Energy Consumption of Wirless Sensor Network

Amr Awamri[1], Dusan Maga[2] and Tarek Nahdi[2]

[1] Benha University, Faculty of Electrical Engineering, Department of Telecommunication, Fareed Nada Street, Benha, Qalubiya Governorate, 13511, Arab Republic of Egypt, *amr.awamry@bhit.bu.edu.eg*

[2] Czech Technical University in Prague, Faculty of Electrical Engineering, Department of Telecommunication Engineering, Technicka 2, 166 27, Prague, Czech Republic: *dusan.maga@fel.cvut.cz, tareknah@fel.cvut.cz*

***Abstract* — Sensor networks are formed from a collection of sensing nodes which communicate with one another, typically through wireless channels, in order to collect spatially distributed data about their environment. Sensor nodes are operating on battery power with a limited energy resources. The energy consumption is one of the most important issues and the designing of the energy consumption protocol is very critical for prolonging the lifetime. This paper introduces the LEACH routing protocol in Homogenous & Heterogeneous system supported by simulation and analysis of the results. From the brief analysis of the simulation we have come to the conclusion that LEACH Heterogeneous System provides a good performance in energy consumption and increasing the level in lifetime of the wireless sensor networks than LEACH Homogeneous System.**

Keywords — Wireless Sensor Networks; Network Lifetime; Energy Consumption; LEACH protocol.

I. INTRODUCTION

With the popularity of laptops, cell phones, PDAs, GPS devices, RFID, and intelligent electronics in the post-PC era, computing devices have become cheaper, more mobile, more distributed, and more pervasive in daily life. It is now possible to construct, from commercial off -the-shelf (COTS) components, a wallet size embedded system with the equivalent capability of a 90's PC. Such embedded systems can be supported with scaled down Windows or Linux operating systems. From this perspective, the emergence of wireless sensor networks (WSNs) is essentially the latest trend of Moore's Law toward the miniaturization and ubiquity of computing devices.

Typically, a wireless sensor node (or simply sensor node) consists of sensing, computing, communication, actuation, and power components. These components are integrated on a single or multiple boards, and packaged in few cubic inches. With state-of-the-art, low-power circuit and networking technologies, a sensor node powered by 2 AA batteries can last for up to three years with a 1% low duty cycle working mode. A WSN usually consists of tens to thousands of such nodes that communicate through wireless channels for information sharing and cooperative processing. WSNs can be deployed on a global scale for environmental monitoring and habitat study, over a battle field for military surveillance and reconnaissance, in emergent environments for search and rescue, in factories for condition based maintenance, in buildings for infrastructure health monitoring, in homes to realize smart homes, or even in bodies for patient monitoring [1], [2], [3], [7] and [8].

After the initial deployment (typically ad hoc), sensor nodes are responsible for self-organizing an appropriate network infrastructure, often with multi-hop connections between sensor nodes. The onboard sensors then start collecting acoustic, seismic, infrared or magnetic information about the environment, using either continuous or event driven working modes. Location and positioning information can also be obtained through the global positioning system (GPS) or local positioning algorithms. This information can be gathered from across the network and appropriately processed to construct a global view of the monitoring phenomena or objects. The basic philosophy behind WSNs is that, while the capability of each individual sensor node is limited, the aggregate power of the entire network is sufficient for the required mission.

Since the nodes in a WSN are battery powered, minimizing the energy consumption of the WSN is key to ensuring that WSN can operate for the longest period of time possible. Much research has been done to develop different types of routing protocols and examine their effect on energy efficiency [5], [6], [10].

II. LOW-ENERGY ADAPTIVE CLUSTERING HIERARCHY (LEACH)

LEACH is a single-hop routing protocol that divides the WSN into clusters and assigns a leader to each cluster (cluster heads). The sensor nodes within a cluster regulate their energy used to transmit data and only use as much energy as is required to reach the leader of the cluster. The cluster heads (CH) then aggregates the data and expends a larger amount of energy to transmit the data directly to the sink. To increase total network lifetime, LEACH periodically rotates the leader responsibility to other nodes. LEACH researchers found that the optimal number of nodes to make CH is 5 percent of the total number of nodes in the WSN. Cluster heads (CH) have many tasks: firstly they are responsible of collecting data from the member nodes; secondly, they transmit the aggregated data to the base station; and thirdly they are responsible for creating a time division multiplexed access (TDMA) schedule which specifies the time slots allocated for each member of the cluster.

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:

$$T(n)=\begin{cases}\dfrac{p}{1-p*\left[r \bmod \left(1/p\right)\right]}, & n\in G,\\ 0, & n\notin G,\end{cases} \quad (1)$$

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.

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 (time division multiplexed access) schedule telling each node when it can transmit. This schedule is broadcast back to the nodes in the cluster.

