



Retrospection of Hierarchical Routing Protocols For Wireless Sensor Networks

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Abstract- This paper is a review of different clustering and routing protocols of wireless sensor networks (WSNs). The main issue in wireless sensor networks is its the low lifetime. Different techniques of clustering the nodes and routing the data from nodes to base station helps in increasing the lifetime of the WSN. The objective of this paper is to review different routing protocols of WSNs, compare them and explore their shortcomings.

Keywords- WSN, Hierarchical routing, LEACH, PEGASIS, EECS, HEER, GROUP, HEED, pLEACH.

I. INTRODUCTION

A wireless sensor network (WSN) consists of spatially distributed independent sensors to observe physical or environmental conditions and to cooperatively pass their data through the network to a main location[2]. The WSN is made of nodes from a few to several hundreds or even thousands, where each node is connected to one (or numerous) sensors. A sensor node might differ in size from that of a shoebox to the size of a grain of sand. The price of sensor nodes is also variable, ranging from a few to hundreds of dollars, depending on the complication of the single sensor nodes. Size and cost restraints on sensor nodes result in equivalent constrictions on resources such as energy, memory, speed and communications bandwidth. Each such sensor network node has typically several parts a radio transceiver, a microcontroller, an electronic circuit for interfacing with the sensors and a battery. The components of a sensor node are microcontroller, transceiver, sensor, power source (mainly batteries) and external memory.

The main function of a sensor is to collect the data and then send it to the base station or sink. The base stations are one or more components of the WSN with much more computational energy and communication resources. They act as a doorway between sensor nodes and the end user as they typically forward data from the WSN on to a server.

The nodes communicate wirelessly and often self-organize after being arranged. Wireless sensors network is the most important technology of 21st century. It has been useful in medical treatments, military surveillance, environment detection, industry, assisted living facilities, home monitoring, detecting and preventing natural disasters, machinery monitoring and other fields. The main characteristics of WSN are:

- Ability to handle the node failures
- Ability to resist harsh environmental conditions
- Scalability to large scale of deployment
- Ease of use

There are many benefits of wireless sensor networks like low cost and small size. The only power source in WSN is batteries and replacing the batteries of so many nodes is a difficult task, so the main research area in the wireless sensor network is increasing its lifetime. To do so, a number of routing protocols has been proposed. In this paper, we will review some of them.

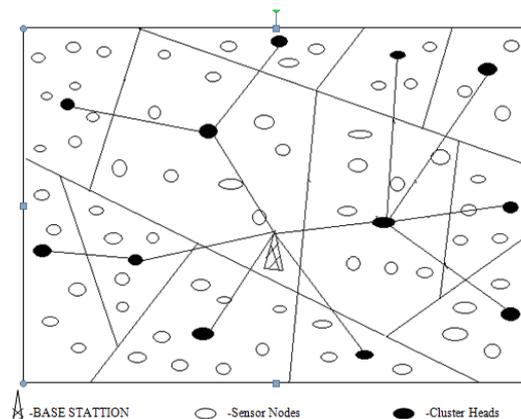


Fig1- Wireless Sensor Network

II. PROTOCOLS IN WSN

To increase the lifetime of a wireless sensor network different protocols for clustering the nodes and then routing the data from nodes to the base station are followed. So, in this paper we will review some of the clustering techniques and the routing protocols based on different parameters. Routing in WSNs is very difficult because of the characteristics [1] that differentiate WSNs from other wireless networks like mobile ad hoc networks. Firstly, due to the huge number of sensor nodes, it is impossible to figure a global addressing scheme, so traditional IP-based protocols won't be useful to WSNs. Secondly; every applications of WSN necessitate the flow of data detected from multiple sensor nodes to the base station. Thirdly, sensor nodes are tightly restricted in terms of energy and storage and need resource management. Fourth, the nodes in WSNs are usually static. Lastly, the data collected by different sensors in WSNs has certain redundancy. So, due to these characteristics WSNs require different routing protocols as compared to other networks. Clustering as the name suggests means to form clusters or groups. Clustering plays an important part in the WSNs. Clustering will group the sensor nodes thus forming clusters and assign a cluster head to each of the clusters formed. Clustering along with routing increase the lifetime of WSNs by two ways: -

Firstly, the energy consumption is reduced within the cluster and secondly, lesser transmissions occur during the data flow from clusters to the base station.

