Don‘t You Touch My Nuts:
Information Hiding in Cyber-physical Systems

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Steffen Wendzel[1,2], Wojciech Mazurczyk[3,4], Georg Haas[1]

[1] Hochschule Worms, Germany
[2] Fraunhofer FKIE, Germany
[3] Warsaw University of Technology, Poland
[4] FernUniversität Hagen, Germany

Information Hiding & Cyber-physical Systems

Information Hiding:
Steganography, copyright marking, anonymity, obfuscation [1]

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Cyber Physical Systems (CPS):
integrations of computation with physical processes [2]

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Information Hiding in Cyber-physical Systems
(specially Steganography for CPS (**CPSSteg**))

Related Work (Chronological Order)

- *Wendzel/Kahler/Rist* (2012) [3]:
  Scenario identification and description of secret data transmission in networked buildings; MLS-based protection approach
- *Tuptuk/Hailes* (2015) [4]:
  Two covert channels (relying on modulation of transmission power and of sensor data) in persuasive computing.
- *Howser* (2015) [5]:
  Data leakage in CPS and MLS-based protection (DLP)
- *Tonejc/Güttes/Kobekova/ Kaur* (2016) [6]:
  Detection of selected covert channels in building automation networks using unsupervised machine learning methods.

Goals & Strategies

- **Goals:**
  - Determining **how much data can be hidden** in a CPS **and for how long**.

- **Possible Benefits:**
  - Storing secret data in a location where currently nobody will search for it, e.g. embedding a cryptographic key in a smart home.
  - *Fighting product piracy* [in progress]

- Analyzed **two different strategies**:
  - Register strategy: utilization of unused memory registers
  - Actuator strategy: storing data in actuator states (e.g. heating level of a heater) in a way that it will not be recognized

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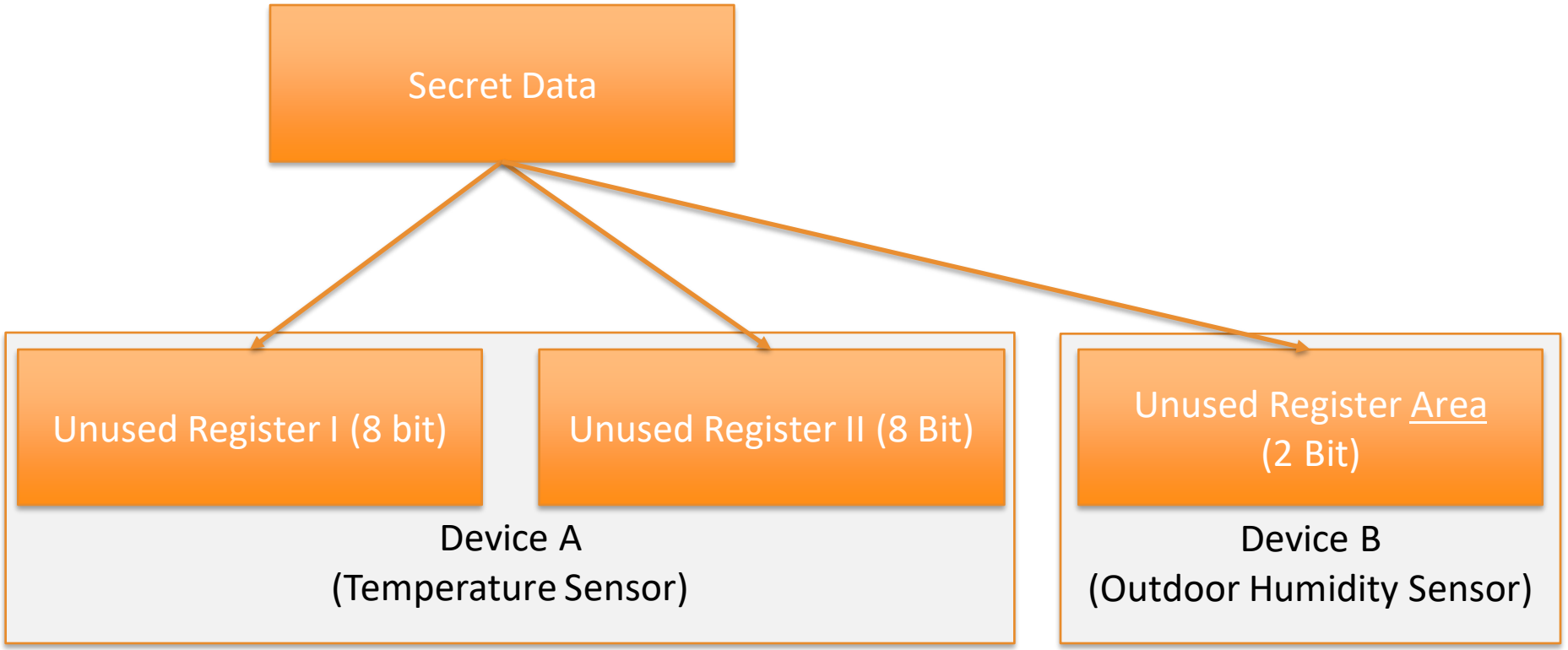
THE REGISTER STRATEGY

