Evaluating Low-Power Wireless Cyber-Phyiscal Systems

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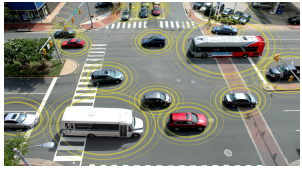
TU Dresden

April 10, 2018 / 1st Workshop on Benchmarking Cyber-Physical Networks and Systems

Motivation

Autonomous Driving



[U.S. Department of Transportation]

Factory Automation

[KUKA Robter GmbH]

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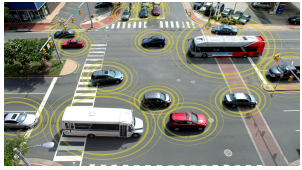

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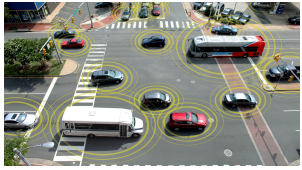

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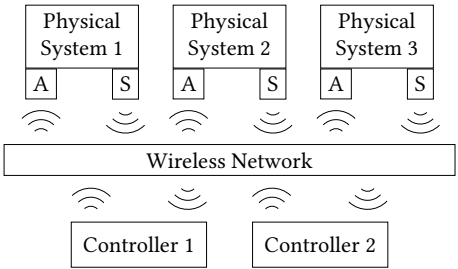
$\Rightarrow$ Need for a standard approach for end-to-end evaluation of the whole wireless CPS, including communication, control, and embedded computing

Model and Challenges of Wireless CPS



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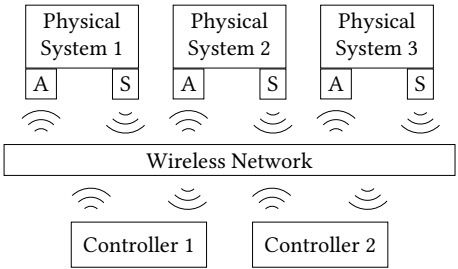

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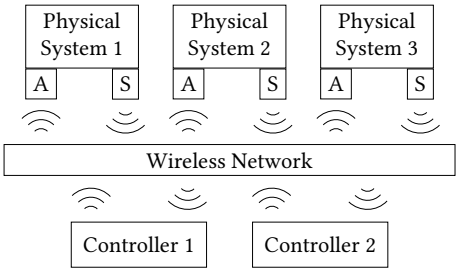

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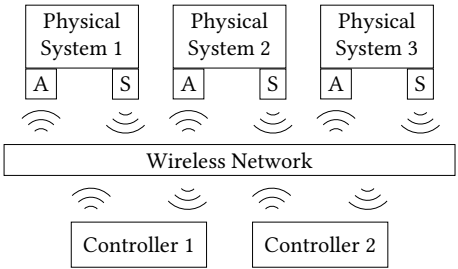

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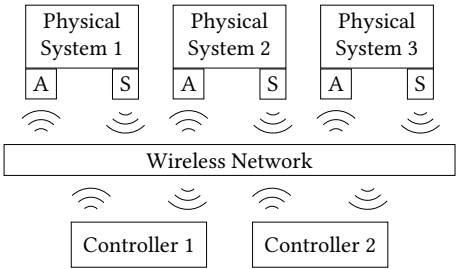

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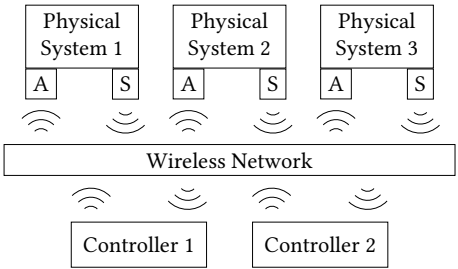

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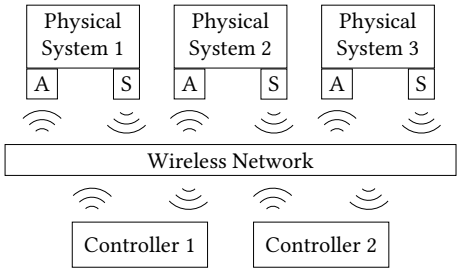

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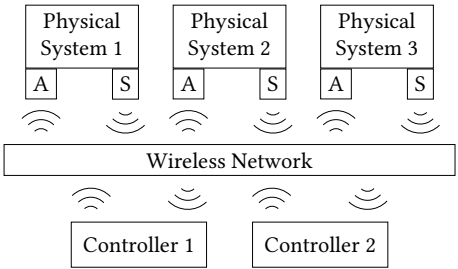

