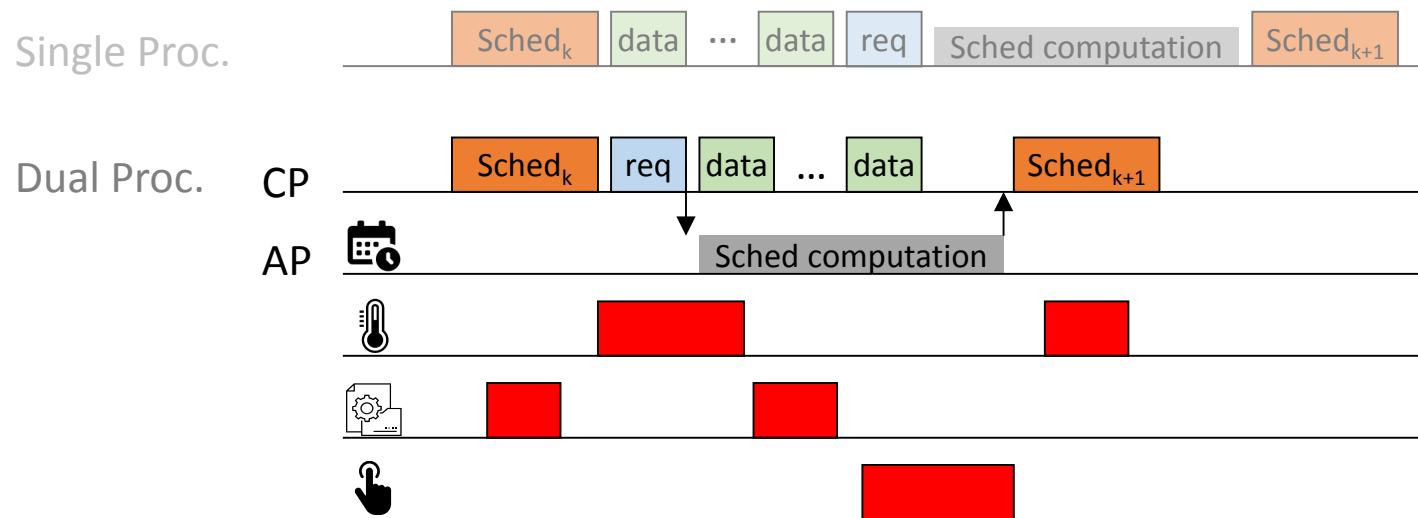
AP



Parallelization of computation enables
performance improvements of the communication



If the two processors are decoupled, a control mechanism is needed to guarantee a timely response



Providing Guarantees in Wireless Cyber-Physical Systems



Using well-defined interfaces
Glossy and Bolt

Implementing complex functions
Real-time scheduler

Providing guarantees in Wireless CPS
DRP – The loose coupling approach

Distributed
Real-time
Protocol

Couple the applications
as loosely as possible

Objective

Maximize the adaptability

Approach

1. Synchronous
communication

—

Glossy-based

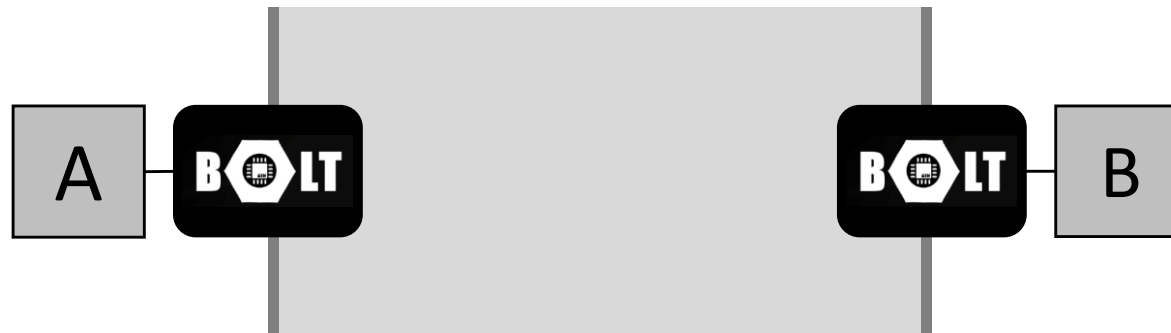
2. Asynchronous applications
within some bounds

