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Analysis of Energy Efficient Routing Protocols in Wireless Sensor Networks

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ABSTRACT

Wireless sensor networking is an emerging technology that has a wide range of potential applications including environment monitoring, smart spaces, medical systems and robotic exploration. Such a network normally consists of a large number of distributed nodes that organize themselves into a multi-hop wireless network. Conventional routing protocols may not be optimal for sensor networks. With the development of MEMS (micro-electro-mechanical-systems), low-power analog and digital electronics, and low-power RF design, the design of wireless sensors has been developed rapidly. In this paper, we look at communication protocols, which can have significant impact on overall energy dissipation of these networks. LEACH (Low-Energy Adaptive Clustering Hierarchy) is a clustering-based protocol that utilizes randomized rotation of local cluster base stations to evenly distribute the energy load among the sensors in the network. Simulations show that LEACH can achieve as much as a factor of 8 reductions in energy dissipation compared with conventional routing protocols. LEACH also distributes energy dissipation evenly throughout the sensors, increasing the lifetime of the system.

Keywords: LEACH, Cluster, Transceiver.

1. INTRODUCTION

Recent advances in MEMS-based sensor technology, low-power analog and digital electronics, and low-power RF design have enabled the development of relatively inexpensive and low-power wireless micro sensors in wireless communication made it possible to develop wireless sensor networks(WSN) consisting of small devices, which collect information by cooperating with each other. These small sensing devices are called nodes and consist of CPU (for data processing), memory (for data storage), battery (for energy) and transceiver (for receiving and sending signals or data from one node to another) [1] and [2] shown in figure 1.1. These sensors are not as reliable or as accurate as their expensive macro sensor counterparts, but their size and cost enable applications to network hundreds or thousands of these micro sensors in order to achieve high quality, fault tolerant sensing networks. Reliable environment monitoring is important in a variety of commercial and military applications. For example, for a security system, acoustic, seismic, and video sensors can be used to form an ad-hoc network to detect intrusions. Micro sensors can also be used to monitor machines for fault detection and diagnosis. Micro sensor networks can contain hundreds or thousands of sensing nodes. It is desirable to make these nodes as cheap and energy-efficient as possible and rely on their large numbers to obtain high quality results. Network protocols must be designed to achieve fault tolerance in the presence of individual node failure while minimizing energy consumption. In addition, since the limited wireless channel bandwidth must be shared among all the sensors in the network, routing protocols for these networks should be able to perform local collaboration to reduce bandwidth requirements. Eventually, the data being sensed by the nodes in the network must be transmitted to a control center or base station, where the end-user can access the data.A wireless sensor network is composed by hundreds or thousands of nodes that are densely deployed in a large geographical area. These sensors measure ambient conditions in the environment surrounding them and then transform these data into electric signals which can be processed to reveal some characteristics about phenomena located in the area around these sensors. Therefore, we can get the information about the area which is far away from us. The applications may be environment control such as office building, robot control and guidance in automatic manufacturing environments, interactive toys, high security smart homes, and identification and personalization. Wireless sensor networks (WSNs) are the products which integrate sensor techniques, embedded techniques, and distributed information processing and communication techniques. The appearance of the wireless sensor network is a revolution in information sensing and detection. Recently, both academia and industries show great interest in sensor networks. The functional component of a typical wireless sensor is given in the following figure

(1.1). Sensor nodes are constrained in energy supply and bandwidth. Recent research in many scientific areas, like physics, microelectronics, control, material science etc. and the collaboration of scientists which used, traditionally, to work towards totally different directions, has lead to the creation of the Micro-Electro-Mechanical Systems (MEMS)[3].The following steps can be taken to save energy caused by communication in wireless sensor networks: to schedule the state of the nodes (i.e. transmitting, receiving, idle or sleep), changing the transmission range between the sensing nodes, using efficient routing and data collecting methods, avoiding the handling of unwanted data as in the case of overhearing. In WSNs the only source of life for the nodes is the battery. By analyzing the advantages and disadvantages of conventional routing protocols using our model of sensor networks, we have developed LEACH, a clustering-based protocol that minimizes energy dissipation in sensor networks. The key features of LEACH are: localized coordination and control for cluster set-up and operation, randomized rotation of the cluster "base stations" or "cluster-heads" and the corresponding clusters, local compression to reduce global communication.

