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A Hybrid MAC Layer for Localization and Data Communication in Ultra Wide Band Based Wireless Sensor Networks

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Manuel Janssen, Andreas Busboom, Udo Schoon, Carsten Koch, Gerd von Cölln

Hochschule Emden/Leer, Germany
University of Applied Sciences, Department of Informatics and Electronics
Email: {Carsten.Koch, Gerd.von.Coelln}@hs-emden-leer.de

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Outline

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- motivation
- system overview
- related MAC protocols
- proposed MAC layer solution
- evaluation results
- summary and outlook

Motivation

Context

- **Offshore operations:** part of research project SOOP - **S**afe **O**ffshore **OP**erations
- contribution to the industrialization of offshore wind energy
- **today:** manual process monitoring (TETRA radio, visual, . . .)
- system architecture as base to generate an overview of the operation
- wireless sensor network (WSN) for communication and localization under harsh environmental conditions

SOOP
Sichere Offshore-Operationen

Dieses Projekt wird mit Mitteln des Europäischen Fonds für regionale Entwicklung gefördert.
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Motivation

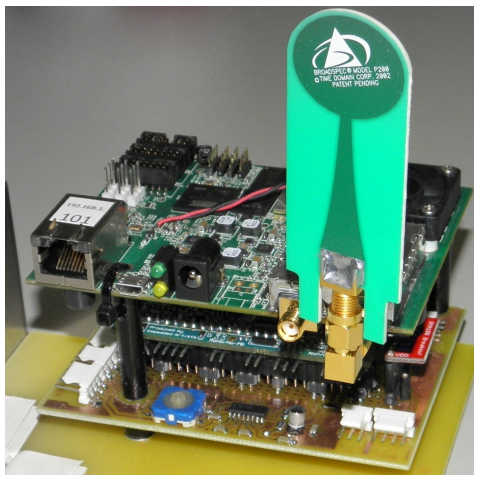
Wireless Sensor Network

- most available approaches either focus on:
  - **localization** (e.g. Active-RFID networks) **or**
  - **communication** (e.g. ZigBee networks)
- required is a combination of both with a rugged radio link for industrial applications
  - in our case: rough maritime environment
- due to the strong requirements
  - decision of the right radio technology felt on **Ultra Wideband (UWB)** [5]
- approach can be easily mapped to many problems in the industries

Components

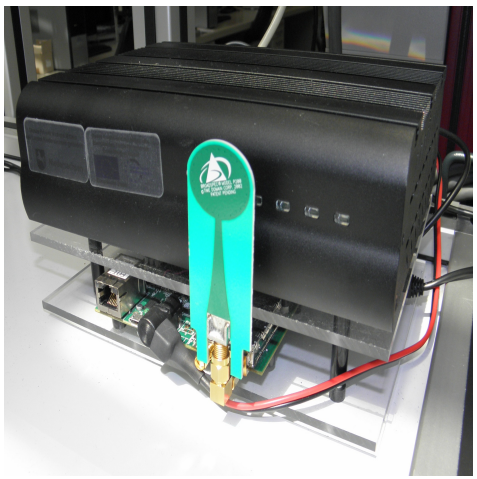
Mobile node (Slave)

- wireless transceiver module
- baseboard with processing unit and sensor interfaces
- NMEA wrapper



Gateway (Master)

