APPLICATIONS OF WIRELESS SENSOR NETWORKS

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Outline

- Wireless sensor networks
  - Why Use WSNs
  - Classification
  - Sensor Usage
- WSN Structures
- Maintenance Options
- WSN Requirements
Conclusion

- WSN are here to stay!
- It’s an interesting, complex, new technology
- Lots of research still to be done
- Applications are what is needed!
Outline

- **Wireless sensor networks**
  - Mote Anatomy
  - Wireless communication
- Potentiality VS Reality
- Market & Future
- Applications of WSN
Why Use sensors?
Sensor Classification

- **Readiness for field deployment**: measures maturity for field deployment in terms of economic and engineering efficiency.
- **Scalability**: a sensor’s scalability to distributed environmental monitoring tasks require that the sensors be small and inexpensive enough to scale up to many distributed systems.
- **Cost**: Sensors are deployed in thousands. It is expected that cost will drop but current generation sensors are still expensive to allow wide deployment.
  - For water quality monitoring, physical sensors are generally more field-ready and scalable than chemical sensors, which are, in turn, substantially more field-ready and scalable than biological sensors
## Sensor classification

<table>
<thead>
<tr>
<th>Sensor Category</th>
<th>Parameter</th>
<th>Field-Readiness</th>
<th>Scalability</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Physical</strong></td>
<td>Temperature</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Moisture Content</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Flow rate, Flow velocity</td>
<td>High</td>
<td>Med-High</td>
</tr>
<tr>
<td></td>
<td>Pressure</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Light Transmission (Turb)</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td><strong>Chemical</strong></td>
<td>Dissolved Oxygen</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Electrical Conductivity</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>pH</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Oxydation Reduction Potential</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Major Ionic Species (Cl-, Na+)</td>
<td>Low–Medium</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Nutrientsa (Nitrate, Ammonium)</td>
<td>Low–Medium</td>
<td>Low–High</td>
</tr>
<tr>
<td></td>
<td>Heavy metals</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Small Organic Compounds</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Large Organic Compounds</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Biological</strong></td>
<td>Microorganisms</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Biologically active contaminants</td>
<td>Low</td>
<td>Low</td>
</tr>
</tbody>
</table>

Applications of Wireless Sensor Networks – July 2011
Libelium study involving a total of **283** interested users in terms of sensors preferences. The users include researchers and practioners (developers).

The results are classified in the next 5 main fields:
- environmental,
- gas,
- physical,
- optical and
- biometric.
Use of environmental sensors

- **Sensors**: Temperature, Humidity (soil, leaf, ambient), Soil moisture, Wind (speed and direction), Pressure, Leaf, Ph, Redox.

- **Application**:
  - Precision agricultural applications are one of the most required in the terms of temperature, humidity (soil, leaf, ambient) and wind (speed and direction).
  - **Ph** and **Redox** sensors being demanded for water quality.
Use of physical sensors

• **Sensors**: accelerometer, presence, vibration, power, hall, ultrasound, water, sound, bend, flex, strain, stress.

• **Application**:
  • Motion of any kind using accelerometers, vibration, and presence sensors.
  • Security applications are waiting to be deployed.
  • World of objects: bend, flex, strain and stress sensors let know how each object is interacting with the world and monitorize its state.
Use of gas sensors

- **Sensors**: Co2, Co, CH4, O2, NH3, SH2, NO2, Pollution.

- **Application**.
  - Organic gases (carbone) derived from the "live systems" such as respiration in humans (CO2), animals (CH4) and combustion (CO) of vegetable elements (fire forest) are the most required sensors.
  - Other toxic gases which can be found in animal farms (NH3, SH2) and the fabric and cars pollution gases (NO2) complete the list.
Use of optical sensors

**Sensors:** Infrared, Sunlight, Radiation, Ultraviolet, color

**Application.**
- Optical sensors to detect human presence through the IR spectrum are the most voted sensors in this area.
- Agriculture applications where the sun light, radiation and ultraviolet sensors are required in order to measure the total amount of energy and light which is absorbed by the plants.
Use of biometric sensors

- **Sensor types:** Electrocardiogram ECG, Oximetry, Pulse, Fall, Sweat
- **Application:**
  - Prevent a possible attack or the fall of an elderly person (using an accelerometer) by monitoring his heart pulse, rate and other heart activities. Used in combination of SMS alarms using the GSM/GPRS module
- **Requirements:** a real time and redundant alarm system so that communication can always be established.
WSN application examples

- Disaster relief operations
  - Drop sensor nodes from an aircraft over a wildfire
  - Each node measures temperature
  - Derive a “temperature map”

