Optimization of Hierarchical Routing Protocol for Wireless Sensor Networks with Identical Clustering

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***Abstract*—This paper presents a uniform clustering approach which aims to cover entire field with identical clusters scattered over the field. The Cluster head is elected using the LEACH protocol for every cluster locally. Both LEACH and I-LEACH (Identical clustering - LEACH) were compared through extensive simulations using NS2 simulator which shows that I-LEACH performs better than LEACH protocol. I-LEACH reduces energy consumption by around 45% and improves the throughput by 60%.**

Index Terms: LEACH, Hierarchical routing algorithms, clustering, wireless sensor networks, I-LEACH.

I. Introduction

In the wireless sensor networks (WSNs), the sensor nodes are usually scattered in a sensor field - an area in which the sensor nodes are deployed. The nodes in these networks coordinate to produce high-quality information and each of these scattered sensor nodes has the capabilities to collect and route data back to the base stations, which are fixed or mobile. In WSNs, conservation of energy, which is directly related to network lifetime, is considered relatively more important than the performance of the network in terms of reliability of data sent. Each node in a sensor network is typically equipped with one or more sensors, a radio transceiver or other wireless communications device, a small microcontroller, and an energy source. Since in most wireless sensor network applications the energy source is a battery [3], energy plays an important role in wireless sensor network. Preserving the energy is an important goal that must be considered when developing a routing protocol for wireless sensor. In general, routing in WSNs can be divided into flat, hierarchical, and location based routing depending on the network structure. Flat Routing is the first category of routing protocols where each node typically plays the same role and sensor nodes collaborate to perform the sensing task. The base station(BS) sends queries to certain regions and waits for data from the sensors located in the selected regions. Since data is being requested through queries, attribute-based naming is necessary to specify the properties of data. Hierarchical Routing is the well-known technique with special advantages related to scalability and efficient communication. In hierarchical architecture, higher-energy nodes can be used to process and send the information, while low-energy nodes can be used to perform the sensing in the proximity of the target.

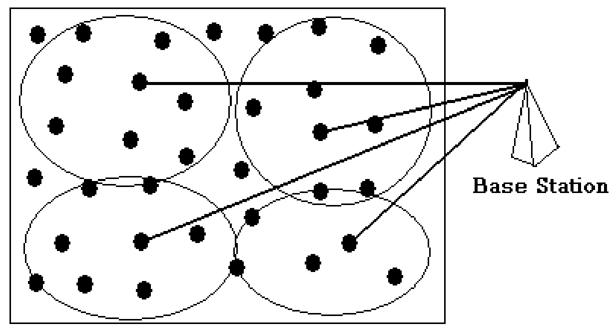

Fig. 1: Clustering

Many routing protocols have been proposed in the literature such as LEACH[3], PEGASIS[4], TEEN[5], APTEEN[6], HEED[7] and GROUP[8]. LEACH is considered as the most popular routing protocol that use cluster based routing in order to minimize the energy consumption. In this paper we propose an improvement on the LEACH protocol that further improves the energy consumption. Simulation results bring out that our protocol outperforms LEACH protocol in terms of energy consumption, lifetime and overall throughput.

In section II we discuss the LEACH protocol in detail, Section III presents the related work, in section IV we introduce our proposed protocol I-LEACH, in section V we evaluate our protocol and present the simulation results and in section VI we conclude the paper.

II. Cluster based Routing

Broadcasting is the process in which a source node sends a message to all other nodes in the network. There are various classifications of broadcasting methods. One of these methods is clustering which is used by LEACH protocol as shown in figure 1. The basic objective of any routing protocol is to make the network useful and efficient. A cluster based routing protocol groups sensor nodes where each group of nodes has a Cluster Head (CH) or a gateway. Sensed data is sent to the CH rather than sending it to the Base

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Station (BS), CH may apply some aggregation method on data it receives then send it to the BS where the data is needed.

