Seminar in Networked Embedded Systems

Summer 2023

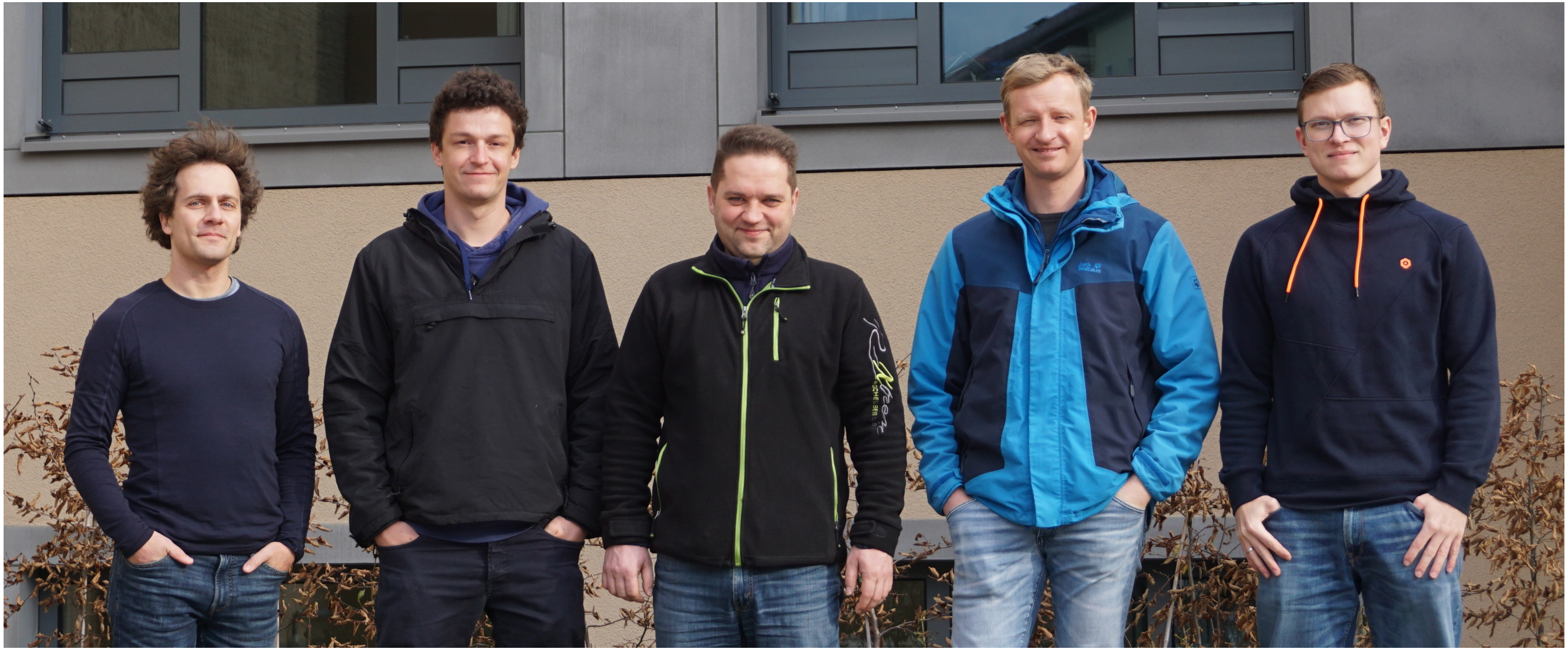
https://nes-lab.org/nes-seminar-summer2023/

Prof. Dr. Marco Zimmerling

NES | NETWORKED EMBEDDED SYSTEMS LAB

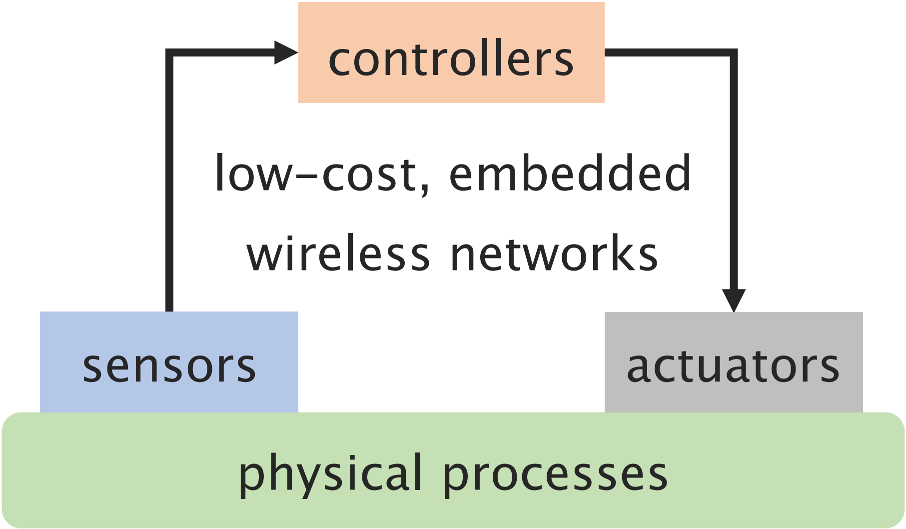
TECHNISCHE UNIVERSITÄT DARMSTADT

Networked Embedded Systems Lab



Networked Embedded Systems Lab

- Research group since 2015
- Focus: Analysis and design of cyber-physical and IoT systems
- Goal: Make these systems dependable and sustainable
- https://nes-lab.org/



About me

- Professor at TU Darmstadt since April 2023
- Previously:
  - Studies at TU Dresden, Uppsala University, and Swedish Institute of Computer Science (RISE SICS, Stockholm)
  - Research internship at IBM T.J. Watson (Hawthorne, NY, USA)
  - PhD at ETH Zurich (Switzerland)
  - Research group leader at TU Dresden
  - Professor at University of Freiburg

Plan for today

1. Teaching goals

2. Organization

3. Available topics

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Why attend this seminar?

