Wireless Sensor Networks
From Research to Reality

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Sensor Networks: The “Standard” (?) Applications (since >10 years)

- Gather information about unknown area
- Discover disasters early
- Detect structural damage
- Inject sensors in the human body
- Detect leakages
The typical (wireless) network is based on ...

- ... an infrastructure
  - PC in the Internet needs DNS, DHCP, default gateway, provider ...
  - Mobile phone (GSM, UMTS ...) needs base station, location register, switching systems, gateways ...
  - Mobile notebook needs WLAN hotspot, handover between hotspots, backbone infrastructure for administration ...

![Diagram of a network with various components such as PSTN, CS core, IP-based core, SS7 signalling, server farm, gateways, proxies, firewall, GGSN, gateway, broadcast, access points, private WPAN, public WLAN, private WLAN, router, RNC, SGSN, BSC, MSC, and GGSN gateways.](image)
What happens if there is no infrastructure left ...
... or it is too expensive to set-up an infrastructure?

- **Precision agriculture**
- **Environmental monitoring**
- **Vehicle protection**
Solution: Wireless Ad-hoc Networks

- Network without infrastructure
  - Use components of participants for networking

- Examples
  - Single-hop: All partners max. one hop apart
    - Bluetooth piconet, PDAs in a room, gaming devices...
  - Multi-hop: Cover larger distances, circumvent obstacles
    - Bluetooth scatternet, TETRA police network, car-to-car networks...

- The next step: Wireless Sensor Networks
Properties of Wireless Sensor Networks

- Sensor nodes (SN) monitor and control the environment
- Nodes process data and forward data via radio
- Integration into the environment, typically attached to other networks over a gateway (GW)
- Network is self-organizing and energy efficient
- Potentially high number of nodes at very low cost per node
Promising Applications for WSNs

• Machine and vehicle monitoring
  • Sensor nodes in moveable parts
  • Monitoring of hub temperatures, fluid levels ...

• Health & medicine
  • Long-term monitoring of patients with minimal restrictions
  • Intensive care with relative great freedom of movement

• Intelligent buildings, building monitoring
  • Intrusion detection, mechanical stress detection
  • Precision HVAC with individual climate

• Environmental monitoring, person tracking
  • Monitoring of wildlife and national parks
  • Cheap and (almost) invisible person monitoring
  • Monitoring waste dumps, demilitarized zones

• ... and many more: logistics (total asset management, RFID), telematics ...
  • WSNs are quite often complimentary to fixed networks!
The big Gap (?) - Research vs. Industrial WSNs

- Big hype in universities and research
  - Roughly since 8 years, many projects
  - Dozens of new conferences and workshops
  - Thousands of papers, simulations, algorithms...
- Industry adapts, but has different requirements
  - Robustness, reliability, robustness, reliability...
  - Low cost, interfaces to standard platforms, integration
  - CE, FCC, ETSI, RoHS, recycling... certificates

- Example
  - Berkely Motes/Crossbow: most successful research platform
    - different components, TinyOS/DB/..., simulator, few certified
  - Dust Networks (far from “dust”)
    - no real OS, high reliability, has to work everywhere, new design
Critical Questions

- **Do we need multi-hop wireless sensor networks?**
  - Sensor nodes may bridge > 1km if needed
  - Single hop by far more robust in reality

- **Do we have high mobility, very dynamic networks?**
  - Most sensor networks are static
  - Changes in topology typically due to failures

- **Do we focus on the right research issues?**
  - Computer Scientists tend to apply everything from “normal” systems to WSNs
  - Often theory only, far from reality

- **What are really the applications we should focus on?**
  - Good question ... up to now not really clear...
Example: ScatterWeb’s Industrial Components

- **Nodes**
  - Fully certified according to international regulations
  - Range > 1.5 km (LOS), > 500m in buildings
  - < 100µA while still running (no sensors, no RF)
  - Can drive external sensors up to 500mA (analog/digital)
  - SPI, serial, I²C, display, camera, joystick interfaces

- **Gateways**
  - Bluetooth, WLAN, Ethernet, serial, USB, RS485, GSM/GPRS, TETRA

- **Software**
  - Auto-configuration, GPS tracking, over-the-air programming, building monitoring, ...

- **Several other systems exist**

- **Examples from** www.scatterweb.com
Example: ScatterWeb’s Modular Sensor Board

- Modular design
  - Core module with controller, transceiver, SD-card slot
  - Charging/programming module
  - Sensor carrier module

- Software
  - Firmware (C interface)
  - TinyOS, Contiki ...
  - Routing, management, flashing ...
  - ns-2 simulation models
  - Integration into Visual Studio, Eclipse, LabVIEW, Robotics Studio ...

