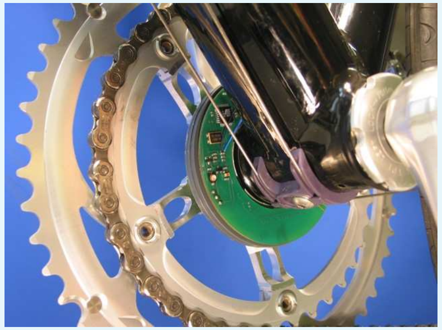
TECHNISCHE UNIVERSITÄT KAISERSLAUTERN

# Ambient Intelligence (AmI) Research in Kaiserslautern

## Assisted Training



## Assisted Working


## Assisted Living


Prof. Dr.-Ing. habil. Lothar Litz
Institute of Automatic Control
University of Kaiserslautern

Brasília, March 23, 2007

# Outline

- Introduction
- Ambient Intelligence Definition
- Kaiserslautern way of AmI-Research
- Bicycle Training Demonstrator
- AmI-based Networked Control Systems
- Outlook

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# Introduction

**Mainframe** | **PC** | **Post-PC Era**

0.001 computer/person | 1 | >100 µC/ person

extensive
data processing

signal processing,
text processing,
multimedia, networks

Ambient
Intelligence

scientific,
commercial
applications

personal
applications

mobile
applications

1960 | 70 | 80 | 90 | 2000 | 10

*„There is no reason for any individual to have a computer in his home“* Ken Olsen, CEO DEC, 1977

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# Ambient Intelligence Definition

'Ambient Intelligenc
represents an 'intel
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in order to provide various services to people.

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# Ambient Intelligence Definition

## Technical attributes

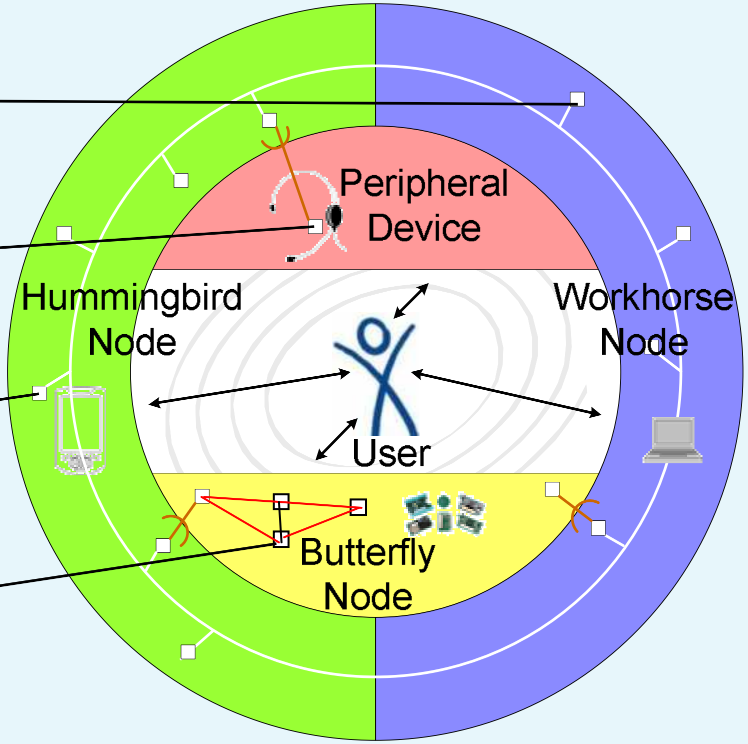
- Distributed sensing, actuating and computing
- Unobtrusive and embedded components
- Intelligent and user-friendly HCI
- Seamless communication
- Pervasive computing

Workhorse Node:
(Watt Node)
PC, Laptop, etc.

Peripheral Device:
Headset, Micro, Touch-screens etc.

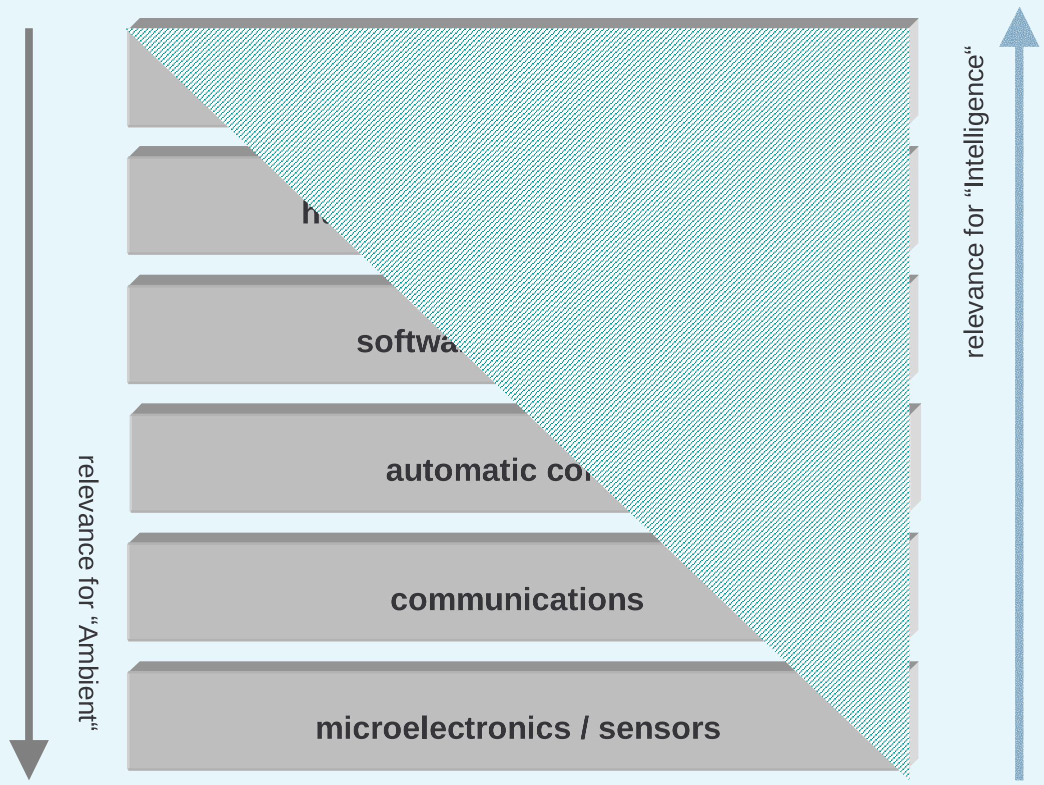
Hummingbird Node:
(Milliwatt Node)
PDA, Handy, DSP, etc.

Butterfly Node:
(Microwatt Node)
Particle, Mica, etc.



# Ambient Intelligence Definition

## Disciplines involved



# Kaiserslautern way of AmI-Research

## The Players

AmI Research Center (TU KL) founded 2003
http://www.eit.uni-kl.de/AmI/frame.html?en

BelAmI-Project – German Ungarian Cooperation founded 2004
http://www.belami-project.org/

Pilot Project „AL " (Bau AG, TU KL, Fed.state) founded 2005
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Initiative „*SmartFactory*^KL" (DFKI, TU KL) founded 2005
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**about 130 researchers in Kaiserslautern, 40 in Hungary**

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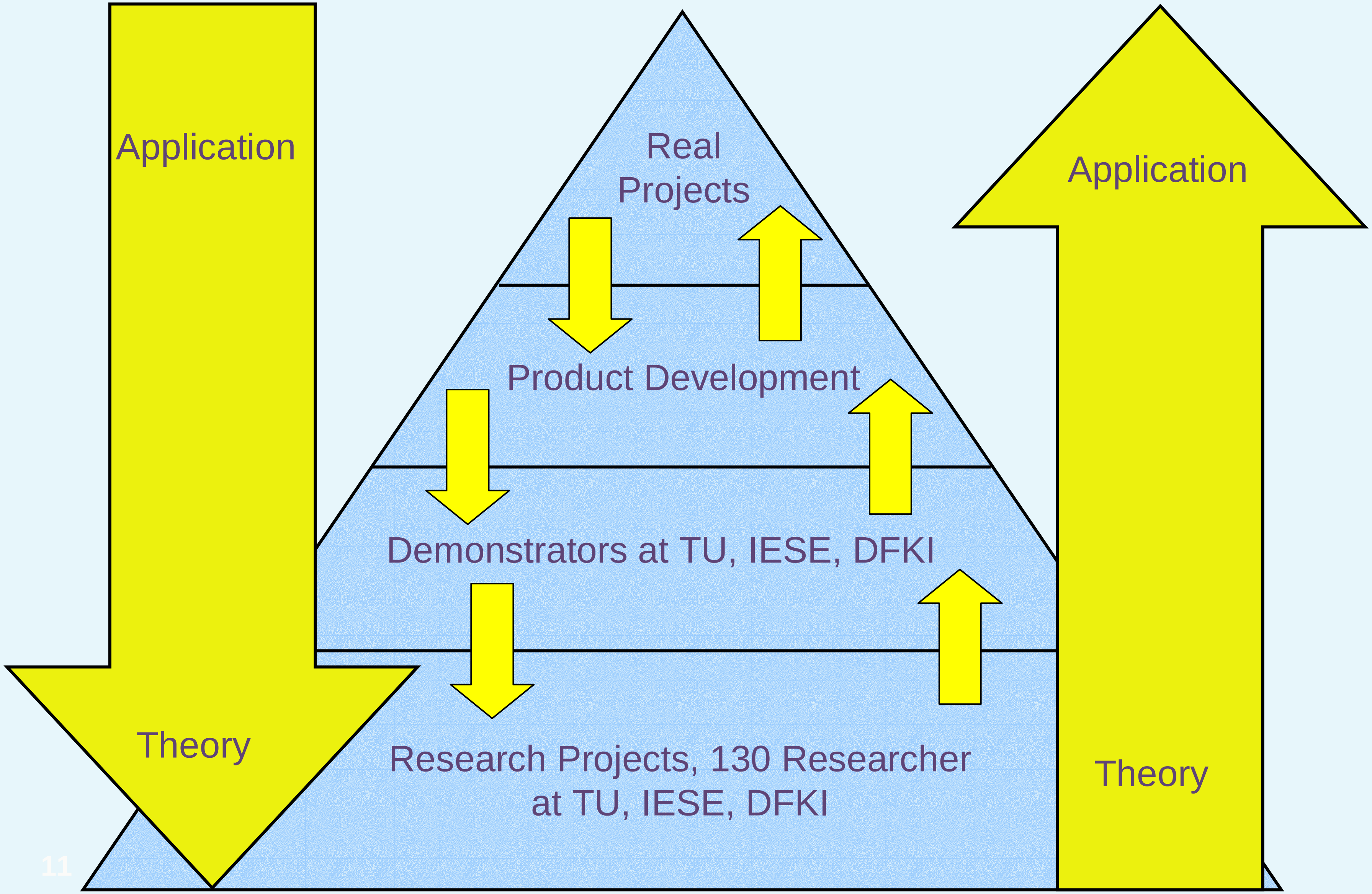
# Kaiserslautern way of AmI-Research

## Interdisciplinary Members of the AmI Research Center

| | |
|---|---|
| – Prof. Dr. Berns | Computer Science |
| – Prof. Dr. Dutke | Social Sciences |
| – Jun. Prof. Dr. Frey | Electrical and Computer Engineering |
| – Prof. Dr. Gotzhein | Computer Science |
| – Jun. Prof. Dr. Jaitner | Social Sciences |
| – Prof. Dr. Kunz | Electrical and Computer Engineering |
| – Prof. Dr. Litz | Electrical and Computer Engineering |
| – Jun. Prof. Dr. Rausch | Computer Science |
| – Prof. Dr. Rombach | Computer Science |
| – Prof. Dr. Tielert | Electrical and Computer Engineering |
| – Prof. Dr. Urbansky | Electrical and Computer Engineering |
| – Prof. Dr. Wehn (Chair) | Electrical and Computer Engineering |
| – Prof. Dr. Zühlke | Mechanical and Process Engineering |

