Algorithms for Wireless Ad Hoc and Sensor Networks

Partha Sarathi Mandal
Department of Mathematics
IIT Guwahati
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Thanks! 😊
Motivation
Motivation

Credits: Matt Welsh (Harvard)
Motivation
Enabling Technology?
## Enabling Technology?

<table>
<thead>
<tr>
<th>Processor</th>
<th>ATmega128, 8-bit, 16MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAM</td>
<td>4KB</td>
</tr>
<tr>
<td>Program Memory</td>
<td>128KB</td>
</tr>
<tr>
<td>External Flash Memory</td>
<td>512KB</td>
</tr>
<tr>
<td>Radio Transceiver</td>
<td>(60kbps, 250kbps)</td>
</tr>
<tr>
<td>Lifetime (2AA, no duty-cycle)</td>
<td>~6 days</td>
</tr>
<tr>
<td>Operating Environment</td>
<td>Untethered, Harsh</td>
</tr>
</tbody>
</table>
Wireless Sensor Networks (WSNs)

- Networks of typically small, battery-powered, wireless devices.
  - On-board processing,
  - Communication, and
  - Sensing capabilities.

WSN device schematics
WSN node components

- Low-power processor.
  - Limited processing.
- Memory.
  - Limited storage.
- Radio.
  - Low-power.
  - Low data rate.
  - Limited range.
- Sensors.
  - Scalar sensors: temperature, light, etc.
  - Cameras, microphones.
- Power.
Transmission range and sensing range
Transmission range and sensing range

\[ R_{\text{trans}} = R_{\text{sensing}} \]
Advances in Wireless Sensor Nodes
Consider Multiple Generations of Berkeley Motes

<table>
<thead>
<tr>
<th>Model</th>
<th>Rene</th>
<th>Mica</th>
<th>Mica-2</th>
<th>Mica-Z</th>
<th>IRIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
<td>1999</td>
<td>2002</td>
<td>2003</td>
<td>2004</td>
<td>2010</td>
</tr>
<tr>
<td>CPU</td>
<td>4 MHz</td>
<td>4 MHz</td>
<td>4 MHz</td>
<td>4 MHz</td>
<td>2.4 GHz</td>
</tr>
<tr>
<td>Flash Memory</td>
<td>8 KB</td>
<td>128 KB</td>
<td>128 KB</td>
<td>128 KB</td>
<td>128 KB</td>
</tr>
<tr>
<td>RAM</td>
<td>512 B</td>
<td>4 KB</td>
<td>4 KB</td>
<td>4 KB</td>
<td>8 KB</td>
</tr>
<tr>
<td>Radio</td>
<td>10 Kbps</td>
<td>40 Kbps</td>
<td>76 Kbps</td>
<td>250 Kbps</td>
<td>250 kbps</td>
</tr>
</tbody>
</table>
Nodes Deployment

Today, we look much cuter!

And we’re usually carefully deployed

Radio
Power
Processor
Memory
Sensors
After Deployment
After Deployment
After Deployment
After Deployment
Ad Hoc Networks vs. Sensor Networks

- Laptops, PDA’s, cars, soldiers
- All-to-all **routing**
- Often with **mobility** (MANET’s)
- **Trust/Security** an issue
  - No central coordinator
- Maybe high **bandwidth**
- **Tiny nodes**: 4 MHz, 32 kB, ...
- Broadcast/Echo from/to sink
- Usually no mobility
  - but link failures
- One administrative control
- Long lifetime → **Energy**

There is no strict separation; more variants such as mesh or sensor/actor networks exist
Applications

Applications
Animal Monitoring (Great Duck Island)

1. Biologists put sensors in underground nests of storm petrel
2. And on 10cm stilts
3. Devices record data about birds
4. Transmit to research station
5. And from there via satellite to lab
Environmental Monitoring

- Microclimate in a tree
- 10km less cables on a tree; easier to set up
- Sensor Network = The New Microscope?
Smart Spaces (Car Parking)

• The good: Guide cars towards empty spots
• The bad: Check which cars do not have any time remaining
• The ugly: Meter running out: take picture and send fine

[Matthias Grossglauser, EPFL & Nokia Research]
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[Matthias Grossglauser, EPFL & Nokia Research]
Structural Health Monitoring (Bridge)

Detect structural defects, measuring temperature, humidity, vibration, etc.

Swiss Made [EMPA]
Virtual Fence (CSIRO Australia)

- Download the fence to the cows. Today stay here, tomorrow go somewhere else.
- When a cow strays towards the co-ordinates, software running on the collar triggers a stimulus chosen to scare the cow away, a sound followed by an electric shock; this is the “virtual” fence. The software also "herds" the cows when the position of the virtual fence is moved.
- If you just want to make sure that cows stay together, GPS is not really needed...

Cows learn and need not to be shocked later... Moo!
Wild Fire detection

1. Wild fire tracking until a perimeter has been formed.
2. A notification is sent to a fire fighter notifying him of the fire's location.
3. The fire fighter injects a guidance agent into
Habitat Monitoring

• The ZebraNet Project
  Collar-mounted sensors monitor zebra movement in Kenya

Source: Margaret Martonosi, Princeton University
Surveillance and tracking for military
Some basic ideas about Distributed System

• What is Distributed System?
• A broad definition
  – A set of autonomous processes that communicate among themselves to perform some task
• Modes of communication
  – Message passing
  – Shared memory
• Includes single machine with multiple communicating processes also
Some basic ideas about Distributed System

• What is Distributed System?
• Distributed system is a collection of independent processes that communicate with each other and cooperate to achieve a common goal.
• A process is set of instructions and variables.
• Each process can proceed with its own speed.
• The only way for one process to coordinate with others is via communication.
• Thus the system consists of a set of processes connected by a network of communication links.
What is Distributed System?

- The **nodes** are processes, and the **edges** are communication channels. It is a **network** of processes.
Why are WSNs challenging from a research point of view?

- **Typically, severely energy constrained**
  - Limited energy sources (e.g., batteries).
  - Trade-off between performance and lifetime.

- **Self-organizing and self-healing**
  - Remote deployments.

- **Scalable**
  - Arbitrarily large number of nodes.

- **Heterogeneity**
  - Devices with varied capabilities.
  - Hierarchical deployments.

- **Adaptability**
  - Adjust to operating conditions and changes in application requirements.

- **Time synchronization**

- **Security and privacy**
  - Potentially sensitive information.
  - Hostile environments.
Localization & Positioning

• Why positioning?
  – Sensor nodes without location information are often meaningless
  – Avoid having “costly” positioning hardware
  – Geo-routin

• Why not GPS?
  – “Heavy, large, and expensive”
  – Battery drain
  – Not indoors
  – Accuracy?

• Solution: equip small fraction with GPS (anchors)
Coverage

- After deployment we should check whether the region is fully covered by the sensor nodes or not.
Data Aggregation

• Data aggregation is a route to the sink, on which nodes combine their own measurement with the ones of other nodes in proximity.

• No. of packets without aggregation is 13
Data Aggregation

• Data aggregation is a route to the sink, on which nodes combine their own measurement with the ones of other nodes in proximity.

• No. of packets without aggregation is 13
• No. of packets with aggregation is 7
• Reduction of packets by aggregation