A number of routing protocols have been proposed for WSN [9], However, few of them are cluster based. Two of the most well known hierarchical protocols are LEACH and PEGASIS. Both of these show significant reduction in the overall network energy over other non-clustering protocol. Apart from the advantages related to scalability and efficient communication Hierarchical or cluster-based routing methods are also utilized to perform energy-efficient routing in WSNs. The creation of clusters and assigning special tasks to cluster heads can greatly contribute to overall system scalability, lifetime, and energy efficiency. Hierarchical routing is an efficient way to lower energy consumption within a cluster, performing data aggregation and fusion in order to decrease the number of transmitted messages to the BS.

A. *LEACH Routing Protocol*

This protocol is proposed by W. R. Heinzelman et.al [3] which minimizes energy dissipation in sensor networks, It is based on a simple clustering mechanism by which energy can be conserved since cluster heads are selected for data transmission instead of other nodes. 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.

Set-up phase: During this phase, each node decides whether or not to become a cluster head (CH) for the current round. This decision is based on choosing a random number between 0 and 1. If number is less than threshold *T(n)*, the node become a cluster head for the current round. The threshold value 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 = desired percentage of cluster head, r = current round and G is the set of nodes which did not become cluster head in last $\frac{1}{P}$ rounds. Once the cluster head is chosen, it will use the CSMA MAC protocol to advertise its status. Remaining nodes will take the decision about their cluster head for current round based on the received signal strength of the advertisement message. Before steady-state phase starts, certain parameters are considered, such as the network topology and the relative costs of computation versus the communication. A Time Division Multiple Access(TDMA) schedule is applied to all the members of the cluster group to send messages to the CH, and then to the cluster head towards the base station. As soon as a cluster head is selected for a region, steady-state phase starts. Figure 2 shows the flowchart of the this phase.

Steady-state phase: 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

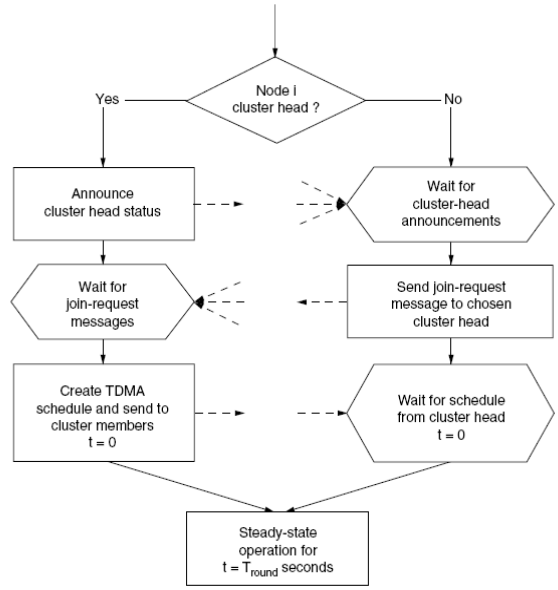

Fig. 2: Flow chart of the Set-up phase of the LEACH protocol

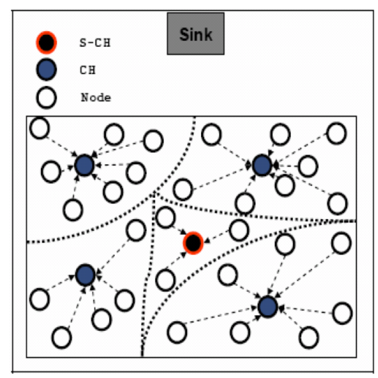

Fig. 3: Data gathering in LEACH protocol.

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 nodes 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 generate the composite single signal. For example, if the data are audio or seismic signals, the cluster-head node can beamform 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. Figure 3 shows the data gathering strategy used by the LEACH protocol. Code Division Multiple Access(CDMA) is utilized between clusters to eliminate the interference from neighboring clusters. LEACH is able to perform local aggregation of data in each cluster to reduce the amount of data that is transmitted to the base station. Although LEACH protocol performs better, it suffers from many drawbacks like;

- CH selection is random, that does not take into account energy consumption.
- It does not scale well to a large area.
- CHs are not uniformly distributed; CHs may be located at the edges of the cluster

III. Related Work

A. E-LEACH Protocol

Energy-LEACH protocol improves the CH selection procedure. It makes residual energy of node as the main metric which decides whether the nodes turn into CH or not after the first round[10]. Same as LEACH protocol, E-LEACH is divided into rounds, in the first round, every node has the same probability to turn into CH, that mean nodes are randomly selected as CHs, in the next rounds, the residual energy of each node is different after one round communication and taken into account for the selection of the CHs. That mean nodes having more energy will become a CHs rather than nodes with less energy.

