Energy-Efficient Communication Protocol for Wireless Microsensor Networks

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Overview

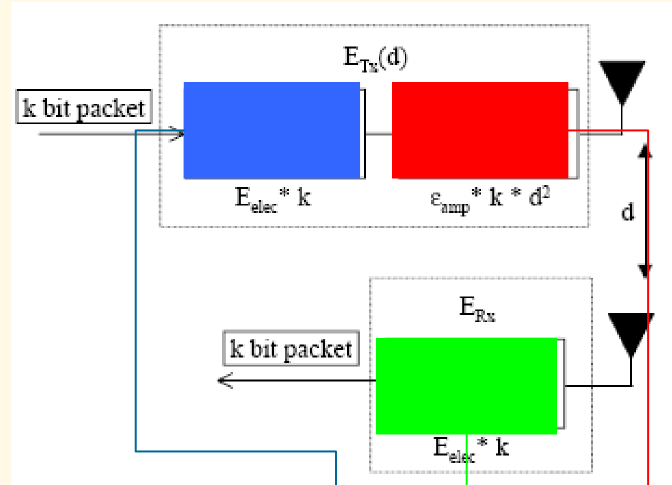
- Introduction
- Radio Model
- Existing Protocols
  - Direct Transmission
  - Minimum Transmission Energy
  - Static Clustering
- LEACH
- Performance Comparison
- Conclusions

Introduction

- LEACH (Low-Energy Adaptive Clustering Hierarchy) is a routing protocol for wireless sensor networks in which:
  - The base station (sink) is fixed
  - Sensor nodes are homogenous
- LEACH conserves energy through:
  - Aggregation
  - Adaptive Clustering

Radio Model

- Designed around acceptable E_b/N_0
- E_{elec} **= 50nJ/bit**
  - **Energy dissipation for transmit and receive**
- ε_{amp} **= 100pJ/bit/m²**
  - **Energy dissipation for transmit amplifier**
- k = Packet size
- d = Distance



$E_{Tx}(k,d) = \quad + $

$E_{Rx}(k) =$

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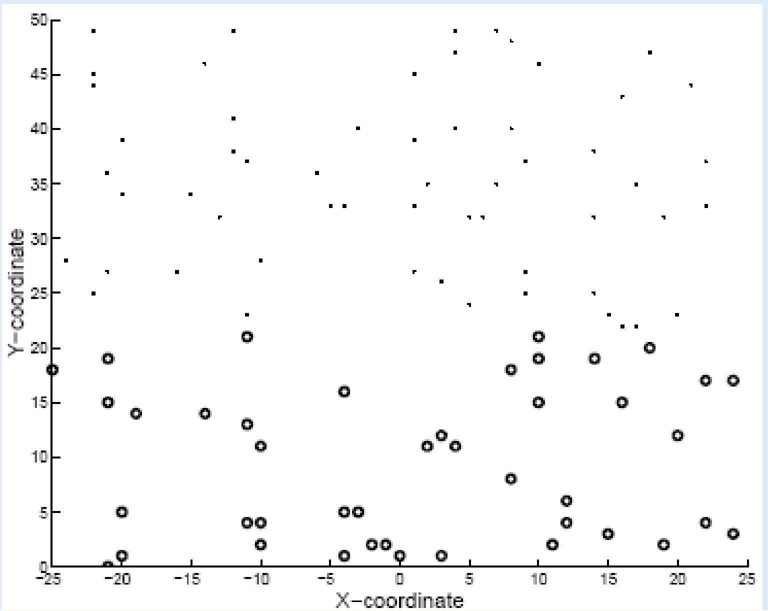
Existing Routing Protocols

- LEACH is compared against three other routing protocols:
  - Direct-Transmission
    - Single-hop
  - Minimum-Transmission Energy
    - Multi-hop
  - Static Clustering
    - Multi-hop

