Radio-Triggered Wake-Up Capability for Sensor Networks

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A presentation of the paper:

Slides adapted from:
Wireless Sensor Networks Power Management Prof. John Stankovic, CS Dept, Univ. of Virginia
Real-Time Communication in Wireless Sensor Networks Richard Arps, Robert Foerster, Jungwoo Lee, Hui Cao
Scheme Design Goals

- Provide energy efficient sensing coverage for a geographic area covered by sensor nodes
  - Extend system life
    - Reduce total energy consumption
    - Minimize sensor wake-up periods
Power Costs - Examples

- **Motes**
  - ATmega 128 - six working modes with different energy saving features
    - Most aggressive sleep can be very small % of active working mode
      - Working - 8 mA
      - Sleep - 100 microA
  - **Radio**
    - 10 microA sleeping
    - 7.5 mA Rcv
    - 12 mA Tx
Power Management Schemes

- Scheme discerns application and decides efficient wake-up/sleep schedule
  - Should not trade-off performance
  - Application Specific
  - Often involves collaboration with other nodes in network
  - Needs time synchronization service
Hardware layer

- Turn off/on
  - CPU
  - Memory
  - Sensors
  - Radio (most expensive)
  - Fully awake ............ Deep Sleep

- SW ensures a node/components are awake when needed
Power Management - Communication Coverage

Minimum awake - still communicate
Sensing Coverage
Nodes present in Network
Possible Solution (1)

- **Periodic wake-up**
  - Each (non-awake) node has a sleep/wakeup duty cycle based on local timer
    - Listen for stay awake message
  - *Most current systems use this technique*
  - Application dependent, often complicated, wastes energy
    - E.g., correct duty cycle depends on speed of targets, sensing ranges, types of sensors, ...
    - May miss wakeup call
Possible Solution (2)

- **Special** low power hardware stand-by component that *(always)* listens for a wakeup beacon (not the full radio component)
  - Uses extra energy (but not as much as full radio component)
Other Related Work

- **UCBerkeley and Intel Research**
  - Wake-up messages awakens whole network
  - In every 4 sec node must be awake for 100ms
  - Timer-based protocols and special hardware needed

- **SMAC**
  - Nodes gauge channel and sync periodically with neighbors
  - Duty cycle of 30-40% achieved
Radio-Triggered Scheme

- **Just-In-Time Wake-up Capability**
  - A node does not wake up until it is needed
  - It uses no active listening energy
  - Uses radio-triggered hardware that extracts energy from the electromagnetic energy in the wakeup signal itself

- Not RFID - they employ powerful readers to send strong radio signals
Application Scenario

- A small number of nodes stay awake
- Most of the network sleeps
- Rare events
Application Scenario

- Awakened nodes detect an event
- Messages are sent to wake up other nodes
Radio-Triggered Requirements

- Node should turn ON immediately
- No false wake-ups
- Should not miss wake-up calls
- While sleeping, expend same amount of energy as schemes without radio-triggered
Radio-Triggered Hardware

- lone antenna
- special radio frequency
- low cost
Basic Radio-Triggered Hardware

Wake up!

Task:
- collect EM energy
- distinguish trigger signals from others
- drive ‘start’ voltage

0.6 V
Effectiveness of basic circuit

\[ P_r = \frac{P_s G_s G_r \lambda^2}{(4\pi \cdot D)^2} \]

- Only 10 ft transmission secured if Berkeley Mica motes used

Gain needed to get 0.6V at \( V_{out} \)
Improve basic circuit to extend range

- Reduced voltage threshold requirement will increase range
  - Use comparator to measure output voltage
  - If $V_{in}$ too low, amplifier can be employed.
Scheme Evaluation

• Application scenario
  - 1000 random motes deployed
  - 10 events daily, each lasts 2 minutes
  - Vehicle tracking Application
  - Nodes use two 1600mAh AA batteries

• Compare the following schemes
  - Always-on
  - Rotation (wake-up/sleep)
  - Radio-Triggered
Solution – Is it worth it?

• Scheme I: Always-on (No power management)
  - The node is on and actively sensing until it is out of power
  - 1% of the energy is used to track vehicles, 99% is used in a peeking state (uselessly sensing for potential passing vehicles)
  - Lifetime 3.3 days
Solution - Is it worth it?

- Scheme II: Rotation-based (Periodic wake-up)
  - Nodes are awakened wirelessly by wake-up messages
  - Duty cycle 4.7%
  - 21% of the energy is used to track vehicles, 7% used in sleeping mode, and 72% is used in peeking state
  - Lifetime 50 days

Energy wasted!!!
Solution - Is it worth it?

- **Scheme III: Radio-triggered**
  - Nodes keep sleeping until events of interest happen
  - Nodes are awakened wirelessly by wake-up messages
  - 74% of the energy is used to track vehicles, 26% used in sleeping mode (minimal CPU energy)

- Lifetime - 178 days
Network Lifespan Comparison

Comparison of lifespan

always-on | rotation scheme | radio-triggered
---|---|---
0 | 50 | 250

Lifespan (days)
Circuit Design Improvements

- Add capacitor and transformer
  - Capacitor rise time and transformer introduce latency
  - Three times operating distance can be realized (30 ft) if 5ms latency acceptable
Circuit Design Improvements

- **Add Amplifier**
  - Use amplifier with low sleep current (880nA: 0.8% of 100uA)
- Does not compromise functionality; will help increase range
Conclusions

• Extracts energy from the radio signals

• Hardware provides wake-up signals to the network node without using internal power supply

• Adequate antenna: does not respond to normal data communication, not prematurely wake up

• Highly flexible and efficient
  - Zero stand-by power consumption and timely wake-up capability

This slide courtesy: Real-Time Communication in Wireless Sensor Networks Richard Arps, Robert Foerster, Jungwoo Lee, Hui Cao

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Questions?