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Performance Analysis of Low Energy Adaptive Clustering Hierarchy and Optimization

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Abstract— Wireless Sensor Networks (WSNs) consist of small nodes with sensing, computation, and wireless communications capabilities. Many routing, power management and data dissemination protocols have been specifically designed for WSNs where energy awareness is an essential design issue. In this report, the performance of LEACH (Low-Energy Adaptive Clustering Hierarchy), a clustering-based protocol that utilizes randomized rotation of local cluster-based protocol that utilizes randomized rotation of cluster base stations (cluster-heads) to evenly distribute the energy load among the sensors in the network is analyzed. LEACH uses localized coordination to enable scalability and robustness for networks, and incorporate data fusion into the routing protocol to reduce the amount of information to the base station. It is able to distribute energy dissipation evenly throughout the sensors. Simulations are run in the simulator tool Castalia to study the effects of different parameters on the network lifetime and optimal values of parameters are determined.

Index Terms— LEACH, Network life time, Performance, Wireless network.

1 Introduction

A wireless sensor network (WSN) consists of spatially distributed autonomous sensors to monitor physical or environmental conditions, such as temperature, sound, pressure, etc. and to co-operatively pass their data through the network to a main location. The more modern networks are bi-directional, also enabling control of sensor activity. The development of wireless sensor networks was motivated by military applications such as battlefield surveillance; today such networks are used in many industrial and consumer applications, such as industrial process monitoring and control, machine health monitoring and so on. The WSN is built of "nodes" from a few to several hundreds or even thousands, where each node is connected to one sensor. Each such sensor network node has typically several parts: a radio transceiver with an internal antenna or connection to an external antenna, a microcontroller, an electronic circuit for interfacing with the sensors and an energy source, usually a battery or an embedded form of energy harvesting. A sensor node might vary in size from that of a shoebox down to the size of a grain of dust, although functioning "motes" of genuine microscopic dimensions have to yet to be created. The cost of sensor nodes is similar variable, ranging from a few to hundreds of dollars, depending on the complexity of the individual sensor nodes, size and cost constraints on resources such as energy, memory, computational speed and communications bandwidth. The propagation technique between the hops of the network can be routing or flooding.

The rest of the work is as follows: Section II explains Least Energy adaptive clustering hierarchy and the algorithm. Section III analyses the performance in terms of network lifetime, average energy consumed, effect of round length on Energy consumed per second , effect of percentage of cluster heads on average energy consumed per Second. The simulation are done using tool Castalia and the results are discussed. Final Conclusion is done in Section IV.

2 Least Energy Adaptive Clustering Hierarchy

2.1 Introduction to LEACH

Low-energy adaptive clustering hierarchy (LEACH) is the first and most popular energy-efficient hierarchical clustering algorithm for WSNs that was proposed for reducing power consumption. Figure 1 shows the block diagram of LEACH. In LEACH, the clustering task is rotated among the nodes, based on duration. Direct communication is used by each cluster head (CH) to forward the data to the base station (BS). It uses clusters to prolong the life of the wireless sensor network. LEACH is based on an aggregation (or fusion) technique that combines or aggregates the original data into a smaller size of data that carry only meaningful information to all individual sensors. It divides the a network into several cluster of sensors, which are constructed by using localized coordination and control not only to reduce the amount of data that are transmitted to the sink, but also to make routing and data dissemination more scalable and robust. A randomize rotation of high-energy CH position rather than selecting in static manner is used, to give a chance to all sensors to act as CHs and avoid the battery depletion of an individual sensor and dying quickly. The operation of LEACH is divided into rounds having two phases each namely:

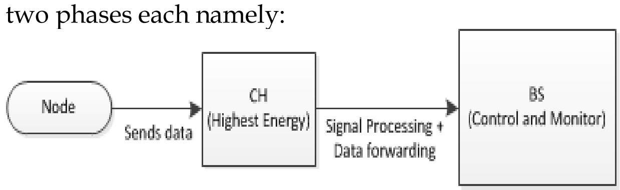

Fig. 1. Block Diagram of LEACH

(i) A setup phase to organize the network into clusters, CH advertisement, and transmission schedule creation and
(ii) A steady-state phase for data aggregation, compression, and transmission to the sink.

