Courtesy: Prof. Parashar, Rutgers University

Wireless Sensor Networks for Habitat Monitoring

Reviewed by Li Zhang

Outline

- Introduction
- Motivation and requirement analysis
- System architecture
- System implementation
- Current results
- Discussion
- Conclusion

Introduction

- Habitat and environmental monitoring can enable **long-term** data collection at **scales** and **resolutions** that are difficult, or even impossible, to obtain.
  - Integration of **local processing and storage**
    - allows sensor nodes to perform complex filtering and triggering functions, as well as to apply application-specific or sensor-specific data compression algorithms.
  - Ability to **communicate**
    - allows information and control to be communicated across the network of nodes; nodes cooperate in performing more complex tasks.
  - Increased **power efficiency**

Introduction (cont.)

- **Application-driven approach**
  - Separates actual problems from potential ones, relevant issues from irrelevant ones; helps to differentiate problems with simple, concrete solutions from open research areas.
  - However, **general solutions** should be seeked from this.
  - Collaboration with scientists in other fields helps to define a broader application space.
- The paper develops a specific habitat monitoring application, which is a **largely representative** of the domain.
  - A collection of requirements, constraints and guidelines

Motivation

- The potential impact of human presence in monitoring plants and animals in field conditions
- **Disturbance effects** are of particular concern in small island situations
- Sensor networks represent a significant advance over traditional invasive methods of monitoring.
- Sensor network deployment may represent a substantially more **economical** method for conducting long-term studies than traditional personnel-rich methods.

Requirement Analysis for GDI

- Great Duck Island (GDI) major interested questions:
  - What is the usage pattern of nesting burrows over the 24-72 hour cycle when one or both members of a breeding pair may alternate incubation duties with feeding at sea?
  - What changes can be observed in the burrow and surface environmental parameters during the course of the approximately 7 month breeding season?
  - What are the differences in the micro-environments with and without large numbers of nesting petrels?
- Each of these questions has **unique data needs** and **suitable data acquisition rates**.

Requirement Analysis for GDI

- Internet access
  - To support remote interactions with in-situ networks
- Hierarchical network
  - Needs sufficient resources to host internet connectivity and database system. However, the habitat of scientific interest are several kilometres further away.
  - A second tier of wireless network provides connectivity to multiple patches of sensor networks deployed at each of the areas of interest.
- Sensor network longevity
  - Individual field seasons typically vary from 9~12 months

Requirement Analysis for GDI

- Operating off-the-grid
  - Every level of the network must operate with bounded energy supplies.
- Management at-a-distance
  - To zero on-site presence for maintenance and administration during the field season
- Inconspicuous operating
  - It should not disrupt the natural processes or behaviors under study.
- System behaviour
  - sensor networks should present stable, predictable, and repeatable behaviour whenever possible.

Requirement Analysis for GDI

- In-situ interactions
  - Local interactions are required during initial deployment, during maintenance tasks, as well as during on-site visits.
- Sensors and sampling
  - The ability to sense light, temperature, ingrared, relative humidity, and barometric pressure is essential.
- Data archiving
  - Archiving sensor readings for off-line data mining and analysis is essential

System Architecture

- Tiered architecture
  - Database replicas: store data retrievable by scientists
  - Base station: connects to database replicas across the internet