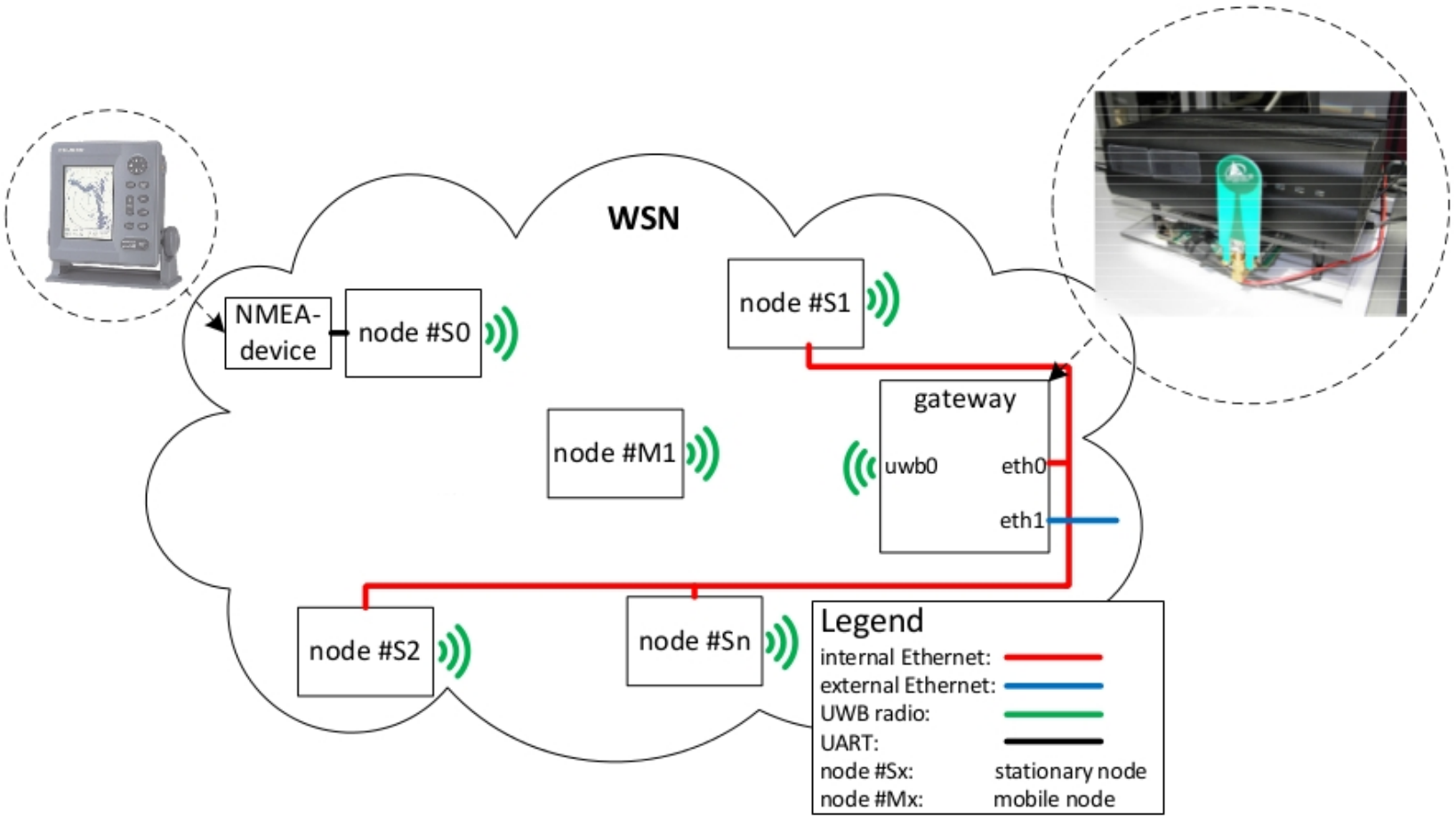
- wireless transceiver module
- IPC connected to a wireless transceiver
- can also be a mobile node



