Energy-Efficient Surveillance System Using Wireless Sensor Networks

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OUTLINE

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- Time-Driven System Design
- Implementation
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- Conclusions
Introduction

- **Energy awareness** is the key research challenge for sensor network protocol design.
- The primary goal is to **track the position of moving targets** in an energy-efficient and stealthy manner.
Introduction (cont.)

- APPLICATION REQUIREMENTS
  - Longevity
  - Adjustable Sensitivity
  - Stealthiness
  - Effectiveness
The author deployed 70 MICA2 motes, along a 280 feet long perimeter in a grassy field.

Each motes is equipped with a 433 MHz radio with 255 selectable transmission power settings.

Each mote is equipped with \textbf{magnetic(HMC1002)}, acoustic, and photo sensors on it.

Repeaters will be deployed as gateways.

The camera devices are controlled by the laptop.
System Overview

- Energy-Efficient Tracking System
System Overview (cont.)

- It is implemented on top of TinyOS.
- Time sync for synchronizing the local clocks of the motes with the clock of base station.
- The localization module is responsible for ensuring that each mote is aware of its location.
- The Sentry Service for power management.
- The Sentry service conserves energy of the sensor network by selecting a subset of motes, which we define as sentries, to monitor event.
System Overview (cont.)

- **Group mgmt** for detection and tracking of events
- The system can reprogram the motes dynamically with new configuration parameters
- The display software also has the logic to filter out any residual false alarms
Our multi-phase cyclic process satisfies following design objectives:

- The **constrained bandwidth** in MICA2 doesn’t allow a high concurrency in communication.
- We can confine the **exposure of sensor activity** within a **short period time** during the initialization phase.
- Sentry rotation responsibility among motes in order to achieve uniform **energy dissipation across the network**.
• Time-Driven System Transition
Phase I: Basic Initialization

- Time Synchronization
  - Using a synchronization beacon broadcast multiple times by the base station at the beginning of each initialization cycle
  - Receivers take the timestamp from the beacon plus a transmission delay as their own local time
  - The timer drift accumulated overtime is rectified by a new system cycle.
Phase I: Basic Initialization (cont.)

- **Diffusion Tree Creation**
  The author encountered two practical issues when implementing the diffusion tree algorithm on the MICA2 platform:
  - *Mote Failures*
  - *Asymmetric Links*
Phase I: Basic Initialization (cont.)

- **Dynamic Reconfiguration**
  The capability of dynamic reconfiguration facilitates retasking of sensor networks in future changes of mission requirements

  - The system supports reconfiguration with the **time synchronization message**
  - The base station piggybacks the values of the **control parameters** in the synchronization message
  - Motes adopt the new values when they accept the synchronization message
Time-Driven System Design (cont.)

- Time Driven System Transition
Phase II: Neighbor Discovery

- Motes notify their neighbors by locally broadcasting **HELLO** messages.
- Hello Message includes:
  - Identifier
  - Status of mote (sentry or not)
- This local information is used to build a **neighborhood table** at each mote, and forms the basis for **sentry selection** in Phase III.
Time-Driven System Design (cont.)

- Time Driven System Transition
Phase III: Sentry Selection

- A mote decides to become a sentry if any one of the following conditions holds
  - It is one of the internal nodes of the diffusion tree
  - It discovers that none of its neighbors either is a sentry or is covered by a sentry
- Two practical issues need to be solved to make this scheme work in a running system
  - Race Conditions (SENTRY DECLARE message)
  - Energy Balancing and Efficiency
Time-Driven System Design (cont.)

- Time Driven System Transition
Phase IV: Status Report

- All the motes use the backbone to report their status to the base station in Phase IV.
- The reports can be used to visualize network topology, residual energy distribution and sentry distribution and detect any failed motes.
- Since the sole purpose of Phase IV is for visualization and debugging, it is optional.
Time-Driven System Design (cont.)