- Sensors attached on demand
  - Acceleration, humidity, temperature, luminosity, noise detection, vibration, PIR movement detection...
ScatterWeb Simulation on ns-2

- Real-world software on simulated Wireless Sensor Nodes
- Simulations of large sensor networks (>1000 nodes)
- Shorter development cycles
- Existing algorithms can be visualized
Example – Simple Directed Diffusion
Simulation of Data Dissemination

But is this reality?
Signal propagation ranges

- **Transmission range**
  - communication possible
  - low error rate
- **Detection range**
  - detection of the signal possible
  - no communication possible
- **Interference range**
  - signal may not be detected
  - signal adds to the background noise

- ... **but only in vacuum we have nice circles!**
Signal propagation

- Propagation in free space always like light (straight line)
- Receiving power proportional to $1/d^2$ in vacuum – much more in real environments ($d =$ distance between sender and receiver)
- Receiving power additionally influenced by
  - fading (frequency dependent)
  - shadowing
  - reflection at large obstacles
  - refraction depending on the density of a medium
  - scattering at small obstacles
  - diffraction at edges
Real world example
Multipath propagation

- Signal can take many different paths between sender and receiver due to reflection, scattering, diffraction

- Time dispersion: signal is dispersed over time
  - interference with “neighbor” symbols, Inter Symbol Interference (ISI)
  - The signal reaches a receiver directly and phase shifted
    - distorted signal depending on the phases of the different parts
Question

• How much worth are algorithms, calculations, protocols, statistics... based on the simple and convenient assumption of circular transmission ranges?

• Many papers simplify this way and present x% performance gain...

• Many authors simply believe in homogeneous signal strength, bidirectional links...
  • Yes there are much better models – but harder to handle!

• Does this help?
  • Maybe if we know the limitations of our models
  • Not if we simply ignore real systems & physics
Sensor Networks: Research Areas

- Real-World Integration
  - Gaming, Tourism
  - Emergency, Rescue
  - Monitoring, Surveillance

- Self-configuring networks
  - Robust routing
  - Low-power data aggregation
  - Simple indoor localization

- Managing wireless sensor networks
  - Tools for access and programming
  - Update distribution

- Long-lived, autonomous networks
  - Use environmental energy sources
  - Embed and forget
Embedded Development Today

• Programming for Wireless Sensor Networks today
  • Embedded Devices
  • Distributed Computing
  • C-Programming
  • Expert knowledge required!

• Better development support
  • Tool integration
  • Realistic simulation tools
  • Heterogeneous testbeds
  • Useful traces
  • Development strategy for heterogeneous systems

```c
void commRx(UINT8 temp) {
  if(commstate) {
    if(temp=='\r') return;    // filter out carriage ret
    if(temp=='\n') {          // line is complete
      SERIAL_STOP;            // set CTS to 1 to stop re
      buf[serial_pos] = '\0'; // terminate
      if(buf==serial_buf1) {   
        buf    = serial_buf2;
        serial_line = serial_buf1;
      }
      else {
        buf    = serial_buf1;
        serial_line = serial_buf2;
      }
      WAKEUPLPM1(usart1_rx, MF_SERIAL_RX);
      serial_pos = 0;
    } // END line complete
    else if(temp=='\b') { if(serial_pos>0) serial_pos--;
      else {
        if(serial_pos==SERIAL_BUFSIZE) return;  // c
        buf[serial_pos++]=temp;
      }
    }
  }
```
...
AppSN - Application Enablers for Rapidly Developed Sensor Networks

- **Goals**
  - enabling new applications and markets
  - robust and energy efficient hard- and software
  - integration into commercial applications and platforms
  - tools that enable more efficient development and deployment of WSNs

- **Participants**
  - SICS (Research Lab, Sweden, Coordinator)
  - CST Group at FU Berlin (University, Germany)
  - CRL (Communications Research Lab, SME, Sweden)
  - EGC (Electronics Guard Center, SME, Sweden)
  - Eightcut (SME, Sweden)
  - Ericsson MW (now Saab, Sweden)
  - ScatterWeb (SME, Germany)
Visual Studio Integration
Visual Studio Integration
Sample Application

- Rapid development using Visual Studio and ScatterWeb.NET SDK
- Goal: 3D visualization, access to the acceleration sensor
  - Proof of concept within minutes
  - SDK provides the sensor data over the WSN
  - Developers can focus on the task
Integration into MS Robotics Studio

