DEVELOPMENT OF A LOW COST, LOW POWER WIRELESS SENSOR NETWORK

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Outline

- Motivation
  - Existing WSN (Wireless Sensor Networks)
  - Objectives of research
- Background
  - WSN Layouts
  - Communications protocols
  - Energy efficient design
- UVM-WSN Architectural Design
- Power Testing
- Conclusion
Motivation for WSN Research

- Collect data over a wide area on a near continuous basis
- Remove the need for wire infrastructure
- Monitor environmental parameters
- Rapidly growing area of interest
- Improve upon existing designs by emphasizing low cost and low energy requirements

Existing Wireless Sensor Networks

- NASA : JPL units monitor conditions in a botanical garden
- 19 Nodes in the network
- Multi-Hop topology
Existing Wireless Sensor Networks (cont.)

- UC-Berkeley: MOTES used to monitor Snow Petral nests on a remote island without intrusion into the nesting environment
- 30+ nodes
- Multi-Hop topology

Specific Sensor Nodes

- UCLA WINS units
  - Early sensor node
- UC-Berkeley MOTES
  - Common platform
- Microstrain Glink
  - Application specific accelerometer
- JPL sensors
  - Deep space use
Problems With Existing WSN

- Not cost effective for large scale deployment
  - MOTES ~$215 per unit w/o sensor board
- Power intensive
  - MOTES last only a few days at a high polling rate on two AA batteries
  - Minimize battery swapping
- Application specific

Research Objectives

- Develop low cost, low power hardware that can implement a hierarchical WSN
- Develop a power aware routing algorithm for moving data within a WSN
- Evaluate the cost and power performance of this WSN with respect to other implementations
Background

- WSN Layouts
- Energy Conservation
  - Energy Aware Routing Protocols
  - Hardware design
- Communication Protocols

WSN Layouts: Hierarchical Layout vs. Flat Layout

![Diagram showing WSN Layouts: Hierarchical Layout vs. Flat Layout](image)
WSN Layouts: Flat Topology

- Uniform node functionality/complexity
- Advantages
  - All nodes can perform any task
- Disadvantages
  - Every node has same functionality and consequently, the same power and cost requirements

WSN Layouts: Hierarchical

- Nodes are divided into different classes
  - Classes based upon functionality
- Advantages:
  - Cost can be reduced since all nodes do not have to meet the same functionality requirements
  - Power is reduced as a result of reduced functionality
- Disadvantages
  - All nodes can’t perform all tasks (e.g. packet forwarding)
Energy Conservation: LEACH

- An energy aware routing protocol
  - Attempts to prolong Quality of Service (QOS) by distributing power intensive tasks
  - All nodes take turns acting as the Clusterhead (the most power intensive node)
  - Results in better QOS over lifetime
- picture

LEACH Effectiveness

![LEACH Effectiveness Graph](image-url)

- MTE routing
- LEACH routing

Number of Active Nodes vs. Epochs
Energy Conservation: LEACH Disadvantages

- Assumes all nodes can hear each other
  - Not a good assumption in a random distribution of sensor nodes
  - All nodes must be constantly listening to facilitate routing protocol
- Assumes a large difference between Clusterhead power requirements and normal node power requirements
  - A small difference would cause LEACH to be less effective

Energy Conservation: Energy Aware Routing

- Similar to LEACH, but is not restricted to clusters
- Advantages
  - Attempts to gain better QOS
- Disadvantages
  - Overhead to implement protocol may overcome the effectiveness of the protocol
Energy Conservation: Hardware Design

- Hardware “Hooks”
  - Allows software developer to closely control the hardware layer on the node
    - Turn up and down the power of the transmitter
    - Power up and down the receiver
    - Put the microcontroller in sleep mode
    - Power down sensor units

Communications Protocols: TDMA

- Time Domain Multiple Access
- Uses a synchronization pulse to assign frames in which a user may transmit on the channel.
  - Advantage
    - Fully utilizes the channel when loads are high
  - Disadvantage
    - Everyone must be able to hear the pulse for synchronization
ALOHA

- Contention based protocol
  - A user uses the channel whenever they are ready
  - If a collision occurs, the user retransmits
- Suitable for low channel loads
  - Higher channel loads result in more collisions

ALOHA Throughput

![Graph showing ALOHA throughput vs number of nodes]
Communications Protocols: CSMA

- Carrier Sense Multiple Access
- Contention Based Protocol
  - User listens before transmitting. If the channel is being used, the user will wait a random amount of time before attempting to transmit again.
- Fewer collisions on the channel

CSMA Throughput
UVM-WSN

- How are some of these ideas used in the UVM implementation?
  - ALOHA Protocol
  - CSMA Protocol
  - Hierarchical Layout
  - Voluntary Assisted Energy Aware Routing Protocol (VAARP)
  - Close Software Control of the Hardware Layer

UVM-WSN Hierarchy of Nodes

- Increasing Node Density in a WSN

- Low Cost, Low Functionality, Low Power Sensor Nodes
- Mid Range Nodes
- High Cost Functionality and power
- Gateway
- Hopper
- ALOHA

Node Type
ALOHA Protocol in the UVM-WSN

- Lowest class of node "ALOHA" node implements the ALOHA protocol with no provision for collision
  - Acceptable because data is non-critical
  - Permits the node to be developed with no receiver.
  - Expect channel load to be low (40 sensors, 0.06 Erlangs)
- Reduces cost and power
  - Less hardware to buy and power
The *ALOHA* Node