Register Strategy: Concept

- We store data in unused registers of CPS components.



Register Strategy: Concept

- Drawbacks:
  - Writing registers may require direct (local bus) access to a CPS device
  - Register size (and thus steganographic storage) limited
  - Each different device model must be analyzed separately (e.g. datasheets)

- Advantages:
  - Several CPS components and CPS types contain unused registers
    - We used a temperature sensor that contains two unused registers; sensor could be embedded in several types of CPS.
  - Good reading and writing performance
  - Valuable to compare performance of **actuator strategy** (later) – is the more sophisticated approach actually *better*?

Register Strategy: Experiments

- Used Maxim Integrated Products, Inc., 1-Wire DS18B20 temperature sensor
  - Communication via 1-Wire protocol

- Approach:
  - Store data in the alarm registers (2x8 bits) of up to 4 sensors.
  - Sort data by sensor-internal unique serial number (can be read via bus connection)

- In experiment, measured time consumption of 100 reading operations from 1, 2 and 4 sensors simultaneously and of 100 writing operations (0x0000 followed by 0xffff in a loop) to one sensor.

Register Strategy: Results

- Reading performance (avg.) per sensor increased with the number of sensors as addresses were only required to be fetched once.
- Values remained robust (0% reading errors within 180.000 operations)
- Thus, performance for steganographic operations not an issue.

Scenario	Avg. Time [µs]	Min. Time [µs]	Max. Time [µs]
Reading 1 Sensor	12.841	12.800	12.844
Reading 2 Sensors	12.804	12.784	12.806
Reading 4 Sensors	12.802	12.788	12.804
Writing 1 Sensor	71.827	71.800	71.834

No general conclusion on storage space possible, *probably* around *#SelectedDevices * 4-8 bits* (available register bits on average).
A single 128 bit crypto key would then require 16-32 devices.

