An Application-Specific Protocol Architecture for Wireless Microsensor Networks

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Contents

Introduction

- Sensor Network Challenges
  - Limited communication bandwidth
  - Limited energy

- Parameters (Design goals)
  - Ease of deployment
  - System lifetime
  - Latency
  - Quality
    - ✓ Neighboring nodes may have same data
    - ✓ End user cares about a higher-level description of events

LEACH (Low-Energy Adaptive Clustering Hierarchy)

- Techniques (to achieve the design goals)
  - Randomized, adaptive, self-configuring cluster formation.
  - Localized control of data transfers
  - Low energy media access control (MAC)
  - Application specific data processing, such as data aggregation and compression.

Background

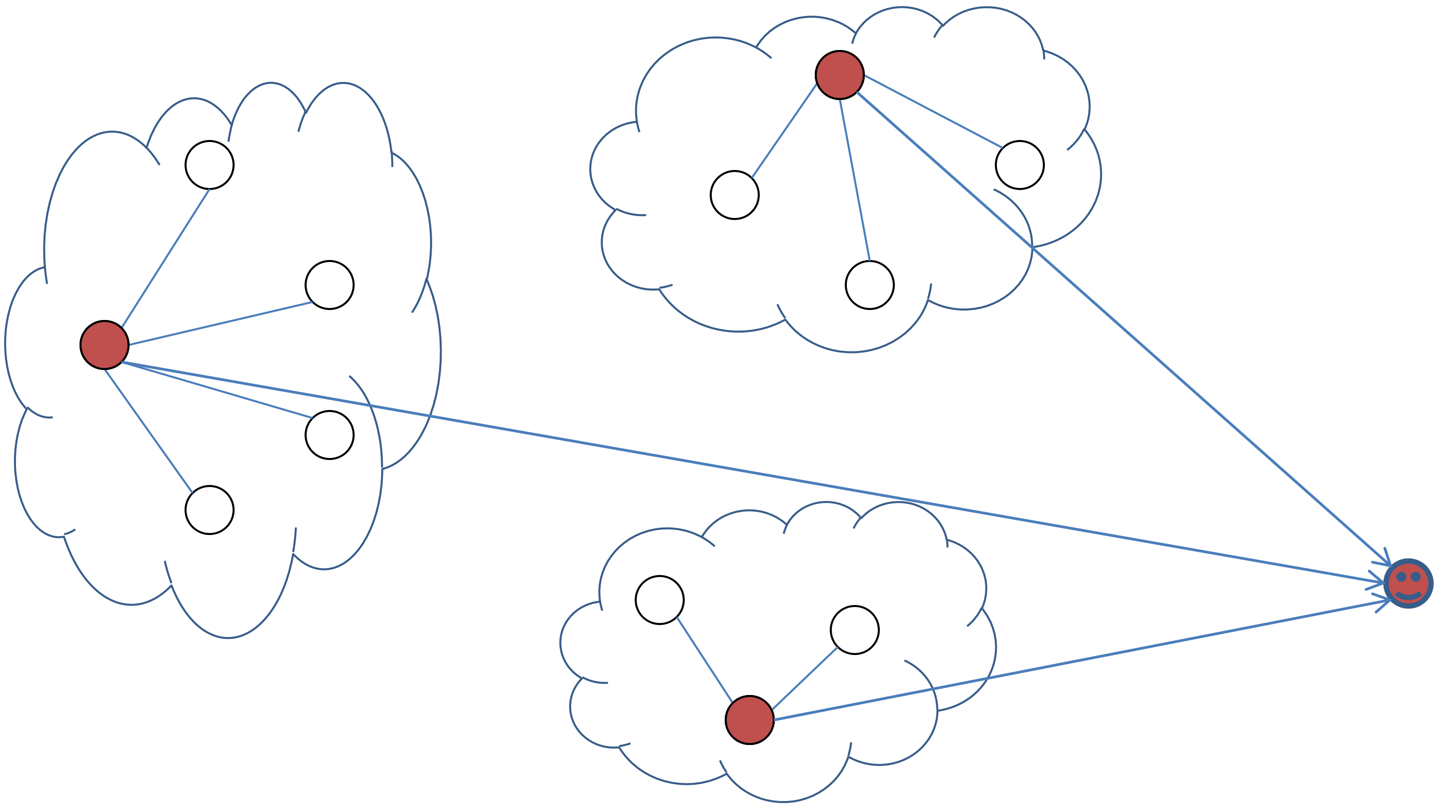
Some application-specific protocols developed for MSN

