FORSCHUNGSINITIATIVE
KO-FAS

Data Communication and System Architecture

Datenkommunikation und Systemarchitektur

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Overview

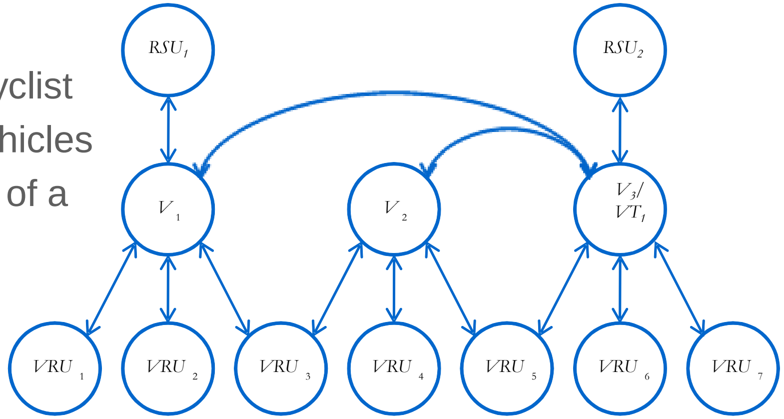
- Part I: System Architecture
  - Architecture of the localization units
  - Architecture of the SafeTAGs
  - Description of the components

- Part II: Data Communication
  - Technical challenges and constraints for the wireless data communication component
  - Digital transceiver development and implementation
  - Fundamentals of the wireless transmission scheme
  - Wireless transceiver evaluation results

Network Nodes

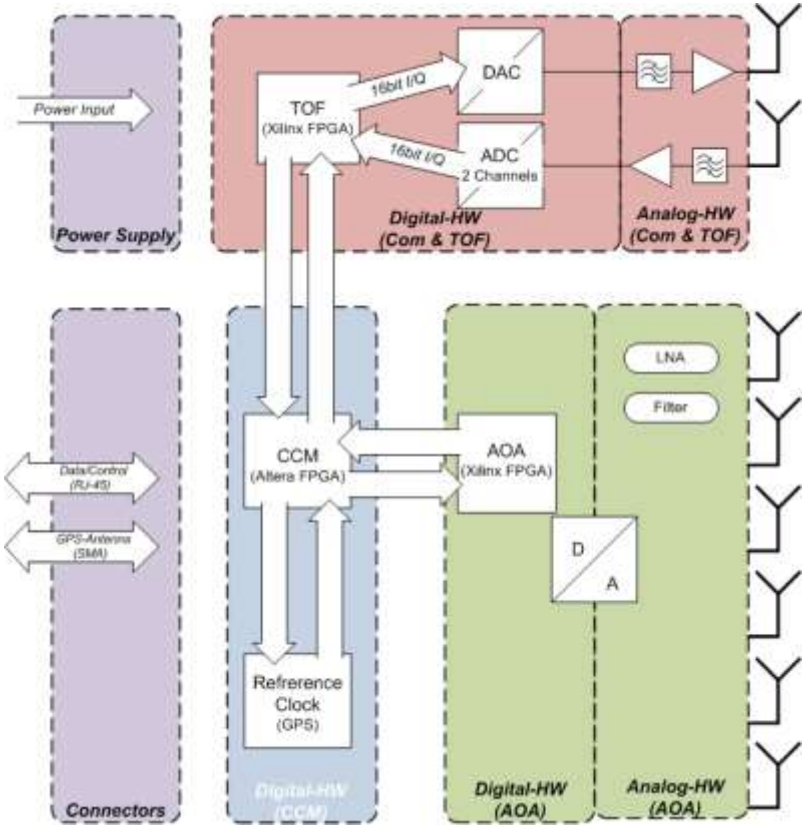
- On Board Unit (OBU) built in vehicles consist of
  - a Localization Unit (LU) that communicates with SafeTAGs and is able to localize them (distance and angle measurements)
  - a Fusion Unit (FU) that reads measurement data from the LU and tracks objects. It reads in further sensor data e.g. from cameras to elaborate the tracking algorithms

- SafeTAG can be
  - a Vulnerable Road User (VRU) such as a pedestrian or cyclist
  - a Vehicle TAG (VT) to support pre-crash safety among vehicles
  - a Road Side Unit (RSU) that gives an OBU the possibility of a precise self localization.



