Energy-Efficient Communication Protocol for Wireless Microsensor Networks

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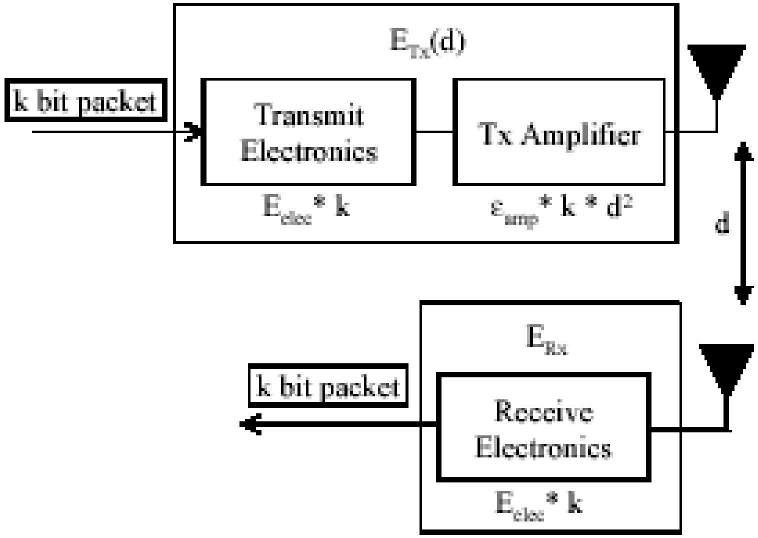
Algorithmics of sensor networks

Sensor networks

- Microsensor network consist of many spatially distributed sensors , which are used to monitor phenomena at different locations.
- A sensor is equipped with a radio transceiver, a small microcontroller and an energy source, usually a battery.
- Usually sensors are physically small and inexpensive.
- Microsensor networks can contain hundreds or thousands of sensor nodes and such netwoks rely on large numbers to obtain high quality results.
- Combining several unreliable data measurements to produce a more accurate signal is known as data fusion.

First order radio model [1/2]



- The radio dissipates E_{elec} = 50 nJ/bit to run the transmitter or receiver circuitry.
- The radio dissipates ϵ_{amp} = 100 pJ/bit/m^2 to run transmit amplifier.

These parameters are slighty better than the current state-of-the-art in radio design.

First order radio model [2/2]

Transmiting a k-bit message a distance d radio expends:

$$\begin{aligned} E_{Tx}(k,d) &= E_{Tx-elec}(k) + E_{Tx-amp}(k,d) \\ &= E_{elec} * k + \epsilon * k * d^2 \end{aligned} \tag{1}$$

Receiving this message, radio expends:

$$\begin{aligned} E_{Rx}(k) &= E_{Rx-elec}(k) \\ &= E_{elec} * k \end{aligned} \tag{2}$$

Note that for above parameter values, receiving a message is not a low cost operation. Different assumptions about the radio characteristics, will change the advantages of different protocols.

Energy analysis of routing protocols

The most energy-efficient protocol to use depends on the network topology and radio parameters of the system. Here we examine following protocols.

- Direct communication protocol
- Minimum-transmission-energy routing protocol
- Clustering
- Low-Energy Adaptive Clustering Hierarchy (LEACH)

It is assumed that the base station is fixed and located far from the sensors and all nodes in the network are homogeneous and energy constrained.

Direct communication protocol

Using a direct communication protocol, each sensor sends its data directly to the base station. The only receptions in this protocol occur at the base station.

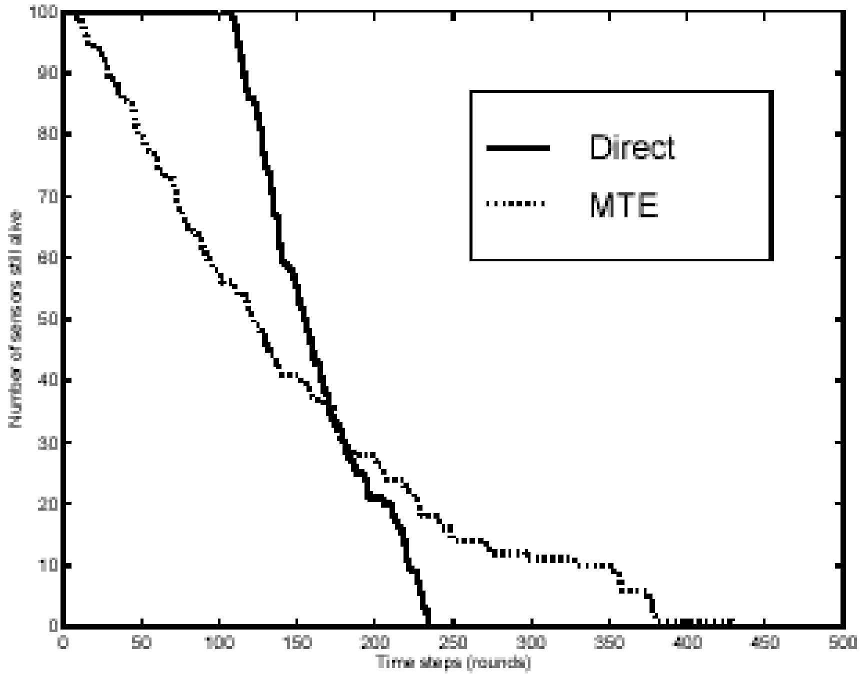
- If the base station is far away from the nodes, direct communication will require a large amount of transmit power from each node. This will quickly drain the battery of the nodes and reduce the system lifetime.
- If either the base station is close to the nodes, or the energy required to receive data is large, this may be an acceptable (and possibly optimal) method of communication.