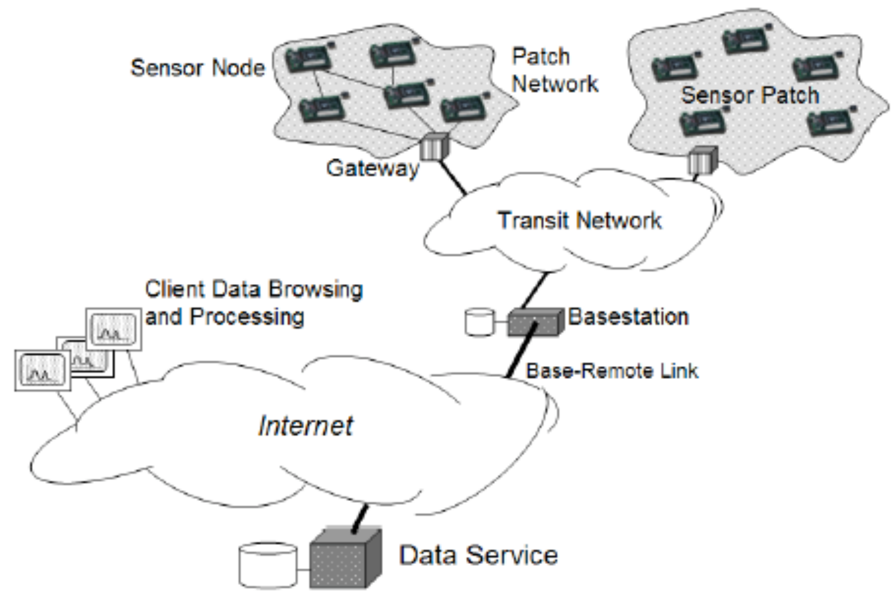

Figure 1: System architecture for habitat monitoring

- **Gateway:** transmit sensor data from the sensor patch through a local transit network to the remote base station that provides WAN connectivity and data logging
- **Sensor nodes:** general purpose computing and networking, application-specific sensing

System Architecture: sensor nodes

- Sensors are small, battery-powered devices that can collect environmental data primarily about its immediate surroundings.
  - They use **small and inexpensive individual sensors** and **dense deployment** of sensor nodes
  - Compared with traditional approaches, which use a few high quality sensors with sophisticated signal processing, this architecture provides **higher robustness** against occlusions and component failures.

System Architecture: sensor nodes

- Computational module + sensor module
  - Computational module is a programmable unit that provides computation, storage, and bidirectional communication with other nodes in the system.
- Networked sensors offer two major advantages:
  - They can be re-tasked in the field.
  - They can easily communicate with the rest of the system.

System Architecture

- Each sensor patch is equipped with a gateway which can communicate with the sensor network and provides **connectivity to the transit network**.
- Base station includes **WAN connectivity and persistent data storage** for the collection of sensor patches.
  - Wireless WAN connection will be wireless (two-way satellite)
  - Reliable components enclosed in environmentally protected housing, and provided with adequate power
    - For example, a ranger station

System Architecture

- The architecture needs to address the possibility of disconnection at every level.
  - Each layer (sensor nodes, gateways, base stations) has some persistent storage which protects against data loss in case of power outage.
  - Each layer also provides data management services
    - Sensor level: data logging
    - Base station: full-fledged relational database service
    - Gateways: some database services over limited window of data
  - System prefers long-latency of data transfer to data loss
    - Uses "custody transfer" model, which is similar to SMTP messages or bundles

System Architecture

- Users interact with the sensor network data in two ways
  - <u>Remote</u>: users access the replica of the base station database
    - Allows for easy integration with data analysis and mining tools
    - Provides remote control of the network
  - <u>On-site</u>: users use small PDA-sized device (gizmo) to directly communicate with the sensor patch
    - Provides the users with a fresh set of readings about the environments and monitors the network
    - Allows users to interactively control the network parameters by adjusting the sampling rates, power management parameters and other network parameters.
    - Is especially useful during the initial deployment and during re-tasking of the network

Implementation Strategy

- Sensor network node
  - Uses UC Berkeley motes
- Sensor Board
  - Mica weather board provides sensors that monitor changing environmental conditions
  - Mica weather board includes temperature, photoresistor, barometric pressure, humidity, and passive infrared sensors
  - The sensors are chosen based on
    - high interchangeability and high accuracy
    - shorter startup time
  - The unique combination of sensors in Mica can be used for a variety of aggregate operations
  - Mica considers Interoperability

Implementation Strategy

- Energy budget
  - Many habitat monitoring applications need to run for nine months—the length of a single field season
  - Since different nodes have different power requirements, we need to budget power with respect to the energy bottleneck of the network
  - The baseline life time of the node is determined by the current draw in the sleep state

    --minimize power in sleep mode

Operation	nAh
Transmitting a packet	20.000
Receiving a packet	8.000
Radio listening for 1 millisecond	1.250
Operating sensor for 1 sample (analog)	1.080
Operating sensor for 1 sample (digital)	0.347
Reading a sample from the ADC	0.011
Flash Read Data	1.111
Flash Write/Erase Data	83.333

Table 2: Power required by various Mica operations.