# Kaiserslautern way of AmI-Research



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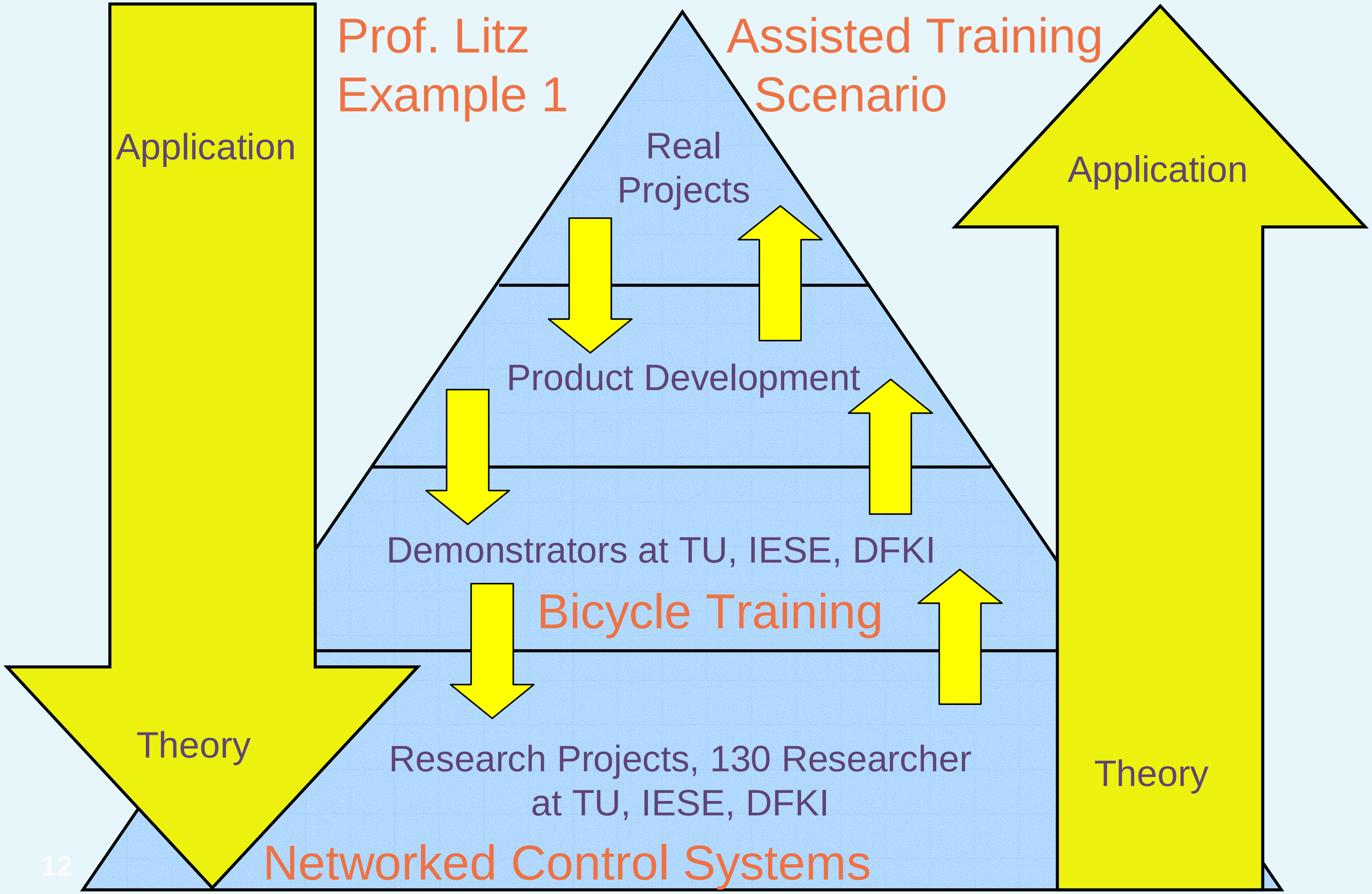
# Kaiserslautern way of AmI-Research



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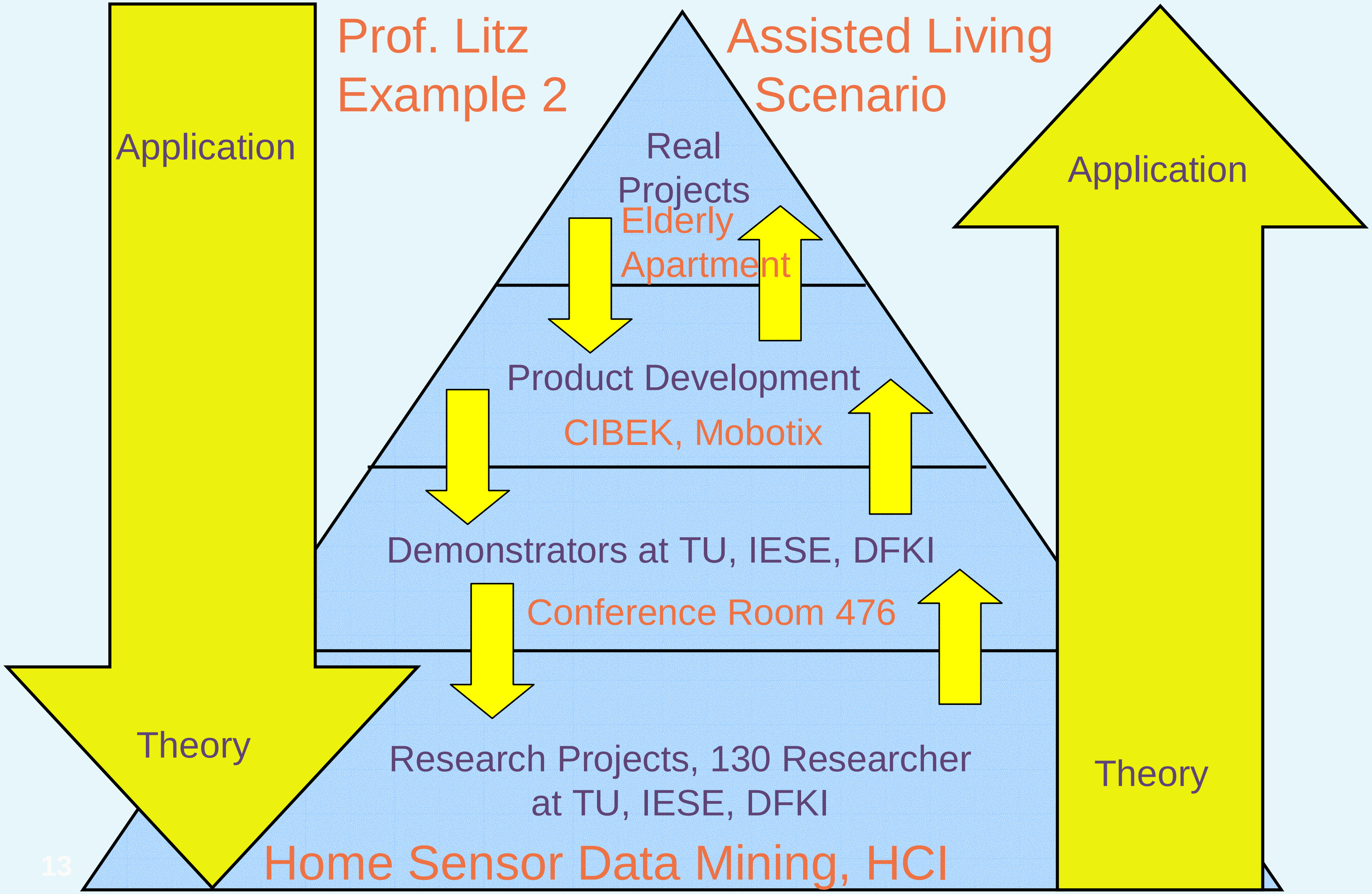

# Kaiserslautern way of AmI-Research

| Scenarios | Demonstrators |
| --- | --- |
| Assisted Training | Bicycle Training Assistance (TU) |
| Assisted Living | Demonstration Apartment (IESE)<br>Conference Room (TU) |
| Assisted Working | Smart Factory (DFKI, TU) |

# Kaiserslautern way of AmI-Research

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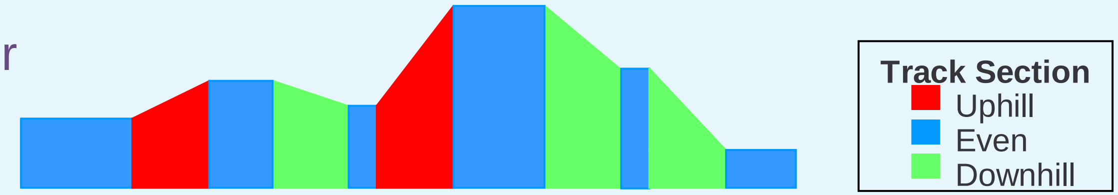
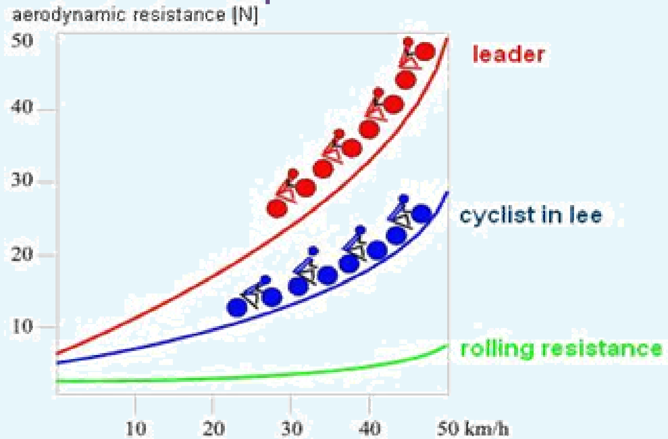
# Bicycle Training Demonstrator

## Assisted Training Scenario

- Training group of (racing) cyclists
- Given track profile
- Out-door and In-door




- Cyclists have different qualities regarding the track sections
- Each cyclist has a given overall physical condition and an individual training plan
- Training effect depends on the speed of the group, the position of the cyclist within the group formation and the time period in head position



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# Bicycle Training Demonstrator

## Research Topics

### Bicyle Training Demonstrator

**Out-door**

- Low power sensors, signal processing and communication
- Ad-hoc communication

**In-door**

- Coconi tests
- Experiments to evaluate the perceptibility of different speech generation methods
- Dynamic integration of devices
- Virtual races

**Common for Both**

- New sensors, e.g. power pedal meter, simplified ECG
- Efficient communication (UWB) for body area networks
- Control algorithms and training strategies for In-Door, Out-Door

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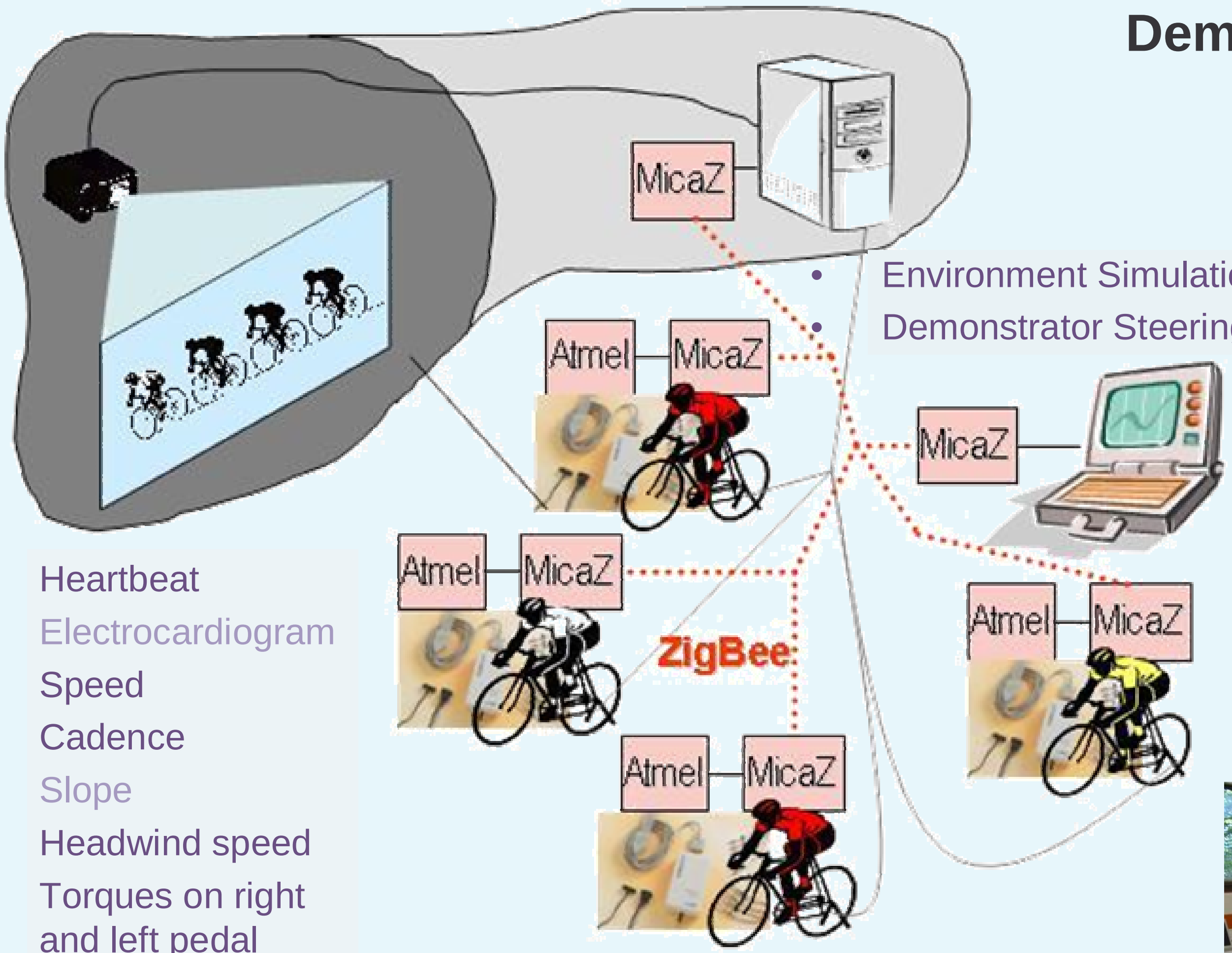
# Bicycle Training Demonstrator

## Demonstrator Structure




- Environment Simulation
- Demonstrator Steering

- Heartbeat
- Electrocardiogram
- Speed
- Cadence
- Slope
- Headwind speed
- Torques on right and left pedal
- Mechanical Power
- GPS
- Borg’s scale