So, clustering and routing both techniques are helpful in dealing with the energy constraint of the WSNs. When clustering and routing both are used together in WSNs then it is known as hierarchal routing. Some of the well-known hierarchal routing protocols for WSNs are: LEACH, PEGASIS, HEER, TSEP, pLEACH, EECS, HEED, and GROUP.

In this review paper, we will study these protocols and do a comparative study on the basis of some parameters like proactive or not, type of nodes etc.

A. LEACH [2]

LEACH (Low Energy Adaptive Clustering Hierarchy) routing protocol is the conventional clustering communication protocol widely used in Wireless Sensor Networks. It is based on the low power consumption adaptive routing algorithm of WSN. In LEACH, in order to balance energy consumption of each node, nodes are selected as cluster head nodes circularly and randomly. This algorithm makes sure that every node gets a chance to become a cluster head.

LEACH operates in two phases which are as follows:

➤ Setup Phase

Every round begins with a set-up phase when the clusters are organized. During the set-up phase, each sensor node tries to select itself as a cluster head according to probability model. For selecting a cluster head, each sensor node generates a random number between 0 and 1. If the δ is less than the threshold [2] $T(n)$, the sensor node selects itself as a cluster head for current round, the threshold is presented as follows:

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

Where n is the total number of sensor nodes in the network, p is the number of cluster head nodes for each round, r as the number of the current round, and G is the set of nodes that have not been selected as cluster heads in the last n/p rounds. In this phase the clusters are also formed. The nodes chosen as cluster heads send a message to the nearby nodes to join them so as to form clusters. When the nodes respond to this message several small clusters are formed in the wireless sensor network.

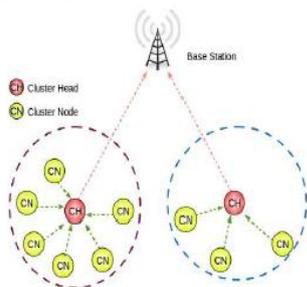


Figure 2-Cluster Formation [8]

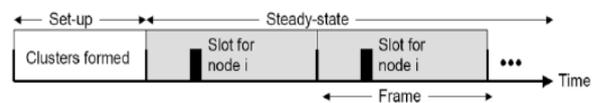


Figure 3- LEACH [2]

➤ Steady Phase

In this phase the nodes send the data to the cluster head which processes the data and further send it to the base station. When all the data reaches the base station then the round is complete and the next round begins. LEACH is the basis protocol but it has some restrictions like: stochastic selection of cluster heads, nodes are homogeneous and choosing low energy nodes as cluster heads

B. PEGASIS [4]

In PEGASIS (Power Efficient Gathering in Sensor Information System) is a chain-based protocol in which every node communicates with closest neighbour and transfer of data to base station is done turn by turn by the nodes. This distributes the load of energy uniformly among the nodes. No cluster formation happens in PEGASIS; here a chain is formed that transmit the data to the base station. This increases the lifetime of every node and allow coordination between the closest nodes. In PEGASIS, every node communicates its data to its closest neighbour and the neighbour is

determined using the signals. Then a chain is constructed using greedy algorithm starting from the farthest node from the sink. It is done to ensure that farthest nodes have close neighbours. After chain construction, data transmission takes place. In each round, each node takes data from a neighbour and joins this data with its own data and transfers to the other neighbour on chain which finally reaches to the leader node. During a round, only one leader node communicates with base station. If a node in a chain dies then the chain is reconstructed.

PEGASIS has assumed that only one node will communicate with the base station and this could create a bottleneck. It is assumed that every sensor node communicates directly with base station which is practically not possible.

