Lifetime Improvement of LEACH Protocol for Wireless Sensor Network

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***Abstract*— The job of developing a generic protocol framework for Wireless Sensor Networks (WSN) is challenging because, limited processing capabilities, memory and power supply of sensor node make it difficult to cater requirements of versatile applications of these networks. This has forced researchers to dissect the traditional layered protocol design approach. As a result cross layer protocols and architectures that attempt to exploit richer interaction among communication layers to achieve performance gains with limited resources have emerged. From among the cross layer protocols proposed in the literature Low Energy Adaptive Clustering Hierarchy (LEACH), is well referred protocol architecture for WSN. This paper simulates using Network Simulator NS2, analyzes and identifies the shortcomings of LEACH protocol. LEACH does not take into account residual energy and distance of node from the Base Station (BS) for the Cluster Head (CH) selection. We propose Improved-LEACH, in which residual energy and distance of node from BS are used as parameters for CH selection. To save energy, we further propose to start the steady state operation of a node only if the value sensed by a node is greater than the set threshold value. The threshold value will be set by the end user at the application layer. Improved-LEACH is then qualitatively and quantitatively analyzed. The quantitative and qualitative metrics presented for comparison framework can be used to analyze tradeoffs produced by different WSN protocols. They can also be design guidelines for new WSN protocols.**

***Index Terms*-- Wireless Sensor Networks, LEACH protocol, simulation and analysis, LEACH network lifetime improvement.**

I. Introduction

A WSN is a network of sensors that, continuously observes a physical phenomena, processes observed data locally and wirelessly communicates information to central Base Station (BS). The BS analyzes information and initiates suitable response if required. The main objective of protocol design of this kind of network is to reliably detect/approximate observations from the combined data provided by sensor nodes and respect their limited energy, memory, and computing capabilities. For most of the networks, protocols are independently developed and optimized for different communication layers, i.e., application, transport, network, data link, and physical layers. Such protocols exhibit very high performance in terms of metrics specific to each of the individual layers, but they are not jointly designed and optimized to maximize network performance in general while reducing the network energy consumption. Considering the limited energy, memory and computational capability of sensor nodes, joint design of layers, i.e., cross-layer design, stands as the most promising alternative [1]. Consequently cross layer protocols that try to exploit richer interaction among communication layers to achieve performance gains have emerged. A discussion on some of these protocols can be found in [2]. From among the proposed cross layer protocols, LEACH is a promising protocol that combines medium access with routing and application-specific data aggregation to achieve good performance in terms of network lifetime, information latency, and acquiring application-dependent quality [3]. This paper identifies deficiencies in LEACH, proposes techniques to overcome them, incorporates them in LEACH and hence proposes Improved-LEACH (I-LEACH).

The remainder of the paper is organized as follows: In Section 2, we discuss LEACH protocol and its working. The deficiencies in LEACH, techniques to overcome them and I-LEACH protocol are introduced in Section 3. In Section 4, we provide simulation and analysis of LEACH and I-LEACH. Finally, the paper is concluded in Section 5.

II. LEACH Protocol

LEACH is a cross layered protocol architecture that combines medium access with routing to collect and deliver data to BS. The main goals of LEACH are: increasing network lifetime, decreasing network energy consumption, reducing number of communication messages by data aggregation. In order to achieve these goals, LEACH uses hierarchical approach and organizes the network into a set of clusters. Each cluster is administered by a selected CH. The CH does the task of creating TDMA-based schedule to assign a time slot to each Cluster Member (CM) for periodic data transmission to CH. CH then aggregates the data to remove redundancy among correlated values. Finally it transmits the aggregated data directly to BS. The function of LEACH is divided into rounds which are further organized in two phases as shown in Figure 1. The setup phase consists of CH selection and cluster formation followed by steady-state phase in which selected CH does data collection, aggregation, and delivery to BS.

A. Setup Phase

It starts with the self-election of nodes to become CHs. The self-election algorithm ensures that CH role rotates among nodes to distribute energy consumption evenly across all nodes.