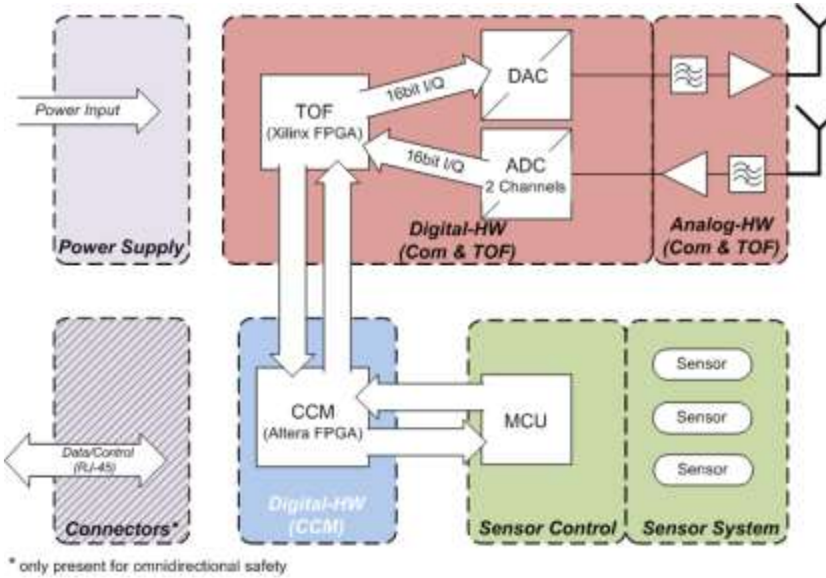
Architecture of the Localization Unit

- TOF Components [TUM]
  - digital hardware implemented in a Xilinx Spartan
  - relative distance measurements to remote objects using Time of Flight (TOF) method
  - analog Radio Frontend used for communication and ToF measurements
- AOA Components [IIS]
  - digital Hardware implemented in a Xilinx Spartan and an Analog Devices DSP
  - Angle of Arrival (AOA) Measurements
  - analog radio frontend with an 2D antenna array used for AoA measurements
- Communication & Control Module (CCM) [sizedn]
  - network communication & management (incl. security, privacy, address management …)
  - implemented on an Altera ArriaIIGX FPGA
  - control and coordination of TOF and AOA sub modules
  - external reference clock for synchronization of spatially distributed OBUs
  - communication to the Fusion Unit (FU) via Ethernet and LocON protocols



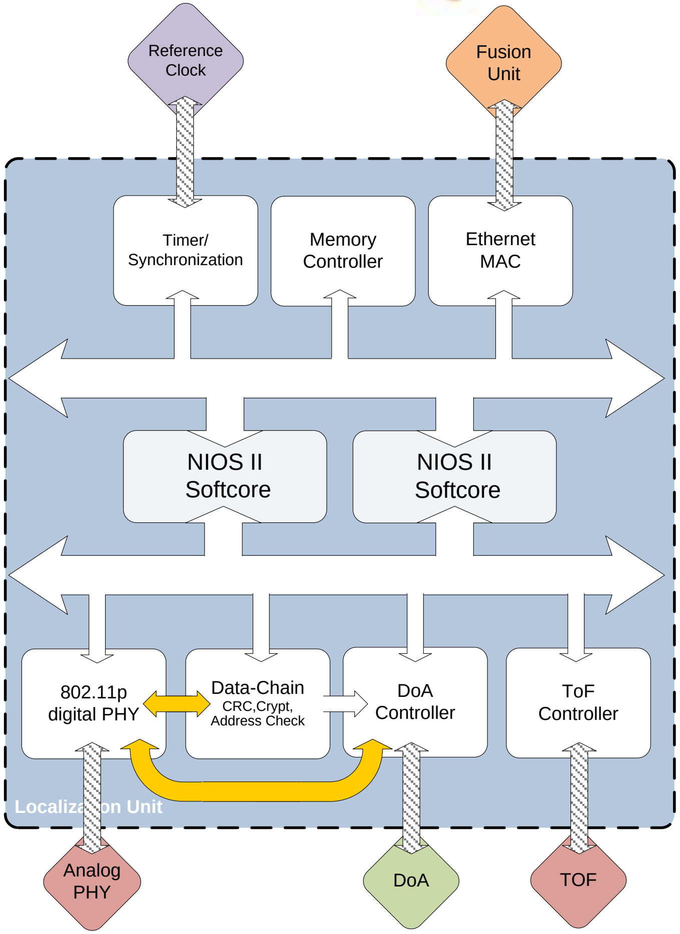
Architecture of the SafeTAG

- TOF Components [TUM]
  - digital hardware implemented in a Xilinx Spartan
  - reply to TOF requests at the specified time slot
  - analog radio frontend used for communication and TOF measurements
- Sensor Control [IIS]
  - access to several local sensors
  - communication with the CCM via a serial Interface and a reduced LocON protocol
  - determination of movement patterns
- Communication & Control Module (CCM) [sizedn]
  - network communication & management (incl. security, privacy, address management …)
  - implemented on an Altera ArriaIIGX FPGA
  - control and coordination of TOF
  - control and coordination of sensor