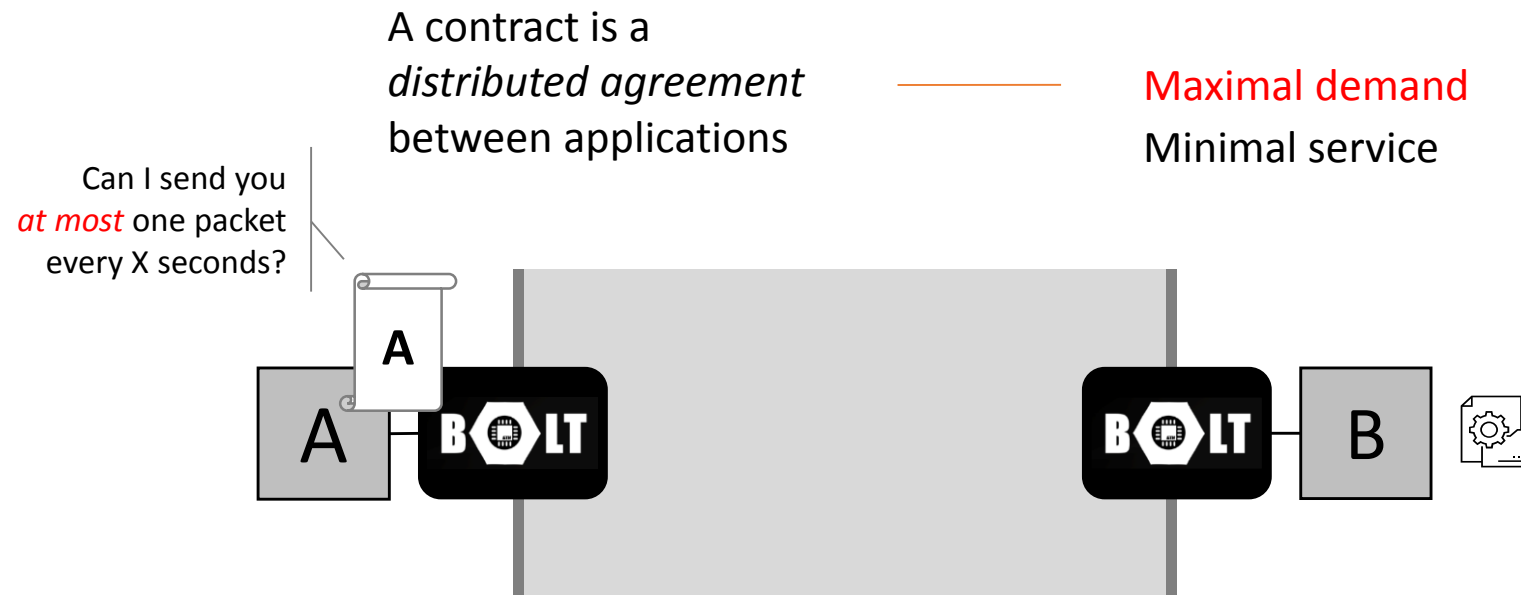
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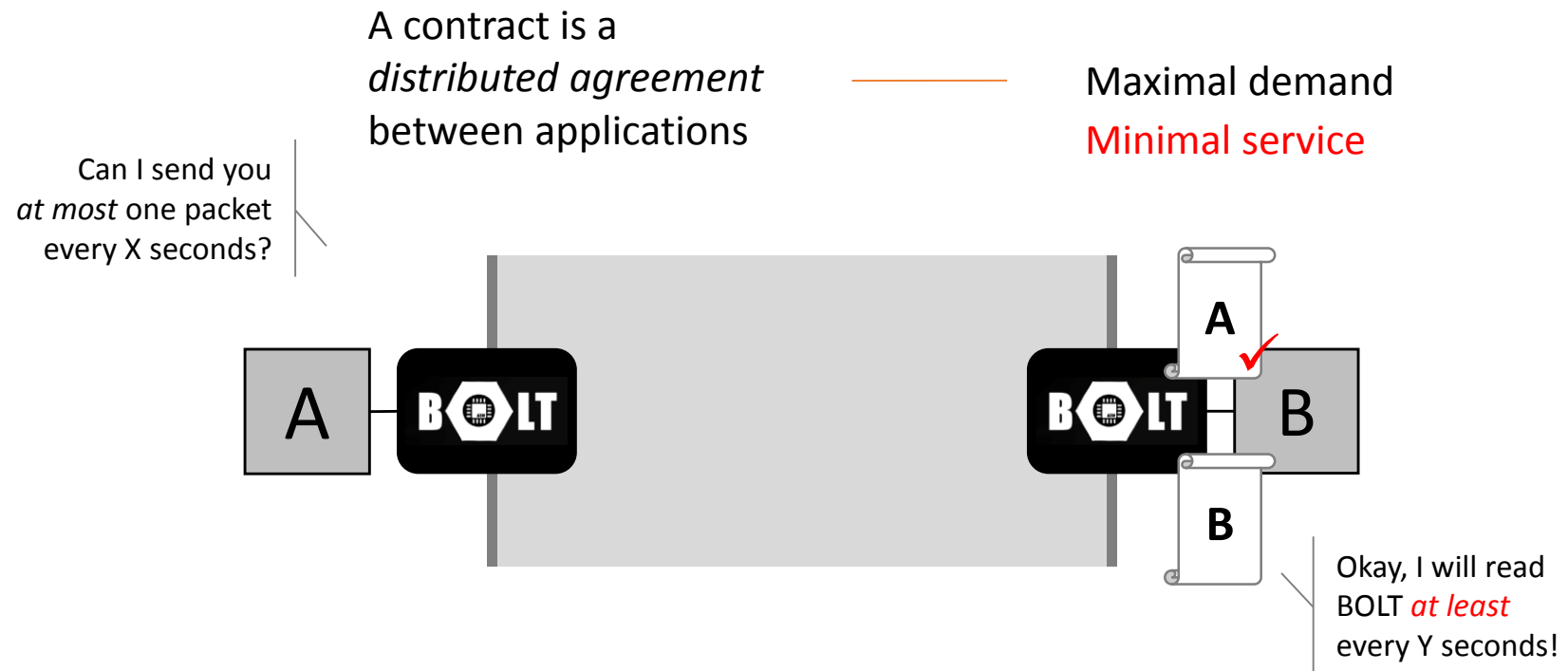
Based on
contracts

