Wireless Sensor Networks

Wake-up Receivers

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Sensor Networks

- Energy is the main concern for WSN
- Potential energy waste sources:
  - Idle Listening
  - Overhearing
  - Retransmission
  - Overmitting
- Reduce power consumption: Duty-cycling
MAC Protocols

- Medium Access
  - Pure-synchronous
Medium Access
- Pseudo-asynchronous
MAC Protocols

- **Medium Access**
  - Pure-asynchronous

Sender

Receiver

Wake-up Signal

Send DATA

Wake-up Front-End

Activate

Wake-up ACK

Receive DATA

DATA ACK

Main Node

time

UNI FREIBURG
Wake-up on Demand Radio

- Communication occurs only when required

Benefits:
- Nodes always in a sleep phase
- Avoid the energy waste sources
- Ultra low power energy consumption

Challenges:
- Hardware cost and Complexity
- Wake-up signals energy
- Wake-up distance
- Network topology
Wake-up Receiver Design

- Gamm et. al., “Low power wake-up receiver for wireless sensor nodes”, International Conference on Intelligent Sensors, Sensor Networks and Information Processing (ISSNIP'10), Brisbane, Australia, Dec. 2010
Wake-up Receiver Design

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Wake-up Receiver Design

- Gamm’s Design:
  - Operating frequency 868 MHz
  - ASK Modulation
    - Wake-up chip operates on 125 KHz
    - Transform 868 MHz to 125 KHz
  - Power consumption < 8.2 µW
  - Receiver sensitivity -53 dBm
  - Wake-up distance up to 100 m
Wake-up Receiver Design

Wake-up Signal Construction:
- Switch the transceiver on/off (ASK)
- Generate 125 KHz periods
- Data rate affects the signal length and distance
Wake-up Receiver Design

- Wake-up Signal Construction:
  - Carrier Burst to stabilize the Wake-up chip
  - Preamble
  - Wake-up Address

![Waveform Diagram](image)

- Power consumption 1.3 $\mu$W
- Receiver sensitivity -55 dBm
- Wake-up distance up to 31 m
Wake-up Receiver Design

- Spenza/Magno Design:
  - Data rate: Trade-off between coverage distance and power consumption

(a) Wake-up latency

(b) Wake-up probability vs. distance
Wake-up Receiver Algorithms

- Motivation to design new protocols:
  - New protocols to adequate the new hardware
  - Wake-up receivers Problems
    - Short wake-up ranges
    - Higher wake-up signal energy compared to data messages
  - Minimize the wake-up signal transmission
  - Maximize the wake-up range
  - Unknown nodes’ locations
Wake-up Receiver Algorithms

- **Requirement:**
  - Nodes’ density guarantee coverage and connectivity of Wake-up graphs

- **How can we reach every single node?**
  - Establish a Minimum Connected Dominating Set
  - The wake-up problem is an Online-variant of the MCDS
Wake-up Receiver Algorithms


- Computing MCDS-UDG is NP-Complete [Lichtenstein, 1982]
  - All deterministic algorithms for UCDS-UDG has a competitive ratio at least $n/2 - 1/2$. 

![Diagram of a graph with vertices s, u1, ..., un-2, and t, with edges connecting s to u1 and u1 to t]
Wake-up Receiver Algorithms

- A straight-forward solution is a grid based algorithm
  - Achieves a constant competitive ratio $5 + o(1)$
  - Flooding on the grid

```
Algorithm 1: Grid based wake-up algorithm
Send wake up from $s$
$G_{\text{done}} \leftarrow \{\text{cell}(s)\}$
$G_{\text{to-do}} \leftarrow \{\text{cell}(u) : \{u, s\} \in E \setminus \{\text{cell}(s)\}\}$
while $G_{\text{to-do}} \neq \emptyset$ do
  Pick a node $w$ such that $\text{cell}(w) \in G_{\text{to-do}}$
  Send wake up from $w$
  $G_{\text{done}} \leftarrow G_{\text{done}} \cup \{\text{cell}(w)\}$
  $G_{\text{to-do}} \leftarrow G_{\text{to-do}} \cup \{\text{cell}(u) : \{u, w\} \in E \setminus \text{cell}(s) \setminus G_{\text{done}}\}$
end
```
A position oblivious wake-up algorithm

- Flooding
- Random Walk
- Epidemic approach
  - Distinguish between covered and uncovered nodes
  - Use simple counter to stop wake-up transmission

- Random $k$-covered wake-up
  - Nodes either transmit or be woken $k$-times
  - Computes CDS with $O(\log n)$
  - Does the algorithm always succeed?
Wake-up Receiver Algorithms

- Counter example when $k = 1$

- Greedy $k$-cover algorithm
  - Measure signal strength to estimate the distance
  - Maximize the wake-up distance
Wake-up Receiver Algorithms

Simulation
- Randomly deployed varying number of nodes
- Area of square length 100 meters
- Wake up communication range of 10 meters
Wake-up Receiver Algorithms

- Measure algorithms’ quality:
  - Coverage: ratio of the uncovered nodes
  - Complexity: number of transmitted wake up

![Graphs showing coverage and complexity over number of nodes]
Wake-up Receiver Algorithms

- Greedy 1-coverage delivers a good combination of message complexity and coverage
Expensive to construct trees from scratch

Hybrid algorithms to combine:
- Duty cycle
- Wake-up receivers