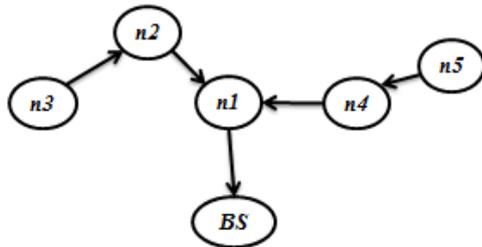


Figure 4- Chain construction and data transmission in PEGASIS partition [3]

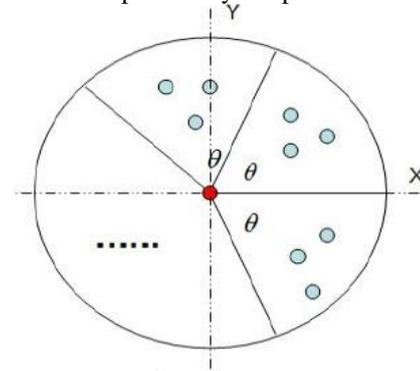


Figure 5- Sectors after partition

C. pLEACH [3]

pLEACH or partition based LEACH is an improved LEACH protocol that divides the whole network into a number of sectors and then perform cluster head selection. The pLEACH algorithm consist of two phases- partition phase and cluster head selection phase.

➤ Partition Phase

Here the sink will calculate optimal number of cluster heads for the network and partition it into sector. For example, if optimal number of cluster head is n , then network will be divided equally into n sectors.

➤ Cluster formation Phase

At the starting of this phase, nodes send their initial energy and location to the sink. The node with highest energy in each sector is appointed as the cluster head by the sink. If two nodes have same energy then the node with smallest ID becomes the cluster head. After this the sink broadcasts the message to all the nodes so that the no cluster head nodes join the closest cluster head to form clusters. When the cluster formation is complete then the transmission of data takes place. After the transmission is accomplished the sink will calculate the residual energy of the nodes for the next round. With pLEACH the cluster heads are evenly distributed among the whole network and energy consumption is also reduced thus increasing the lifetime of the WSN.

D. HEER

In HEER [10] (Hybrid Energy Efficient Reactive) protocol; cluster head (CH) is selected on the basis of the ratio of residual energy of node and average energy of network. Additionally, to save more energy, Hard Threshold (HT) and Soft Threshold (ST) are used. HEER is a reactive protocol used for both homogeneous and heterogeneous networks. Here, all the nodes make use of the initial and residual energies to select a CH. The node with higher initial and residual energy has greater possibility of becoming a CH. The probability [5] of a node becoming the cluster head is for normal nodes:

$$P = P_{opt} E_i(r) / (1 + am) E(r)$$

And for the advanced nodes

$$P = (1 + a) P_{opt} E_i(r) / (1 + am) E(r)$$

Where a and m are variables that control the percentage of advanced and normal nodes in the heterogeneous network, $E_i(r)$ is the initial energy of node and $E(r)$ is the residual energy.

When cluster are formed, the CH transfers two threshold values, i.e. HT and ST. The nodes checks their location repeatedly and if a parameter from the attributes set reaches its HT value, the node switches on its transmitter and communicates data. The Current Value (CV) [10], on which first transmission occurs, is stored in an internal variable in the node called Sensed Value (SV). This reduces the number of transmissions. Now the nodes will again transmit the data in same cluster period only when

$$CV - SV = ST$$

That is, if CV differs from SV by an amount equal to or greater than ST, then it further reduces the number of transmissions. So, HEER reduces the number of transmissions to great extent thus reducing the energy consumption and increasing the lifetime of the network.

