System Architecture for Data Communication and Localization under Harsh Environmental Conditions in Maritime Automation

IEEE 10th International Conference on Industrial Informatics
Beijing, China

Thorsten Wehs, Manuel Janssen, Carsten Koch, Gerd von Cölln

Hochschule Emden/Leer, Germany
University of Applied Sciences, Department of Informatics and Electronics
Email: {koch, coelln}@technik-emden.de

27. July 2012

Outline

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- motivation
- system overview
- radio technology
- experiment and performance
- summary and outlook

Motivation

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) which combines communication and localization for harsh environmental conditions

SOOP
Sichere Offshore-Operationen

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

Wireless sensor network

- most available approaches focus on localization **or** communication
  - Active-RFID networks $\Rightarrow$ good localization
  - ZigBee networks $\Rightarrow$ good communication
- usage of a rugged radio link for industrial applications
  - use case: rough maritime environment
- approach can be easily mapped to many problems in the industries

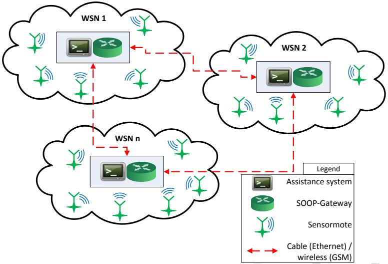
Overall architecture

Mission assistance

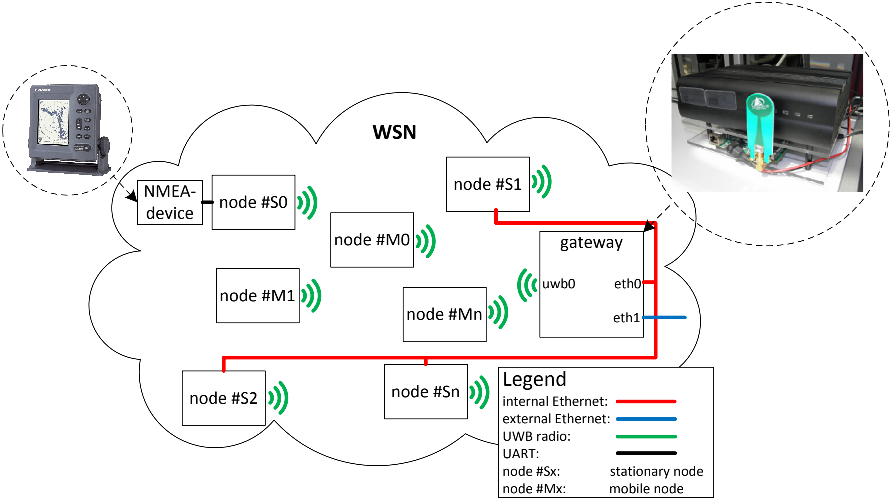
- distribution of wireless sensor nodes to mobile and stationary parts on vessels
- a gateway concentrates whole sensor data
- assistance system determines possible hazards and warns the crew [3]

Clustering

- interconnection of independent WSNs on
  - very huge vessels
  - supply and jack up vessels
  - ...



WSN architecture



Sensor node

Features

- wireless transceiver module
- decentralized localization technique
- NMEA device wrapper
- interface for sensors
- communication via SCAI protocol [2]

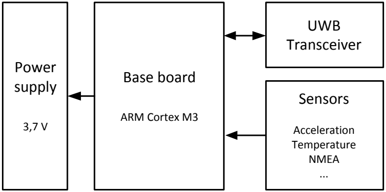


Figure: block diagram of the sensor node

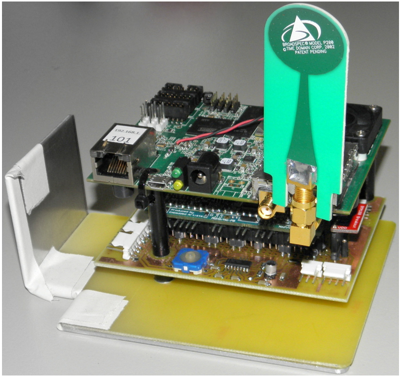


Figure: prototypical sensor node (stacked, power supply not shown)

State of the art

Some popular technologies

- WLAN (IEEE 802.11)
- IEEE 802.15.4 (Zigbee, WirelessHart, ISA 100.11a) [1], [7]
- Chirp Spread Spectrum (CSS) [4]

	WLAN	IEEE 802.15.4	CSS	UWB
Frequency band [GHz]	2.4/5 (ISM)	2.4 (ISM)	2.4 (ISM)	3.1 - 5.3
Range [m]	30-100	220-250	$>$ 800	88
Low Energy	-	+	o	+
Data Rate	300 mbps	250 kbps	250 kbps	159 kbps
Robustness	-	o	o	+
Distance determination	few meters	1-2 meter	sub meter	$<$ 7 cm

