ODMAC: An On-Demand MAC Protocol for Energy Harvesting – Wireless Sensor Networks

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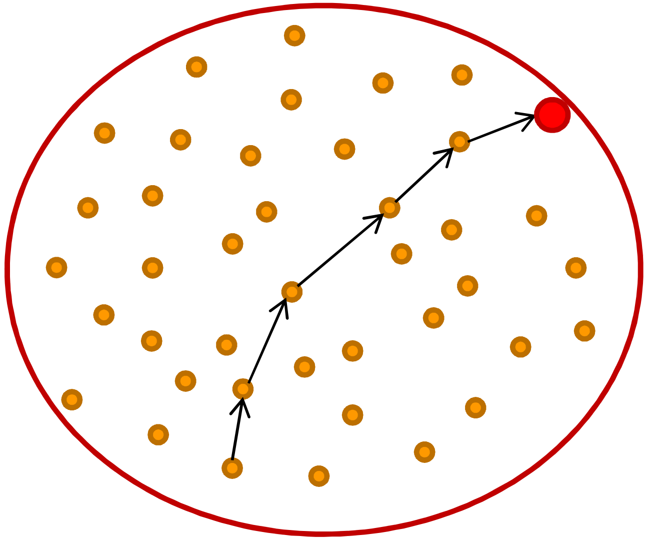
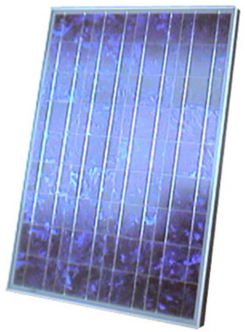
Outline

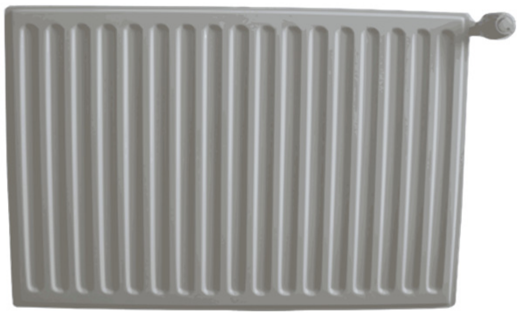
- Motivation
- ODMAC: An On-Demand MAC protocol for Energy Harvesting WSNs
- Evaluation through Simulations
- Conclusive remarks



Energy Harvesting

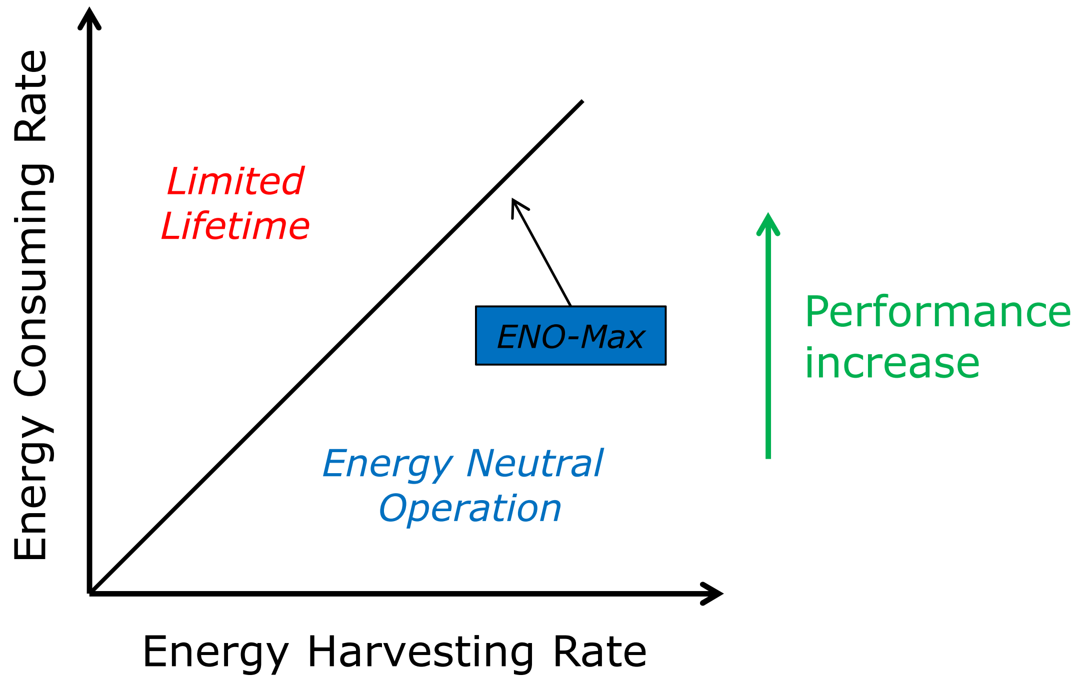
- Battery-powered WSNs
  - Eventually will die and need battery replacement
    - Often not even possible (e.g. underground sensors)
  - Sacrifice performance for lower energy consumption
- Energy-Harvesting WSNs
  - Extracting energy from the environment
    - Solar, mechanical, thermal, etc.
    - Energy sources have spatiotemporal variations
  - Batteries / Super-capacitors operate as energy buffers





