Towards Mission-Critical Control at the Edge and Over 5G

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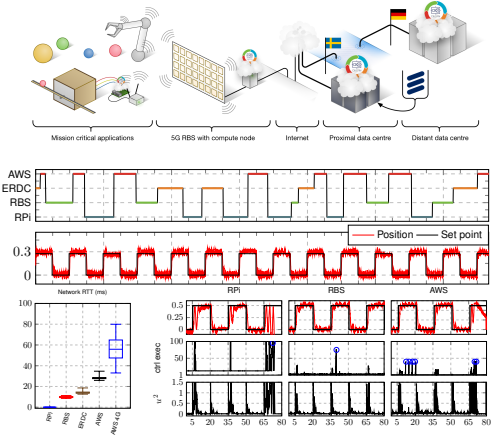
Concept and Reference Platform



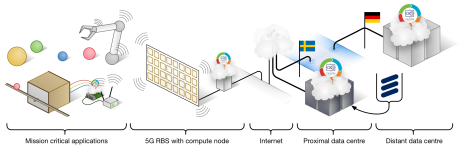
Affiliation

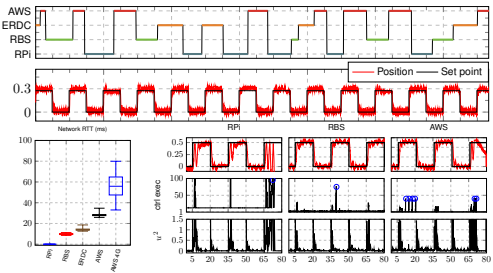
Towards Mission-Critical Control at the Edge and Over 5G

- We built a prototype fog compute platform
  - Next generation (5G) mobile broadband
  - A rich application environment through an IoT platform-as-a-service (Calvin)
  - Powerful tracing capabilities (LTTng)
- We demonstrate the capabilities of this platform
  - Able to control a physical systems at high frequencies
  - While relocating application components (on-the-fly)) over geographical disperse and heterogeneous environments
- Show an example of how the clouds can boost our control systems

Outline

1. Motivation
2. Platform and application
3. Verification results
4. Ongoing work

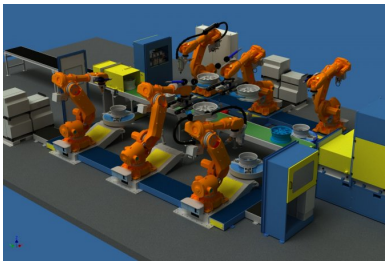




Motivation

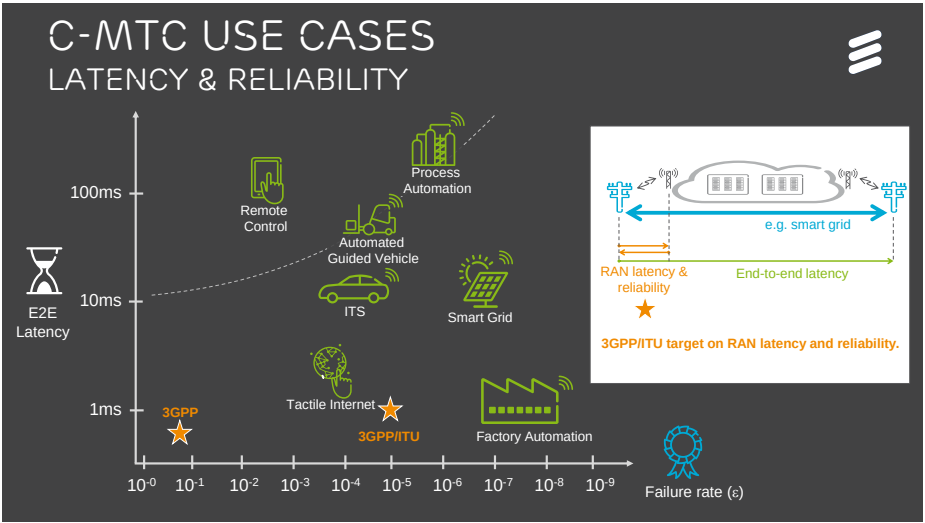
Towards Mission-Critical Control at the Edge and Over 5G