Direct-Transmission

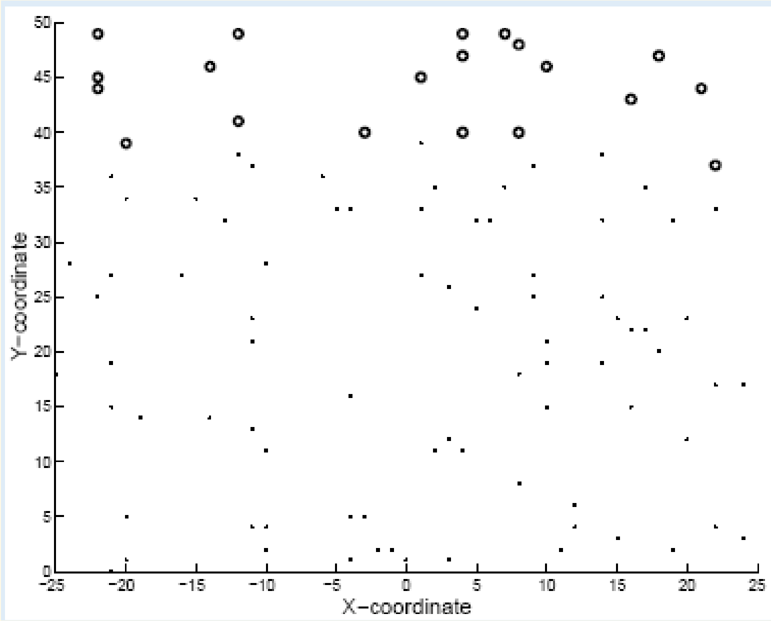
- Each sensor node transmits directly to the sink, regardless of distance
- Most efficient when there is a small coverage area and/or high receive cost



Sensor Status after 180 rounds with 0.5J/node

Minimum Transmission Energy (MTE)

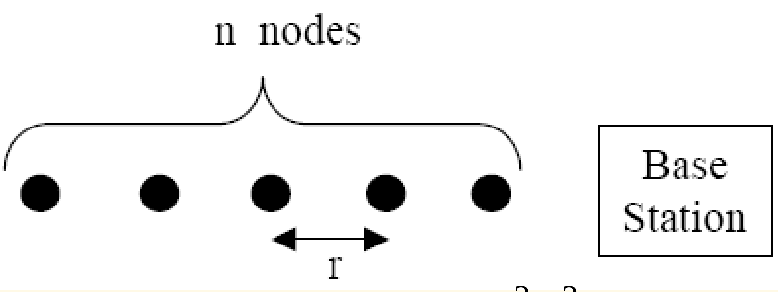
- **Traffic is routed through intermediate nodes**
  - **Node chosen by transmit amplifier cost**
  - **Receive cost often ignored**
- **Most efficient when the average transmission distance is large and E_{elec} is low**



Sensor Status after 180 rounds with 0.5J/node

MTE vs Direct-Transmission

When is Direct-Transmission Better?



$$E_{direct} = k(E_{elec} + \varepsilon_{amp} n^2 r^2)$$

$$E_{MTE} = k((2n-1)E_{elec} + \varepsilon_{amp} n r^2)$$

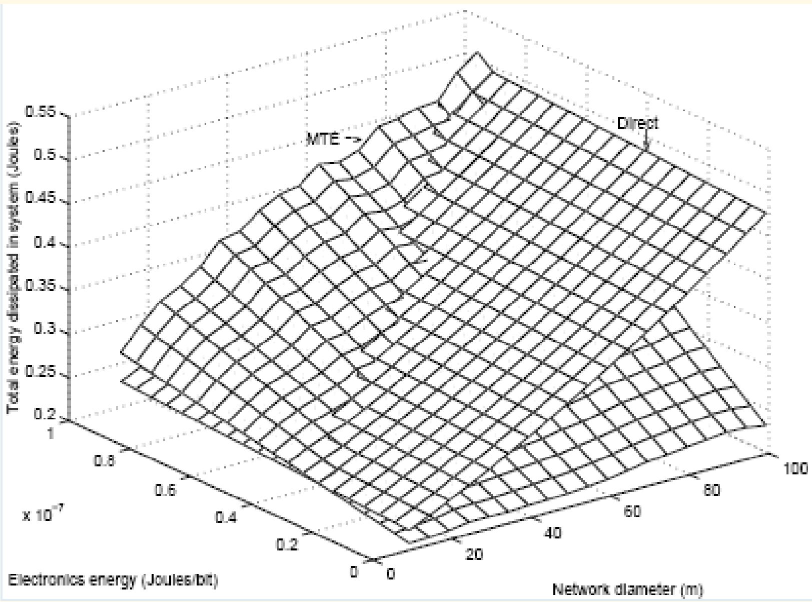
For MTE, a node at distance *nr* requires *n* transmits of distance *r*, and *n*-1 receives