- Biodiversity mapping
  - Use sensor nodes to observe wildlife
Intelligent buildings (or bridges)

- Reduce energy wastage by proper humidity, ventilation, air conditioning (HVAC) control
- Needs measurements about room occupancy, temperature, air flow, ...
- Monitor mechanical stress after earthquakes
Machine surveillance and preventive maintenance
- Embed sensing/control functions into places no cable has gone before
- E.g., tire pressure monitoring

Precision agriculture
- Bring out fertilizer/pesticides/irrigation only when and where needed

Medicine and health care
- Post-operative or intensive care
- Long-term surveillance of chronically ill patients or the elderly
WSN application examples

Great Duck Island

[UCB, 2002]
Great Duck Island

- Monitoring seabird nesting environment (Leach’s Storm Petrel)
Great Duck Island
Great Duck Island

- Impacts of human presence on plants and animals
  - Minimal disturbance is crucial while monitoring
  - Especially seabird colonies
  - 20% mortality of eggs due to a 15-min visit
  - Repeated disturbance $\Rightarrow$ birds may abandon
- Leach’s storm petrels desert nesting burrows if disturbed in first 2 weeks of incubation
- Natural answer: wireless sensor networks
Great Duck Island

- Motivation: Life Scientists’ Perspective
- Usage pattern of nesting burrows over the 24-72 hour cycle when one or both members of a breeding pair alternate incubation and feeding at sea
- Changes in burrow and surface environmental parameters during the 7-month breeding season
- Differences in micro-environments with and without large numbers of nesting petrels
Great Duck Island

- Motivation: Sensor Networks Perspective
- Application-driven approach better than abstract problem statements
  - Separate actual problems from potential ones
  - Relevant versus irrelevant issues
- Develop an effective sensor network architecture
- Learn general solutions from specific ones
Great Duck Island

- **Data Acquisition Rates**
  - Presence/absence data: using temperature differentials
    - Every 5-10 min
  - General environmental parameters:
    - Every 2-4 hours
  - Popular vs unpopular sites:
    - Every 1 hour, at the beginning of the breeding season
Great Duck Island

- Sensor network longevity: 9 months
  - Solar power where possible
  - Stable operation crucial
- Sensors: light, temperature, infrared, relative humidity, barometric pressure
- Remote data acquisition, management, and monitoring over the Internet
  - In-situ operations also
Great Duck Island

- Remarks on the Architecture
  - Hierarchical network
  - Solar panel at gateways and base-station
  - In-situ retasking possible
    - Example: collect temperature beyond a certain threshold, no need for all temperature readings
  - Base-station has satellite connectivity
Great Duck Island
Great Duck Island

Example Data


Figure 4: Thermopile data from a burrow mote on GDI during a 19-day period (July 18, 2002 to August 5, 2002).
WSN application examples

[Princeton, 2004]
WSN application examples

- ZebraNet: an application to track zebras on the field
  The objective of the application is to gather dynamic data about zebra positions in order to understand their mobility patterns.
- What are the motivations for the zebras to move? water? food? weather?
- How do they interact?
- The sensors are deployed in collars that are carried by the animals.
- The users are the biologists.
WSN application examples

1) Earthquake or eruption occurs
2) Nodes detect seismic event
3) Each node sends event report to base station
WSN application examples


- Tungurahua, Ecuador
WSN application examples
Figure 2: Sensor network architecture. Nodes form a multihop routing topology, relaying data via a long-distance radio modem to the observatory. A GPS receiver is used to establish a global timebase. The network topology shown here was used during our deployment at Reventador.
WSN application examples

- Challenges Encountered
  - Event detection: when to start collecting data?
  - High data rate sampling
  - Spatial separation between nodes
  - Data transfer performance: reliable transfer required
  - Time synchronization: data has to be time-aligned for analysis by seismologists
Bridge Monitoring

Structural health monitoring (SHM) is a sensor-based preemptive approach

In California, 13% of the 23,000 bridges have been deemed structurally deficient, while 12% of the nation's 600,000 bridges share the same rating.

New York may be the first state with a 24/7 wireless bridge monitoring system.

Another application in India: Bri-Mon
WSN application examples

Agriculture

e.g., TU Delft Deployment
Smart Agriculture
Objectives:

- Using a combination of sensors such as humidity, temperature, and light, detect the risk of frost, possible plant diseases and find watering requirements based on soil humidity.

- manage crop cultivation to know the exact condition in which plants are growing from the comfort of your own home.