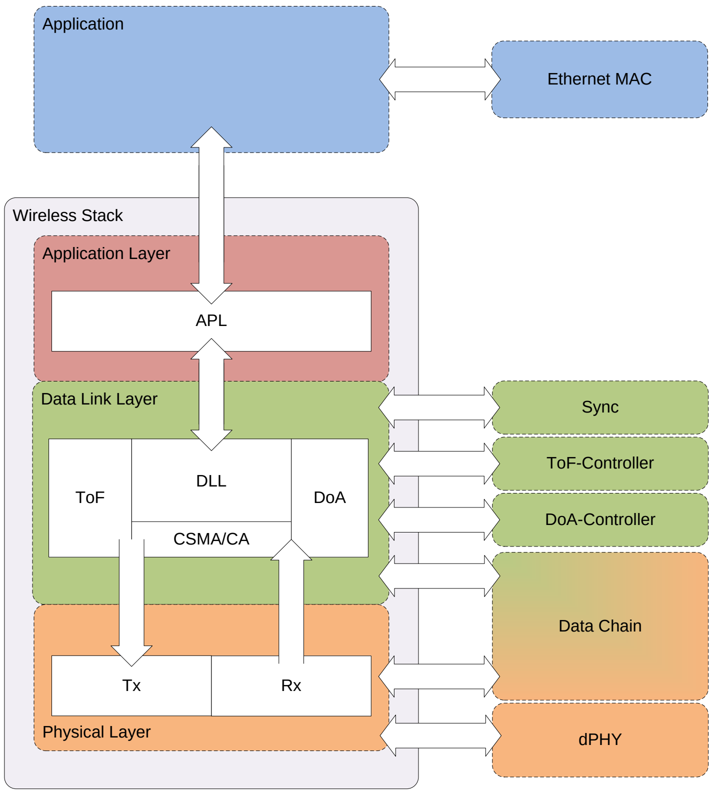
Design of the Localization Unit's CCM

- NIOS II Soft-core Dual-Core CPU
  - network management
  - coordination and control of the single IP-Cores and external sub modules (e.g. TOF, AOA)
- Timer/Synchronization
  - synchronization of spatially distributed OBUs via external Reference Clock (e.g. GPS)
  - provides Timer/Counter in synchronized mode
- Gigabit Ethernet MAC
  - interconnect to FU
  - debug and monitoring interface during development & integration process
- Localization Controller (TOF, AOA)
- Data Chain
  - interconnects CPU (Firmware) and dPHY
  - Automated frame check (CRC ,address validation)
  - en-/decryption of data frames
- IEEE 802.11p digital PHY (dPHY) [HHI]
  - baseband modulation conforming to the IEEE 802.11p standard for Car2X communication



