Energy-Efficient Communication Protocol for Wireless Microsensor Networks

W. R. Heinzelman, A. Chandrakasan, and H. Balakrishnan, “Energy-Efficient Communication Protocol for Wireless Microsensor Networks,” in *Proc. Hawii Int. Conf. on System Sciences*, 2000.

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Contents

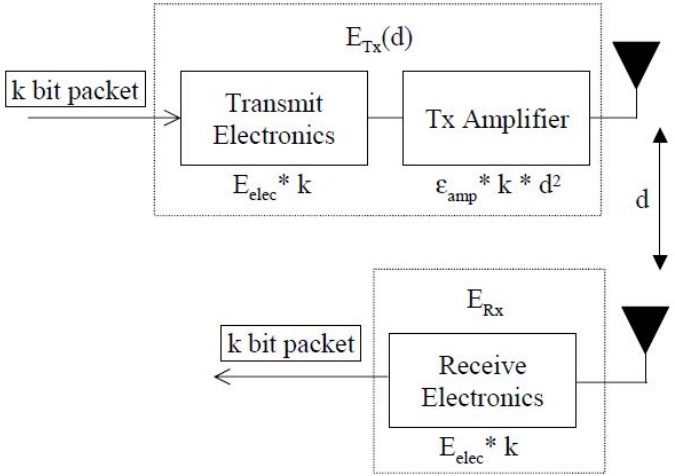
Introduction

- Wireless distributed sensor network
- Advantage and disadvantage of massive cheap sensor network
- Conventional distributed sensor network protocols
- LEACH (Low-Energy Adaptive Clustering Hierarchy) Simulation

First Order Radio Model: Model Assumptions

1. Symmetry: Energy required to transmit a message between two nodes is **same** for a given signal-to-noise ratio (SNR).
2. All sensors are sensing the environment at a fixed rate.
3. Radio characteristics (50 nJ/bit, 100 pJ/bit/m^2)
4. r^2 energy loss due to channel transmission

First Order Radio Model



Operation	Energy Dissipated
Transmitter Electronics ($E_{Tx-elec}$) Receiver Electronics ($E_{Rx-elec}$) ($E_{Tx-elec} = E_{Rx-elec} = E_{elec}$)	50 nJ/bit
Transmit Amplifier (ϵ_{amp})	100 pJ/bit/m^2

To **transmit** a k-bit message with a distance d:

$$E_{Tx}(k,d) = E_{Tx-elec}(k) + E_{Tx-amp}(k,d)$$
$$E_{Tx}(k,d) = E_{elec} * k + \epsilon_{amp} * k * d^2$$

To **receive** a k-bit message:

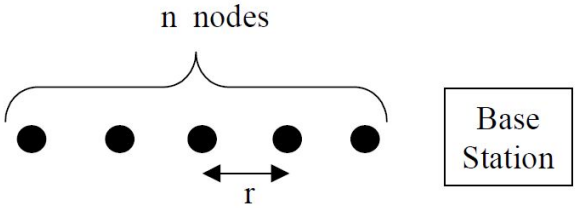
$$E_{Rx}(k) = E_{Rx-elec}(k)$$
$$E_{Rx}(k) = E_{elec} * k$$

NOT LOW COST!

Energy Analysis: Routing Protocols

- Direct communication for each node
  - Require a large amount of transmit power
  - Optimal in some situations
- Minimum-energy routing protocol
  - Nodes transmit data to the base station through intermediate nodes
  - Intermediate nodes are chosen based on minimization of the transmit amplifier energy
  - Minimum-transmission-energy (MTE) routing protocol is used

Energy Analysis (Cont.)