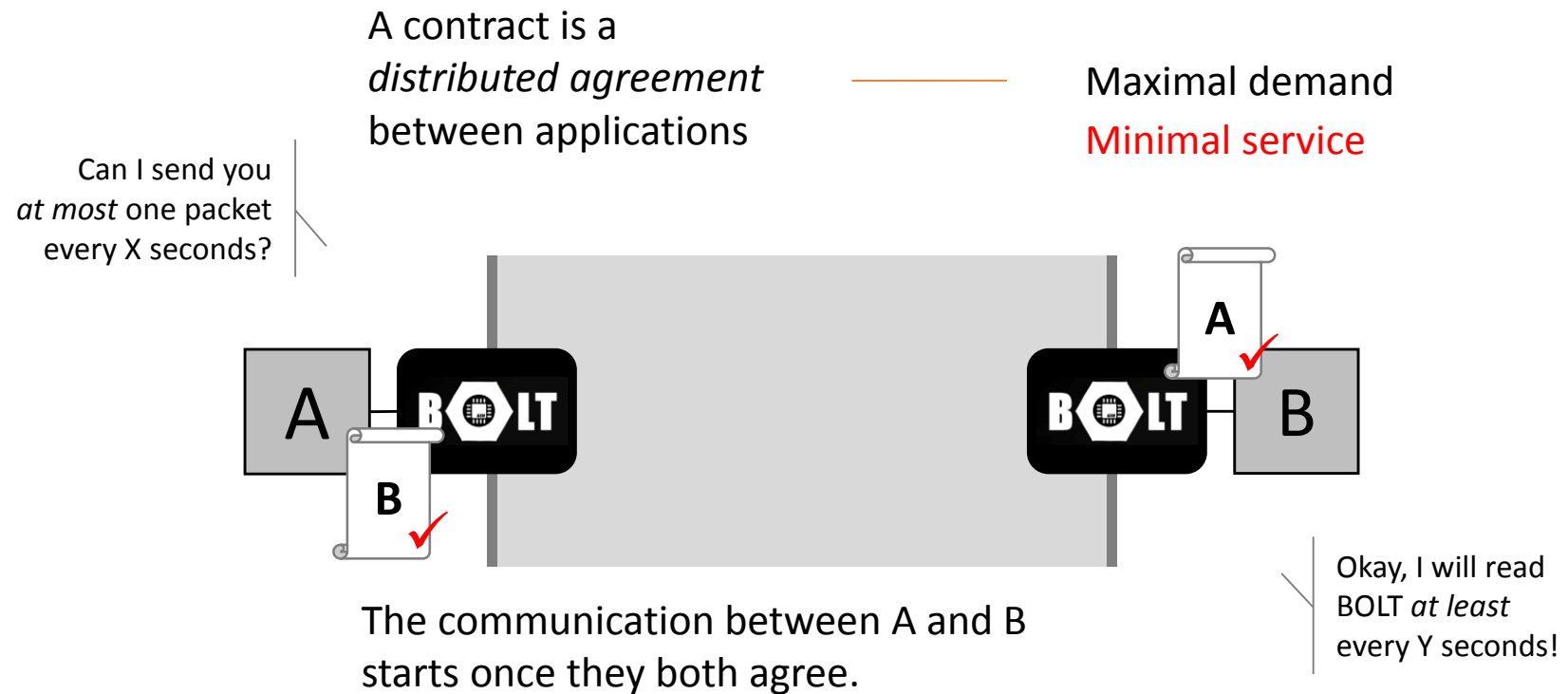
A contract is a
distributed agreement
between applications

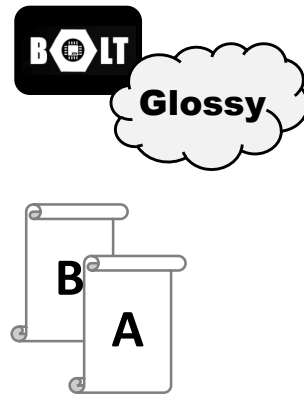
Maximal demand
Minimal service











Predictable **interfaces**

+

Predictable **application behavior**
bounded by the contracts

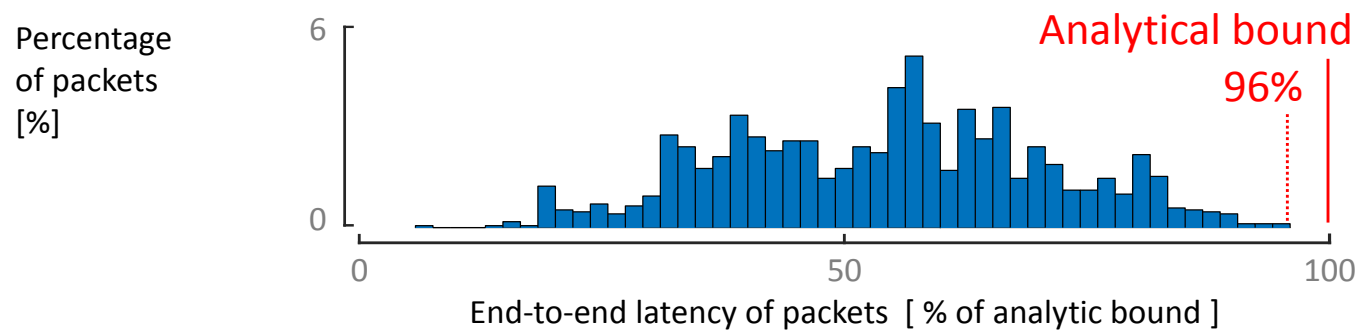
Jacob et al.