- High speed closed loop control for cyber-physical systems
  - Cloud is an enabling technology, autonomous systems included
- Connected, convenient, mobile
  - 5G opens up for new types of applications



Critical Machine-Type Communication

Ultra-Reliable Low Latency Communication



Massive MIMO (5G) test-bed

12 May 2016 | 21:00 GMT

5G Researchers Set New World Record For Spectrum Efficiency

They showed a 22-fold increase over existing 4G networks

By **Amy Nordrum**

Photo: University of Bristol

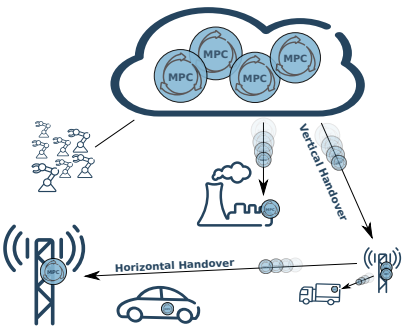
Platform and application

Control Over the Cloud

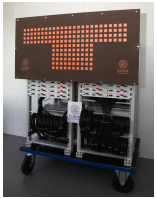
- Mission-critical
  Essential to business operation or to an organization.
- Time-sensitive
  Only relevant or applicable for a short period of time.
  (Current target of systems operating at 10-100 Hz)
- Networks
  Delays, jitter and lost signals

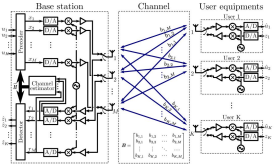
Fog computing

Multi-tenancy, heterogeneity, structural changes, scaling and migration



Massive MIMO (5G) test-bed





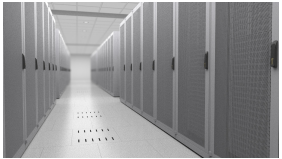
S. Malkowsky et al.: The World's First Real-Time Testbed for Massive MIMO

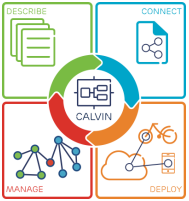
Lund University Massive MIMO (LuMaMi)

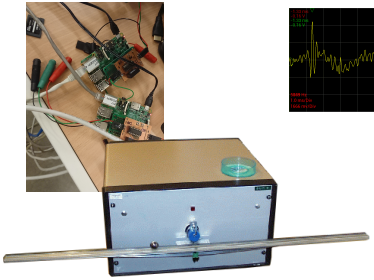
- M-MIMO is candidate RAT for 5G
- Many devices simultaneously
- High reliability wireless
- Low latency*
- Medium Access Control break-out

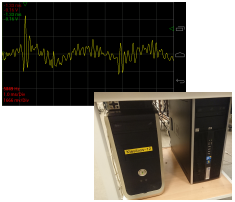
*W. Tärneberg et al.: *Utilizing Massive MIMO for the Tactile Internet: Advantages and Trade-offs*, IEEE SECON Workshops

