Benchmarking Networked Control Systems

Sebastian Gallenmüller, Stephan Günther, Maurice Leclaire, Georg Carle
Chair of Network Architectures and Services, Technical University of Munich

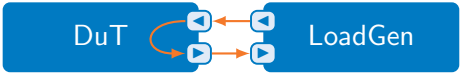
Samuele Zoppi, Wolfgang Kellerer
Chair of Communication Networks, Technical University of Munich

Fabio Molinari
Control Systems Group, Technische Universität Berlin

Richard Schöffauer
Heisenberg Communications and Information Theory Group, Freie Universität Berlin

Motivation

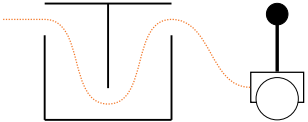
Network Domain



Network domain has well-known benchmarks

(e.g., RFC 2544 [1])

Control domain

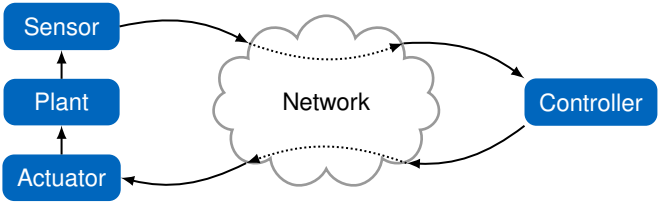


Control domain has its own benchmarks

(e.g., [2])

- Benchmarks are well understood by the respective community
- We want to combine approaches from both domains

Setup: A networked control system



- Single controller
- Single plant (inverted pendulum)
- Network can be wired or wireless

→ Simple setup for easy debugging and easy reproducibility for others and ourselves

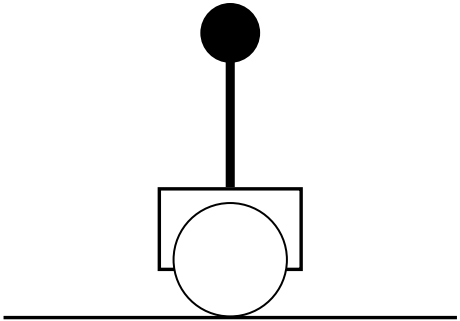
Benchmarking framework

Benchmark is executed in an environment we call scenario:

- application software (controller application, application of plant),
- network stack (as part of an operating system),
- network topology,
- physical conditions,
- communication channel interference,
- hardware (plant, controller, network interfaces).

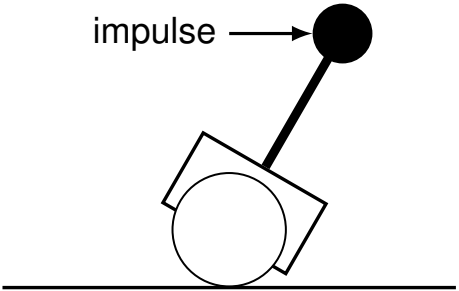
During the benchmark the NCS has to perform challenges.

Benchmarking challenge: inverted pendulum



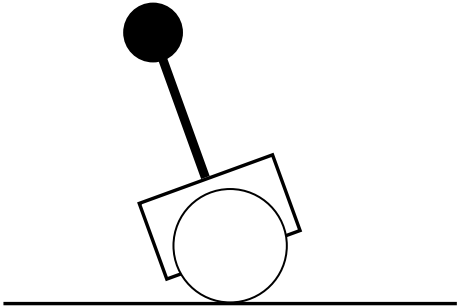
- Inverted pendulum angle is kept in target range by its controller

Benchmarking challenge: inverted pendulum



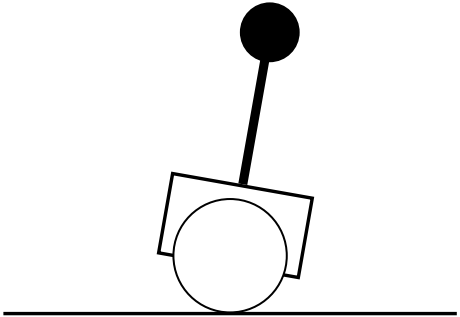
- Specified impulse is applied to inverted pendulum