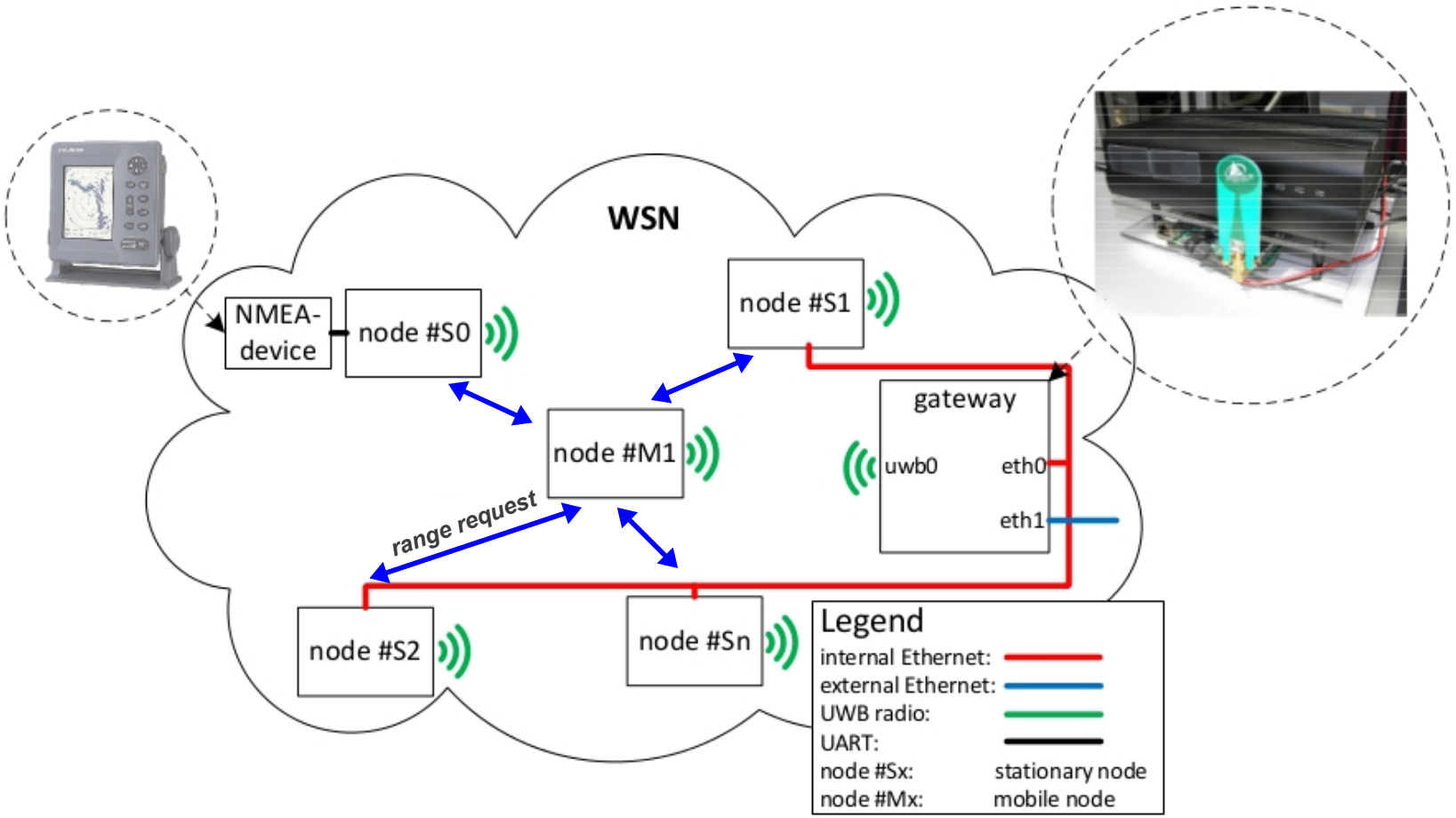
Stationary node (Anchor)

