Environmental Sensor Networks

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Introduction

• Environmental monitoring has a long history, including analogue loggers such as early paper plotters measuring barometric pressure and the recording of specific environmental parameters. Loggers record data at specific intervals and require manual downloading by a maintenance team.

• A sensor network is designed to transmit the data from an array of sensors to a data repository on a server. They do not necessarily use a simple one-way data stream over a communications network. Elements of the system will make decisions about what data to pass on, such as local area summaries and filtering in order to minimise power use while maximising information content.
Generic sensor network architecture.
System diagram of the Base Station

[Diagram showing components of the Base Station, including solar panel, 12V battery, power supply, PIC microcontroller, radio modem, GPS PIC, GSM PIC, dGPS module, and real-time clock.]
Simplified system diagram of a Probe
Sensor Nodes

Sensor nodes have the following requirements:

- Low-cost – so many units can be produced.
- Low power – for long-term operation.
- Automated – maintenance free
- Robust – withstand errors and failures.
- Non-intrusive – low environmental disturbance.
- Low pollution
Communications

The nature of the environment meant the communications must meet the following requirements:

- High-power omnidirectional for probes
- Long-range for base to reference
- Low data-rate
- Error-detection and correction
- Backup channels are needed
A range of different computer systems and software are required to build a sensor network:

- Microcontrollers – for sensor nodes
- Small OS – for nodes
- Low-power systems – for base stations
- Routing and message-passing
- Server – for the sensor network server
- Publishing software – visualisation and services
Challenges for environmental sensor networks

• Miniaturisation
• Power Management
• Radio Communication
• Scalability
• Remote Management
• Usability
• Standardisation
• Security
HARDWARE
Low Power Wireless Sensor Network Devices
Faster, Smaller, Numerous

- **Moore’s Law**
  - “Stuff” (transistors, etc) doubling every 1-2 years

- **Bell’s Law**
  - New computing class every 10 years

Streaming Data to/from the Physical World
Open Experimental Platform

Services
Networking

TinyOS

WeC 99 “Smart Rock”
Small microcontroller
8 kB code
512 B data
Simple, low-power radio
10 kbps ASK
EEPROM (32 KB)
Simple sensors

Rene 11/00

Dot 9/01
Designed for experimentation
-sensor boards
-power boards

Mica 1/02
NEST open exp. Platform
128 kB code, 4 kB data
40kbps OOK/ASK radio
512 kB Flash

Telos 4/04
Robust
Low Power
250kbps
Easy to use

Mica2 12/02
38.4kbps radio
FSK

Rene 11/00

Dot 9/01

Mica 1/02
NEST open exp. Platform
128 kB code, 4 kB data
40kbps OOK/ASK radio
512 kB Flash

Commercial Off The Shelf Components (COTS)
## Mote Evolution

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<td>no</td>
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<td>yes</td>
<td>no</td>
<td>no</td>
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Design Principles

• Key to Low Duty Cycle Operation:
  – Sleep – majority of the time
  – Wakeup – quickly start processing
  – Active – minimize work & return to sleep
Telos Platform

- A new platform for low power research
  - Monitoring applications:
    - Environmental
    - Building
    - Tracking
- Long lifetime, low power, low cost
- Built from application experiences and low duty cycle design principles
- Robustness
  - Integrated antenna
  - Integrated sensors
  - Soldered connections
- Standards Based
  - IEEE 802.15.4
  - USB
- IEEE 802.15.4
  - CC2420 radio
  - 250kbps
  - 2.4GHz ISM band
- TI MSP430
  - Ultra low power
    - 1.6µA sleep
    - 460µA active
    - 1.8V operation

Open embedded platform with open source tools, operating system (TinyOS), and designs.
CC2420 Radio
IEEE 802.15.4 Compliant

- CC2420
  - Fast data rate, robust signal
    - 250kbps : 2Mchip/s : DSSS
    - 2.4GHz : Offset QPSK : 5MHz
    - 16 channels in 802.15.4
    - -94dBm sensitivity
  - Low Voltage Operation
    - 1.8V minimum supply
  - Software Assistance for Low Power Microcontrollers
    - 128byte TX/RX buffers for full packet support
    - Automatic address decoding and automatic acknowledgements
    - Hardware encryption/authentication
    - Link quality indicator (assist software link estimation)
      - samples error rate of first 8 chips of packet (8 chips/bit)
Power Calculation Comparison