Minimum-transmission-energy protocol

In minimum-transmission-energy protocol(MTE), nodes route data destined ultimately for the base station through intermediate nodes. The intermediate nodes are chosen such that the transmit amplifier energy is minimized.

- Each data message must go through n (low-energy) transmits and n receives. Depending on the radio characteristics the total energy expended in the system might actually be greater using MTE routing than using direct communication protocol
- In MTE routing, the nodes closest to the base station will be used to route a large number of data messages to the base station. Thus these nodes will die out quickly. In addition, as nodes close to the base station die, that area of the environment is no longer being monitored.

System lifetime comparison



- The nodes die out quicker using MTE routing than direct transmission.
- The last node dies sooner in direct transmission than MTE routing.

Clustering

Nodes are organized into clusters that communicate with a local base station, and these local base stations transmit the data to the global base station.

- This greatly reduces the distance nodes need to transmit their data, as typically the local base station is close to all the nodes in the cluster.
- If the base station is an energy-constrained node, it would die quickly, as it is being heavily utilized.

LEACH

LEACH is a self-organizing, adaptive clustering protocol that uses randomization to distribute the energy load evenly among the sensors in the network. The operation of LEACH is broken up into rounds, where each round begins with a set-up phase followed by a steady-state phase.

- Set-up phase
  - Cluster-head Advertisement
  - Cluster Set-Up
  - Transmission schelude creation
- Steady-state phase
  - Data transmission to cluster heads
  - Signal prosessing (Data fusion)
  - Data transmission to the base station

Advertisement phase [1/2]

Initially each node decides whether or not to become a cluster-head for the current round. This decision is made by the node n choosing a random number between 0 and 1. If the number is less than a threshold T(n), the node becomes a cluster-head for the current round. The threshold is set as:

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

where P = the desired percentage of cluster heads, r = the current round, and G is the set of nodes that have not been cluster-heads in the last $\frac{1}{P}$ rounds. There exist an optimal number of nodes that should be cluster heads.

Advertisement phase [2/2]

Each node that has elected itself a cluster-head for the current round broadcasts an advertisement message to the rest of the nodes. 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.

After this phase is complete, each non-cluster-head node decides the cluster which it will belong for this round. This decision is based the received signal strength of the advertisement. In the case of ties, a random cluster-head is chosen.

Cluster set-up

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. Each node transmits this information back to the cluster-head again using a CSMA MAC protocol.

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. This schedule is broadcast back to the nodes in the cluster.

Transmission in one cluster will affect (and hence degrade) communication in a nearby cluster. To reduce this type of interference, each cluster communicates using different CDMA codes. Efficient channel assignment is a difficult problem.