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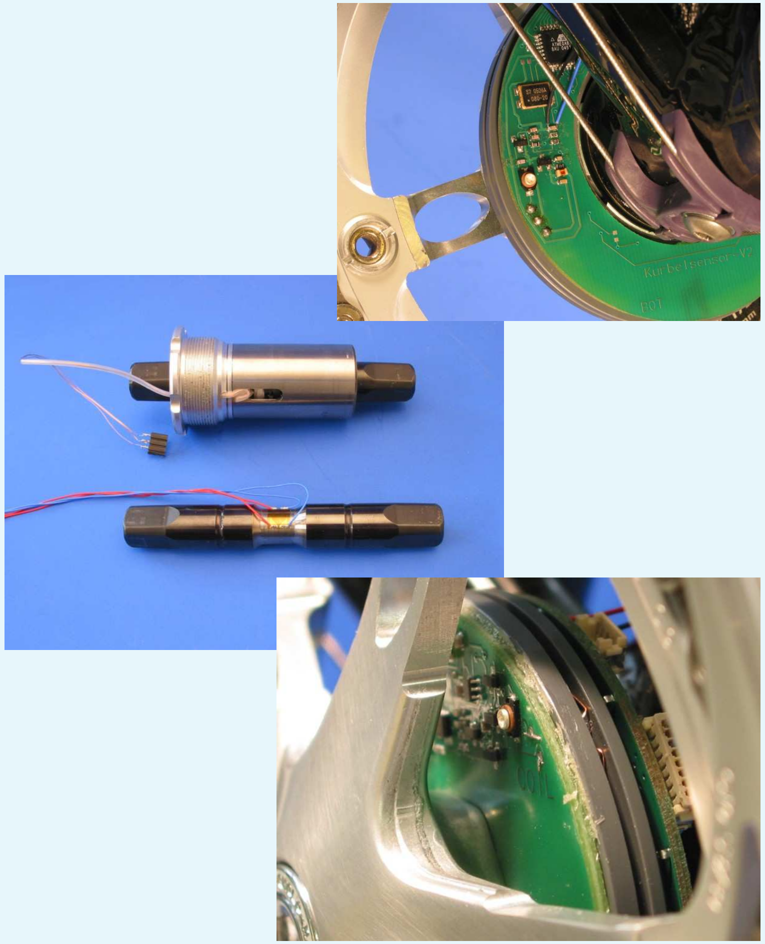
# Bicycle Training Demonstrator

**In-house Development: Sensors by Prof. Dr. Tielert**

- Sensor integrated in crank set: measures total power
- Sensor integrated in bottom bracket: measures difference power
- Measuring pedal power for left and right pedal in 30° degrees sectors
- Inductive air gap coupling (8 MHz) for data transmission and energy supply
- Sub-milliwatt energy consumption of the electronics
- Combined with magnetic pedal cadence meter



# Bicycle Training Demonstrator

**In-house Development:** **HW-Concept by Profs Dr. Wehn, Tielert**

**MasterZ = Masterboard + MicaZ**

Windsensor

LCD-Display


Antenna of MicaZ

Control Keys


**Interfaces :**

Bottom-Bracket, Crankset

Heartbeat-Sensor

Windsensor

Free for Extension

Removeable attachment

# Bicycle Training Demonstrator

**In-house Development:** **HW-Concept by Profs Dr. Wehn, Tielert**

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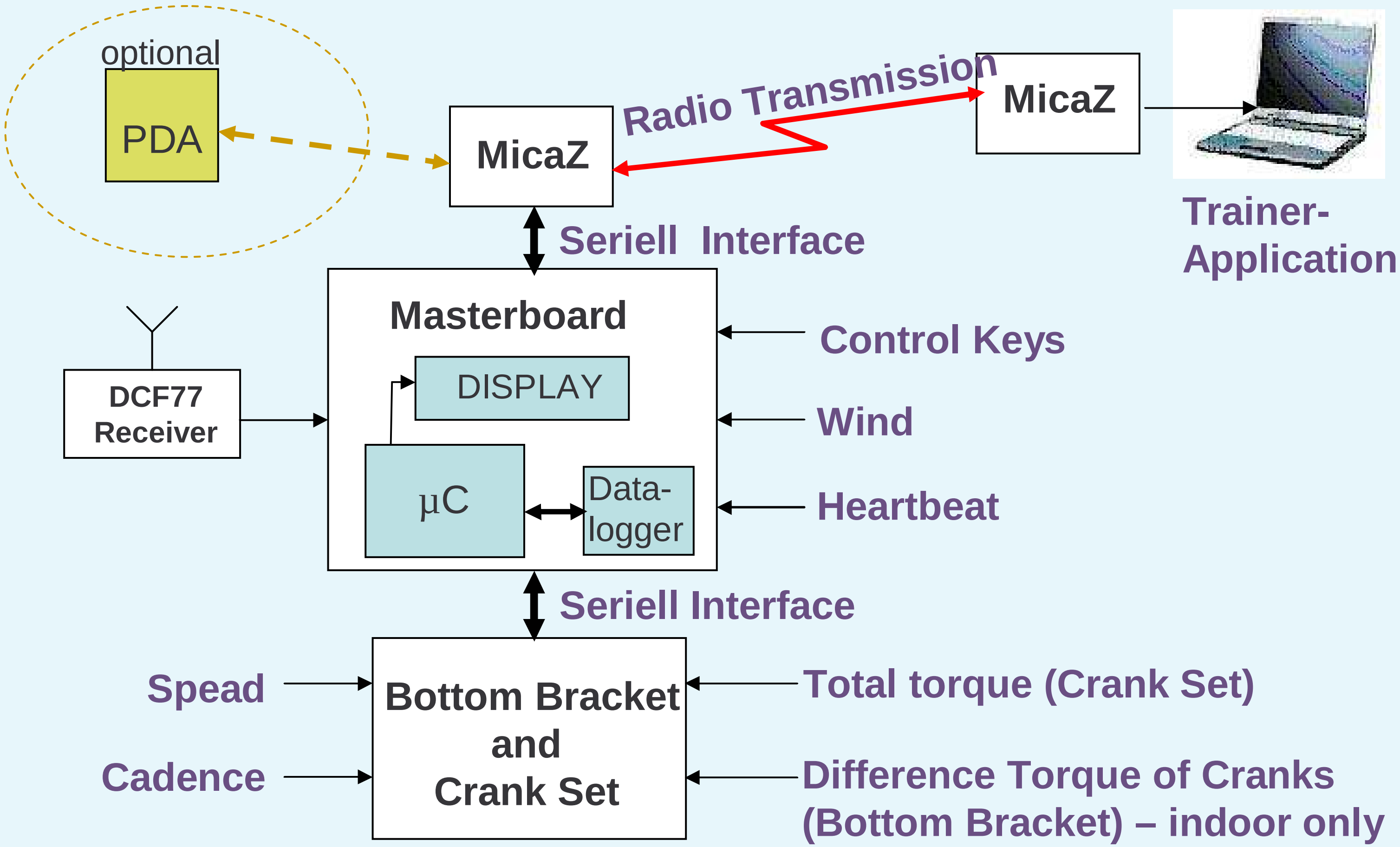
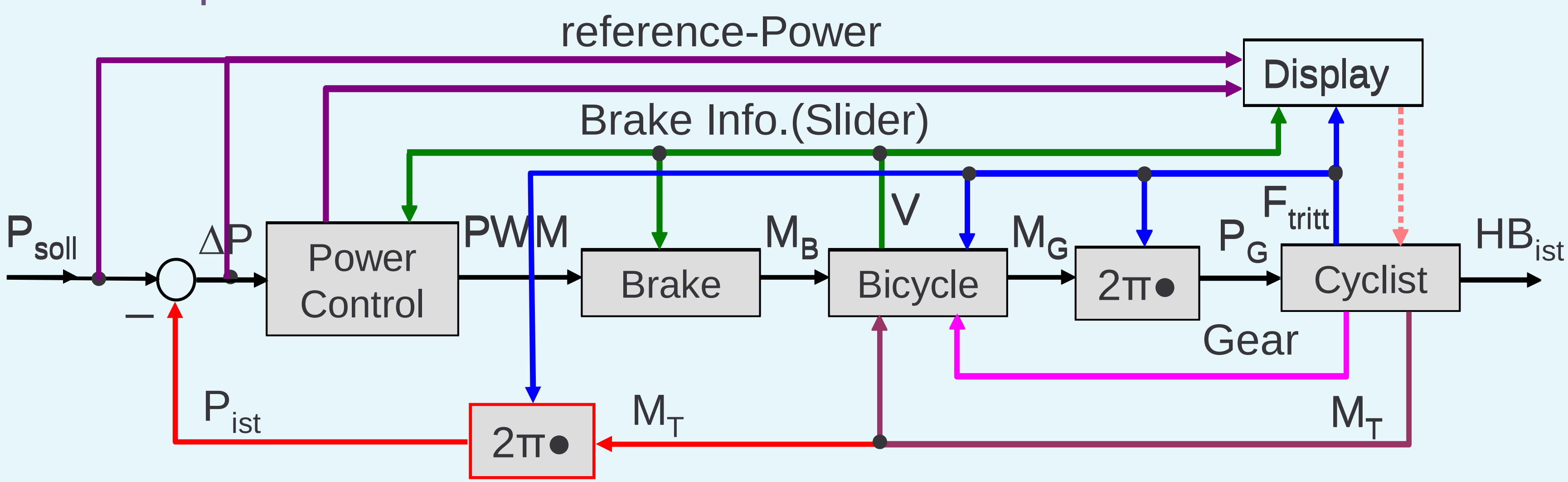


# Bicycle Training Demonstrator

**In-house Development: MPC by Profs Dr. Litz, Jaitner**

- Control development to run the Indoor Demonstrator with „Human in the loop“




- Mathematical Modeling of Cyclist`s Power-Heartbeat Behavior
- Optimization by Predictive Control with two set values:
  Reference-value of Group Speed
  Time for changing the head position

# Bicycle Training Demonstrator

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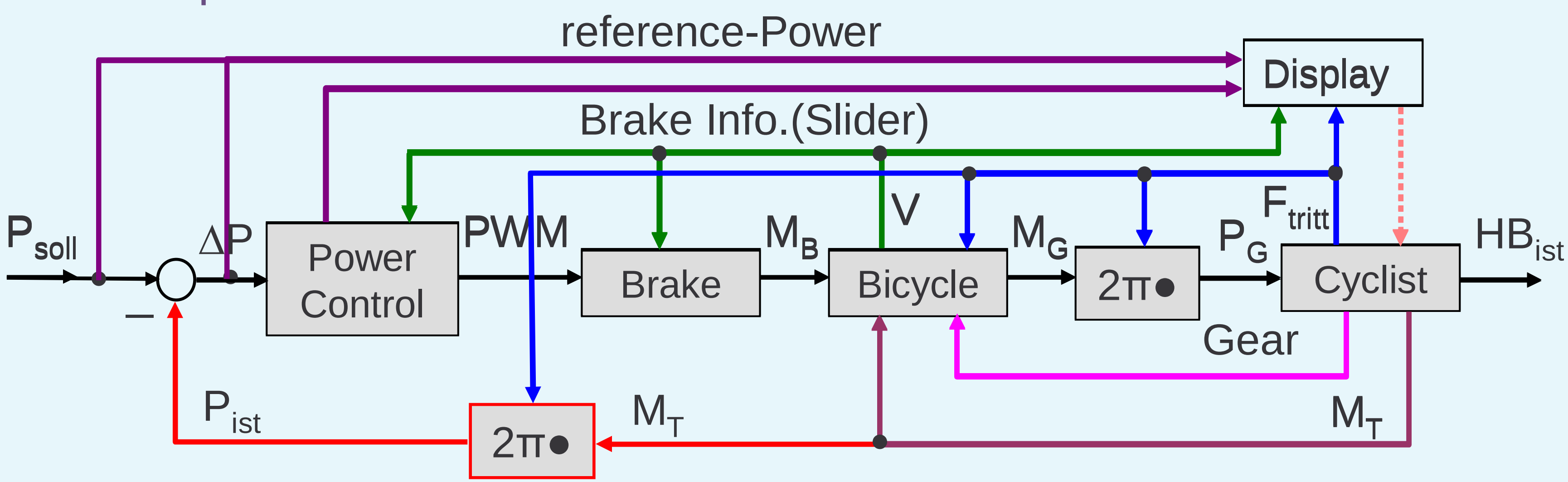


$$\Delta HB(k) = K_1 \cdot P(k) + K_2 \cdot \Delta HB(k-1) + K_3 \cdot (1 - e^{-k \cdot T_A / \tau}) \cdot P(k)$$

$$+K_4 \cdot \sum_{i=1}^{k-1} T_A \cdot \left( HB(i) - HB_{iANS} \right) \cdot \sigma \left[ HB(i) - HB_{iANT} \right]$$

$$-K_5 \cdot \sum_{j=K}^{k-1} T_A \cdot \left( HB_{iANS} - HB(j) \right) \cdot \sigma \left[ HB_{iAT} - HB(j) \right]$$