Energy Neutral Operation

- Energy Neutral Operation (ENO) provides continuous lifetime
- ENO-Max also maximizes the performance
  - Performance is strongly correlated with energy consumption



Designing EH-WSNs

Design Objective

- Operate at the maximum sustainable performance (ENO-Max)

Requirements for EH-WSNs

- *Adaptability*: Sensors should be able to adapt their energy consumption according to the energy harvesting rate
- *Performance*: Sensors should use their energy efficiently
- *Flexibility*: Capable sensor should be able to help the others

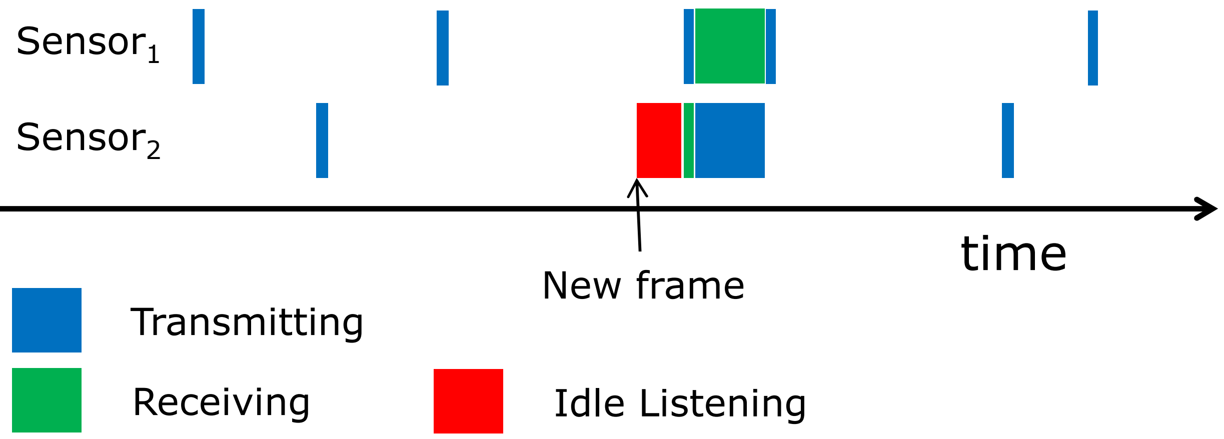
Requirements for MAC protocols

- Support for *individual duty cycles*
  - Sleeping / Activity periods cannot be synchronized!
- Efficient use of energy (e.g. mitigate idle listening)

Proposed approach: ODMAC

On Demand MAC (ODMAC)