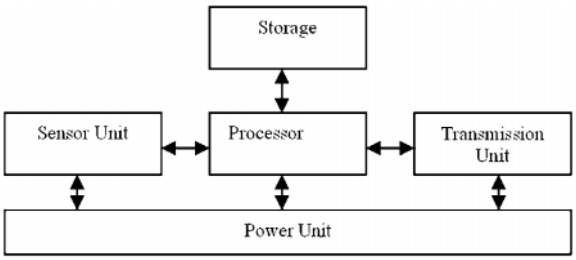

Fig 1.1: Logical Diagram of a Wireless Sensor Networks

The use of clusters for transmitting data to the base station leverages the advantages of small transmit distances for most nodes, requiring only a few nodes to transmit far distances to the base station.

However, LEACH outperforms classical clustering algorithms by using adaptive clusters and rotating cluster-heads, allowing the energy requirements of the system to be distributed among all the sensors. In addition, LEACH is able to perform local computation in each cluster to reduce the amount of data that must be transmitted to the base station. This achieves a large reduction in the energy dissipation [4].The use of clusters for transmitting data to the base station leverages the advantages of small transmit distances for most nodes, requiring only a few nodes to transmit far distances to the base station. However, LEACH outperforms classical clustering algorithms by using adaptive clusters and rotating cluster-heads, allowing the energy requirements of the system to be distributed among all the sensors. In addition, LEACH is able to perform local computation in each cluster to reduce the amount of data that must be transmitted to the base station. This achieves a large reduction in the energy dissipation [4].

The performance of wireless sensor networks is based on the factors [5] : Latency, Scalability, Energy Awareness, Node Processing Time, Transmission Scheme, Network Power Usage.

Classification of Protocols[1]	*Representetive Protocols*
Data Centric Protocols	Flooding and Gossiping, SPIN
Hierarchical Protocols	LEACH,PEGASIS
Location Based Protocols	MECN,GAF,GEAR
Network Flow & QoS Aware Protocol	SAR & SPEED

2. FIRST ORDER RADIO MODEL

Here the different assumptions about the radio characteristics, including energy dissipation in the transmit and receive modes will change the advantages of different protocols. In our work, we assume a simple model where the radio dissipates E_elec = 50 nJ/bit to run the transmitter or receiver circuitry and E_amp = 100 pJ/bit/m^2 for the transmit amplifier to achieve an acceptable Eb/No. We also assume an d^2 energy loss due to channel transmission. Thus, to transmit a k-bit message a distance d using our radio model, the radio expands[5] and [9]

$$E_{Tx}(k,d) = E_{Tx-elec}(k) + E_{Tx-amp}(k,d) = E_{elec} * k + \in_{amp} * k * d^2 \quad (1)$$

and to receive this message, the radio expands:

$$E_{Rx}(k) = E_{Rx-elec}(k) = E_{elec} * k \quad (2)$$

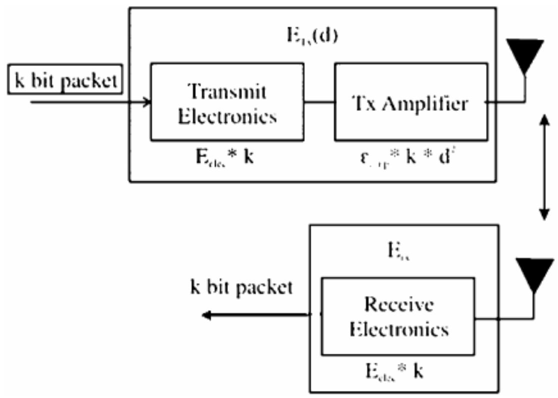

Fig 2.1: First Order Radio Model

Where $\in_{amp}$ is amplification factor for transmitter amplifier in multipath. We make the assumption that the radio channel is symmetric such that the energy required to transmit a message from node A to node B is the same as the energy required to transmit a message from node B to node A for a given signal to noise ratio.