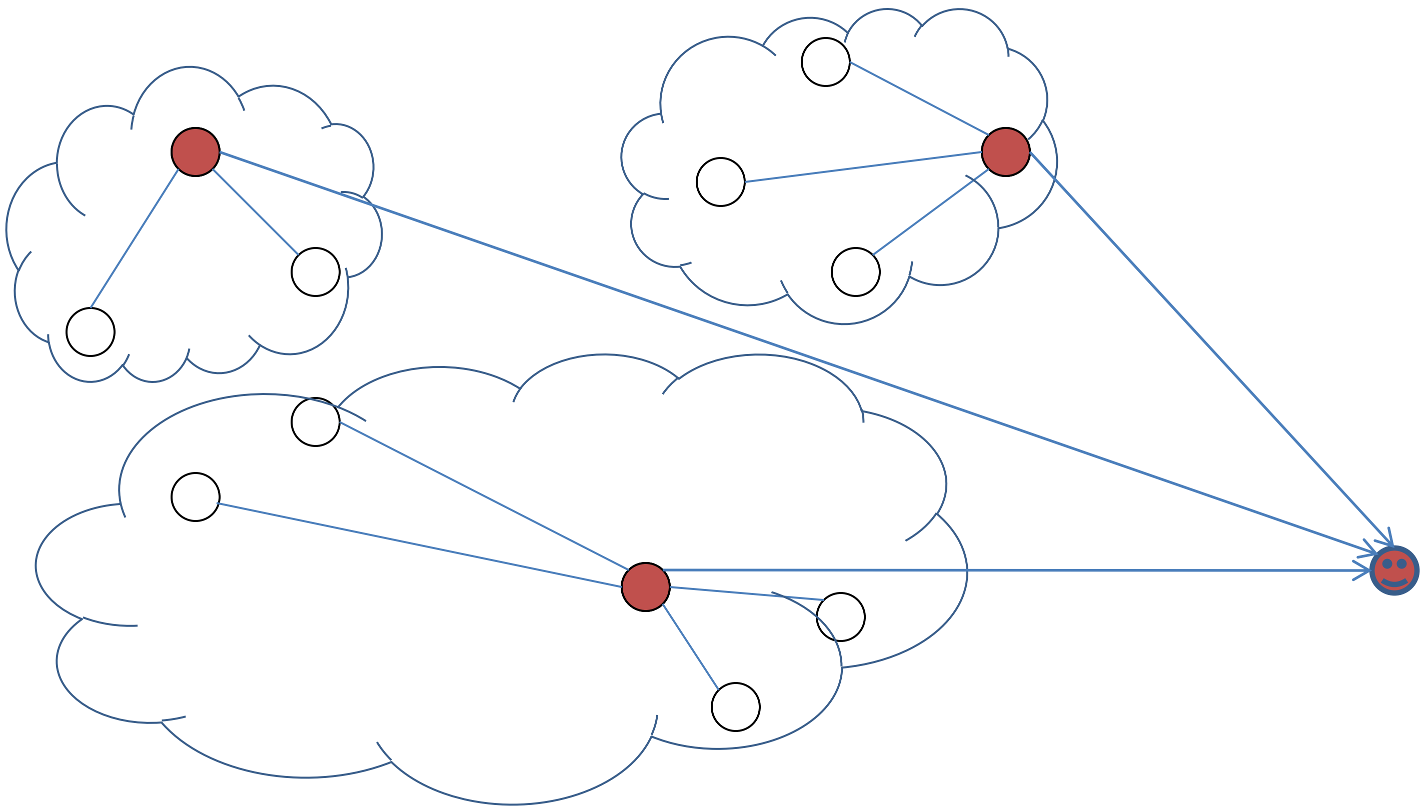
- Time division multiple-access(TDMA) MAC protocol for low-energy operation.
- “Power-aware” routing protocols for wireless networks.
- “Minimum transmission energy”(MTE) routing
- Clustering
  - Nodes send data to central cluster head
  - Cluster head forwards data
  - Cluster head has to be high energy node
  - Fixed Infrastructure

LEACH Protocol Architecture

LEACH in brief

- Randomized rotation of cluster heads among the sensors
- All non-cluster head nodes transmit data to their cluster head
- CH receives this data and performs signal processing functions on the data and transmits data to the BS





