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Energy Efficient Wireless Sensor Network For Polyhouse Monitoring

Suprotim Sinha Majumdar, Marut Pattanaik and JV Alamelu

Department of Electronics and Instrumentation Engineering,
MS Ramaiah Institute of Technology, Bangalore, Karnataka, India
suprotim_majumdar@yahoo.co.in

ABSTRACT

A wireless sensor network (WSN) in its simplest form can be defined as a network of sensors, denoted as nodes, that blankets a region and provides information about it. It can sense the environment and communicate the data gathered from the monitored field via wireless links [1]. WSNs have numerous applications ranging from indoor deployment scenarios in the home and office, to outdoor deployment scenarios in natural environment, polyhouses and military settings. In all modern polyhouses, several measurement nodes are required to track down the local climate parameters in different parts of the polyhouse to make the monitoring system work properly. In this paper, we are showing the use of WSN in a polyhouse system. We aim at proving that that the implementation of LEACH protocol to our wireless sensor network would, in fact, reduce the average energy dissipation per node per transmission. Thus leading to a drastic increase in the lifetime of the sensor nodes.

Key words: Polyhouse, wireless sensor network (WSN,) energy, communication, motes, Low-energy adaptive clustering hierarchy (LEACH)

INTRODUCTION

The wireless sensor network is a new hot spot in the field of wireless network. The development of wireless sensor networks (WSNs) has given engineers a new tool for remote monitoring applications. A Wireless Sensor Network (WSN) consisting of small-size wireless sensor nodes equipped with radio and one or more sensors is an attractive and cost efficient option to build the desired measurement system. Determining where to place WSN measurement nodes is an important step in the development of any remote monitoring application. WSN nodes broadcast their link quality, which is dependent on RF environment, and the attached example application can be used to monitor and log the link quality of several WSN nodes, aiding in the deployment of your WSN system.

POLYHOUSE MONITORING USING WSN

Polyhouse farming is an alternative new technique in agriculture, gaining foothold in rural India. It reduces dependency on rainfall and makes the optimum use of land and water resources due to assured system. A typical, traditional farm of 4000 square meters (1 Acre) would generate an estimated annual income from Rs.20,000 to 150,000, (Depending upon type of cultivation i.e. Cereals, Vegetables, and Fruits) whereas estimated annual income from similar sized poly house is Rs.1,00,000 to 5,00,000 [2]. Potentially, polyhouse farming can help the farmer to generate income throughout the year growing multiple crops and fetching premium pricing for off-season vegetables.

In older polyhouses it was enough to have one wired measurement node in the middle to provide the information to the monitoring system. All this has changed in present polyhouses. However, more measurement data is also needed to make this kind of monitoring system work properly. It is possible to easily change the location of the nodes according to the requirement, which vary for different plant, based on the possible changes in the external weather or polyhouse structure. Wireless sensor network (WSN) can form a useful part of the monitoring system architecture in modern polyhouses [3]. Wireless communication can be used to collect the measurements and to communicate between the centralized control and the nodes located to the different parts of the polyhouse.

HARDWARE SETUP

The wireless sensor node used in this work is the WiSense WSN1101N Mote [4] consisting of MSP430G2955 controller board with 56 KB flash and 4 KB RAM, a CC1101 Radio transceiver with SMA connector and whip antenna. The mote includes a LM75BDP118 temperature sensor and TSL45315CL digital ambient light sensor. The mote is powered by two 1.5 V batteries. In this work, 4 motes were used. One of the motes was configured as a network coordinator device or Fully Functional Device (FFD) while the other 3 motes, Reduced Function Devices (RFDs) were connected in a star topology, used to sense and transmit data to the network coordinator. In another setup, a network coordinator was used, along with 2 repeaters and a sensor node in tree topology. The various network configurations used during the course of this work are as in the following Fig. 1.

Operating Conditions

Operating voltage of 3 V. Can be operated at as low as 2.1 V. FFD enters sleep mode when it is not receiving sensor data to conserve energy. Current values for nodes (FFD and RFD) @ 3.0 V are as in Table 1.

