Wireless Sensor Networks: A Real Melting Pot

Magdy A. Bayoumi
Director, The center for Advanced Computer studies
Dept. Head, Computer Science Dept.
University of Louisiana at Lafayette
The Team

- Sherine
- Soumik
- Ruth
- Ahmed
- Mitune
- Ashok
- Shaheen
Sensors are the CORE for:

- Wearable Computers
- Embedded Computing
- Ubiquitous Computing
- Perception Systems
- They are the interface of the digital world to the real world
Hot News:

Wall Street Journal, Feb. 28, 2007:

“Monitoring your heart, wireless, via the Internet”

Implanted device (sensors) inside the heart; the Chronicle from Medtronic Inc. Send all information wireless to the network.
Wireless Sensors Networks:

- Evolution in Computer Architectures
- Advances in Communication Networks
- Modern Circuit Design
- Advances in Devices
- New Design Paradigms
Technology is everywhere
Moore’s Law

The number of transistors will double every 18 months

Gordon Moore
Moore’s Law Continues
Transistors doubling every 2 years toward the billion-transistor microprocessor

Source: Intel
Growth of cellular market

Cellular mobile subscribers worldwide (Source: ITU)

million

90 91 92 93 94 95 96 97 98 99 0 1 2 3 4 5 6 7 8 9 10
0 1.5 billion
0.5 billion
Wireless World

Application space
- To business large/concentrated
- To business: small/dispersed
- To home: connectivity

Short-range LAN: business, home
- High mobility voice

Technology
- Fixed
- "Fixed" 3G (WLL)
- Satellite
- Fixed m-wave
- Laser
- W-LAN (802.11, BlueTooth)
- Home RF
- Mobile
- Nomadic
- Technically infeasible

Bandwidth
- Low
- Total data pipe bandwidth
- High
Examples – Research Groups

☐ U. of California – Berkeley
☐ UCLA
☐ Cornell
☐ USC
☐ U. of Louisiana
☐ MIT
Blurring the boundary between the digital and physical worlds

As these devices proliferate, we must

- Deal with uncertainties in both systems and environments
- Move from “building unreliable systems from reliable parts” to “building reliable systems from unreliable parts”
Why Wireless Network?

- Wireless is now cheaper to install, it will be 10% of the cost of the wired system by 2010.
- Rapid deployment.
- Wire crack or fail->high maintenance.
- Flexibility in placement.
- Connectors are expensive and not reliable.
What is Wireless Sensor Network

- Network that are formed when a set of small untied sensor devices that are deployed in an ad hoc fashion cooperate on sensing a physical phenomenon
Characteristics

- Sensor network protocols and algorithm must possess self-organizing capabilities.
- Cooperative effort.
- The sensor must carry out simple computations and transmit only the required and partially processed data.
- The number of sensors can be a several orders of magnitude higher than the nodes in an ad hoc network.
- Sensors are densely deployed (20 nodes/m³).
Characteristics

continued...

- **The communication is not end-to-end.** The function of the network is to report the phenomenon of interest to the observer who is not necessarily interested in (or aware of) specific sensors as another end-point of communication.

- **Energy is much more limited** in sensor networks than in other wireless network since it is often impossible to recharge the batteries of sensor nodes.
Six Aspects of a Sensor Network Arch.

- **Design Principles**
  - Guidelines and constraints, what functionality, what state
  - To what are we agnostic

- **Functional Architecture**
  - Logical building blocks/protocols, interfaces, interconnections, interdependencies

- **Programming Architecture**
  - API/ISA – what logical data types and operations are expressible

- **Protocol Architecture**
  - Distributed algorithms to provide each component service, defn. of the information exchanged between instances
  - *Most existing work is of this form*

- **System Support Architecture**
  - Capabilities of the node to support the network arch.

- **Physical Architecture**
  - Set of nodes, interconnects, communication fabrics upon which network is constructed
Sensor Networks Requirements
(as outlined by NIST)

- Large number of sensors (stationary or Mobile):
  Scalability is a major issue.

- Low energy use:
  The lifetime of a node may be determined by the battery life.

- Network self-organization:
  Hostile location; fault-tolerance.

- Collaborative signal processing:
  The end goal is detection/estimation of some events of interest
  and not just communications.