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- More challenging for systems with fast dynamics and unstable systems

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- Minimum end-to-end delay then is a few tens of ms

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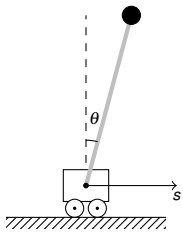
Physical System: Cart-pole System



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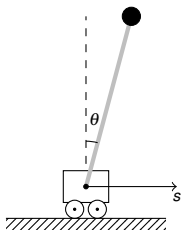

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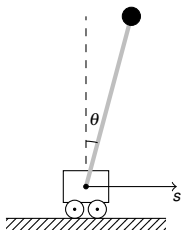

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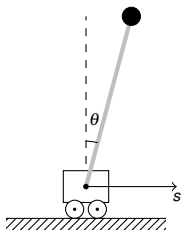

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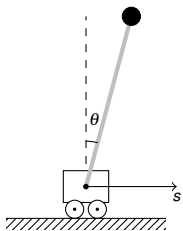

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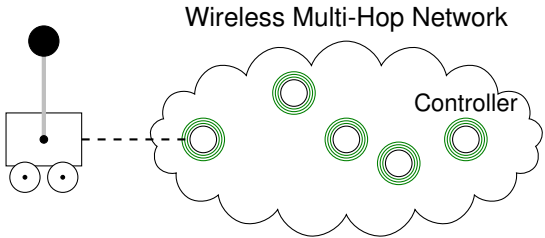

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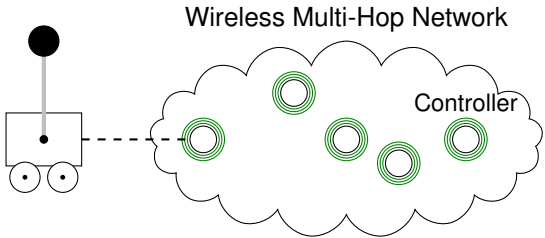

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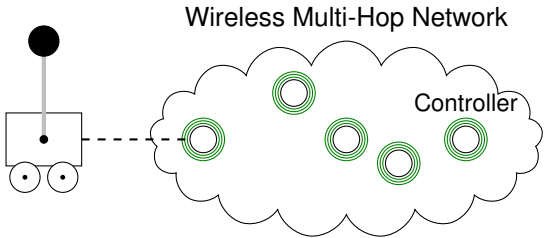

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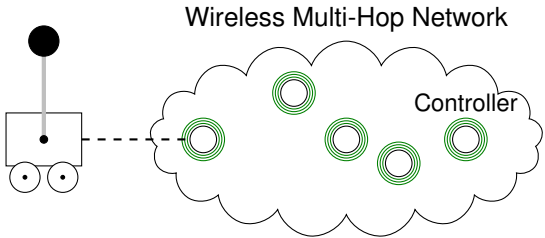

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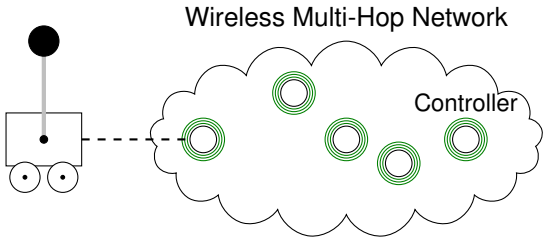

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- Application example: Factory automation

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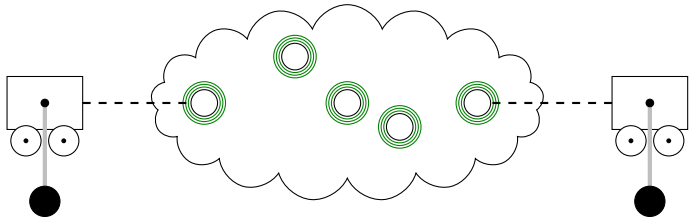

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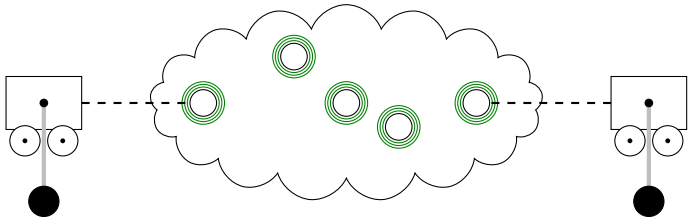