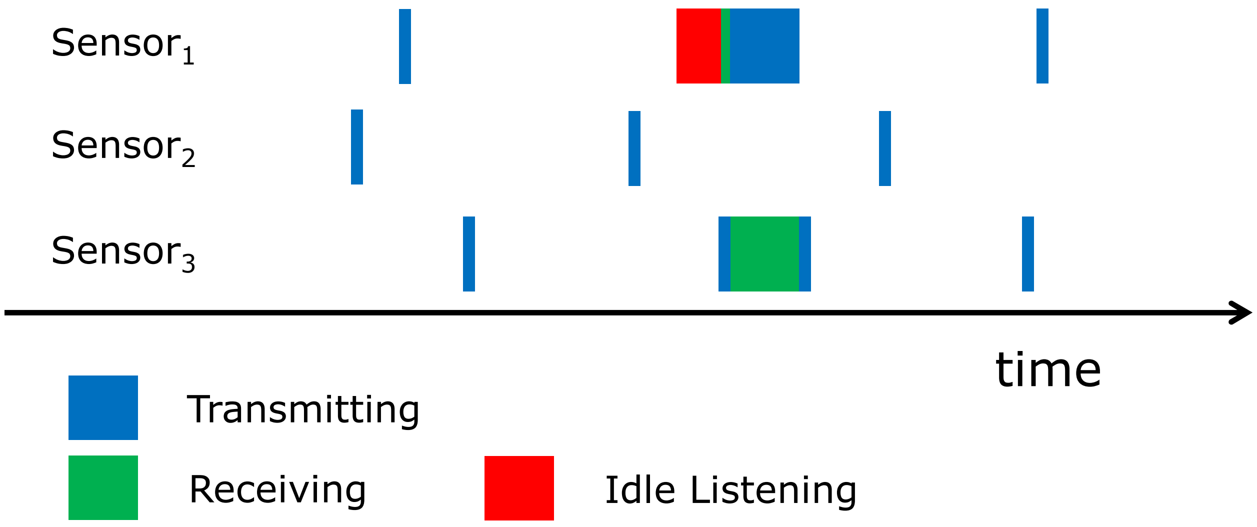
- Sensors periodically broadcast beacons
    - According to their ***individual duty cycle***
    - Stating their availability to *receive* frames
- Sensors with data to transmit are waiting for an appropriate beacon
    - Some energy wasted in idle listening (*challenge*)
- Sensors send a new beacon after a transmission to avoid congestion
- Typical back-off mechanism to avoid collisions



ODMAC: Opportunistic Forwarding

Opportunistic Forwarding

- Forward the frame to the sensor that wakes up first
- Decreases the *sleeping delay* => Increases performance
- Decreases the energy wasted in idle listening
- For now, all the sensors closer to the sink are potential forwarders
    - Future Work: Routing algorithm extensions to account for other metrics



Duty Cycle Adaptation

- ***Goal***: Adjust performance to the available environmental energy

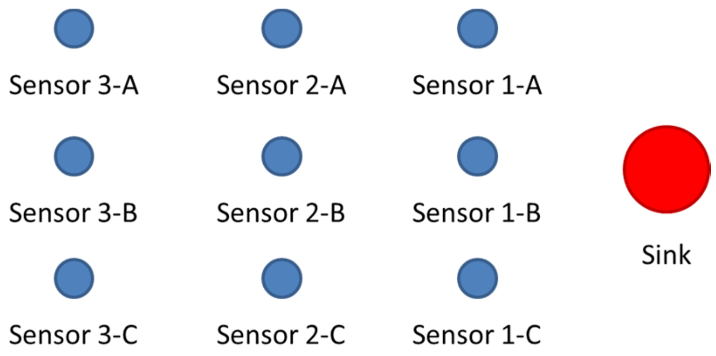
- Two application-specific performance metrics
  - End-to-end delay (beaconing rate)
  - Amount of measurements (sensing rate)

- Dynamic Duty Cycle Adaptation
  - ***SProb***: Probability that if there is a need for adjustment to the duty cycle, this will favor the sensing duty cycle
  - Simple algorithm (out of the scope)
    - Select an optimum battery level and periodically make adjustments to the duty cycle

Evaluation using Simulations

OPNET Simulator

- Energy Model
  - Accounts for the energy consumption when transmitting, receiving and listening
  - Periodic energy harvesting
- Topology
  - 9 sensors (3 groups of 3 sensors)
  - Each sensor can talk with the sensors of its *own group* and the *neighboring groups*

