22. VD/ITG Fachtagung Mobilkommunikation, Osnabrück

09./10. May 2017, Session: Industrial Radio II

HiFlecs: Innovative Technologies for Low-Latency Wireless Closed-Loop Industrial Automation Systems

C. Bockelmann*, A. Dekorsy*, A. Gnad, L. Rauchhaupt, A. Neumann, D. Block, U. Meier, J. Rust, St. Paul, F. Mackenthun, A. Weinand, H. Schotten, J. Siemons, T. Neugebauer, M. Ehlich

*University of Bremen, Department of Communications Engineering

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HFlecs

Hochperformante, sichere Funktechnologien
und deren Systemintegration in zukünftige industrielle
Closed-Loop Automatisierungslösungen

Coordination: Prof. Dr. Armin Dekorsy, University of Bremen

ifak IMST inIT GÖTTING NXP PHOENIX CONTACT Lenze
SCHUBERT SIEMENS TECHNISCHE UNIVERSITÄT KAISERSLAUTERN Universität Bremen*

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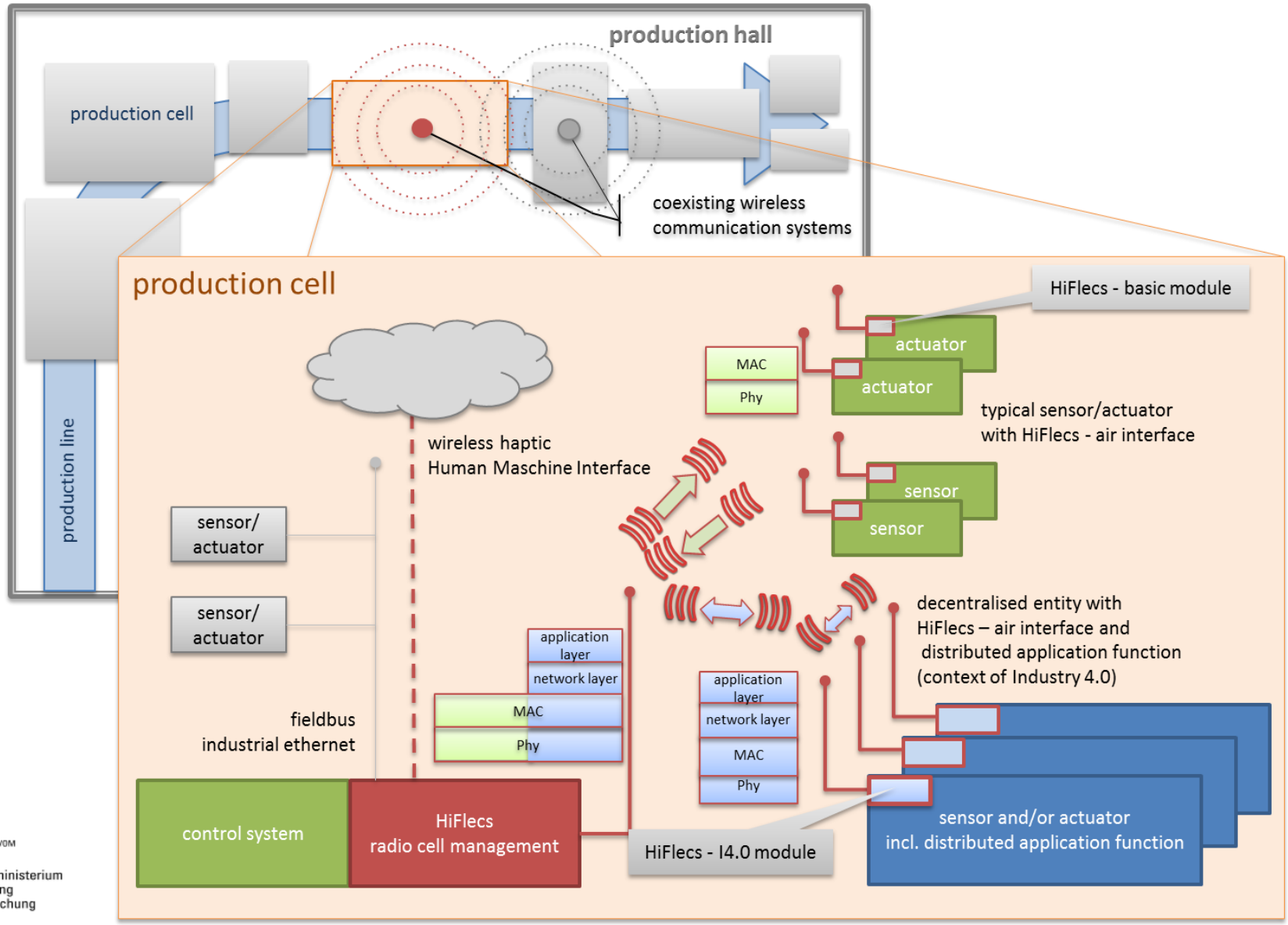
Project Goal