- Integration of ScatterWeb sensor nodes into Robotics Studio
- Programming of sensor network using Visual Programming Language (VPL)
- Control of arbitrary robots via the sensor network
- msdn.microsoft.com/robotics/
LabVIEW

- Leading solution for Virtual Instrumentation
  - Graphical development
  - Measurement and control apps
  - Common in industry and electrical engineering
LabVIEW Integration

• Through .NET SDK
  • Easy access to .NET objects in LabVIEW
  • Reduced cost of maintenance
  • Additional LabVIEW look-and-feel components

• Direct access
  • For custom implementations
  • LabVIEW VISA through ScatterWeb RS-232/USB or LAN interface
  • Using ScatterWeb command language
Eclipse Development Platform

- Eclipse Platform
  - Mature Development Environment for Java and C
  - Broad community
  - Commercial, Noncommercial

- Programming interfaces
  - Java Technology
  - General direction as .NET SDK

- Integration in Eclipse environment
QMSB – Programming Sensor Nodes

- Tool adapted to ScatterWeb Modular Sensor Boards
- Simple graphical programming of the nodes
- Highly optimized code
- Completely free
Monitoring and Management Software

- Over-the-air reprogramming
- Auto-reconfiguration
- Topology control
- GUIs for XP, CE ...
Visualization of Sensor Information
Visualization of Sensor Information
Example Application: Scratching Detection

- Video surveillance system
- Cameras
- Radio gateway
- Direction of event forwarding
- Loudspeaker
- Detectors
Example Application: Building Monitoring

Monitored buildings near Stockholm

Integration into professional monitoring systems
Example Application: Temperature Measurement in the Baltic Sea

Sensor Network

GPRS wireless connection

Radio

Buoy with Sensors

Baltic Sea

Temperature Sensors

Weight/Anchor

Ground

Sweet Water
Chain of Sensors
Example Application: Monitoring of Construction Sites

- Replacement of fixed infrastructures
- Installation by layman
Experiment: Fence Protections
Sensor Integration
Event Detection

Different Types of Events (Raw Data)

- Kicking
- Shaking
- Peeking
- Climbing
- Leaning

Time (s) vs. Intensity Graph
Application Example: Bird Monitoring

Skomer Island / UK

Manx Shearwater
Combination of RFID and ScatterWeb

- Main challenge: robustness
- Joint project with Oxford University and MSRC
Robustness – the real Challenge of WSNs

- WSNs have to work – as simple as this sounds as complicated it is to achieve!
- Example: www.sensorgis.de
  - ScatterWeb collects temperature data from various sensor
  - GPRS at gateway
Monitoring Rocks in the Swiss Alps
Results
Project FeuerWhere

Data transmission & localization

- Mobile, self-organizing WSN
- TETRA trunked radio network
First Steps done, but still Open Issues

- Robustness and seamless integration
  - WSNs have to offer standard APIs (see .NET example)
  - WSNs have to work 24/7 (that includes a lot of self-x technologies)

- Better development support
  - Realistic simulation tools
  - Heterogeneous testbeds
  - Useful traces
  - Tool integration
  - Development for heterogeneous systems

- NOT
  - Yet another bizarre routing algorithm
  - Yet another simulation far away from reality

Tools for scientists and developers
Today’s WSNs

• Wireless sensor networks are available
  • Different sensor nodes, several gateways
  • Even with special sensors: cameras, body temperature...
  • Basic software
    • Routing, energy conservation, management

• Several prototypes for different applications
  • Environmental monitoring, industrial automation, wildlife monitoring ...

• Many see new possibilities for monitoring, surveillance, protection
  • Sensor networks as a cheap and flexible new means for surveillance
  • Monitoring and protection of goods
    • Chemicals, food, vehicles, machines, containers, ...
  • Large application area besides military
    • Law enforcement, disaster recovery, industry, private homes, ...
The Future of WSNs

- Fundamental requirements today only partially fulfilled
  - Long life-time with/without batteries
  - Self-configuring, self-healing networks
  - Robust routing, robust data transmission
  - Management and integration

- Think of new applications
  - Intelligent environments for gaming
  - ... <your idea here>

- Still a lot to do...
  - Integration of new/future radio technologies
  - Cheap indoor localization (+/- 10cm)
  - More system aspects (security, middleware, ...)
  - Prove scalability
  - Make it cheaper, simpler to use

- Already today: Flexible add-on for existing environmental monitoring networks