- Queering ability:
  Individual nodes may be queried.
Sensor Node

- The sensor node is made up of four basic components:
  - Sensing Unit
  - Processing Unit
  - Transceiver Unit
  - Power Unit
The sensor node must:
- Consume extremely low power.
- Handle its own power.
- Low Production cost.
- Be dispensable and autonomous.
- Operated unattended.
- Be adaptive to the environment.
Berkeley Motes

- Small (under 1” square) microcontroller
- It consists of:
  - Microprocessor
  - A set of sensors for temperature, light, acceleration and motion
  - A low power radio for communicating with other motes
- C compiler Inclusion
- Development ongoing
Issues governing a Sensor node Design

- Reduction of power consumption of each component in the sensor node and the network as a whole.
- Nodes must be able to perform a combination of computation, wireless communications and sensing.
- Nodes also contain a conventional battery, (preferably rechargeable) supplemented by a renewable source that generates power using scavenging techniques (vibration, solar, EM, piezoelectric, radioactive, etc..)
- Reduction of communication and communication associated energy consumption. A prudent Metric in a sufficiently dense network is the communication energy per node.
Disadvantages of current sensor network platforms

- Reliance on COTS microcontrollers that are not optimized for running event-driven applications that are mostly idle.
- Necessity of running a software layer to provide event-handling abstractions that introduces significant software overhead.
- Example: TinyOS (or similar OS) running on top of ATMEL(ATMega128), TI(MSP430) or INTEL (ARM based) microcontrollers.
Sensor Data Aggregation Processor

- First Prototype at CACS of a Processor which performs the class of computations for wireless Sensor networks called **data-aggregation**.

- **Aggregation applications** are those where the desired answer depends on the sensed value at multiple nodes.

- Examples of aggregation functions are “maximum” and “average”. A user may be interested in knowing the max (or average) of a value in the WSN or in some restricted area of the WSN.

- The Processor performs “snapshot aggregation” (If the function needs to be performed once) and “periodic aggregation” (user needs an update in periodic intervals).

- Built on AMI 0.5um process. Can serially process Sensor data at a Maximum rate of 50 Mbps. Average power consumption at 50Mbps is 300mW.
Integrated Sensor Processor
Sensor Network Design Factors

1. Sensor mobility:
   Fixed; movable planned/known; random motion.

2. Number of sensors in the application domain & scalability required:
   1 to 10; 10 to 1000; 1000 to 100000; 100000+.

3. Power source & life:
   Wired; wireless on pre-existing; wireless separate supply.

4. Security:
   High; low; encryption.
5. Sensor intelligence:
   Single or multi-function; dumb; addressable- 2 way, multi-path, broadcast.

6. Actuation processes:
   Tightly coupled or separate actuator; auto or manual trigger Local, intermediate or NOC decision point.

7. Intelligence & information distribution schema:
   All to central NOC or distributed intelligence at remote sites; secure vs. non-secure sites; level of remote data storage.

8. Level of fusion & collaboration:
   Multi sensor or multi node direct communication; query capability from sensor site, other in field, NOC.
Sensor Network Design Factors
continued...

9. "Hop" constraints:
   Internodes; to actuation; to NOC.

10. Ranges allowable & optimal:
    Internodes; to router or node sink; to secure site.

11. Communication medium:
    Wired; wireless entirety; wired to router/node sink then wireless; multi mode
Factors affecting wireless sensor network.

- Data reliability.
- Battery life.
- Cost.
- Transmission range.
- Data rate.
- Data latency.
- Physical size.
- Data security.
Ubiquitous Computing and Monitoring System (UCoMS) for Discovery and Management of Energy Resources
Project Aims

- Drilling and production data logging and storage to expand seismic databases using wireless network systems
- Massive grid computing power to support reservoir development optimization and seismic simulation
- Safety monitoring of well platforms & transport pipes
- Support of long-term platforms monitoring
- Use of decommissioned platforms as experimental testbed
### UCoMS Wireless Network Prototype

<table>
<thead>
<tr>
<th>Wireless Sensor Network</th>
<th>Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>□ Sensor Node</td>
<td>• Smart Sensors</td>
</tr>
<tr>
<td>◁ Sink (aggregation node)</td>
<td>- Two dozens (small-scale)</td>
</tr>
<tr>
<td></td>
<td>- Sixty four (full-size)</td>
</tr>
<tr>
<td></td>
<td>• Eight laptops</td>
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</table>

