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Green & Smart Large Scale Wireless Sensor & Actuator Networks

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Background

Senior Research Scientist at Siemens Corporate Technology since 1996

Coordinator of WSAN activities at Siemens Corporate Technology since 2003 with contributions of up to 11 Global Technology Fields

Manager of Siemens contribution to EU project SOCRADES on SOA for industrial automation systems 2006-2009 (www.socrades.eu)

Project manager of research project ZESAN funded by German Ministry of Education and Research 2007-2010

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Applications - Examples

Product memory
- Decentralized production control
- Product self diagnostics for service
- Quality control in retail

Process monitoring & control
- Machine condition monitoring
- Distributed process monitoring
- Self-organized process control

Logistics support
- Freight condition monitoring
- Navigation on construction sites

Monitoring of cities and infrastructures
- Metering
- Condition monitoring
- Threat detection

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Typical Requirements

- Large networks with several 100 to many 1000 nodes
- Sometimes harsh environments or climate conditions
- Plug&play behavior
- Long battery lifetimes (2-12 years)
- Short latencies for critical messages like alarms
- Self-monitoring, self-healing
- Localization accuracy <1m to ~20m
- Changing network environment due to mobility
- Seamless integration into automation landscape

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Wireless Sensor & Actuator Networks – A Suitable Solution for Monitoring & Control?

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Benefit

- ✓ Avoids $100/ft - $2000/ft for wiring deployment
- ✓ Allows for deploy & run solutions
- ✓ Simplifies temporary installations
- ✓ Monitoring of mobile equipment becomes easier or possible at all
- ✓ Wireless HMI
- ✓ Distributed computing
- ✓ Localization services possible

Weaknesses

- ➢ Unreliable wireless links
- ➢ Long latencies in multi-hop networks
- ➢ Limited data rate
- ➢ As an open system wireless networks must guarantee interoperability with other networks and must be robust w.r.t. wireless attacks
- ➢ Finite battery lifetime adds additional maintenance costs
- ➢ Network planning, monitoring and management needed
- ➢ Limited localization accuracy

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Wireless Technologies for Large Multi-hop Sensor & Actuator Networks

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IEEE 802.15.4: Low power, low data rate PHY/MAC layer for sensor networks

IEEE 802.15.4a: Alternative PHY layers UWB and Chirp Spread Spectrum

ZigBee: Based on IEEE 802.15.4; adds networking, transport and application layer functionality; mainly applied in building automation

6LoWPAN: IPv6 on IEEE 802.15.4 low-power wireless networks

Wireless HART: Wireless extension of HART standard (same application layer); based on IEEE 802.15.4, but with TDMA (10ms time interval); frequency hopping (similar to Dust‘s TSMP)

ISA SP 100: Committee of appliers and suppliers for the development of a standard for wireless communication in field automation; will probably contain Wireless HART and/or 6LoWPAN

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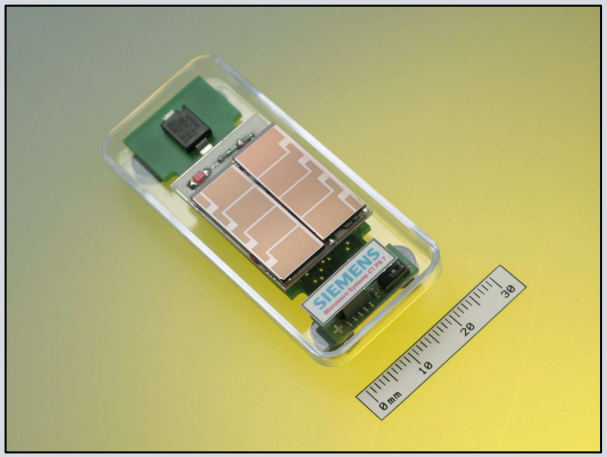
Micro-Energy Harvesting

Typical power consumption
- Sleep mode: ~ 10µW + P(Sensor)
- Radio on: ~ 10-40mW +P(Sensor)