Table -1 Current value at 3.0 volt for MSP

Operation	Values
Receive mode	19 mA
Transmit mode	30 mA
Sleep mode	5 mA

The energy calculations for the network are as follows,

Number of transmissions in a day = 72 (one in 20 minutes)

Time taken per cycle = $15 * 10^{-3}$ sec

Receive mode Power consumption = 72 mW per cycle

Energy consumed in receive mode, ER = $1.08 * 10^{-3}$ Joules

Transmit mode Power consumption = 105 mW

Energy consumed in transmit mode, ET = $1.575 * 10^{-3}$ Joules

Remaining time in sleep mode.

Total Power consumption = 4 mW

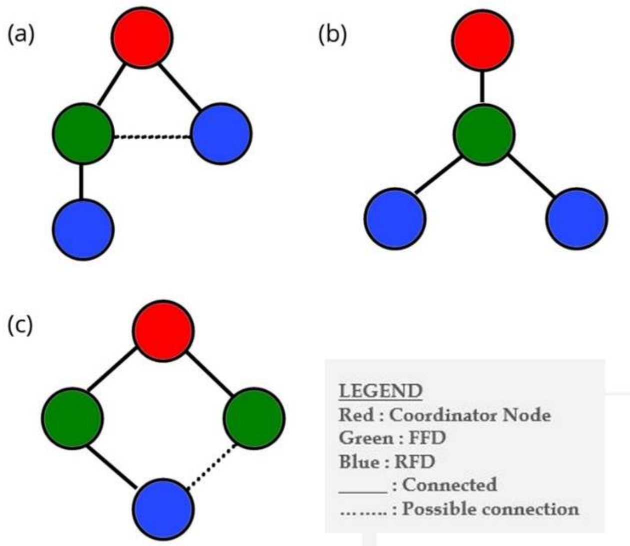


Fig. 1 Network Configurations

DIRECT VS MINIMUM TRANSMISSION

Direct Transmission

In a direct communication protocol [5], each sensor node sends a direct message to the base station. In case the base station is located far from the nodes, the communication will utilize a large amount of transmit power from every node. This causes the battery to drain out faster and as a result, the system lifetime of the sensor node is reduced. On the other hand, the only receptions in this protocol occur at the base station, so if either nodes are close to the base station, or the energy required to receive data is great, this may be an adequate method of communication.

The amount of energy spent is defined by:

$$\mathcal{E}amp \text{ x } k(3d_1 + d_2)^2 \quad (1)$$

where d_1 is the distance between successive nodes and d_2 is the distance from the node to the base station. k is a constant. $\mathcal{E}_{amp}$ is the energy consumed by the amplifier during transmission.

Minimum Transmission

Another method we can implement is a minimum-energy routing protocol. Data is routed from the nodes to the base station through one or more intermediary nodes. Some nodes act as routers for data messages from other nodes as well as perform the task of sensing the environmental changes. This protocol only considers the energy of the transmitter and disregards the energy dissipation of the receiver in choosing the routes. In this case, the intermediate nodes are chosen such that the energy consumption of the transmitter amplifier is minimized.

The amount of energy spent is defined by:

$$\mathcal{E}_{amp} \text{ x } k(3d_1^2 + d_2^2) \quad (2)$$

where d_1 is the distance between successive nodes and d_2 is the distance from the node to the base station. k is a constant. $\mathcal{E}_{amp}$ is the energy consumed by the amplifier during transmission.

