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Analysis of LEACH and Its Variants for Routing In Wireless Sensor Networks

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ABSTRACT
Wireless sensor networks (WSNs) have revolutionized many segments of our economy as well as our lives. Various modern devices require sensory data from the real world around them. This data is provided by WSNs, which consists of several tiny sensor nodes. Different routing protocols govern the movement of this information. Energy efficiency is one of the main design objective for these sensor networks. Low-Energy Adaptive Clustering Hierarchy (LEACH) is a classical cluster based routing protocol for WSNs having good performance. In this paper we mainly focus on implementing wireless sensor network using LEACH protocol to analyze performance of WSNs in terms of energy, throughput and lifetime using ns-2 and present a survey of variants of LEACH , that has produced different routing protocols for WSNs and highlight their features.
***Keywords* -** Cluster, Energy, LEACH, Lifetime, Wireless Sensor Network

I. Introduction

WSNs with number of tiny sensor nodes; find wide applicability in various fields, as they enable reliable monitoring and analysis of the environment. Within its radio communication range each sensor node communicates wirelessly with a few other local nodes. These sensor nodes are equipped with small batteries with limited power capacities. If each node transmits its sensed data directly to the base station, then its power depletes quickly [1]. The advancement in technology results in extremely small and low powered devices, equipped with programmable computing, multiple parameter sensing and wireless communication capability [2].The sensor nodes are small embedded computing devices that interface with sensors or actuators and communicate using short-range wireless transmitters. Such nodes act autonomously as well as cooperatively to form a logical network, in which data packets are routed towards management nodes, called sinks or base stations. In order to save energy, it is necessary to schedule the state of the nodes, vary the transmission range between the sensing nodes and use efficient routing protocols.

On the basis of network structure, routing in wireless sensor networks can be classified as:

i) Flat-based routing: All the nodes in this topology have assigned the same function to perform the sensing task.
ii) Hierarchical-based routing: In this architecture, higher energy nodes process and send the information, while low-energy nodes perform sensing in the proximity of the target.
iii) Location-based routing: Routing path for the data is decided according to the position of sensor nodes in the field.

II. LEACH Protocol

It is a cluster based routing protocol that minimizes energy dissipation in sensor networks and is proposed by W. R. Heinzelman [3]. In this protocol, the total number of nodes are divided in many small groups or cluster for equal distribution of power consumption inside the network. A cluster head (CH) is a sensor node that can be selected either randomly or in a predefined sequential manner inside a cluster to transmit an aggregated sensor data to the distant base station. At every iteration, the CH shifts to other and communicates directly to each node inside the cluster to collect data and sends it to the sink or router or to another CH to propagate data towards sink. LEACH operation is divided into two phases i.e., Setup phase and Steady-state phase.

2.1 Setup phase

In this phase clusters are formed and a CH is chosen for each cluster. Every node produces a random number between 0 and 1, and if this number is less than threshold value T (n), then it becomes CH. In every round, T(n) is set to 0, for the node which already worked as CH before, so that this node will not be selected again. For the nodes that have not been selected once, the possibility of being selected is T(n). If only one node left then T (n) =1, means this node will be certainly selected as CH[3,4,7].

T (n) is defined as follows :

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

Where,
p= percentage of number of CH in the total number of nodes,
r = number of current round,

G= set of nodes that have not been elected in the past 1/p rounds of election.

When any of the nodes is selected as CH, it informs other nodes. Based on the received signal strength non-CH nodes choose their CH for this round. The CH node sets up a TDMA schedule and transmits this schedule to all the nodes in its cluster [3,4, 5, and 6].

2.2 Steady-state phase

In this phase, the non-CH nodes start sensing data and send it to their CH according to the TDMA schedule. The CH node compresses the received data and sends it to the base-station . Communication is via direct-sequence spread spectrum and each cluster uses a unique spreading code to reduce inter-cluster interference. After certain period of time, the network again goes into the setup phase and enters another round of selecting cluster heads(CHs).

2.3 Limitations of LEACH Protocol

A few of these assumptions are as follows:

i) All nodes can transmit with enough power to reach the base station if needed.
ii) Nodes always have data to send.
iii) Nodes located close to each other have correlated data.
iv) It is not obvious how the number of predetermined CHs are going to be uniformly distributed throughout the network. Therefore, there is a possibility that the elected CHs will be concentrated in one part of the network. Hence, some nodes will not have any CH nearer to them.
v) It assumes a homogeneous distribution of sensor nodes in the given area.
vi) CHs are selected randomly in LEACH, hence nodes with less energy may be chosen, which could lead to these nodes die too fast. Moreover, in LEACH protocol CHs communicate with base station in single-hop manner, it is energy consuming and therefore it could not adapt to large network[7].