- Learn fundamentals of doing research
  - Read and understand papers
  - Summarize and present complex concepts
  - Give constructive feedback
- Learn about cutting-edge research in cyber-physical systems, wireless sensor networks, and the Internet of Things
  - Maybe your future thesis topic
  - Opportunities for HiWis

Plan for today

1. Teaching goals
2. Organization
3. Available topics

Your tasks

- Read a research paper
- Present the paper to your peers
  - Give a 15-minute talk
  - Write a 2-page abstract
  - Prepare a poster
- Active participation
  - Try to attend all sessions
  - Ask critical questions, provide constructive feedback, etc.

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  Typical format at top international conferences
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Posters

Your poster abstract should have "Poster abstract:" at the beginning of the manuscript's title. You may include links to additional online material such as videos. Videos of accepted posters will be linked from the SenSys web pages and permanently included in the ACM Digital Library. Posters and demos must be submitted as a single PDF containing no more than 2 pages. The submission should be self-contained ready for publication, including the title, authors, institutional affiliations and contact information, abstract, main body, and references. Please DO NOT anonymize your submission. Upon acceptance, instructions for the final camera-ready abstract will be provided. Demos of previously published work are welcomed if the previous work is cited in the submission.

https://sensys.acm.org/2022/demos/

Talks (10–20 minutes)

Carsten

Poster and demo session (2–3 hours)

Posters

Demos

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Advice today
Help from mentor

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Advice on reading a paper

- “How to read a paper” by S. Keshav (2 pages) http://ccr.sigcomm.org/online/files/p83-keshavA.pdf

- “How to read a research paper” by M. Mitzenmacher and N. Ramsey (2 pages) https://ccc.inaoep.mx/~esucar/Clases-semdr/Lecturas/ramsey00.pdf

Basic approach: Three passes

- Skim abstract, conclusions, section titles, figures (10 min)
  - What is the general problem area? Is it interesting for me?

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  - What is the general problem area? Is it interesting for me?
- Quickly read rest of the paper (1 hour, at most 2 hours)
  - What are the paper's contributions (i.e., basic idea of proposed method, how is it analyzed/evaluated, how well does it work, …)
  - Don't be afraid to skip certain parts (e.g., detailed descriptions) and note things you have not yet fully understood

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  - Don't be afraid to skip certain parts (e.g., detailed descriptions) and note things you have not yet fully understood
- Carefully read entire paper again (3-6 hours or even more)
  - How does it really work? Need to consult other relevant literature?

Your tasks

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  - Prepare a poster
- Active participation
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  - Ask critical questions, provide constructive feedback, etc.

Talk: Format and rules

- Present a recent research paper published at a top venue
- Slides and speech in English
- 15 minutes + questions

- Prepare your own slides
  - No copy & paste from existing slides (e.g., authors' slide deck)
  - You may use results (e.g., plots) and examples from the paper

Talk: Specific advice

- Content
  - Motivation: What is the problem? Why is it important? *high-level*
  - Contribution: What is the main novel idea? *some details*
  - Conclusion: 1-slide summary *high-level*
- Presentation
  - Examples are your secret weapon
  - Stick to the time limit
  - Practice, practice, practice

Talk: General advice

- “How to give a great research talk” by S.P. Jones https://www.microsoft.com/en-us/research/academic-program/give-great-research-talk/

- “Creating effective slides” by J. Doumont http://youtu.be/meBXuTIPJQk *highly recommended*

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Poster Abstract: Exploiting Protocol Models for Generating Feasible Communication Stack Configurations

Marco Zimmerling, Federico Ferrari, Matthias Woehrle, and Lothar Thiele
Computer Engineering and Networks Laboratory
ETH Zurich, Switzerland
{zimmerling,ferrari,woehrle,thiele}@tik.ee.ethz.ch

ABSTRACT

Communication stacks are composed of distinct layers that, in principle, operate independently and interact through well-defined interfaces. However, resource constraints in sensor networks typically necessitate optimizations, leading to implicit assumptions and dependencies among layers (*e.g.*, a collection protocol assumes the MAC protocol provides sufficient bandwidth). These dependencies are often tracked manually, yet become extremely complex as protocols evolve and requirements change. We propose to model assumptions and dependencies explicitly, as constraints on protocol parameters. This allows for using standard tools to generate feasible protocol configurations. We demonstrate the effectiveness of our approach using the example of FTSP running on top of a low-power listening MAC protocol.

Categories and Subject Descriptors

C.4 [**Performance of Systems**]: *Modeling techniques*; D.2.1 [**Software Engineering**]: Requirements/Specifications—*Methodologies*

General Terms

Performance, Reliability

Keywords

Protocol Configuration, Constraint Programming

1. INTRODUCTION

Keeping track of the various interactions and dependencies between the different layers of a communication stack is a critical yet inherently complex task. Choi *et al.* [1] tackle the problem of inter-protocol interference on the network layer and propose an isolation layer to avoid collisions and guarantee protocol fairness. Indeed, unintended interactions are even more likely between protocols on different layers: protocols frequently make assumptions on the behavior of other protocols to meet the application requirements [6].

We propose to explicitly model assumptions of protocols to expose hidden dependencies between individual layers. While creating such a model is a considerable initial overhead, it frees the designer from managing the various dependencies manually. Moreover, it allows for automatically generating feasible and consistent configurations of the complete stack for *i)* different protocol combinations, *ii)* different deployment settings, *iii)* different protocol parametrizations, and *iv)* when requirements change.

IPSN'10, April 12–16, 2010, Stockholm, Sweden.
ACM 978-1-60558-988-6/10/04.