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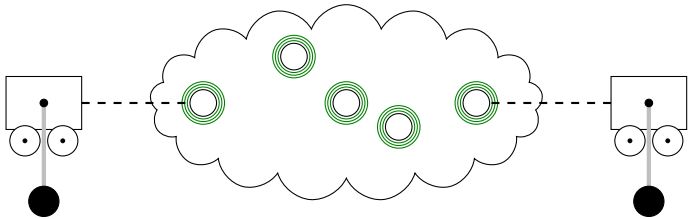

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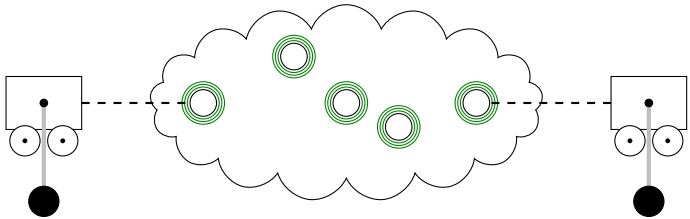

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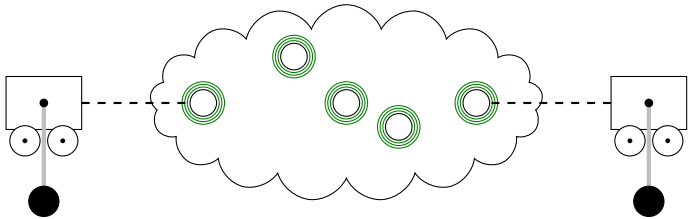

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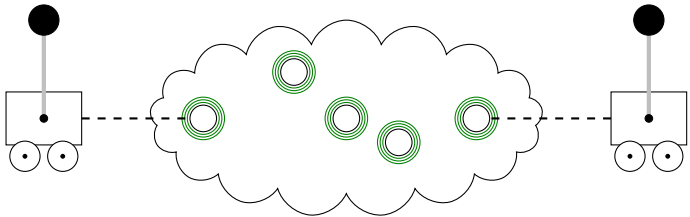
- Application examples: Platooning, formation control for drones

Control Tasks: Synchronization and Stabilization



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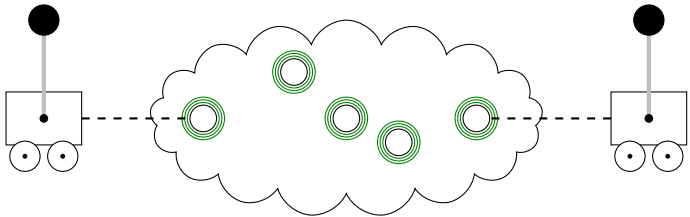

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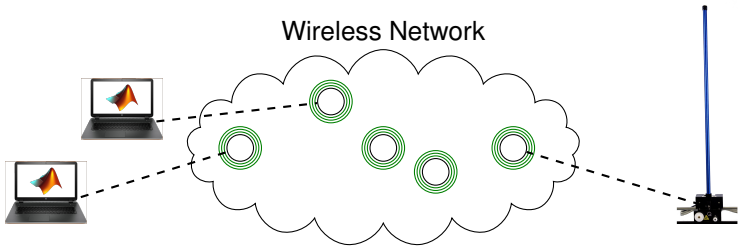

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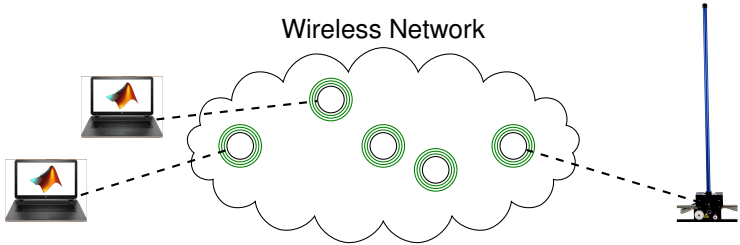

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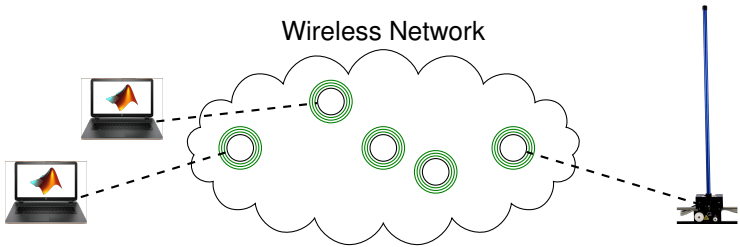

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  - Classical network metrics (*e.g.*, packet drop rate, latency, . . .)