<table>
<thead>
<tr>
<th>IBW Network</th>
<th>Equipment</th>
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<tbody>
<tr>
<td><img src="image" alt="IBW Network Diagram" /></td>
<td>• Tsunami Wireless Ethernet Bridges</td>
</tr>
<tr>
<td></td>
<td>- Four nodes (small-scale)</td>
</tr>
<tr>
<td></td>
<td>- Eight nodes (full-size)</td>
</tr>
<tr>
<td></td>
<td>• Ten laptops</td>
</tr>
</tbody>
</table>

#### Personnel
- UL Lafayette
  - 4 PIs
  - 4 Research Assistants
  - CMPS 6x9
  - CMPS 575/576
- Southern University
  - Graduate students
  - Undergraduate students
<table>
<thead>
<tr>
<th>Medium Access</th>
<th>SYN-MAC</th>
<th>Unique Features</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Problem:</strong></td>
<td><strong>Objective:</strong> High channel efficiency</td>
<td>• High efficiency</td>
</tr>
<tr>
<td>• Congestion</td>
<td><strong>Propose Approach:</strong> Binary countdown</td>
<td>• Simplicity</td>
</tr>
<tr>
<td>• High collision</td>
<td><strong>Preliminary Result:</strong> Significantly higher channel efficiency than IEEE 802.11</td>
<td>• Robustness</td>
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<tr>
<td>• Low throughout</td>
<td></td>
<td>• QoS support</td>
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<td></td>
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<td>• Fairness</td>
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<td></td>
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<td>• Decentralization</td>
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</table>

**Proposed Work**
- Protocol design
- Implementation
- QoS support
- Eval. & fine-tune
- Prototyping

- Low throughout
- Congestion
- High collision

- Throughput (Mbps)
- Number of Active Nodes (n)

- Throughput of IEEE 802.11
- $k=5$
- $k=10$
- $k=15$

Significantly higher channel efficiency than IEEE 802.11
<table>
<thead>
<tr>
<th><strong>S-Path Routing</strong></th>
<th><strong>M-Path Routing</strong></th>
<th><strong>Unique Features</strong></th>
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</thead>
<tbody>
<tr>
<td><strong>Problem</strong></td>
<td><strong>Using Multiple Paths</strong></td>
<td>• High reliability</td>
</tr>
<tr>
<td>– Link failures</td>
<td></td>
<td>• High data rate</td>
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<tr>
<td>– Unreliable</td>
<td></td>
<td>• Low overhead</td>
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<tr>
<td>– Low data rate</td>
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<tr>
<td><strong>Objective:</strong></td>
<td><strong>Preliminary Results</strong></td>
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<td>Improve</td>
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<td>perform</td>
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<td><strong>High Performance</strong></td>
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<td><strong>Wireless Networks</strong></td>
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**Proposed Work**

- Route discovery
- Protocol design
- Implementation
- Eval. & fine-tune
- Comparison
- Prototyping
<table>
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<tr>
<th>Reliable Transport</th>
<th>Approach: Cross-layer Based TCP</th>
<th>Unique Features</th>
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</thead>
<tbody>
<tr>
<td><strong>Problem:</strong></td>
<td><strong>Use Cross-layer Model</strong></td>
<td>Flexible</td>
</tr>
<tr>
<td>– Distinguish causes of packet errors</td>
<td>– Link quality</td>
<td>Adaptive</td>
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<tr>
<td><strong>Objective:</strong></td>
<td>– Congestion</td>
<td>Dynamic channel and path metrics</td>
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<tr>
<td>– Improve TCP throughput</td>
<td>– Path stability</td>
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<tr>
<td></td>
<td>• Control TCP data rate</td>
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<td>• TCP response to packet loss</td>
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<td>Proposed Work</td>
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<td></td>
<td>• Distributed feedback control mechanisms</td>
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<td></td>
<td>• Implementation</td>
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<td>• Evaluation</td>
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<td>• Prototyping</td>
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# Energy Efficiency and System Optimization

| Problem: cross-layer parameter and protocol interaction hinders performance |
| Objective: improve energy efficiency, system lifetime. |

## Proposed Work: Modeling and Protocol Design

- Empirical data collection.
- Derive multiple factor empirical models.
- Development cross-layer architecture and protocols to minimize power consumption and increase system lifetime.

Simulation results: 4-way interaction plot