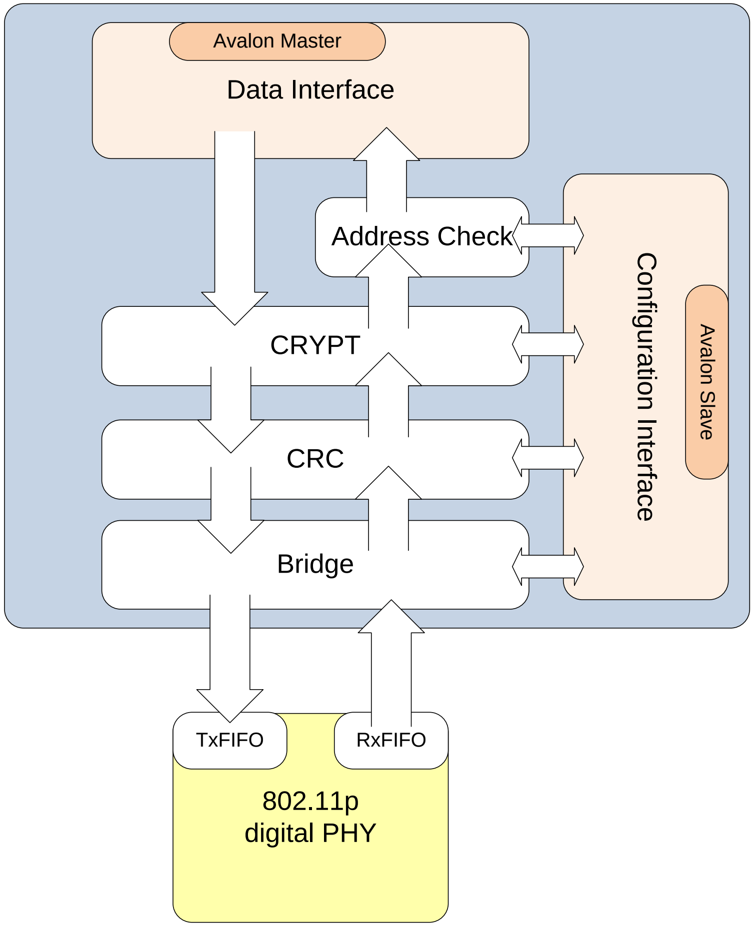
Software Design

- Wireless Communication Stack
  - covers physical layer (PHY), Data Link Layer (DLL) and Application Layer (APL)
- Application
  - interconnection between LU and FU
  - data transmission
- Application Layer
  - data transmission
  - user prioritization
- Data Link Layer
  - network management (e.g. connection tables, state machines)
  - configuration of the Data Chain for address checking
  - medium access (time slots, CSMA/CA)
  - TOF and AOA management
  - synchronization using the Synchronization IP-Core
  - handling of communication frames
- Physical Layer
  - driver for the buffer descriptor interface to the data chain
  - implements register access to configure the dPHY (e.g. channel, operation mode …)



Data Chain Components

- Interconnects dPHY and CPU and therefore the firmware.
- Avalon Slave Interface
  - configures the single blocks of the data chain
- Avalon Master Interface
  - Direct Memory Access using a Buffer Descriptor Interface
  - provides simple read/write functions to the user firmware
- Data En-/Decryption of user sensible data
- CRC calculation/validation
- Address Checking on Rx path
  - cnfigurable due to the flexibility of the wireless protocol (e.g. in number of addresses, length or positions in the frame)
- Bridge to the dPHY FIFO and Control interface



Wireless Data Communication – Technical Constraints

- Robust transmission even in difficult radio channel environment
  - time varying multipath radio channel with LOS / OLOS / NLOS
- High receiver sensitivity for maximum communication range at limited transmit power
  - coherent transmission scheme
- High data rate at high spectral efficiency
  - sufficient information throughput even at high user density
- Standardized PHY layer communication technology
  - interoperability with other C2X systems
  - easier system industrialization

