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A Review on Various Hierarchical Routing Protocols in Wireless Sensor Networks

Kavita[1], Parveen Singla [2]

[1]M.Tech Scholar (ECE) [2]Assistant Professor
[1,2] Electronics and Communication Engineering Department
Panipat Institute of Engineering & Technology, Samalkha
[1] *ks219647@gmail.com*

Abstract: *During the creation of network topology in wireless sensor network, the process of creation of routes is usually influenced by energy considerations. The energy consumption of a wireless link is proportional to square or even higher order of the distance between the sender and the receiver. In hierarchical routing architecture, sensor nodes self-configure themselves for the formation of cluster heads. Hierarchical routing can be centralized or non- centralized. In non centralized hierarchical routing, the sensor nodes self configures for the cluster head on the basis of selecting a random number. They don't consider the case of residual energy. But in centralized routing the base station is responsible to create cluster. In this paper, we have studied various hierarchical routing strategies.*

Keywords: *hierarchical routing, WSN, LEACH, Leach-C, SEP, stable election protocol*

1. INTRODUCTION

The sensor devices used in wireless sensor network have very limited resources such as low processing speed, a low storage capacity, limited battery and limited bandwidth for communication. Additionally, the nodes are battery powered and the network has to operate for long periods of time, so the limited energy resources significantly limit their overall operation. In order to minimize energy consumption, most of the device components, including the radio, should be kept switched off or in stand by mode most of the time to save power. Another important characteristic is that sensor nodes have significant processing capabilities in the ensemble, but not individually. Nodes do not have any administrator, so they have to organize themselves, administering and managing the network all together [1]. Furthermore, changes in the physical environment, where a network is deployed, make also nodes experience wide variations in connectivity and thus influencing the networking protocols [2, 3]. The main design goal of WSNs is not only to transmit data from a source to a destination, but also to increase the lifetime of the network. This can be achieved by employing energy efficient routing protocols [1-11]. Depending on the applications used, different architectures and designs have been applied in WSNs. The performance of a routing protocol depends on the architecture and design of the network, and this is a very important feature of WSNs [2-5]. However, the operation of the protocol can affect the energy used for the transmission of the data.

2. SURVEY ON HIERARCHICAL ROUTING STRATEGIES

In this section we have surveyed few popular hierarchical routing strategies in wireless sensor network. Hierarchical routing technique is given in figure 1. In hierarchical routing architecture, nodes send the data to their leader known as cluster head and cluster head is responsible for transmitting data to base station as shown in figure 1.

2.1 PEGASIS and Hierarchical PEGASIS:

In PEGASIS [2] each sensor node forms a pattern so that each node will receive from and transmits it to nearest neighbor. Each node takes turn being the leader for transmission to the base station so that the average energy spent by each node per round is reduced. The performance evaluation in [2] shows that PEGASIS is able to enhance the sensor network lifetime twice as much as the network implementing LEACH protocol. For gathering data in each round, each node receives data from one neighbor, fuses with its own data, and transmits to the other neighbor on the chain. The idea in nodes dying at random places is to make the sensor network robust to failures. However, one of the major drawbacks of PEGASIS is that it introduces excessive delay for distant node on the chain. Moreover, the single node acting as a leader of the chain can sometimes become a bottleneck.

S. Lindsey et. al. [4] shows that Hierarchical-PEGASIS is an extension to PEGASIS. In Hierarchical PEGASIS, the delay is decreased during transmission from the node to base station. Messages can be sending simultaneously. There are two approaches to avoid collisions and possible signal interference among the sensors. The first one uses CDMA type signal coding techniques. The protocol with nodes having CDMA capability constructs a chain of nodes and forms a tree like hierarchy. Each selected node in a particular level transmits data to the node in the upper level of the hierarchy. This method guarantees that data is transmitted in parallel and reduces the delay significantly. The effects of interference are reduced by carefully scheduling simultaneous transmissions [2].