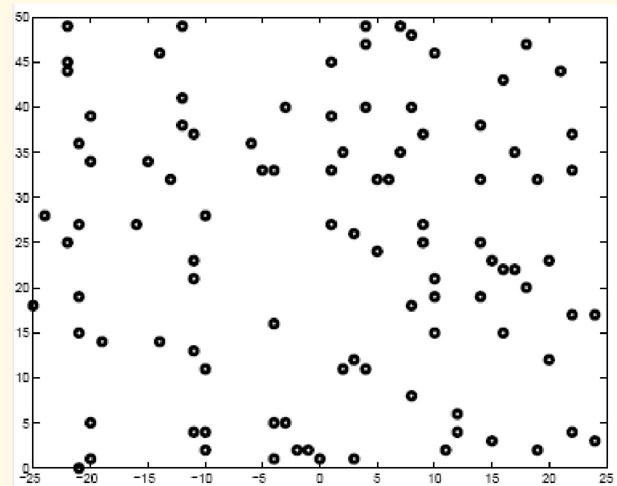
$E_{direct} < E_{MTE}$ when:

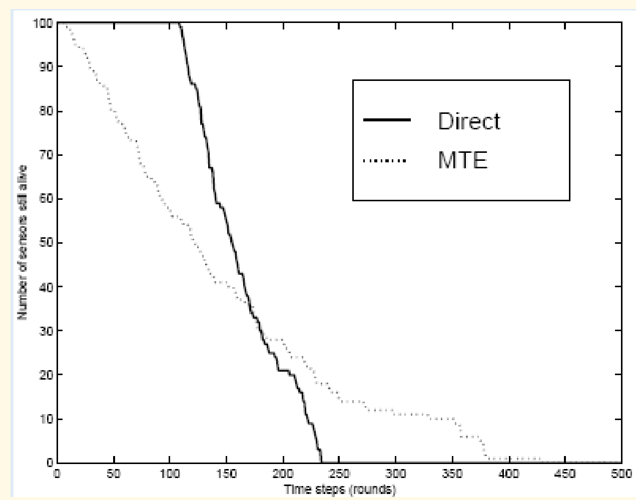
$$\frac{E_{elec}}{\varepsilon_{amp}} > \frac{r^2 n}{2}$$

- High radio operation costs favor direct-transmission
- Low transmit amplifier costs (i.e. distance to the sink) favor direct transmission
- Small inter-node distances favor MTE

MTE vs. Direct-Transmission (cont)



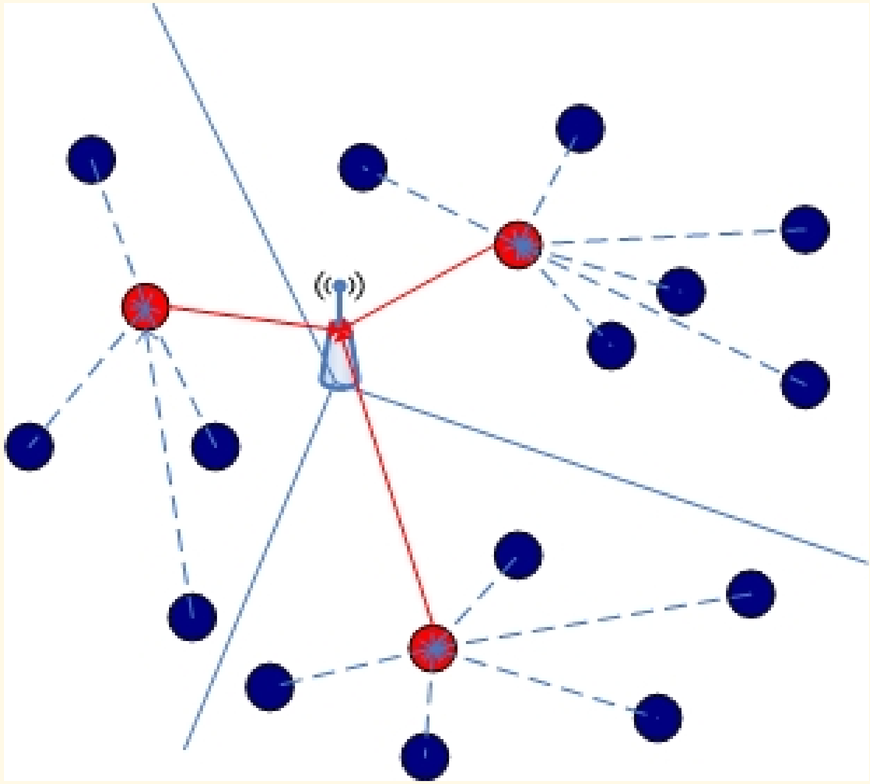




- 100-node random network
- 2000 bit packets
- ε_{amp} = 100pJ/bit/m2

Static Clustering

- Indirect upstream traffic routing
- Cluster members transmit to a cluster head
  - TDMA
- Cluster head transmits to the sink
  - Not energy-limited
- Does not apply to homogenous environments