E. TSEP

TSEP [8] (Threshold sensitive Stable Election Protocol) is reactive routing protocol. In reactive routing transmission is done only when a specific threshold is reached. TSEP has 3 levels of heterogeneity that is the nodes have 3 levels of energy namely- normal, intermediate and advanced. The energy [8] of normal nodes will be E_0 , for the advance nodes E_{ADV} and for the intermediate nodes be E_{INT} .

$$E_{ADV} = E_0(1 + a)$$

$$E_{INT} = E_0(1 + a/2)$$

Where a is additional energy. For the cluster head selection TSEP each node will generate a number between 0 and 1 and if the generated number is less than the threshold value then node will become the cluster head. The threshold [8] for different nodes is different, for normal nodes

$$T_{NR} = \frac{P_{NR}}{1 - P_{NR} \left[r, \text{mod}_{\frac{1}{P_{NR}}} \right]}$$

For advanced nodes,

$$T_{ADV} = \frac{P_{ADV}}{1 - P_{ADV} \left[r, \text{mod}_{\frac{1}{P_{ADV}}} \right]}$$

For intermediate nodes,

$$T_{INT} = \frac{P_{INT}}{1 - P_{INT} \left[r, \text{mod}_{\frac{1}{P_{INT}}} \right]}$$

Energy dissipation is less in TSEP because of the energy heterogeneity. After cluster formation the CHs broadcast two values hard threshold and soft threshold. Hard Threshold (HT) is an absolute value of sensed attribute outside which node will transmit data to CH. Soft Threshold (ST) is the least sensed value at which the nodes switch on their transmitters and transmit the data. After this nodes start sensing the data and transmit it to the base station. All nodes keep on sensing constantly. As parameters from attribute set reaches hard threshold value, transmitter is turned on and data is transmitted to CH, but this is for the first time when this condition is met. This sensed value is kept in an internal variable in the node, called Sensed Value (SV). Then for second time and the other, nodes will transmit data if and only if sensed value is greater than hard threshold value or if difference between currently sensed value and the value stored in SV variable is equal to or greater than soft threshold. So, by keeping these both thresholds in attention, number of data transmissions can be reduced. And further transmissions are decreased by soft threshold, as it will remove transmissions when there is a minor change in value.

TSEP helps in transmitting the time critical data to the user and energy consumption is quite less due to the thresholds but the only limitation of this protocol is that if the particular threshold is not attained than user won't get any data from the network.

F. GROUP

In Genetic algorithm inspired Routing Protocol (GROUP) [9], a chain is formed, however in place of permitting all nodes to become the leader, to communicate with the base station the same number of times, the network lifetime is increased by allowing the separate nodes to transmit uneven number of times to the base station depending on their residual energy and location. Besides, instead of forming a greedy chain, modern heuristic optimization techniques like Genetic Algorithms are used in GROUP. Genetic Algorithm [12] is mainly a probabilistic exploration algorithm based on the principles and conception of natural selection and evolution. The GROUP has following steps:

i. Initialization

Generate an irregular population of n chromosomes.

ii. Selection

Selection process determines which two chromosomes out of the total population of n chromosomes will take part in breeding to create offspring.

iii. Generation

A new group is created using crossover and mutation operations. Crossover specifies the grouping of the two parent chromosomes to produce an offspring and mutation adds variation in the next generation.

iv. Leader Selection

After the chain is formed the node with maximum value of residual energy becomes the leader that will communicate with the base station.

G. EECS

Energy efficient clustering scheme [6] (EECS) is used for data gathering application in WSNs. EECS is a clustering scheme just like LEACH, where the network is divided into clusters with one cluster head in each cluster and communication among cluster head and BS is straight (single-hop). EECS functions in three phases which are as follows:

i. Cluster Head Election

In this phase, numerous cluster heads are selected. Nodes become candidate nodes with a probability T and then broadcast the COMPETE_HEAD_MSGs within radio range R to broadcast their wills of becoming the cluster head. Each CANDIDATE node checks whether there is a CANDIDATE node with more residual energy within the radius R . Once the CANDIDATE node finds a more powerful CANDIDATE node, it will give up the idea of being cluster head without receiving sub successive COMPETE HEAD MSGs. Otherwise, it will be elected as HEAD in the end.

ii. Cluster Formation

In this phase, each HEAD node broadcasts the message across the network, while the normal nodes receive all the message form CH and decide which cluster to join on the basis of the distance. The normal nodes select the cluster head that require least communication according to the received signal strength.

iii. Data Transmission

In this phase data receiving, data aggregation and data transmission takes place. Here the cluster head will receive the data from the nodes within its cluster and then data aggregation takes place and then the aggregated data is transmitted to the base station. The energy dissipation [6] in this phase is given by:

$$E(CH) = m_i l E_{slic} + (m_i + 1) l E_{DA} + l (E_{slic} + E_{emp} d^4) \quad [6]$$

The cluster heads in EECS are evenly distributed as compared to that in the LEACH.