3. ENERGY AWARENESS OF PROTOCOLS

Here we examine two protocols, namely direct communication (direct transmission) with the base station and minimum-energy (minimum transmission energy) multi-hop routing using our sensor network and radio models. Here, we discuss a conventional clustering approach to routing and the drawbacks of using such an approach when the nodes are all energy-constrained. Using a direct communication protocol, each sensor sends its data directly to 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 (since d in Equation 3 is large). This will quickly drain the battery of the nodes and reduce the system lifetime.

The second conventional approaches we consider minimum-energy routing protocol. In these protocols, nodes route data destined ultimately for the base station through intermediate nodes [9]. Thus nodes act as routers for other nodes data in addition to sensing the environment. These protocols differ in the way the routes are chosen. In some of these protocols, only consider the energy of the transmitter and neglect the energy dissipation of the receivers in determining the routes. In this case, the intermediate nodes are chosen such that the transmit amplifier energy (Etx_amp (k, d) = E_amp* k *d^2) is minimized, thus node A would transmit to node C through node B if and only if:

$$E_{Tx-amp}(k, d=d_{AB}) + E_{Tx-amp}(k, d=d_{BC}) < E_{Tx-amp}(k, d=d_{AC}) \quad (3)$$

or

$$d_{AB}^2 + d_{BC}^2 < d_{AC}^2 \quad (4)$$

In this minimum-transmission-energy (MTE) routing protocol, rather than just one (high-energy) transmit of the data, each data message must go through *n* (low energy) transmitters and *n* receivers. Depending on the relative costs of the transmit amplifier and the radio electronics, the total energy expended in the system might actually be greater using MTE routing than direct transmission to the base station. To illustrate this point, consider the linear network having n nodes where the distance between the nodes is r ($d = nr$). If we consider the energy expended transmitting a single k-bit message from a node located a distance nr from the base station using the direct communication approach and equation 1 and 2, we have:

$$\begin{aligned} E_{direct} &= E_{Tx}(k, d = n*r) = E_{elec}*k + \in_{amp} *k*(nr)^2 \\ &= k(E_{elec} + \in_{amp} n^2r^2) \end{aligned} \quad (5)$$

In MTE routing, each node sends a message to the closest node on the way to the base station. Thus the node located a distance nr from the base station would require n transmits a distance r and $n-1$ receives.

$$\begin{aligned} E_{MTE} &= n*E_{Tx}(k, d=r) + (n-1)*E_{Rx}(k) \\ &= n(E_{elec}*k*r^2) + (n-1)*E_{elec}*k \\ &= k((2n-1)E_{elec} + \in_{amp} nr^2) \end{aligned} \quad (6)$$

Therefore, direct communication requires less energy than MTE routing if:

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

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

$$\frac{E_{elec}}{\in_{amp}} > \frac{r^2 n}{2} \quad (7)$$

4. LEACH PROTOCOL

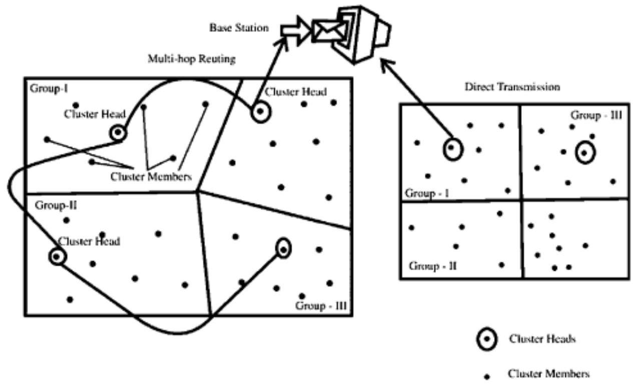

Fig 4.1: LEACH Operation Showing Set-up, Steady State Phases using Multi-hop, also Showing Direct Transmission