Components

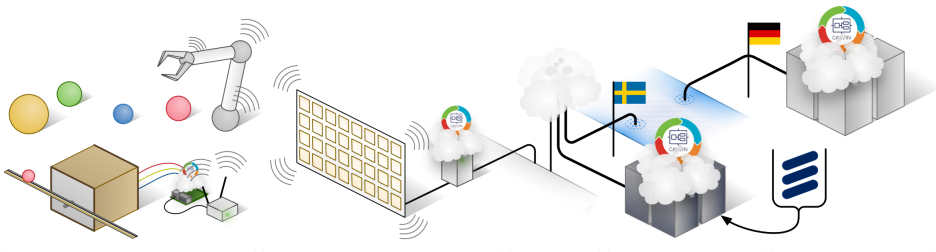








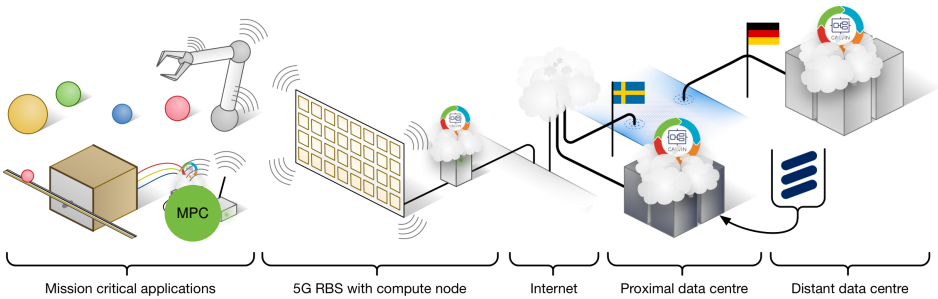
A Platform for Control Over the Cloud



Calvin: IoT Platform-as-a-Service

- Open Source
  Python runtime and C [+μPython] micro runtime
- Flow programing with stateful actors
- Deployment
- Network communication
- Application state
- Application component migration

A Platform for Control Over the Cloud



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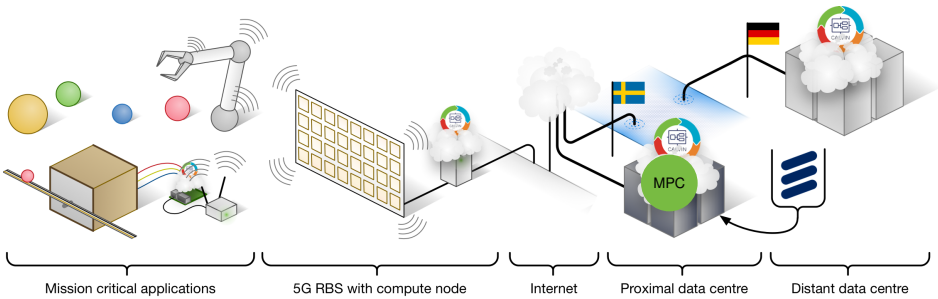

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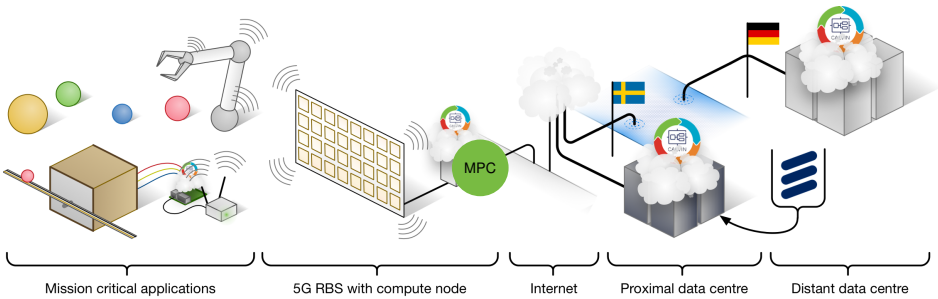

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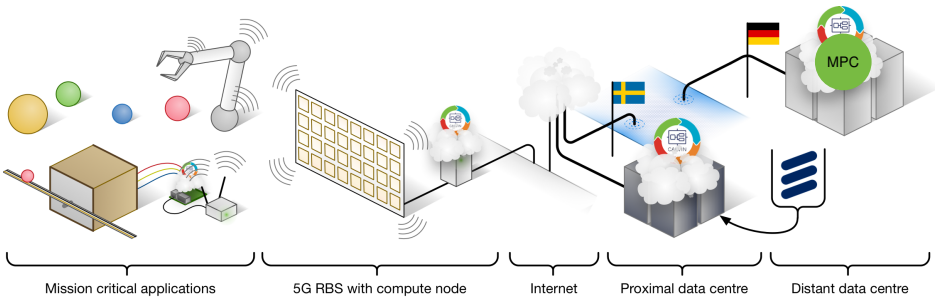