# Bicycle Training Demonstrator

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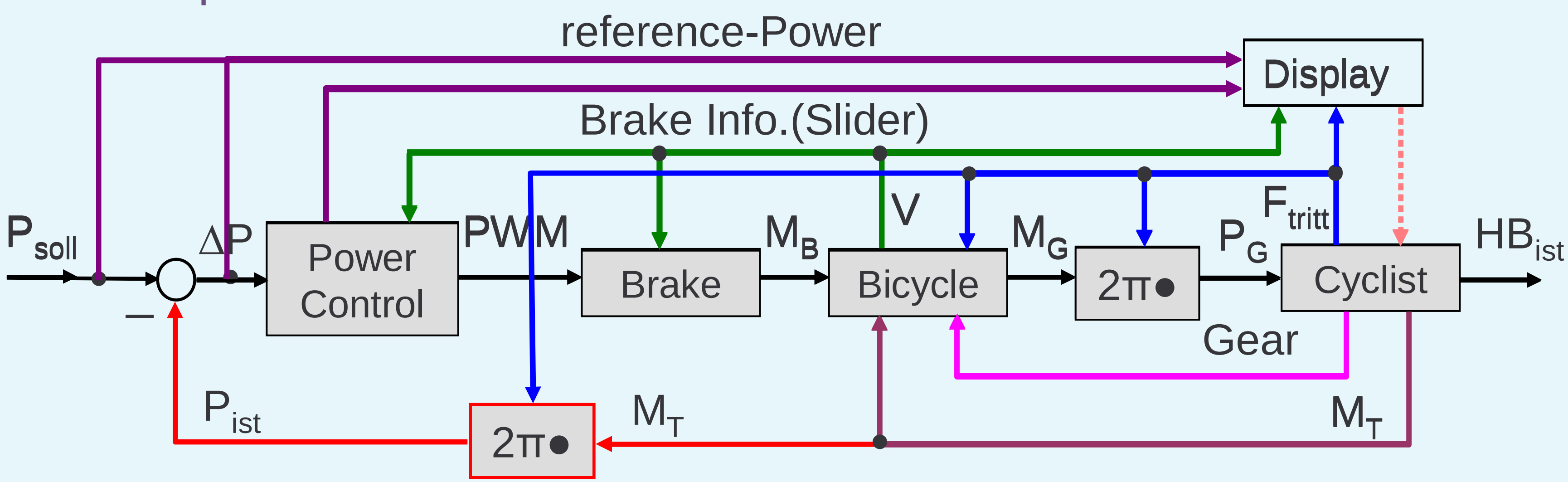


$$J = \sum_{i=1}^{L}\left[\sum_{m=1}^{M}\left(\sum_{n=1}^{N} K_n \cdot \lambda \cdot \left(HB_{soll} - HB_{ist}\right)^2\right) + C \cdot change(i)\right] \rightarrow \min$$

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# Bicycle Training Demonstrator

## Another In-house developments: Profs Gotzhein, Rausch

## Status of the development

### Sensor Systems

- Wind Senor : field test
- Encoded Heartbeat : Tested
- Torque, Power: field test

### Crank Set / Bottom Bracket

- Tested in laboratory environment,

### Communication

- System with multihop completed, up to 32 bicycles, field tests running

### ECG

- in development

### Master Board

- Tested and completed

### Control Algorithms

- Model Predictive Controller: developed in simulation environment, not tested

### Outdoor training Tests

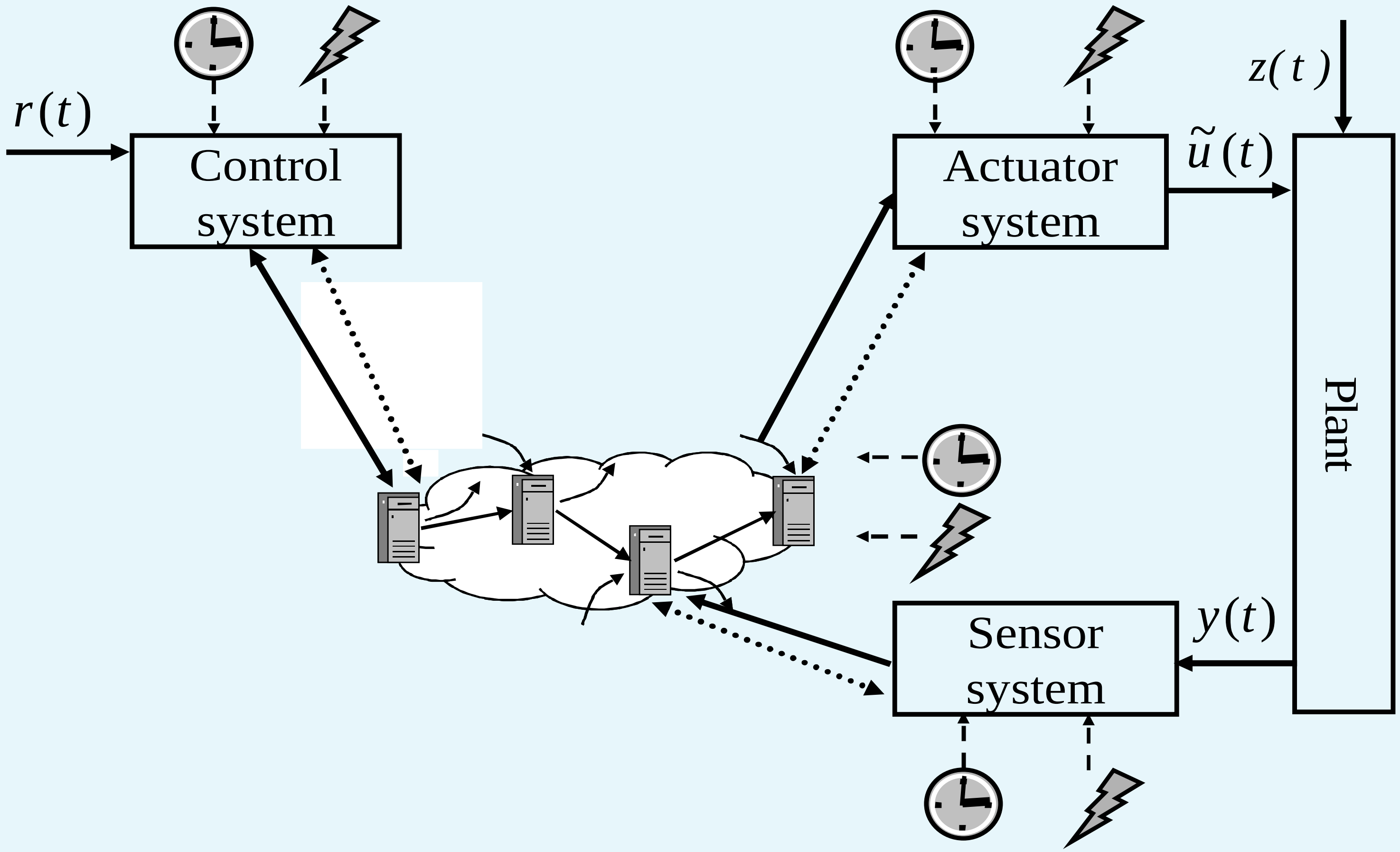
- Field tests with technical evaluation: in preparation

### Indoor training Tests

- Technical Evaluation planned for 7/2007
- First tests planned for 10/2007

# AmI-based NCS

## General Structure



# AmI-based NCS

**NCS-specific constraints:**

- Limited Bandwidth /Transmission Rate
- Limited Range (⇒ Multihopping)
- Moving Objects (⇒ Ad-Hoc-Structure)
- Variable frame transport times
- Stochastic frame losses
- Passing and corruption of frames
- Sleeping Mode
- Limited energy
- Limited computing power (CPU, Storage)
- Limited number of bits in the frame

# AmI-based NCS

## Constraints for Control Design

NCS Architectures

- Time / event-triggered
- Direct / hierarchical /cascaded structure

General Network Effects

- Stochastic Delays
- Packet losses including corrupted, passed and aged packets

Additional AmI Specific Constraints

- Limited quantization
- Limited energy

# AmI-based NCS

## Constraints for Control Design

NCS Architectures

- Time / event-triggered
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General Network Effects

- **Stochastic Delays**
- Packet losses including corrupted, passed and aged packets

Additional AmI Specific Constraints

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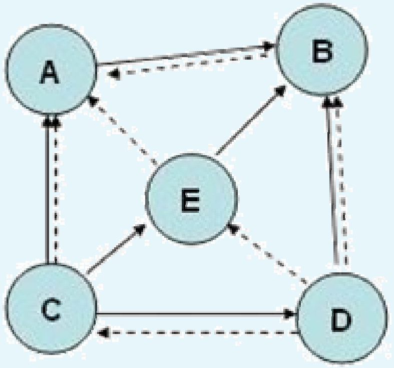
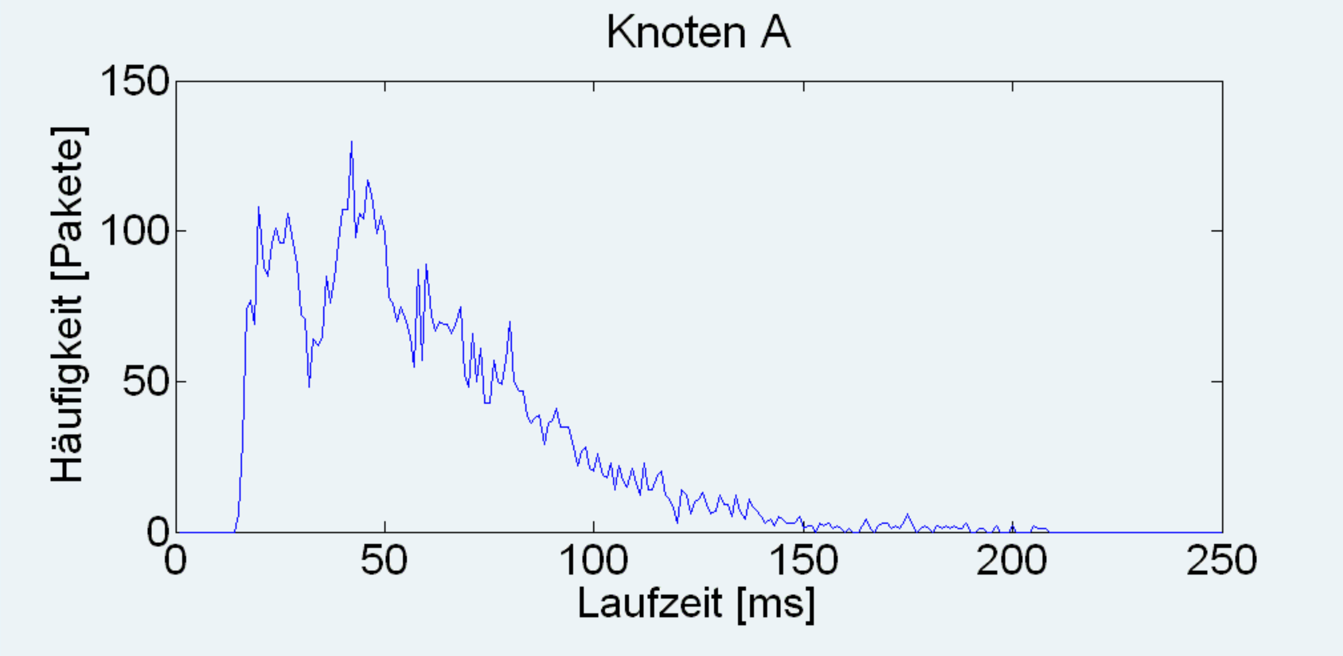
## AmI-based NCS

### Example of stochastic delays

Transmissions:

C $\rightarrow$ B   and   D $\rightarrow$ A



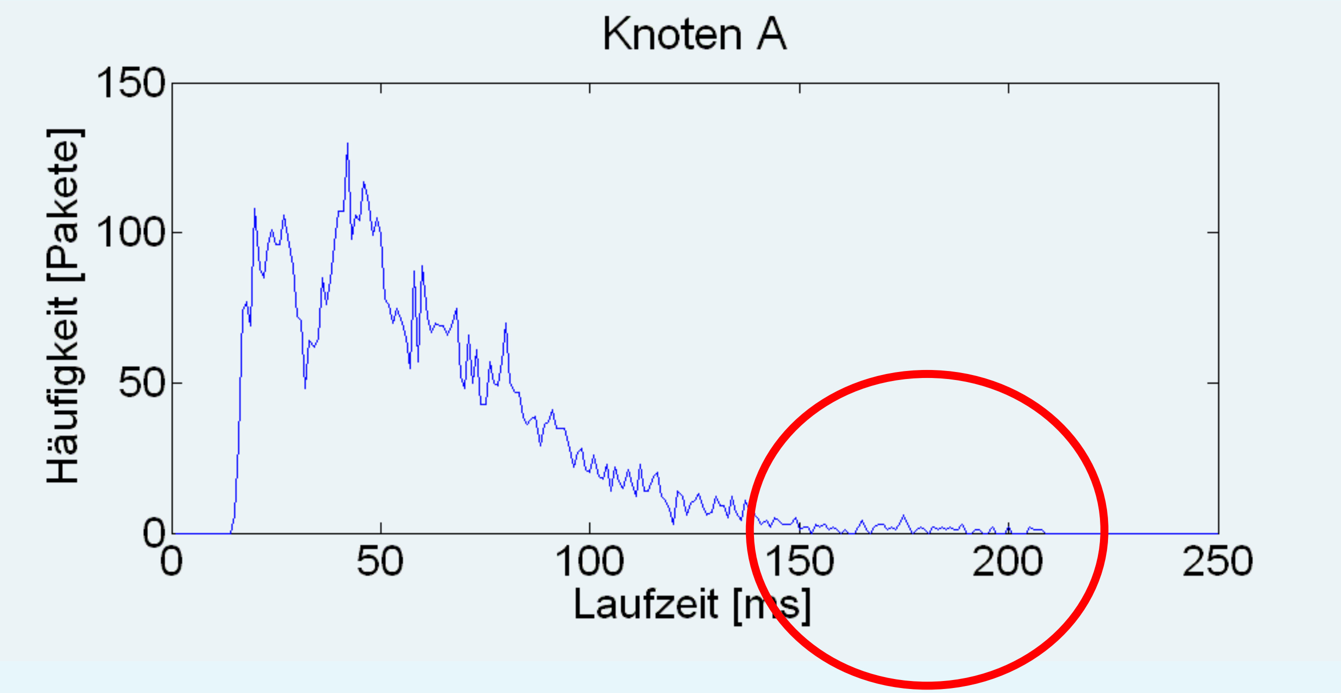



# AmI-based NCS

## Our Attempts for Control over AmI-Networks

- MPC-based Adaptive Control
- QoS-adaptive Heuristic Control
- Time stuffing

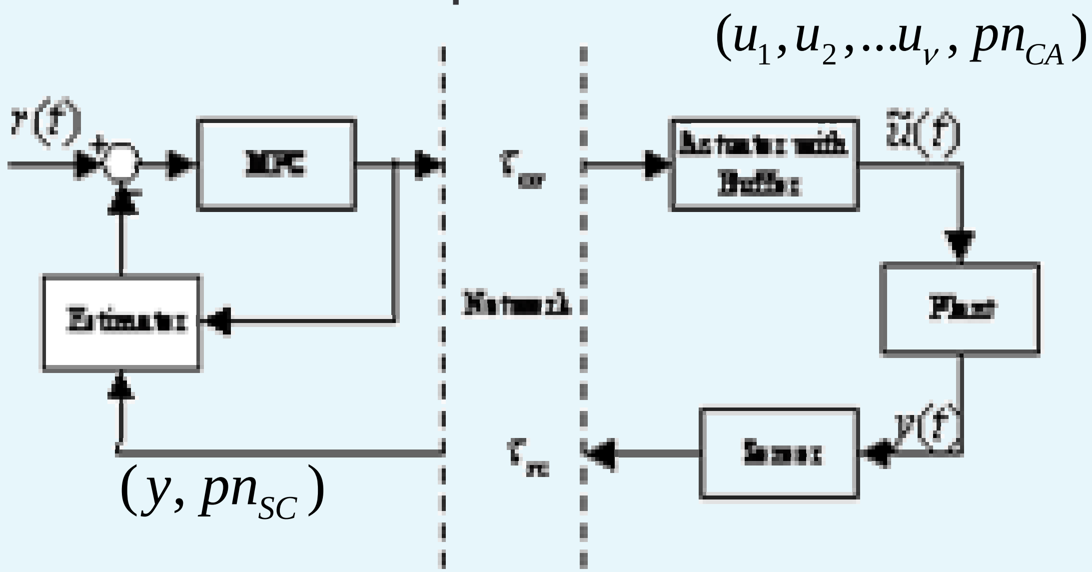
$$\tau_{SC} + \tau_C + \tau_{CA} < T_N$$
$$T_N = iT_S, \; i = 1, 2, \ldots$$



# AmI-based NCS

## MPC – based Control

- Structure and Principle




- Detection of “Packet Losses”
  - $pn_{new} < pn_{last}$
  - packet is corrupted or
  - is lost $\tau_{SC} > T_{SC}, \tau_{CA} > T_{CA}$ $T_{SC} + T_{CA} = iT_S, i = 1, 2, ...$

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# AmI-based NCS

## QoS-adaptive Heuristic Control

- Measuring the QoS
  - Sensor samples time-triggered
  - Clocks are synchronized occasionally
  - 4-bit packet number instead of timestamp

$$p_L = pn_{new} - pn_{last} - 1 \quad \forall \; pn_{new} > pn_{last}$$

- Controller can
  - calculate transport delay $\tau_{SC}$
  - recognize the packet losses $(p_L)$
  - adapt to QoS

# AmI-based NCS

## QoS-adaptive Heuristic Control

- General adaptation attempt
  - Offline calculation of the best controller individuals for different $\tau_{SC}$ by genetic algorithm maximizing QoC
  - Online adaptation by switching to the best Controller individual according to the measured $\tau_{SC}$
  - Online adaptation of the sampling time T according to the measured number of packet losses
  - Online adaptation by two further heuristic schemes to increase the Quality of Control (QoC)
- Comparison with a robust non adaptive Time-Triggered Controller (TT)

- Definition of the Quality of Control (QoC)

$$QoC = 100\left(1 - \frac{IE}{IE_{\max}}\right), \qquad IE = (1-\lambda)\, IAE + \lambda \cdot ITAE$$

$$0 \leq QoC < 100, \quad \lambda = 0.5 \text{ e.g.}$$

# AmI-based NCS

## QoS-adaptive Heuristic Control

- Heuristics

  H1: Dropping of overtaken and corrupted packets

  H2: Adaptation of control parameters according to the measured delays $\tau_m$

  H3: Adaptation of the sampling time $T_m$ according to the packet losses

  H4: Immediate reaction on set point change

- Control algorithm

$$u_m = u_{m-1} + \left[k_P(\tau_m) + 0.5 \cdot k_I(\tau_m) \cdot T_m\right] \cdot e_m + \left[0.5 \cdot k_I(\tau_{m-1}) \cdot T_{m-1} - k_P(\tau_{m-1})\right] \cdot e_{m-1}$$

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# AmI-based NCS

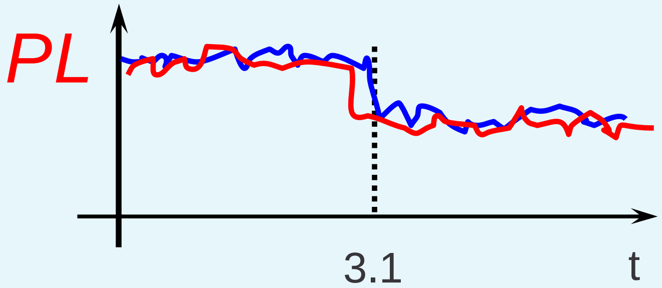
## QoS-adaptive Heuristic Control

Example from literature: $$G(s) = \frac{2029.826}{(s+26.29)(s+2.296)}$$

Two out of four chosen network scenarios:

$\tau_{1,NS1} \in [45ms, 35ms]$ $\tau_{2,NS1} \in [25ms, 35ms]$

$PL_{1,NS1} \in [35\%, 45\%]$ $PL_{2,NS1} \in [20\%, 30\%]$



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# AmI-based NCS

## QoS-adaptive Heuristic Control

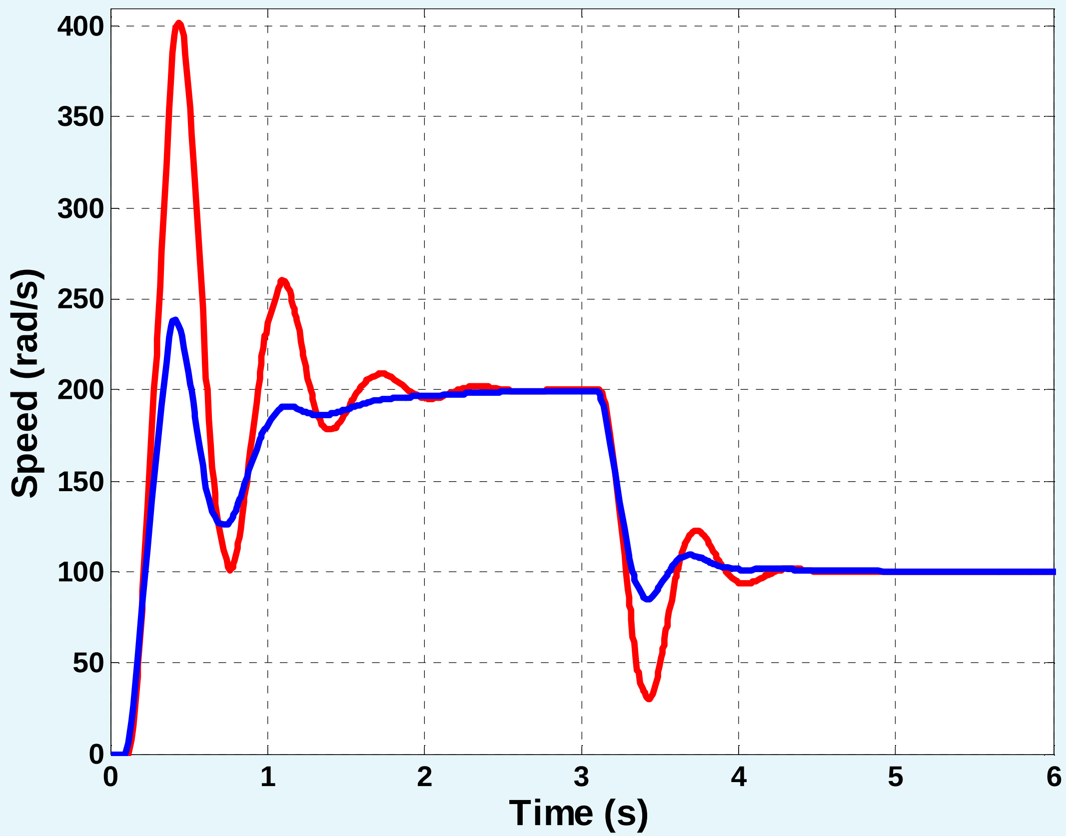
Results by QoC

| HV | µ | σ | min | max | adaptive better in % |
|---|---|---|---|---|---|
| **1001** | 62,22 | 10,69 | 19,24 | 71,30 | 97,40 |
| **1101** | 61,24 | 11,70 | 22,77 | 73,98 | 92,82 |
| **1011** | 64,29 | 9,84 | 15,73 | 72,76 | 100,0 |
| **1111** | 67,54 | 5,99 | 44,05 | 73,14 | 100,0 |
| **TT** | 52,12 | 10,01 | 6,63 | 63,82 | - |

# AmI-based NCS

## QoS-adaptive Heuristic Control

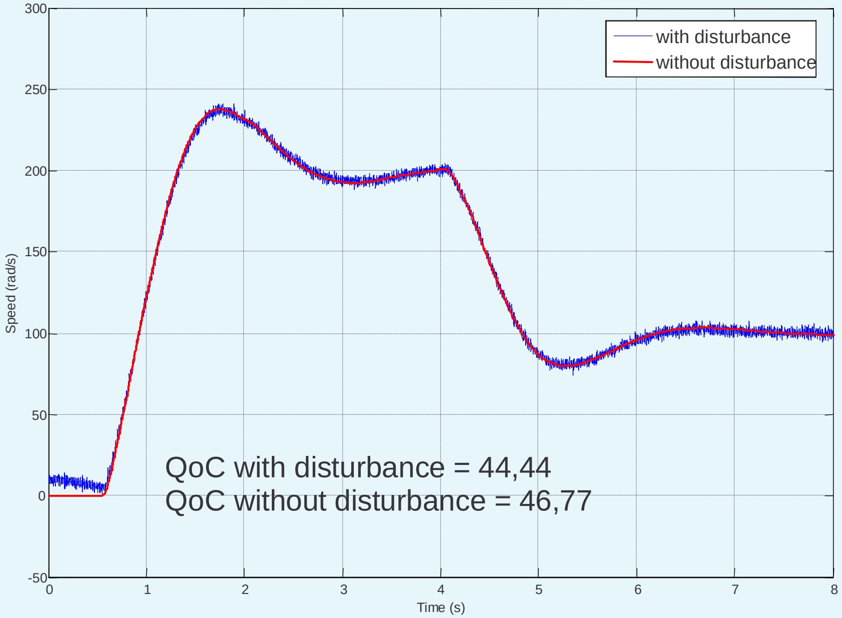
Comparison of **1111** and **TT**:

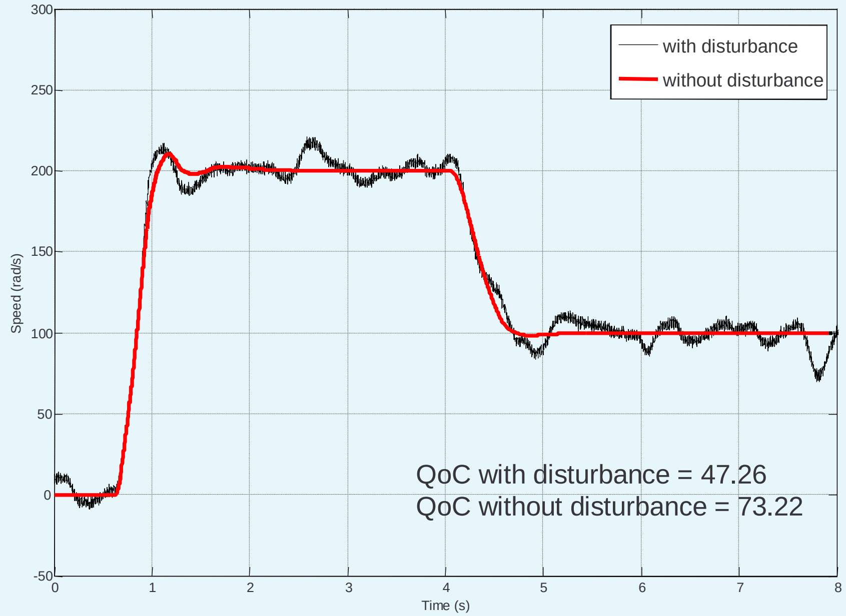


# AmI-based NCS

## QoS-adaptive Heuristic Control and MPC

Comparison of **1111** and **MPC**:




QoS-adaptive Heuristic Control

- Worser QoC
- Less Computational Power
- Less Noise Sensitive

MPC-based Adaptive Control

- Better QoC
- More Computational Power
- More Noise Sensitive

# AmI-based NCS

## QoS-adaptive Heuristic Control and stability proof

- BMI-approach for NCS (Yue, D.; Han, Q.; Peng, C.: *State Feedback Controller Design of Networked Control Systems*, 2004)
- Measure for Packet losses and delays:

$$(i_{k+1} - i_k)h + \tau_{k+1} \le \eta,\ k = 1, 2, \ldots$$

- Approach: Lyapunov functional

$$V(t) = \underline{x}^T(t)\underline{P}\underline{x}(t) + \int_{t-\eta}^{t}\int_{s}^{t} \dot{\underline{x}}^T(v)\underline{T}\dot{\underline{x}}(v)\,dv\,ds$$

- Stability condition:

$$\begin{bmatrix} \underline{N}_1 + \underline{N}_1^T - \underline{M}_1\underline{A} - \underline{A}^T\underline{M}_1^T & \underline{N}_2^T + \underline{N}_1 - \underline{A}^T\underline{M}_2^T - \underline{M}_1\underline{B}\underline{K} & \underline{N}_3^T + \underline{A}^T\underline{M}_3^T + \underline{M}_1 + \underline{P} & \eta\underline{N}_1 \\ * & -\underline{N}_2 - \underline{N}_2^T - \underline{M}_2\underline{B}\underline{K} - \underline{K}^T\underline{B}^T\underline{M}_2^T & -\underline{N}_3^T + \underline{M}_2 - \underline{K}^T\underline{B}^T\underline{M}_3^T & \eta\underline{N}_2 \\ * & * & \underline{M}_3 + \underline{M}_3^T + \eta\underline{T} & \eta\underline{N}_3 \\ * & * & * & -\eta\underline{T} \end{bmatrix} < 0 \qquad \underline{P} > 0, \underline{T} > 0$$

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# AmI-based NCS

## QoS-adaptive Heuristic Control and stability proof

| Scenario | Delays (in ms) | Packet losses (in %) | Controller parameter ($k'_P$, $k'_I$) |
|---|---|---|---|
| 1a | [5;15] | [5;10] | 0,1555; 0,3545 |
| 1b = 2a | [45;55] | [35;45] | 0,1042; 0,2343 |
| 2b | [25;35] | [20;30] | 0,0804; 0,1782 |

| Scenario | $\eta$ (in s) |
|---|---|
| 1a | 0,0483 |
| 1b = 2a | 0,1095 |
| 2b | 0,0779 |

Feasibility test with Matlab is positive

-> all scenarios are stable

(under given conditions)

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# AmI-based NCS

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Feasibility test with Matlab is positive

-> all scenarios are **stable**

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?

# AmI-based NCS

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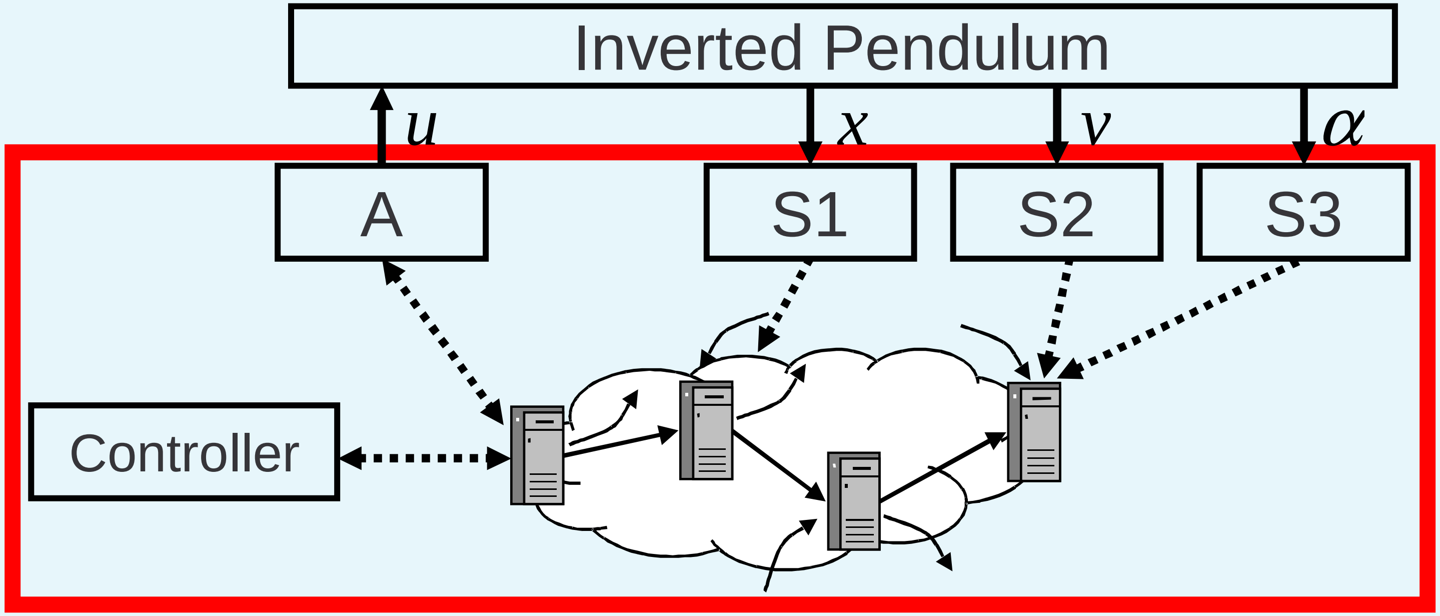
## An experiment with an NCS System




- Effects
  - Packet losses
  - Quasi packet losses
  - Disturbances

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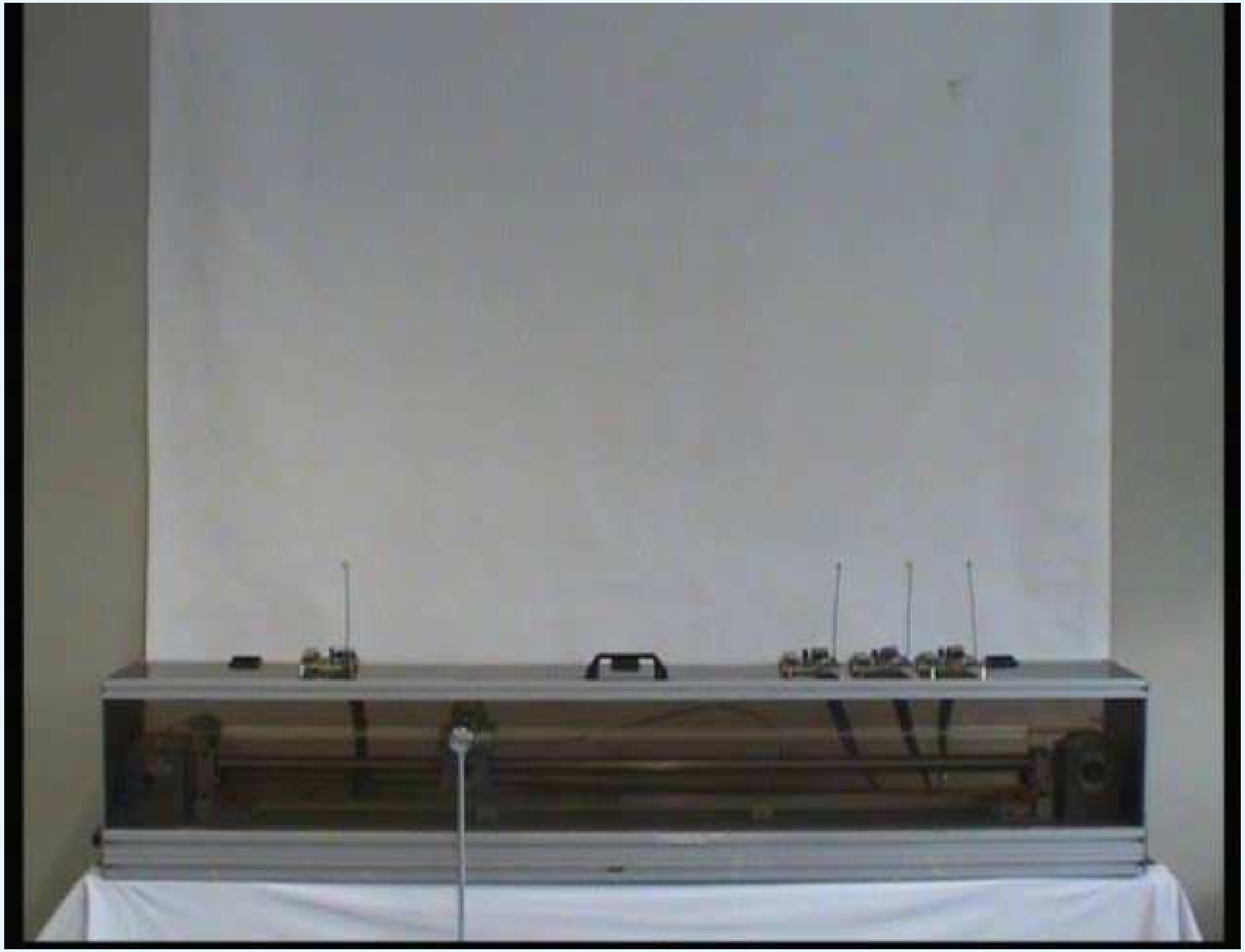
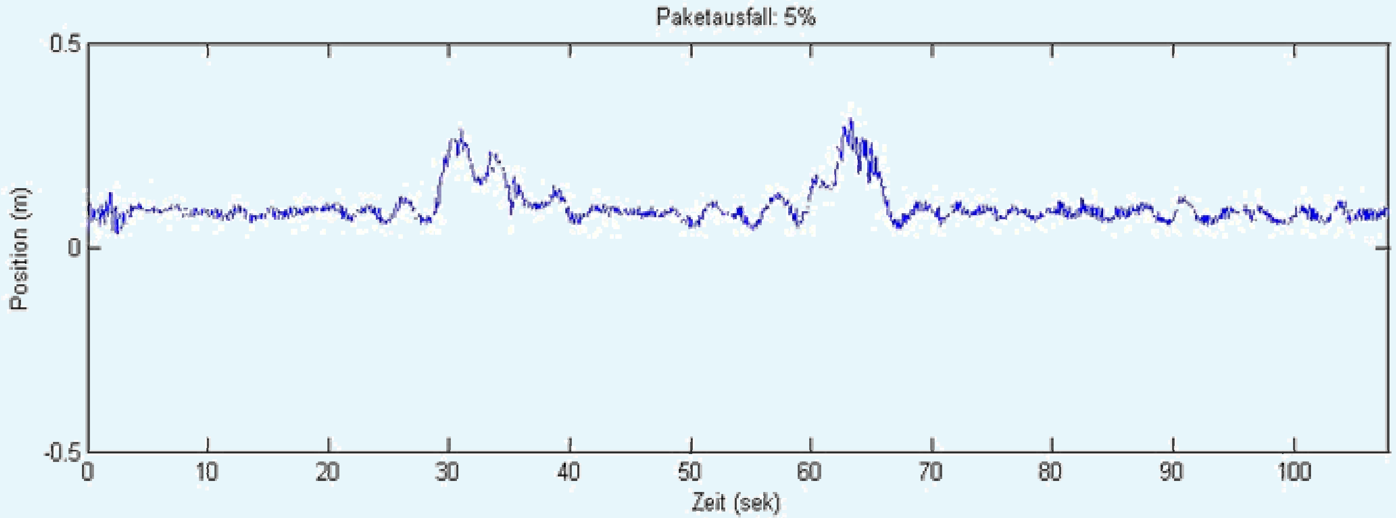
# AmI-based NCS