In LEACH, the operation of the whole network is divided into many rounds. Every round includes set-up phase and steady-state phase LEACH is a self-organizing, adaptive clustering routing protocol. The key idea is to reduce the number of nodes communicating directly with the base station. LEACH balances nodes energy consumption in network by choosing cluster head randomly. Nodes organized by several clusters automatically and communicate with cluster header, the cluster process data aggregation and communicate with base station. LEACH performs local data fusion to compress the amount of data being sent from the clusters to the base station, further reducing energy dissipation and enhancing system lifetime. If base station is far from the area that sensor nodes are deployed in, the distance from nodes to base station are similar approximately. The energy costs of clusters are same approximately, when clusters transmit data to base station. In this situation, LEACH can make very good optimization result in energy conservation. We consider the problems about number of cluster in networks and derive out the best percentage of clusters in networks. In LEACH, the cluster formation algorithm was created to ensure that the expected number of clusters per round is L, a system parameter. We can analytically determine the optimal value of L in LEACH using the computation and communication energy models. Assume that there are N nodes distributed uniformly in an (M * M) region. If there are L clusters, there are on average N/L nodes per cluster (one cluster head and [(N/L)-1] non-cluster head nodes). Each cluster head dissipates energy receiving signals from the nodes, aggregating the signals, and transmitting the aggregate signal to the BS. Since the BS is far from the nodes, presumably the energy dissipation follows the multipath model (d^4 power loss). Therefore, the energy dissipated in the cluster head node during a single frame is [5]

$$E_{CH} = kEelec\left(\frac{N}{L}-1\right)+kE_{DA}\frac{N}{L}+kE_{elec}+k\in_{mp} d^4_{toBS} \tag{8}$$

where k is the number of bits in each data message, d_{toBS} is the distance from the cluster head node to the BS, E_{DA} is data aggregation. Each non-cluster head node only needs to transmit its data to the cluster head once during a frame. Presumably the distance to the cluster head is small, so the energy dissipation follows the Friss free-space model (d^2 power loss). Thus, the energy used in each non-cluster head node is[5].

$$E_{non-CH} = kE_{elec} + k\in_{fs} d^2_{toCH} \tag{9}$$

Where d_{toCH} is the distance from the node to the cluster head & $\in_{fs}$ is free space (short) distance amplification factor for transmitter. The area occupied by each cluster is approximately M^2/L.

If the density of nodes is uniform throughout the cluster area, then

$$\rho = \left(1/\left(M^2/L\right)\right) \tag{10}$$

$$E\left[d^2_{toCH}\right] = \frac{1}{2\pi}\frac{M^2}{L} \tag{11}$$

Therefore, in this case

$$E_{non-CH} = kE_{elec} + k\in_{fs}\frac{1}{2\pi}\frac{M^2}{L} \tag{12}$$

The energy dissipated in a cluster during the frame is

$$E_{cluster} = E_{CH} + \left(\frac{N}{L}-1\right)E_{non-CH} \approx E_{CH} + \frac{N}{L}E_{non-CH} \tag{13}$$

and the total energy for the frame is[5]

$$E_{total} = LE_{cluster} =$$

$$= k\left(E_{elec}N + E_{DA}N + L\in_{mp} d^4_{toBS} + E_{elec}N + \in_{fs}\frac{1}{2\pi}\frac{M^2}{L}N\right) \tag{14}$$

5. SIMULATION RESULTS

The protocol described above was simulated in MATLAB. First we generated the random 100-node network shown in Figure 5.1 and using equations 1 – 4, we simulated transmission of data from every node to the base station (located 100 m from the closest sensor node, at (x = 0, y = 100)).