III. Variants of LEACH

3.1Threshold sensitive Energy Efficient sensor Network protocol (TEEN)

It is a hierarchical protocol with the use of a data-centric mechanism and is very much suitable for time critical data sensing applications in terms of energy consumption and response time. It is responsive to sudden changes in the sensed attributes. In the sensor network architecture closer nodes form clusters and this process goes on the second level until base station is reached. After the clusters are formed, the CH broadcasts two thresholds to the nodes. These are hard and soft thresholds for sensed attributes. Hard threshold is the minimum possible value. The soft threshold can be varied, depending on the target application. A smaller value of the soft threshold gives a more accurate picture of the network but energy consumption increases. Thus there is a trade-off between energy efficiency and accuracy. The drawback of this scheme is the complexity of forming clusters in multiple levels. Moreover, TEEN only transmits time-critical data while sensing the environment continuously and the nodes will never communicate if the thresholds are not reached[2,11].

3.2 Adaptive Threshold sensitive Energy Efficient sensor Network protocol (APTEEN)

It is an extension to TEEN and aims at both capturing periodic data collections and reacting to time critical events. CHs also perform data aggregation in order to save energy. The nodes in such a network gives an overall picture of the network at periodic intervals in an energy efficient manner. Such a network enables the user to request past, present and future data from the network. The performance of APTEEN lies between TEEN and LEACH with respect to energy consumption and lifetime of the network. The drawbacks of TEEN can be overcome using APTEEN which uses periodic data transmission. APTEEN transmits data, based on the threshold values unlike LEACH which transmits data at all times. But this energy saving increases the response time[8,11].

3.3 Power-Efficient Gathering in Sensor Information Systems (PEGASIS)

It is a chain-based protocol and is an improvement over LEACH protocol. In this protocol each node communicates only with its closer neighbor . The data which moves from one node to another node, aggregates and send to the base station. In contrast to LEACH, only one node is used to transmit data to the base station instead of using multiple nodes. Hence it extends the network lifetime by using collaborative techniques. Moreover, bandwidth consumed in communication is reduced as there is only local coordination between closer nodes. PEGASIS has been shown to outperform LEACH by about 100–200% for different network sizes and topologies. It is due reduction in the number of transmissions and receptions using data aggregation as well as due to the elimination of overhead caused by dynamic cluster formation in LEACH. However, it results in excessive delay for distant node on the chain [9,11].

3.4 Hybrid Energy-Efficient Distributed clustering HEED (Hybrid Energy-Efficient Distributed clustering)

This is a stand-alone distributed clustering protocol that periodically selects CH by only considering communication distance and the node residual energy. Thus, a node with high residual energy has a higher chance to become a CH. HEED terminates the clustering process within a constant number of iterations, incurs low message overhead, and achieves fairly uniform CH distribution across the network. But, it does not guarantee the number of selected CH. If the energy of all nodes is similarly low, most nodes can become CH[10].HEED outperforms LEACH in terms of prolonging network lifetime by distributing energy consumption for a large network[11].

3.5 Density based Cluster Head Selection

This is a subtractive clustering technique. It overcomes the shortcomings of basic LEACH protocol in handling node's non-uniform and time variant energy distribution. In this algorithm the sensor node with the highest probability is taken up as the first cluster center and eliminates all nearby sensor nodes to determine the next probable cluster and its center location. This process continues until all sensor nodes are covered. A CH performs data aggregation and monitors inter as well as intra-cluster transmission of data in the network. A multi-layer selection criteria is considered for the selection of CH. The first level is the Energy Filtration. It checks the energy level of all the nodes in dominating set (DS). The next level is based on Node Connectivity via single hopping. The third level is based on considering the node identity. Initially nodes are provided a unique identity (ID), which is basically a number. Lowest identity (LID) is simple algorithm that selects a node with its ID lowest among the remaining nodes in the given set . In third level LID is considered only for the first round of CH selection. In LEACH, the CHs are elected randomly, so the optimal number and distribution of CHs cannot be ensured. The nodes with low residual energy have the same priority to be a CH as the node with high residual energy, resulting in some node with low residual energy may die first. Hence in this new approach , the phenomenon of aging is used as the load balancing parameter for selecting CH. Once, a node from IDS becomes a CH, its probability to get re-elected as CH reduces. Therefore proper load distribution within clusters increases the lifespan of the sensor network[12].

3.6 LEACH protocol using Fuzzy Logic (LEACH-FL)

This protocol takes three variables battery level, distance and node density into consideration. As LEACH only depends on probability model, some CHs may be very close to each other and can be located in the edge of the WSN. These in-efficient CHs could not maximize energy efficiency. A CH election method using fuzzy logic has been introduced to overcome the defects of LEACH. In this the network lifetime can be efficiently prolonged by using fuzzy variables : concentration , energy and centrality. In this approach a part of energy is spent to get the data of the three variables especially concentration and centrality[5].