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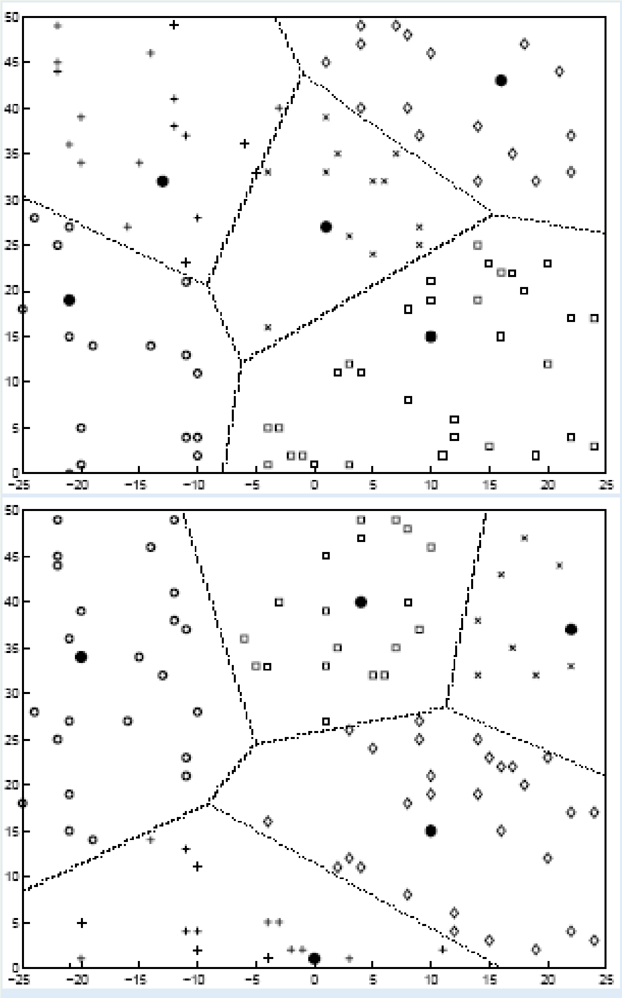
LEACH

- **Adaptive Clustering**
  - **Distributed**
- **Randomized Rotation**
  - **Biased to balance energy loss**
- **Heads perform compression**
  - **Also aggregation**
- **In-cluster TDMA**

LEACH: Adaptive Clustering

- **Periodic independent self-election**
  - **Probabilistic**
- **CSMA MAC used to advertise**
- **Nodes select advertisement with strongest signal strength**
- **Dynamic TDMA cycles**

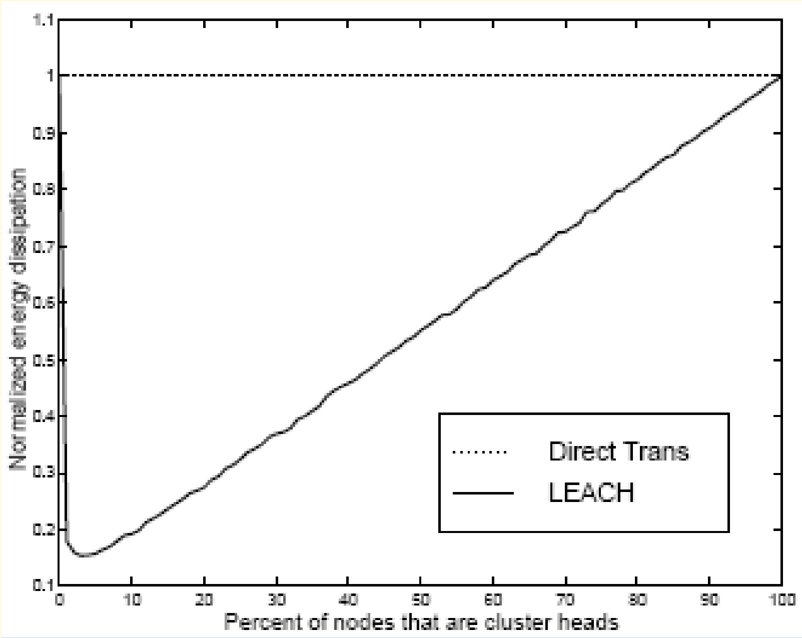


t_1

t_2

LEACH: Adaptive Clustering

- **Number of clusters determined *a priori***
  - **Compression cost of 5nj/bit/2000-bit message**
- **"Factor of 7 reduction in energy dissipation"**
  - **Assumes compression is cheap relative to transmission**
  - **Overhead costs ignored**