LEACH

Low-energy adaptive clustering hierarchy (LEACH) [6] is a widely used energy-efficient clustering algorithm used in wireless sensor networks. The LEACH algorithm randomly selects a few sensor nodes as cluster heads (CH), as in Fig. 2, and in other subsequent rounds, reverses this procedure by selecting other nodes instead of the previously selected cluster heads. The task that the cluster head nodes perform is compressing data that it receives from nodes that belong to the respective cluster, and conveying an aggregated packet to the base station. A predetermined percentage of nodes, *P*, are elected as cluster heads in the following manner. A number, r is chosen randomly (between 0 and 1) by a sensor node. If this random number is found to be less than a certain threshold value, *T(n)*, the node is elected as a cluster head for the present round. This threshold value is determined by an equation that incorporates the predetermined percentage to become a cluster-head, the present round, and the set of nodes that have not been selected as a cluster-head in the last *(1/p)* rounds, denoted by *G*. The equation is given by:

$$T(n) = \frac{p}{1-p(r \bmod \left(\frac{1}{p}\right))} \; if \; n \in G \tag{3}$$

Each elected CH sends a broadcast to the rest of the nodes in the network to notify that it has been elected as the new cluster head. A sensor node which is not a cluster head selects the cluster heads to which it is located the nearest to.

LEACH clustering terminates after a finite number of iterations. However, it does not assure good cluster head distribution. A few nodes may choose a cluster so that the distance between its cluster head and sink (base station) is greater than the distance between itself and the sink. According to the LEACH protocol energy model, the energy cost increases as the distance between nodes increases. Since battery power is a constraint in the sensor nodes, it lets the nodes die on complete consumption of energy.

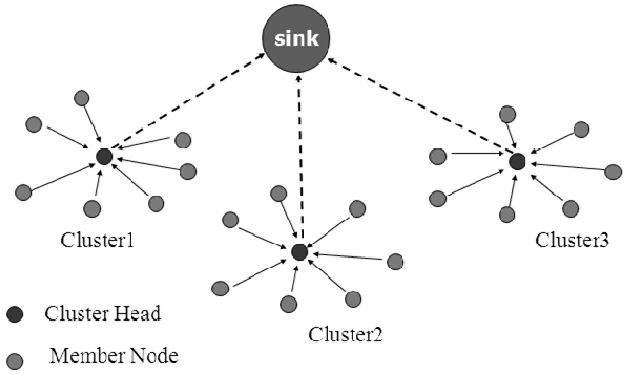


Fig. 2 LEACH clustering communication hierarchy for WSN's [7]

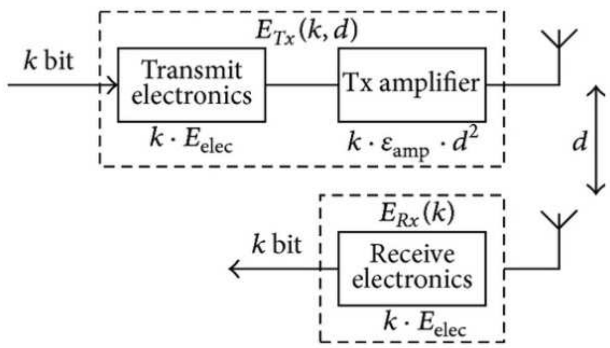


Fig. 3 First order radio model

IMPLEMENTATION OF LEACH PROTOCOL FOR POLYHOUSE MONITORING USING WIRELESS SENSOR NETWORKS

To evaluate the protocol on the hardware, we had created a simulation taking into consideration the parameter settings for our radio model. According to the radio energy dissipation model of Fig. 3, the energy needed for transmission by the transmit amplifier $E_{Tx}(l,d)$ for an *l*-bit message over a distance d meters between a transmitter and receiver is:

$$E_{Tx}(l,d) = \begin{cases} l \times E_{elec} + l \times \varepsilon_{fs} \times d^2 & if \; d \leq d_0 \\ l \times E_{elec} + l \times \varepsilon_{mp} \times d^4 & if \; d \geq d_0 \end{cases} \tag{4}$$

where $d_0 = \sqrt{(\mathcal{E}_{fs}/\mathcal{E}_{mp})}$ is the threshold distance [8], E_{elec} denotes the energy consumption in the electronics for sending or receiving one bit, and $\mathcal{E}_{fs}d^2$ and $\mathcal{E}_{mp}d^4$ denote the amplifier energy consumption for short and long distance transmissions. For the node to receive an *l*-bit message, the energy $E_{Rx}(l)$ required by the receiver is given by

$$E_{Rx}(l) = l \times E_{elec} \tag{5}$$

The values for all the radio model parameters are specified in Table 2.