- CH selection and rotation algorithm

The CH selection algorithm is simple and lightweight using random choice for CH selection. This reduces the overhead for determining optimal CH. To decide if it is its turn to become a CH, a node, n, generates a random number, v, between 0 and 1. It then compares it with CH selection threshold, T(n) which is designed to ensure with high probability that a pre-determined fraction of nodes, P, is elected as CH for each round. Threshold also ensures that nodes which served in past 1/P rounds are not selected as CH in the current round. To meet up these necessities, the threshold of a contending node n is articulated as follows:

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

Where P is desired percentage of nodes which are CH, r is current round, G is set of node that has not been CH in past $1/P$ rounds. The nodes for which $v<T(n)$, become CH.

- Cluster Formation Algorithm

Every node that has opted to become a CH broadcasts its new role to the network using a non-persistent CSMA MAC protocol. On receiving the CH broadcasts, each non cluster head node (NCH) decides a cluster to join. The decision may be based on received signal strength of CH broadcast message, among other factors. The NCH, then inform selected CH their wish to become member of cluster. Once the cluster is formed, CH creates and distributes a TDMA-based schedule to assign a time slot to each of its CM. To reduce inter cluster interference each CH selects a CDMA code, which is then distributed to all CMs. The completion of setup phase triggers beginning of the steady-state phase.

B. *Steady State Phase*

During this phase, NCH nodes periodically collect sensor data and transmit it to CH in their allocated slots. The entire steady-state operation is broken into frames which are further broken into slots of constant duration. NCH nodes send collected sensor data to their respective CH at most once per frame during their allocated transmission slot and enter the sleep mode otherwise. Data transmissions are scheduled to avoid collisions and increase sleep time of each NCH node. With slots of constant duration, time to send a frame of data depends on the number of nodes in the cluster.

III. LIFE TIME IMPROVEMENT OF LEACH

The major deficiency of LEACH is that it uses probabilistic approach to select a CH which only takes care that nodes that have not already been CH till recent round r, may become CH in round r+1. The CH selection algorithm does not consider node's residual energy and location with respect to BS. This kind of CH selection technique is not competent enough to ensure proper CH selection and it is quite possible that nodes located at long distances from BS and/or the ones having less residual energy may be selected as CHs. For efficient CH selection, mechanisms that consider the node's distance from BS and its residual energy are required. The current implementation of LEACH is designed for applications requiring periodic detections which assume that sensors transmit data to their CH during their allocated TDMA slots.

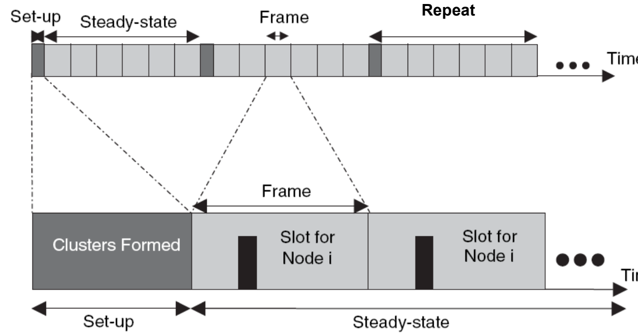

Figure 1. Time line showing LEACH operation.

This increases node's energy consumption. Many applications require information to be sent to BS only on occurrence of specific events and even for periodic detections it might require to send information only when there are significant changes in it.

A. *Proposed technique: Improved-LEACH*

We propose techniques to overcome deficiencies of LEACH identified above. The proposed techniques are incorporated in LEACH and I-LEACH is proposed. Ideally to increase lifetime of network, node having more residual energy should have high probability to become the CH. Hence we propose to use node's $E_{current}/E_{init}$ for selection of CH. The energy consumed in transmission of data from CH to BS is directly proportional to distance between them. We propose to consider the distance between node and BS for selection of CH. This is done by equally dividing the network into four quadrants as shown in Figure 2. If node lies in the same quadrant of BS (3^{rd} quadrant in Figure 2) then energy is given more weight age compared to distance from BS for CH selection. If node lies in diagonally opposite quadrant of the BS (2^{nd} quadrant in Figure 2) then energy is given less weight age than distance from for CH selection. If node lies in 1^{st} or 4^{th} quadrant then equal weight is given to distance and energy of node. The resulting threshold CH selection, T(n), used by n to determine if it will be a CH in the current round is defined as:

$$T(n) = \begin{cases} \left[\dfrac{P}{1 - P * (r \bmod \frac{1}{P})}\right] \left[\left(\alpha * \left(\dfrac{E_{current}}{E_{init}}\right)\right) + \left((1-\alpha) * d_{nBS}\right)\right] \text{if } n \in G, \text{ n is in same quadrant as BS} \\ \left[\dfrac{P}{1 - P * (r \bmod \frac{1}{P})}\right] \left[\left((1-\alpha) * \left(\dfrac{E_{current}}{E_{init}}\right)\right) + \left(\alpha * d_{nBS}\right)\right] \text{if } n \in G, \text{ n is in } 2^{nd} \text{quadrant} \\ \left[\dfrac{P}{1 - P * (r \bmod \frac{1}{P})}\right] \left[\left(\left(\dfrac{\alpha}{2}\right) * \left(\dfrac{E_{current}}{E_{init}}\right)\right) + \left(\left(\dfrac{\alpha}{2}\right) * d_{nBS}\right)\right] \text{if } n \in G, \text{ n is in } 1^{st} \text{ or } 4^{th} \text{ quadrant} \\ 0 \quad \text{otherwise} \end{cases} \quad (2)$$

Where P is desired percentage of nodes which are CH, r is current round, G is set of node that has not been CH in past $1/P$ rounds, α is a constant with value 0.75, d_{nBS} is distance of node from BS, $E_{current}$ is the current energy, and E_{init} is the initial energy of sensor node. To decide if it is its turn to become a CH, a node, n, generates a random number, v, between 0 and n_{quad}, where n_{quad} depends on the quadrant of the node. If $v>T(n)$, node becomes CH. The equation for CH selection considers energy of node, its distance from BS and the fact that node has not already been CH till recent round r for it to become CH in round $r+1$. To save energy, we propose to start the steady state operation of a node only if the value sensed by a node is greater than the set threshold value. The threshold value will be set by the end user at the application layer.

B. Flow Chart of Improved-LEACH

The techniques discussed above are incorporated in LEACH and hence I-LEACH is proposed. The flow chart of I-LEACH is in Figure 3. During the set-up phase of I-LEACH, each node calculates current location (possibly determined using a GPS receiver) and hence its quadrant. It also finds its residual energy.

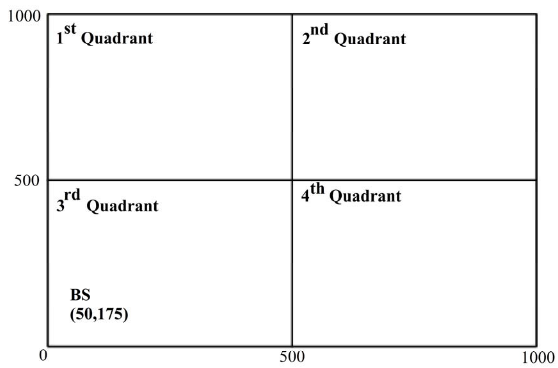

Figure 2. Dividing network into four quadrants with BS at location (50, 175)

Each node then generates a random number, v, between 0 and n_{quad}. For the network shown in Figure 2, 0< n_{quad} <107 for nodes in 3rd quadrant, 0< n_{quad} <796 for nodes in 2nd quadrant, is 0< n_{quad}<304 for nodes in 1st and 4th quadrant. It then compares random number v with CH selection threshold, T(n) which is calculated using (2). The nodes for which v>T(n), becomes CH. The cluster formation technique is same as LEACH. Each CM then compares the sensor reading with its threshold value set at the application layer. The steady-state is triggered only if the sensor reading is more than the set threshold value or else NCH goes to sleep.