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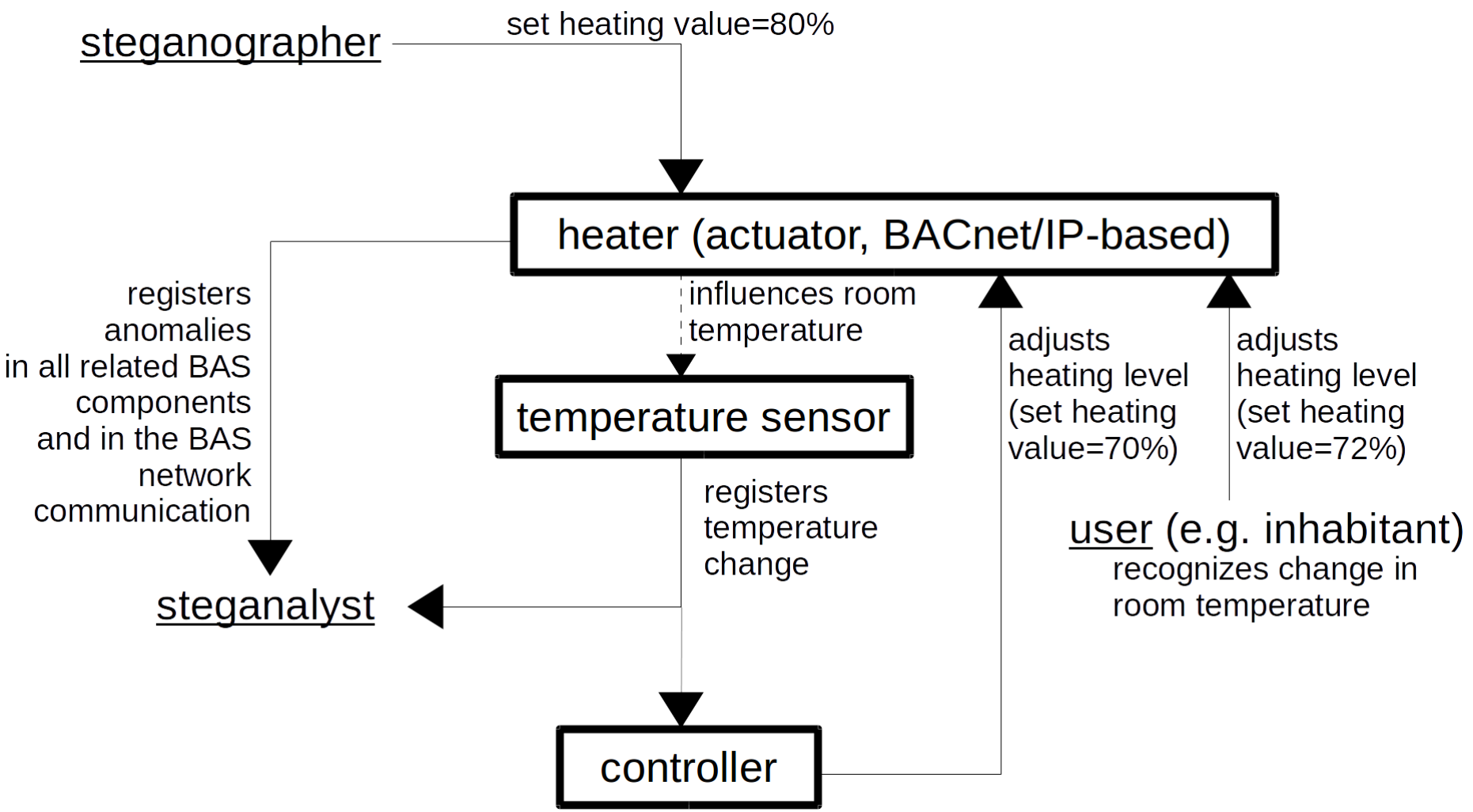
THE ACTUATOR STRATEGY

Actuator Strategy: Concept



Animal Scatter Hoarding

- For storing collected food, determine locations (caches) which remain mostly untouched by competing animals.
- Split food storage over many storage locations

Image source: Wikipedia, © SajjadF

Adaptive Information Hiding

- How to **determine suitable actuators** for secret data storage?
  - Scan for devices in a CPS environment, e.g. BACnet: “Who-Is” broadcast to determine present devices
  - Afterwards scan these devices to determine their objects and present values
  - Monitor changes of all actuator values over time and sort out unsuitable devices (e.g. door openers or devices with frequently changed states)

- Not a perfect solution:
  - Steganographer operates on the assumption that the CPS will behave as it behaved in the past (based on recordings of its historic behavior)
  - But future CPS behavior cannot be predicted with 100% accuracy based on the historic behavior
    - imagine an open house presentation: building automation system’s actuators will most likely be used in different way, e.g. a previously unused room will be heated
  - Still requires use of error detecting/correcting codes, e.g. parity bits or spreading of redundant data over several devices

Actuator Strategy: Experiments

- Simulated scatter hoarding using the BACnet protocol
  - ISO standard for communication in automated buildings
  - **How well can we store steganographic data under different conditions?**