The simulation was performed by considering a total number of n sensor nodes that are distributed uniformly in a sensor field of size 100 x 100 meters, and are divided into k clusters. The energy required for a cluster head per round to receive data packets from the sensor nodes and forward them a distance d_{toBS} to the baste station is

$$E_{CH}(l,d) = \begin{cases} l \times [E_{elec}\left(\frac{n}{k}-1\right) + E_{DA}\frac{n}{k} + E_{elec} + \varepsilon_{fs} \times d_{toBS}^2] & if \; d_{toBS} < d_0 \\ l \times [E_{elec}\left(\frac{n}{k}-1\right) + E_{DA}\frac{n}{k} + E_{elec} + \varepsilon_{mp} \times d_{toBS}^4] & if \; d_{toBS} \geq d_0 \end{cases} \tag{6}$$

where E_{DA} denotes the energy dissipation for aggregating data.

Table -2 Parameter Settings of Sensor Node Radio for Simulation

Parameters	Values
Initial energy (E_0)	0.8 J/node
Transmitter Electronics (E_{elec})	1.08 nJ/bit
Receiver Electronics (E_{elec})	1.575 nJ/bit
Data Packet Size (l)	256 bits
Transmitter Amplifier ($\mathcal{E}_{fs}$) if $d \leq d_0$	10 or 100 pJ/bit/m^2
Transmitter Amplifier($\mathcal{E}_{mp}$) if $d \geq d_0$	0.0013 pJ/bit/m^4

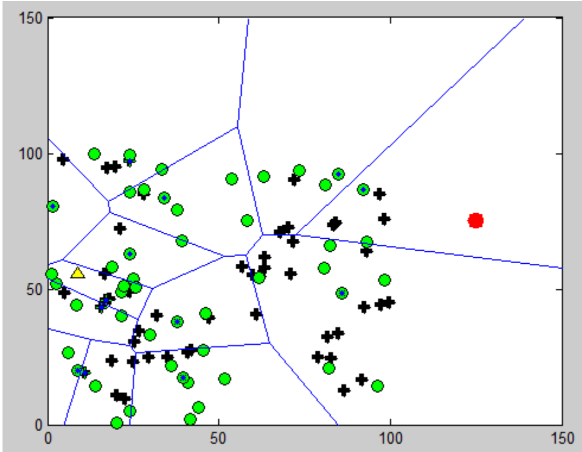
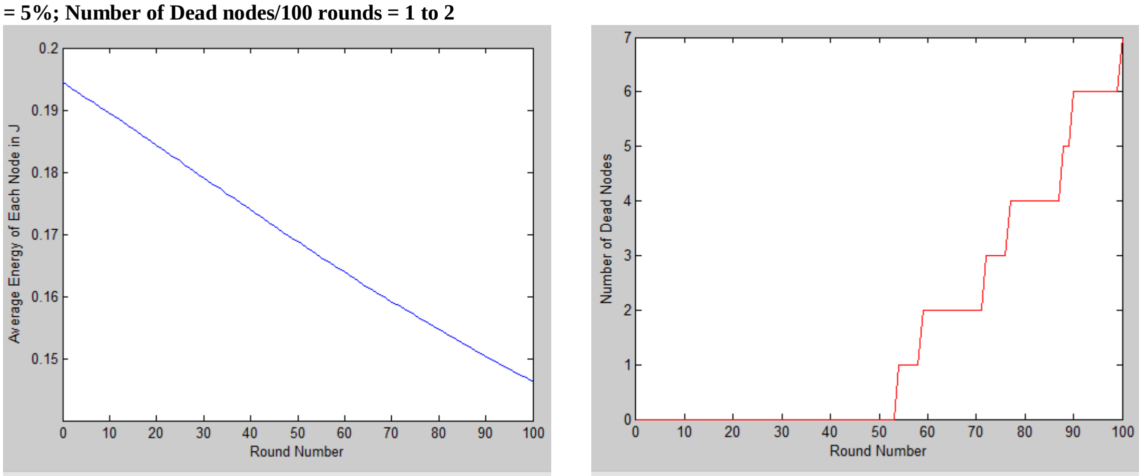