LEACH: Randomized Rotation

- **Cluster heads elected every round**
  - **Recent cluster heads disqualified**
  - **Optimal number not guaranteed**
- **Residual energy not considered**
- **Assumes energy uniformity**
  - **Impossible with significant network diameters**

- P = Desired cluster head percentage
- r = Current Round
- G = Set of nodes which have not been cluster heads in 1/P rounds

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

LEACH: Operation

- **Periodic process**
- **Three phases per round:**
  - **Advertisement**
    - **Election and membership**
  - **Setup**
    - **Schedule creation**
  - **Steady-State**
    - **Data transmission**

LEACH: Advertisement

- **Cluster head self-election**
  - **Status advertised broadcast to nearby nodes**
- **Non-cluster heads must listen to the medium**
  - **Choose membership based on signal strength**
    - **RSSI**
    - **E_b/N_0**

LEACH: Setup

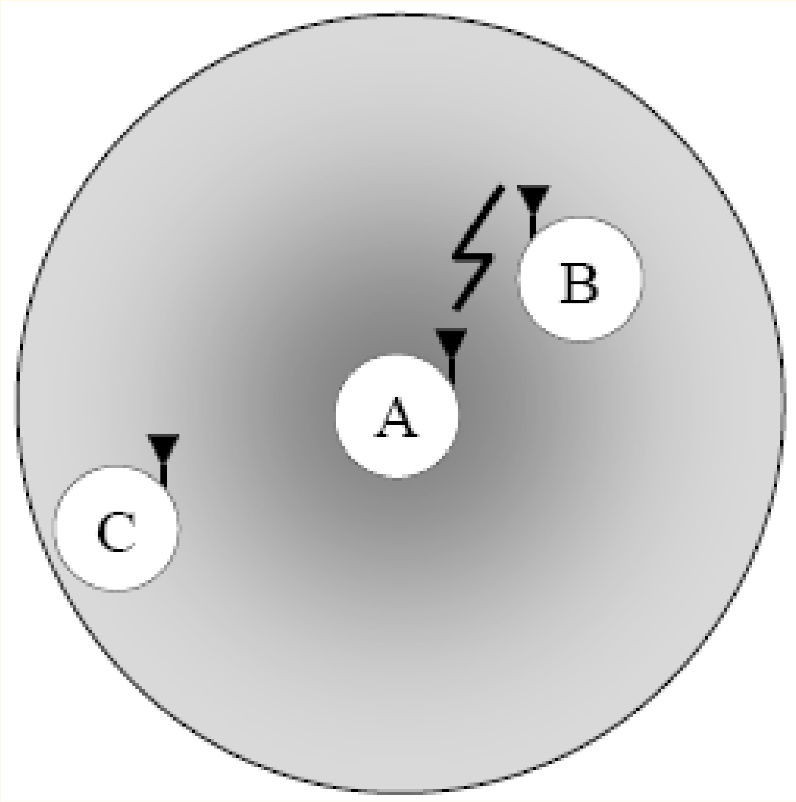
- Nodes broadcast membership status
  - CSMA
- Cluster heads must listen to the medium
- TDMA schedule created
  - Dynamic number of time slices

LEACH: Data Transmission

- **Nodes sleep until time slice**
- **Cluster heads must listen to each slice**
- **Cluster heads aggregate/compress and transmit once per cycle**
- **Phase continues until the end of the round**
  - **Time determined *a priori***

LEACH: Interference Avoidance

- TDMA intra-cluster
- CDMA inter-cluster
  - Spreading codes determined randomly
    - Non-overlapping modulation may be NP-Complete
  - Broadcast during advertisement phase