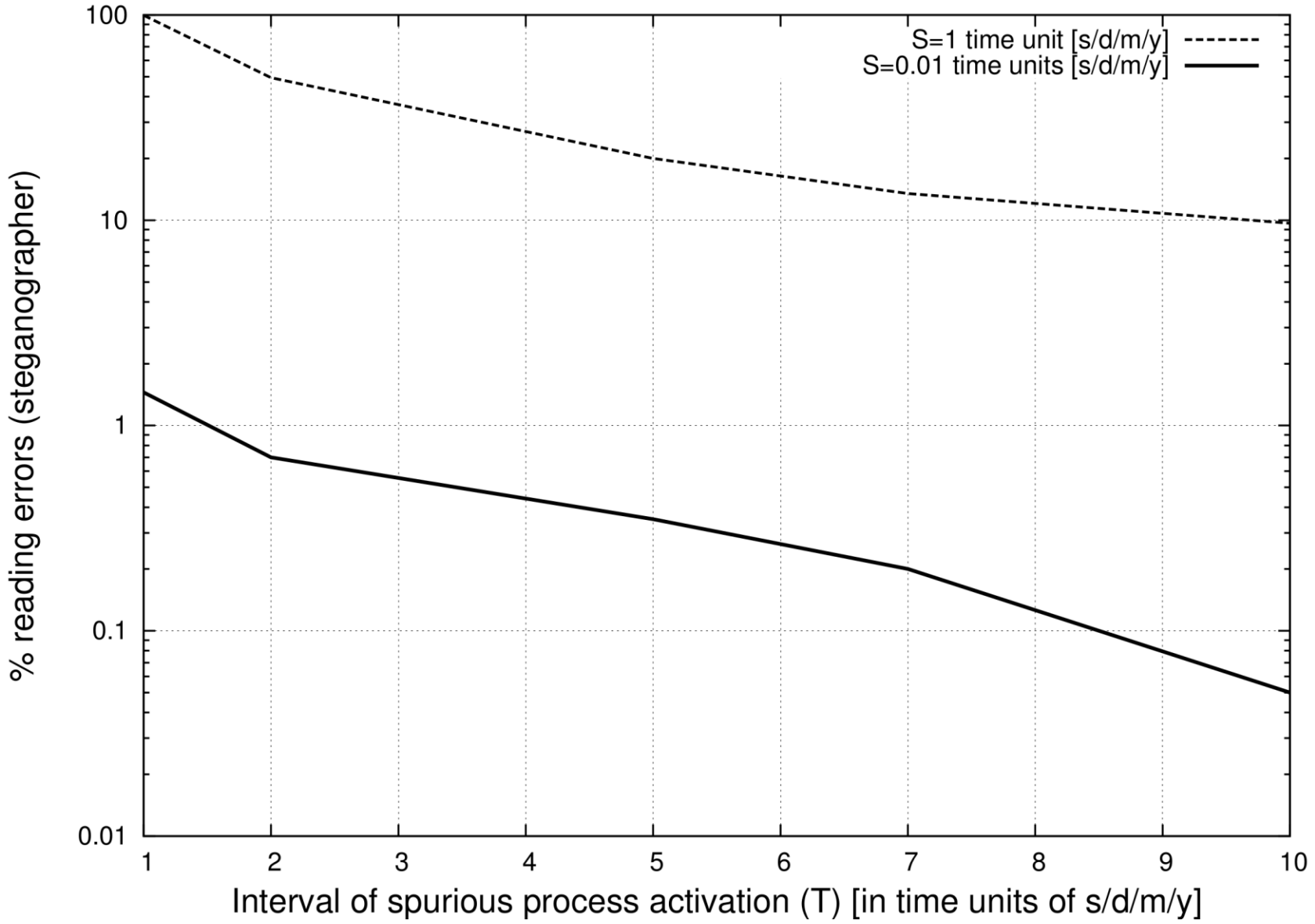
- **In general:** Wrote 100.000 values to an actuator (iterating through values 0°C…100°C). After each value written, the current value was read from the device.

- **Experiment 1**: Introduction of a Spurious Process [7] (**Read-only**)
  - Spurious read-only process (resulted in slow-down of steganographer's process but no data loss as BACnet protocol was able to re-send non-acknowledged packets).