B. TL-LEACH Protocol

In LEACH protocol, the CH collects and aggregates data from sensors in its own cluster and passes the information to the BS directly. CH might be located far away from the BS, so it uses most of its energy for transmitting and because it is always on it will die faster than other nodes. A new version of LEACH called Two-level Leach was proposed. In this protocol; CH collects data from other cluster members as original LEACH, but rather than transfer data to the BS directly, it uses one of the CHs that lies between the CH and the BS as a relay station[11].

C. M-LEACH protocol

In LEACH, each CH directly communicates with BS no matter the distance between CH and BS. It will consume lot of its energy if the distance is far. On the other hand, Multihop-LEACH protocol selects optimal path between the CH and the BS through other CHs and use these CHs as a relay station to transmit data over through them [12].

First, multi-hop communication is adopted among CHs. Then, according to the selected optimal path, these CHs transmit data to the corresponding CH which is nearest to BS. Finally, this CH sends data to BS. M-LEACH protocol is almost the same as LEACH protocol, only difference is communication mode is multi-hop between CHs and BS.

D. LEACH-C protocol

LEACH offers no guarantee about the placement and/or number of cluster heads. In [13], an enhancement over the LEACH protocol was proposed. The protocol, called LEACH-C, uses a centralized clustering algorithm and the same steady-state phase as LEACH. LEACH-C protocol can produce better performance by dispersing the cluster heads throughout the network. During the set-up phase of LEACH-C, each node sends information about its current location (possibly determined using GPS) and residual energy level to the sink. In addition to determining good clusters, the sink needs to ensure that the energy load is evenly distributed among all the nodes. To do this, sink computes the average node energy, and determines which nodes have energy below this average.

Once the cluster heads and associated clusters are found, the sink broadcasts a message that obtains the cluster head ID for each node. If a cluster head ID matches its own ID, the node is a cluster head; otherwise the node determines its TDMA slot for data transmission and goes to sleep until its time to transmit data. The steady-state phase of LEACH-C is identical to that of the LEACH protocol.

E. VLEACH protocol

In VLEACH[14] protocol, the cluster contains vice-CH, the node that will become a CH of the cluster in case the CH dies. In the original leach, the CH is always on receiving data from cluster members, aggregate these data and then send it to the BS that might be located far away from it. The CH dies earlier than the other nodes in the cluster because of its operation of receiving, sending and overhearing. When the CH dies, the cluster becomes useless because the data gathered by cluster nodes will never reach the base station. In VLEACH protocol, besides having a CH in the cluster, there is a vice-CH that takes the role of the CH when the CH dies. Because of this, cluster nodes data will always reach the BS; no need of electing a new CH each time the CH dies. This extends the overall network life time.

IV. Proposed Improvement on LEACH: I-LEACH

Proposed I-LEACH employs the distributed clustering approach as compared to LEACH protocol. The entire sensor field is divided into the identical clusters. The cluster head (CH) from each cluster is determined by the threshold based approach as in LEACH protocol. The clustering strategy was altered by incorporating the location awareness. The field was divided in to equal sized sub regions, where number of the subregions is equal to the number of cluster heads to be selected that is 5% which is optimum choice. We have also verified that when 5% of sensor nodes are cluster, the network performs better having higher throughput and extended lifetime. Following is the algorithm for the I-LEACH protocol.

I-LEACH Algorithm

Let N_i or N_j denote a common node
$S(N_i)$ = (N_1, N_2 ....N_n) denote the set of n nodes
$E(N_i)$ denote energy in a node
N_{xyz} denote node location
C_i denote a cluster ID
$CH(N_i)$ denote a cluster head node.