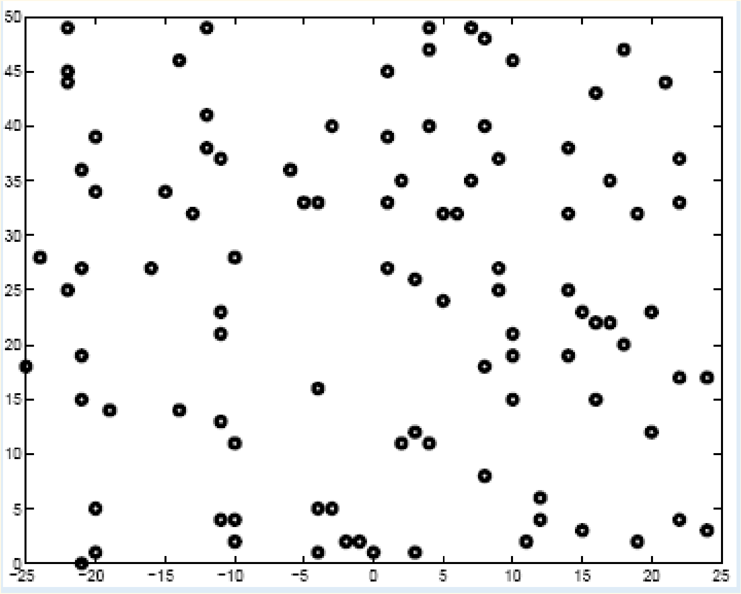


LEACH: Hierarchical Clustering

- **Not currently implemented**
- ***n* tiers of clusters of cluster heads**
- **Efficient when network diameters are large**

Performance: Parameters

- MATLAB Simulator
- 100-node random network
- E_{elec} = 50nj/bit
- ε_{amp} = 100pJ/bit/m2
- k = 2000 bits



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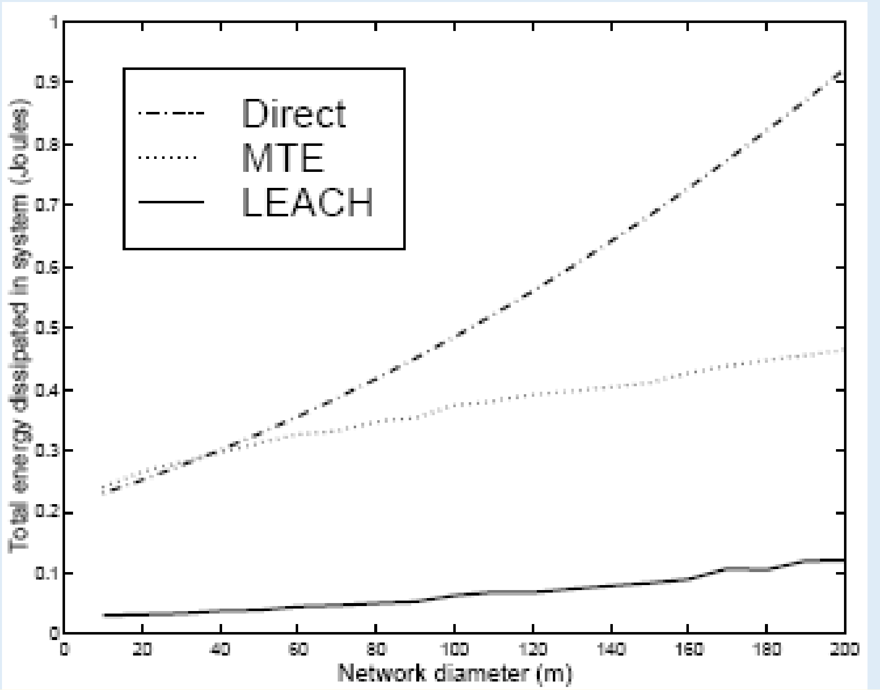
Performance: Network Diameter

- **LEACH vs. Direct Transmission**
  - **7x-8x energy reduction**
- **LEACH vs. MTE**
  - **4x-8x energy reduction**