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. Fig.1 shows the structure of an evolutionary algorithm in LEACH protocol [13].

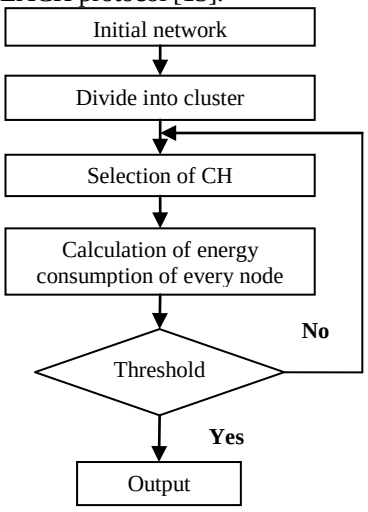

Figure 1. Steps in LEACH

The simulations of LEACH protocol mainly performed with assumption that all sensor of networks are charged homogeneously. There is also another type of simulation. In this simulation the sensor of networks are charged heterogeneously where some advanced nodes with different energy capabilities [6]. Usually CHs die faster than other nodes because CHs need more power capabilities to aggregate data to base station [10]. Thus it's important to study CH death rate and power consumption, over all network life time can be increased if we increase CH life time.

III. Calculation of Energy Consumption

For the calculation of the energy consumption a communication model is used (fig. 2) [13]. In this model the transmitter dissipates energy to run the radio electronics and the power amplifier, and the receiver dissipates energy to run the radio electronics [13], [14]. Using the radio model an estimation of energy consumed in transmission or reception by a sensor node at each cycle is given.

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 E_b /N_o. These parameters are slightly better than the current state of-the-art in radio design1. We also assume an r^2 energy loss due to channel transmission. Thus, to transmit a k-bit message a distance d using our radio model, the radio expends:

$$\begin{aligned}E_{Tx}(k,d)&=E_{Tx-elec}(k)+E_{Tx-amp}(k,d)\\ E_{Tx}(k,d)&=k*E_{elec}+k*E_{amp}*d^2\end{aligned} \quad (2)$$

And to receive this message, the radio expends:

$$\begin{aligned}E_{Rx}(k)&=E_{Rx-elec}(k)\\ E_{Rx}(k)&=k*E_{elec}\end{aligned} \quad (3)$$

IV. Analysis of Results for LEACH Protocol in Homogeneous & Heterogeneous System

In this paper, an analysis of the power consumption for CH's in case of LEACH protocol is made. The analysis take into consideration the percentage of heterogeneous nodes, the analysis has been performed for homogeneous (0% heterogeneous nodes), 10%, 20% heterogeneous nodes.

During the study of LEACH protocol important parameters are taken into consideration the round number vs the number of Dead Cluster Heads and round number vs the average energy of CH.

With the nodes being deployed, some assumptions were made concerning the node features and these are as follows:

- Nodes always have to send data.
- All nodes start with the same initial energy.
- Clusters and nodes are static.
- Nodes are assumed to have a limited transmission range after which another equation for energy dissipation is used.

A. *LEACH Protocol in Homogeneous System*

Fig.2 shows the results of setup stage in LEACH protocol, CH has been randomly selected. The simulations were configured with a network size of 100 x 100 meters and with 200 nodes randomly distributed; the base stations were located at position (150, 50). All of the sensor nodes periodically sensed the environment and transmitted the data to the cluster heads. Every result shown is an average of 50 experiments. O indicates Normal nodes and dark O indicates CHs. X indicates BS.

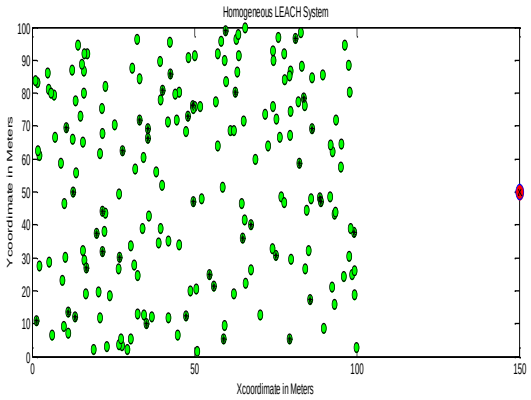

Figure 2. Initialization of the wireless sensor network

B. *LEACH Protocol in Heterogeneous System*

A heterogeneous network is a network where part of the sensor nodes namely advanced nodes, are equipped with more initial energy than the rest of the normal nodes and these advanced nodes with extra energy can improve the lifetime of the network [10]. The same procedure as in the normal LEACH protocol is followed i.e., the formation of the clusters is same in this heterogeneous system and also the cluster head selection by comparing the residual energy of the individual in every round. The structure of the LEACH Heterogeneous system for wireless sensor networks is shown in Fig.3; Here 200 nodes are distributed in 100x100 meters area. BS is located at the (150, 50). 'O' indicates Normal nodes and 'red o' indicates Normal nodes CHs. '+' symbol indicates Advance Node and 'red +' indicates Advance Node CHs. X indicates BS.