LEACH Protocol Architecture

LEACH Step by Step

- Cluster Head Selection
- Cluster Formation
- Steady State Phase
- LEACH-C: BS Cluster Formation

Cluster Head Selection Algorithms

- $P_i(t)$ is the probability with which node *i* elects itself to be Cluster Head at the beginning of the round r+1 (which starts at time t) such that expected number of cluster-head nodes for this round is *k*.

$$E[\#CH] = \sum_{i=1}^{N} P_i(t) * 1 = k. \quad (1)$$

k= # of clusters during each round
N= # of nodes in the network

- Each node will be Cluster Head once in N/k rounds.
- Probability for each node *i* to be a cluster-head at time *t*

$$P_i(t) = \begin{cases} \frac{k}{N - k*(r \bmod \frac{N}{k})} & : \quad C_i(t) = 1 \\ 0 & : \quad C_i(t) = 0 \end{cases} \quad (2)$$

$C_i(t)$ = it determines whether node i has been a cluster head in most recent *(r mod(N/k))* rounds.

Cluster Head Selection Algorithms (cont.)

$$E\left[\sum_{i=1}^{N} C_i(t)\right] = N - k * \left(r \bmod \frac{N}{k}\right) \qquad (3)$$

$\sum_{i=1}^{N} C_i(t)$ = total no. of nodes eligible to be a **cluster-head** at time *t*.

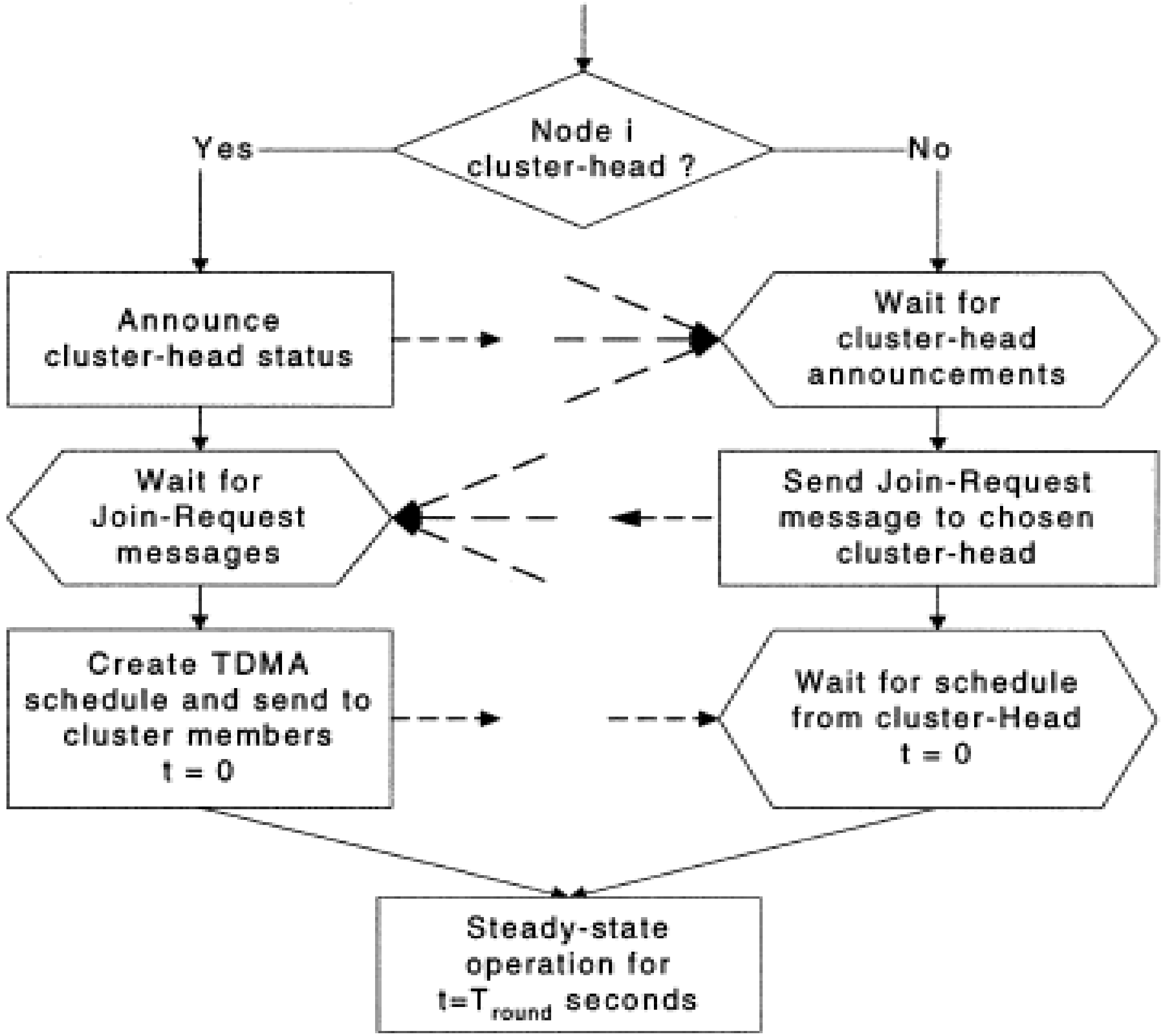
This ensures energy at each node to be approx. equal after every N/k rounds.