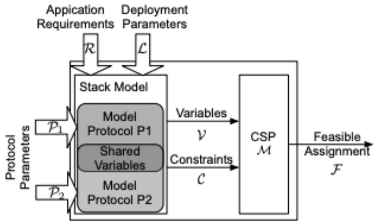

Figure 1: Overview of the approach.

2. APPROACH

Figure 1 outlines our approach. The stack model comprises different protocol models and their individual parameters $\mathcal{P}_i$ (*e.g.*, the sleep interval of the MAC protocol). Shared variables appearing in more than one protocol model signal dependencies and interactions among protocols. In addition, the stack model takes as inputs deployment parameters $\mathcal{L}$ (*e.g.*, the number of nodes) and a set of application requirements $\mathcal{R}$ (*e.g.*, the required data yield). From this model, we extract a set of constraints $\mathcal{C}$ on variables $\mathcal{V}$ for which we seek to find feasible assignments $\mathcal{F}$, the protocol configurations.

In particular, we can formulate a constraint satisfaction problem (CSP) $\mathcal{M} = \langle \mathcal{V}, \mathcal{D}, \mathcal{C} \rangle$, where $\mathcal{V}$ is an n-tuple of decision variables $\mathcal{V} = \langle v_1, v_2, \ldots, v_n \rangle$, $\mathcal{D}$ is a corresponding n-tuple of domains $\mathcal{D} = \langle D_1, D_2, \ldots, D_n \rangle$ such that $v_i \in D_i$, and $\mathcal{C}$ is a k-tuple of constraints $\mathcal{C} = \langle C_1, C_2, \ldots, C_k \rangle$ [3]. A constraint C_i is a pair $\langle R_i, S_i \rangle$, where S_i is a k_i-tuple of variables in $\mathcal{V}$ and R_i is a relation of arity k_i over the domains of the variables in S_i. Solving the CSP $\mathcal{M}$ involves finding a value for each variable in $\mathcal{V}$, where the constraints $\mathcal{C}$ specify that some subsets of their domains $\mathcal{D}$ cannot be used together. We can use standard CSP solvers for this task, which combine interference (constraint propagation) and search algorithms. If we are interested in an optimal protocol configuration, $\mathcal{M}$ can be transformed into a constraint optimization problem (COP) by adding an objective function.

Our approach is modular and allows for fast iterations when application requirements or deployment characteristics change. Since every protocol parameter can also be specified as a constraint, we can analyze the effect of deviating conditions. Most importantly, the stack model and thus the generated protocol configurations capture all protocol dependencies, which reduces the risk of unintended interactions at runtime.

Poster Abstract: All-to-all Communication in Multi-hop Wireless Networks with Mixer

Fabian Mager*, Johannes Neumann*, Carsten Herrmann†, Marco Zimmerling*, Frank Fitzek†
* Networked Embedded Systems Group, TU Dresden, Germany
†Deutsche Telekom Chair of Communication Networks, TU Dresden, Germany
firstname.lastname@tu-dresden.de johannes.neumann@mailbox.tu-dresden.de

ABSTRACT

Cyber-physical systems (CPS) use distributed feedback loops to control physical processes. Designing practical distributed CPS controllers often benefits from a logically centralized approach, where each node computes the control law locally based on global knowledge of the system state. We present Mixer, an all-to-all communication scheme that enables all nodes in a multi-hop low-power wireless network to exchange sizable packets with one another. Mixer's design integrates synchronous transmissions with random linear network coding, harnessing the broadcast nature of the wireless medium. Results from testbed experiments with an early Mixer prototype show that our design reduces latency by 1.1–2.6× for 16–96-byte packets compared with the state of the art, while providing a reliability above 99.9 % in most settings we test.

1. OVERVIEW

Wireless cyber-physical systems (CPS) bring unprecedented opportunities by integrating sensing, control, and actuation into feedback loops for controlling physical processes. Computing the control law locally at each node rather than at a centralized controller offers better scalability and fault tolerance. To ease the design of practical distributed CPS controllers, it is often beneficial if one can assume that all nodes have global knowledge of the current system state [5]. To this end, a communication scheme is needed that supports exchanging sizable packets among all nodes in a multi-hop wireless network in a fast, reliable, and efficient manner.

State-of-the-art solutions, such as Chaos [2], partially meet these requirements. However, Chaos was primarily designed for data aggregation, and scales sub-optimally when nodes need to exchange larger chunks of raw data, called *payloads*.

Mixer in a nutshell. We present Mixer, an all-to-all communication scheme for multi-hop wireless networks. By integrating synchronous transmissions with random linear network coding [1], Mixer nodes combine several payloads before relaying. To exploit the former, we built Mixer on top of Chaos [2], but using the latter, Mixer needs fewer transmissions than Chaos to convey the same amount of information, significantly reducing latency especially for larger payloads.

SenSys '16 November 14-16, 2016, Stanford, CA, USA

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DOI: http://dx.doi.org/10.1145/2994551.2996706

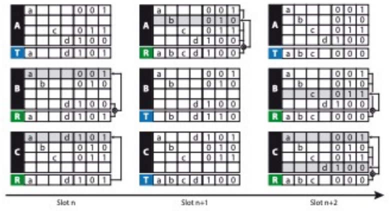


Figure 1: Example execution of Mixer in a 2-hop network with 4 nodes A, B, C, and D. *Using network coding, Mixer exchanges four different payloads within three slots—without network coding, at least one more slot would be needed.*

Network coding. The basic idea of network coding is to apply coding operations on incoming payloads at every node in the network. In Mixer, a coding operation is a linear combination of received payloads. This translates into a system of linear equations, which is maintained by every node.

$$\underbrace{\overset{E}{\begin{pmatrix} e_{11} & \ldots & e_{1n} \\ \vdots & \ddots & \vdots \\ e_{n1} & \ldots & e_{nn} \end{pmatrix}}}_{\text{Encoding Matrix}} * \underbrace{\overset{p}{\begin{pmatrix} p_1 \\ \vdots \\ p_n \end{pmatrix}}}_{\text{Payloads}} = \underbrace{\overset{c}{\begin{pmatrix} c_1 \\ \vdots \\ c_n \end{pmatrix}}}_{\text{Encoded Payloads}} \quad (1)$$

Each row in the *encoding matrix* E represents an *encoding vector* e, determining which payloads are combined to create an *encoded payload*. The elements of E must be from a finite field, in our case GF(2), so encoding means to XOR several payloads. But how should a node choose e? One way, known as random linear network coding [1], is to choose e randomly each time before relaying. This approach is advantageous as it does not require the nodes to know the network topology.