Benchmarking challenge: inverted pendulum



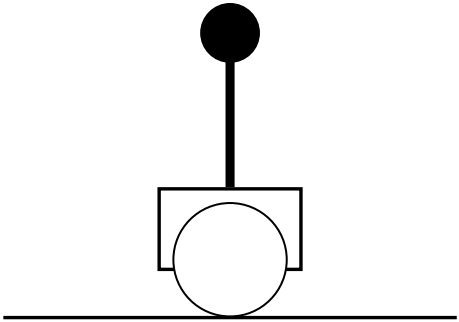
- Stabilization ongoing

Benchmarking challenge: inverted pendulum



- Stabilization ongoing

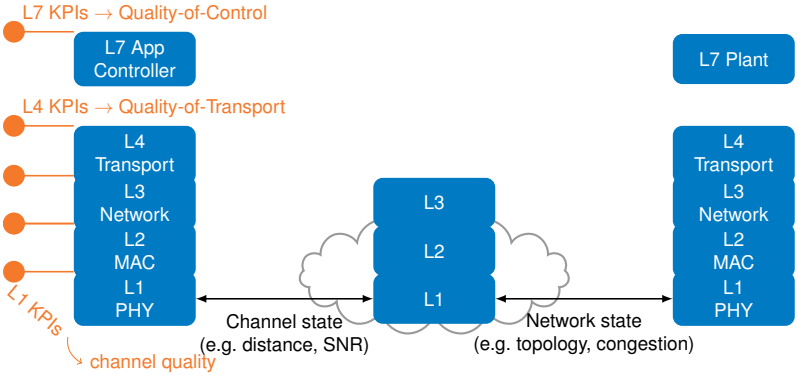
Benchmarking challenge: inverted pendulum



- Inverted pendulum is back to the target range

→ Result is a set of key performance indicators (KPIs)

Combining network domain and control domain KPIs



- Based on the ISO/OSI stack
- Application layer (7): properties of the application (here; inverted pendulum)
- Lower levels (1-4): properties of the network

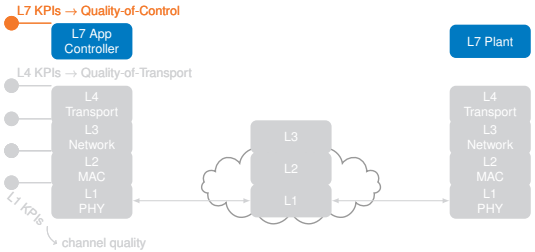
Control domain: Key performance indicators

Generic KPIs (controlling static reference value):

- Maximum disturbance (impulse that can still be corrected)
- Recovery time (time to revert back to reference)
- Energy needed during recovery

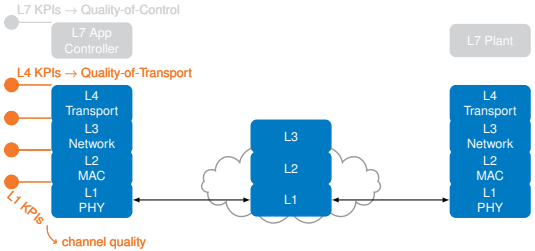
Specific KPIs (for inverted pendulum):

- Maximum pendulum angle
- Starting conditions: max. angle, max. current for motors, max. oscillation period between two max. angles)
- Robustness: max. allowed impulse



Network domain: Key performance indicators

- Packet rate
- Loss rate
- Delay
- Inter-packet time
- Jitter
- Bandwidth-delay product



Reproducibility

Three stages of reproducibility (according to ACM):

1. Repeatablility
2. Replicability
3. Reproducibility

Wireless networks often behave non-deterministically (jitter, packet loss)

➔ Measurements not repeatable ☹

Reproducibility vs. non-determinism

- Shielded room for fully repeatable, wireless environments
- → Expensive, high effort for reproduction

Reporting KPIs:

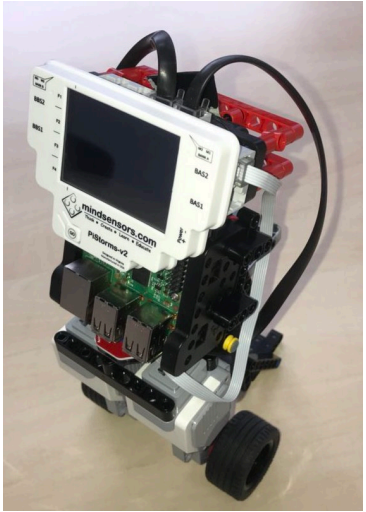
- KPIs often reported as aggregated numbers, such as median, average
- Aggregated numbers often not sufficiently descriptive (e.g., average latency)
- → Report KPIs as histogram or entire packet logs

We propose:

- Record logs of experiments (packet loss, interference)
- → Logs can either be used to make it reproducible (given the right equipment)
- → Logs can also be used to explain the observed behavior (e.g., packet loss due to interference)
- Identify relevant factors
- Model the channel behavior considering these factors
- Report a model and its parameters to repeat

Evaluation platform

- High affordability
- Wide availability
- Easy extensibility:
  - Software:
    - Open source
    - Python
    - Linux (ev3dev, Debian-based)
  - Hardware:
    - Lego Mindstorms
    - Raspberry Pi with sensors
    - USB network adapters
- We plan to release in the near future:
  - Construction plans
  - Software



Conclusion

- Provide a holistic benchmarking framework for NCS:
  - Control domain
  - Network domain
- A layered model of KPIs:
  - Quality of control KPIs (Layer 7)
  - Quality of transport, quality of the communication channel (Layer 4 - 1)
- Our framework offers reproducible benchmarks:
  - Reporting the environment / scenario for benchmarking
  - Reporting logs / histograms to enable reproducibility
- Low cost evaluation platform

Bibliography

[1] S. Bradner and J. McQuaid.
RFC 2544: Benchmarking Methodology for Network Interconnect Devices, Mar. 1999.

[2] T. Niemueller, G. Lakemeyer, S. Reuter, S. Jeschke, and A. Ferrein.
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