IV. SIMULATION AND ANALYSIS OF LEACH AND I-LEACH

All the simulations were carried out using Network Simulator NS2 [4]. Table I shows the basic simulation settings for all simulations. To reduce the occasionalism, twenty simulations with different seeds were carried out for each scenario and average values were adopted as the results.

TABLE 1
SIMULATION SETTINGS FOR ALL SIMULATIONS

Parameter	Description
Nodes	1000
Network size	1000m x 1000m
BS location	(50,175)
Radio Propagation speed	3×10^8 m/s
Processing delay	50 µs
Radio speed	1 Mbps
Data size	500 bytes
Initial energy	20 J
Bit rate	1 Mbps
Antenna gain factor	1
Antenna height above the ground	1.5 m
Signal wavelength	0.325 m
Radio amplifier energy	10 pJ/bit/m^2
Radio electronics energy	50 nJ/bit m

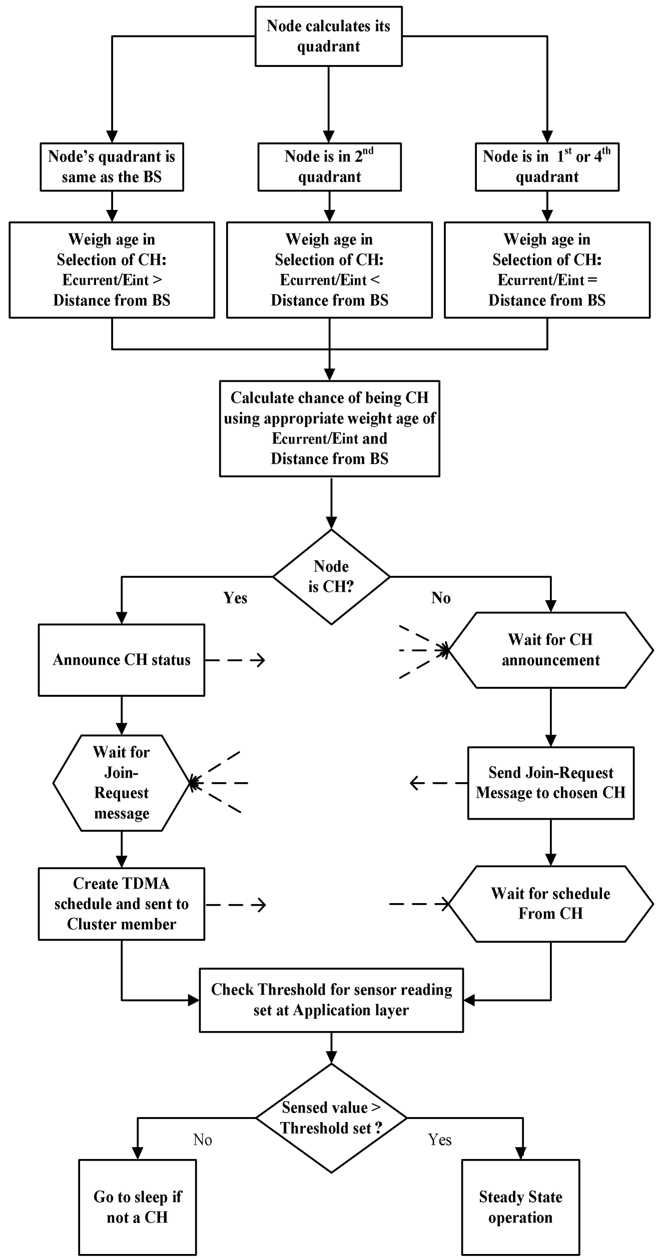

Figure 3. Flow chart of Improved-LEACH

- *Lifetime of the Network*

Figure 4 shows the total number of nodes that remain alive over the simulation time. Nodes remain alive for long time for I-LEACH because its CH selection algorithm considers residual energy and distance of node from BS while LEACH uses probabilistic method which does not consider any node parameters for CH selection. This in turn decreases the average energy consumption of nodes. Energy consumption in I-LEACH is further decreased by starting the steady state phase only when sensor reading goes beyond a pre defined threshold value or an interesting event has occurred as compared to periodic sensing in case of LEACH.