- wireless transceiver module

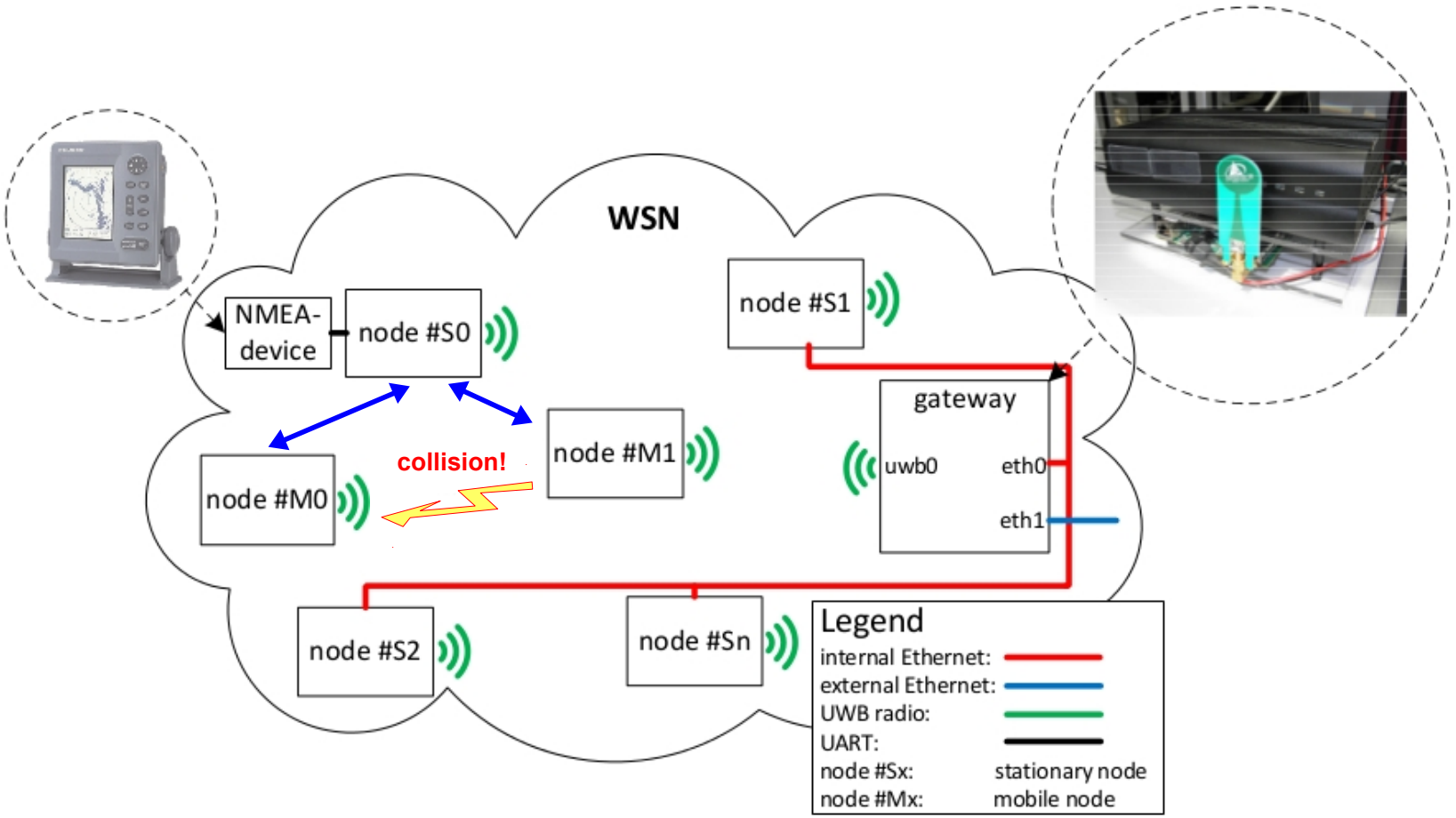
WSN architecture



WSN architecture



Challenge


WSN
NMEA-device
node #S0
node #S1
gateway
uwb0
eth0
eth1
node #M0
collision!
node #M1
node #S2
node #Sn
Legend
internal Ethernet:
external Ethernet:
UWB radio:
UART:
node #Sx: stationary node
node #Mx: mobile node

Classical methods

Channel based (contention free) [2]:

- FDMA - Frequency Division Multiple Access
- TDMA - Time Division Multiple Access
- CDMA - Code Division Multiple Access

Packet based (contention access) [2]:

- ALOHA, Slotted ALOHA, ...
- CSMA/CD, CSMA/CA, ...
- Token Ring, ...

IEEE 802.15.3 MAC

IEEE 802.15.3 MAC

- supports additional physical layers such as Ultra Wideband (UWB)
- centralized beacon enabled protocol [1]
- based on a time-slotted superframe structure [4]