Digital Transceiver Development and Implementation Approach

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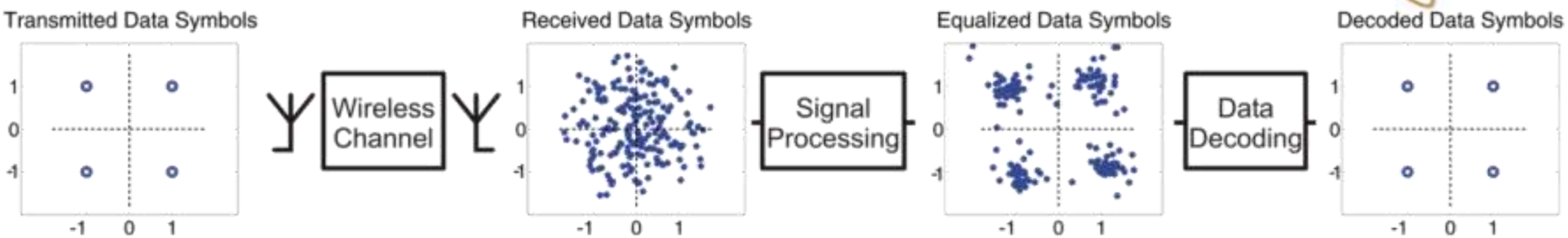
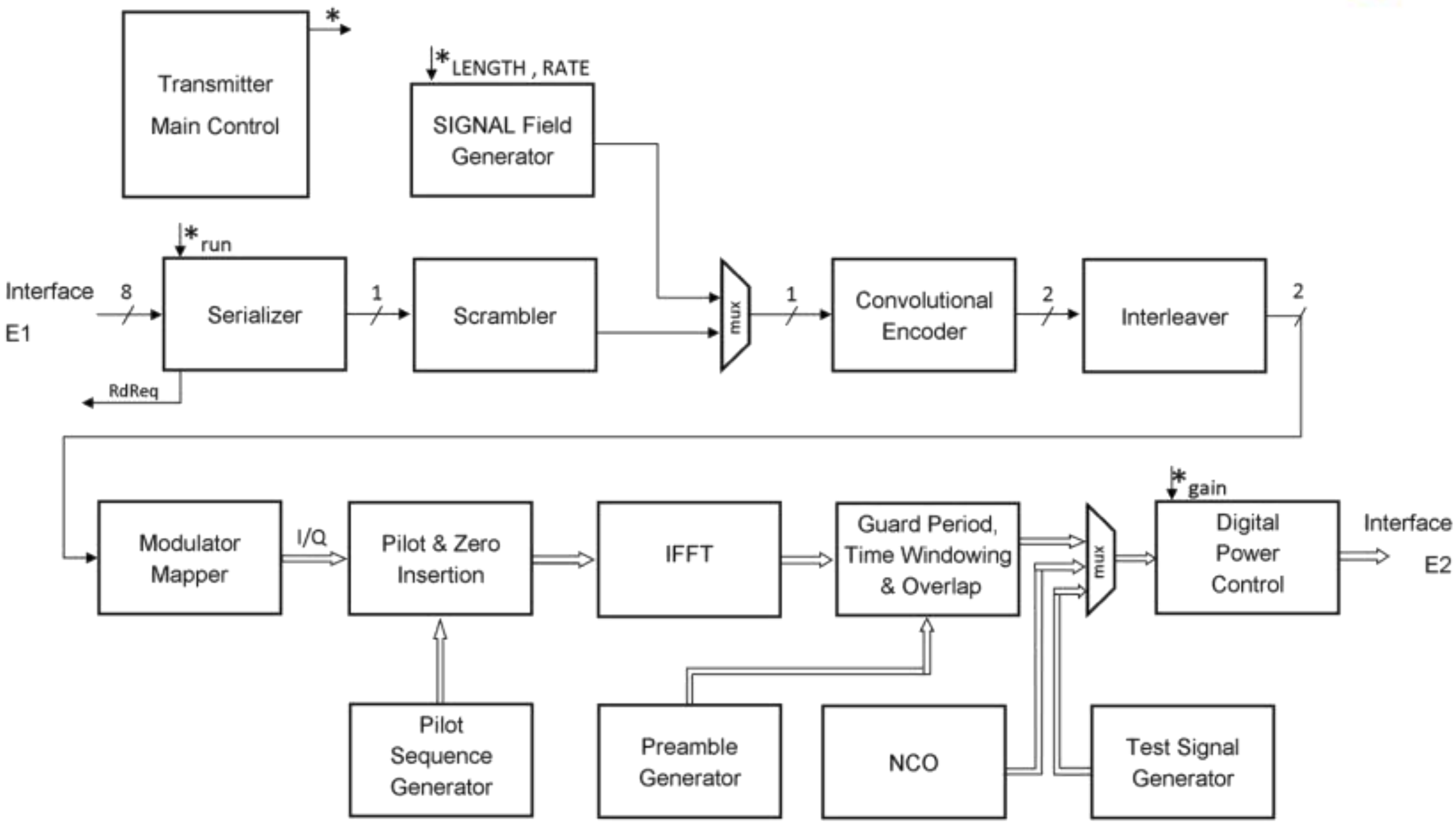
- A PHY transmission mode of the IEEE 802.11p Car-to-X communication standard has been selected for application
  - OFDM, QPSK modulation, FEC code rate ½, data rate of 6 Mbit/s
- Signal processing procedures are implemented on FPGA platform utilizing high level design tools for maximum productivity
  - IP core designation: dPHY
  - dedicated interface definition to support system integration
    - multi mode and multi purpose RF frontend, dedicated MAC processor
  - additional transceiver functions for
    - convergence of data transmission and angle-of-arrival (AOA) estimation
    - signal monitoring and debugging