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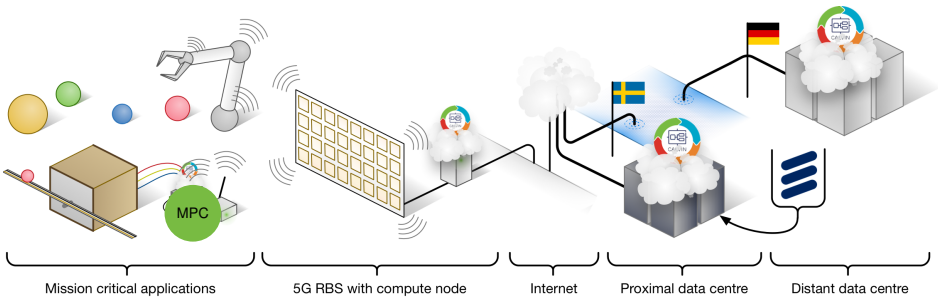

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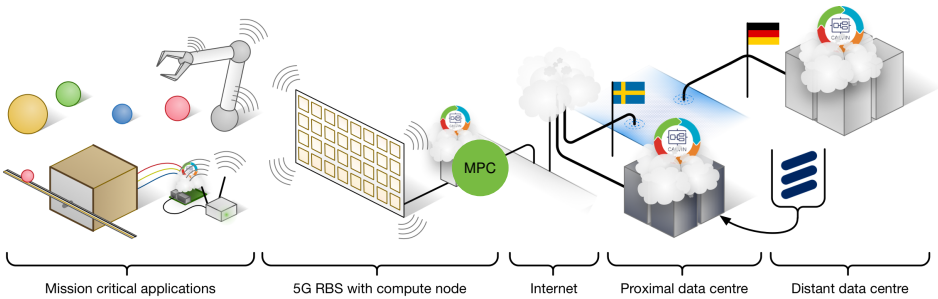
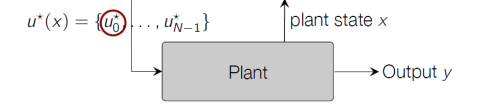


Model Predictive Control

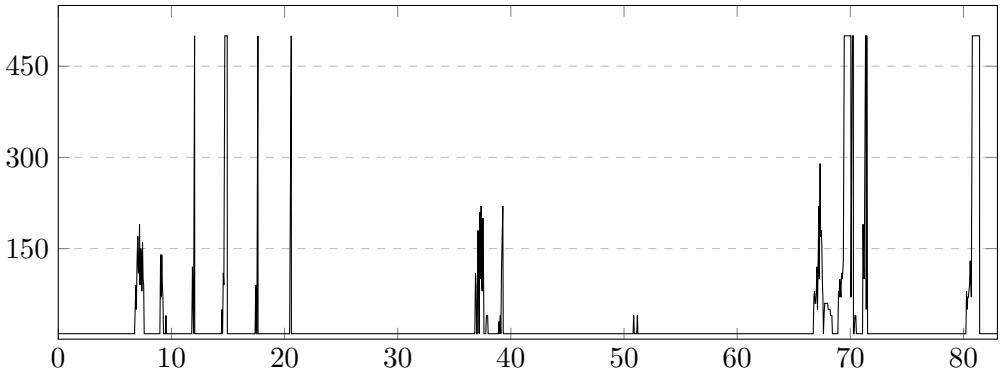
- On-line optimization
  - Resource demanding
  - Variable execution time
  - Adaptable

$$
\begin{aligned}
u^\star(x) := \operatorname{argmin} \quad & x_N^T Q_f x_N + \sum_{i=0}^{N-1} x_i^T Q x_i + u_i^T R u_i \\
\text{s.t.} \quad & x_0 = x && \text{measurement} \\
& x_{i+1} = A x_i + B u_i && \text{system model} \\
& C x_i + D u_i \leq b && \text{constraints} \\
& R \succ 0, Q \succ 0 && \text{performance weights}
\end{aligned}
$$