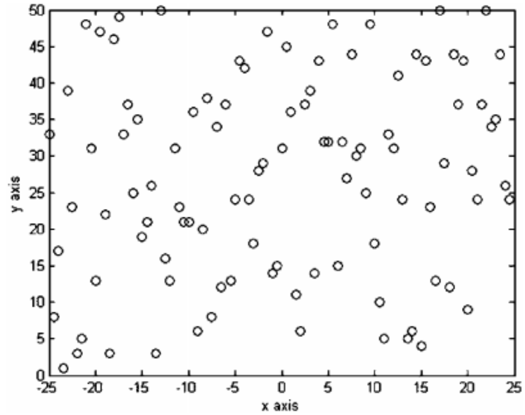

Fig 5.1: 100-node Random Network

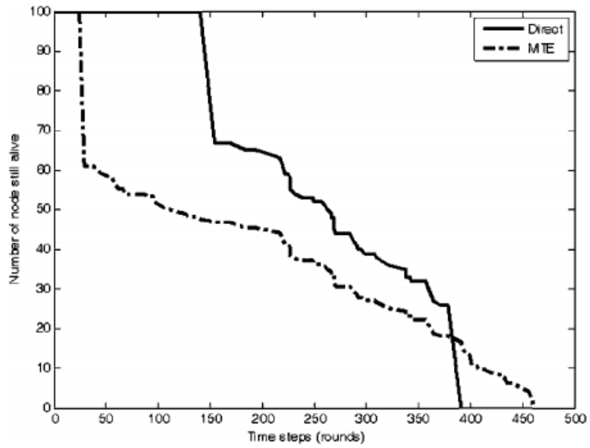

Fig 5.2: System Lifetime using Direct Transmission and MTE Routing with 0.5j/node

This shows that direct transmission is more energy-efficient on a global scale than MTE routing. Thus the most energy-efficient protocol to use depends on the network topology and radio parameters of the system. It is clear that 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, causing the energy required to get the remaining data to the base station to increase and more nodes to die. In addition, as nodes close to the base station die, that area of the environment is no longer being monitored. To prove this point, we run simulations using the random 100-node network shown in Figure 5.1 and had each sensor send a 2000-bit data packet to the base station during each time step or "round" of the simulation. After the energy dissipated in a given node reached a set threshold, that node was considered dead for the remainder of the simulation.

Figure 5.2 shows the number of sensors that remain alive after each round for direct transmission and MTE routing with each node initially given 0.5 J of energy as shown by equation no. .6. This plot shows that nodes die out quicker using MTE routing than direct transmission.

In the first simulation, 100 sensor nodes deployed random in a 100*100 area, we run the simulations with different position of base station, different number of nodes, and different topology of WSN. The dead nodes appears firstly in the networks that runs the protocol in this paper simulation with the same position of base station.

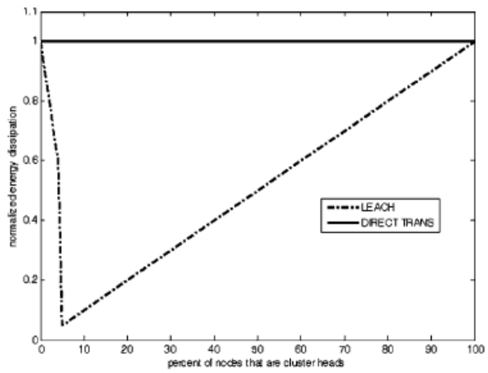

Fig 5.3: Normalized Total System Energy Versus the Percent of Nodes that are Cluster Heads