Fundamentals of the Wireless Transmission Scheme

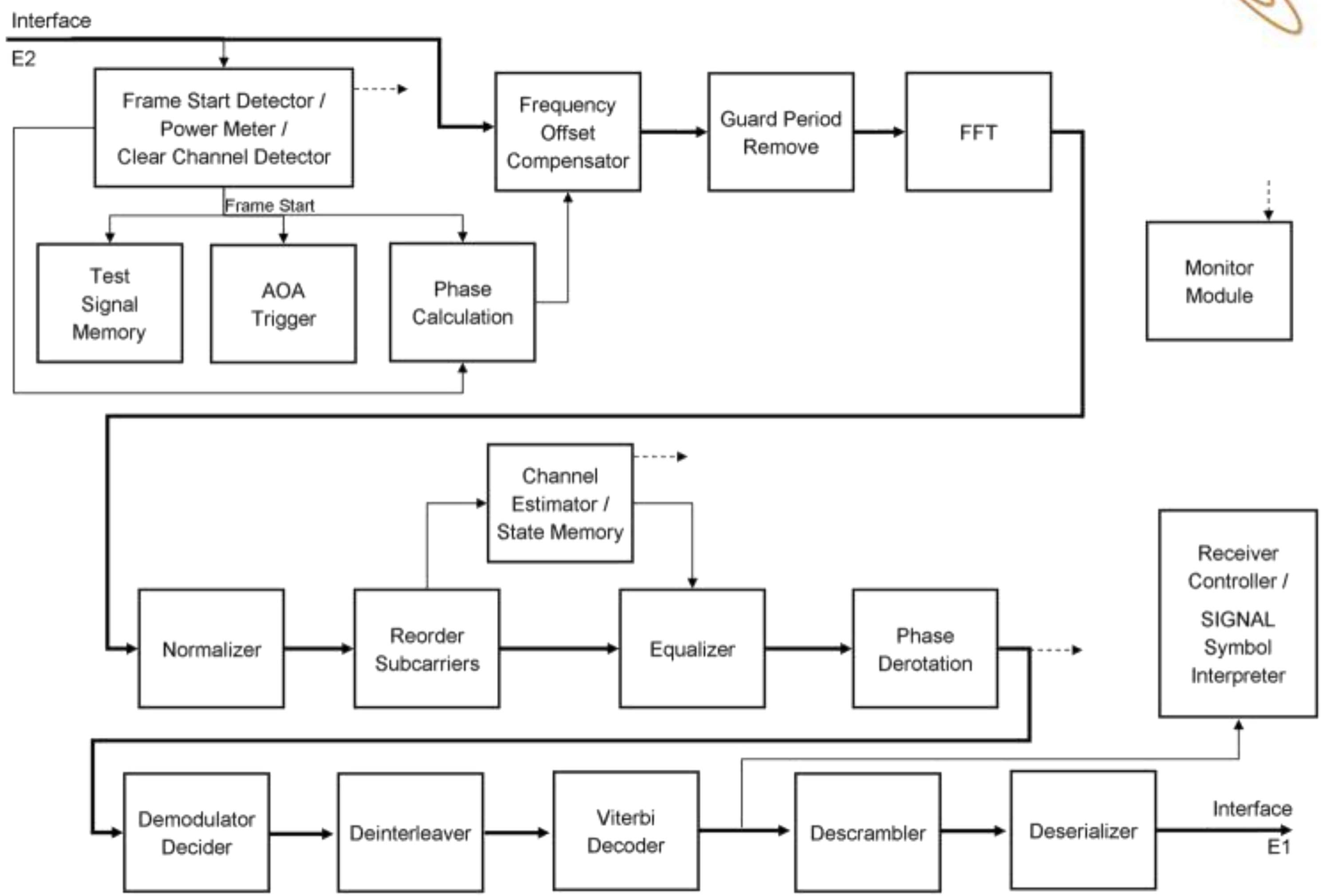


- Multipath radio channel
  - signal- and symbol distortion
- OFDM (Orthogonal Frequency Division Multiplexing) with Cyclic Prefix (CP)
  - CP against inter symbol interference (ISI) and suppression of signal transients
  - convolution theorem of time discrete signals can be applied for frequency domain channel correction of the sub-carriers
  - severe variations of the channel transfer function cause error floor for un-coded transmission even at high SNR
  - forward error correction (FEC) for point-to-multipoint transmission
- Time variant radio channel
  - preamble of the communication frames for channel state estimation