Using (2) and (3), expected # of Cluster Heads per round is,

$$\begin{aligned} E[\#CH] &= \sum_{i=1}^{N} P_i(t) * 1 \\ &= \left(N - k * \left(r \bmod \frac{N}{k}\right)\right) * \frac{k}{N - k * (r \bmod \frac{N}{k})} \\ &= k. \end{aligned} \qquad (5)$$

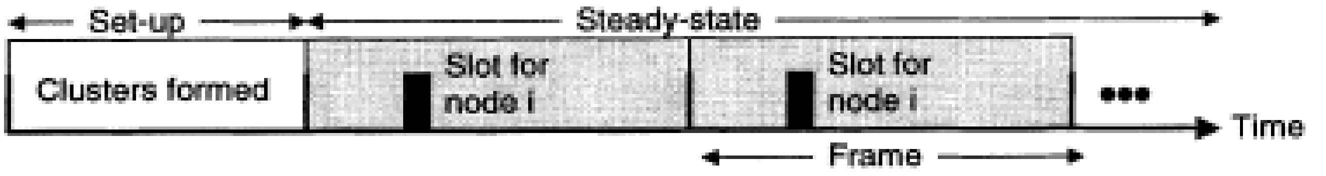
Cluster Formation Algorithm

- Cluster Heads broadcasts an *advertisement message* (ADV) using *CSMA MAC protocol*.
  - **ADV = node's ID + distinguishable header.**
- Based on the *received signal strength* of ADV message, each non-Cluster Head node determines its Cluster Head for this round.
- Each non-Cluster Head transmits a join-request message (Join-REQ) back to its chosen Cluster Head using a CSMA MAC protocol.
  - **Join-REQ = node's ID + cluster-head ID + header.**
- Cluster Head node sets up a TDMA schedule for data transmission coordination within the cluster.
- TDMA Schedule
  - Prevents collision among data messages.
  - Energy conservation in non cluster-head nodes.