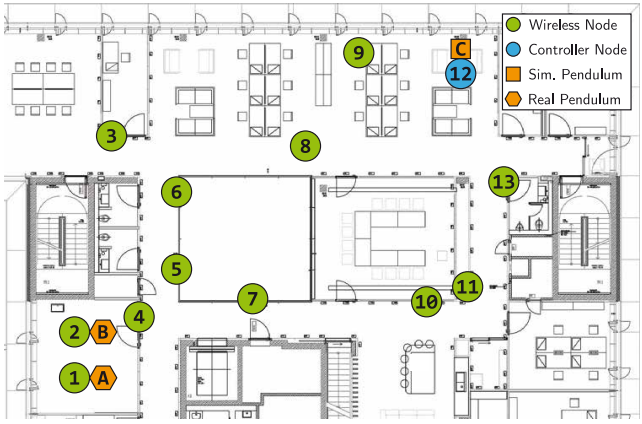
Proposed Metrics for Evaluating Control and Networking

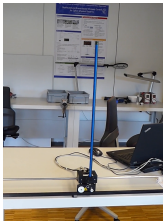
- Wireless CPS can be evaluated using different metrics
- Primary metrics:
  - End-to-end performance
  - Quality of control (*e.g.*, quadratic error between desired and actual state)
  - Energy consumption
  - Compare different CPS implementations of the same scenario
- Secondary metrics
  - Evaluate individual parts of the system
  - Classical network metrics (*e.g.*, packet drop rate, latency, . . .)
  - Control side: Packet drop tolerance, robustness to disturbances, . . .

Requirements for an Evaluation Approach

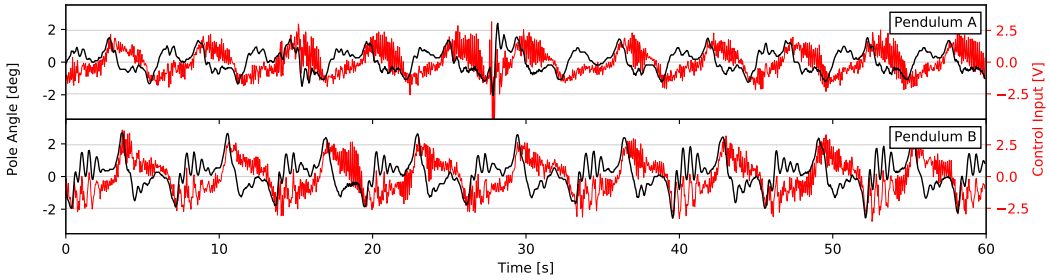
- Suitable physical System
  - Well-known system
  - Dynamics should match timescale of control, computing, and network elements
- Realistic and versatile
  - Variety of realistic control tasks and communication requirements
  - Push state of the art low-power wireless networking and embedded computing to its limits
- Promote adoption and reproducibility
  - Affordable in terms of cost and efforts required to adopt it
  - Reproduce experiments
- Agnostic to control and network
  - Should be applicable to different *system* solutions

Current Research: Reliable Feedback Control over Multiple Hops





Multi-Hop Stabilization of two Cart-poles



- Reliable stabilization of two pendulums

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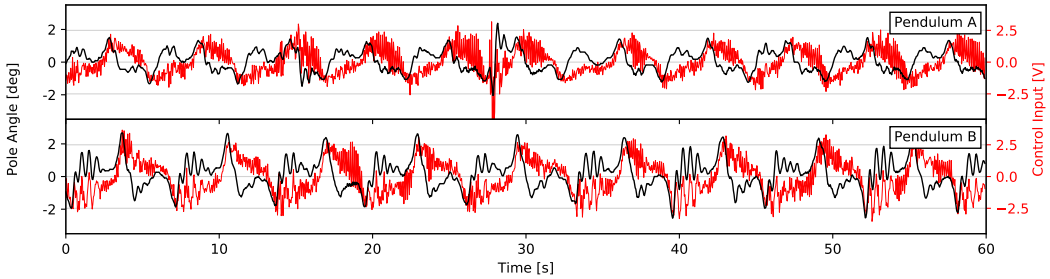
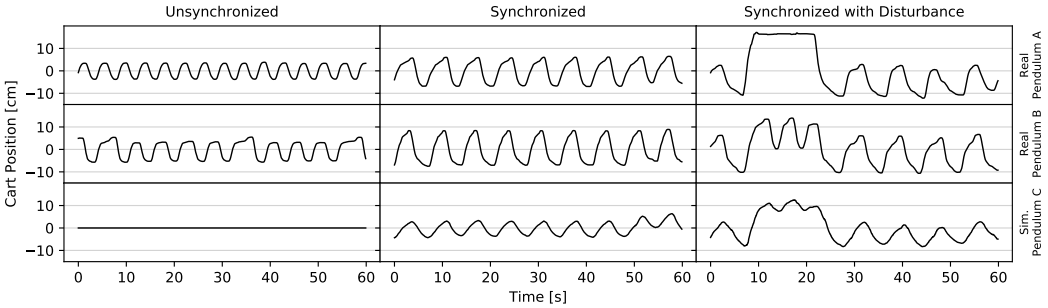