End-to-end Real-time Guarantees in
Wireless Cyber-physical Systems

Proc. of the IEEE RTSS, 2016

- Analyzable system
- End-to-end guarantees can be provided

Simulation correlates closely with the analysis

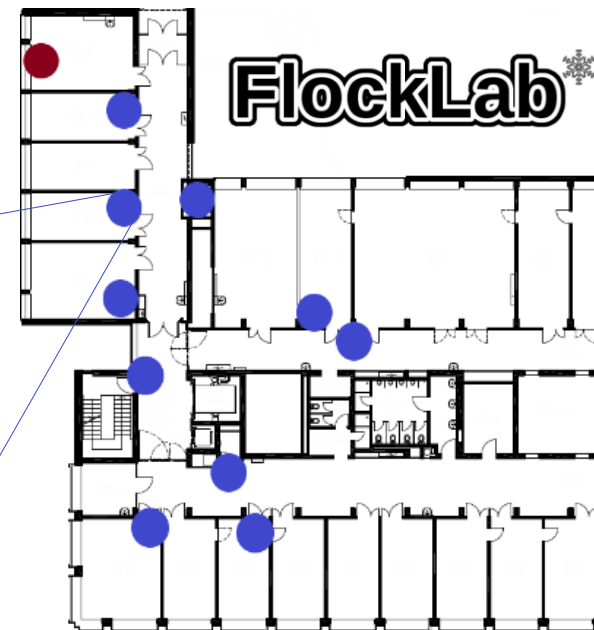


- All deadlines are satisfied
- Analytic bound is tight

DRP has been implemented
and tested on a real-network

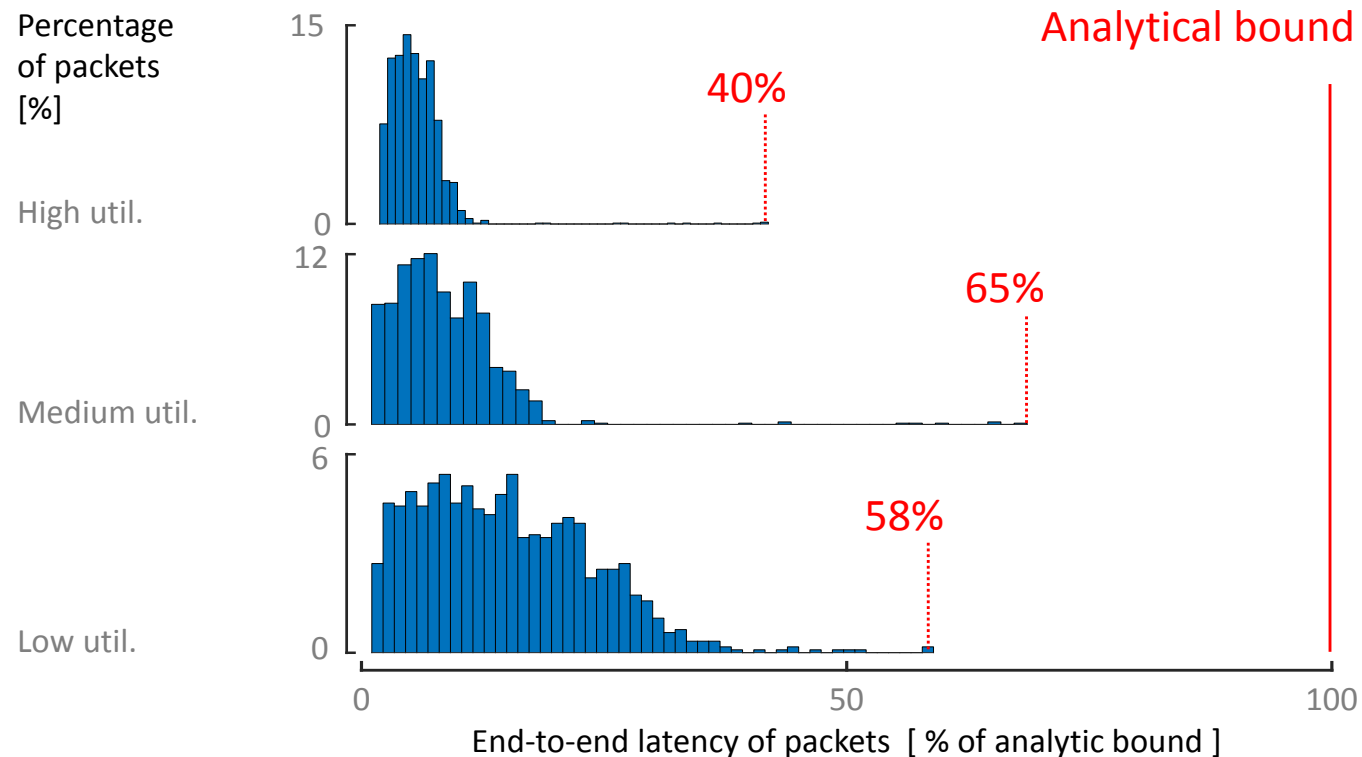
Initial tests

- 10 nodes + 1 host



FlockLab ❄️

For more generic test cases the pessimism increases



For more generic test cases the pessimism increases
which means most packets are received quickly!