Flowchart of the distributed cluster formation algorithm for LEACH

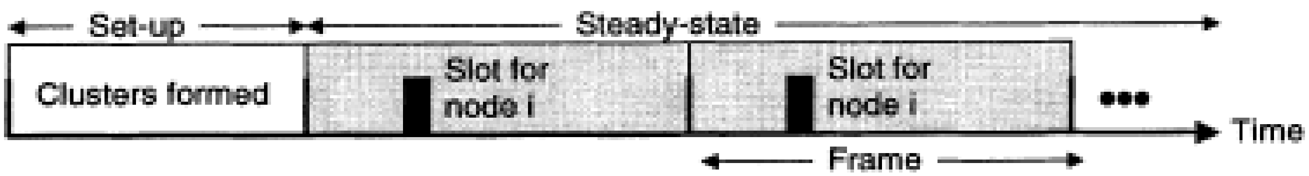
Steady State Phase



Time line showing LEACH operation

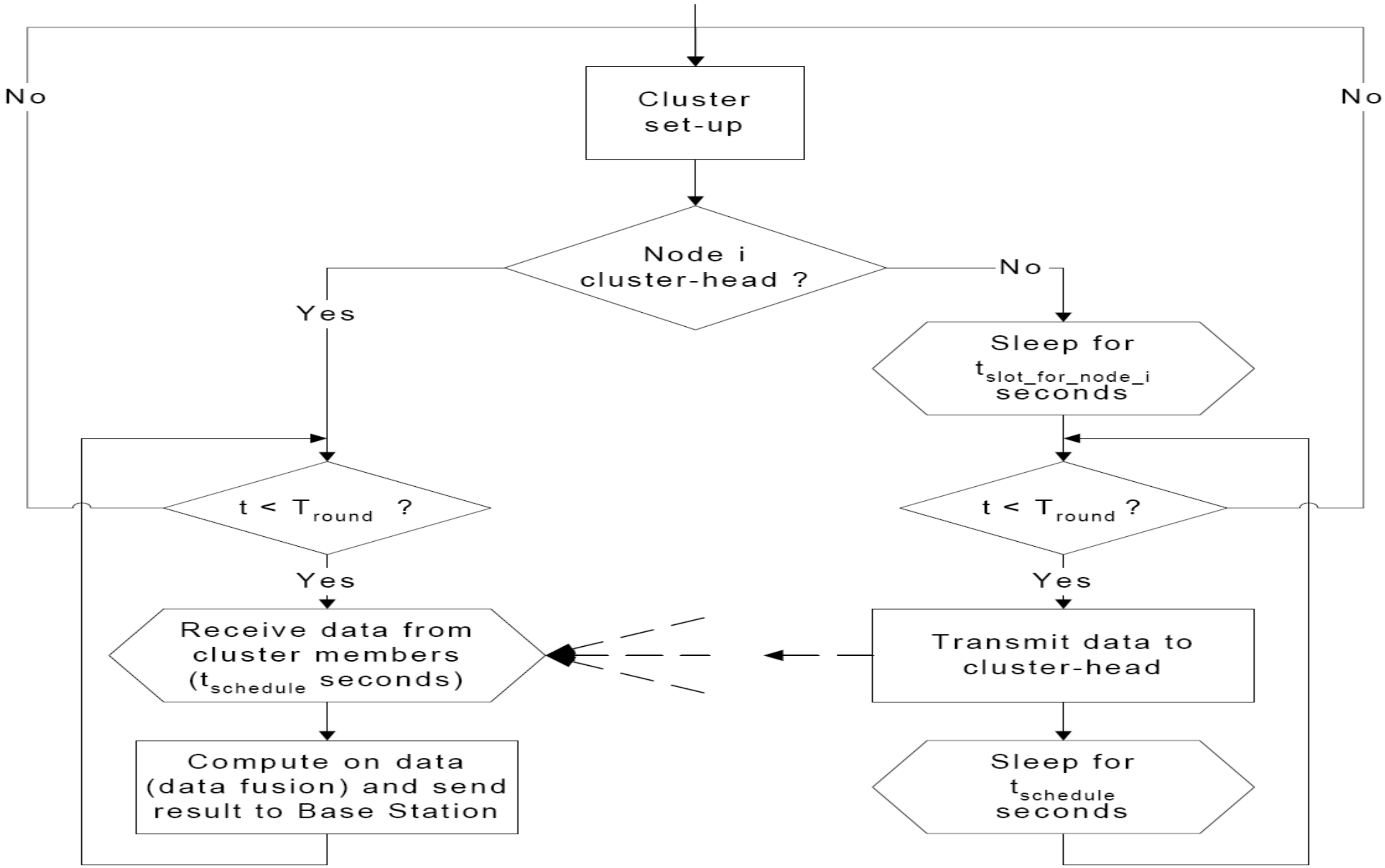
- TDMA schedule is used to send data from node to cluster head.
- Cluster head aggregates the data received from nodes in the cluster.
- Communication is via direct-sequence spread spectrum (DSSS) and each cluster uses a unique spreading code to reduce inter-cluster interference.
- Data is sent from the cluster head nodes to the BS using a fixed spreading code and CSMA.

Steady State Phase



Time line showing LEACH operation

- Assumptions
  - ❖ Nodes are all time synchronized and start the setup phase at same time.
  - ❖ BS sends out synchronized pulses to the nodes.
  - ❖ Cluster Head must be awake all the time.
- To reduce inter-cluster interference, each cluster in LEACH communicates using direct-sequence spread spectrum (DSSS).
- Data is sent from the cluster head nodes to the BS using a fixed spreading code and CSMA.