After choosing a random encoding vector e, a node computes an encoded payload and puts it together with e into a packet. According to (1), nodes receiving the packet store the encoded payload in vector c and e in matrix E if this increases the rank of E. The system of linear equations has a single unique solution when E reaches full rank; that is, a

Abstract: Format and rules

- Use LaTeX template available on course website
- In English (British or American, not a mix of both)
- 2 pages + additional page for references

- Summarize the paper in your own words
  - No copy & paste from the paper, except for figures (e.g., results)
  - Must be understandable without consulting the original paper

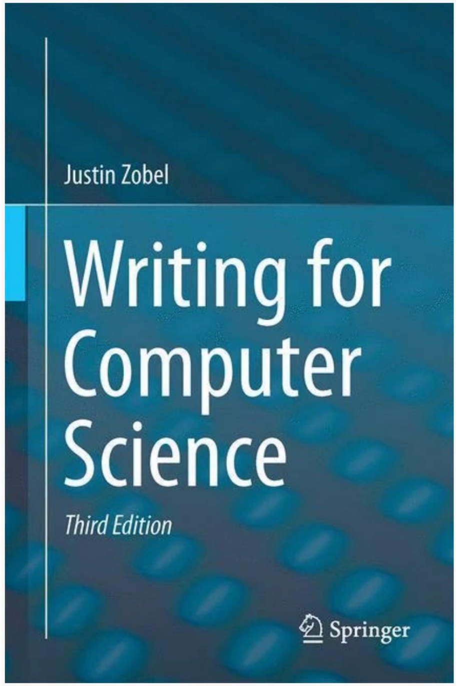
Abstract: Specific advice

- Content
  - Imagine you want to persuade someone to read the full paper
  - Focus on the core problem, key idea, main result, etc.

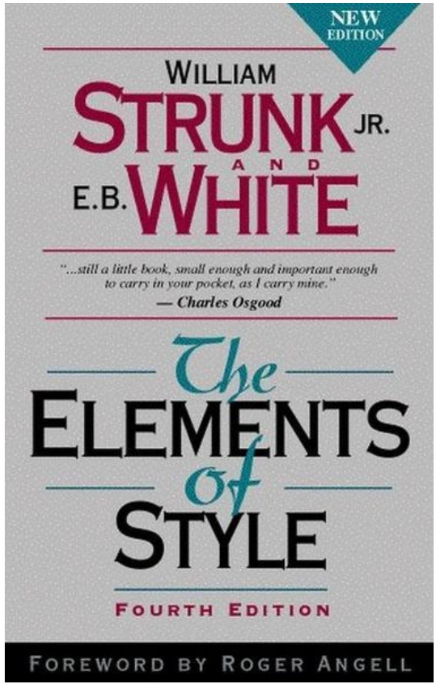
- Presentation
  - Write in a neutral way (“the authors” or ”the experiments”, not “we”)
  - Bad English distracts from good content
  - Revise, revise, revise

Abstract: General advice on writing

- ”Writing for computer science” by J. Zobel



- ”The elements of style” by W. Strunk and E.B. White



Your tasks

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- Present the paper to your peers
  - Give a 15-minute talk
  - Write a 2-page abstract
  - Prepare a poster
- Active participation
  - Try to attend all sessions
  - Ask critical questions, provide constructive feedback, etc.

