Low-Energy Adaptive Clustering Hierarchy An Energy-Efficient Communication Protocol for Wireless Micro-sensor 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

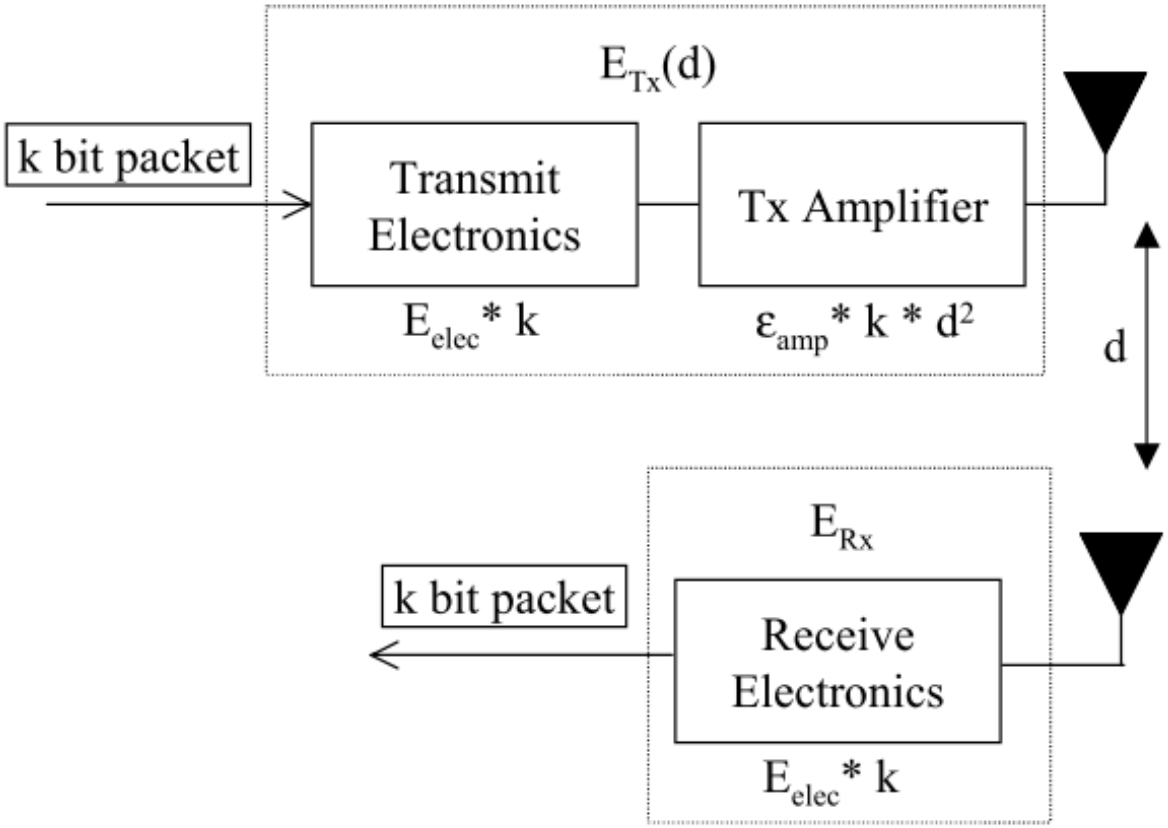


Figure 1. First order radio model.

Energy Analysis

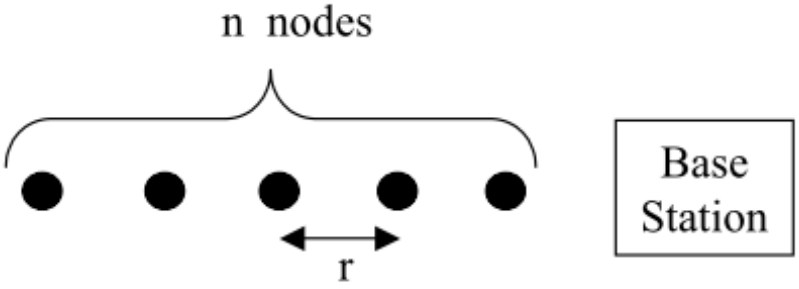


Figure 2. Simple linear network.

$$E_{direct} = E_{Tx}(k, d = n * r)$$
$$= E_{elec} * k + \epsilon_{amp} * k * (nr)^2$$
$$= k(E_{elec} + \epsilon_{amp} n^2 r^2)$$

$$E_{MTE} = n * E_{Tx}(k, d = r) + (n-1) * E_{Rx}(k)$$
$$= n(E_{elec} * k + \epsilon_{amp} * k * r^2) + (n-1) * E_{elec} * k$$
$$= k((2n-1)E_{elec} + \epsilon_{amp} n r^2)$$

LEACH

- In LEACH, the nodes organize themselves into local clusters, with one node acting as the local ***base station*** or ***cluster-head***.
- These cluster-head nodes broadcast their status to the other sensors in the network.
- Each sensor node determines to which cluster it wants to belong by choosing the cluster-head that requires the **minimum communication energy**.
- the cluster-head nodes are **not fixed**.
- The decision to become a cluster-head depends on the amount of energy left at the node.