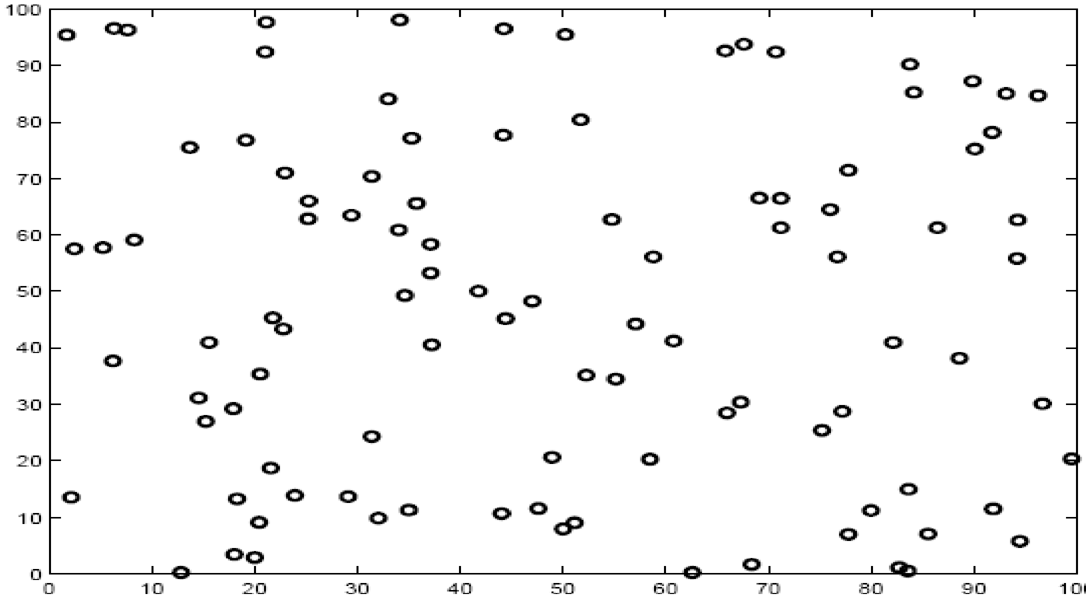
Flow chart for steady state phase

LEACH-C: BS Cluster Formation

Uses a central control algorithm to form clusters

- During setup phase each node sends its location and energy level to BS
- BS assigns cluster heads and clusters
- BS broadcasts this information
- The steady-state phase is same as LEACH