Design for low power

- Mica2 (AVR)
  - 0.2 ms wakeup
  - 30 µW sleep
  - 33 mW active
  - 21 mW radio
  - 19 kbps
  - 2.5V min
  - 2/3 of AA capacity
- MicaZ (AVR)
  - 0.2 ms wakeup
  - 30 µW sleep
  - 33 mW active
  - 45 mW radio
  - 250 kbps
  - 2.5V min
  - 2/3 of AA capacity
- Telos (TI MSP)
  - 0.006 ms wakeup
  - 2 µW sleep
  - 3 mW active
  - 45 mW radio
  - 250 kbps
  - 1.8V min
  - 8/8 of AA capacity

Supporting mesh networking with a pair of AA batteries reporting data once every 3 minutes using synchronization (<1% duty cycle)

453 days 328 days 945 days
Sensors

• Integrated Sensors
  – Sensirion SHT11
    • Humidity (3.5%)
    • Temperature (0.5°C)
    • Digital sensor
  – Hamamatsu S1087
    • Photosynthetically active light
    • Silicon diode
  – Hamamatsu S1337-BQ
    • Total solar light
    • Silicon diode

• Expansion
  – 6 ADC channels
  – 4 digital I/O
  – Existing sensor boards
    • Magnetometer
    • Ultrasound
    • Accelerometer
    • 4 PIR sensors
    • Microphone
    • Buzzer
Examples
Great Duck Island: Petrel Monitoring

UCB

• Goal: build ecological models for breeding preferences of Leach’s Storm Petrel
  – Burrow (nest) occupancy during incubation
  – Differences in the micro-climates of active vs. inactive burrows
  – Environmental conditions during 7 month breeding season
• Inconspicuous Operation
  – Reduce the “observer effect”
• Unattended, off-the-grid operation
• Sensor network
  – 26 burrow motes deployed
  – 12 weather station motes deployed (+2 for monitoring the insides of the base station case)
"Wetness" is a measure of current in the water sensor. This graph shows that the turtle came out of the water to sun itself for only brief periods and went back into the colder water.

Mica2Dot hardware, GPS, Solar cells on the backs of snapping turtles.
James Reserve Forest (CENS)

- Heterogeneous
- Robotics
- Imaging
  - Full motion cameras
  - In nesting boxes
  - Time lapse images
- Microclimate array & soil moisture
Volcano Monitoring (Welsh, Harvard)

- Motes with seismic sensors deployed on active volcano in Ecuador
- Science dictates: high fidelity during events, large spatial separation, time synchronization.
- Nature of the application allows triggered data collection rather than continuous.
Aquatic Observing Systems (CENS)

Fig A.  (i) The boat  
(ii) Environmental sensors (a) Water sampler (b) Fluorometer & sampler  
(iii) Navigation Sensors (a) GPS, (b) Compass, (c) Wind direction, and (d) Wind speed
Deployment Up a Tree

- Dense temporal and spatial data collection
- 44 days from Apr 27 to Jun 10
- 33 sensor nodes
- Sampling every 5 minutes
- Temperature, relative humidity, PAR
Sensor Node Platform & Package

- Mica2Dot node from Crossbow
  - 4MHz processor
  - 433 MHz radio, 40 Kbps
  - 512 KB Flash
  - Sensors
- Packaging
TASK Software

- Duty cycling – node on 4 sec every 5 min
- Time synchronization
- Tree route discovery between gateway and nodes
- TinyDB data collection and querying
- Data logging in Flash as backup
Temporal Distributions

Temperature

Relative Humidity

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Temporal Distributions
Spatial Distributions

Incident PAR

Reflected PAR

Node Height (m)

μmol/m²/s

μmol/m²/s
Subtracting Timestamp Mean
One Day in the Life of a Tree
One Day in the Life of a Tree
Visualizing Change

Temperature (°C)

Relative Humidity (%RH)
Visualizing Change
Outliers & Battery

- Once battery voltage falls, temperature reading goes bad
- Opportunity to automatically reject outliers
Performance of the Network: Data Transmitted
Next step . . .
Web-based Wireless Environmental Sensing Network (WWESN)
System Requirements

To enable global reachability to environmental data and facilitate remote monitoring of natural processes through Internet

- Internet Access
- Flexibility of design
- Reliability
- Power Autonomy
- Low-cost
- Sensors
- Data storage & presentation
- Camera
Network Architecture
Software Model
Results

[Image of a webpage showing a wireless environmental sensing network (WESN) with images and timestamps]

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Questions?