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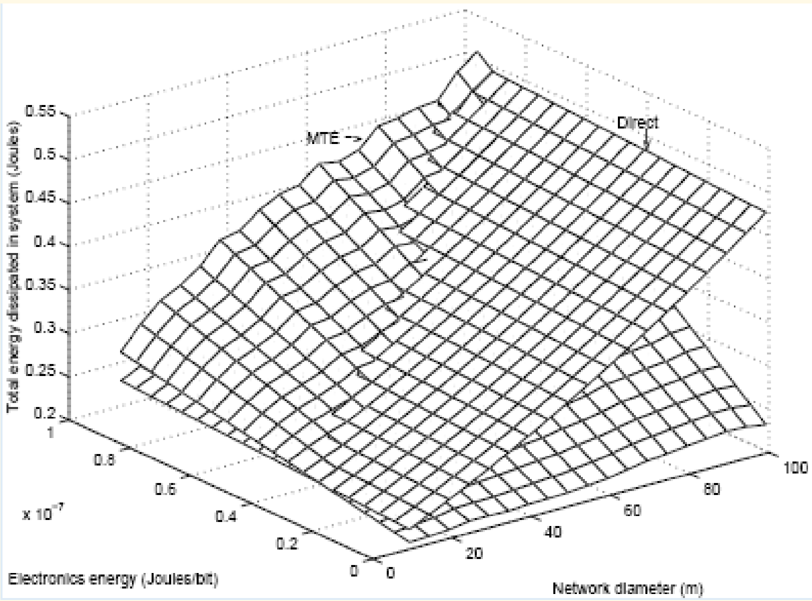
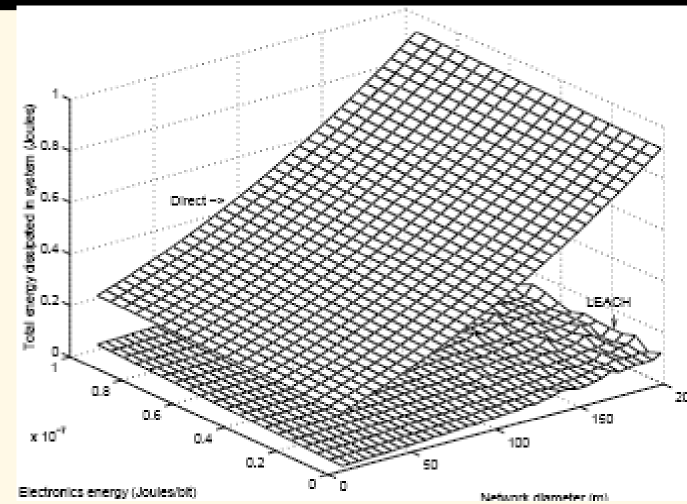
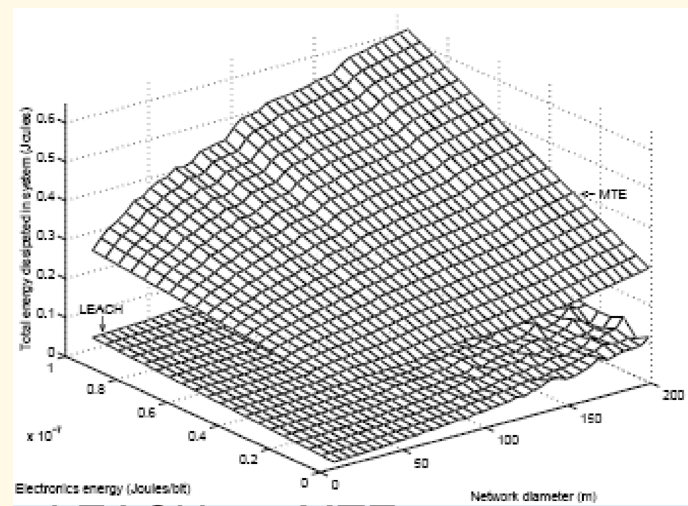
Performance: Energy and Diameter



MTE vs. Direct Transmission



LEACH vs. Direct Transmission

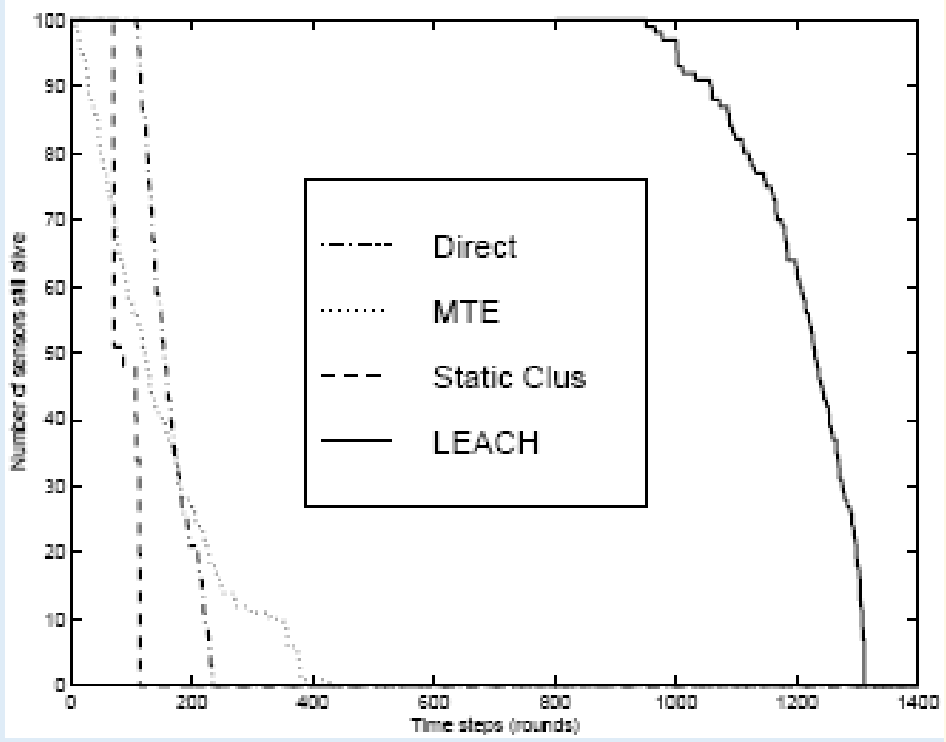


LEACH vs. MTE

- LEACH performs in most conditions
- At low diameters and energy costs, performance gains negligible
  - Not always same for costs
- Comparable to MTE for some configurations