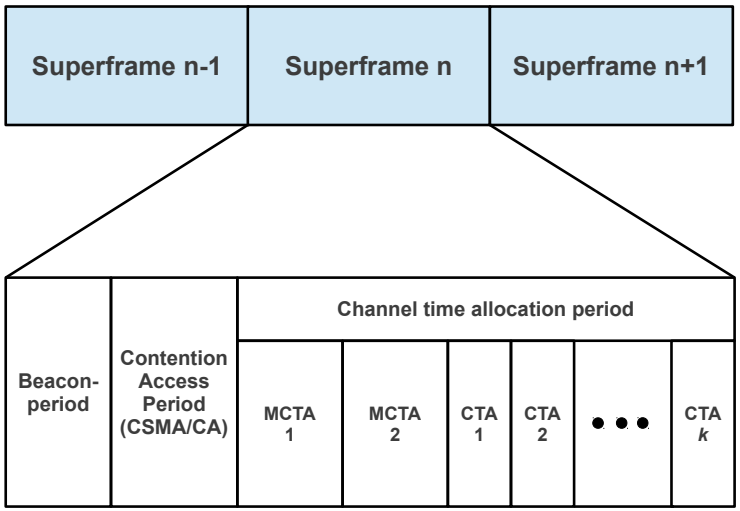


Figure: the IEEE 802.15.3 time-slotted superframe structure

Protocol structure

Properties

- replaced contention access period by contention free period
- cause CSMA/CA could be a difficult task in UWB-WSNs [3]
- also it is non deterministic and unsuitable for time critical applications
- fully collision free and predictable multiple access
- combines TDMA and CDMA
- enables simultaneous channel access