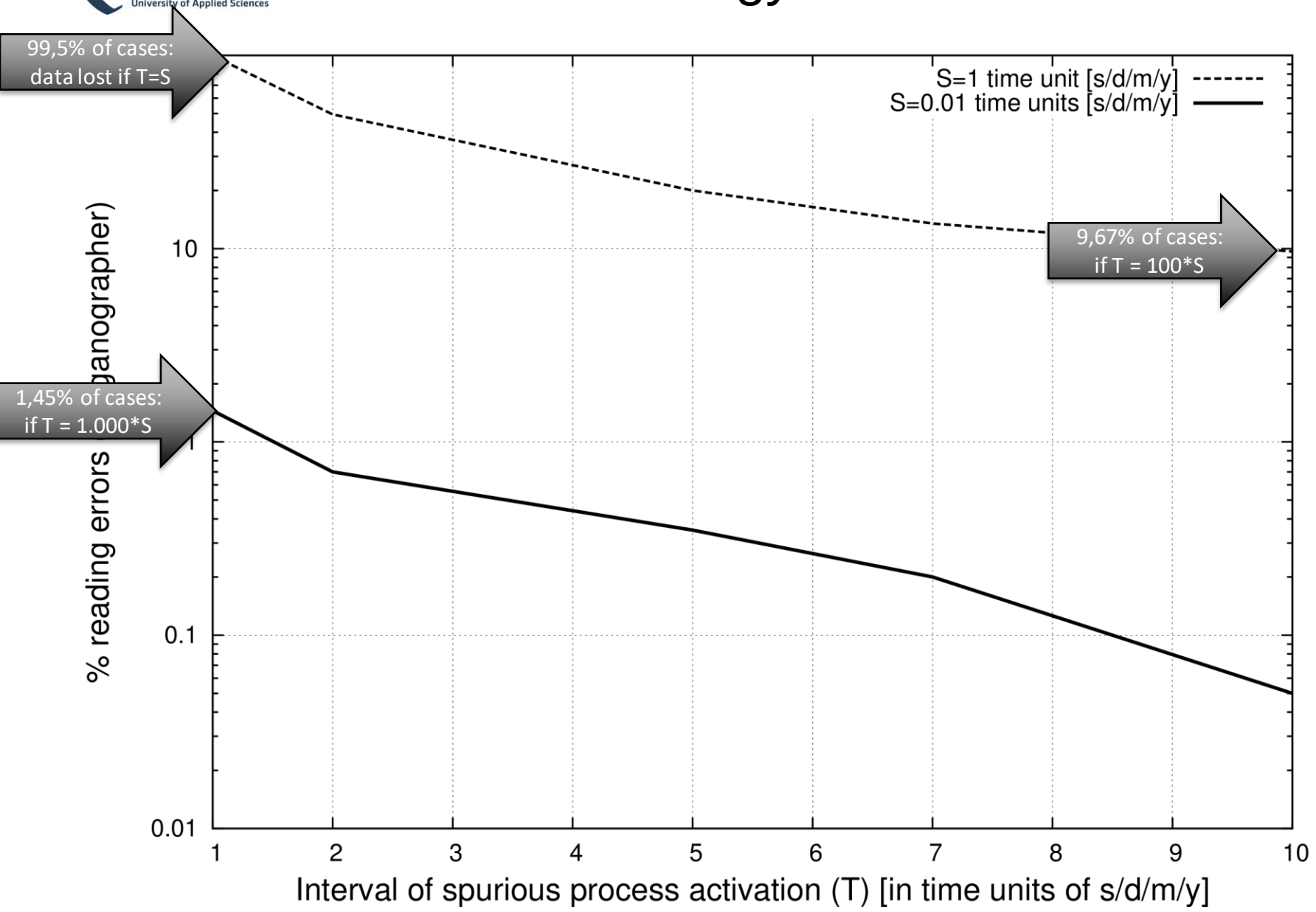
Actuator Strategy: Experiments

- **Experiment 2**: Spurious Process (**Read-Write**)
  - SP represents inhabitant or control logic that changes actuator states
  - Competing animal detects hoarding location (read) and steals food (replacing stored value with a random value)
  - Spurious process writes data every T seconds while the desired storage time was S seconds.
  - Simulated situations reaching from highly spurious ($T = S$) to few spurious intrusions ($S \ll T$).