Poster: Format and rules

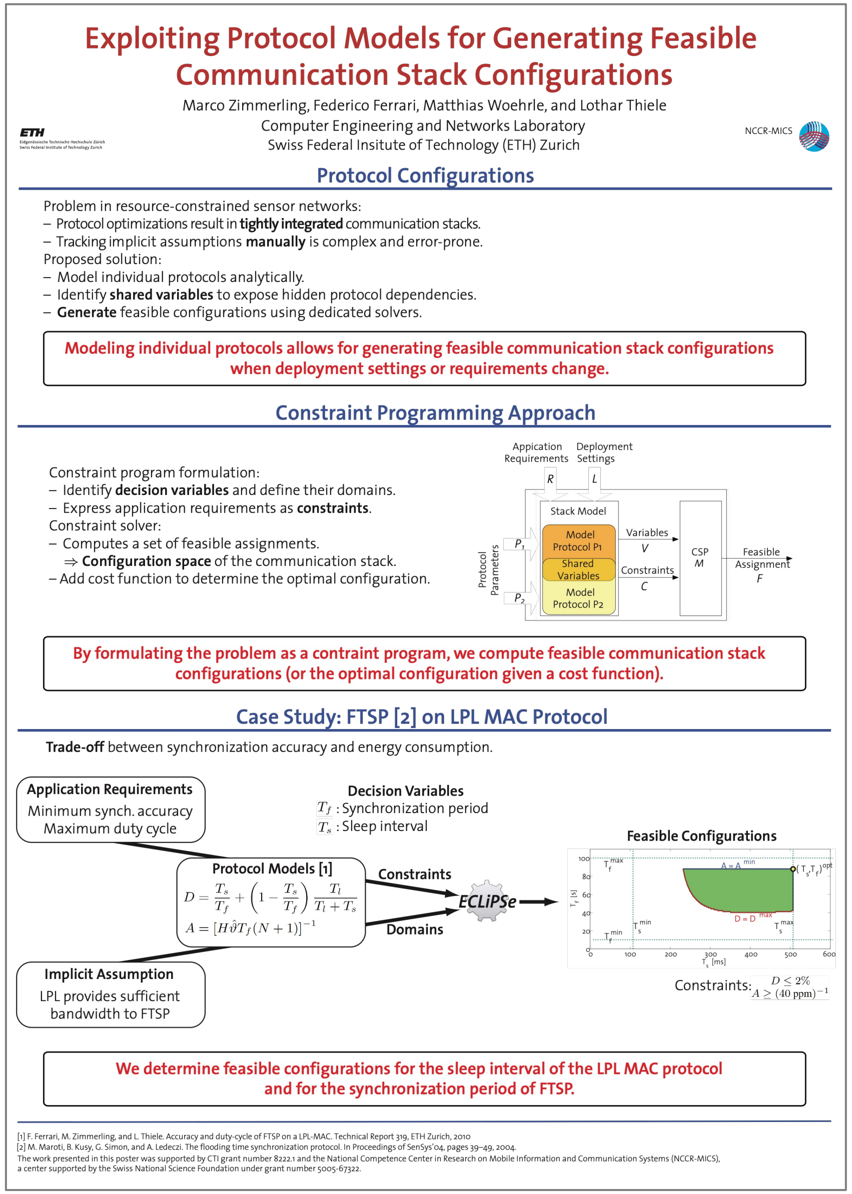
- May use PowerPoint template available on course website
  - Adobe Illustrator, LaTeX `beamerposter`, etc. also possible
- In English (British or American, not a mix of both)
- A0 format with sufficient margins (i.e., about 3cm)

- Summarize the paper in your own words
  - No copy & paste from the paper, except for figures (e.g., results)

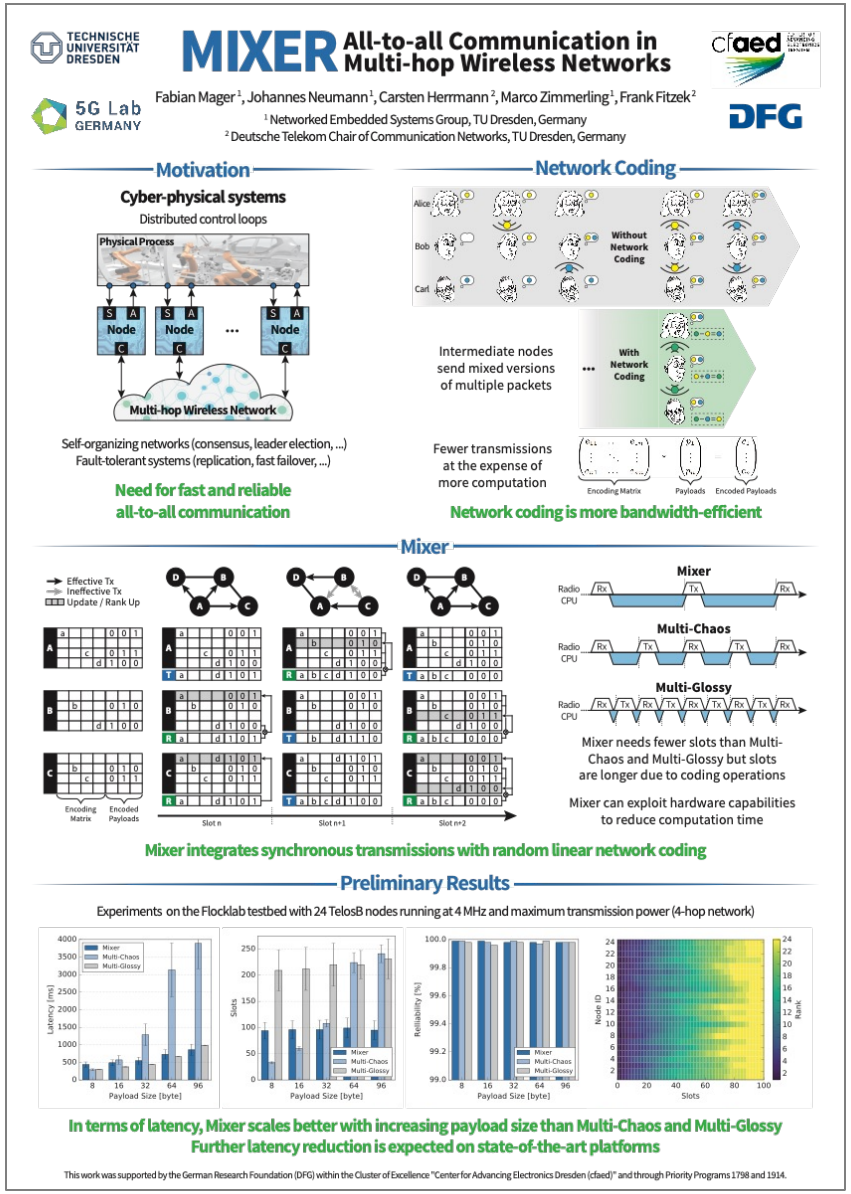
Poster: Specific advice

- Content
  - Imagine using a graphical illustration, plot, etc. on the poster to explain a complex concept to a visitor in 2-3 minutes
  - Focus on the core problem, key idea, main result, etc.