Analysis and Simulation



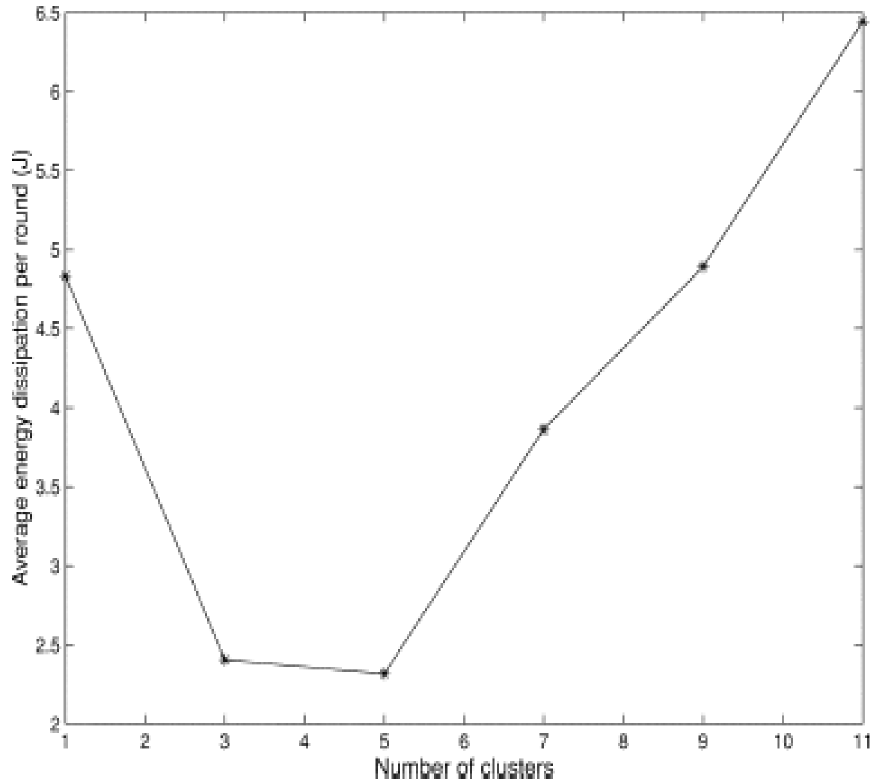
100 node random test network

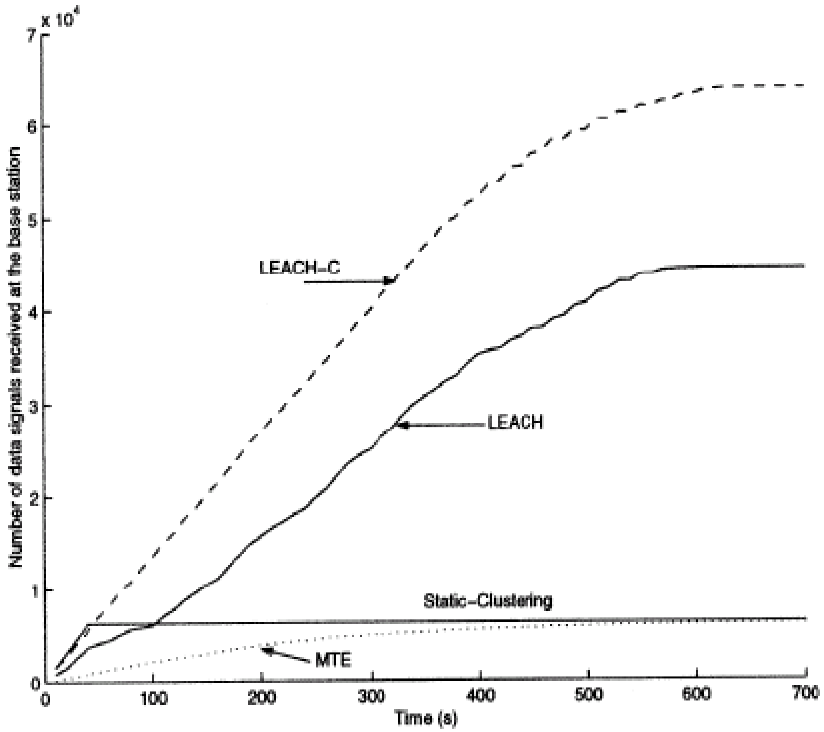
Nodes	100
Network size	100 m × 100 m
Base station location	(50, 175)
Radio propagation speed	3×10^8 m/s
Processing delay	50 μs
Radio speed	1 Mbps
Data size	500 bytes

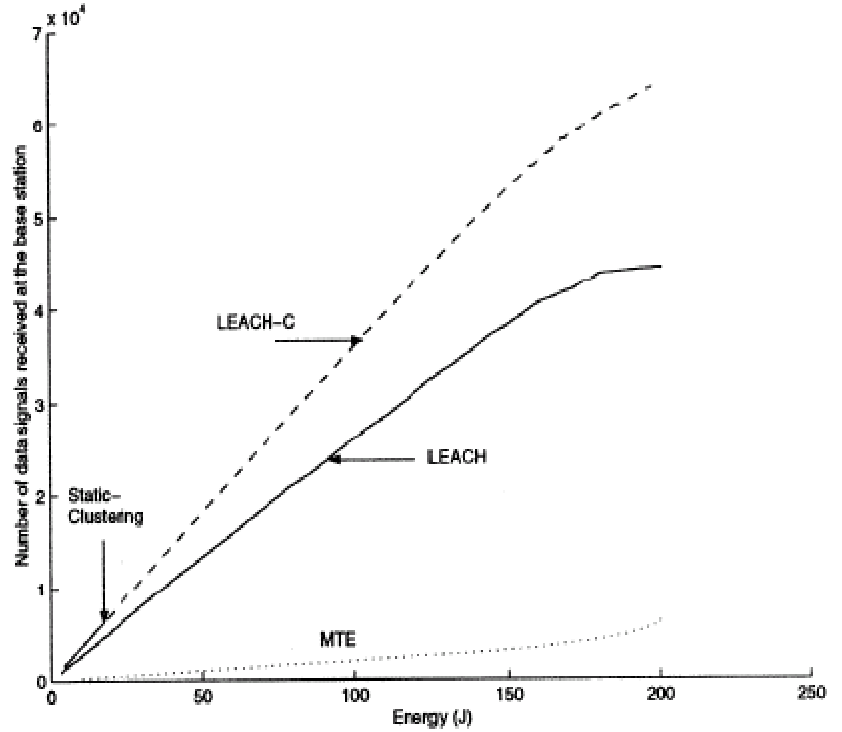
Analysis and Simulation (cont.)