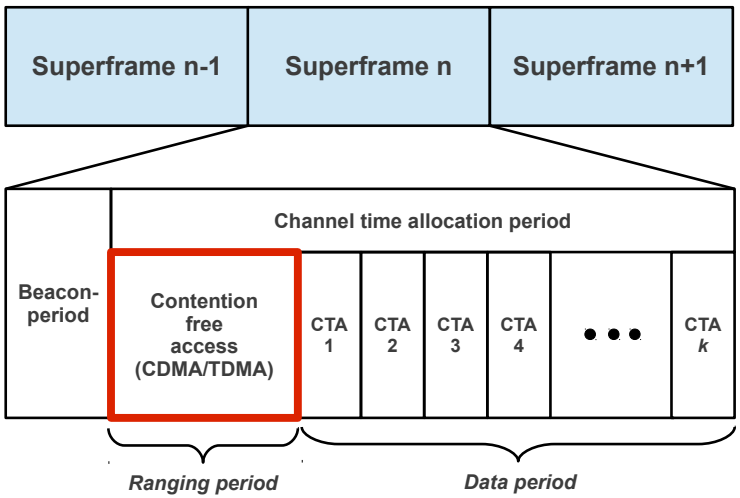


Figure: modified time-slotted superframe structure from the IEEE 802.15.3 MAC

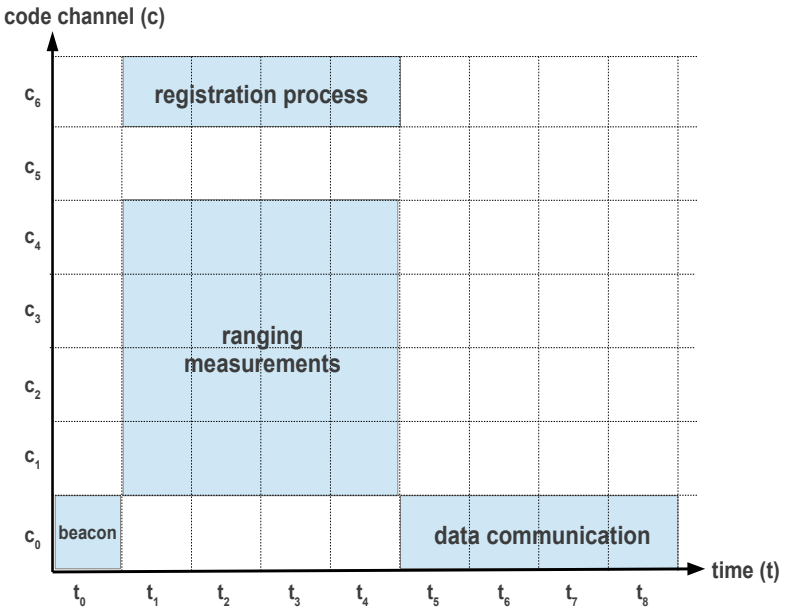
Slot configuration

Structure

- two-dimensional slot configuration
- m-time slots $*$ n-code channels

Different stages

1. beacon period
2. ranging period and registration process
3. data period



Slot duration

- ranging slot $= 40ms$
- data slot $= 60ms$

Scheduling and slot assignment

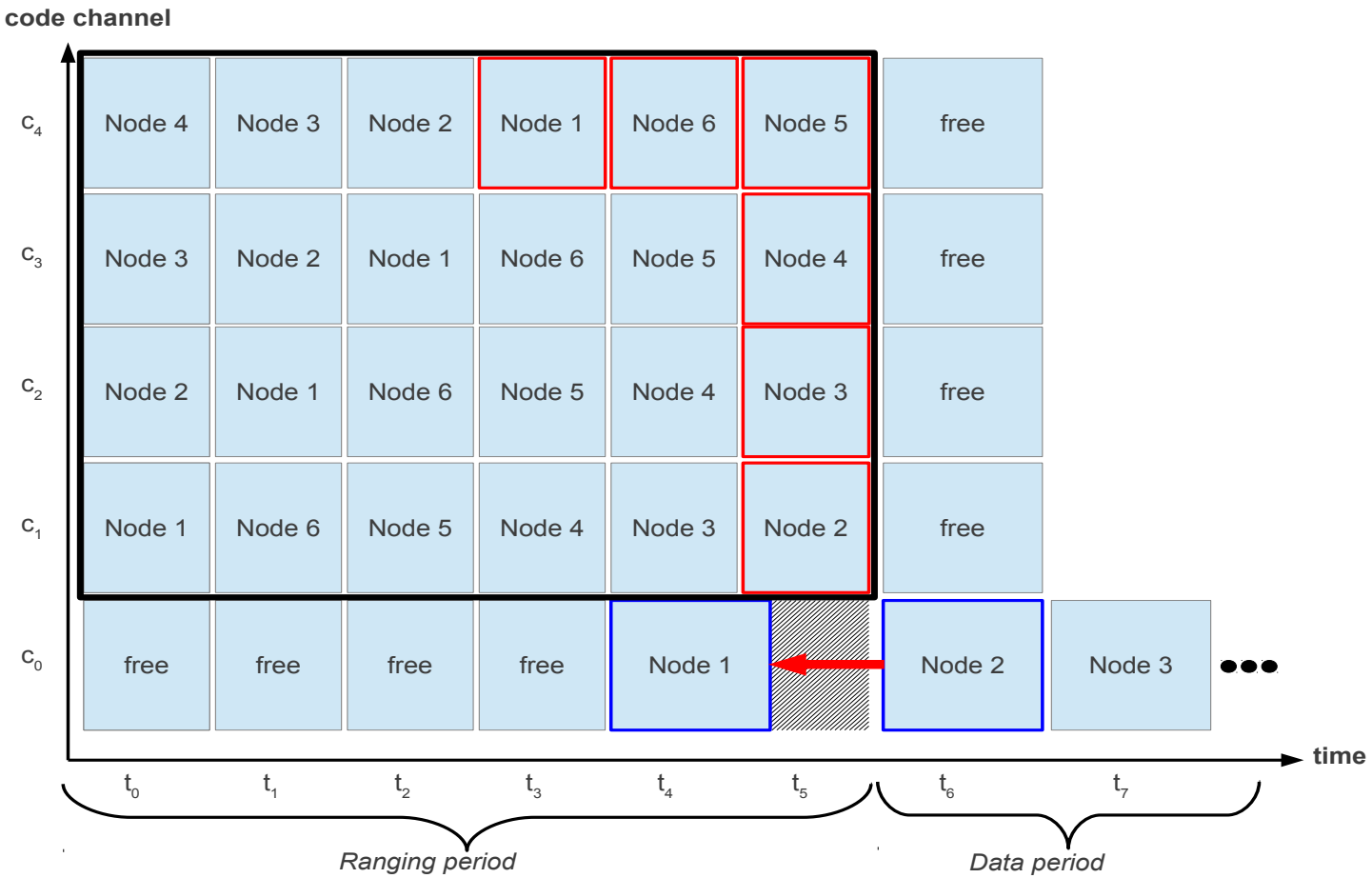


Figure: Scheduling segment with 6 mobile nodes (slaves)