Design
of
an industrial radio system

- Extremely low latency (< 1ms)
- Extremely high availability and reliability




System Concept



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Requirement Profiles

Profile A

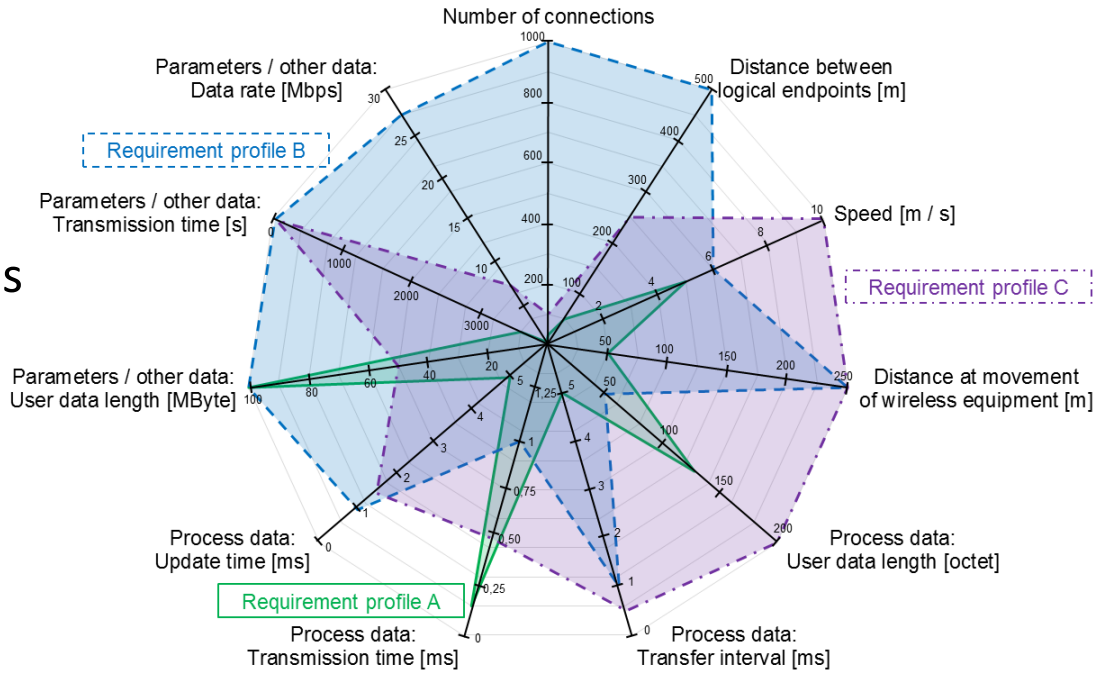
- Driverless transport of large goods
- Marriage in vehicle assembly
- Shuttle vehicles in packaging machines

Profile B

- Industrial plant with decentralized drive technology
- Robot cell with product feed and removal of the peripheral axes
- Storage and retrieval machines or shuttle systems

Profile C

- High bay warehouse
- Robot cells with interchangeable tools



Parameter	A	B	C
Transmission time [ms]	0,15	1,00	0,50
Update time [ms]	5,00	1,00	1,50
Data length [Bit]	1024	400	1600
Packet Loss Rate	$5 * 10^{-7}$	N/A	N/A
Consecutive Losses	2	N/A	2
No. of devices	32	1000	100

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Core Technologies

Adaptive PHY/MAC technologies

- Scalable latency and resource usage
- Use of multicast/broadcast-properties
- Dynamically reconfigurable hardware

Integrated information security

- Plug & Trust
- Physical layer security
- Latency optimized encryption

HiFlecs Radio System

Coexistence-Management

- Cognitive spectrum sensing
- Self-regulated coexistence-management

Mapping of distributed application functionality

- Interface between application and radio
- Dynamic, distributed object model

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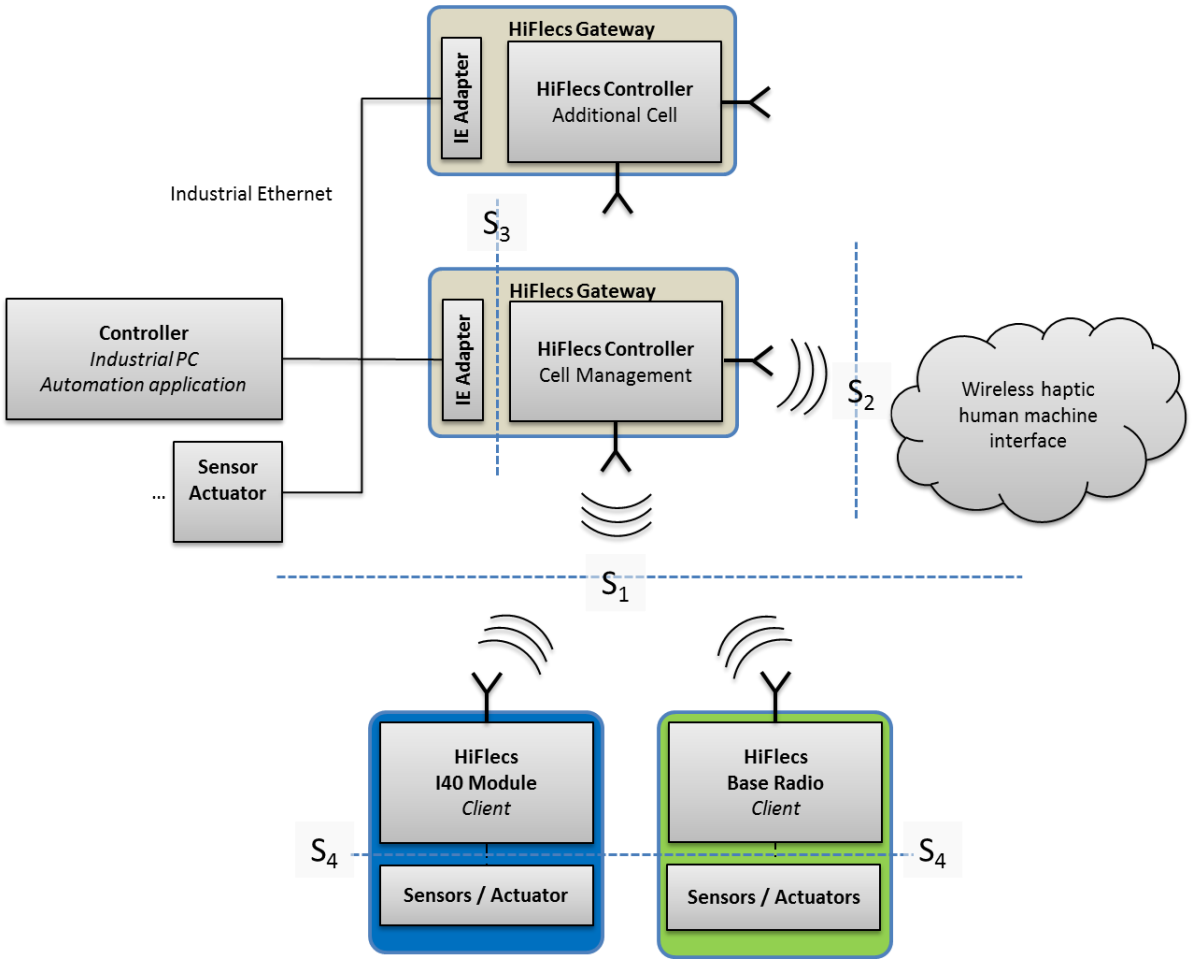
System Architecture, Interfaces and Channels