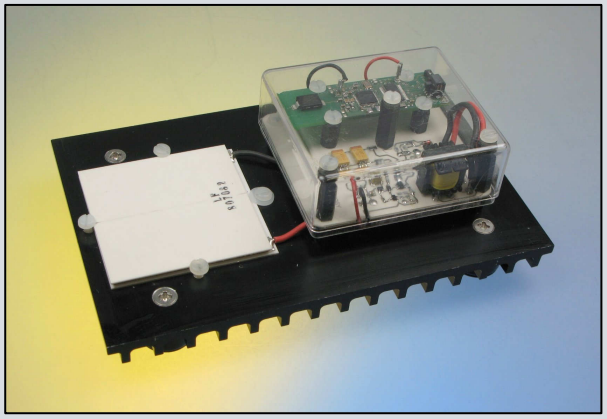
Solar cells
- Power: few µW/cm² (indoor, 200 lux) to few mW/cm² (outdoor, sunshine)
- For indoor no standard test conditions exist

Thermo-electric converters
- Power factor: ~ 1 - 50 µW/(cm² K²)
- Challenge: Getting rid of heat

Kinetic converters
- Inductive, capacitive, piezo-electric
- Power: ~10-500 µW/cm³
- Challenge: Often resonance conditions required



Wireless sensor with indoor solar cell: Cycle time of 118 s at 200 lux resp. 6,5 s at 4.000 lux



Wireless sensor with Peltier element: Cycle time of about 20 s at a temperature difference of 12 K

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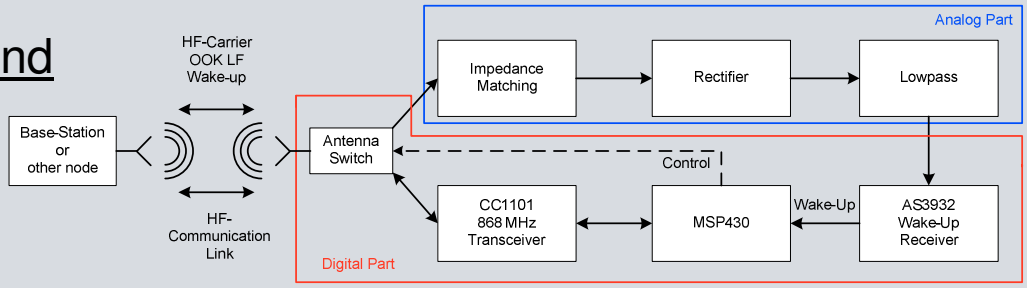
Wake-up Radio

Motivation: Long battery lifetime and short reaction times!



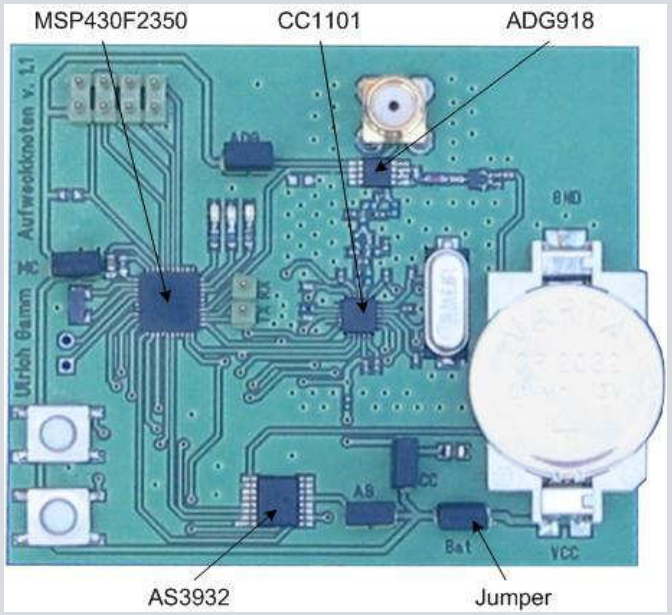
How does it work?

Amplitude modulation of 868MHz/2.4GHz signal with 125kHz. A low power 125kHz receiver detects this signal and wakes up the remaining modules.