- Evaluation of two methods on a linear network
  - Direct: $E_{direct} = E_{Tx}(k, d = n * r) = k(E_{elec} + \epsilon_{amp} n^2 r^2)$
  - MTE: $E_{MTE} = n * E_{Tx}(k, d = r) + (n-1) * E_{Rx}(k) = k((2n-1)E_{elec} + \epsilon_{amp} n r^2)$

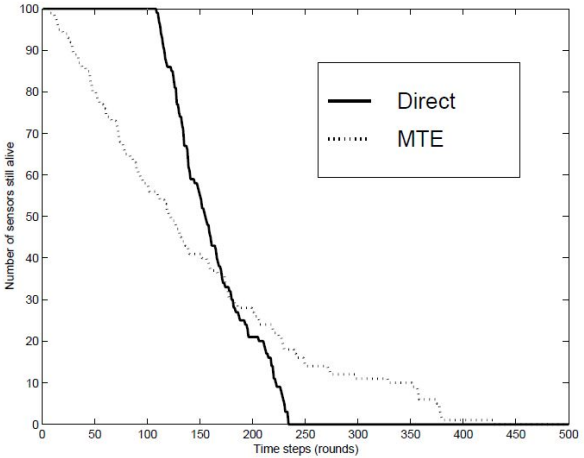
$$E_{direct} < E_{MTE}$$

$$E_{elec} + \epsilon_{amp} n^2 r^2 < (2n-1)E_{elec} + \epsilon_{amp} n r^2$$

$$\frac{E_{elec}}{\epsilon_{amp}} > \frac{r^2 n}{2}$$

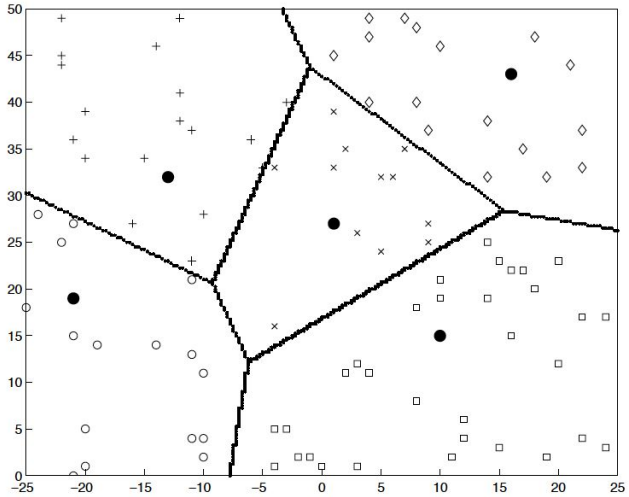
Most energy-efficient protocol depends on **network topology** and **radio parameters**

Energy Analysis (Cont.)



- Shortcoming of MTE routing protocol
  - Cascading effect
    - Nodes closest to the base station die out quickly
    - Energy required to transmit the remaining data to base station increases
  - As nodes die, that area of environment is no longer monitored
- 100-node simulation is run to compare these two protocols
  - The figure of **system lifetime** using direct transmission and MTE routing with 0.5 J/node is shown on top-right corner

LEACH: Prior Work

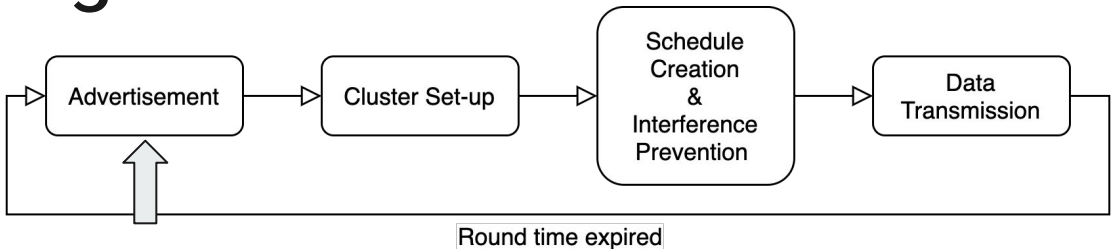


- Static-clustering algorithm
  - Fixed cluster-heads
  - Whole cluster stops working if a cluster-head dies
- Adaptive-clustering algorithm
  - Prior work: the Near Term Digital Radio (NTDR) project
  - LEACH - Low-Energy Adaptive Clustering Hierarchy

LEACH: Algorithm Assumptions

- Advertisement Phase
  - All nodes begin with the same amount of energy
  - Being a cluster-head removes approximately the same amount of energy for each node
  - Symmetric propagation channels