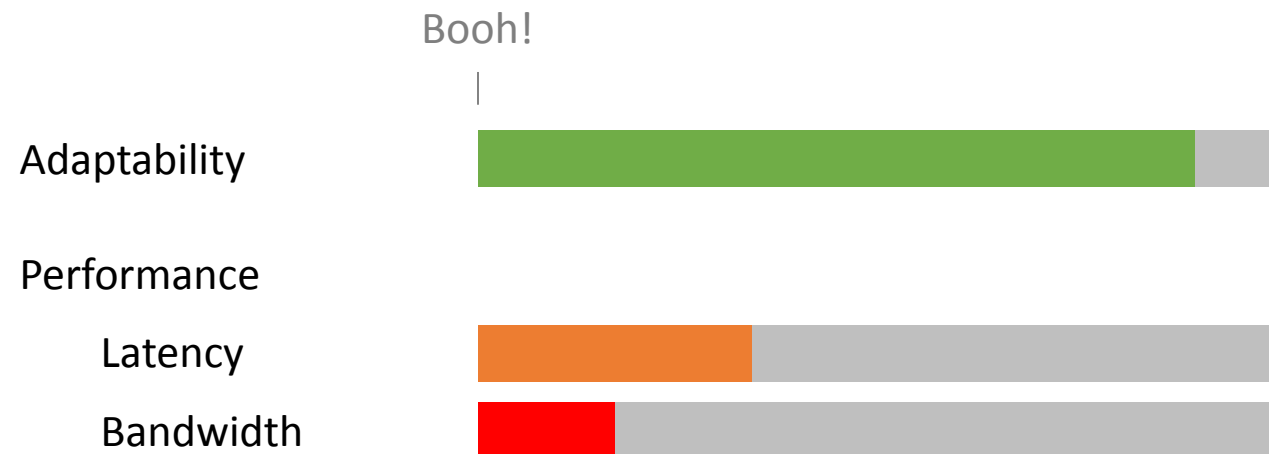
Utilization		High (92 %)	Medium (60 %)	Low (41 %)
Maximum latency	[% of bound]	41 %	65 %	58 %
	[s]	24 s	39 s	35 s
Medium latency	[% of bound]	4 %	7 %	15 %
	[s]	2 s	4 s	9 s

50% of packets!

Parameters

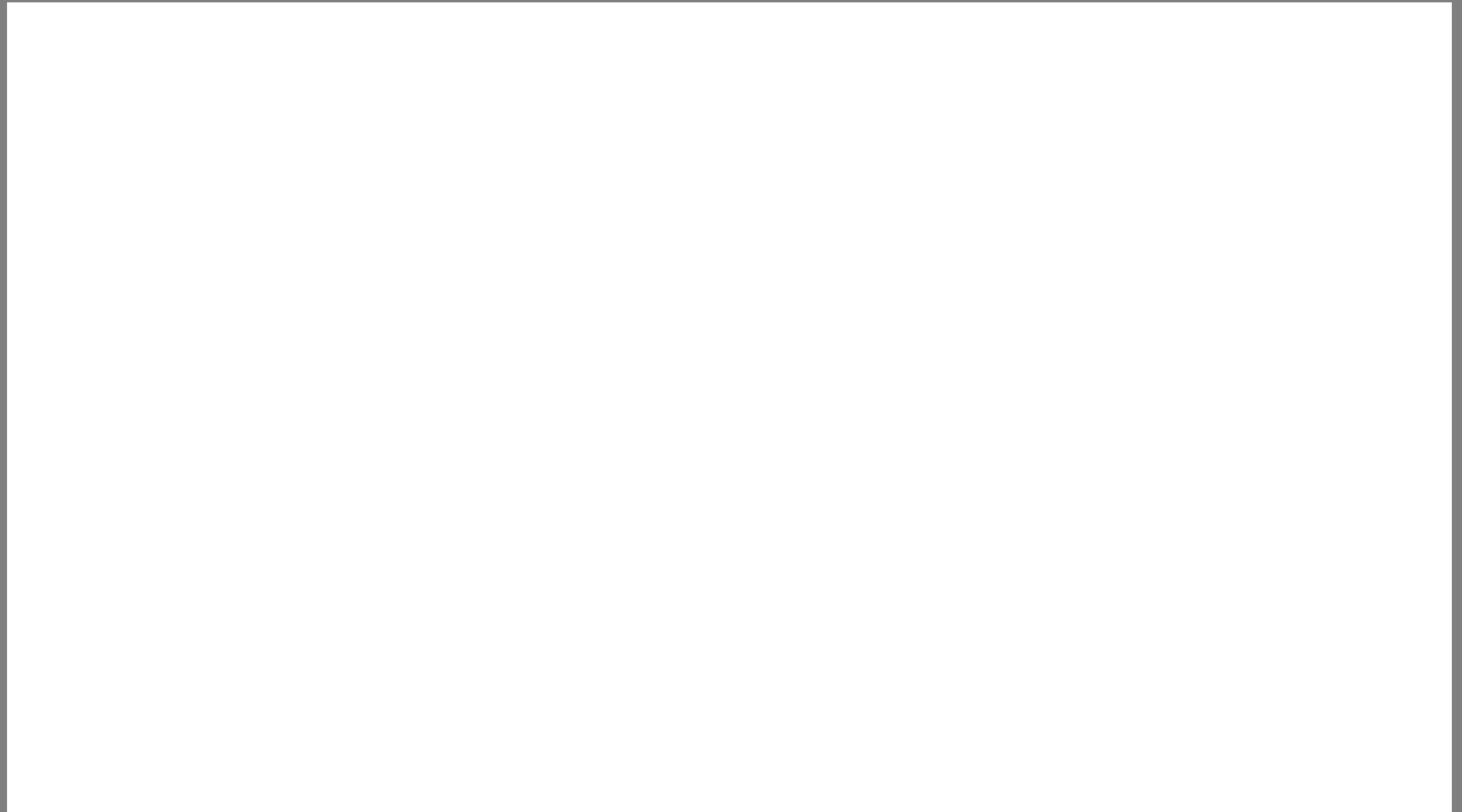
- Period 15 s
- End-to-end deadline 60 s