- Presentation
  - Prefer (simple) figures and examples over (long) text
  - Still enough text to catch people's interest (no typos allowed)
  - Revise, revise, revise


Exploiting Protocol Models for Generating Feasible Communication Stack Configurations
Marco Zimmerling, Federico Ferrari, Matthias Woehrle, and Lothar Thiele
Computer Engineering and Networks Laboratory
Swiss Federal Institute of Technology (ETH) Zurich
NCCR-MICS
Protocol Configurations
Problem in resource-constrained sensor networks:
– Protocol optimizations result in tightly integrated communication stacks.
– Tracking implicit assumptions manually is complex and error-prone.
Proposed solution:
– Model individual protocols analytically.
– Identify shared variables to expose hidden protocol dependencies.
– Generate feasible configurations using dedicated solvers.
Modeling individual protocols allows for generating feasible communication stack configurations when deployment settings or requirements change.
Constraint Programming Approach
Constraint program formulation:
– Identify decision variables and define their domains.
– Express application requirements as constraints.
Constraint solver:
– Computes a set of feasible assignments.
⇒ Configuration space of the communication stack.
– Add cost function to determine the optimal configuration.
Application Requirements
Deployment Settings
Stack Model
Model Protocol P1
Shared Variables
Model Protocol P2
Variables
Constraints
CSP
Feasible Assignment
Protocol Parameters
By formulating the problem as a contraint program, we compute feasible communication stack configurations (or the optimal configuration given a cost function).
Case Study: FTSP [2] on LPL MAC Protocol
Trade-off between synchronization accuracy and energy consumption.
Application Requirements
Minimum synch. accuracy
Maximum duty cycle
Decision Variables
T_f : Synchronization period
T_s : Sleep interval
Protocol Models [1]
Constraints
Domains
ECLiPSe
Feasible Configurations
Implicit Assumption
LPL provides sufficient bandwidth to FTSP
Constraints: $D \leq 2\%$ $A \geq (40\text{ ppm})^{-1}$
We determine feasible configurations for the sleep interval of the LPL MAC protocol and for the synchronization period of FTSP.

mmh


TECHNISCHE UNIVERSITÄT DRESDEN
MIXER All-to-all Communication in Multi-hop Wireless Networks
5G Lab GERMANY
cfaed
DFG
Fabian Mager, Johannes Neumann, Carsten Herrmann, Marco Zimmerling, Frank Fitzek
Networked Embedded Systems Group, TU Dresden, Germany
Deutsche Telekom Chair of Communication Networks, TU Dresden, Germany
Motivation
Cyber-physical systems
Distributed control loops
Physical Process
Multi-hop Wireless Network
Self-organizing networks (consensus, leader election, ...)
Fault-tolerant systems (replication, fast failover, ...)
Need for fast and reliable all-to-all communication
Network Coding
Without Network Coding
With Network Coding
Intermediate nodes send mixed versions of multiple packets
Fewer transmissions at the expense of more computation
Network coding is more bandwidth-efficient
Mixer
Mixer
Multi-Chaos
Multi-Glossy
Mixer needs fewer slots than Multi-Chaos and Multi-Glossy but slots are longer due to coding operations
Mixer can exploit hardware capabilities to reduce computation time
Mixer integrates synchronous transmissions with random linear network coding
Preliminary Results
Experiments on the Flocklab testbed with 24 TelosB nodes running at 4 MHz and maximum transmission power (4-hop network)
In terms of latency, Mixer scales better with increasing payload size than Multi-Chaos and Multi-Glossy
Further latency reduction is expected on state-of-the-art platforms

better

Important dates

- Deadlines
  - April 25: Send paper preferences (1st/2nd/3rd choice)
  - April 26: Papers assigned and talks (tentatively) scheduled
  - June 6: Abstracts and posters
- If you would like to get feedback from your mentor
  - Send slides/abstract/poster at least 7 days in advance
  - Mentor will provide feedback exactly once on each artifact
  - May also meet mentor virtually to clarify questions

Meetings

- All meetings with talks will be
  - classroom-first (this room: 2.1.01, Mornewegstrasse 30/32)
  - no live streaming or recording

- Poster presentations on July 4 (tentative) will be
  - classroom-first (location: TBD)
  - no live streaming or recording
  - We will take care of printing you posters in A0 format!

Plan for today

1. Teaching goals
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Example applications

precision agriculture

smart cities

disaster mitigation

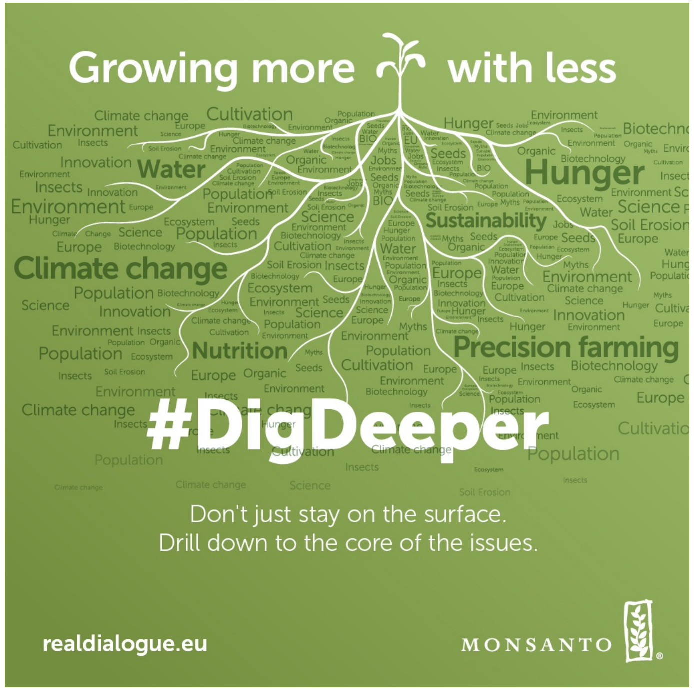
Example applications

precision
agriculture

smart
cities

disaster
mitigation

Precision agriculture



- Current agricultural practices waste water, pesticides, etc. causing environmental impact and economic losses
- Use distributed sensing, decision making, and actuation to reduce impact and losses while increasing crop yield