LEACH: Algorithm Details

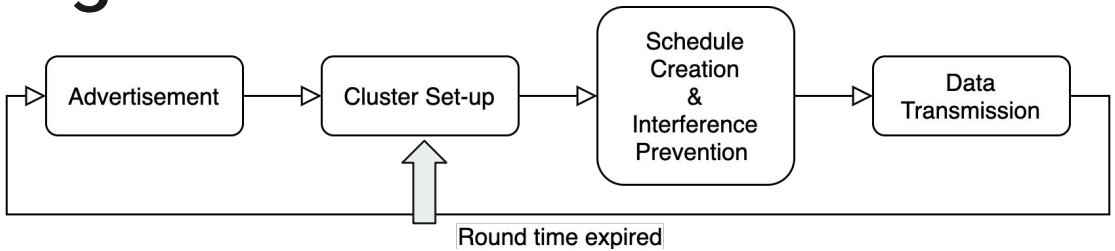


- Advertisement Phase: cluster-head election
  - Node n chooses a random number between 0 and 1. If the number is less than T(n), then it becomes a cluster-head for that round

$$T(n) = \begin{cases} \frac{P}{1-P*(r mod \frac{1}{P})} & \text{if n} \in \text{G} \\ 0 & \text{otherwise} \end{cases}$$

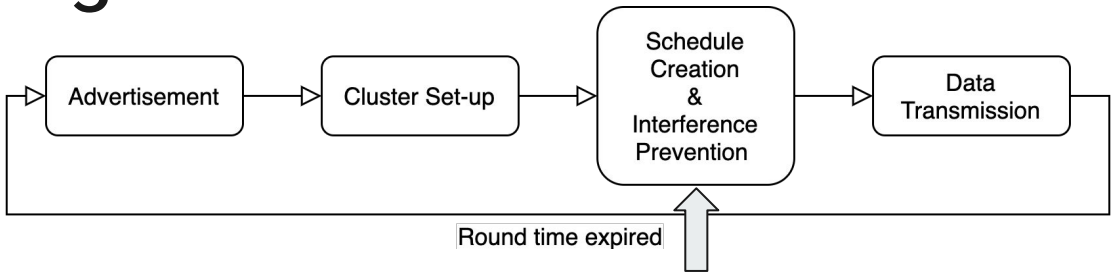
  - Broadcast advertisement using a **CSMA MAC** protocol

LEACH: Algorithm Details



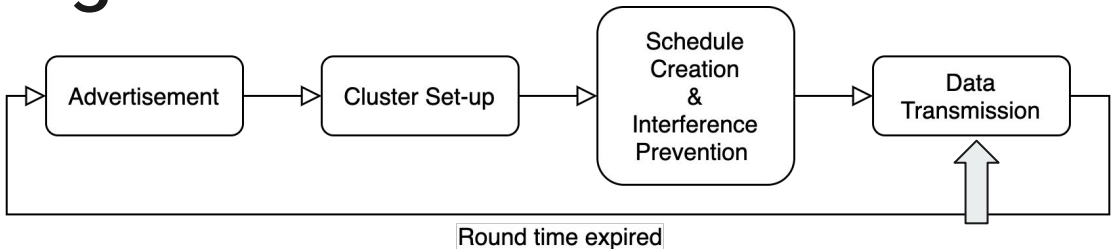
- Cluster Set-up Phase: joining a cluster
  - Choose cluster-heads based on their signal strengths
  - Inform the cluster-head using a **CSMA MAC** protocol again

LEACH: Algorithm Details



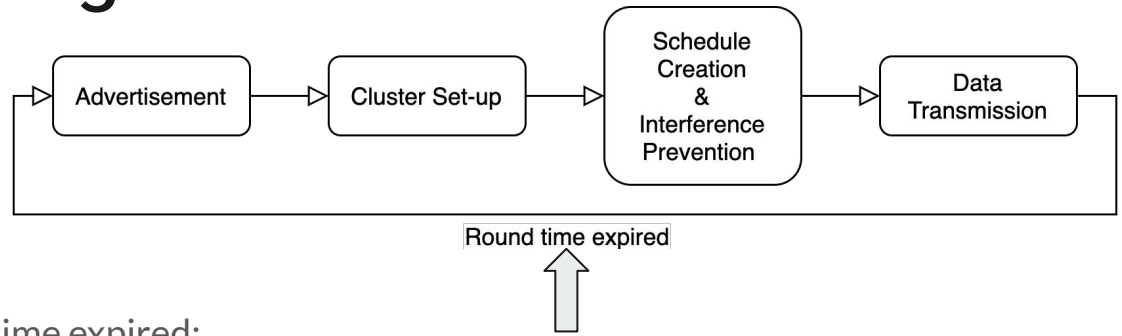
- Schedule Creation: telling each node when to transmit data
  - TDMA (Time-division Multiple Access) scheduling
  - Broadcast schedules and specific in-cluster CDMA communication codes