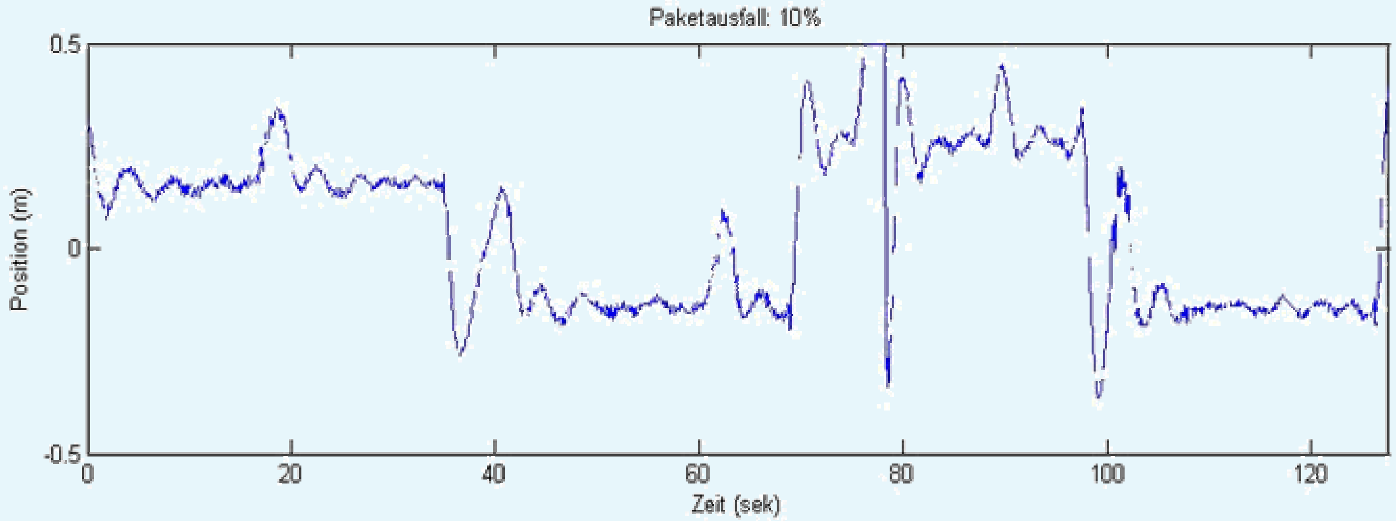
## An experiment with an NCS System



# AmI-based NCS

## An experiment with an NCS System



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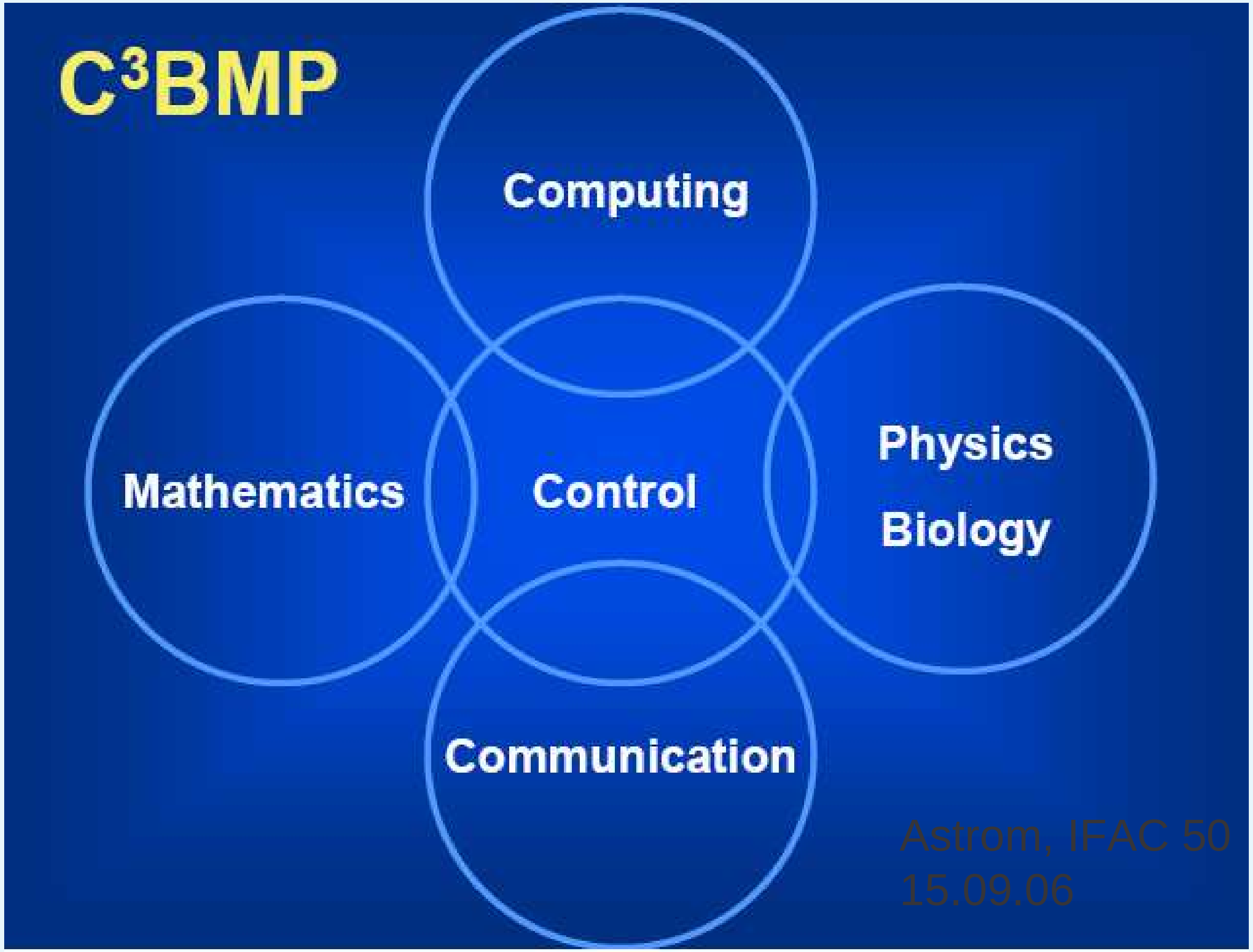
# Outlook NCS-Systems

**Needs for the future:**

- Mapping of the technical problems to mathematical design methods
- Treating several limited resources at the same time
- Non conservative stability criteria
- Stability criteria for nonlinear systems
- Performance - measures for a proper judgment of different solutions
- Cross-Design-Methods with optimization of the trade-Offs

# Outlook NCS-Systems

**Needs for the future:**



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Thanks for your attention !

# Status of development

## Sensor Systems

- Wind Senor : field test
- Encoded Heart-beat : Tested

## Crank Set / Bottom Bracket

- Tested in laboratory environment,

## Communication

- System with multihop completed, up to 32 bicycles, field tests running

## UWB and ECG

- in development

## Master Board

- Tested and completed

## Control Algorithms

- Model Predictive Controller developed

## Outdoor training Tests

- Field tests in preparation

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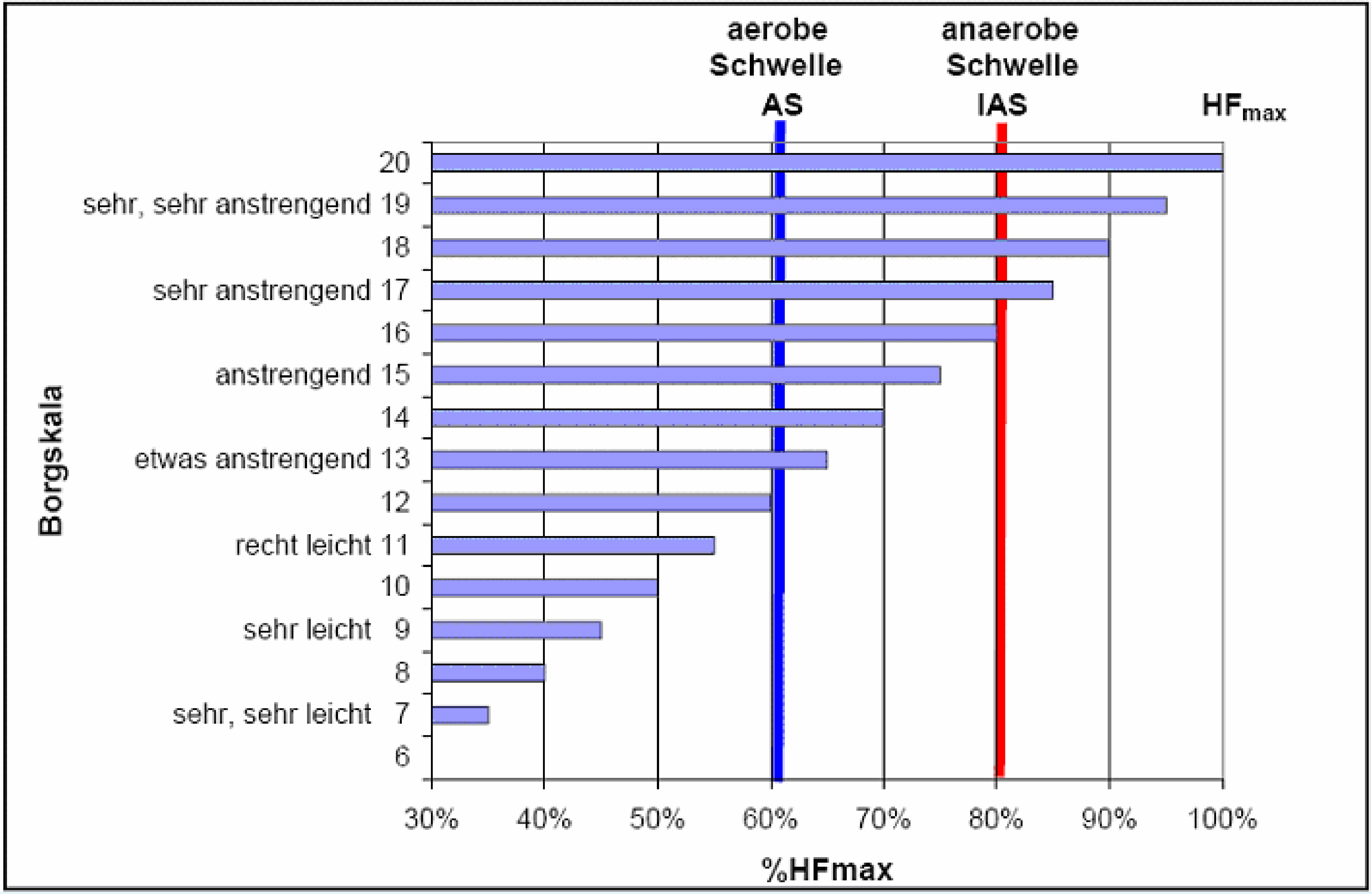
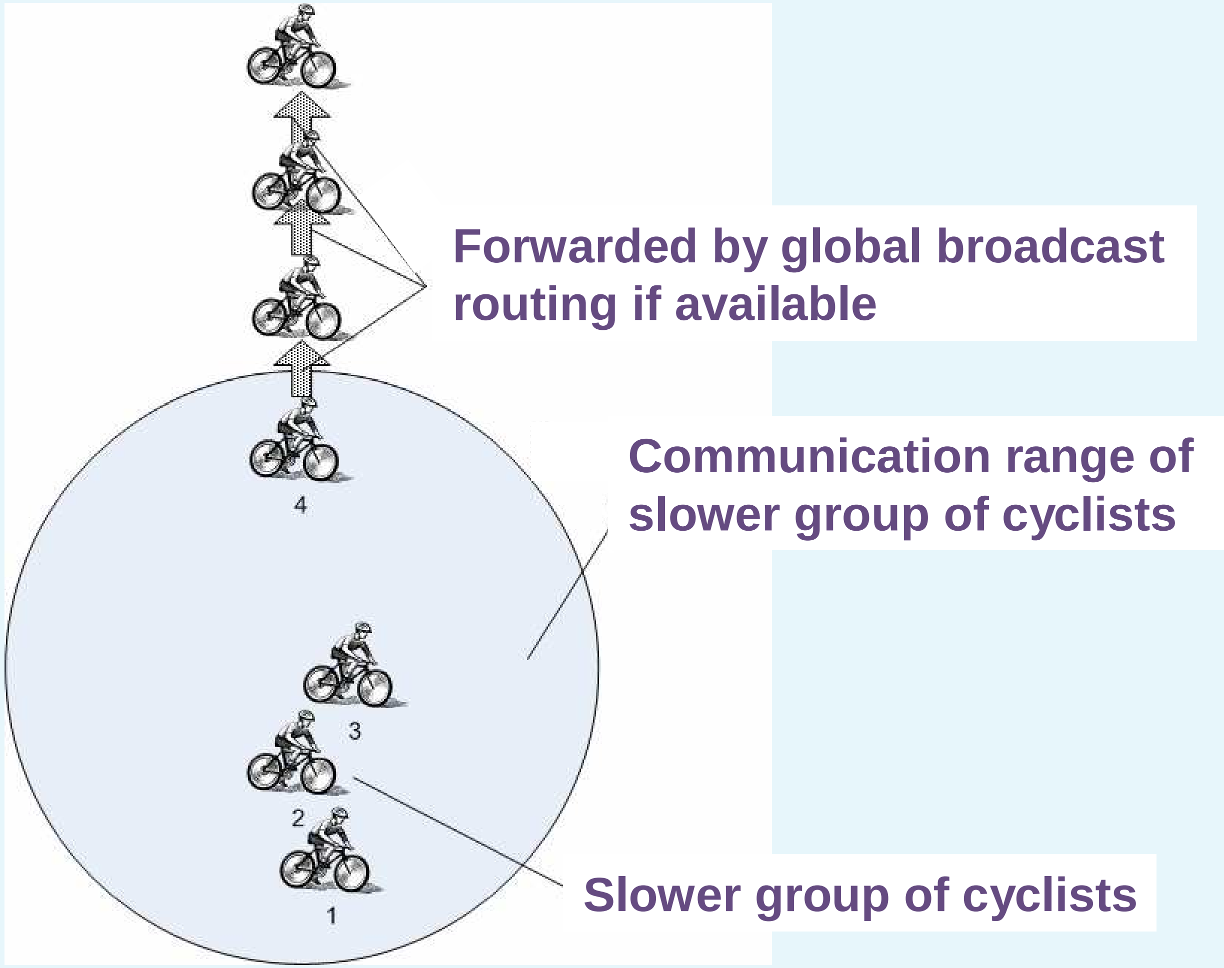
# Borg‘s scale (6 – 20 )