Implementation Strategy

- Sensor deployment
  - To withstand the variable weather conditions on DGI, environmental protective packaging that minimally obstructs sensing functionality is used
- Patch gateways
  - Using different gateway nodes directly affects the underlying transit network available
  - Current two designs
    - An 802.11b single hop with an embedded Linux system
    - A single hop mote-to-mote network

    These two designs differ in communication frequency, power requirements, and software component. Currently, only mote solution is used

Implementation Strategy

- Base-station installation
  - To provide remote access to the habitat monitoring networks
  - The collection of sensor network patches is connected to the Internet through a wide-area link---a two way satellite connection
- Database management system
  - Uses Postgres SQL database
  - Stores time-stamped readings from the sensors
  - Is replicated every 15 minutes over the wide-area satellite link to Postgres database in Berkeley

Implementation Strategy

- User interface
  - Many user interfaces will be implemented on top of the sensor network database
  - Gizmo design for local users is not well developed yet

Results

- The sensor network has been deployed for four weeks as of the writing of this paper
- Occupancy data are down in the figure

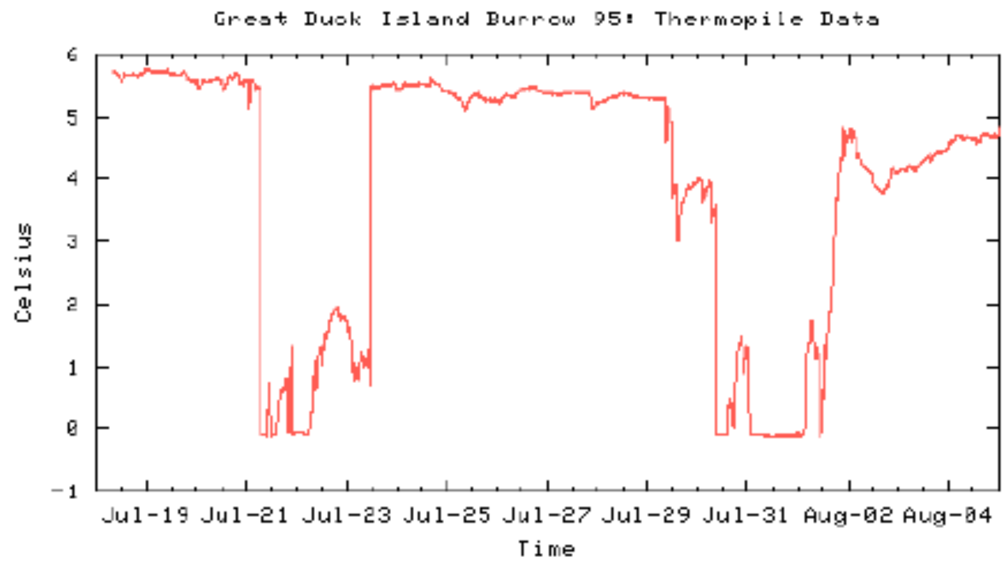

Figure 4: Thermopile data from a burrow mote on GDI during a 19-day period (July 18, 2002 to August 5, 2002).

Discussions

- All system components must operate in accordance with the system's power budget
- In a running system, the energy budget must be divided amongst several system services
  - Data sampling and collection
  - Communications
  - Network re-tasking
  - Health and status monitoring
- Data sampling and collection
  - By analyzing the requirements we can place a bound on the energy spent on data acquisition
  - Trade the cost of data processing and compression against the cost of data transmission

Discussions (cont.)

- Communications
  - Power efficient communication paradigms for habitat monitoring must include a set of routing algorithms, media access algorithms, and managed hardware access.
    - The routing algorithms must be tailored for efficient network communication while maintaining connectivity when required to source or relay packets
      - Most efficient for low duty cycle sensor networks is to simply broadcasting data to a gateway during scheduled communication period. (single hop)
      - Multi-hop scheduled protocol must be used for hard to reach research locations that are beyond the range of a single wireless broadcast from mote to gateway
        - Scheduled communication
        - Low power MAC protocol

Discussion (cont.)

- Network re-tasking
  - Adjust the functionality of individual nodes
    - Simple parameter, such as scalar parameters, may be adjusted through the application manager
    - Complex functionality adjustment may be implemented through virtual machines like Mate or reprogramming
- Health and status monitoring
  - Health and status messages sent to the gateway can be used to infer the validity of the mote's sensor reading
  - Including battery voltage level in transmitted sensor reading helps remote analysis of node failures

Conclusion

- Habitat and environmental monitoring represent an important class of sensor network applications
- Sensor network system must deliver the data of interest in a confidence-inspiring manner
- Tight energy bounds and the need for predictable operation guide the development of application architecture and services

Further Discussion

- The authors claimed in the paper that the work is largely representative of the domain. Do you think so after reading the paper?
- Health and status monitoring is important. Battery voltage seems to provide limited information for inferring the validity of the mote's sensor readings. No other methods are brought up in the paper.
- Difference between scheduled communication and low power MAC protocols?