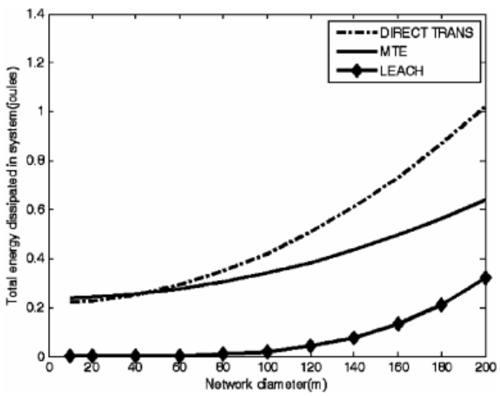

Fig 5.4: Total System Energy Dissipated Dissipated using Direct Communication MTE Routing and LEACH for the 100- node Random Network

We simulated the LEACH protocol for the random network shown in Figure 5.3 using the radio parameters and a computation cost of 5 nJ/bit/message to fuse 2000-bit messages while varying the percentage of total nodes that are cluster heads. It shows how the energy dissipation in the system varies as the percent of nodes that are cluster-heads is changed. It shows that 0 cluster-heads and 100% cluster-heads is the same as direct communication. From this plot, we find that there exists an optimal percent of nodes N that should be cluster-heads. If there are fewer than N1(5% normalized node) cluster-heads, some nodes in the network have to transmit their data very far to reach the cluster-head, causing the global energy in the system to be large. If there are more than N1 cluster-heads, the distance nodes have to transmit to reach the nearest cluster-head does not reduce substantially, yet there are more cluster-heads that have to transmit data the long-haul distances to the base station and there is less compression being performed locally. For our system parameters and topology, it also shows that LEACH can achieve over a factor of 8 reduction in energy dissipation compared to direct communication with the base station, when using the optimal number of cluster-heads. The main energy savings of the LEACH protocol is due to combining lossy compression with the data routing. There is clearly a trade-off between the quality of the output and the amount of compression achieved. In this case, some data from the individual signals is lost, but this results in a substantial reduction of the overall energy dissipation of the system. We simulated LEACH (with 5% of the nodes being cluster-heads) with the random network. Figure 5.4 shows how these algorithms compare using Eelec = 50 nJ/bit as the diameter of the network is increased. This plot shows that LEACH achieves approximately 8 times reduction in energy compared with direct communication and approximately 7 times reduction in energy compared with MTE routing.In addition to reducing energy dissipation, LEACH successfully distributes energy-usage among the nodes in the network such that the nodes die randomly and at essentially the same rate.

6. LEACH ALGORITHM DETAILS

The operation of LEACH is broken up into rounds, where each round begins with a set-up phase, when the clusters are organized, followed by a steady-state phase, when data transfers to the base station occur. In order to minimize overhead, the steady-state phase is long compared to the set-up phase.

6.1. Advertisement Phase

Initially, when clusters are being created, each node decides whether or not to become a cluster-head for the current round. This decision is based on the suggested percentage of cluster heads for the network (determined a priori) and the number of times the node has been a cluster-head so far.

6.2. Cluster Setup 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. 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.

6.3. 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.

6.4. Data Transmission

Once the clusters are created and the TDMA schedule is fixed, data transmission can begin.

6.5. Hierarchical Clustering

The version of LEACH described in this paper can be extended to form hierarchical clusters. In this scenario, 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. For larger networks, this hierarchy could save a tremendous amount of energy.

7. CONCLUSION

Our simulations show that:

- LEACH reduces communication energy by as much as 8 times compared with direct transmission and minimum transmission-energy routing.
- The first node death in LEACH occurs over 8 times later than the first node death in direct transmission, minimum-transmission-energy routing, and a static clustering protocol, and the last node death in LEACH occurs over 3 times later than the last node death in the other protocols.

8. FUTURE WORK

Based on our MATLAB simulations described above, we are confident that LEACH will outperform conventional communication protocols, in terms of energy dissipation, ease of configuration, and system lifetime/quality of the network. Providing such a low-energy, ad hoc, distributed protocol will help pave the way for future microsensor networks.

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