Example applications

precision
agriculture

smart
cities

disaster
mitigation

Smart cities

- Smart city applications include intelligent transportation, power grid, waste water management, home automation
- Use distributed sensing, decision making, and actuation to, e.g., reduce air pollution and improve quality of life

Example applications

precision agriculture

smart cities

disaster mitigation

Disaster mitigation

Disaster mitigation

- Understand, e.g., thawing permafrost in high-alpine regions to predict impeding rockfall events
- Use distributed sensing, decision making, and actuation to mitigate harm to humans and critical infrastructure

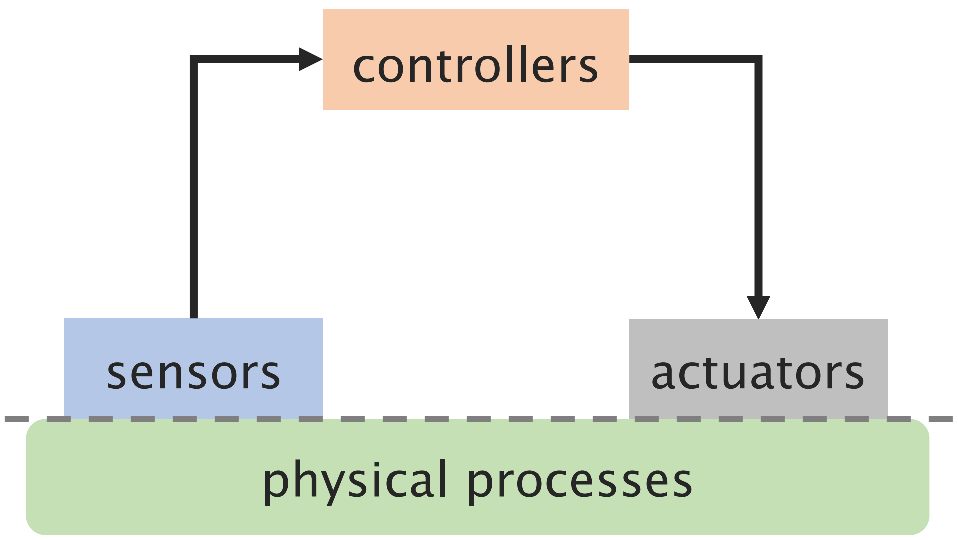
Cyber-physical systems

physical world
governed by nature

physical processes

Cyber–physical systems

cyber world
governed by hardware + software

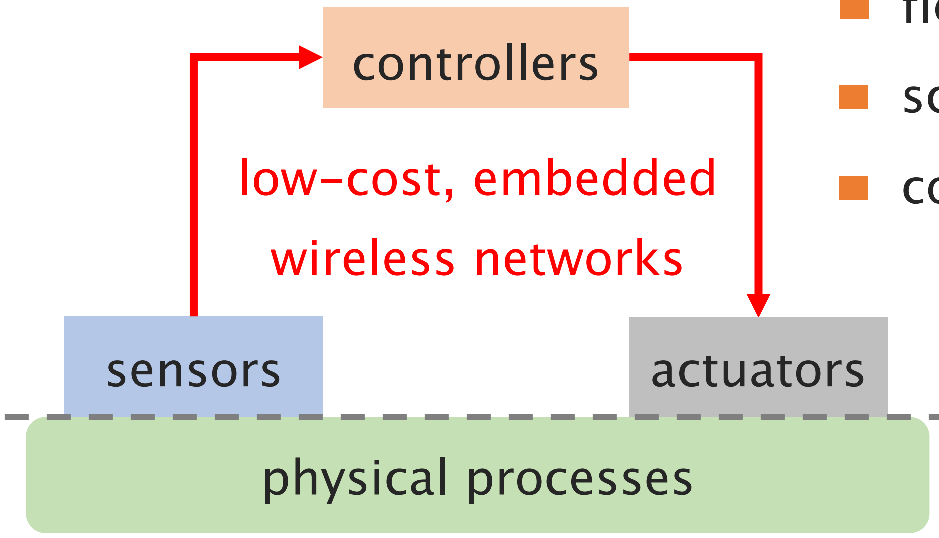


physical world
governed by nature

Cyber–physical systems

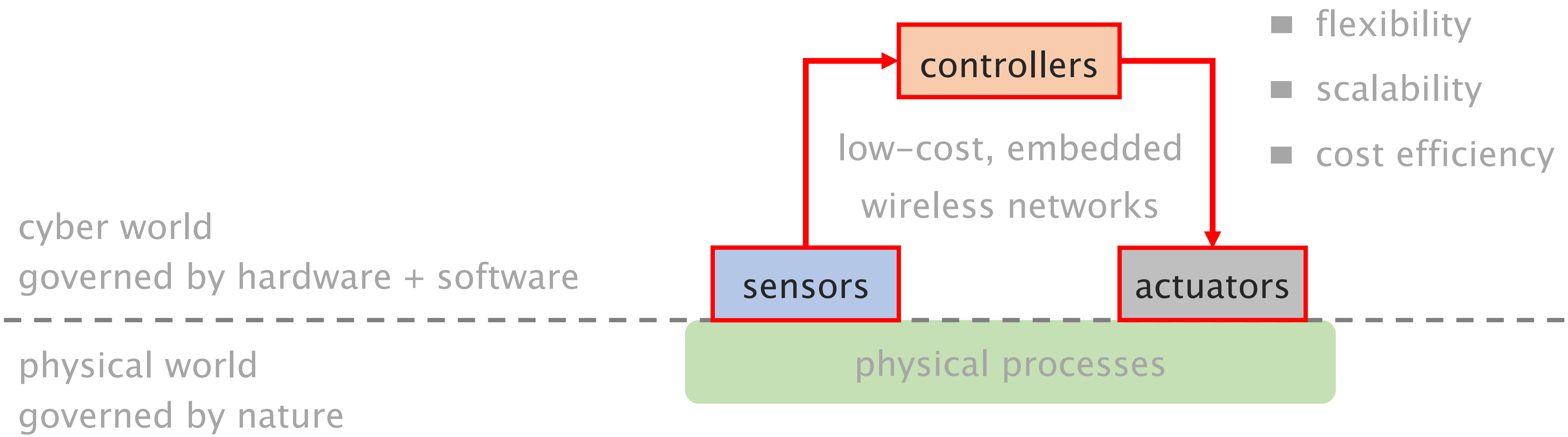
cyber world
governed by hardware + software