Communication flow

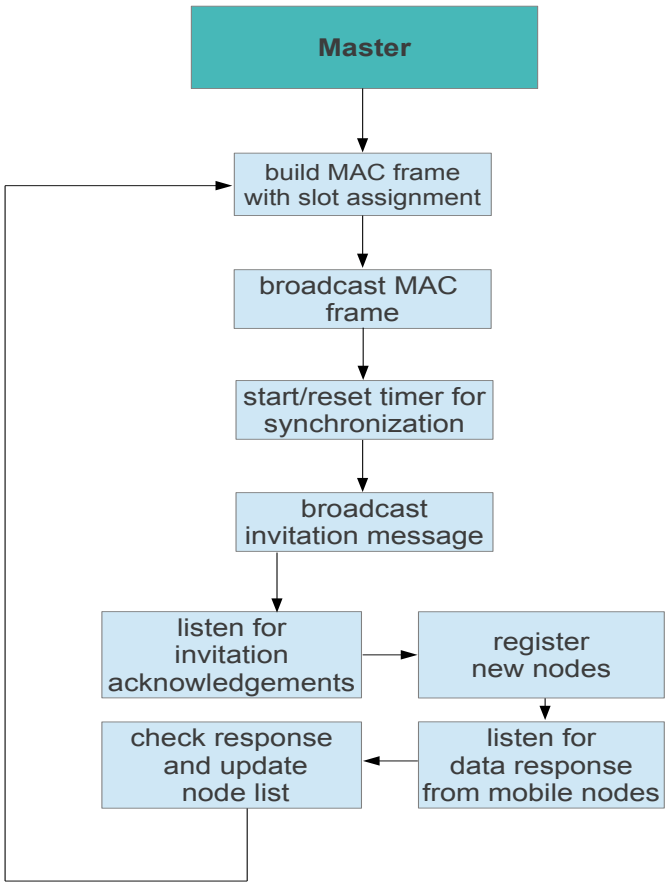


Figure: flow chart of the gateway (master)

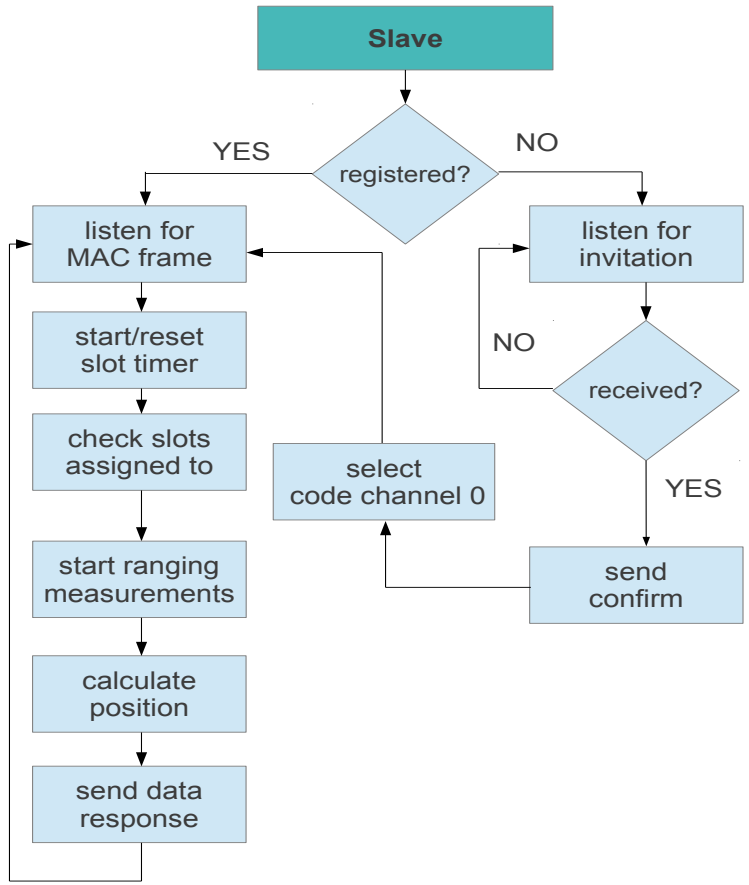


Figure: flow chart of a mobile node (slave)