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2.2 Algorithm

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.

1) Setup Phase:

a) 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. 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 where P = the desired percentage of cluster heads (e.g. P = 0:05), r = the current round, and G is the set of nodes that have not been cluster-heads in the last 1/P rounds. Using this threshold, each node will be a cluster-head at some point within 1/P rounds. During round 0 (r = 0), each node has a probability P of becoming a cluster-head. The nodes that are cluster-heads in round 0 cannot be cluster-heads for the next 1/P rounds. Thus the probability that the remaining nodes are cluster-heads must be increased, since there are fewer nodes that are eligible to become cluster-heads. After 1/P 1 rounds, T = 1 for any nodes that have not yet been cluster-heads, and after 1/P rounds, all nodes are once again eligible to become cluster-heads. Future versions of this work will include an energy-based threshold to account for non-uniform energy nodes. In this case, assuming that all nodes begin with the same amount of energy and being a cluster-head removes approximately the same amount of energy for each node. 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 CSMAMAC protocol, and all cluster-heads transmit their advertisement using the same transmit energy. The non-cluster-head nodes must keep their receivers on during this phase of set-up to hear the advertisements of all the cluster-head nodes. After this phase is complete, each non-cluster-head node decides the cluster to which it will belong for this round. This decision is based on the received signal strength of the advertisement. Assuming symmetric propagation channels, the cluster-head advertisement heard with the largest signal strength is the cluster-head to whom the minimum amount of transmitted.

b) Cluster Setup Phase

Figure 2 shows the cluster formation algorithm. 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.

2) Steady State Phase:

a) Schedule Creation

The cluster-head node receives all the messages for nodes that would like to be included in the cluster. Based on

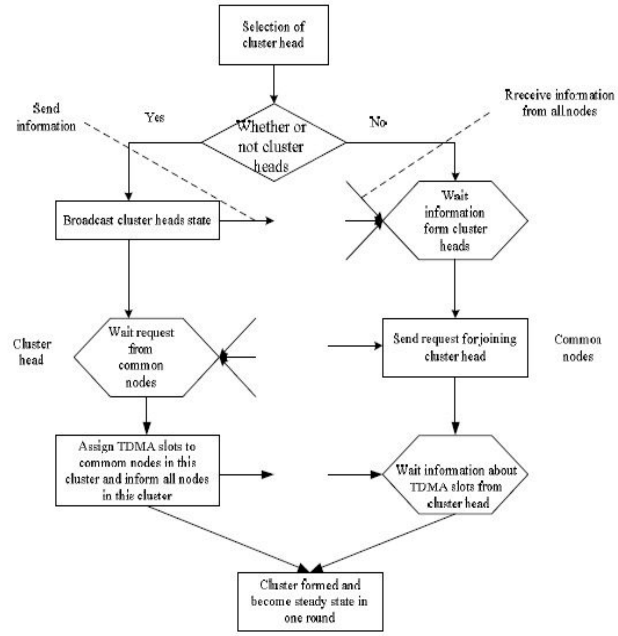


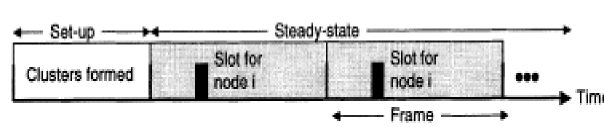
Fig.2 Cluster Formation Algorithm

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.

b) Data Transmission

Once the clusters are created and the TDMA schedule is fixed, data transmission can begin. Assuming nodes always have data to send, they send it 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. The cluster-head node must keep its receiver on to receive all the data from the nodes in the cluster. When all the data has been received, the cluster head node performs signal-processing functions to compress the data into a single signal. For example, if the data are audio or seismic signals, the cluster-head node can beam form the individual signals to generate a composite signal. This composite signal is sent to the base station. Since the base station is far away, this is a high-energy transmission. This is the steady-state operation of LEACH networks which is shown in Figure 3. After a certain time, which is determined a priori, the next round begins with each node determining if it should be a cluster-head for this round and advertising this information.