- **Reduced Cost**
  - MOTES ~$215 – *ALOHA* ~$15
- **Reduced Power**
  - No Receiver
- **Small Size**
- **Simple Bus Interface**
  - I2C to sensor board

*ALOHA* Node Summary

- Reads sensor array and transmit data very infrequently (≈14 seconds)
  - Temperature data in natural setting
- Sleeps until watchdog timeout between transmissions
  - Current is less then 1 mA in sleep mode
CSMA Protocol in the UVM-WSN

- Middle class of nodes: The “Hopper”
- Can perform packet forwarding tasks for the ALOHA node that result in a multi-hop network topology
  - Implements the CSMA protocol for transmission as a receiver is available on the node.
  - No additional costs in power or node price to implement CSMA

The *Hopper* Node

- Similar in functionality to a MOTES node in a flat topology network
- Cost: ~$29
- Small Size
- Simple bus interface
  - I2C to sensor board or to *Gateway* node
**Hopper Node Summary**

- Transmits data from its own sensor array infrequently (~14 seconds)
- Forwards packets from *ALOHA* or other *Hopper* nodes in a multi-hop network topology
- Can interface to a *Gateway* board to transfer data to an Ethernet connection

**Oscilloscope Demo**

- Shows multi-hop action of *Hopper* nodes
- Shows data packets transmitted from *ALOHA* nodes
The *Gateway Node*

- Provides an interface between the UVM-WSN and the outside world
- Implements a TCP/IP stack
- Communicates with a *Hopper* node via the I2C bus
- Implements the power-over-Ethernet standard

*Gateway Node Summary*

- Most complex of the hierarchy of nodes
- Allows direct connection to the UVM-WSN as an embedded server
- Not complete at this time
Website Demo

- HP VEE polling a serial connection to the WSN.
- Updates periodically on incoming *Hopper* packets

VAARP

- Attempts to improve QoS through energy aware routing
- Implemented by the *Hopper* nodes to distribute packet forwarding tasks
- Compares rates of discharge and attempts to offload serviced *ALOHA* nodes to other *Hopper* nodes on the channel.
VAARP behavioral description

- Every epoch of operation, each *Hopper* node attempts to offload responsibility for an *ALOHA* node to another *Hopper* node.
- Transmits a packet with the *ALOHA* node to be offloaded and the current rate of discharge.
- Other nodes choose to assist or not based upon their own discharge rates.

VAARP Simulation Setup

- VAARP Simulations
  - VAARP vs. Static
  - VAARP vs. Static for midlife
  - VAARP performance vs. number of *Hopper* nodes
VAARP vs. Static Simulation Results

VAARP vs. Static Simulation Results (cont.)
VAARP Simulation Result
Midlife Die-off Scenario

VAARP vs. Number of Hopper Nodes

- Determines the number of *Hopper* nodes required to support an array of 40 *ALOHA* nodes.
VAARP simulation conclusions

- VAARP is effective in adapting to recover from lost *Hopper* nodes
- VAARP performs best under the following criteria:
  - A large discrepancy between normal operating power and transmission power in a node
  - Large differences in the number of *ALOHA* nodes that different *Hopper* nodes are servicing.
- VAARP may not be worth the trouble for small networks
  - Shown by simulation and verified in power test

Power Test

- Quantifies the power consumption of the UVM-WSN
- Compares power performance of UVM-WSN with and without VAARP
- Compares UVM-WSN with Berkeley MOTES network
UVM-WSN Power Test Setup

- Monitored behavior of *Hopper* nodes during each epoch
- Monitored power consumption of *ALOHA* nodes as a whole and an individual unit
- Recorded values for each epoch

Results from UVM-WSN

<table>
<thead>
<tr>
<th>Node</th>
<th>On</th>
<th>Off</th>
<th>Lifetime hrs (two AA)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Hopper</em></td>
<td>42 mW</td>
<td>33 mW</td>
<td>108</td>
</tr>
<tr>
<td><em>ALOHA</em></td>
<td>8 mW</td>
<td>.16 mW</td>
<td>23016</td>
</tr>
</tbody>
</table>
Results from MOTES

<table>
<thead>
<tr>
<th>Mode</th>
<th>listening (no sensor board) mW</th>
<th>listening (with sensor board) mW</th>
<th>Lights on listening mW</th>
<th>Full Transmit mW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>49.41</td>
<td>58.24</td>
<td>99.45</td>
<td>123</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Network</th>
<th>Total Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>UVM-WSN with static routing</td>
<td>104.01 mW</td>
</tr>
<tr>
<td>UVM-WSN with VAARP</td>
<td>104.07 mW</td>
</tr>
<tr>
<td>TinyDB MOTES network</td>
<td>407.66 mW</td>
</tr>
</tbody>
</table>

Results of VAARP testing

- **Case 1 Static Routing**
- **Case 1 VAARP**
- **Case 3 Static Routing**
- **Case 3 VAARP**
Conclusions From Research

- Hierarchical design effective in reducing cost and energy consumption of WSN
- UVM-WSN implements a reduced cost, low power sensor network
- VAARP effective only under certain scenarios or circumstances such as harsh environments

Future Work

- Change transmitter/receiver pair to higher bit rate more reliable set and a different modulation scheme
- Implement an error correction and checking code
- Implement data logging functionality in the Hopper node firmware
- Optimize Hopper node for power efficiency
Future Research

- Investigate power scavenging to remove demand for batteries
- Direct node localization using GPS or echo location
- Investigate frequency hopping in WSN
- Determine throughput of a channel when users are utilizing both the ALOHA and CSMA protocols

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Questions?