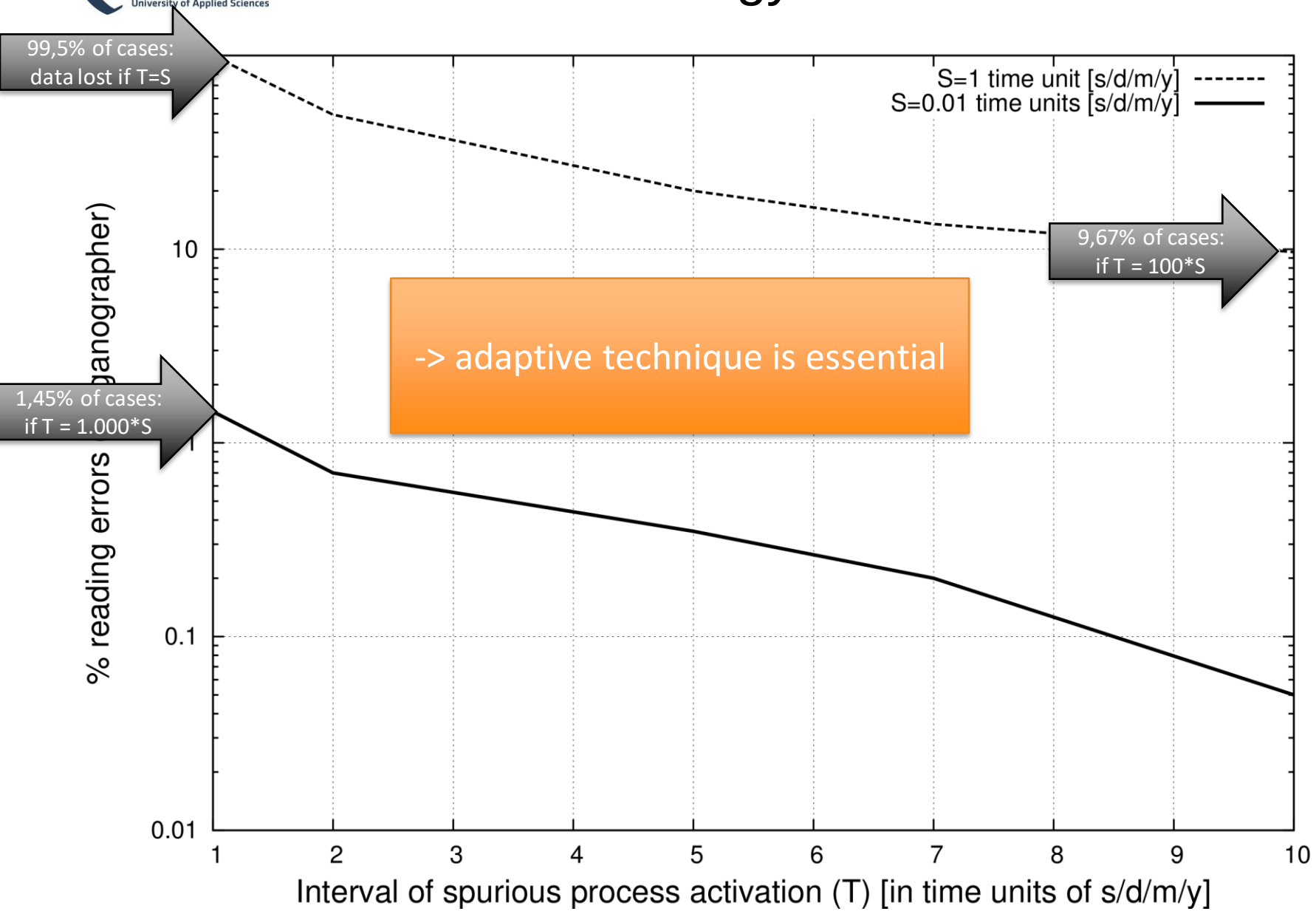
Actuator Strategy: Results



Actuator Strategy: Results



Actuator Strategy: Results



Actuator Strategy: Results

- Storage capacity of actuators highly depends on actuator type (e.g. boolean on-off switches or heaters that provide a fine distinction between heating levels).
- We can assume storage capacity of *2-7* bits per *useful* actuator
  - *18-64* actuators for a 128 bit AES key (**more than in case of register approach!**)

- If we further assume *5-10*% of actuators could be utilized in medium-sized BACnet environments (e.g. 1.000-20.000 actuators), we could store approx. *350* bits - *1.7* Kbytes if *7* secret bits/device can be stored.

- **Advantage: unified accessibili**ty of actuator approach using common protocol (BACnet) over register approach (individual register access needed!)
  - Especially in larger installations

- Performance: ~0.0055 sec per value that must be written/read
  - some actuators much slower
  - some bus systems much slower
  - 0% reading errors without RW spurious process

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CONCLUSION

Conclusion

- The amount of data we can store in a CPS highly depends on
  - How we embed data (hiding method)
  - How many devices are available (e.g. #actuators)

- Similarly, these factors influence the robustness of the embedded data.

Limitations and Future Work

- Structure, environments and capabilities of CPS can vary strongly between different CPS types (e.g. smart building vs. wearable).
  - Further studies needed for other CPS types.
  - Caused influence of steganographer on CPS (and its physical environment) not necessarily clear -> CPSSteg considered risky.
    - Probably not suitable for ICS.

- Novel approaches for Information Hiding in CPS can be expected.
  - We plan to utilize **BACnet COV Subscription** relationships to encode steganographic data.
  - Embedding data for copyright marking, e.g. DRM for smart buildings to fight piracy of products (e.g. using CPS traffic obfuscation or covert channels).

References

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