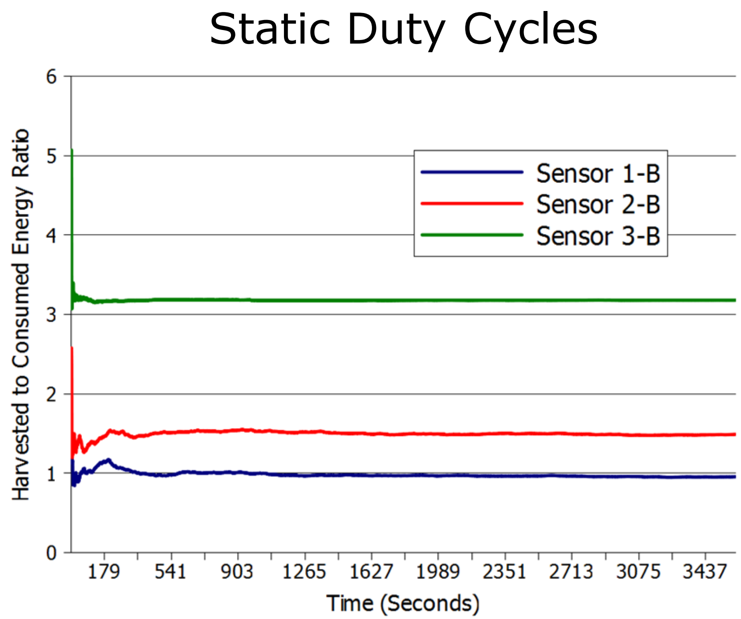


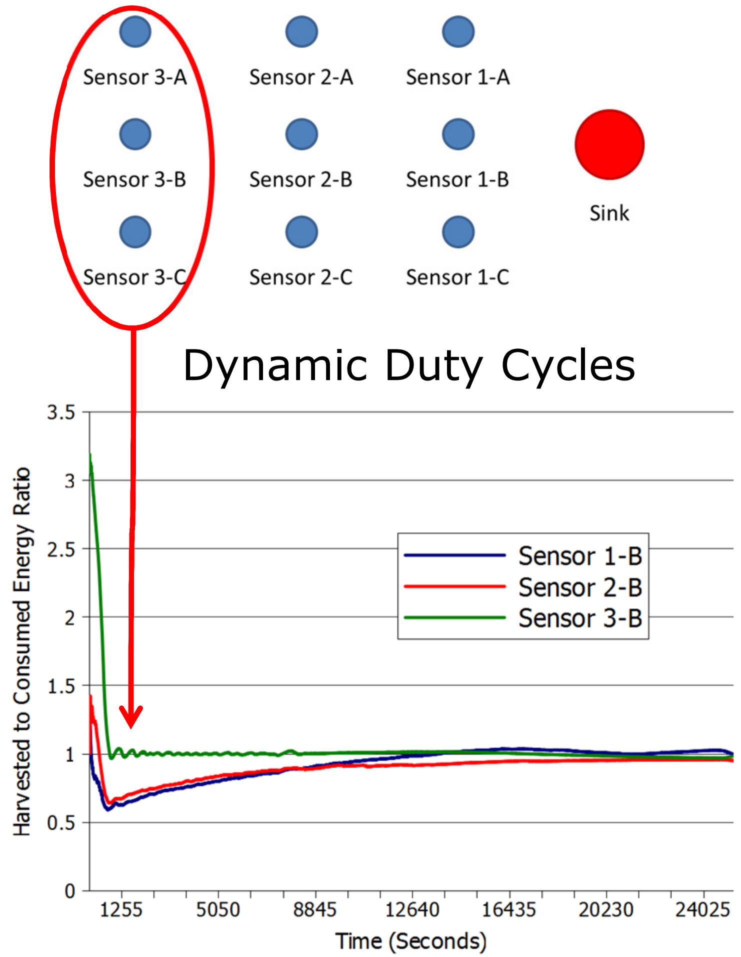
- Evaluation Metrics
  - Harvested to consumed energy ratio (sustainability)
  - End-to-end delay, average sensing rate (performance)
- Parameters
  - Ptx = 10dBm, Rate = 1Mbps, CW = 8
  - Dynamic Duty Cycle Adaptation is OFF (unless otherwise noted)
  - Energy Harvesting Rate is 400μW (unless otherwise noted)

