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A Survey on Hierarchical Routing Protocols to Optimize Network Lifetime for WSN's

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Abstract: *During the creation of network topology in wireless sensor network, the process of creation of routes is usually influenced by energy considerations. Because the energy consumption of a wireless link is proportional to square or even higher order of the distance between the sender and the receiver, multi-hop routing is assumed to use less energy than direct communication. However, multi-hop routing introduces significant overhead to maintain the network topology and medium access control. In the case that all the sensor nodes are close enough to the BS, direct communication could be the best choice for routing since it reduces network overhead and have a very simple nature. But in most cases, sensor nodes are randomly scattered so multi-hop routing is not possible. In this paper, we have studied different types of hierarchical routing protocols for wireless sensor networks.*

1. INTRODUCTION

A wireless sensor network may consist of hundreds or up to thousands of sensor nodes and can be spread out as a mass or placed out one by one. The sensor nodes collaborate with each other over a wireless media to establish a sensing network, i.e. a wireless sensor network as shown in figure 1. Because of the potentially large scale of the wireless sensor networks, each individual sensor node must be small and of low cost [7-11]. The availability of low cost sensor nodes has resulted in the development of many other potential application areas, e.g. to monitor large or hostile fields, forests, houses, lakes, oceans, and processes in industries. The sensor network can provide access to information by collecting, processing, analyzing and distributing data from the environment. Many Routing protocols are existent in the wireless sensor network. Depending on how the sender of a message gains a route to the receiver, routing protocols can be classified into three categories, namely, proactive [1], reactive [2], and hybrid protocols [3]. In proactive protocols, all routes are computed before they are really needed, while in reactive protocols, routes are computed on demand. Hybrid protocols use a combination of these two ideas. Since sensor nodes are resource poor, and the number of nodes in the network could be very large, sensor nodes cannot afford the storage space for "huge" routing tables. Therefore reactive and hybrid routing protocols are attractive in sensor networks [11]. In many application areas the wireless sensor network must be able to operate for long periods of time, and the energy consumption of both individual sensor nodes and the sensor network as a whole is of primary importance. Thus energy consumption is an important issue for wireless sensor networks.

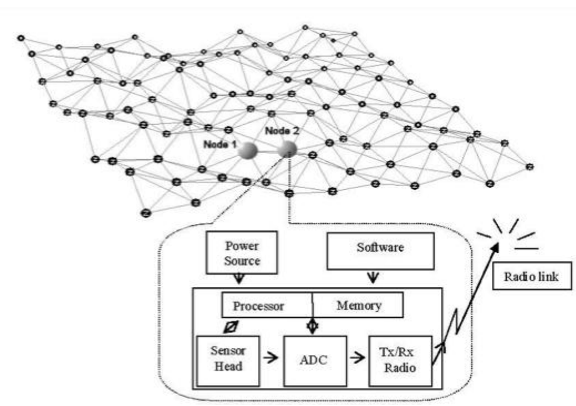

Figure 1: Node architecture in a Wireless Sensor Network

2. HIERARCHICAL ROUTING

In centralized routing, the base station is responsible for formation of cluster head.

2.1 PEGASIS and Hierarchical PEGASIS:

In PEGASIS [2] each sensor node forms a pattern so that each node will receive from and transmit to a close 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. PEGASIS outdoes LEACH'S performance by (1) purging the over head of dynamic cluster formation, (2) decreasing the distance non leader-nodes must transmit, (3) reducing the number of transmissions among all nodes, and (4) using only one transmission to the base station per round. Principal goals in the operation PEGASIS are (a) augment the lifetime of each sensor node by using collaborative techniques (b) reducing the bandwidth of communication by allowing the local coordination among neighboring sensor nodes. 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. Note that node *I* will be in some random position *j* on the chain. Nodes take turns transmitting to the BS, and the author has used node number *I (mod N)* (where N represents the number of nodes) to transmit to the BS in round *i*. Thus, the leader in each round of communication will be at a random position on the chain, which is important for nodes to die at random locations. The idea in nodes dying at random places is to make the sensor network robust to failures. In a given round, the author is using a simple control token passing approach initiated by the leader to start the data transmission from the ends of the chain. The cost is very small since the token size is very small. Node N_2 is the leader, and it will pass the token along the chain to node N_0. Node N_0 will pass its data towards node N_2. After node N_2 receives data from node N_1, it will pass the token to node N_4, and node N_4will pass its data towards node N_2.PEGASIS performs data fusion at every node except the end nodes in the chain. Each node will fuses its neighbor's data with its own to generate a single packet of the same length and then transmit that to its other neighbor (if it has two neighbors). Node N_0will pass its data to node N_1. Node N_1fuses node N_0*'s* data with its own and then transmits to the leader N_2. After node N_2passes the token to node N_4, node N_4 transmits its data to node N_3. Node N_3fuses node N_4*'s* data with its own and then transmits to the leader. Node N_2waits to receive data from both neighbors and then fuses its data with its neighbors' data. Finally, node N_2 transmits one message to the SINK. 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.