- Time Driven System Transition
Phase V-A: Power Management

- We have proposed and implemented two different schemes to control non-sentry mote between sleep-wakeup cycle
  - Proactive control
  - Reactive control

[Diagram showing the sleep-wakeup cycle for proactive and reactive sentry motes with timer-driven events]
Phase V-A: Power Management (cont.)

- The reactive scheme is more stealthy, because no unnecessary beacons are sent unless an event occurs.
- The non-sentries do not periodically synchronize their clocks with their sentries, the clocks of non-sentry motes may drift in course of time.
- It has to retransmit the awake beacon multiple times in order to awaken non-sentries when an event occurs.
Phase V-B: Event Tracking and Reporting

- **When an event happens**, motes wakeup and start tracking, **when event disappears**, motes toggle back to power management states.
- The system we have designed also performs in-network aggregation by organizing the motes into **groups**.
- All motes that detect **the same event join the same group**.
- Group members periodically report to the group leader.
Phase V-B: Event Tracking and Reporting (cont.)

- **Degree of aggregation (DOA)**
  - It is defined in our system as the *minimum number of reports about an event* that a leader of a group waits to receive from its group members before reporting the event’s location to the base station.
MICA2’s capabilities have
- Selectable transmission power setting (255 channel)
- A snooze function with up to six sleep modes
- A wireless reprogramming capability

The paper divide system components into four major groups
The implementation of our system on the MICA2 motes was driven by several requirements that arise from platform limitations:

- Energy Efficiency
- Bandwidth Efficiency
- Simplicity
- Flexibility
TinyOS doesn’t have a part of the most important issues were the following:

- Concurrency Control
- Packet Scheduling
- Aggregation
The first set of experiments evaluate the MICA2 radio in different environments. We measure a set of MICA2 communication ranges under different sending power settings with two senders and one receiver.
Performance Evaluation (cont.)

Evaluation of Capability of MICA2 Radio

- MICA2 communication ranges under different antenna lengths and different elevations above the ground.

<table>
<thead>
<tr>
<th>Table 1: Impact of Antenna Lengths on RF Range</th>
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<tbody>
<tr>
<td>Antenna</td>
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<td>17.3 cm</td>
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<td>34.6 cm</td>
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<tr>
<th>Table 2: Impact of Elevations on RF Range</th>
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<tbody>
<tr>
<td>Elevation</td>
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<tr>
<td>Mote A</td>
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<tr>
<td>Mote B</td>
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</tbody>
</table>
Impact of Aggregation on Transmission Overhead

- DOA-min number of reports about an event that a group leader waits to receive before send to base
- Car speed 5-10 mph
- The author deployed 70 MICA2 motes of a road at a distance of 7-8 ft
Performance Evaluation (cont.)

**Impact of Aggregation on False Alarms**

- **False alarms** are normally caused by events such as burst distortions of readings due to power state transitions and incorrect readings from faulty sensors.

- One way to improve the reliability of event detection is to increase the redundancy

![Graph showing impact of aggregation on false alarms]
The authors were able to reduce the latency and false negatives for higher degree of aggregation (DOA ≥ 4), by increasing the speed of the vehicle from about 5 mph to about 10 mph.

A higher degree of aggregation may adversely affect the tracking performance.
In order to compare the message overhead between the reactive and proactive schemes, using the Nido simulator (for Tiny os)  
- 10 motes capable of magnetic sensing were deployed.  
The duration of each simulation run was 600 s.  
The awake Duration of the motes was fixed at 2 s for each run.
Performance Evaluation (cont.)

Expected Lifetime of a Sensor Network Using Sentry-based Power Management

Impact of Sleep Duration on Power Consumption

- Number of active hours per day
- Time elapsed

- Expected lifetime (days)
- Voltage (V)
Conclusions

- Most of the published work studies an individual protocol and performs evaluations via simulations.

- In contrast, in this paper implement an entire integrated suite of protocols and application modules and evaluate the performance on a system composed of 70 MICA2 motes in a realistic outdoor setting.