Fig. 4 Network after clustering

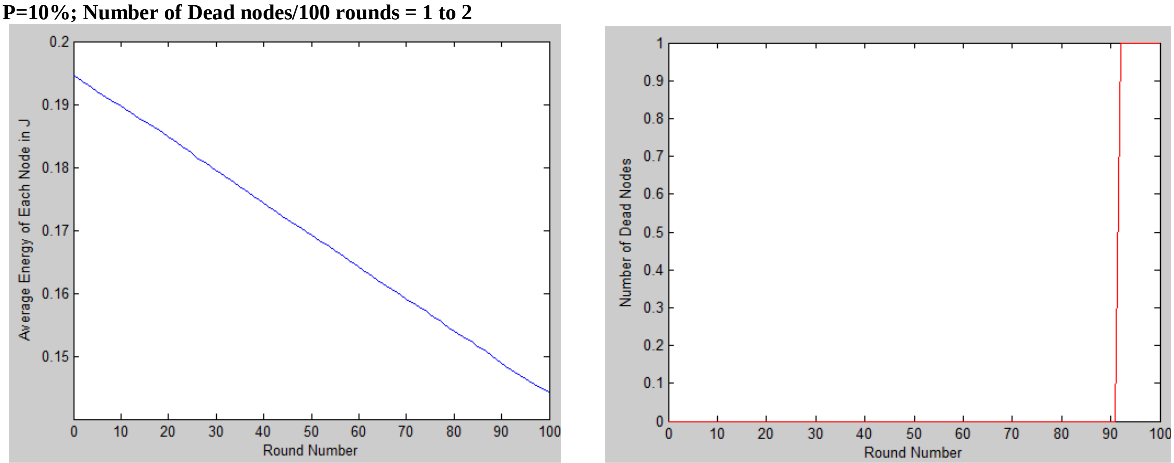
MATLAB SIMULATION

In this work it is assumed that all the sensor nodes are distributed randomly over a sensor field in a polyhouse of the dimensions 100x100 meters. The number of rounds of transmissions completed by the end of the simulation is 100. All sensor data must reach the base station (BS), which is located outside the sensor field, propagated through links selected by random Cluster heads (CH) from a total of 100 nodes. The probability that a sensor node will be selected as a cluster head is denoted by *P*. We have varied *P* from 5% to 40% to determine the Optimal Probability (P_{opt}). Nodes that have been cluster heads cannot become cluster heads again for P rounds, where P is the desired percentage of cluster heads. Therefore, each node has a 1/P probability of becoming a cluster head in each round. Once each round is completed, each node that is not a cluster head selects the closest cluster head and joins that cluster (Voronoi tessellation). The cluster head then creates a schedule for each node in its cluster to transmit its data. The following Figs show the varied outputs of average energy of each node and the number of dead nodes at the end of 100 rounds of transmission for P equal to 5% to 40%.