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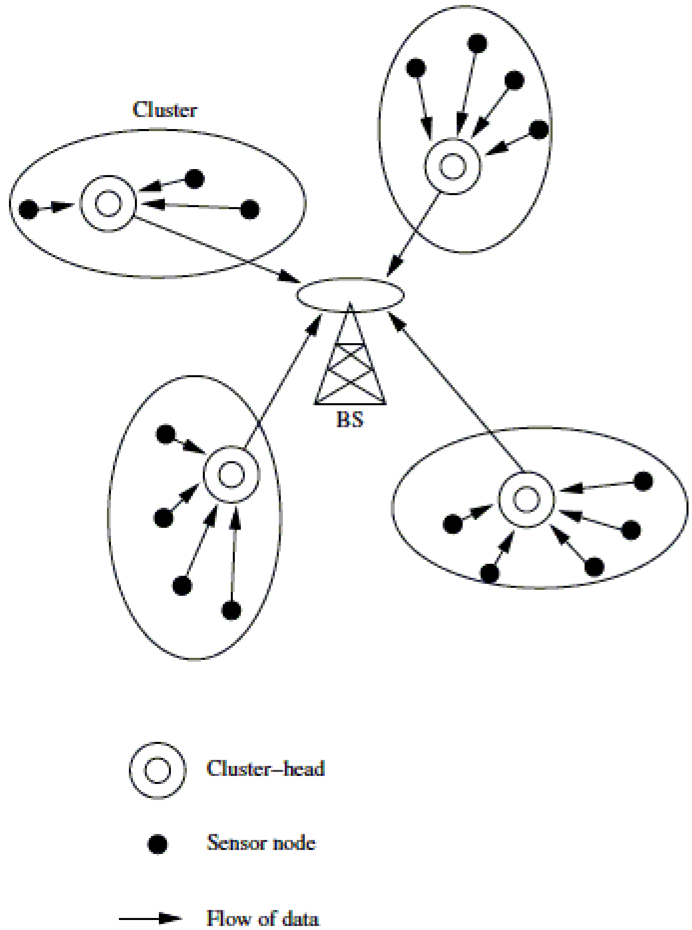

Figure 1: Hierarchical routing in WSN

2.2 Reactive Network Protocols (TEEN and APTEEN)

A. Manjeshwar et. al. [7] presents a new network protocol called TEEN (threshold sensitive energy efficient sensor network protocol). It is targeted at reactive networks and is the first protocol developed for reactive networks. The threshold is of two types. First is Hard Threshold, It is the absolute value of the attribute beyond which, the node sensing this value must switch on its transmitter and report to its cluster head. Another is Soft Threshold, it is a small change in the value of the sensed attribute which triggers the node to switch on its transmitter and transmit. The nodes sense their environment continuously. The nodes will next transmit data in the current cluster period, only when both the following conditions are true:

1) The current reading of the sensed attribute is greater than the hard threshold.
2) The current value of the sensed attribute differs from sensed value. It should be equal to or greater than the soft threshold.

A.Manjeshwar et.al. [5] introduces a new protocol developed for hybrid networks known as Adaptive Periodic Threshold-sensitive Energy Efficient Sensor Network Protocol or APTEEN. In this protocol, once the cluster heads are decided in each period and after that cluster head first broadcasts the following parameters such as Attributes; it is a set of physical parameters which the user is interested in obtaining data about, Thresholds parameter consists of a hard threshold as well as soft threshold. Hard threshold is a particular value of an attribute beyond which a node can be triggered to transmit data and soft threshold is a small change in the value of an attribute which can trigger a node to transmit data again, schedule; a TDMA schedule that is used for assigning a slot to each node and Count Time; It is the maximum time period between two successive reports sent by a node.

2.3 LEACH-C

LEACH-C is a centralized version of LEACH, is proposed in [2-3]. LEACH-C utilizes the base station for cluster formation. During the setup phase of LEACH-C, the sink receives information regarding the location as well as energy level of each wireless sensor node. Using this information, the sink finds a fixed

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number of cluster heads and configures the network into clusters. The cluster groupings are chosen to minimize the energy required for non-cluster-head nodes to transmit their data to their respective cluster heads. Although the other operations of LEACH-C are identical to those of LEACH, results presented in [3] indicate a definite improvement over LEACH. The authors of [3] cite two key reasons for the improvement:
i) The base station utilizes its global knowledge of the network to produce better clusters
ii) The number of cluster heads in each round of LEACH-C equals a predetermined optimal value. The formula for cluster head selection is given in (1).