LEACH Algorithm

- Advertisement Phase
- Cluster Phase
- Schedule Creation
- Data Transmission
- Hierarchical Clustering

Advertisement Phase

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

- For this “cluster-head-advertisement” phase, the cluster-heads use a CSMA MAC protocol, and all cluster-heads transmit their advertisement using the same transmit energy.
- decideClusterHead {} in ns-leach.tcl

Cluster Phase

- After each node has decided to which cluster it belongs,it must inform the cluster-head node that it will be a member of the cluster.
- findBestCluster{} and informClusterHead{}
- Each node transmits this information back to the cluster-head again using a CSMA MAC protocol.
- During this phase, all cluster-head nodes must keep their receivers on.

Schedule Creation

- The cluster-head node receives all the messages for nodes that would like to be included in the cluster.
- Based on the number of nodes in the cluster, the cluster-head node creates a TDMA schedule telling each node when it can transmit.
- createSchedule{}

Data Transmission

- Non-cluster-head send data during their allocated transmission time to the cluster-head.
- The radio of each non-cluster-head node can be **turned off** until the node's allocated transmission time, thus minimizing energy dissipation in these nodes.
- When all the data has been received, the cluster head node performs signal processing functions to compress the data into a single signal.
- This composite signal is sent to the base station.

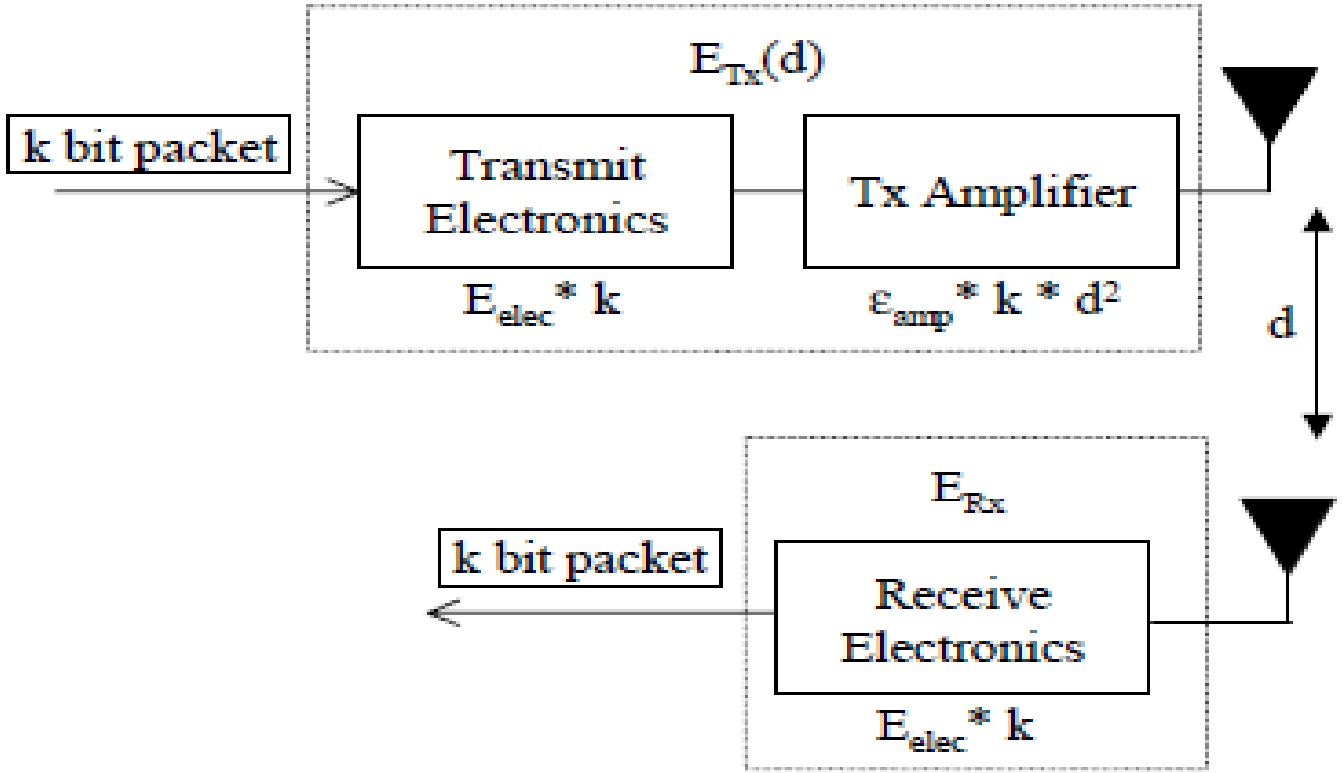
Hierarchical Clustering

- the cluster-head nodes would communicate with “super-cluster-head” nodes and so on until the top layer of the hierarchy, at which point the data would be sent to the base station.