Data channels

- Process channel
  - sensor/actor process data
  - real-time traffic, cyclic, symmetric (UL,DL)
- Parameter channel
  - Control loop parameter data
  - non-real-time, acyclic,not symmetric
- Management channel
  - Plug&Play, Plug&Trust signalisation
  - non-real time, best effort, not symmetric
- Client-to-Client channel
  - Exchange of application data (QoS)

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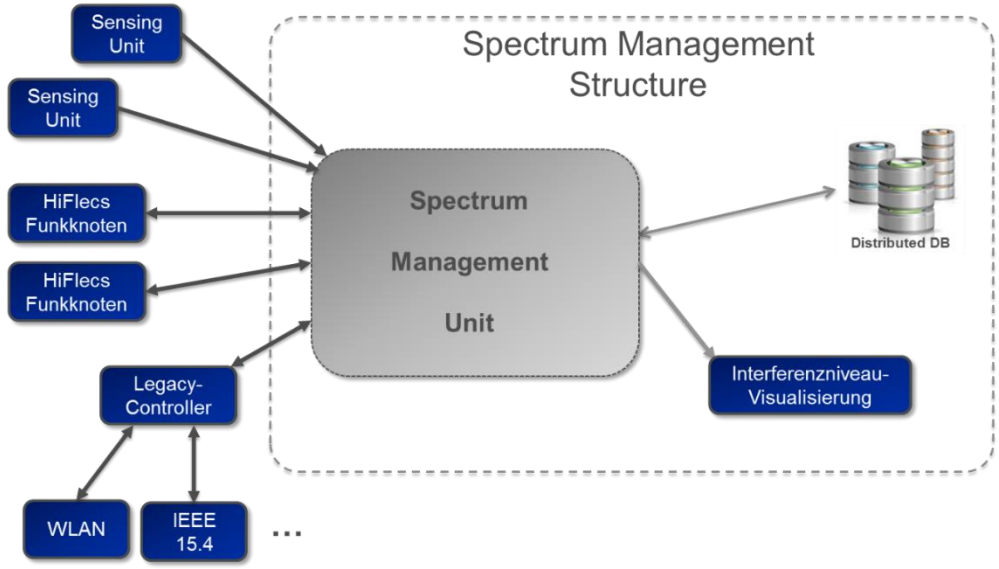
Coexistence Management

HiFlecs meets regulation requirements in 5,8-GHz-ISM-Band [1][2]

Approaches:

- Database-based spectrum management



- Spectrum sensing and classification

[1] ETSI, „EN 300 440-1 - V1.6.1 - Electromagnetic compatibility and Radio spectrum Matters (ERM); Short range devices; Radio equipment to be used in the 1 GHz to 40 GHz frequency range; Part 1: Technical characteristics and test methods," 2010.

[2] CEPT, ECC, ERC Recommendation 70-03: Relating to the use of Short Range Devices (SRD), Tromso 1997, 2015.

Spectrum Sensing and Classification

Challenge:

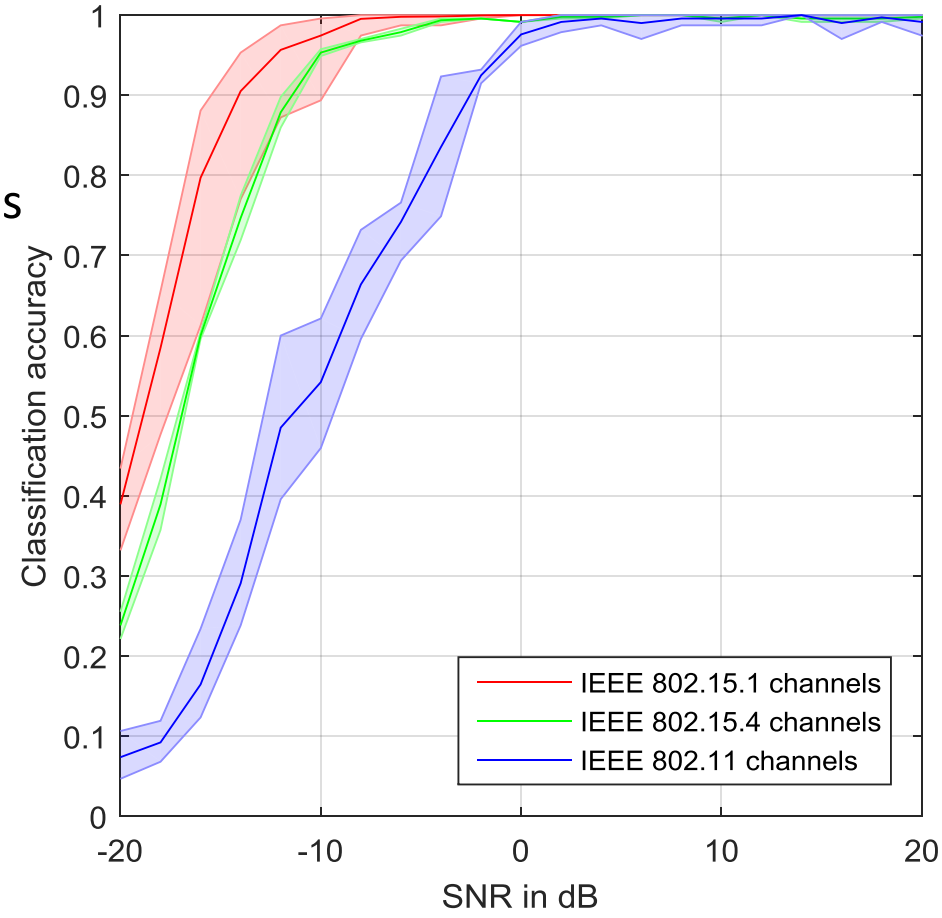
- Fast and reliable classification of active wireless systems in shared frequency bands