- *Number of nodes alive per amount of data received at BS*

Figure 5 shows number of nodes that remain alive per amount of data in Kbytes received at the BS. The total amount of data received at BS when all nodes have died in LEACH is 16 Kbytes whereas in I-LEACH it is 42 Kbytes because lifetime of I-LEACH network is more than LEACH.

- *Total amount of data received at BS over time*

Figure 6 shows total data received at BS over time. It is more in I-LEACH compared to LEACH because number of nodes alive over time is more in I-LEACH.

- *Total amount of data received at BS against energy consumed*

Figure 7 shows total data received at BS against energy consumed. In this case again I-LEACH outperforms LEACH because location of the node is considered in CH selection and hence nodes which are near BS are given more chance to become CH compared to the ones far from the BS which in turn saves energy of CH to communicate with the BS.

- Quantitative and qualitative analysis of I-LEACH

In the quantitative and qualitative analysis of I-LEACH analysis, we investigate following performance metrics [2]:

1) Network lifetime

For a network with spare deployment of nodes Network Lifetime is time until the First Node Dies (FND); for dense deployment of nodes it is time till half of the Nodes are Alive (HNA), and for redundant deployment of nodes it is time till Last Node Dies (LND).

2) Network settling time

It is time required for collection of nodes to organize them automatically and transmit first message.

3) Network join time

It is the time required for a node to become integrated into the network.

4) Latency

It is average time between start of disseminating data from source nodes and its arrival at corresponding receiver nodes.

5) Protocol overhead

It is total bytes of control packets required to maintain proper network operation.

6) Localization

It is the problem of determining node's location. Some protocols require local or global location knowledge of the nodes in the network.

7) Adaptation to Transmission media

In decision making protocol should consider characteristics of wireless transmission media like hidden, exposed terminal problem, High BER, fading, spatial reuse etc.

8) Traffic Adaptability

Protocol should adapt to traffic fluctuation over time and over part of network to another.

9) Dependability and QoS

Depending on application WSN design may be required to offer reliable, real time, secured, private communication and facilitate mobility.

10) Fairness

In order to let BS have full information of entire sensed area, protocols should provide fair bandwidth allocation and access among all sensor nodes.

11) Heterogeneity

For work distribution between nodes and BS protocol must consider fact that BS has good power, storage and processing capabilities as compared to nodes.

12) Time Synchronization

Protocol may require time synchronization either strict or loose is required for synchronizing sleeping cycles of nodes.

13) Topology change control

In case of change in topology the protocol might need information regarding complete restructuring or only incremental updates.

14) Link Type

Protocol may perform efficiently in upstream (node to BS) or downstream (BS to node) links.

15) Node requirements

It is defined as characteristics of node required for running the protocol.

16) Application dependently

WSN may be deployed on land, underground, underwater or space. The sensor may have to detect event or do periodic measurement. The protocol may be designed to work best under specific conditions.

17) Self configurability

Protocol for WSNs is most likely required to do self-configuration of the network.

18) Node density

Number of nodes per unit area can vary considerably for different application or within the same application over time and space. Protocol should adapt to such variations.

The results of quantitative and qualitative analysis are shown in Table 2 and Table 3 respectively. The results show that I-LEACH shows a nominal increase in network settling and join time. This is due to time required in calculation of energy and location of node, including them in the CH selection and getting the sensor reading threshold value from the application layer. All these add up to increase the network settling and join time which in turn nominally increases latency.