H. HEED

HEED [7] (Hybrid Energy-Efficient Distributed clustering) periodically selects cluster heads according to a mixture of the node residual energy and a secondary parameter, like node distance to its neighbours. To increase the lifetime of a wireless sensor network along with residual energy, the inter cluster communication cost is also considered.

Before initiating the HEED protocol, a probability [7] of becoming the cluster head is set

$$CH_{prob} = C_{prob} \frac{E_{resi}}{E_{max}}$$

Where C_{prob} is the percentage of cluster heads among n nodes, E_{resi} is the residual energy and E_{max} is the maximum energy. A number of iterations are involved in the clustering process and to terminate the protocol a threshold value that is inversely proportional to E_{max} is set and CH_{prob} should be greater than this threshold. During the iteration, a set of tentative cluster heads is formed and on the basis of the low cost function nodes are selected from the tentative cluster head set. If a node selects to become a cluster head, it broadcast an announcement message consisting of node ID, its cost and selection status where the selection status is set to tentative_CH. If a node finishes HEED without selecting a cluster head that is final_CH then it announces itself to be a cluster head with selection status as final_CH. During later iterations if a lower cost cluster head is found then the tentative_CH becomes a regular node. Then after cluster heads are selected then the data is transferred to the base station. A node is considered as dead if it has lost 99.9% of its initial energy.

III. COMPARISON OF PROTOCOLS

All the above protocols are used to prolong the lifetime of the wireless sensor network but they differ in many ways. We can compare them on the basis of the types of node in them, the stages in which the algorithm proceeds and if the protocol is reactive or proactive.

The comparison of the above explained protocols are made in Table 1.

The LEACH is the basis protocol which is used for clustering and it is a proactive protocol that is executed on homogeneous network. HEED, pLEACH, GROUP and EECS are also similar to LEACH but they make use of different techniques for clustering like GROUP uses genetic algorithm and pLEACH uses a partition based technique. HEER and TSEP are reactive [15] protocols that are executed in heterogeneous networks. These protocols mainly transmit the data to the base station. PEGASIS is different from the basic clustering protocol as no clusters are formed in PEGASIS, instead chain is formed. It is also a proactive protocol and as no clusters are formed it is for data transmission only.

Protocols	Type of nodes	Reactive/Proactive	Algorithm Stages
LEACH	Homogeneous	Proactive	Cluster formation
PEGASIS	Homogeneous	Proactive	Data transmission
pLEACH	Homogeneous	Proactive	Cluster formation
HEER	Heterogeneous	Reactive	Data transmission
TSEP	Heterogeneous	Reactive	Data transmission
GROUP	Homogeneous	Proactive	Cluster formation
EECS	Homogeneous	Proactive	Cluster formation
HEED	Homogeneous	Proactive	Cluster formation

Table 1- Comparison of different protocols

IV. CONCLUSIONS

Wireless sensor networks are used in many applications whether they are for military or household purposes. WSNs have been an area of interest due to the problem of its low battery life and many protocols are developed from time to time to prolong its lifetime.

In this paper, various hierarchal protocols are explained and compared. The working of these protocols is studied in detailed and also their pros and cons are also reviewed. Comparison among the protocols are derived on three parameters that are- type of nodes, reactive or proactive protocol and the algorithm stages. Some protocols are similar according to these parameters but the technique is different for different protocols.

In future, wireless sensors will be used in every field whether it is industry or for domestic use. So to further prolong the lifetime of WSN energy harvesting concepts can be used. By using energy harvesting nodes [16], the WSN operations would never discontinue except hardware failure and it will increase the capacity of work.

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