Radio Model

- Designed around acceptable E_b/N_0
- E_{elec} = 50nJ/bit
  - Energy dissipation for transmit and receive
- ε_{amp} = 100pJ/bit/m^2
  - Energy dissipation for transmit amplifier
- k = Packet size
- d = Distance

Radio Model


$E_{Tx}(d)$
k bit packet
Transmit Electronics
Tx Amplifier
$E_{elec} * k$
$\varepsilon_{amp} * k * d^2$
d
E_{Rx}
k bit packet
Receive Electronics
$E_{elec} * k$

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

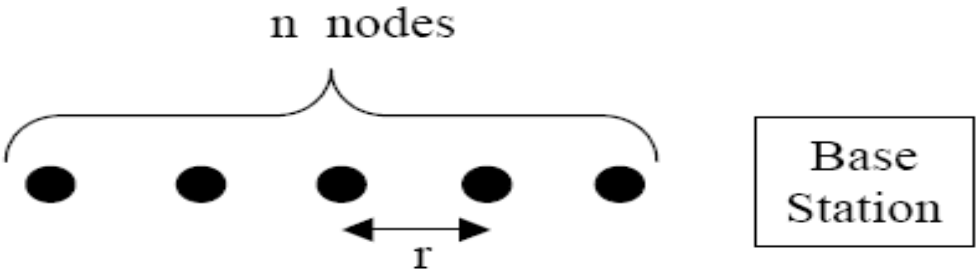
- Each sensor node transmits directly to the sink, regardless of distance
- Most efficient when there is a small coverage area and/or high receive cost

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

Energy Analysis of DT and MTE

- direct communication energy equations
- MTE communication energy equation
- Simple linear network model



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

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

Energy Analysis of DT and MTE

- Simulation on mat lab using energy equation
- 100-node random network
- 2000 bit packets
- ε_{amp} = 100pJ/bit/m2
- 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

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 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-CA
- Cluster heads must listen to the medium
- TDMA schedule created
  - Dynamic number of time slots

LEACH: Data Transmission

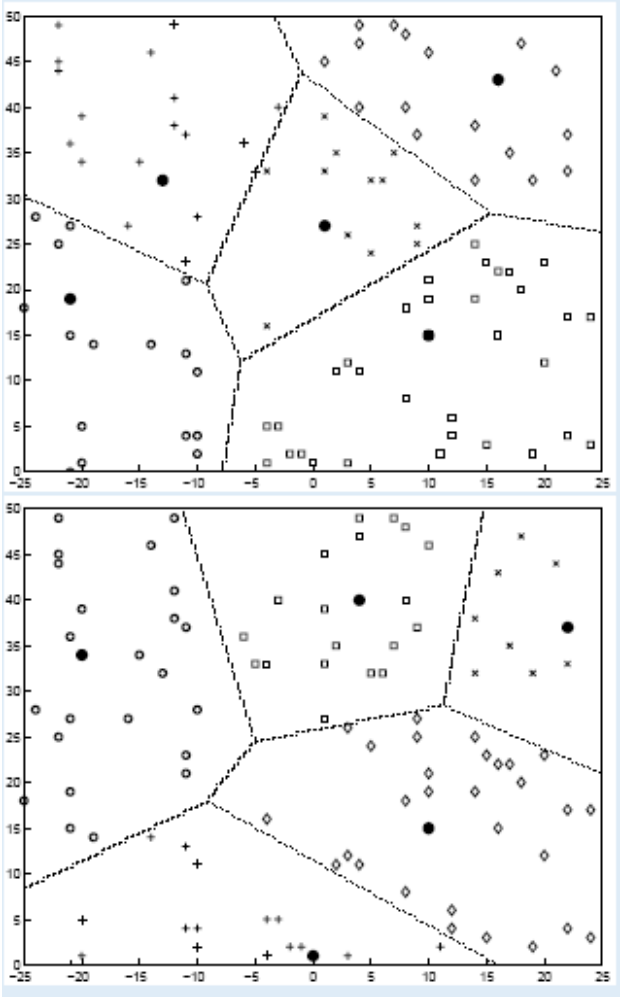
- Nodes sleep until its time slots
- Cluster heads must listen to each slot
- Cluster heads aggregate/compress and transmit to Sink
- Phase continues until the end of the round

Low-Energy Adaptive Clustering Hierarchy (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 CA used to advertise
- Nodes select advertisement with strongest signal strength
- Dynamic TDMA time slots



LEACH: Adaptive Clustering

- Number of clusters determined
  - 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 considered
- 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: Hierarchical Clustering

- Not currently implemented
- Efficient when network diameters are large

Conclusions

- LEACH is completely distributed
  - No centralized control system
- 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