V. CONCLUSION

When designing protocol architectures for WSN, it is important to consider the severe energy constraints of the nodes, end application, data aggregation, ease of deployment, self configuration of nodes and constraints of wireless channel. These features are considered in LEACH, where amount of data transmitted is reduced by data aggregation at CH; energy savings is done by coupling media access and routing protocols. Since each node in LEACH probabilistically decides whether or not to become CH without considering node parameters, there might be cases when nodes with less residual energy and/or the ones which are far from the BS might be selected as CH. I-LEACH, our proposed work is improved LEACH in which CH selection is based on node's $E_{current}/E_{init}$ and its distance from BS. To save energy, I-LEACH starts steady state operation only if the value sensed by a node is greater than set threshold value set at the application layer. Simulation results show that I-LEACH outperforms LEACH in terms of network lifetime, amount of data transferred to BS against time taken and energy consumed. Calculation of energy and location of node, including them in the CH selection and getting the sensor reading threshold value from the application layer takes a little amount of time which increases network settling and join time and hence increases latency nominally. During our simulation we identified some more areas of improvement in LEACH as discussed next. The assumption that network is homogenously distributed; all nodes are capable of reaching BS and use of two hops to send data to BS decreases scalability of LEACH. Further as area of network increases, one hop intra and inter cluster routing scheme increases energy consumption and decreases network scalability. Clustering and CH selection for each round brings extra overhead at the beginning of each round, which may diminish the gain in energy. The improvement of these deficiencies would be part of our future work.

VI. REFERENCES

[1] Raja Jurdak, "Wireless Ad Hoc and Sensor Networks: A Cross-Layer Design Perspective" Springer Publications, 2007.

[2] Sachin Gajjar, Shrikant N. Pradhan, Kankar Dasgupta, "Performance Analysis of Cross Layer Protocols for Wireless Sensor Networks", Proceedings of ICACCI '12, August 03 - 05 2012.

[3] Wendi B. Heinzelman, Anantha P. Chandrakasan, Hari Balakrishnan, "An Application-Specific Protocol Architecture for Wireless Microsensor Networks", IEEE Transactions On Wireless Communications, Vol. 1, No. 4, October 2002.

[4] The Network Simulator NS-2, [Online] Available: http://www.isi.edu/nsnam/ns/.