LEACH: Algorithm Details



- Data Transmission:
  - Cluster-head receives data from nodes based on the TDMA schedule
    - With transmission time pre-allocated, non-cluster-head nodes can be turned off
  - Cluster-head compresses data into a single signal, e.g. beamforming
  - Cluster-head transmits data to the global base station

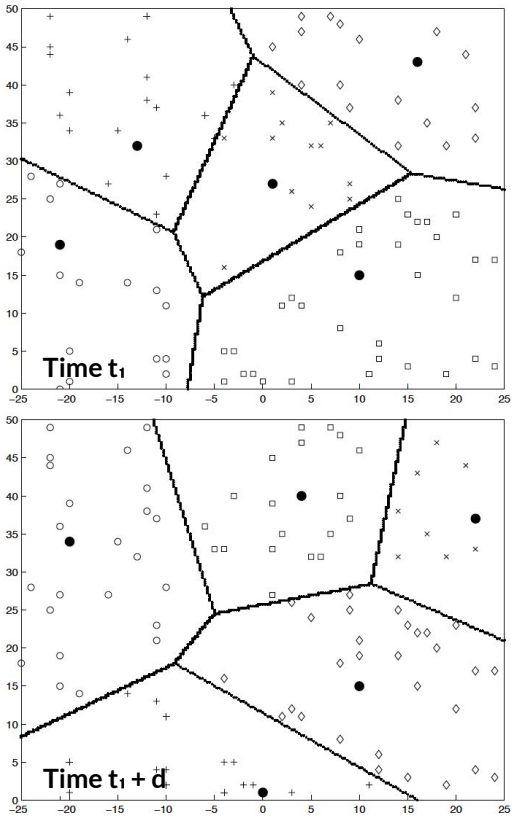
LEACH: Algorithm Details



- Round time expired:
  - Determined by a priori
  - Next round begins with each node determining if it should be a cluster head for this round

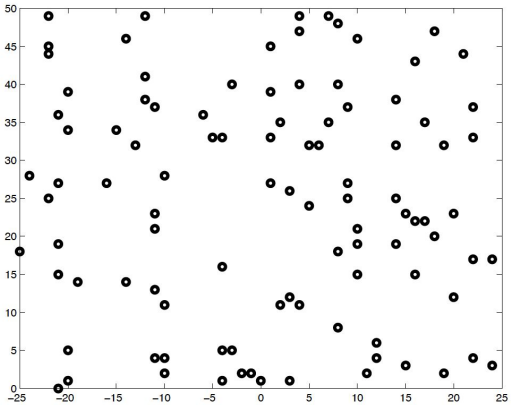
Simulations & Results

- Determining high-energy cluster-head position
  - LEACH includes randomized rotation
  - Single sensors' battery are not drained, energy consumption is distributed with each rotation
  - Possibility for non-optimal cluster-head positions



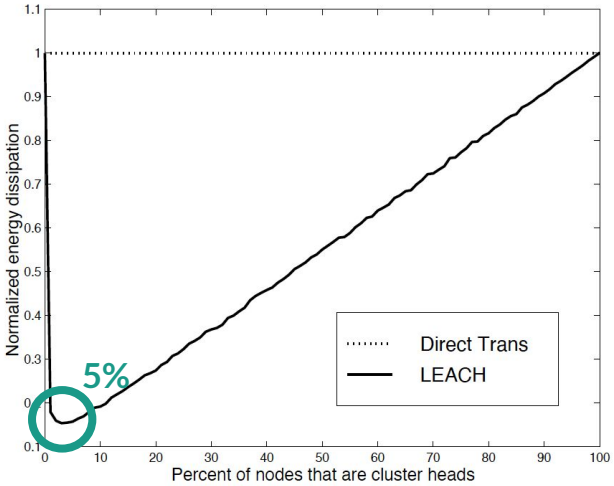
Simulations & Results

- Simulation on determining optimal number of clusters
  - Same 100-node random network
  - Energy dissipation: E_{elec} = 50 nJ/bit
  - Computation cost: 5 nJ/bit/message
  - 2000 bits per message