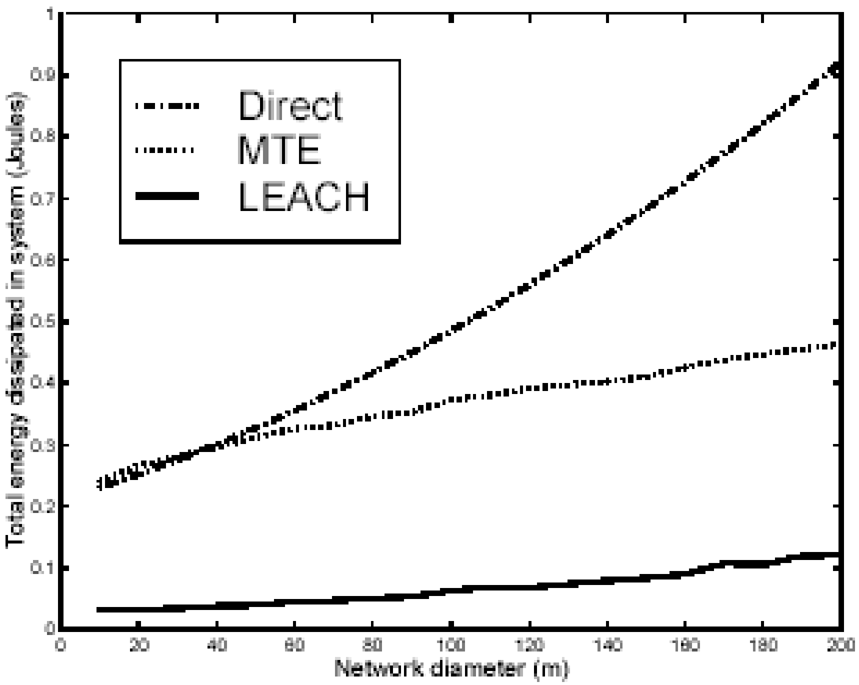
Data transmission

Once the clusters are created and the TDMA schedule is fixed, data transmission can begin. Nodes send their data during their allocated transmission time to the cluster head. This transmission uses a minimal amount of energy (chosen based on the received strength of the cluster-head advertisement). 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.

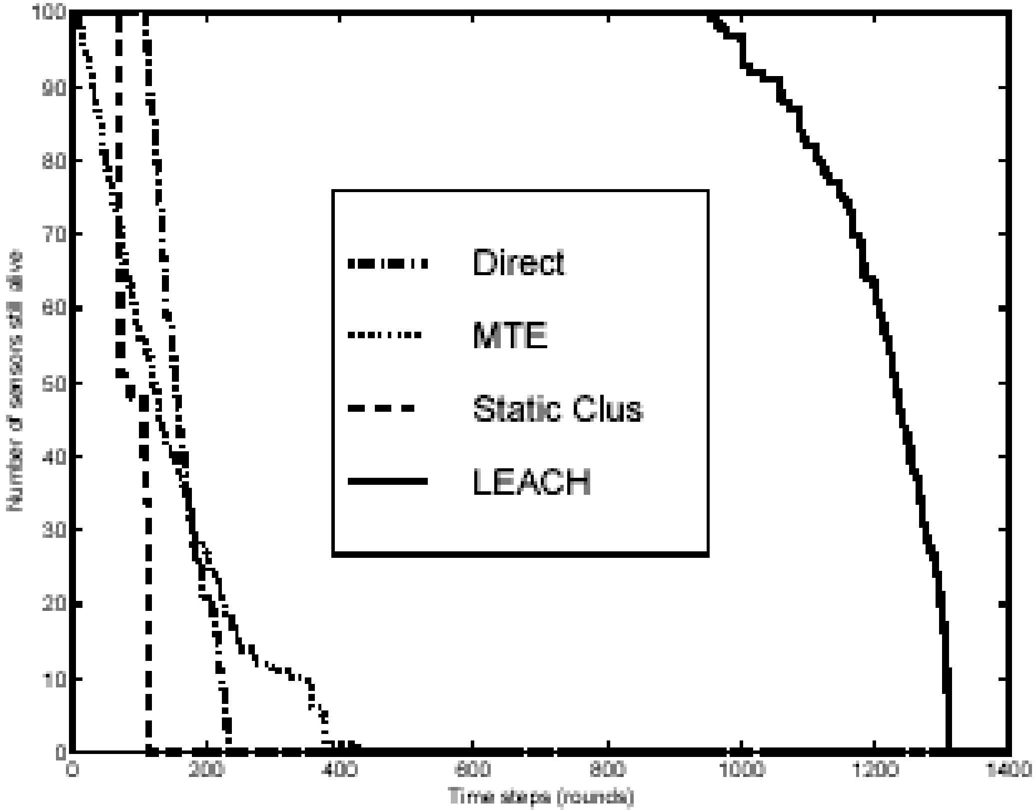
Experimental results [1/3]

Matlab simulation with 100 random nodes, with 5% of the nodes being cluster heads.



- LEACH achieves between 7x and 8x reduction in energy compared with direct communication and between 4x and 8x reduction in energy compared with MTE routing.

Experimental results [2/3]



System lifetime using direct transmission, MTE routing, static clustering and LEACH with 0.5J/node.

Experimental results [3/3]

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

Another important advantage of LEACH is the fact that nodes die in essentially a random fashion.

Improvements to LEACH

- Hierarchical clusters
  The cluster-head nodes would communicate with "super-clusterhead"nodes and so on until the top layer of the hierarchy, at which point the data would be sent to the base station.
- Energy-based threshold function.

Other interesting ideas(not mentioned in the text)

- Ensure that the cluster head nodes are uniformly distributed by dividing advertisement phase into smaller sub-phases.
- The use of combined LEACH and MTE routing with the cluster heads acting as routers.

Remarks

LEACH is promising routing protocol for the sensor networks, however there were not enough experimental data on diffrent network topologies and different radio parameters to make any final conclusions.

Further study is required to estimate the full potential of the LEACH routing protocol.