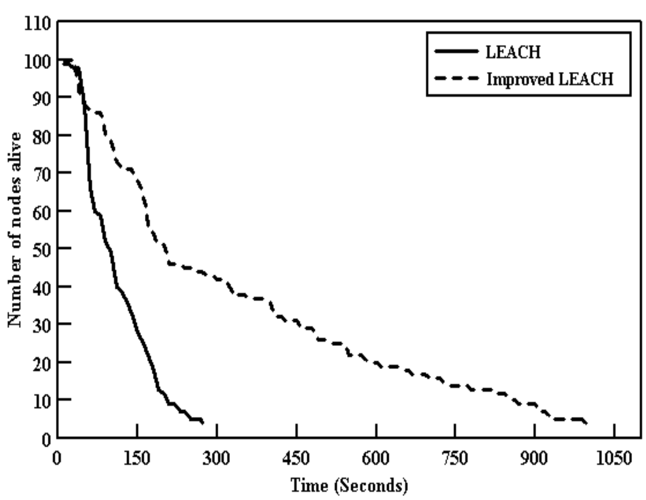

Figure 4. Number of nodes alive over time

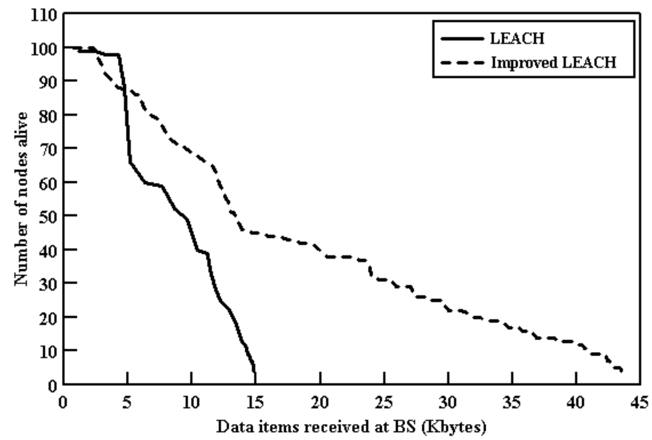

Figure 5. Number of nodes alive per amount of data sent to BS

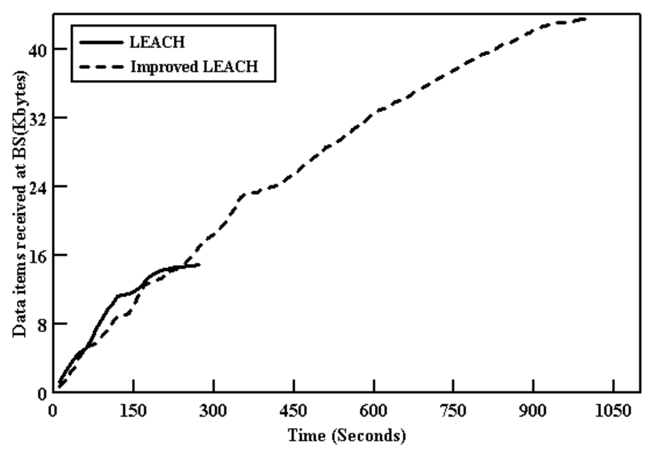

Figure 6. Total amount of data received at the BS over time

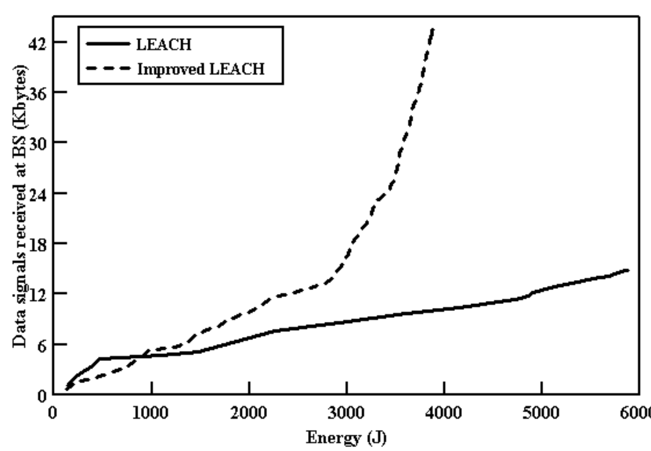

Figure 7. Total amount of data received at BS against energy consumed

TABLE 2
QUANTITAIVE ANALYSIS OF LEACH AND I-LEACH

Parameter	LEACH	Improved-LEACH
Network Lifetime (secs)		
FND (First node dies)	10	30
HNA (Half of the nodes alive)	100	210
LND (Last node dies)	271	996
Network Settling time (secs)	1.180	1.716
Network join time (secs)	6.989	10.386
Latency (secs)	0.267	0.677
Protocol overhead (bytes)	16	16

TABLE 3
QUALITATIVE ANALYSIS OF I-LEACH

Parameter	Improved-LEACH
Localization	Each node need to determine its current location (possibly using a GPS receiver)
Adaptation to Transmission media	Direct Sequence Spread Spectrum is used to avoid inter-cluster interference and CSMA is used to avoid collision among CH sending information to BS
Traffic Adaptability	With threshold detection technique it can handle periodic as well as bursty traffic
Dependability and QoS	There is no support for real time, secured and private communication
Fairness	It is fair for communication between the nodes to CH by each node having their unique time slot to send data to CH but for communication between CH to BS it is not fair since CSMA is used
Heterogeneity	It is not considered since CH selection is done by nodes
Time Synchronization	Local Time Synchronization among the cluster members is required
Topology change control	Nodes can join or leave the cluster during the setup phase and thus change in topology can be handled
Link type	Proposal is for Bidirectional Link
Node requirements	Nodes should be capable to transmit with enough power to reach BS, can use power control to vary amount of transmit power, has computational power to support different MAC protocols and perform signal processing functions. Each node need to determine its energy level
Application dependently	Proposal is for nodes deployed on LAND in a heterogeneous manner with each node having enough power to reach BS if needed
Self configurability	Nodes self configure to form clusters
Node density	Cluster formation is adaptive to change in number of nodes per unit area