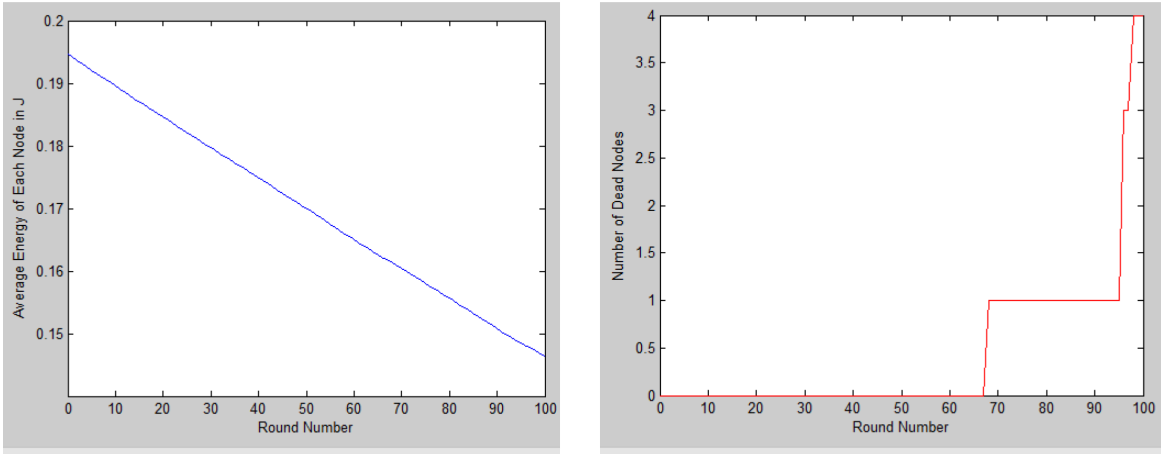
A. P = 5%; Number of Dead nodes/100 rounds = 1 to 2



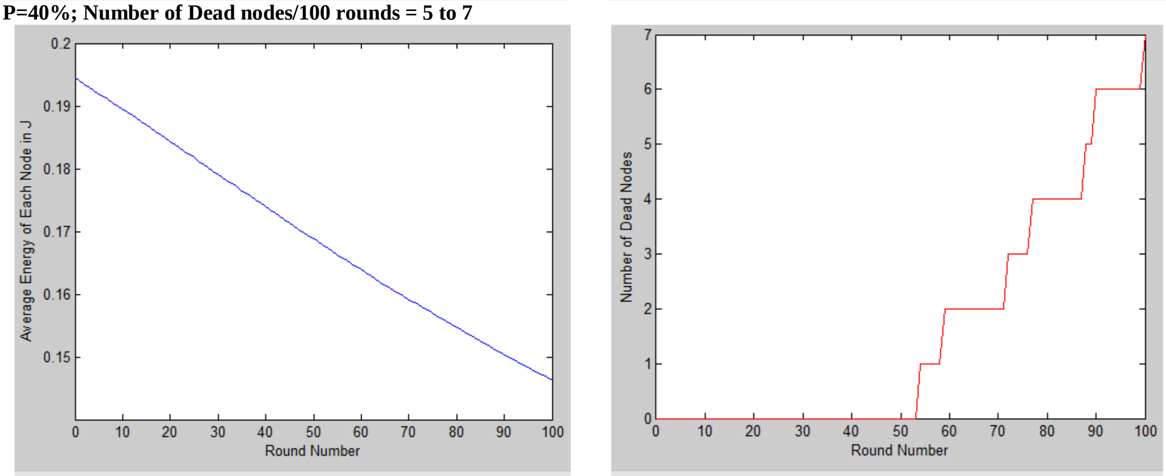
B. P=10%; Number of Dead nodes/100 rounds = 1 to 2



C. P=20%; Number of Dead nodes/100 rounds = 2 to 4



D. P=40%; Number of Dead nodes/100 rounds = 5 to 7



Based on the above observations, it was found that a 10% probability (P) was the most feasible one for selection of cluster heads in a network based on the LEACH protocol.

ENERGY VERSUS DISTANCE COMPARISION

Practical Results

The energy consumption of the node is dependent on the number of transmissions executed by the node and the distance between the node and the sink/coordinator. Keeping the number of transmissions per unit time constant (1 transmission/sec), it is observed that the variation of energy consumed by the sensor node with increasing distance from the sink, by considering that Transmit mode Power consumption is 105 mW.

Table- 3 shows the mote results. The node was made to execute 100 transmissions from a certain distance from the coordinator and the time taken to perform this task was noted. The transmission delay for this was calculated and correspondingly, the energy consumption per transmission was calculated.