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

2.4 Base station Controlled Dynamic Clustering Protocol (BCDCP)

S. Ghiasi et. Al. [6] states that in BCDCP, these tasks are accomplished by means of an iterative cluster splitting algorithm. This simple algorithm first splits the network into two sub clusters, and proceeds further by splitting the sub clusters into smaller clusters. The base station repeats the cluster splitting process until the desired number of clusters N_{CH} is attained. The iterative cluster splitting algorithm ensures that the selected cluster heads are uniformly placed throughout the whole sensor field by maximizing the distance between cluster heads in each splitting step. Furthermore, in order to evenly distribute the load on all cluster heads, utilize the balanced clustering technique where each cluster is split so that the resulting sub clusters have approximately the same number of sensor nodes. BCDCP operates in two major phases: *setup* and *data communication*.

(a) Setup phase: Activities involved in this phase are cluster setup, cluster head selection, CH-to-CH routing path formation, and schedule creation for each cluster. The routing paths are selected by first connecting all the cluster head nodes using the minimum spanning tree approach [5] that minimizes the energy consumption for each cluster head, and then randomly choosing one cluster head node to forward the data to the base station. The BCDCP protocol utilizes a time-division multiple accesses (TDMA) scheduling scheme to minimize collisions between sensor nodes trying to transmit data to the cluster head. In general, for a cluster with M nodes, an m-bit schedule creation scheme is used where m represents the smallest integer value greater than or equal to $\log_2 M$.

(b) The Data Communication Phase

The data communication phase consists of following three major activities: data gathering, data fusion and data routing. BCDCP utilizes code-division multiple access (CDMA) codes to counteract this problem. Each cluster is assigned a spreading code that the nodes in the cluster use to distinguish their data transmissions from those of nodes in neighboring clusters. Once the data gathering process is complete, the cluster head uses the same spreading code assigned to the cluster to route data back to the base station.

2.5 Scaling Hierarchical Power Efficient Routing (SHPER)

A hierarchical scheme used in SHPER [9] protocol in a similar way as in other protocols discussed earlier. However, contrary to other non-centralized routing protocols, the election of the cluster heads is not randomized rather it is based on the residual energy of the nodes. Cluster head selection is done by the base station itself. Base station asks each node to send their residual energy initially. And based on the energy of each node and the predefined percentage of cluster heads, base station selects the cluster head. The operation of SHPER protocol may be divided in two phases: *Initialization phase*, and *Steady state phase.*

a) Initialization Phase: Initially, all the nodes switch on their receivers in order to receive TDMA schedule from the base station. The base station broadcasts TDMA schedule, the size of TDMA schedule depends on the number of the nodes in the network, to all the nodes for collecting the global information about the network topology. Table 1 demonstrates the TDMA schedule. According to this schedule each node advertises itself. Each time that a node advertises itself, the other nodes which hear this advertisement realize their relative distance from this node, according to the received signal strength of the advertisement.

Table 1: The schedule creation scheme used in SHPER for a cluster with four nodes

Cluster Head ID	Time Slot1	Time Slot2	Time Slot3
00	01	10	11
01	00	10	11
10	00	01	11
11	00	01	10

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After the completion of node advertisement procedure, the base station selects the nodes as cluster head. The total number of cluster heads is predefined. The base station randomly elects some of the nodes as high level cluster head from which it has received an advertisement reply message and some of the nodes as low level cluster head from which it have not received message. The id's of the new elected cluster heads and the values of the thresholds are broadcasted by the base station. These thresholds used in this protocol are similar to the thresholds as described in TEEN [7] and APTEEN [5]. The non-cluster head nodes decide as to which cluster they want to fit in. This assessment is based on the largest signal strength of the advertisement message heard previously. The signal to noise ratio is compared from various cluster heads surrounding the node. The non cluster-head nodes notify the respective cluster-head about the decision to join the cluster. After each node has decided to which it has to belong, it informs its cluster head that I will be a member of yours cluster. Each cluster head receives all the messages from the nodes that want to be included in its cluster and according to their number, generates a TDMA schedule of corresponding size as described in Table 1.

Steady State phase*:* In this phase, by using the data of the received messages, the base station determines the new cluster heads. More precisely, the node which has the highest residual energy, in each cluster, is chosen as a new cluster head and the process continues again as given in the initialization phase. But in each time, the new hard and soft thresholds are defined.