physical world
governed by nature



- flexibility
- scalability
- cost efficiency

Networked embedded systems (NES)



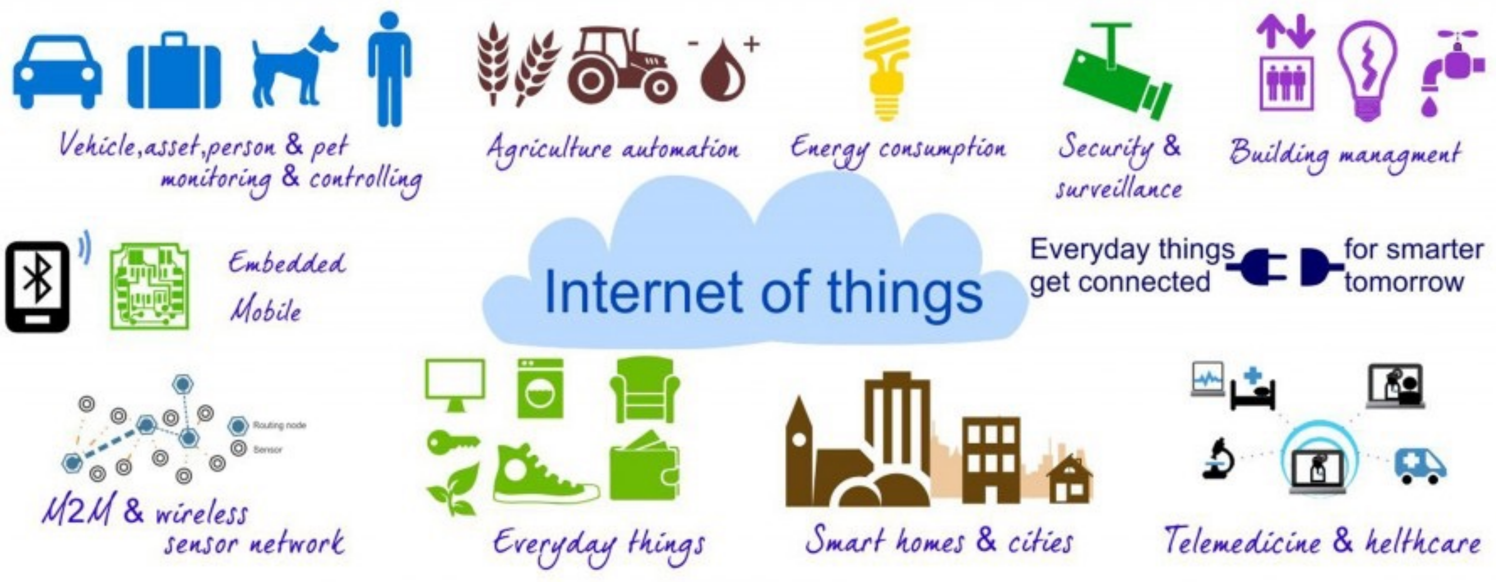
Hardware and software components for sensing, communication, computation, and actuation that enable cyber-physical systems

Traditional NES

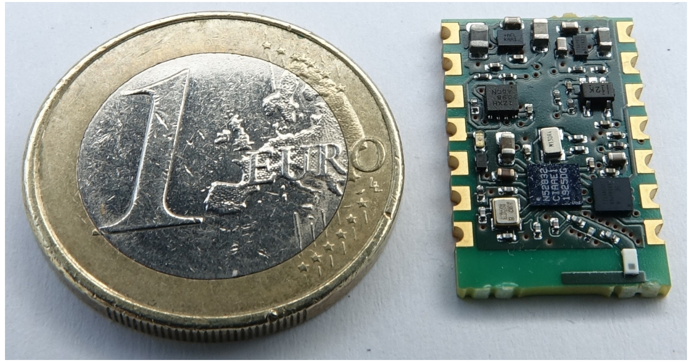
- Anti-lock braking system
- Electronic stability control
- Airbag
- Automatic gearbox
- Smart keys

- Flight control system
- Anti-collision control
- Pilot information system
- Flap control system
- Entertainment system

Emerging NES



Everywhere Wireless



- Trends: Battery-free devices, embedded machine learning, low-power wireless communication, edge computing, etc.

Topics to choose from

- 18 research papers published in top international venues: https://nes-lab.org/nes-seminar-summer2023/
  - Battery-free and energy-harvesting systems
  - Embedded machine learning
  - Wireless communication and networking
  - Localization
  - Sensing and edge computing
  - Emerging applications (e.g., underwater)

Topics to choose from

- Submit your preferences by April 25, 11:59pm
  - You pick three papers (1st/2nd/3rd choice)
  - By email to marco.zimmerling@tu-darmstadt.de
  - Please use the paper numbers listed on the course website
  - We assign one paper and a mentor to each of you