Hierarchical-PEGASIS [2] is an extension to PEGASIS, which decreases the delay during transmission from the designated node to the sink. In order to improve the performance by reducing the delay in PEGASIS, messages are transmitted 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. Since the tree constructed in this manner is balanced, the delay will be in *O (log N)* where *N* is the number of nodes. Node N_3 is the designated leader for round 3. Since, node N_3 is in position 3 (Counting from 0) on the chain, all nodes in an even position will send to their right neighbor. Nodes that are receiving at each level rise to next level in the hierarchy. Now at the next level, node N_3 is still in an odd position (1). Again all nodes in an even position will aggregate its data with its received data and send to their right. At the third level, node N_3 is not in an odd position, so node N_7 will aggregate its data and transmit to N_3. Finally, node N3 will combine its current data with that received from N_7 and transmit the message to the sink. The other approach (non-CDMA based) is quite different and allows only spatially separated nodes to transmit at the same time. Using this approach, a three-level hierarchy of the nodes is created first. The effects of interference are reduced by carefully scheduling simultaneous transmissions [2].

2.2 Reactive Network Protocol: TEEN:

In this section, we present a new network protocol called TEEN (Threshold sensitive Energy Efficient sensor Network protocol)[4]. It is targeted at reactive networks and is the first protocol developed for reactive networks, to our knowledge Functioning. In this scheme, at every cluster change time, in addition to the attributes, the cluster-head broadcasts to its members,

Hard Threshold (HT): This is a threshold value for the sensed attribute. 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. Soft Threshold (ST): This 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 first time a parameter from the attribute set reaches its hard threshold value, the node switches on its transmitter and sends the sensed data. The sensed value is stored in an internal variable in the node, called the sensed value (SV). The nodes will next transmit data in the current cluster period, only when both the following conditions are true:

1) The current value of the sensed attribute is greater than the hard threshold.
2) The current value of the sensed attribute differs from SV by an amount equal to or greater than the soft threshold. Whenever a node transmits data, SV is set equal to the current value of the sensed attribute.

Thus, the hard threshold tries to reduce the number of transmissions by allowing the nodes to transmit only when the sensed attribute is in the range of interest. The soft threshold further reduces the number of transmissions by eliminating all the transmissions

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which might have otherwise occurred when there is little or no change in the sensed attribute once the hard threshold [4].

2.3 LEACH-C

A centralized version of LEACH, LEACH-C, is proposed in [5]. Unlike LEACH, where nodes self-configure themselves into clusters, LEACH-C utilizes the base station for cluster formation. During the setup phase of LEACH-C, the base station receives information regarding the location and energy level of each node in the network. Using this information, the base station finds a predetermined 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 [5] indicate a definite improvement over LEACH. The authors of [5] cite two key reasons for the improvement:

• The base station utilizes its global knowledge of the network to produce better clusters that require less energy for data transmission.

• The number of cluster heads in each round of LEACH-C equals a predetermined optimal value, whereas for LEACH the number of cluster heads varies from round to round due to the lack of global coordination among nodes.

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

2.4 Base station Controlled Dynamic Clustering Protocol (BCDCP)

A centralized routing protocol called Base-Station Controlled Dynamic Clustering Protocol (BCDCP), which distributes the energy dissipation evenly among all sensor nodes to improve network lifetime and average energy savings. This protocol utilizes a high-energy base station to set up clusters and routing paths, perform randomized rotation of cluster heads, and carry out other energy-intensive tasks. The key ideas in BCDCP are the formation of balanced clusters where each cluster head serves an approximately equal number of member nodes to avoid cluster head overload, uniform placement of cluster heads throughout the whole sensor field, and utilization of cluster-head-to- cluster head (CH-to-CH) routing to transfer the data to the base station [6].

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. During each setup phase, the base station receives energy level from all the sensor nodes in the network. Based on this information, base station computes the average energy level for all the nodes and then chooses a set of nodes, denoted S, whose energy levels are above the average value. Cluster heads for the current round will be chosen from the set S, which ensures that only nodes with sufficient energy get selected as cluster heads, while those with low energy can prolong their lifetime by performing tasks that require low energy costs. The next major tasks for the base station are:

• To identify NCH cluster head nodes from the chosen set (i.e., {cluster head nodes} €S).