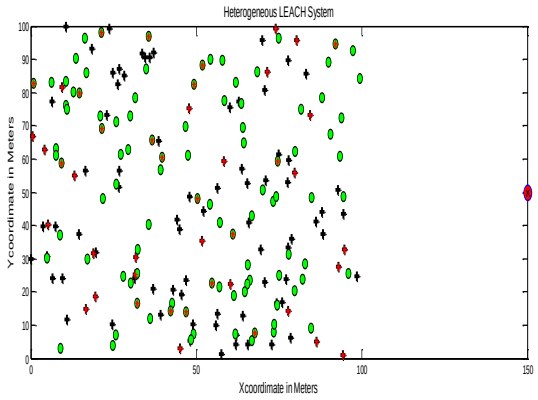

Figure 3. Heterogeneous LEACH system. '+'symbol indicates Advance Node.

The results of the simulation are presented on Fig. 4 and 5. Fig.4 and 5 describe the comparison between the Leach Homogeneous and Leach-Heterogeneous System in terms of number of dead nodes and average energy of each Node. Simulation results using MATLAB shows that the LEACH heterogeneous system significantly reduces energy consumption and increases the total lifetime of the wireless sensor network.

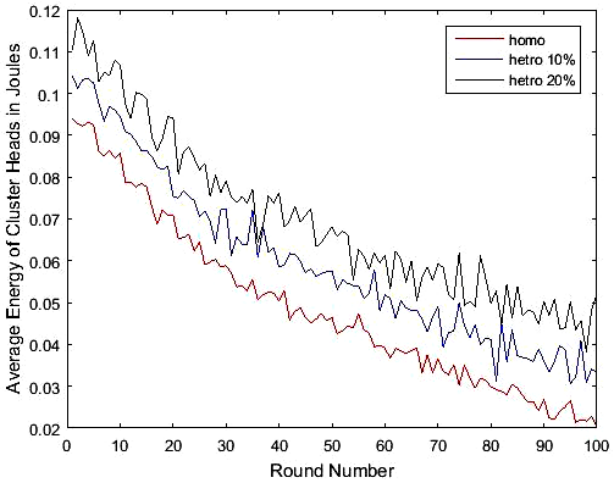

Figure 4. Average Energy consumed in Cluster Heads in LEACH system

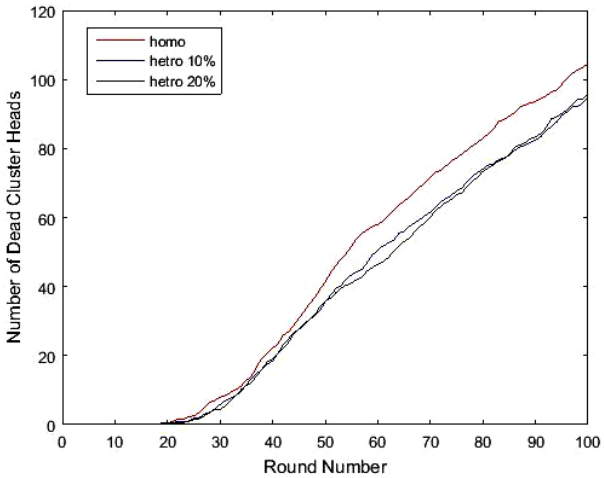

Figure 5. Number of dead Cluster Heads in LEACH system

It can be seen that nodes remain alive for a longer time (rounds) in Leach-Heterogeneous system than LEACH - Homogeneous system.

CONCLUSION

In this paper, we evaluated LEACH routing protocol for Wireless Sensor Networks. The main reason of the evaluation of LEACH protocol is the study of the energy consumption due to the limited amount of energy in the sensor nodes. From the brief analysis of the simulation we have come to the conclusion that LEACH Heterogeneous System provides a good performance in energy consumption and increasing the level in

lifetime of the wireless sensor networks than LEACH Homogeneous System.

The analysis of the energy consumption of wireless sensor network shows the importance of powering nodes from non-renewable energy sources, such as batteries and fuel cells. This method of powering has improved over the years, this improvement is fairly gradual compared with other areas of electronics and cannot satisfy all of the simultaneous demands for long life, low volume, low weight and limited environmental impact. Therefore Wireless sensor networks can be powered by environmentally **scavenged energy** (**Energy Harvesting**). There are a great many sources of energy and conversion devices which have been considered for energy harvesting. **Energy harvesting** device can provide the level of the power required by the sensor node in Wireless sensor network.

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