Table- 3 Mote results for a Polyhouse – Energy vs Distance

Sl.	Dist.	Transmission Time	Energy
1	0	20	2.10E-03
2	5	22	2.31E-03
3	10	24	2.52E-03
4	15	20	2.73E-03
5	20	30	3.15E-03
6	25	40	4.20E-03
7	30	55	5.78E-03
8	35	68	6.14E-03
9	40	74	7.77E-03

Table- 4 MATLAB results for Polyhouse System – Energy vs Distance

Sl. No.	Dist.	LEACH Protocol Energy
1	0	1.05E-04
2	5	1.12E-04
3	10	1.20E-04
4	15	1.90E-04
5	20	3.60E-04
6	25	7.50E-04
7	30	1.47E-03
8	35	2.62E-03
9	40	4.40E-03

MATLAB Results

In a similar manner to the mote testing as mentioned above, the distance vs energy variation was performed on the simulation. The energy consumption on the simulation was found to be far less than the energy consumption on the hardware. The following Table 4 represents the energy variation with respect to distance as simulated on Matlab. The energy variation observed is due to the implementation of LEACH protocol.

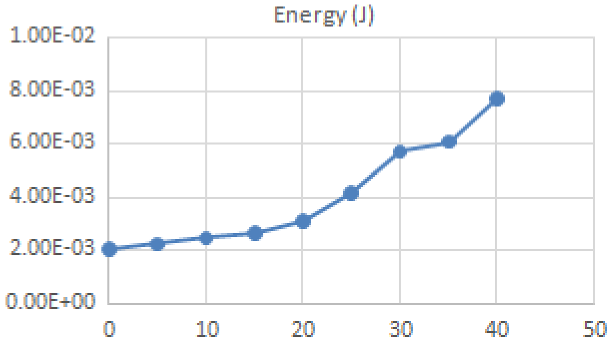


Fig. 5 Hardware Test Results Plot (Distance vs. Energy)

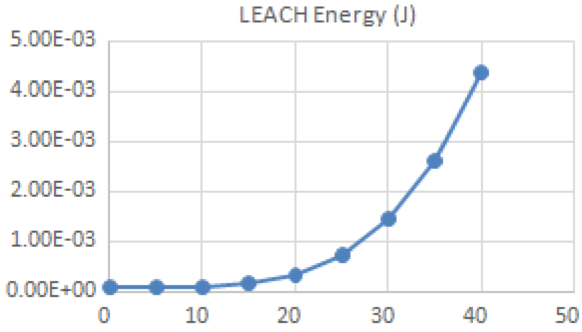


Fig. 6 Software Test Results Plot (Distance vs. Energy)

Analysis of Simulation

Fig. 5 and Fig. 6 confirm that the energy consumption per node per transmission is lesser when LEACH protocol is implemented as an energy-efficient algorithm, as compared to the mesh network routing implemented using the WiSense motes. Therefore, in a network which has a large number of nodes, say in excess of 50 nodes, LEACH protocol would improve the lifetime of the nodes, and consequently of the network significantly.

CONCLUSION

The results show that the implementation of LEACH protocol to our wireless sensor network would, in fact, reduce the average energy dissipation per node per transmission by almost half. This would increase the lifetime of the sensor nodes drastically, especially, in a polyhouse network, as tested. In addition to networking for data collecting and monitoring purposes within a polyhouse network, further work may include the development of the automation and control part, in order to complete the wireless control loop. The control commands will be counted and calculated at the base station (coordinator node), and then transmitted wirelessly to the actuators via the motes located in the different parts of the polyhouse. This would help to automatically monitor and control the polyhouse parameters from a remote location. Further power and energy optimization may be tried out using various sensors and devices. Also, there is scope of testing the network in the presence of network interference and greater distances. More number of parameters can be monitored by interfacing and adding other sensors like - Carbon Dioxide Gas Sensor, Humidity Sensor, etc. to the node.

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