• To group the other nodes into clusters such that the overall energy consumption during the data communication phase is minimized.

Furthermore, in order to evenly distribute the load on all cluster heads, utilize the balanced clustering technique [6] where each cluster is split so that the resulting sub clusters have approximately the same number of sensor nodes. Accordingly, a single iteration of the cluster splitting algorithm consists of the following four steps:

• **Step 1**: From the set S which contains all the nodes that are eligible to become cluster heads, choose two nodes, S1 and S2, which have the maximum separation distance.

• **Step 2**: Group each of the remaining nodes in the current cluster with either S1 or S2, whichever is closest.

• **Step 3**: Balance the two groups so that they have approximately the same number of nodes; this forms the two sub clusters.

• **Step 4**: Split S into smaller sets S1 and S2 according to the sub cluster groupings performed in step 3.

The second major activity within the setup phase is the formation of routing paths. As discussed earlier, the BCDCP protocol uses a CH-to- CH multihop routing scheme to transfer the sensed data to the base station. Once the clusters and the cluster head nodes have been identified, the base station chooses the lowest-energy routing path and forwards this info to the sensor nodes along with the details on cluster groupings and selected cluster heads. 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

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the smallest integer value greater than or equal to $\log_2 M$.

(b) The Data Communication Phase

The data communication phase consists of three major activities:

- Data gathering
- Data fusion
- Data routing

Using the TDMA schedule, each sensor node transmits the sensed information to its cluster head. Since sensor nodes are geographically grouped into clusters, these transmissions consume minimal energy due to small spatial separations between the cluster head and the sensing nodes. Once data from all sensor nodes have been received, the cluster head performs data fusion on the collected data, and reduces the amount of raw data that needs to be sent to the base station. The compressed data, along with the information required by the base station to properly identify and decode the cluster data, are then routed back to the base station via the CH-to-CH routing path created by the base station. Besides, we also assume that the fused data from a given cluster head undergoes further processing as it hops along the CH-to-CH routing path. Another key issue that needs to be addressed here is the radio interference caused by neighboring clusters that could hinder the operation of any given cluster [6]. 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

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 and APTEEN. 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. In order to be able to indirectly route its messages to the base station, each lower level cluster head selects the upper level cluster node that it is going to belong to, in order to be able to indirectly route its messages to the base station. This selection is based on the discovery of the path $r=(c_1,c_2,\ldots,c_n)$, between the source cluster head c_1 and the base station c_n that spans $n\text{-}2$ intermediate cluster head nodes $c_2,\ldots,c_{n-1}$, for which the Routing Index $RI(r)$ shown in equation (2), is the maximum :

$$RI(r)=\sum_{i=2}^{n-1}E_r-\sum(C_i,C_{i+1}) \qquad (2)$$

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.Each cluster head sends transmission schedule (TDMA) to the nodes that are under its cluster that when to transmit data in order to avoid collision. Each node, during its allocated transmission time, sends to the cluster head quantitative data concerning the sensed

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events and using the hard and soft threshold values. Along with the data concerning the sensed attributes the node transmits the current value of its residual energy. The radio of each non cluster head node can be turned off until the node's allocated transmission time comes, thus minimizing energy dissipation in these nodes. In this way, each cluster head receives the data from its cluster nodes. Each cluster head aggregates the data it has received along with its own data and makes composite message. This composite message contains the id of the node which has highest residual energy among the cluster nodes, along with the most excessive (e.g. maximum) value of the sensed variable and the id of the corresponding node that has sensed it. Then, during its own time slot, each cluster head transmit its composite message to the base station either directly or indirectly via intermediate upper level cluster heads following the path suggested by the index calculation given in formula 2. The base station collects all the messages that are transmitted to it.

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:

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

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. These 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:

$$T(s_{adv}) = \begin{cases} \frac{p_{adv}}{1-p_{adv}\cdot(r \ mod \ \frac{1}{p_{adv}})} & \text{if } s_{adv} \in G'' \\ 0 & \text{otherwise} \end{cases} \qquad (4)$$

where G" is the set of advanced nodes that have not become cluster heads within the last 1padv 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

3.1 Advantages of a Hierarchical Architecture [10]

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.

***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.

3.2 Disadvantages of a Hierarchical Architecture

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.

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.

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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 basic advantage of hierarchical routing is that, it will balance the energy consumption in the network by rotating cluster head. Hierarchical routing also optimizes energy consumption by aggregating the data.

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