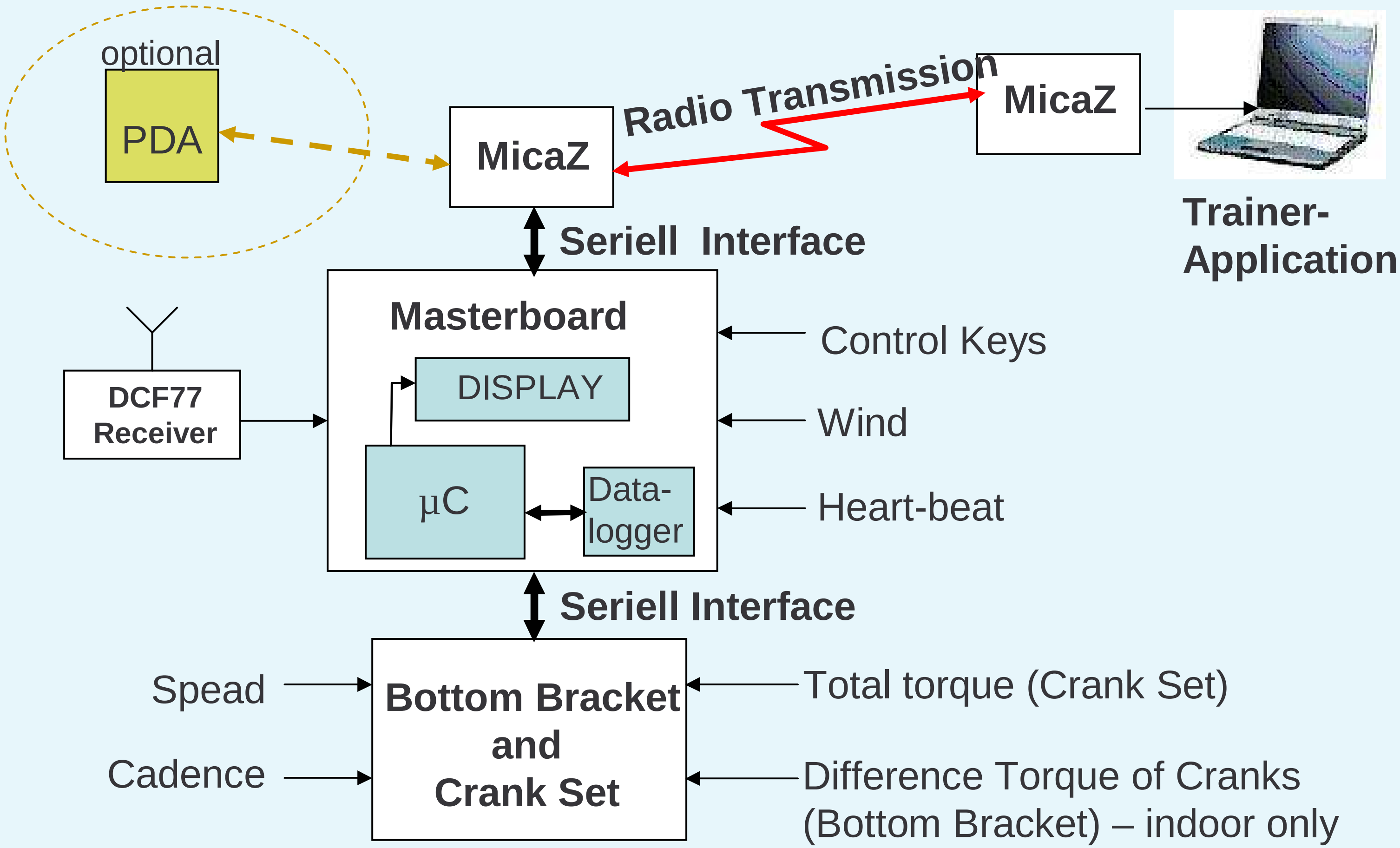
## (no exertion – maximal exertion)



# Multi-Hop Broadcast Routing



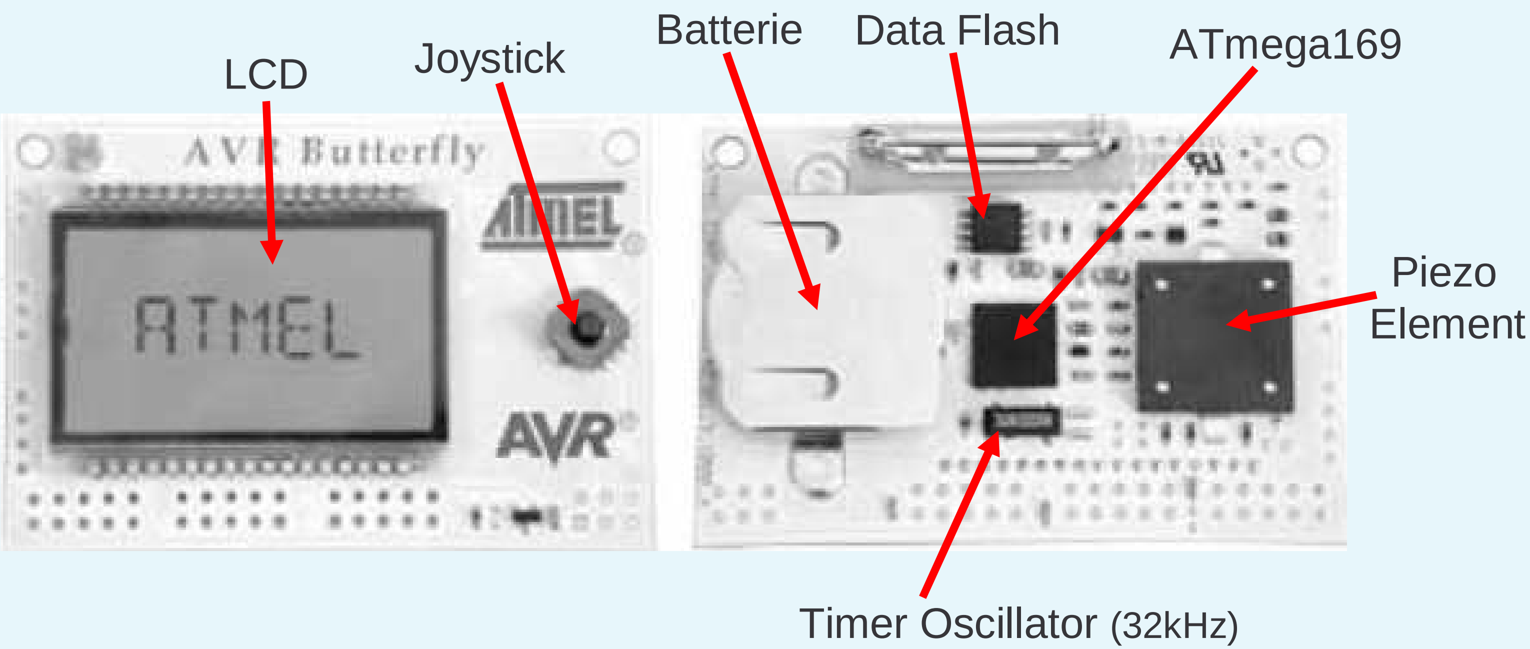
# Hardware Concept



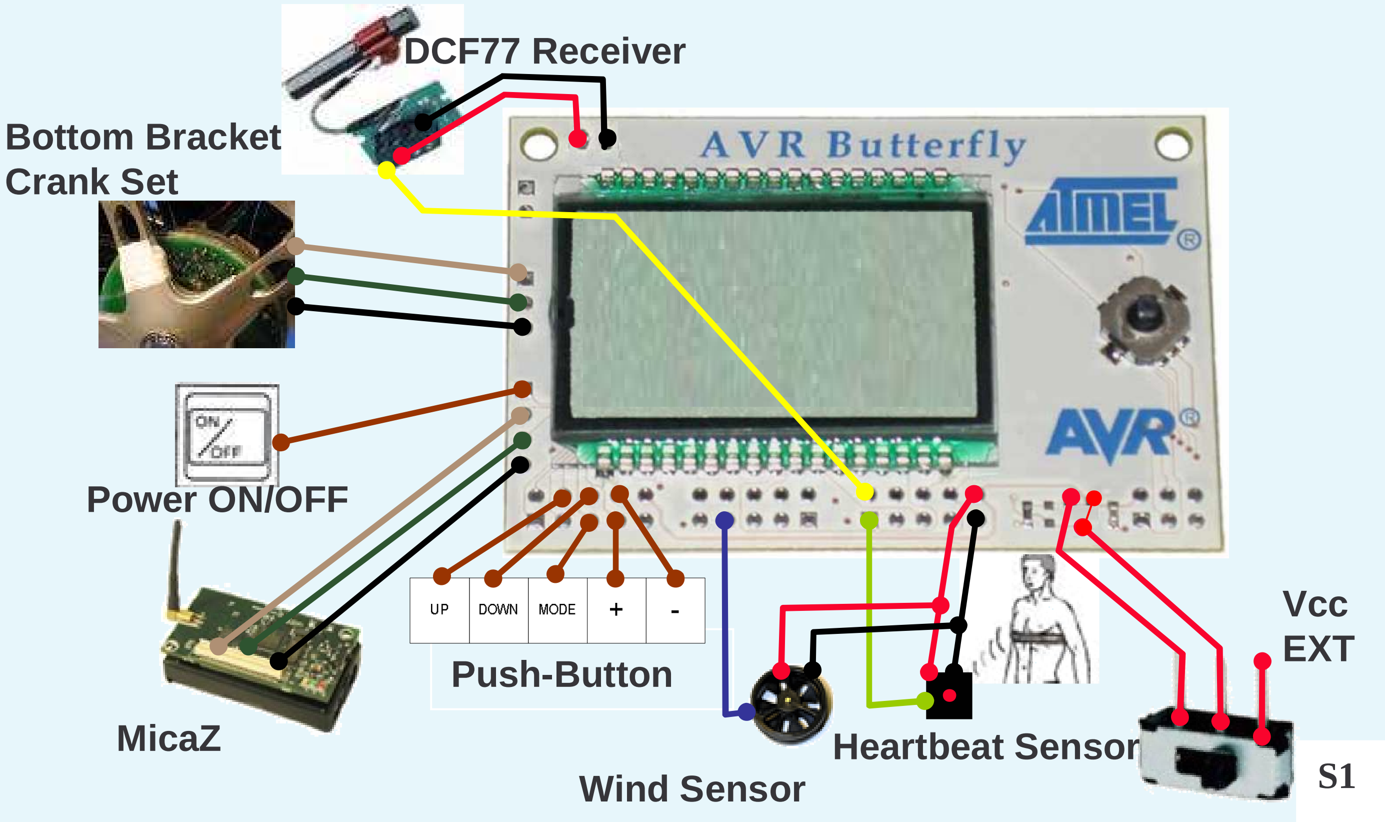
# Master Board

**ATmega169 :**
8 MHz
Flash: 16 Kbytes
SRAM:  1 kBytes
LCD Driver: 4 X 25 Segment

**Data Flash :**
2048 Pages with 264 Bytes → 4 MBytes
Memory for 2,7h Training Duration
(storing data every second)



# Master Board and Interfaces



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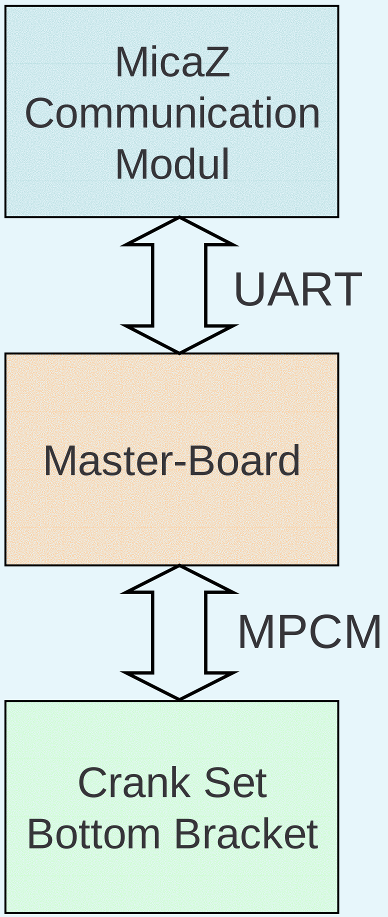
# Master Board – Interfaces




**Interface :**
**MicaZ – Master-Board**

- Software UART
- BAUD Rate 38,4 kbps

**Interface:**
**Master-Board - Bottom Bracket/ Crank Set**

- UART in MultiProcessorCommunicationMode
- BAUD Rate 76,8 kbps

# Communication Protocol

## Message Format (Masterboard ↔ MicaZ)

| Start Of Frame | | Header | | | | Data | End Of Frame | |
|---|---|---|---|---|---|---|---|---|
| 0xFF | 0x01 | Length | ID | Type | Version | Data | 0xFF | 0x02 |

**Length** : Length of the message (Header+Data)
**ID** : Bicycle-Identifikation (set by MicaZ)
**Type** : Type of the message (DATA, COMMAND, SET-UP…)
**Version** : Version of the message type
(<0x00>: Initialisation, <0x01>: Single Training,
<0x02>: Group Training, <0x10>: Output Datalogger)

## Message Format (Masterboard ↔ Crank Set/Bottom Brackets)

| Address | Start Of Frame | | Header | | | | Data | End Of Frame | |
|---|---|---|---|---|---|---|---|---|---|
| Address | 0xFF | 0x01 | Length | Address | Type | Version | Data | 0xFF | 0x02 |

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# Bicycle Training Demonstrator

**In-house Development: MacZ - Layer by Prof. Dr. Gotzhein**

## Communication requirements

- Spontaneous messages
- Sensor values
- Periodical data
- Messages with guaranteed delay
- Alert messages
- Voice communication
- Actuator control

## Hybrid QoS MAC Layer

- Enhanced- Best- Effort Transmission
- Distributed Multihop-time-synchronization

  Synchronization of the whole network

  after a constant time-delay
- Supporting different Transmission slots

  Priority oriented transmission

  Reserve oriented transmission

  Alert messages
- Recognition of external networks

  and automatic synchronization