Approach:

- Short sensing snapshots (12.8ms)
- Multi-layer convolutional neural network

Key result:

- 100% classification down to -5 dB SNR



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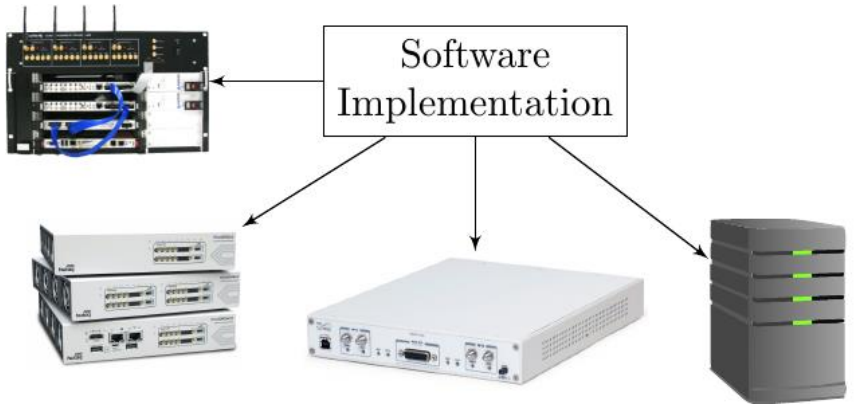
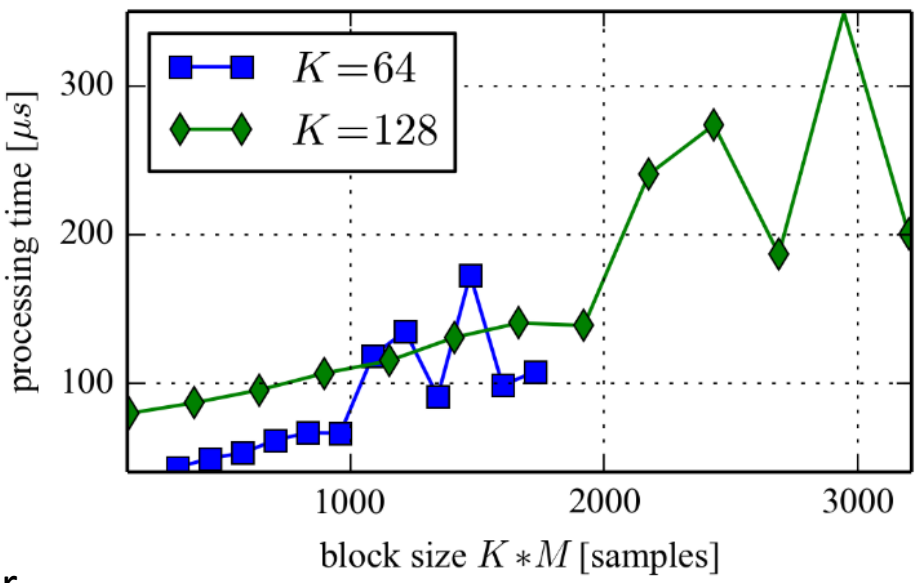
Latency optimized SDR Baseband Implementation



Waveform Processing Latency



Generalized Frequency Division Multiplex (GFDM) waveform

- Low-complexity GFDM modulator/demodulator
- Improved Schmidl & Cox synchronization

Polar Codes

- State-of-the-Art high throughput implementation

Processing and Transmission Latency < 1ms

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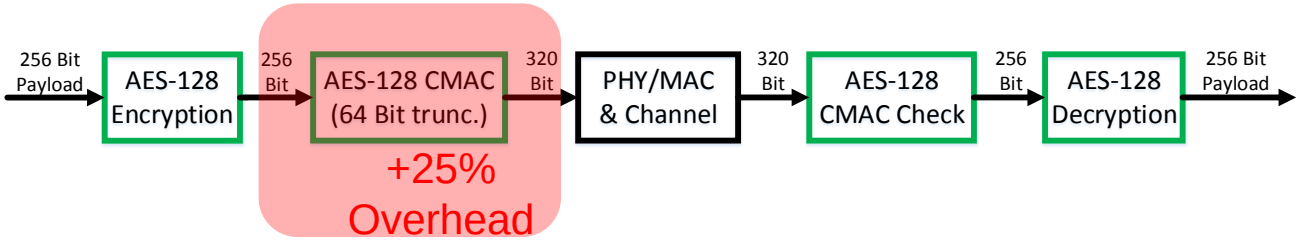
Security: Message Encryption and Authentication



Classical Encryption and Message Authentication:

- Tight integration of encryption (AES) and authentication (CMAC) with baseband
- Determines minimum block sizes
- Large overhead for small message sizes especially in uplink