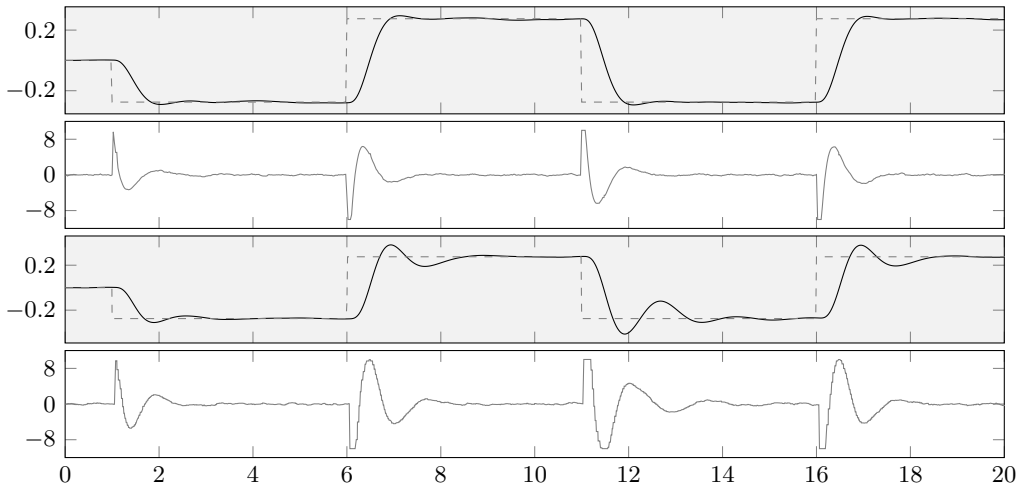


Online-optimization

- The execution time of a controller can vary drastically
- Depends on the disturbances acting on the process and whether constraints are active



Controller induced delay



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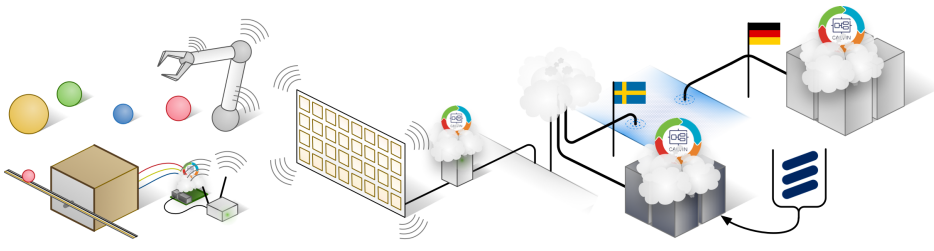


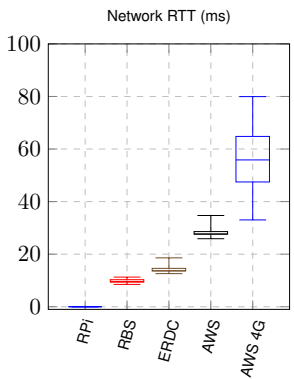
Verification

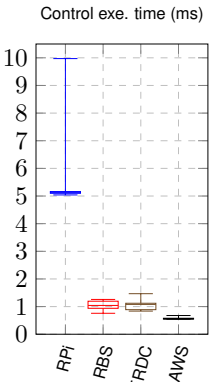
Experiments

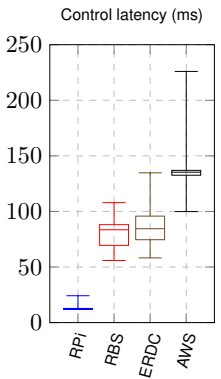
1. Run control from all geographical locations
2. Run control while migrating the controller
3. Exemplify the effect of modified resource demand

Control from anywhere

- Competitive latencies but not single digit and a lot of overhead in the software platform