Wireless Digital Transceiver Transmitter Structure

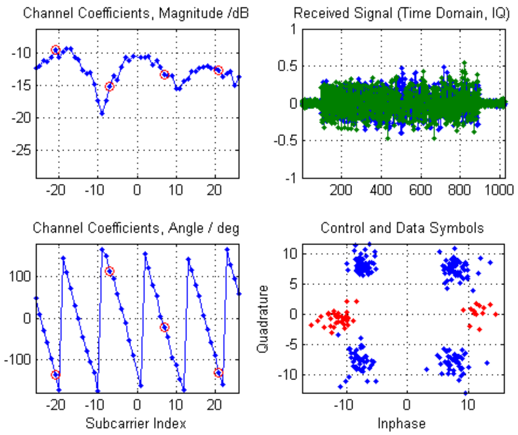


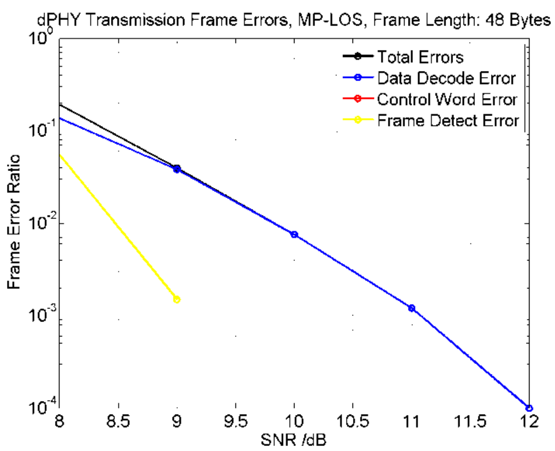
Wireless Digital Transceiver Receiver Structure

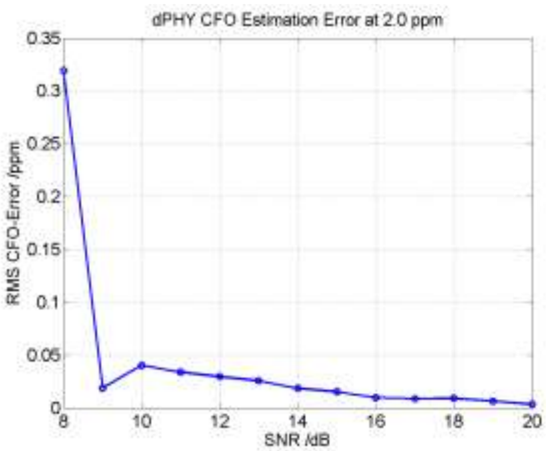


Transceiver Test Methods and Evaluation Results

1. Implementation of a digital real time channel emulator module for DSP evaluation without RF frontend effects
2. Transceiver tests on the HHI wireless platform HiRATE
3. Lab tests on the target platform (SIZEDN, TU-München)
4. Field tests of on-board units (OBU) and SafeTags



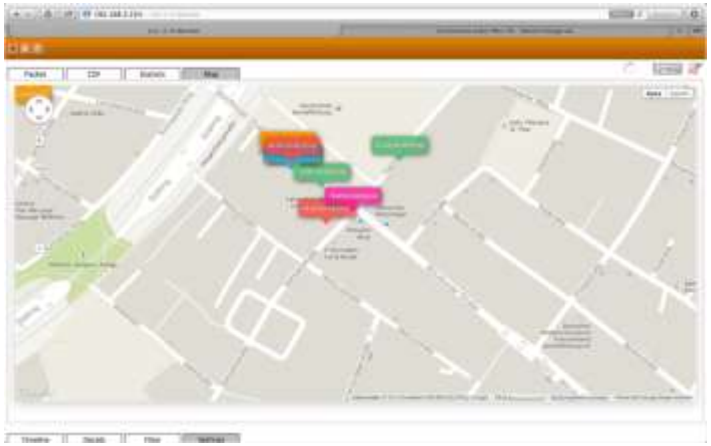




Interoperability with Ko-PER Communication Units

- The Ko-TAG wireless data communication transceiver uses the same communication standard as the Ko-PER/sim^{TD} communication units
  - different platforms
- The two communication systems are compatible on the physical layer (PHY)
  - communication tests between Ko-TAG transponder and Ko-PER/sim^{TD} CCU in both directions
  - field application for tracking Ko-PER vehicles with Ko-TAG transponder devices in reception mode
- The common PHY layer specification is prerequisite for interoperability in the same ITS frequency band
  - harmonization of the communication protocols is required