Physical-Layer Security based message authentication

- Avoids CMAC overhead
- Leads to reduced latency

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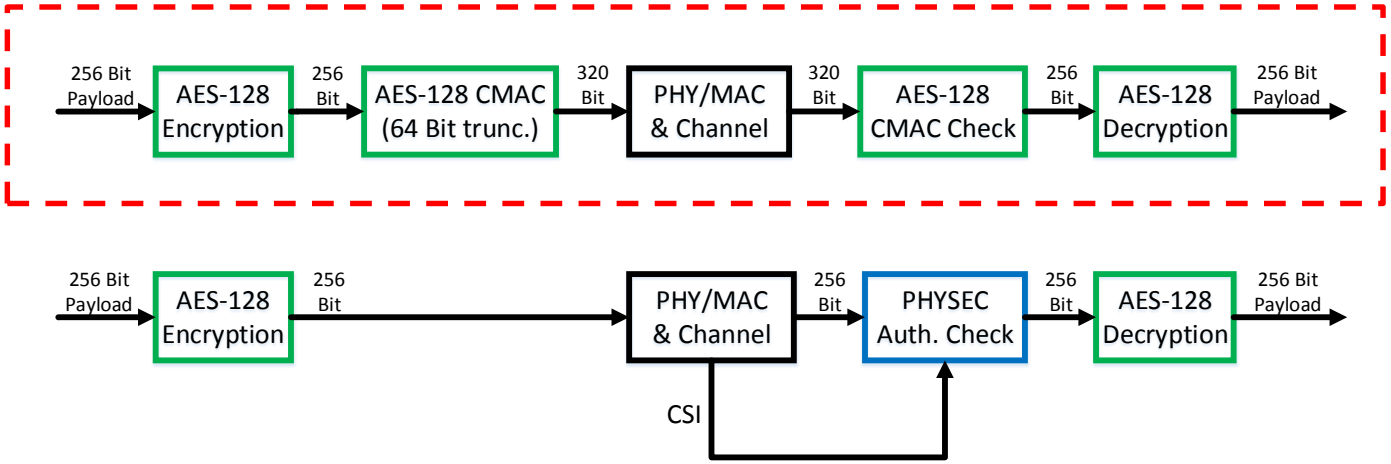
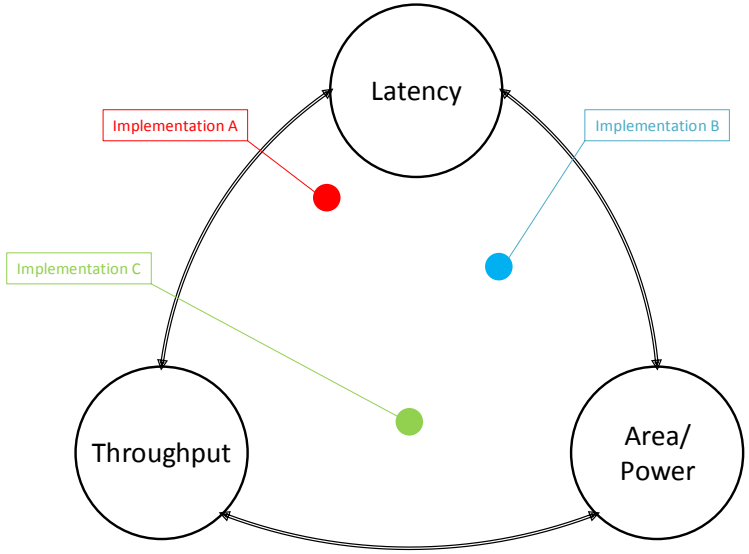
Low Latency Encryption



Low Latency Cipher Implementation:

- Dedicated hardware implementation
- Different optimization goals possible for HiFlecs Controller/Client
  - Controller: Higher Throughput
  - Client: Low Area/Power



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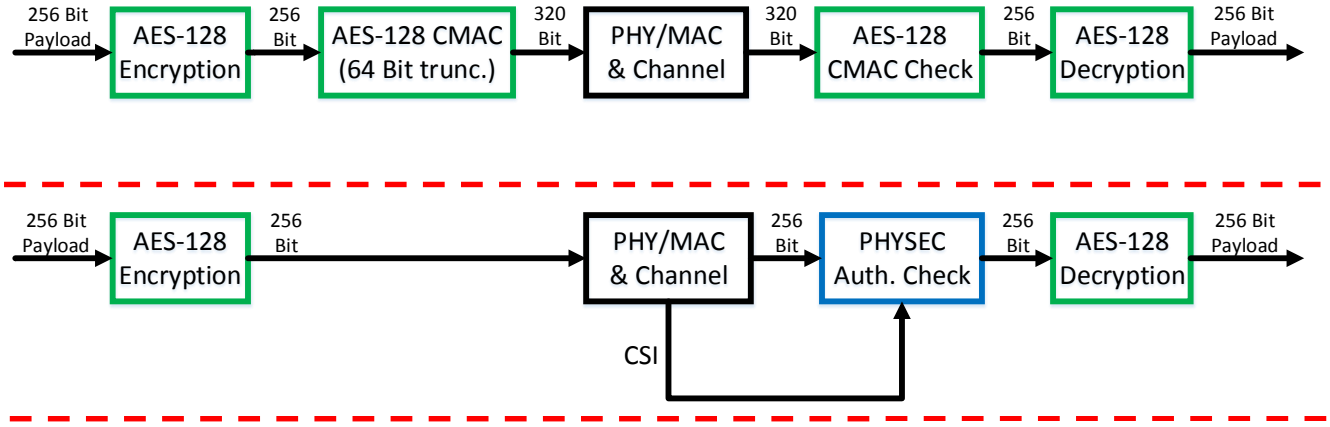
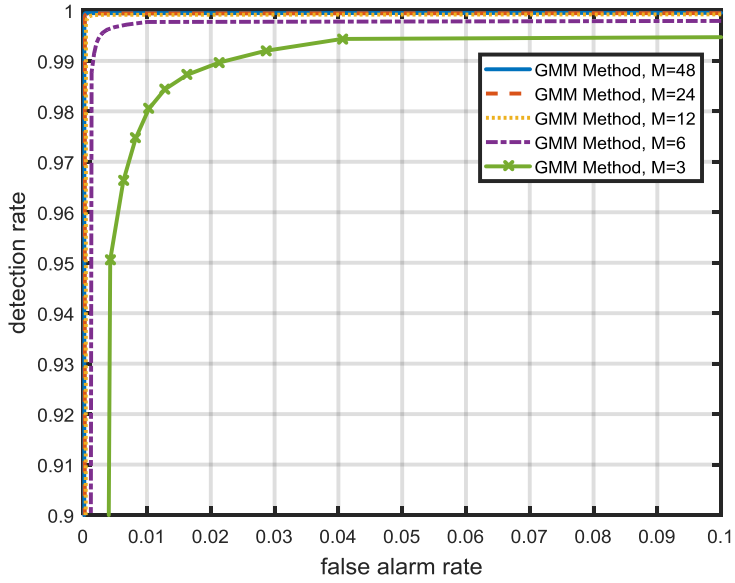
Physical layer security based authentication