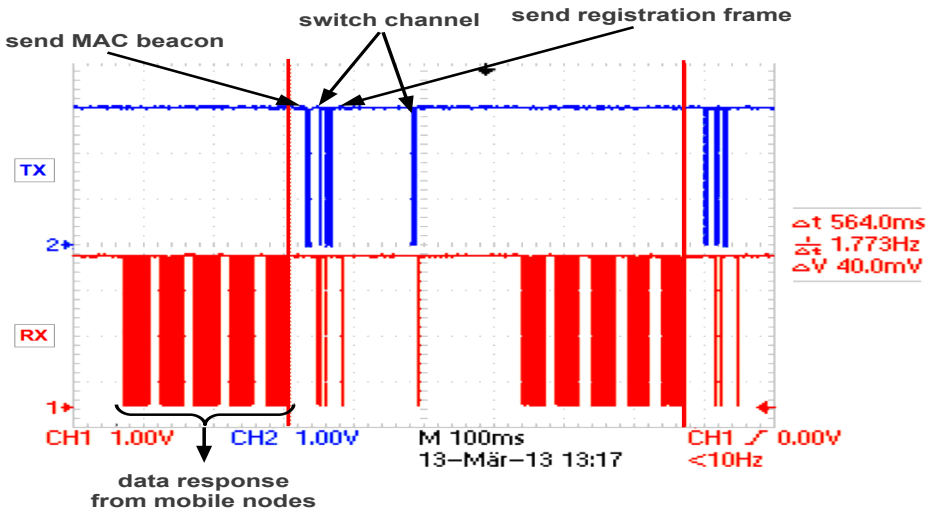
Evaluation results

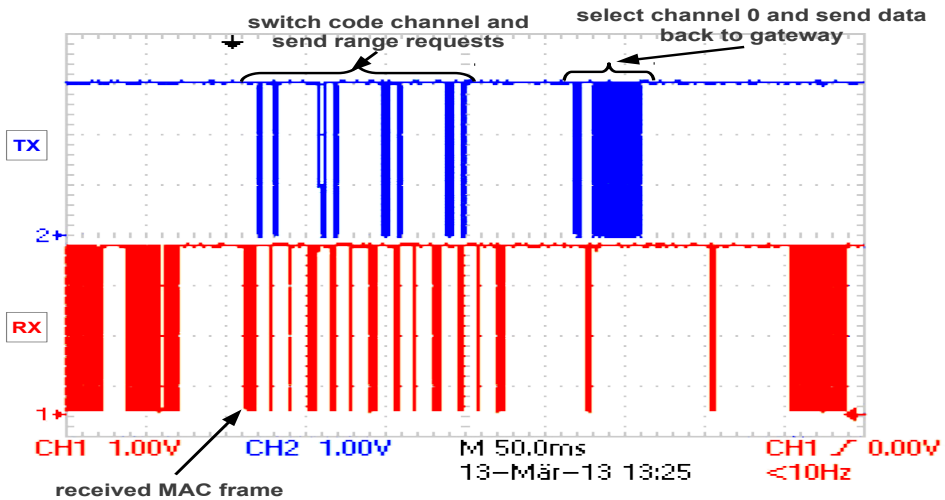
Network setup

- one gateway station (master)
- five mobile nodes (slaves)
- four stationary nodes (anchors)

Results

- totaltime of $564\ ms$
- update frequency of $\approx 1.8\ Hz$
- twice as fast as compared to classical methods like TDMA ($1136\ ms \approx 0.9\ Hz$)





Summary and outlook

The aim of the paper was to present a new efficient MAC layer for UWB based WSNs which combines **localization** and **data communication** for industrial applications

Summary

- propose of an efficient MAC layer for industrial applications
- possibility of simultaneous channel access
- overcomes limitations of related MAC protocols
- scalable depending on the network configuration
- verification of performance by comparison to classical methods (TDMA)

Outlook

- decrease power consumption by extend sleep modes in unused slots
- currently working on a multi master architecture to ...
  - increase the network range
  - enhance the reliability of the whole network system
  - optimization of sequential data period

Literature

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Duration of each superframe

The total time of each superframe is:

- $t_{sf} = B + R + D$
  - **B** is the duration of the beacon period ($\approx 36\ ms$)
  - **R** is the duaration of the ranging period (assumption: $r \iff c$)

$$t_{rp} = \begin{cases} 4 + (r-4) * t_{r_{slot}} & , \ 0 < m \leq 4, \\ \frac{r*m}{c} * t_{r_{slot}} & , \ m > 4 \end{cases}$$

  - **D** is the duration of the data period:

$$t_{dp} = m * t_{d_{slot}}$$