

“Optimizing Sensor Networks in the Energy-Latency-Density Design Space”: *Schurgers, Tsiatsis, Ganeriwal, Srivastava*  
(From IEEE Transactions on Mobile Computing, 2002)

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## Goal of Study

- Use of STEM (Sparse Topology and Energy Management) to improve energy efficiency in wireless sensor networks
- Exploit the difference between monitoring state and transfer state
- Reduce energy usage by radios
- Maintain acceptable functionality

## Approach

- Make acceptable trade-offs between energy, latency, and network density
  - Mainly concerned with trading increased energy efficiency for increased latency
  - Increased network density also used to improve energy savings
- Use a mathematical model that governs the system of tradeoffs
- Select desired operating point in the latency-density-lifetime design space based on parameter settings
- Simulate using Parsec, event-driven parallel simulation language

## Related Work and Techniques

- Flat multihop routing
  - Topology management techniques
    - SPAN
    - GAF
  - Trade network density for energy savings
  - Characteristic absence of monitoring state traffic is not exploited
- Clustering
  - Possibly hierarchical
- Separate paging channel
  - Assumes listen mode of paging radio is ultra low power
- Radio duty cycling – S-MAC (Medium Access Control)

## STEM

- Assume a problem with little receive/transmit time and large periods of time in monitoring state – sleep state
- Event detection awakens main processor
  - Only turned on if communication with other nodes is necessary
- Considerable power used when radio is turned on, regardless of mode – 12-14 times that of Off mode.
- Nodes should be off when monitoring, but need to know when to turn radio back on
  - Solution: periodically turn radio on
  - Low-power listen mode
  - Decouples transfer and wakeup functions

## STEM Setups

- Dual radios in separate frequency bands
  - Radio only used in transfer state
  - Radio used only in wakeup band for paging
  - Allows use of radio efficiency beyond that of a single radio
- STEM-B
  - Beacon setup
  - Send signals to single nodes, sending back an acknowledgement of received signal
- STEM-T
  - Tone setup
  - Wakeup tone sent by initiator and received by all nodes in area
  - No acknowledgement of signal reception

## Experimental Methodology

- Create a field of size  $L \times L$  with  $N$  nodes randomly distributed
- Uniformly random deployment, density denoted by  $\lambda$ , average number of neighbors of a node
- Vary duty cycle of transmit period to change energy savings

## Important Results

- STEM-T produces optimal energy savings due to much shorter transmit times
  - Best at trading latency for energy
  - Tradeoff is that multiple nodes wake up with each transmission
- STEM-B combined with GAF generates better results than STEM-T with GAF
  - STEM-B alone has problems with beacon conflicts
  - Makes use of density more effectively, since STEM-T will use more energy with a denser grid (more unneeded wakeups)
- STEM+GAF generates 1% of the energy of a system without STEM → Node lifetime increases 100 times

## Significance of Work

- Dramatically lowers energy use in a system with STEM compared to one without
  - Can extend lifetimes of sensor nodes
- Uses three design constraints, creating great flexibility for users
  - Density, latency, energy/lifetime
- Incorporated GAF work with STEM, expanding realm of possible techniques
- STEM-T signals all nearby nodes, does not require acknowledgement, but never had a lost signal

## Research Issues

- Apply to realistic systems. Relative to the problem definition, most systems tested in this paper are “unrealistic”
- Better leader/election system?
- When do you trade off STEM-T with STEM-B?
- When do you use the hybrid model?

## Drawbacks

- While a relatively small cost, dual radio nodes are more expensive than single radios.
- STEM-T decreases in effectiveness as the density increases.
- Leader/election overhead is not simulated in this research (too difficult) – created some discrepancies in results, can modify outcomes
- Assumption of low frequency transmission/reception of messages – what do you do with high frequency systems?