Physical Layer Security Approach:

- Exploit wireless channel characteristics for transmitter identification
- Machine learning based detection methods
- Experimental performance evaluation promising



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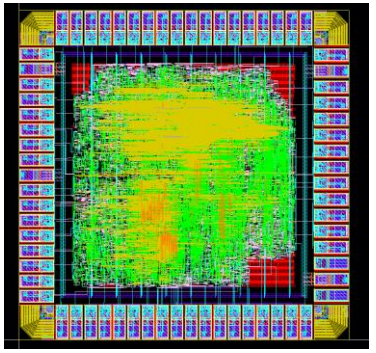
Reconfigurable Hardware

Dynamically reconfigurable, and fault-tolerant hardware architecture

- Programmable central processing unit (CPU)
  - Can be linked to the baseband signal processing task
  - Flexible (non-time critical) processing
- Specialized hardware accelerators
  - Fast Fourier Transform (FFT)
  - Logarithmic-Converter (LCU)
- Sophisticated function approximation technique
  - automated and accuracy-driven design of elementary functions
- Dynamic reconfiguration of the size of input data at runtime



➡ Enabler for flexible implementation of technical components

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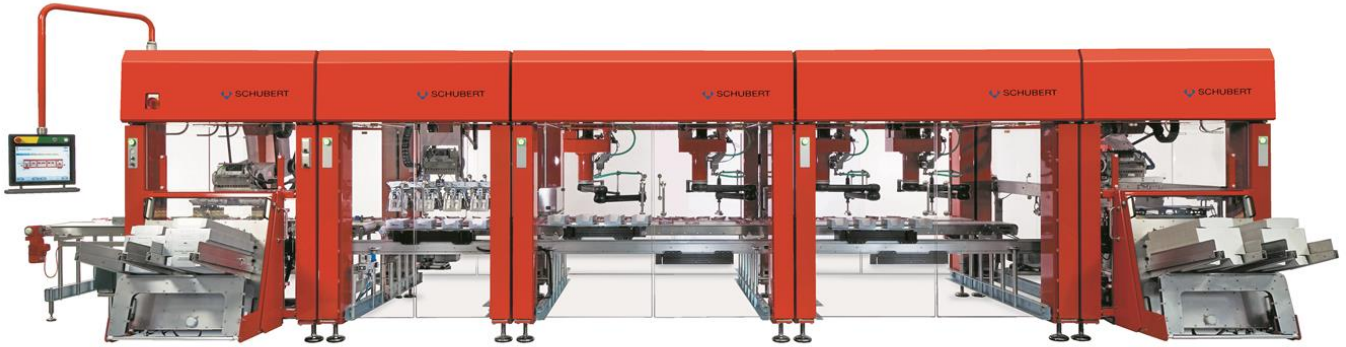
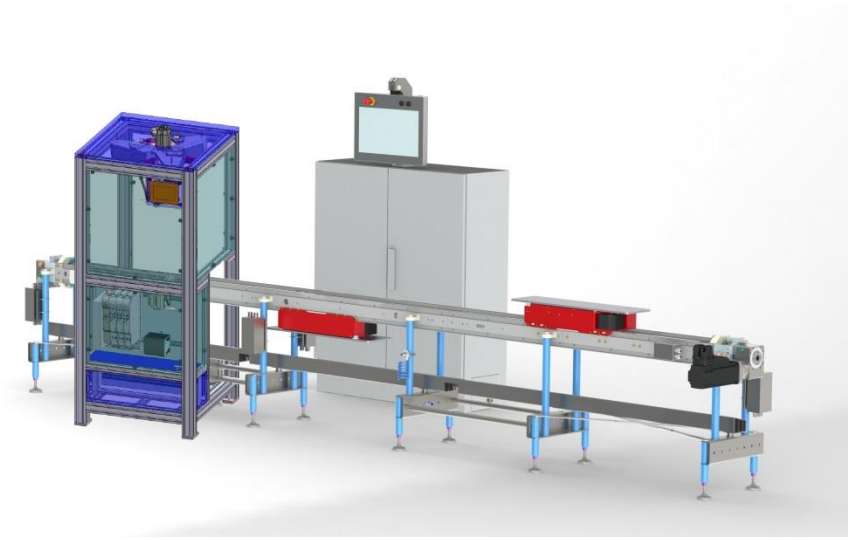
Demonstrator: Transmodul line of a packing machine



- Wireless data transmission between control module (SPS) and transport modules by HiFlecs
- Synchronization with delta-robot and linear measurement system via HiFlecs (cycle time 1ms)