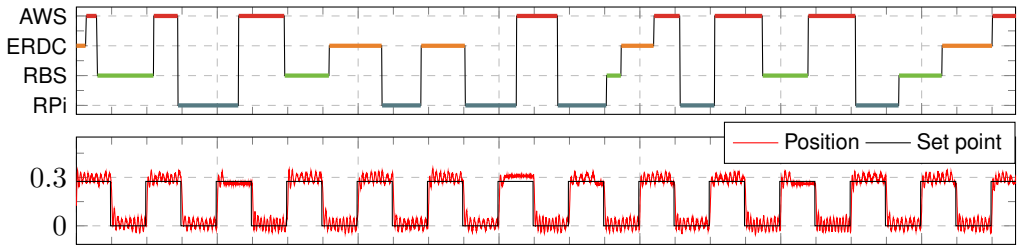






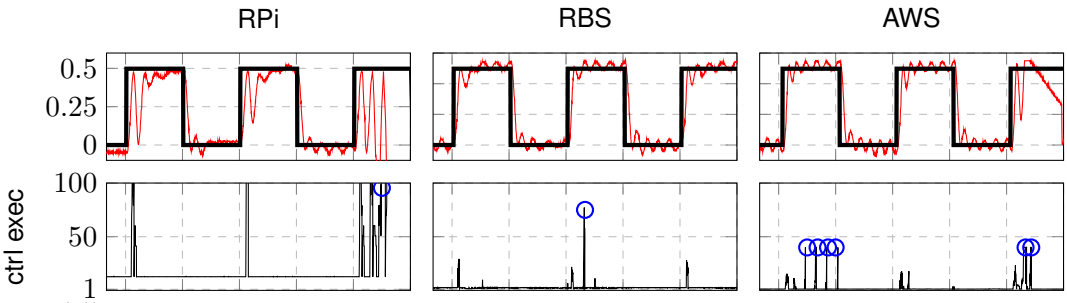
Software migration

- We can move the control software randomly in the system while remaining operational



Increased computational demand

- With some tuning, we cause problems due to computational delay



Ongoing work

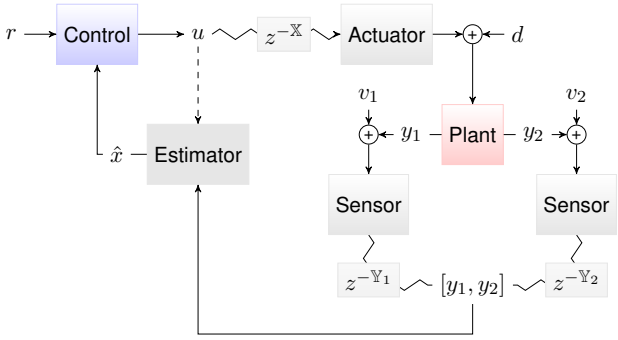
Ongoing work

Alexandre Martins
Autonomous learning camera systems in resource constrained environments
Department of Automatic Control

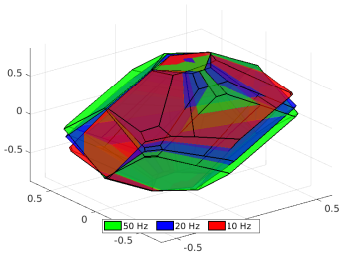
Haorui Peng
Networking for mobile edge cloud under 5G
Department of Electrical and Information Technology

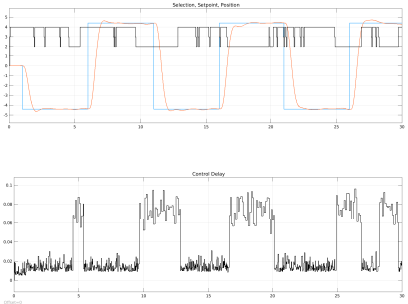
Johan Ruuskanen
Even-based estimation and fusion for Cloud Systems
Department of Automatic Control

Ongoing work



Ongoing work





Thank you for your attention