- control conditions in nurseries and closely monitor high performance of delicate crops, such as vines or tropical fruit, where the slightest change in climate can affect the final outcome

- determine the optimum conditions for each crop, by comparing the figures obtained during the best harvests
Animal Rearing (courtesy of Libelium)
Natural Environment (courtesy of Libelium)
Objectives

- **detect and prevent forest fires.** Detect flames, heat and gases that help to identify the molecules of chemical compounds generated during combustion (CO and CO2). With GPS, allow the exact geolocation of the nodes.

- **Prevention.** After installing the WSN, the network can also acquire the daily values for temperature and relative humidity in order to determine the **likelihood of a fire** in each zone under surveillance.

- **Alarm.** Send an **alarm** indicating the status of the fire or the probability level and the area.
Objectives:

- Install a wireless sensor network near animals to help optimise their rearing conditions.
- Monitor the temperature of litters to keep it at suitable levels;
- Measure levels of gases produced by livestock such as methane (CH4), ammonia (NH3) and Hydrogen Sulphide (SH2);
- Control animals’ stress levels by monitoring flock restlessness with vibration and movement sensors.
WSN application examples

[CodeBlue: Harvard]
Roles of participants in WSN

- **Sources** of data: Measure data, report them “somewhere”
  - Typically equip with different kinds of actual sensors

- **Sinks** of data: Interested in receiving data from WSN
  - May be part of the WSN or external entity, PDA, gateway, ...

- **Actuators**: Control some device based on data, usually also a sink
Structuring WSN application types

Gateway and Sensor Nodes: M-to-1 communication
Sensor Nodes with GPRS/GSM interfaces and SD cards: M-to-N communication (new)
Structuring WSN application types

- **Interaction patterns** between sources and sinks classify application types
  - **Event detection:** Nodes locally detect events (maybe jointly with nearby neighbors), report these events to interested sinks
  - **Periodic measurement**
  - **Function approximation:** Use sensor network to approximate a function of space and/or time (e.g., temperature map)
  - **Edge detection:** Find edges (or other structures) in such a function (e.g., where is the zero degree border line?)
  - **Tracking:** Report (or at least, know) position of an observed intruder ("pink elephant")
Deployment options for WSN

- How are sensor nodes deployed in their environment?
  - Dropped from aircraft: **Random deployment**
    - Usually uniform random distribution for nodes over finite area is assumed
    - Is that a likely proposition?
  - Well planned, fixed: **Regular deployment**
    - E.g., in preventive maintenance or similar
    - Not necessarily geometric structure, but that is often a convenient assumption
  - **Mobile** sensor nodes
    - Can move to compensate for deployment shortcomings
    - Can be passively moved around by some external force (wind, water)
    - Can actively seek out “interesting” areas
Maintenance options

- Feasible and/or practical to maintain sensor nodes?
  - E.g., to replace batteries?
  - Or: unattended operation?
  - Impossible but not relevant? Mission lifetime might be very small

- Energy supply?
  - Limited from point of deployment?
  - Some form of recharging, energy scavenging from environment?
    - E.g., solar cells
Characteristic requirements for WSNs

- **Type of service of WSN**
  - Not simply moving bits like another network
  - Rather: provide *answers* (not just numbers)
  - Issues like geographic scoping are natural requirements, absent from other networks

- **Quality of service**
  - Traditional QoS metrics do not apply
  - Still, service of WSN must be “good”: Right answers at the right time
Characteristic requirements for WSNs

- **Fault tolerance**
  - Be robust against node failure (running out of energy, physical destruction, ...)

- **Lifetime**
  - The *network* should fulfill its task as long as possible — definition depends on application
  - Lifetime of individual nodes relatively unimportant
  - But often treated equivalently
Characteristic requirements for WSNs

- **Scalability**
  - Support large number of nodes

- **Wide range of densities**
  - Vast or small number of nodes per unit area, very application-dependent

- **Programmability**
  - Re-programming of nodes in the field might be necessary, improve flexibility

- **Maintainability**
  - WSN has to adapt to changes, self-monitoring, adapt operation
  - Incorporate possible additional resources, e.g., newly deployed nodes
Required mechanisms

- Multi-hop wireless communication
- Energy-efficient operation
  - Both for communication and computation, sensing, actuating
- Auto-configuration
  - Manual configuration just not an option
- Collaboration & in-network processing
  - Nodes in the network collaborate towards a joint goal
  - Pre-processing data in network (as opposed to at the edge) can greatly improve efficiency
Conclusion

- WSN are here to stay!
- It’s an interesting, complex, new technology
- Lots of research still to be done
- Applications are what is needed!
Credits

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