7: d_{ij} denote distance measured from node N_i to N_j
8: thresh(N_i) denote the threshold value of node N_i
Initialization
9: Create node N_i
10: Set node position N_{xyz}
Cluster formation
11: Divide the sensor field into identical sub-region R_i
12: Select CH from each sub-region R_i based on threshold value.
13: **if** $N_i \in R_i$ && $thresh(N_i) < Threshold$ && $hasnotbeenCHyet$ **then**
14: N_i = CH (N_i) for sub-region R_i
15: **else**
16: N_i = N_j (normal node)
17: **end if**
Send Data to Base station
18: CH(N_i) sends data to Base station
Repeat the steps 12 to 18 for different rounds
End of algorithm

V. Simulation Results

The performance of the proposed I-LEACH is compared with basic LEACH protocol in terms of Average energy consumption, Life time of the network and Average throughput. All experiment results presented in this section are average of three simulation runs in 100 nodes network and average of three simulation runs in 200 nodes network. The following table shows the simulation results at various simulation runs. It can be observed from the simulation results that the LEACH protocol does not give consistent performance with different simulation runs. There is large variation in life-time of the network as well as throughput of the network. When the number of nodes are doubled in LEACH there is surprise reduction in throughput and life-time. I-LEACH protocol performs well compared to LEACH. For 100 nodes as well as 200 nodes networks the throughput and life-time results are steady and consistent. I-LEACH scales well compared to LEACH protocol.

TABLE I: Simulation Results

No of Nodes	Runs	LEACH		I-LEACH	
		Life Time(s)	**Throughput (Packets)**	**Life Time(s)**	**Throughput (Packets)**
100	1	372.30	35905	566.90	51106
	2	404.60	27889	603.50	50517
	3	433.80	44871	570.20	50563
200	1	417.90	31987	480.60	40824
	2	341.50	22166	500.80	37865
	3	250.49	17011	480.10	37644

A. Average Energy consumption

As we started with equal amount of energy (2J) with each sensor nodes, so total energy with the network will be 200J in the case of 100 nodes and 400J in the case of 200 nodes. Figure 4 and figure 5 shows the comparison of average energy consumption at various time between LEACH and I-LEACH protocols for 100 nodes and 200 nodes network.

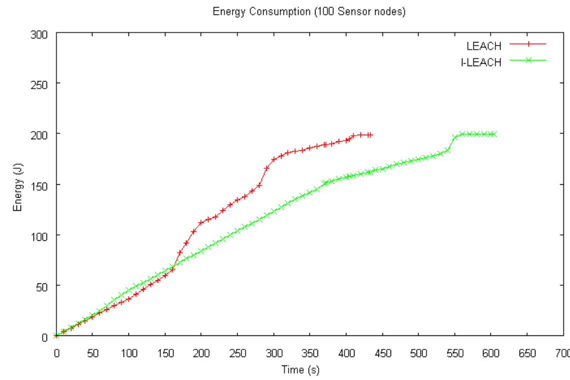

Fig. 4: Time Vs Energy consumption (100nodes)

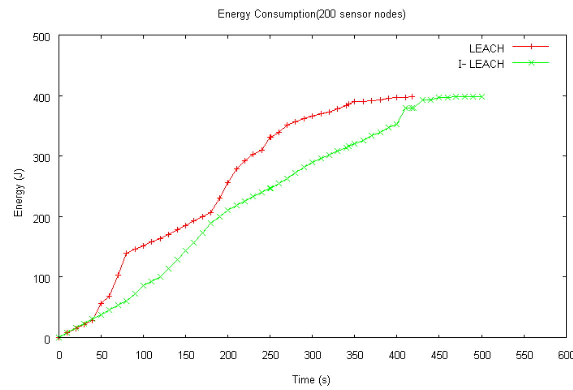

Fig. 5: Time Vs Energy consumption (200nodes)

B. Life time of the network

The total number of nodes which are alive at the end of each rounds is shown in figure 6 and figure 7 for the 100 and 200 nodes network respectively. The simulation will stop if total number of live nodes is less than five in the case of 100 nodes network while total number of live nodes is less than ten in the case of 200 nodes network (5 percent of the total nodes).