Achieving ENO-Max State

Details

- Beacon Period is 0.2 sec
- Sensing Period is 0.6 sec
- Sprob is 0.5

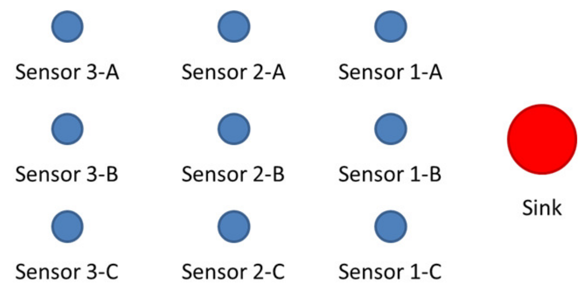


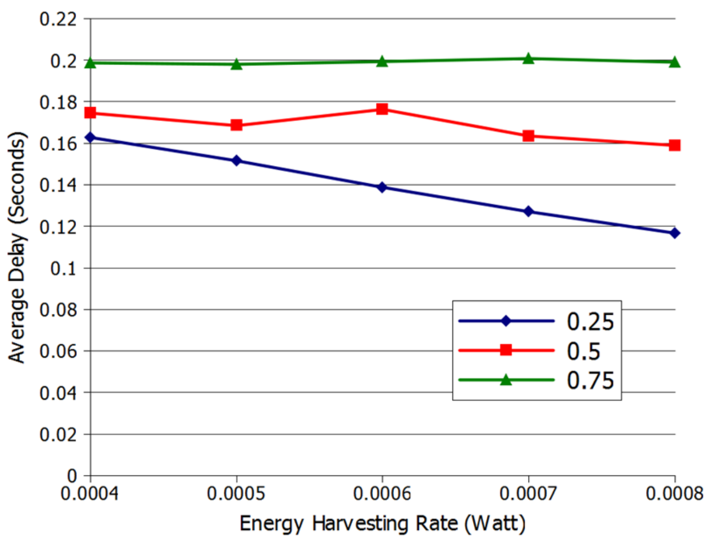


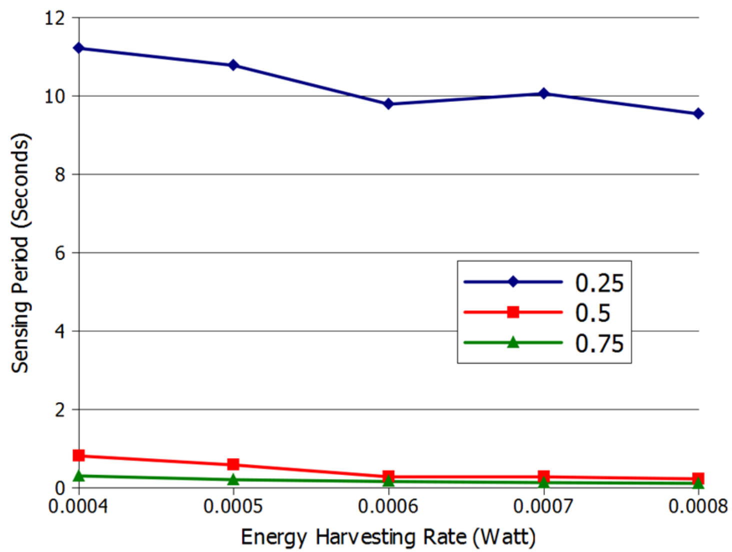
Energy Availability vs. Performance

Details

- Sensor 1-B has activated the Dynamic Duty Cycle Adaptation mechanism
- Beacon Period is 0.2 sec
- Sensing Period is 0.6 sec
- Different values for *SProb*