2.6 Stable Election Protocol (SEP): A percentage of the population of sensor nodes is equipped with more energy resources than the rest of the nodes. Let m be the fraction of the total number of nodes n, which are equipped with α times more energy than the others. We refer to these powerful nodes as advanced nodes, and the rest (1−m)×n as normal nodes. We assume that all nodes are distributed randomly over the sensor field.

Suppose that Eo is the initial energy of each normal sensor. The energy of each advanced node is then Eo* (1+α). The total (initial) energy of the new heterogeneous setting is equal to:

n * Eo * (1 + α * m)

So, the total energy of the system is increased by a factor of 1+α * m.

(i) each normal node becomes a cluster head once every 1 popt · (1+α ·m) rounds per epoch;

(ii) each advanced node becomes a cluster head exactly 1 + α times every 1 popt· (1+α·m) rounds per epoch;

and (iii) the average number of cluster heads per round per epoch is equal to n × popt

Cluster Head Election for normal nodes is based on following equation:

$$T(s_{nrm}) = \begin{cases} \frac{p_{nrm}}{1-p_{nrm}\cdot(r \bmod \frac{1}{p_{nrm}})} & \text{if } s_{nrm} \in G' \\ 0 & \text{otherwise} \end{cases} \quad (3)$$

where r is the current round, G' is the set of normal nodes that have not become cluster heads within the last 1/pnrm rounds of the epoch, and T(snrm) is the threshold applied to a population of n · (1 − m) (normal) nodes. This guarantees that each normal node will become a cluster head exactly once every 1/popt· (1+α·m) rounds per epoch, and that the average number of cluster heads that are normal nodes per round per epoch is equal to n · (1 − m) × pnrm.

Cluster Head Election for advanced nodes is based on following equation:

$$T(s_{adv}) = \begin{cases} \frac{p_{adv}}{1-p_{adv}\cdot(r \bmod \frac{1}{p_{adv}})} & \text{if } s_{adv} \in G'' \\ 0 & \text{otherwise} \end{cases}$$

(4)

where G" is the set of advanced nodes that have not become cluster heads within the last 1 padv rounds of the epoch, and T(sadv) is the threshold applied to a population of n x m (advanced) nodes. This guarantees that each advanced node will become a cluster head exactly once every (1/popt)x((1+α·m)/(1+α)) rounds.

3. ADVANTAGES AND DISADVANTAGES OF HIERARCHICAL ARCHITECTURE [10]

Advantages of hierarchical structure are following:

i) Data Aggregation: With all the messages for a cluster going through a central location, the cluster head is able to perform data aggregation on the information before sending the data to the sink.

ii) Localized Power Consumption: The power consumed in a cluster is less than in a whole network, as there is a smaller amount of overhead when setting up the network. Only a small portion of the network (a cluster) is set up, pointing to a cluster head. Once this has been done, all messages travel a smaller number of hops to reach the cluster head, thereby saving on their available energy resources.

Disadvantages of hierarchical structure are following:

i) Hotspots: Cluster heads perform more functions that the average sensor node and this consumes their energy at a greater rate. To alleviate this problem, some protocols rotate the cluster head amongst all the nodes in the cluster or network. The possiblity of a section getting seperated from the network still exists.

ii) Hardware Requirements: Some protocols require specific hardware, usually a high power transmitter that is capable of reaching the sink node directly. As soon as this happens, the clusterhead position can no longer be rotated amongst the other nodes, unless of course all the nodes have this facility. As with all features, the cost of the development and production of the nodes will increase.

4. CONCLUSION

WSNs differ from traditional wireless communication networks in several of their characteristics. One of them is power awareness, due to the fact that the batteries of sensor nodes have a restricted lifetime and are difficult to be replaced. Therefore, all protocols must be designed in such a way as to minimize energy consumption and preserve the longevity of the network. That is why, routing protocols in WSNs aim mainly to accomplish power conservation while in traditional networks they focus primarily on the Quality of Service (QoS). In this paper, we have surveyed hierarchical routing protocols in wireless sensor network. From the above study we can conclude that there are many routing protocols and you can any one of them for your network based on the application. The heterogeneous structure such as SEP will enhance network lifetime as compared to other hierarchical routing. In future, we will propose a routing protocol based on the heterogeneous architecture of wireless sensor network.

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