Loose coupling provides high flexibility
but results in relatively poor performance

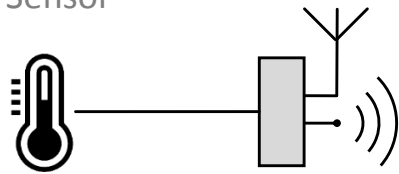


Prof. Langendoen Group's Seminar

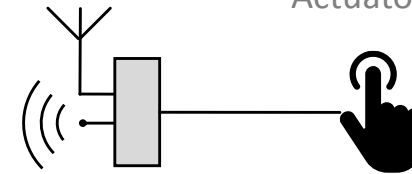
January 31, 2018 | TU Delft | The Netherlands

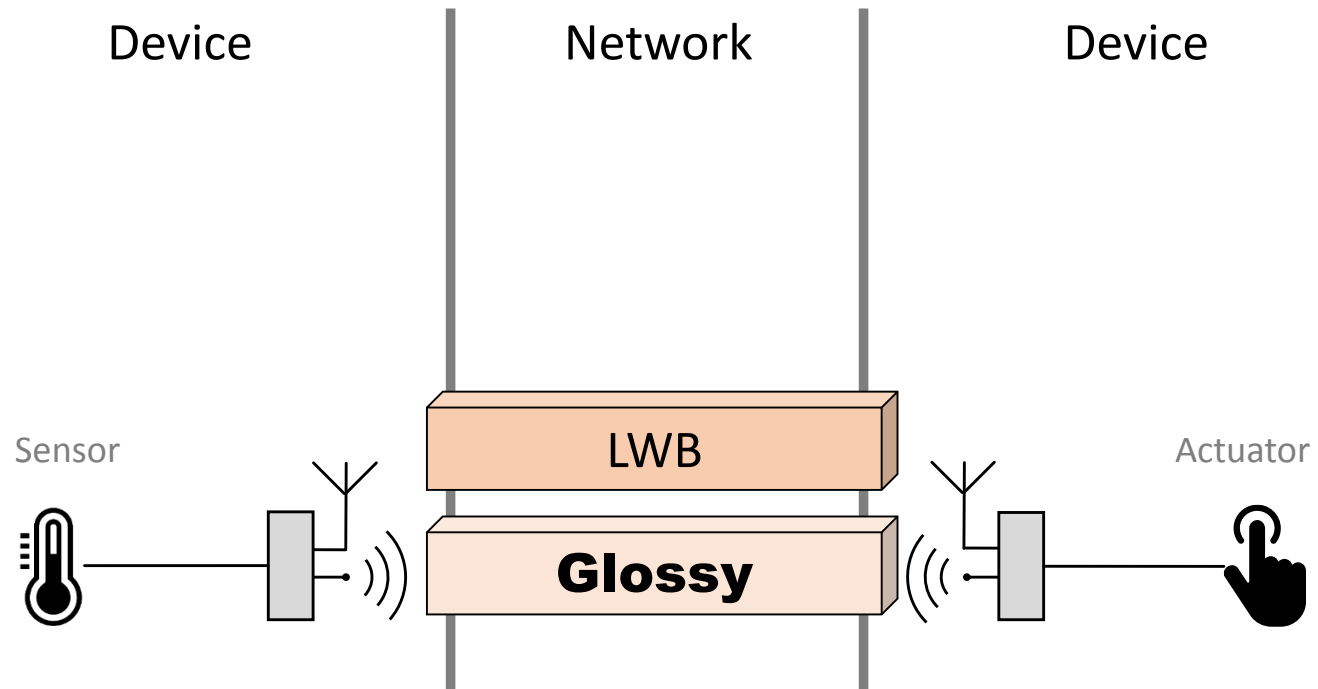


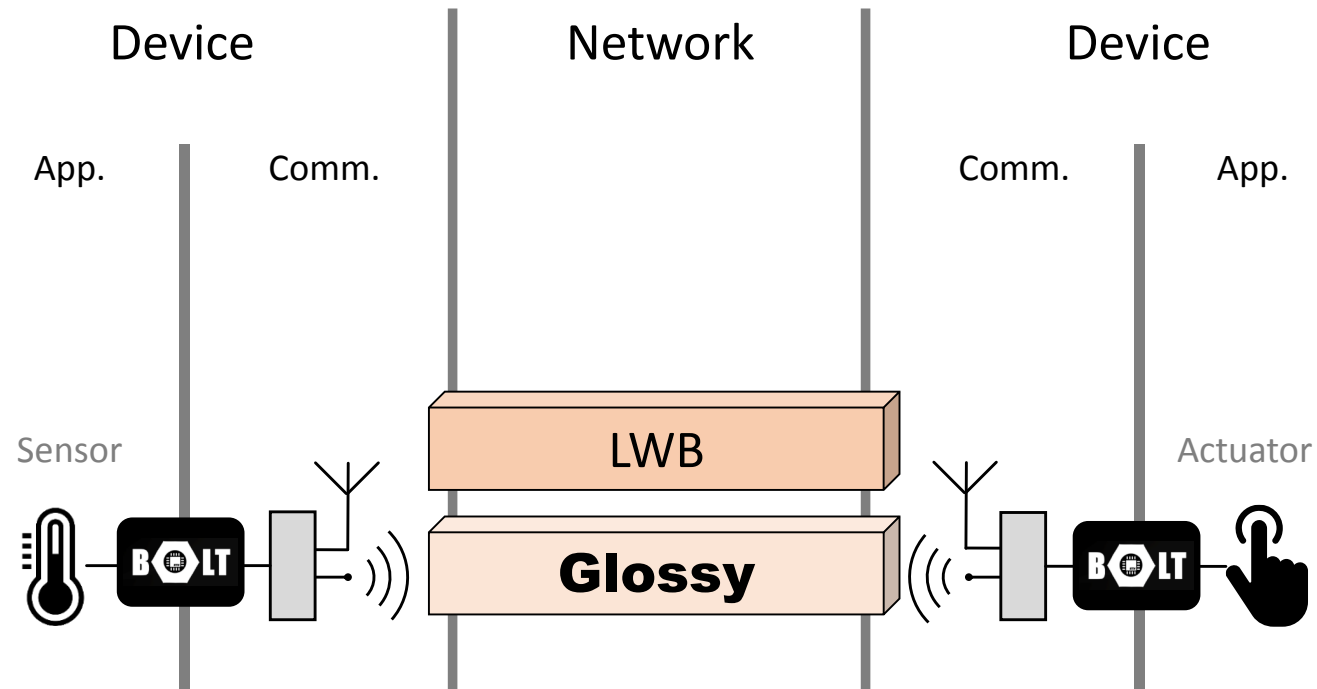
Sensor

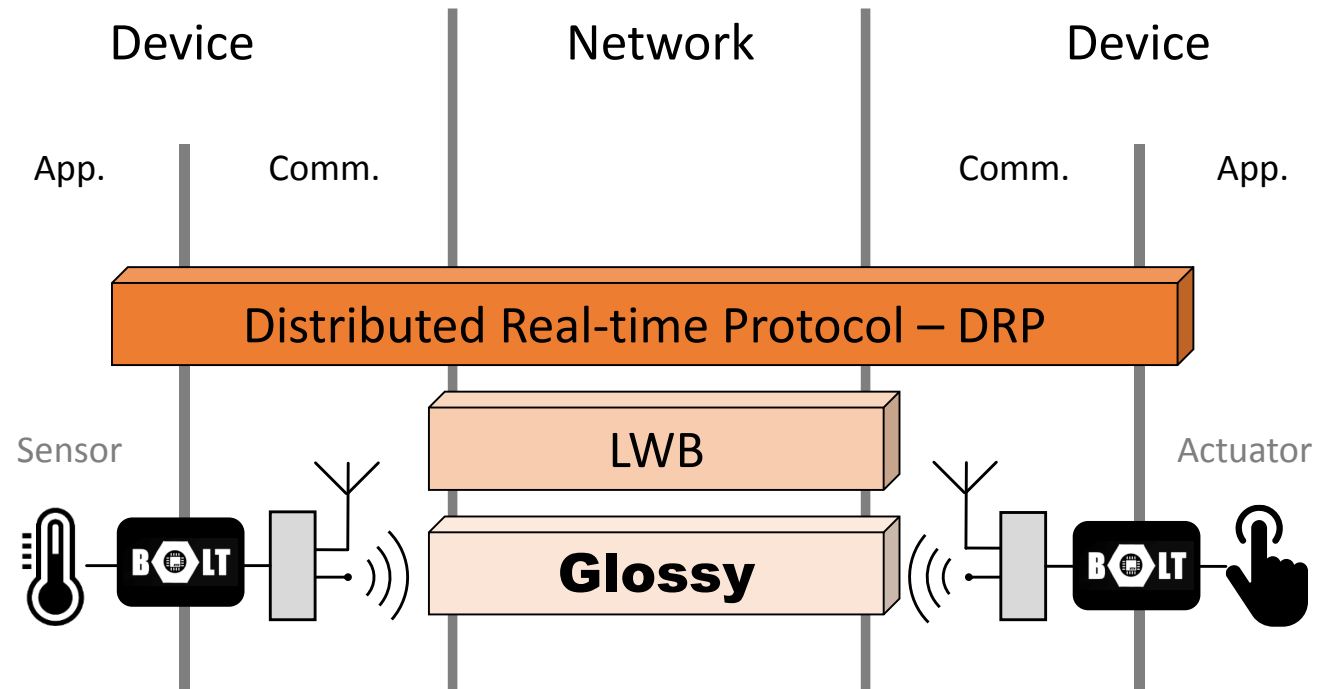


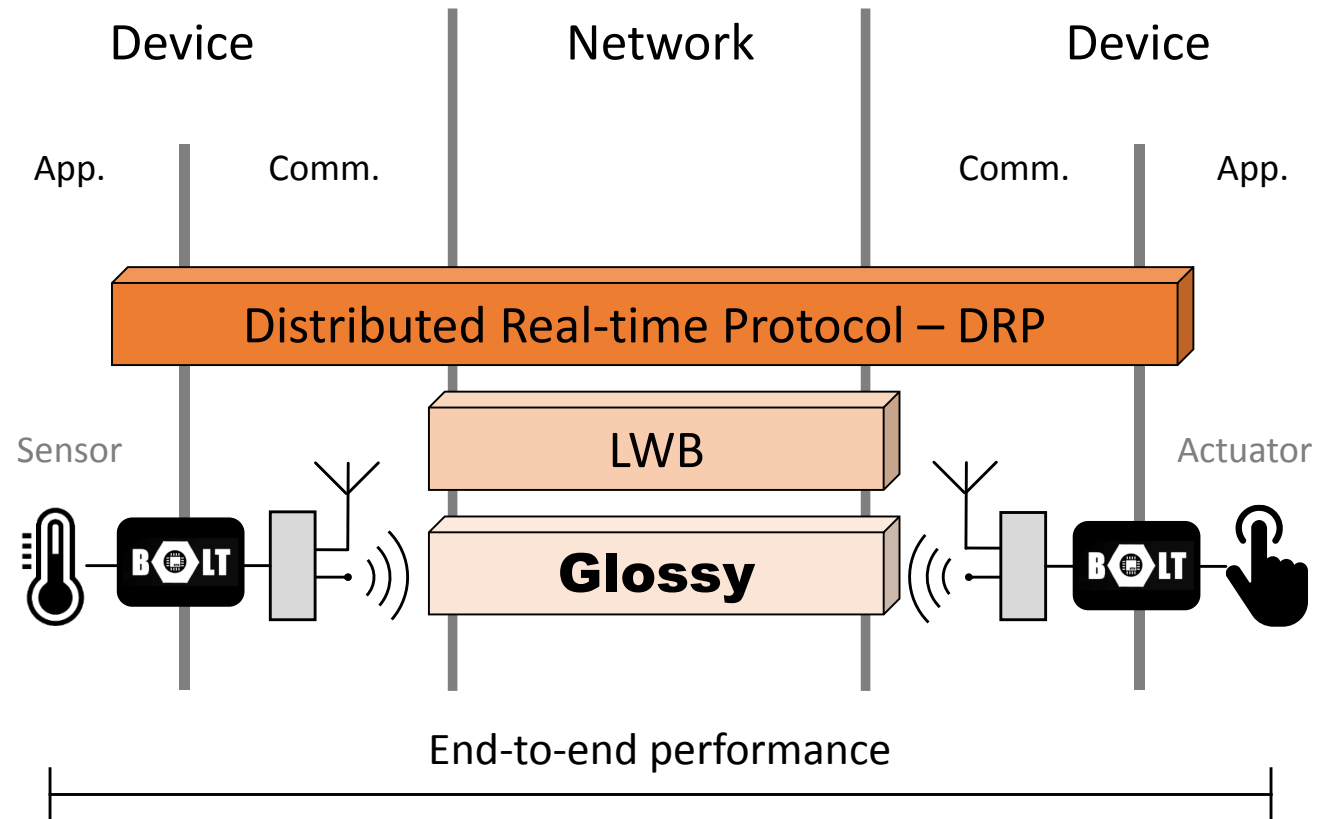
Actuator











Relevant guarantees can be provided
for Cyber-Physical Systems
built *on low-power wireless* networks

Another example

Jacob et al.

TTW: A Time-Triggered-Wireless Design for CPS

Proc. of DATE, 2018

... and you can do it too!

Most software is open source,
tools and hardware are available and more is coming!

Glossy and Low-power Wireless Bus

 sourceforge.net/p/contikiprojects/code/HEAD/tree/ethz.ch/glossy/

 github.com/ETHZ-TEC/LWB/

Bolt

 www.bolt.ethz.ch

 github.com/ETHZ-TEC/Bolt/

Flocklab

 www.flocklab.ethz.ch

Coming soon

- DRP
- 'Glossy Middleware'

Providing Guarantees in Wireless Cyber-Physical Systems



Romain Jacob
ETH Zurich

Let's keep in touch!
jacobr@ethz.ch



Prof. Langendoen Group's Seminar

January 31, 2018 | TU Delft | The Netherlands

Work realized under
the supervision of

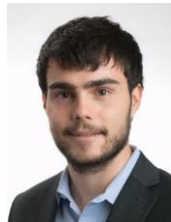


Prof. Lothar Thiele



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Marco Zimmerling
Research group leader
TU Dresden



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Former colleague
ETH Zurich

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