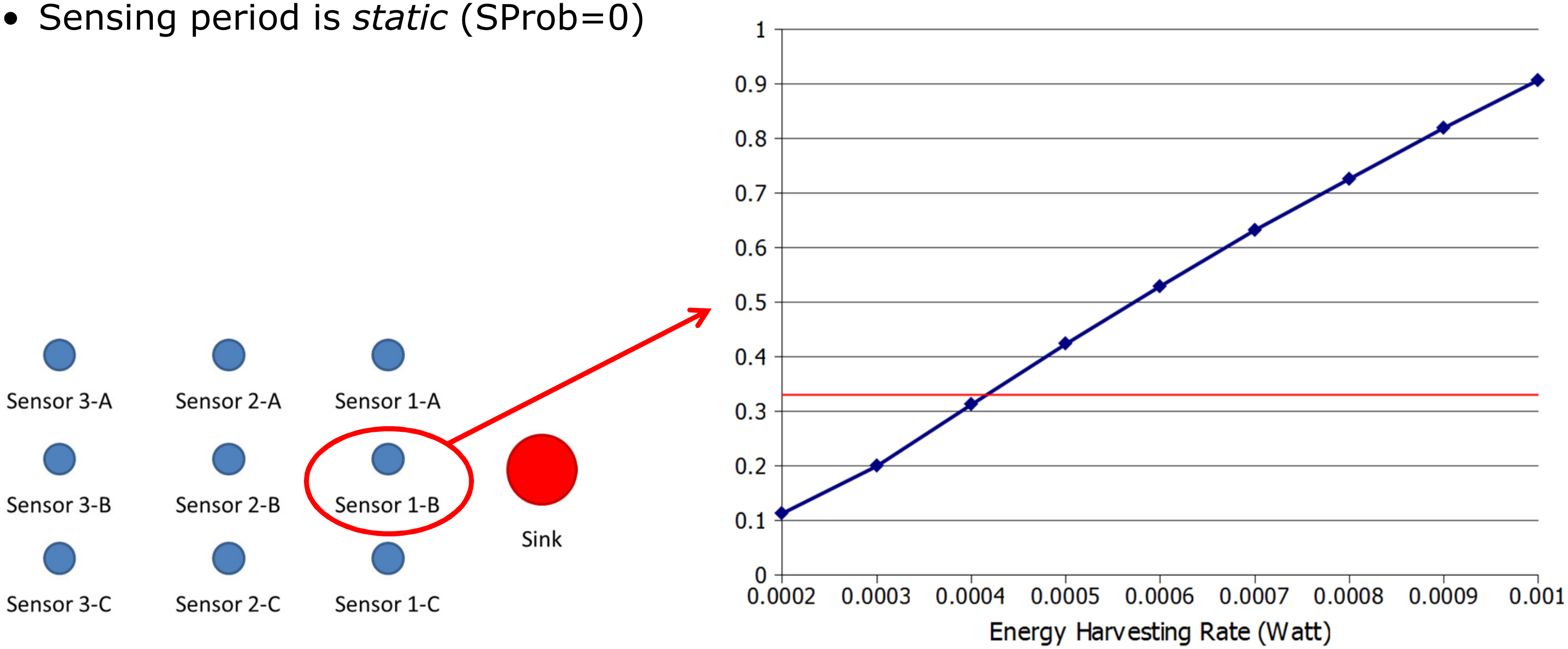




Load Balancing

Details

- All nodes have fixed duty cycles
- Apart from Sensor 1-B
- Sensing period is *static* (SProb=0)



Ongoing Work

- Apply boundaries to the sensing and beacon periods
  - Defined by the application
  - Incorporate a way to “slow down” the too capable nodes

- Introduce acknowledgements/retransmissions and
  - Evaluate them under channel errors

- Exploit beacons to propagate control messages (e.g. acks)
  - Energy-free flooding

- Study ODMAC using an analytical model
  - Arbitrary topologies
  - Effect of power adaptation
  - Incorporate routing decisions

Concluding Remarks

- The environmental energy sources have a dynamic nature

- EH-WSNs need to be able to adapt to the available energy
  - Use the surplus of harvested energy to increase performance
  - Decrease performance to maintain a sustainable operation

- MAC protocols need to *efficiently* support *individual duty cycl*es

- ODMAC
  - Receivers decide on the period they offer forwarding services
  - Opportunistic forwarding reduces the energy wasted on idle listening
  - Distributed autonomous load balancing
  - Supports different application-based performance metrics

The End

Questions?