IV. Simulation

To analyze lifetime, throughput and the effective use of energy of a network, LEACH algorithm is followed. It is based on two different radio models i.e., free space model and two-ray ground propagation model depending upon the distance between transmitter and receiver[3,4]. When this distance is less than threshold value i.e. $d_{crossover}$, algorithm adopts free space model (d^2 power loss),otherwise it adopts two-ray ground propagation model (d^4 power loss). The crossover is defined as follows:

$$d_{crossover} = (4*\pi*\sqrt{L}*ht*hr) / \lambda \qquad (2)$$

Transmit power is attenuated based on the distance 'd' between the transmitter and receiver and the threshold value is given as:

$$Pr(d) = (Pt* Gt *Gr*\lambda^2) / (4* \pi*d)^{2*}L \qquad (3)$$

if $d< d_{crossover}$ free space model

$$Pr(d) = (Pt*Gt*Gr*ht^2*hr^2)/d^4 \qquad (4)$$

if $d \geq d_{crossover}$ two-ray ground propagation

where, L = 1 is system loss factor,
ht = height of transmitting antenna
hr = height of receiving antenna
λ = wavelength of carrier signal
Pt = transmitted power
Pr = received power at distance d,
Gt = gain of transmitting antenna
Gr = gain of receiving antenna

A simple model for radio energy dissipation will be considered where the transmitter dissipates energy to run the radio electronics and the power amplifier, and the receiver dissipates energy to run the radio electronics as shown in Fig.1[3].

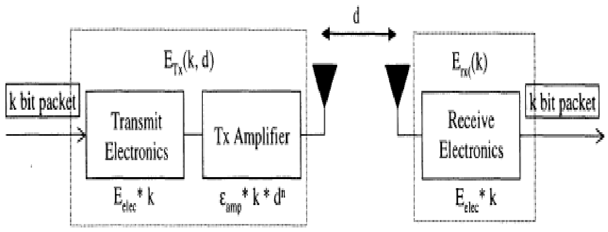

figure1: Energy consumption model

Therefore if the transmitter sends k-bit message to the receiver up to a distance of d, the energy consumption of the transmitter and the receiver can be calculated by the following equations:

$$E_T x (k, d) = Eelec-T x (k) + Eamp-T x (k, d) \qquad (5)$$

$$E_{Tx} (k, d) = E_{elec} * k+\varepsilon_{fs}*k*d^2, \quad d<d_{crossover} \qquad (6)$$

$$E_{Tx} (k, d) = E_{elec}* k+\varepsilon_{mp}*k*d^4, \quad d\geq d_{crossover} \qquad (7)$$

$$E_{Rx}(k) = Eelec-Rx (k) \qquad (8)$$

$$E_{Rx}(k) = E_{elec} * k \qquad (9)$$

where, E_{Tx} (k, d) is the energy consumed by the transmitter to send a k-bit long packet over distance d, Eelec−T x (k) is the energy used by the electronics of the transmitter, and Eamp−T x (k, d) is the energy expended by the amplifier. Whereas,

$E_{Rx}(k)$ is the energy consumed by the receiver in receiving a k-bit long packet, which is given by the energy used by the electronics of the receiver; ϵfs and ϵmp represent the energy consumption factor of amplification in the two radio models[5].

V. Simulation analysis and results

Simulation is carried out using network simulator ns-2, considering 100 nodes within the area of 1000x1000 sqm. εfs is 100pj/bit/m^2, ε_{mp} is 0.013pj/bit/m^4 and Eelec−T x is equal to Eelec−Rx which is equal to Eelec and is 50nj/bit, loss factor is 1, transmitting and receiving antenna gain is 1and radio frequency is 914MHz, using bidirectional communication model.

Table.1 Simulation Results

% CH	Life time(s)	Throughput (bits)	Energy Consumed(J)
2	418	41968	429.28
3	351.6	38441	393.52
4	301.09	19431	464.04
5	524.1	53777	326.799
6	423	39411	393.965
7	270.99	23677	344.68
8	111.99	5309	394.694

Results show that the energy consumption is comparatively lesser, lifetime and throughput is comparatively higher when the no. of cluster heads are 5 percentage of the sensor nodes.

VI. Conclusion and future scope

The energy of sensor nodes plays a very important role because the lifetime of WSNs depends upon the energy of these nodes. The Hierarchical routing protocol LEACH is energy efficient for the sensor network and is designed to improve the lifetime of a network. Moreover, proper selection of CH can be a better solution for making an efficient WSN in terms of throughput, energy consumption and life-time of sensor nodes. Analysis of the variants of LEACH protocol for WSNs , describes various modifications over the primitive LEACH protcol and highlight their features. Future scope of this Hierarchical-based routing protocol may be the use of multi-hop routing taking into account the improved way of choosing CHs by considering energy as well as density of the sensor nodes to further prolong the lifetime of wireless sensor network and to save energy.

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