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- robustness in harsh environmental conditions and
- precise distance estimation for precise localization,

there is only one solution

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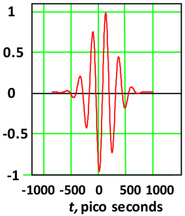
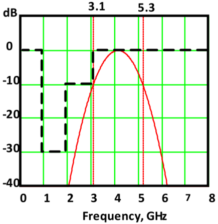
there is only one solution - **Ultra Wideband (UWB)**

Ultra Wideband

Features

- no carrier waves ⇒ pulse based
- very short duration pulses ($\approx 500\,$ps)
- frequency bandwidth: $2.2\,$GHz
- only about $50\,\mu$W transmit power [5]
- causes no interferences to existing radio systems
- high accuracy distance determination [5]
  - $\approx 3\,$cm in line-of-sight (LOS)
  - $\approx 7\,$cm in moderate non-line-of-sight (NLOS)





Experiment and performance

- measurements in comparable environments

	LOS		NLOS (heavy metal obstructions)		NLOS (25 cm reinforced concrete wall)	
Ground truth [cm]	100	600	100	600	100	600
Mean [cm]	101	599	106	594	137	629
Median [cm]	103	600	110	602	140	629
Std. deviation [cm]	4.1	3.2	7.8	8.4	4.5	1.9
Min [cm]	87	588	77	552	127	620
Max [cm]	104	604	113	606	143	632
Failures [%]	2	0	0	0	1	1

Table: 100 single measurements for each scenario and distance were performed

Summary and outlook

The aim of the paper was to depict a new approach for wireless sensor networks which combines **localization** and **communication** for industrial applications

Summary

- basic architecture for offshore localization and communication system conceived
- prototypical hardware system for outdoor and indoor localization
  - sensor node: up to 80 m distances
  - gateway: SCAI protocol implemented
- verification of UWB as robust radio technology
- promising measurement results (≈ 8 cm even in heavy NLOS)

Outlook

- LOS/NLOS detection
- NLOS compensation
- scaling the number of nodes
- algorithm optimized reference node positioning

Literature

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Technical report, OFFIS - Institute for Information Technology, 2011.

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Security analysis for offshore operations, 2011.

[4] Dr. Frank Schlichting.
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[5] Time Domain.
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[6] W. S. Murphy, Jr. and W. Hereman.
Determination of position in three dimensions using trilateration and approximate distances.
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[7] R. S. Wagner and Richard J Barton.
Standards-based wireless sensor networking protocols for spaceflight applications, 2010.

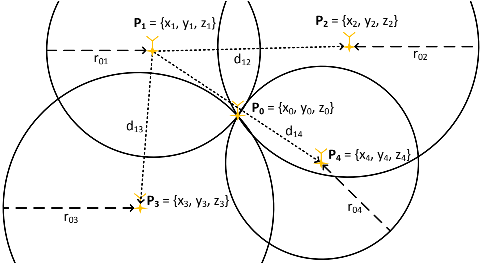
Localization

Method: lateration (no angles!)

- known positions: $\{\mathbf{P_1}, \ldots, \mathbf{P_4}\}$
- unkown position: $\mathbf{P_0}$

Three phases algorithm

1. determine distances $\{r_{01}, \ldots, r_{04}\}$
2. calculate distances $\{d_{12}, \ldots, d_{14}\}$
3. solve system of linear equations [6]



$$\begin{bmatrix} x_2 - x_1 & y_2 - y_1 & z_2 - z_1 \\ x_3 - x_1 & y_3 - y_1 & z_3 - z_1 \\ x_4 - x_1 & y_4 - y_1 & z_4 - z_1 \\ \vdots & \vdots & \vdots \\ x_n - x_1 & y_n - y_1 & z_n - z_1 \end{bmatrix} \cdot \begin{bmatrix} x_0 - x_1 \\ y_0 - y_1 \\ z_0 - z_1 \end{bmatrix} = \frac{1}{2} \cdot \begin{bmatrix} r_{01}^2 - r_{02}^2 + d_{12}^2 \\ r_{01}^2 - r_{03}^2 + d_{13}^2 \\ r_{01}^2 - r_{04}^2 + d_{14}^2 \\ \vdots \\ r_{01}^2 - r_{0n}^2 + d_{1n}^2 \end{bmatrix}$$

Gateway

Features

- suited for installation in a navigation bridge
  - retail x86 architecture
  - running linux OS
- coordination of the network
  - prioritization
  - fault detection
  - sensor node configuration
- sensor data preprocessing
  - plausibility check
  - aggregation to higher level informations
- provide data to assistance system

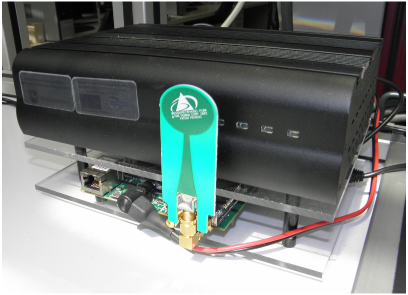


Figure: IPC connected with a sensor node (sensor node unstacked)