Ko-PER data packet analyzer on Ko-TAG platform

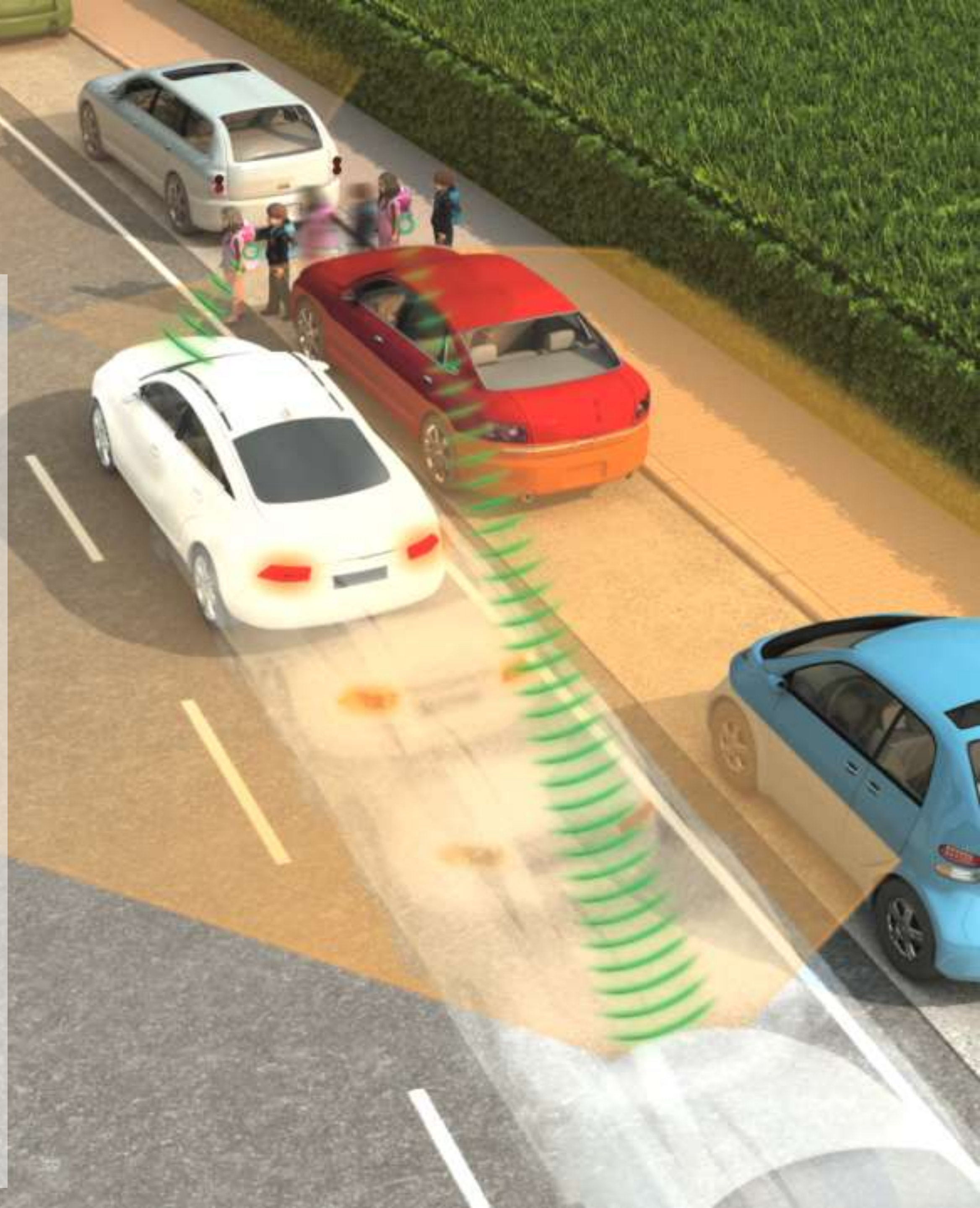


Ko-PER vehicle detector on Ko-TAG platform

Conclusions

- Modular system architecture allows easy reuse of components among different devices
- Reliable digital transceiver development and implementation for wireless Car2X data communication of Ko-TAG system devices was achieved
  - use of dPHY as IP-Core allows adaptation to fulfill system requirements and to improve system performance
- Communication interoperability with Ko-PER / sim^{TD} communication units (CCU) has been achieved
- A demonstration of the transceiver operation takes place tomorrow at the Ko-TAG pavilion (Flachstraße)
  - real time operation with visualization of wireless data communication and signal processing results

Thank you for your attention!



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