- Reliable stabilization of two pendulums
- Angle and input inside safe regime

Multi-Hop Synchronization of three Cart-poles



- Different frequency for real pendulums without synchronization, simulated pendulum perfectly stable

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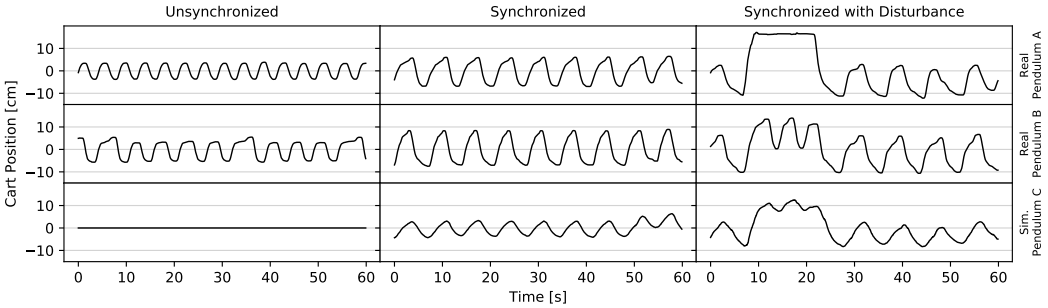

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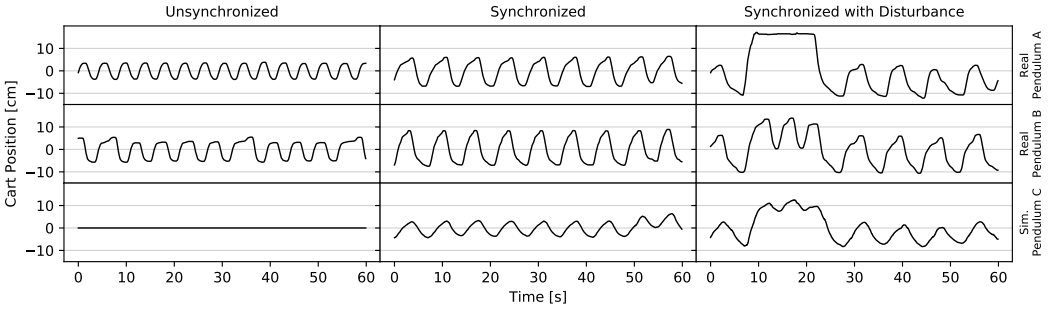

- Different frequency for real pendulums without synchronization, simulated pendulum perfectly stable
- Oscillate with similar frequency in synchronization experiment
- If one pendulum is fixed, the others react and try to synchronize

Conclusions

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- Cart-pole as experimental platform
- Allows for different scenarios that evaluate different capabilities
- Facilitate adoption and integration through simulated pendulums

References

- D. Baumann, F. Mager, H. Singh, M. Zimmerling, and S. Trimpe. “Evaluating Low-Power Wireless Cyber-Physical Systems”. In: *Proceedings of the 1st Workshop on Benchmarking Cyber-Physical Networks and Systems (CPSBench 2018)*. 2018. URL: https://arxiv.org/abs/1804.09582
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- F. Ferrari, M. Zimmerling, L. Thiele, and O. Saukh. “Efficient network flooding and time synchronization with glossy”. In: *Proceedings of the 10th IEEE International Conference on Information Processing in Sensor Networks (IPSN)*. 2011, pp. 73–84

Questions

- Is the cart-pole a good system for benchmarking?
- Are experimental results from a laboratory environment interesting for industry?
- Are these the relevant metrics? Are there other?
- What is missing to a real benchmark?