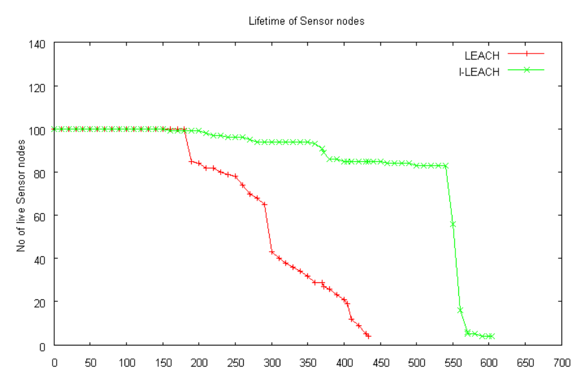

Fig. 6: Time Vs No of live sensor nodes(100 nodes)

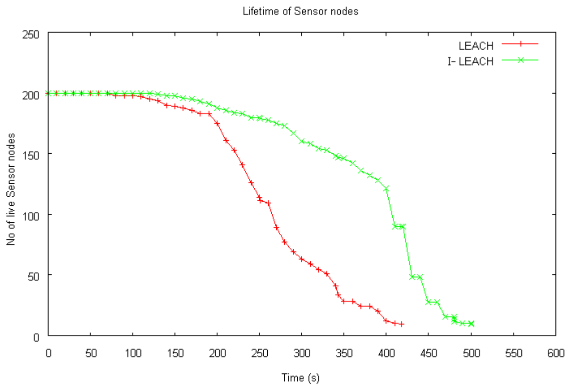

Fig. 7: Time Vs No of live sensor nodes(200 nodes)

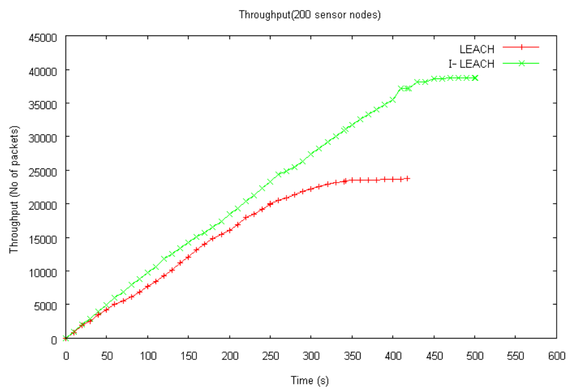

Fig. 8: Time Vs Throughput(200 nodes).

C. Average throughput

It will measure the average number of packets reaching at the sink (base station) node. The location of the sink is (50,50) in the 100 nodes network while (100,100) in the case of 200 nodes network. Figure 8 shows throughput achieved for 200 nodes network.

VI. Conclusion

The core operation of a WSN is to gather and convey the collected data to a distant BS for further processing and analysis. Gathering information from a WSN in an energy effective manner is of paramount importance in order to prolong its life. This calls for use of an appropriate routing protocol to ensure efficient data transmission through the network. In this research work, the cluster based routing protocol LEACH is improved by suggesting distributed cluster formation approach. The simulation results indicate that the proposed clustering approach is more energy efficient and scalable and hence effective in prolonging the network life time compared to LEACH. It also outperforms LEACH with respect to throughput of the network. I-LEACH improves energy consumption by around 45% and throughput by 60%.

VII. Future Work

Our Implementation performs better compared to the basic LEACH protocol, still there are certain optimizations possible in the protocol. In the present implementation the base station is considered to be static but in real deployment of the sensor nodes the base station could be moving also. The other consideration is the size of the network. As the network grows the location of the base station might be an issue, the cluster head may be out of the coverage of base station. In such scenario the network architecture may be modified to multilevel clustering so every cluster head comes directly or indirectly under the communication range of base station. The next improvement possible is at the MAC layer assumptions. We have considered 802.11 for communication requirements which can be replaced with the 802.15.4(ZigBee) communications as the later has several advantages over the former. The ZigBee standard enjoys low power requirements, low latency, high reliability and larger range because of mesh networking.

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