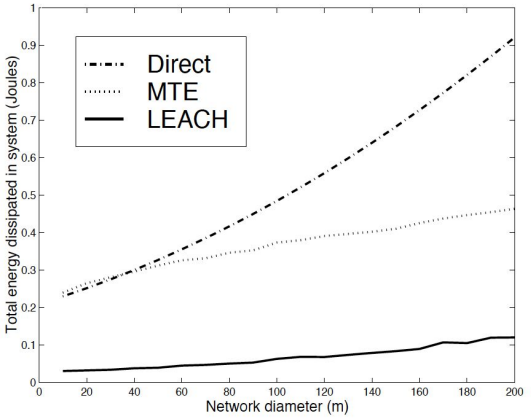
Simulations & Results

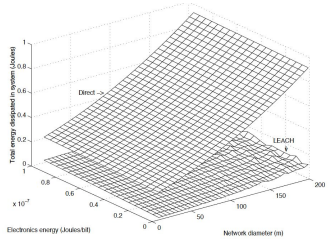
- System priori sets the optimal percentage $\hat{N}$ of cluster-heads to have in the system
- Note that 0% and 100% cluster-heads have the same energy efficiency as direct communication

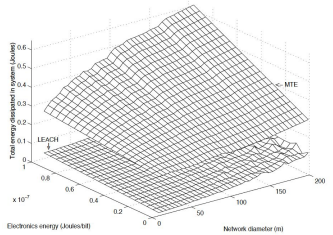


Simulations & Results

- Simulation on comparison of direct, MTE, and LEACH protocols
  - LEACH can achieve ***7x~8x*** reduction in energy compared to direct communication and ***4x~8x*** compared to MTE routing
  - Main energy saving is due to lossy compression
  - TDMA Scheduling allows each non-cluster-head node turns off transmitter except during its transmit time
- Total system energy dissipated using direct communication, MTE routing, and LEACH as network diameter and electronics energy vary

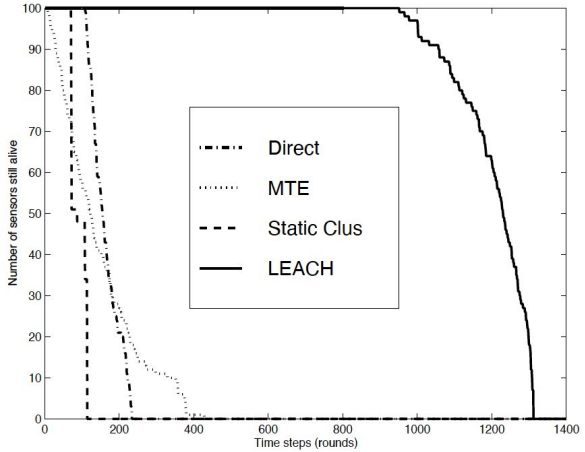






Simulations & Results

- Lifetime result using LEACH does not vary significantly with different energy thresholds and different initial energy of nodes
  - ~8 times longer for the first node to die
  - ~3 times longer for the last node to die
- Simulations results do not account for any necessary routing start-up costs.



Future Work

- Radio model protocol to implement an “event-driven” simulation for sensor to only TX data if an event occurs in their environment
- LEACH algorithm advertisement phase will include an energy-based threshold to account for non-uniform energy node
- Hierarchical clustering/multiple clusters to form super cluster-heads
    - Explore no support from base station to save energy using same protocol

Comments

- The overhead of the LEACH algorithm was not quantified: what is the energy cost of running “Setup phase” of LEACH and normal LEACH data transmission?
- Did not present any detail for base station communication protocols
- Not clear about when it is ok to sacrifice accuracy for energy efficiency

Questions?