Performance: System Lifetime

- Setup costs ignored
- 0.5J of energy/node
- LEACH more than doubles network lifetime
- Static clusters fail as soon as the cluster head fails
  – Can be rapid



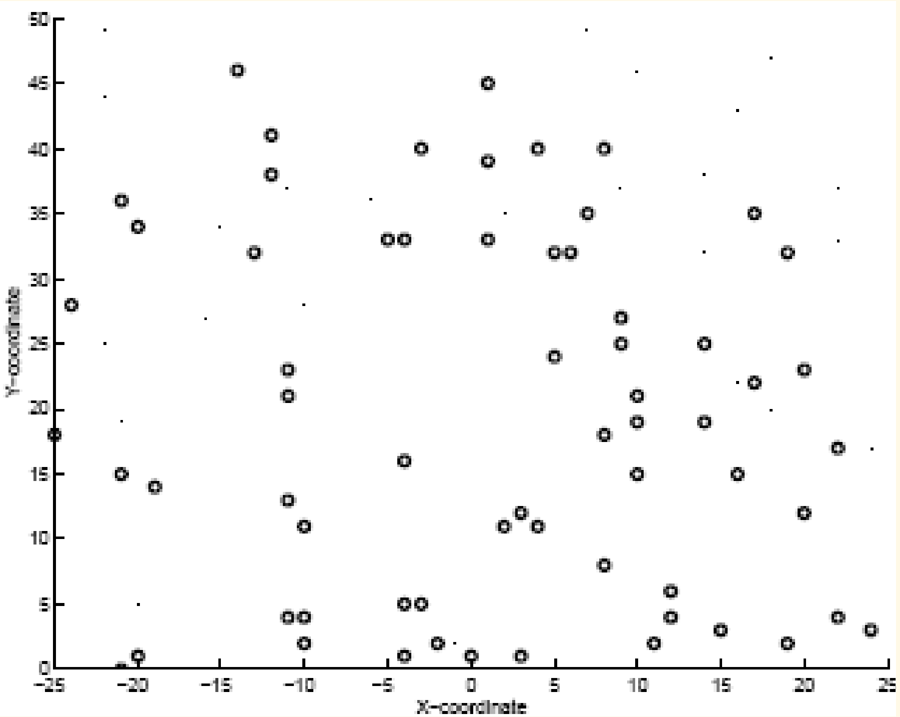
Performance: System Lifetime

- **Experiments repeated for different maximum energy levels**
- **LEACH gains:**
  - 8x life expectancy for first node
  - 3x life expectancy for last node

Energy (J/node)	Protocol	Round first node dies	Round last node dies
0.25	Direct	55	117
	MTE	5	221
	Static Clustering	41	67
	LEACH	394	665
0.5	Direct	109	234
	MTE	8	429
	Static Clustering	80	110
	LEACH	932	1312
1	Direct	217	468
	MTE	15	843
	Static Clustering	106	240
	LEACH	1848	2608

Performance: Coverage

- **LEACH**
  - Energy distributed evenly
  - All nodes serve as cluster heads eventually
  - Deaths randomly distributed
- **MTE**
  - Nodes near the sink die first
- **Direct Transmission**
  - Nodes on the edge die first



Conclusions

- **LEACH is completely distributed**
  - **No centralized control system**
- **LEACH outperforms:**
  - **Direct-Transmission in most cases**
  - **MTE in many cases**
  - **Static clustering in effectively all cases**
- **LEACH can reduce communication costs by up to 8x**
- **LEACH keeps the first node alive for up to 8x longer and the last node by up to 3x longer**

Future Work

- Extend ns to simulate LEACH, MTE, and Direct Transmission
- Include energy levels in self-election
- Implement hierarchical clustering

Areas for Improvement

- LEACH assumes all cluster heads pay the same energy cost
  - Death model incorrect
- Compression may not be as cheap as claimed
  - Unclear how much savings are from compression assumptions and how much from adaptive clustering
- Optimal number of cluster heads must be determined in simulation, before implementation
- Round durations never specified or explained

Questions