Results

Sleep mode current: 2.7 µA

Wakeup range: 45m at 11dBm Tx power



Source: IMTEK, Univ. Freiburg

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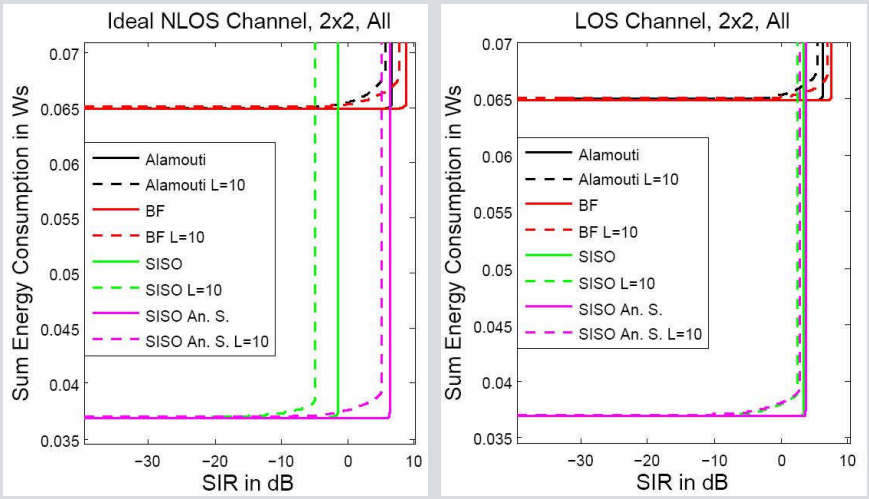
MIMO increases reliability

Multiple-antenna systems

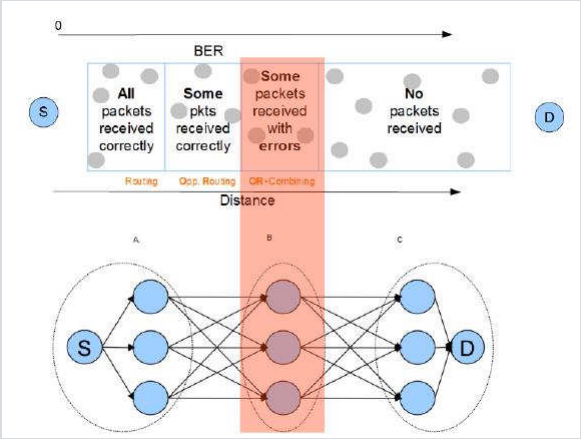
- SISO antenna selection: low power and improved reliability (NLOS)
- Further enhancements of reliability possible with advanced MIMO technologies like beam forming



Source: Fraunhofer German-Sino Lab for Mobile Communciation

Cooperative MIMO

- Cluster-based routing + packet combing + long jumps
- Improves reliability of long hops and thus reduces latency (relevant for alarm messages)



Source: TKN, Technical Univ. Berlin

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In-Network Processing

Motivation

- Transmitting raw sensor data to central processing unit leads to high traffic load for sensor nodes close to gateway
- Transmission of a IEEE 802.15.4 packet of 127 bytes requires about 150 µWs energy; the same energy can be used to execute ~800 elementary computation steps (multiplication plus addition)

Adaptive data transmission

- New data and a couple of forecasts are transmitted only if current data deviate too much from previous forecast
- Energy savings up to ~50% possible

Distributed inference

- Examples are regression or pattern matching
- Typically based on consensus or message passing protocols
- Drawback: Often whole network is involved in processing

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Vision

Wireless sensor & actuator networks will enhance our senses and range of active impact as they allow for large deployments at relatively low costs.

Self* behavior simplifies deployment and management significantly.

Interaction via requests like "report construction activities close to pipeline“ initiate automated search for appropriate SW components in the web to be downloaded and installed.

The networks automatically learn new or changing relations among and between sensings and actions.

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Recommendations

Decreasing energy consumption of sensors, transceivers and microprocessors.

More powerful and low cost energy harvesting and storage technologies.

Bio-analogue technologies for energy-harvesting (e.g. photo-synthesis) or communication (e.g. pheromones)

Protocols for energy efficient and reliable meshed MIMO networks.

Solutions for distributed inference which themselves can limit their activity within a relevant sensor network area and which can flexibly adapt the inference model to a possibly novel task.

Solutions and technologies for recycling of sensor nodes.

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