Feasibility and Benefits of Passive RFID Wake-up Radios for Wireless Sensor Networks

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Presented by
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Outline

- Introduction
- Related work
- Our device: WISP-Mote
- Performance evaluations
- Conclusion and future works
Introduction

- Idle listening: a large source of energy drain in Wireless Sensor Networks (WSNs)

- Two solutions:
  - Duty cycling – nodes wake up periodically regardless of whether or not any other nodes have data to transmit to them
  - Wake-up Radio – nodes are awakened by neighboring nodes remotely when necessary
Wake-up Radios

- Passive wake-up radios:
  - Do not consume energy at the receiver side
  - Shorter wake-up range than active

- Active wake-up radios:
  - Consume energy at the receiver side
  - Better wake-up range than passive
Related Work

- J. Ansari et al. [1] presented an implementation using a Radio Triggered Wake-up with Addressing Capabilities (RTWAC). 876nA, 10 m wake-up range.
- Lin Gu et al. [2] proposed a passive radio wake-up circuit that theoretically could operate at a range of 10 feet with 5 ms latency based on SPICE simulation results.
- If add a comparator and an amplifier (1230nA) to the wake-up circuit, it could theoretically reach up to 100 feet with 55 ms latency.
- However, there are no existing physical implementations of passive wake-up radios described in the literature.
Related Work

- Jurdak et al. [3][4] proposed an **RFID-based** wake-up mechanism, namely RFIDImpulse, and presented analytical models of energy consumption.
- Their results show that RFIDImpulse performs better than BMAC and IEEE 802.15.4 (without wake-up radio) for low and medium traffic scenarios.
- However, an important assumption is that all nodes have the capability to wake up their neighbors, which is not feasible in real scenarios, due to the considerable amount of energy consumed by the RFID reader as well as its large size.
How to Wake Up a Node?

- Microcontroller: provide computation and data processing, control the radio and sensors, and manage memory and power.

- Watchdog timer: wake up the system after a timer fires (duty cycling).

- The only other way to wake up a node from the sleep state is to send an external interrupt signal through certain pins of the MCU.
  - We used RFID tags to send external interrupt signal.
Intel WISP
Intel WISP (Cont.)

- A WISP (Wireless Identification and Sensing Platform) [5] is a passive RFID tag with simple sensing and computing capabilities, developed by Intel Research for research purposes.

- A WISP can be powered and read by an off-the-shelf UHF RFID reader.
Device specifications

**WISP**
- TI MSP430 F2132 (512B RAM, 8K+256B Flash)
- Accelerometer and Temperature Sensor

**Tmote Sky** [6]
- TI MSP430 F1611 (10k RAM, 48k Flash)
- 250kbps 2.4GHz IEEE 802.15.4 Chipcon Wireless Transceiver
- Humidity, Temperature, and Light sensors
- Fast wakeup from sleep (<6μs, typically 292ns)
Our device: WISP-Mote
Wake-up Range Improvement

- The communication range of the WISP is limited, less than 2 meters, if it runs the UHF RFID standard C1G2 protocol.

- To extend the wake-up range, we disable the WISP-to-reader communication and eliminate all other computation burdens in the WISP MCU.

- Using this approach, we could extend the wake-up range to approximately 5 meters.
Wake-up Probability (w/ C1G2)
Wake-up Probability (improved)
## Energy Consumption Measurements

<table>
<thead>
<tr>
<th>Operation</th>
<th>Average current consumption</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wake-up</td>
<td>10.4 mA</td>
<td>5 ms</td>
</tr>
<tr>
<td>Transmit 12 byte packet</td>
<td>18.2 mA</td>
<td>30 ms</td>
</tr>
<tr>
<td>Receive and idle listening</td>
<td>20.2 mA</td>
<td></td>
</tr>
<tr>
<td>Sleep</td>
<td>0.2 mA</td>
<td></td>
</tr>
</tbody>
</table>
Use of WISP-Motes in a Data Mule Scenario
Performance Evaluations

**WISP-Mote**
- Once a MULE is within the *wake-up range* of a node, the node is awakened and senses the channel if it has buffered data.
- If the channel is busy, the node will remain active and sense again in the next slot.
- Once the channel is free, the WISP-Mote will start transmitting its buffered data.

**Duty cycling**
- Nodes periodically wake-up, and if the node has buffered data, it will sense the channel.
- If a node receives an Adv packet from a MULE, it responds by sending its buffered data.
- If the MULE is busy, the node will keep active and sense again in the next slot.
- If there are no MULEs within range, it will return to sleep.
Main Assumptions

- Propagation delay is ignored.
- We consider slotted CSMA MAC and assume there are no collisions and no link failures. Once a node senses a free channel, it will send a packet with guaranteed arrival at the MULE.
- The MULE’s appearance in one time slot is enough for a node to detect it and finish one packet transmission.
- MULEs have the ability to communicate directly to the data sink. Therefore, packet delay is counted from the time a packet is generated until the time it is delivered to a MULE.
- We ignore the energy cost for sensing activities as these will not impact the performance evaluation.
Simulation Setup

- In our network simulations:
  - Nodes are uniformly randomly deployed in a 200m x 200m square region with a density of 0.001 nodes/m².
  
  - MULEs begin with uniformly random locations, and they move at each time slot according to a Random Direction Mobility Model: Each MULE randomly selects a speed from [5 m/s, 15m/s] and a direction from [0, 2\pi] and moves according to this speed and direction until it reach the network boundary.

- Each node generates a packet every 10 minutes.

- We compare the average packet delay and the energy consumed in 2 hours of operation for the WISP-Mote scenario and for the duty cycling scenario.
Duty Cycling vs. WISP-Mote

![Graphs showing the comparison between Duty Cycling and WISP-Mote with varying MULE quantities and duty cycle percentages. The graphs depict the average packet delay and energy consumption per node.](image-url)
Effect of Packet rate

![Graph showing the effect of packet rate on average packet delay and energy consumption per node.](image)
Effect of Mobility Models

- Average packet delay (s)
  - Snake
  - Random Direction
  - Random Walk

- Energy consumption per node (mJ)
  - Snake
  - Random Direction
  - Random Walk

MULE Quantity

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Our contributions

- Physically implemented a passive RFID wake-up device using existing hardware: Intel WISP and Tmote Sky motes

- Measured the power consumption of WISP-Mote in different operation stages

- Showed the benefits of WISP-Mote by comparing with a duty cycling architecture for a single-hop Data MULE data collection scenario
Future Work

- Develop the addressing capability with improved wake-up range

- Investigate on a more realistic MAC protocol for network simulations
References

References

Thank you!