Grafiken: Gerhard Schubert GmbH

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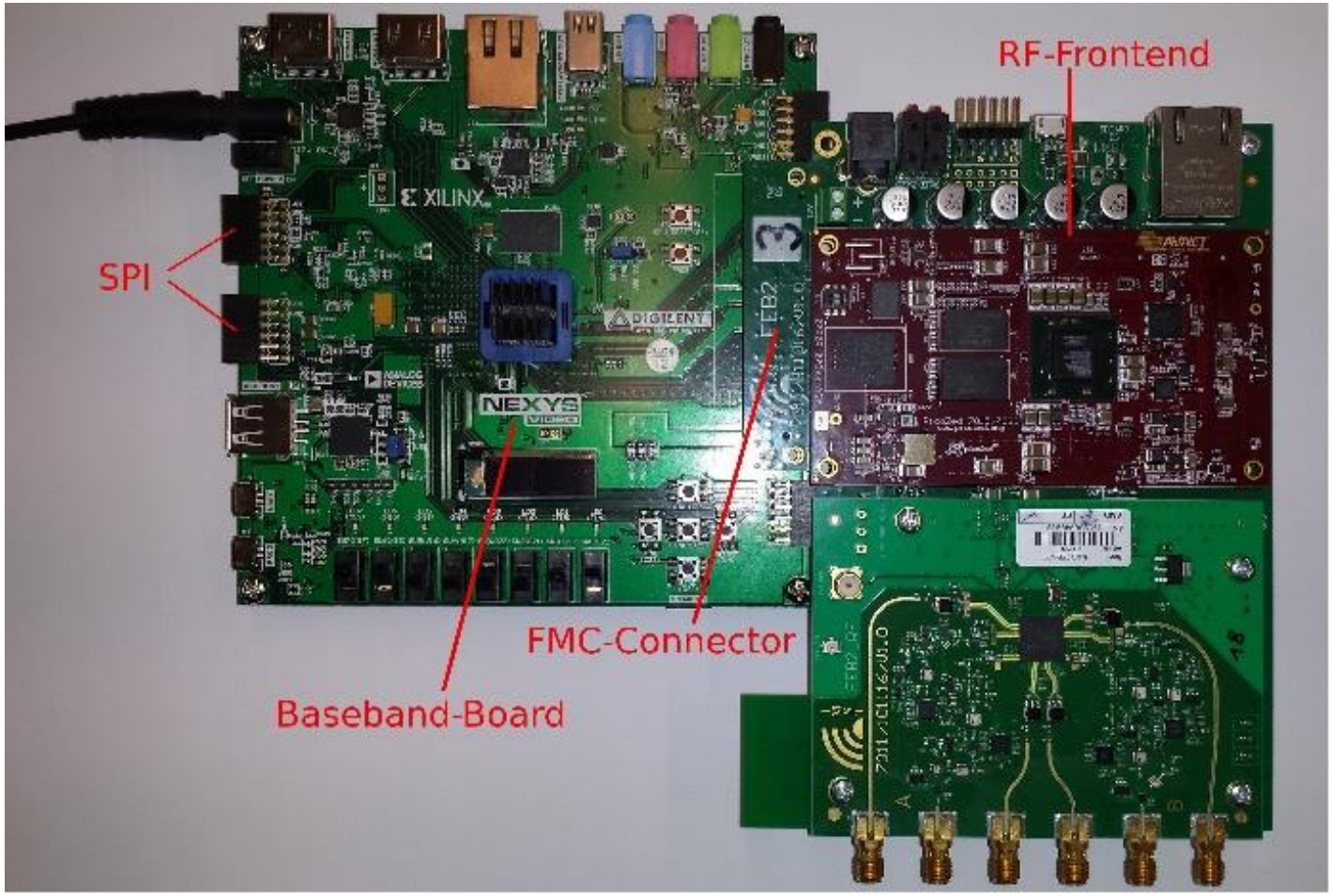
Demonstrator: Radio Hardware



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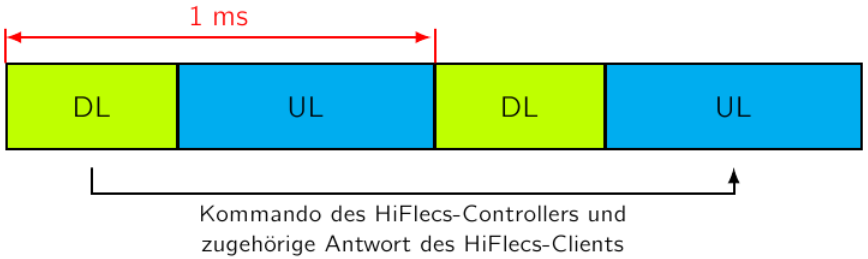
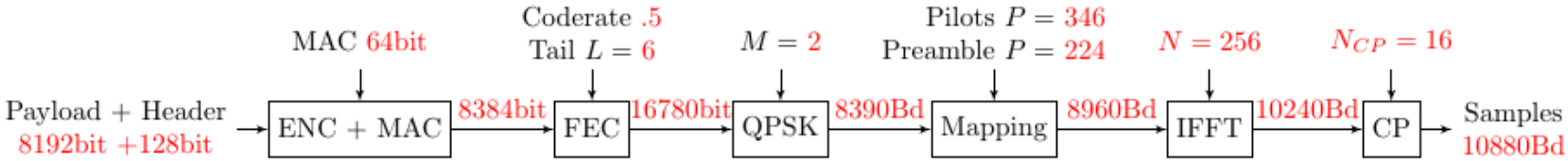
Demonstrator: PHY-Process Data Channel (PPDCh)

TDD-Framestructure:

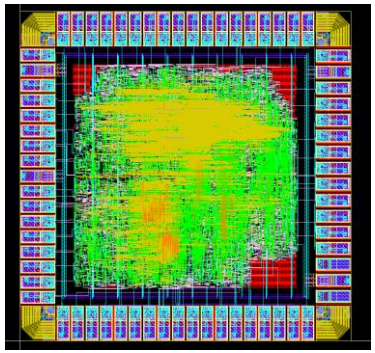


Downlink: OFDMA, Message Authentication Code (MAC), synchronisation, pilots, AGC preamble



sample rate $f_s = 25.6$Msps
frame duration $T_f = 425.0\mu s$

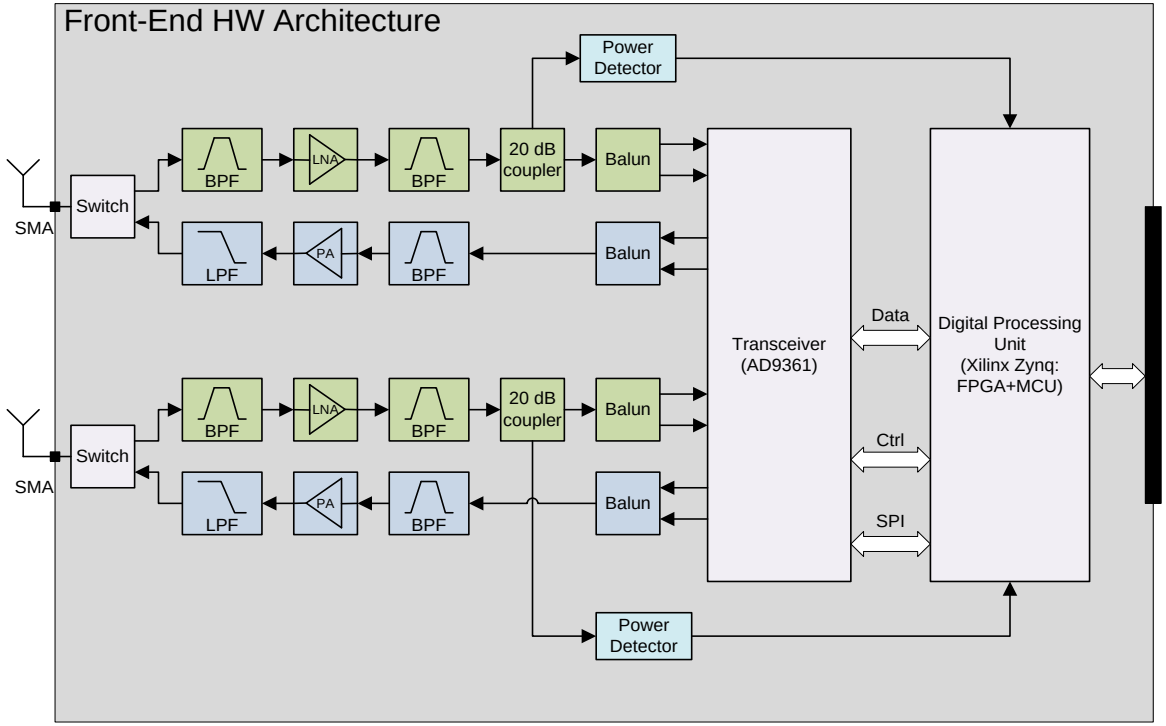
active subcarriers $N_{on} = 224$
timeslots $M_t = 40$
bandwidth $B = 22.4$MHz

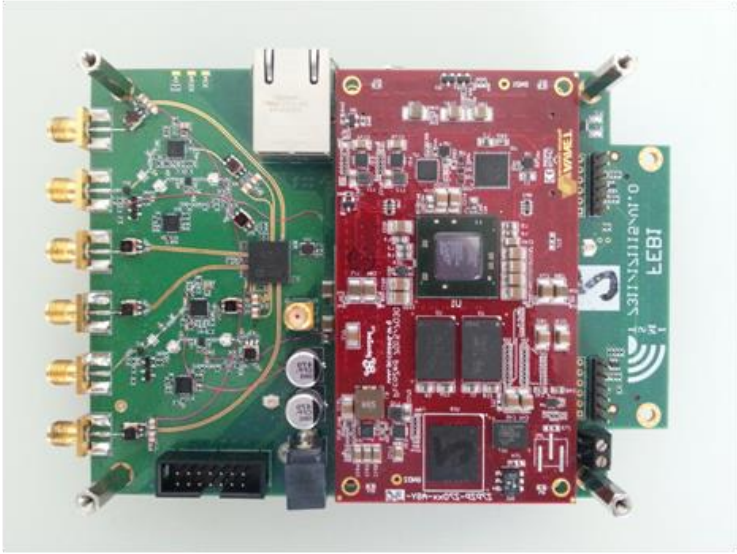


ASIC

Demonstrator: FrontEnd

- Two complete (i.e. RX and TX) RF-paths, a transceiver and digital processing unit
- Operation modes: TDD(single/dual antenna), FDD (dual antenna)
- Key feature: Fast Automatic Gain Control (AGC)





HiFlecs in a nutshell

- HiFlecs is a closed-loop control wireless communication system
- Key features:
  - Use of SotA technologies, but with appropriate parameter settings
  - Appropriate application programming interfaces (APIs)
  - Adjusted to control determinism (e.g. clock cycle)
  - Integrated security
  - Integrated coexistence management
- Consortium:
  - Builds upon expertise on mobile (3G-5G) and industrial (Wireless HART, IWLAN) communication systems
  - Direct transfer of HiFlecs system concept to industrial R&D by partners (Phoenix Contact, Lenze, Siemens, Götting, Schubert)
- Design and feasibility study is ongoing (end Jan 2018)
- Internal Technical Reports, 15+ publications, 7+ invited talks,