Fig 3.Timeline showing steady state LEACH operation



3) Multiple Clusters

The preceding discussion describes how the individual clusters communicate among nodes in that cluster. However, radio is inherently a broadcast medium. As such, transmission in one cluster will affect (and hence degrade) commu-

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nication in a nearby cluster.

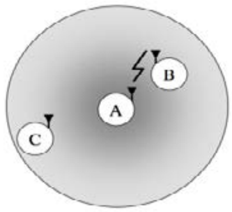

Fig.4 Radio Interference

For example, Figure 4 shows the range of communication for a radio. Node A's transmission, while intended for Node B, corrupts any transmission to Node C. To reduce this type of interference, each cluster communicates using different CDMA codes. Thus, when a node decides to become a cluster-head, it chooses randomly from a list of spreading codes. It informs all the nodes in the cluster to transmit using this spreading code. The cluster-head then filters all received energy using the given spreading code. Thus neighboring clusters' radio signals will be filtered out and not corrupt the transmission of nodes in the cluster. Efficient channel assignment is a difficult problem, even when there is a central control center that can perform the necessary algorithms. Using CDMA codes, while not necessarily the most bandwidth efficient solution, does solve the problem of multiple-access in a distributed manner. LEACH is performed with the use of CASTALIA and its performance is analyzed.

3 PERFORMANCE ANALYSIS

3.1 Analyzing the Energy Efficiency of LEACH:

In the following sections, simulations are performed for various parameter combinations using the Castalia Simulator in order to study the effect of various parameters on the Network Lifetime.

3.2 Network Lifetime

Network Lifetime may be calculated in a number of ways:

* Time to first node failure
* Time to x% of node(s) failures
* Time to first network segmentation (any node not begin able to get data to a sink)
* Time to x% network segmentation

The calculated network life based on the first two methods and discovered that the time to first node failure is not a reliable measure of lifetime as the first node to die is inevitably the sink node as it is in a constant RX state. Thus, the average energy consumed per second is used to calculate lifetime as illustrated in the following sections. Average Consumed Energy is calculated as:

Average Energy Consumed/second=Energy Consumed in Simulation time/Simulation time

Lifetime = Initial Energy/Average Energy Consumed per second

To calculate the lifetime using first node death, the node that consumes the most energy is identified and a similar procedure is followed.

3.3 Simulation Parameters

The network in defined in a fixed field of M x M size (in m) with N nodes randomly distributed across it. There exists one sink node. The nodes form clusters and transmit randomly generated packets (of a constant payload) to the sink node. All the simulations are performed with 3 different random distributions and then averaged. Only Static nodes are used. Free space path loss is assumed. The initial energy available to the nodes is 18720 J, which is the equivalent of two AA batteries. The parameters for a sample simulation are described in Table 1.

TABLE 1
SIMULATION PARAMETERS

Simulation time limit	200s
Field Size	70x70
No. of Nodes	100
Node deployment	[1.99]->random distribution
Round Length	20s
Percentage of cluster heads	0.05

a) Simulation Results:

Table 1 shows the received packet breakdown in terms of the sum of the received packets. The results obtained for the simulation defined by parameters given in Table II are given in figure 5.

```
ResourceManager:Consumed Energy
+--------+
|        |
+--------+
| 4.879  |
+--------+
```

Fig.5 Average Energy Consumed

TABLE 2
RECEIVED PACKET BREAKDOWN : SUM

Failed with no interference	1229
Failed with interference	10269
Failed, non RX state	27925
Received despite interference	2433
Received with no interference	86844

b) Network Lifetime

Network lifetime can be obtained by extrapolating the results obtained. Using energy consumed by sink node:

Average Energy consumed/second = 13.598/200=0.06799 J/s

Network Lifetime= 18720/0.06799=275334.608031s
Network Lifetime (In days) = 3.18 days
Using Average Consumed Energy:
Average Energy Consumed/seconds = 4.879/200
= 0.024395 J/s
Network Lifetime = 18720/0.024395 = 767370.362s
Network Lifetime (In days) = 8.88 days

3.4 Interference

It is seen that increase in the number of nodes decreases network lifetime. As the number of node increases, network congestion increases which lead to increase in the number of packets that are dropped due to interference.