Optimum Number of Clusters

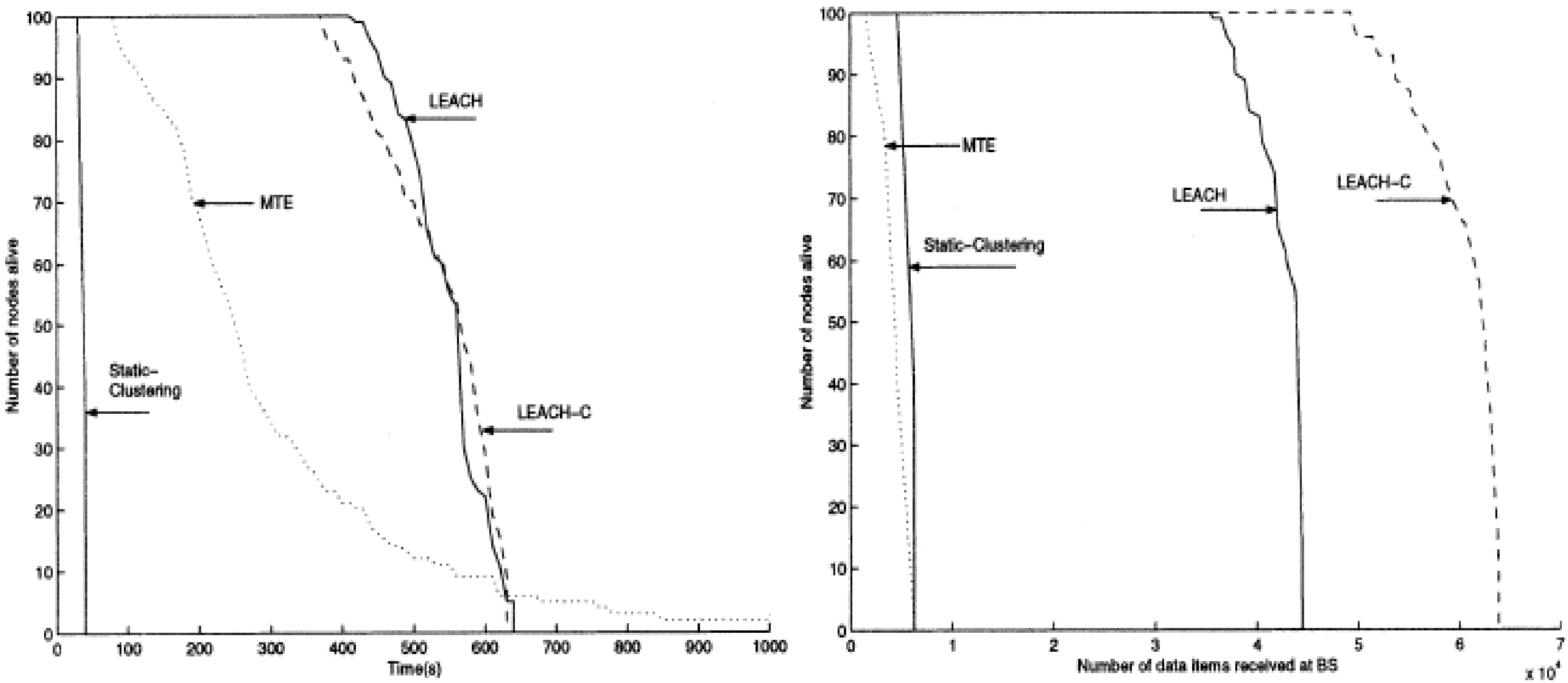
$$k_{opt} = \frac{\sqrt{N}}{\sqrt{2\pi}}\sqrt{\frac{\epsilon_{\rm fs}}{\epsilon_{\rm mp}}}\frac{M}{d^2_{\rm toBS}}.$$







- LEACH distributes more data per unit energy than MTE
- LEACH-C delivers 40% more data per unit energy than LEACH



(a) (b)

- LEACH and LEACH-C's nodes lifetime is much longer than MTE's
- LEACH can deliver 10 times the amount of effective data to the BS for the same number of node deaths

Conclusion

- Microsensor network protocols must be designed for
  - Bandwidth efficiency
  - Energy efficiency
  - High quality

- LEACH
  - Better energy utilization and system lifetime
  - Load balancing is achieved
  - All nodes die at a time

Reference

Heinzelman Wendi Rabiner, Chandrakasan Anantha, and Balakrishnan Hari. An Application-Specific Protocol Architecture for Wireless Microsensor Networks. *IEEE Transactions On Wireless Communication, Vol. 1, No. 4, October 2002*

Questions&Comments???

THANK YOU