TABLE 3
EFFECT OF ROUND LENGTH ON ENERGY CONSUMED PER SECOND

Round Length	N=100, M=70	N=100, M=250	N=100, M=500	N=500, M=500
20	23.6725	26.915	35.3975	25.195
40	20.95	24.99625	32.74375	22.33875
60	19.763333	23.525	33.660833	21.418333
80	19.44625	23.080625	32.14625	20.614375
100	19.156	22.424	32.0885	20.639
150	20.363333	24.179667	33.402333	20.007667
200	18.7995	21.34925	32.60825	20.3075
250	17.9878	21.8156	32.8102	19.8176
300	17.868333	21.8365	32.1615	19.599

Increase in the field size with a limited number of nodes leads to extensive use of the highest transmission level to transmit which leads to more energy expenditure and thus leads to decreased network lifetime. Increase in field size also leads to loss of packets due to path loss.

3.5 Effect of Round length

The round length determines how often cluster heads are designated. If the round length is increased the frequency of the assignment of cluster heads will decrease which will lead to a reduction in the amount of energy consumed. Simulations were done for various values of round length, number of nodes and field sizes. The results are summarized in Table III and Figure 6.

Here, N- Number of nodes M- Field size of MxM. It is observed that increasing the round length leads to a general decrease in energy consumed per second. But, if too large a round length is used, some nodes may die earlier as they have been cluster heads too long and thus expended more energy.

3.6 Effect of Percentage of Cluster Heads

As stated before, the round length consists to two parts. The time length of each round t-round = (α + t)

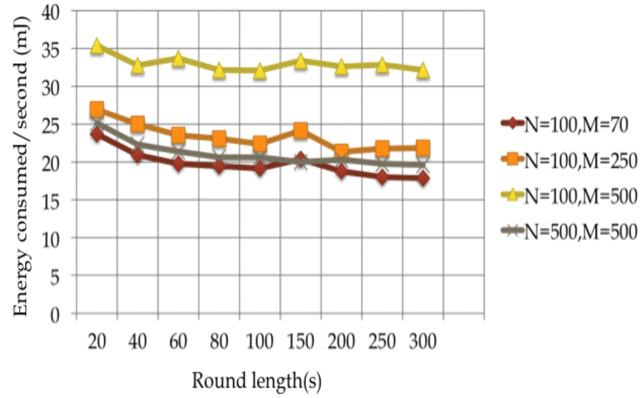

Fig 6 Effect of Round Length on Energy Consumed per second

where, α=set-up phase and t= steady data transmission time

Let the number of sensor nodes in a network be N, which includes K clusters. There exist at average N/K nodes in each cluster (one cluster head and (N/k-1) non cluster nodes). Given the initial energy E0 of sensor node, the lifetime can be deduced according to

1. Network life time /Average Energy Consumed/second
2. No. of cluster heads /Network life time.
3. No. of cluster heads / Energy for set up phase.

Assuming constant payload, any modification in the energy for set up phase will affect the lifetime. The number of cluster heads selected affects the energy for the setup phase. This number varies with varying percentage of cluster heads. So an optimal number of cluster heads for prolonged network lifetime is needed. Simulations were done for varying values of percentage of cluster heads, varying field size and number of nodes. The results are summarized in figure 9 and TABLE IV and Table V.

TABLE 4
EFFECT OF PERCENTAGE OF CLUSTER HEADS ON ENERGY CONSUMED PER SECOND

Percentage of Cluster Heads	N= 100, M= 70	N= 100, M= 250	N= 100, M= 500	N= 100, M= 750	N= 100, M= 1000
0.05	24.345	28.89	37.49	42.96	47.64
0.15	30.89	30.87	32.195	33.7	36.35
0.25	39.935	39.695	38.23	38.045	38.03
0.35	48.59	45.92	44.225	44.37	43.74
0.45	46.575	46.445	46.295	46.575	46.99
0.5	58.465	57.21	55.69	54.665	54.15

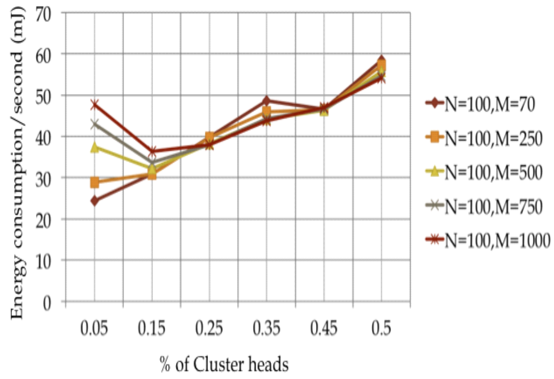

Fig 7 Effect of Percentage of Cluster Heads on Average Energy Consumed per Second-1

TABLE 4
EFFECT OF PERCENTAGE OF CLUSTER HEADS ON ENERGY CONSUMED PER SECOND

Percentage of Cluster Heads	N=500 M=500	N=500 M=250
0.05	25.395	25.335
0.15	33.04	33.775
0.25	42.135	42.3
0.35	48.98	48.96
0.45	46.845	47.565
0.5	57.45	58.13

From figure 7 and figure 8, it is seen that even though the amount of energy consumed per second increases with increase in the number of cluster heads, there is a drop in the energy consumed where the percentage of cluster heads is optimal. Optimal value of k can be determined by locating the point at which minimum energy is consumed. The optimal value of k changes with increasing M. It increases with increasing M. Thus, there is a need to increase the percentage of nodes that are cluster heads with an increase in the field size. But, it is also seen that the ratio of no. of nodes to field size also has an effect. If the field size is larger compared to the no. of nodes then, a larger no. of cluster heads is required.

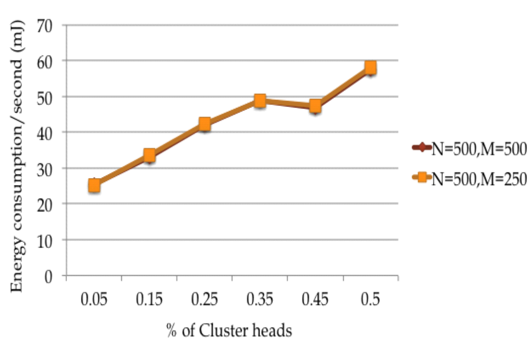

Fig.8 Effect of Percentage of Cluster Heads on Average Energy Consumed per Second-2

4 CONCLUSION

LEACH is simulated in the simulation tool Castalia that possesses an advanced channel model, advanced radio model, extended sensing model, MAC and Routing protocols are available and it is designed for adaptation and expansion. Accurate radio/channel models, event-driven simulation engine, platform independence allow for first level protocol validation. Specifically, simulations show that increasing the number of nodes in a fixed field size leads to a decrease in network lifetime due to increase in the number of cluster heads and increase in the amount of interference. Increasing the field size leads to a decrease in network lifetime due to increase in the amount of power required to transmit across large distances and an increase in the number of dropped packets due to path loss. Increase in round length leads to an increase in the network lifetime but may lead to early node death in some cases. Increase in the number of cluster heads leads to decrease in lifetime due to the fact that cluster heads expend more energy than normal nodes. The optimization is achieved by selecting the values of field size, number of nodes, round length and percentage of cluster heads based on the results obtained.

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