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A Survey on Centralized and Hierarchical Routing Protocols for Wireless Sensor Networks

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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 are studying different types of centralized and hierarchical protocols like SHPER, BCDCP and LEACH for wireless sensor networks. Also, we have proposed a new protocol which will use advantages of each of these protocols.*

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. 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.

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.

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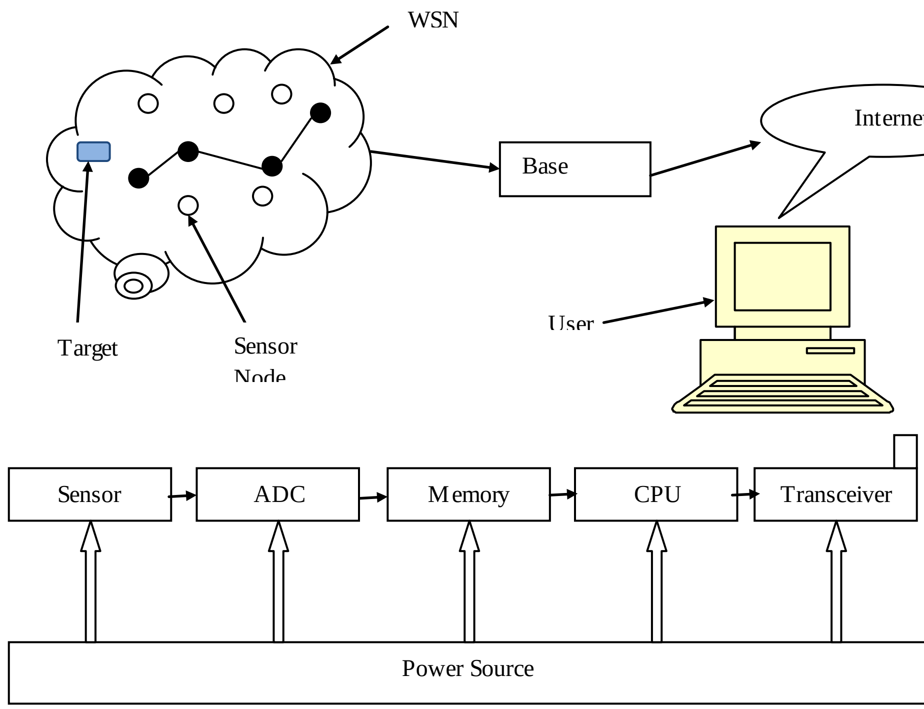

Figure 1: Wireless Sensor Network

2. CENTRALIZED HIERARCHICAL ROUTING

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

i) 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.

ii) 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

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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.

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.

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 [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 random choice of the cluster head that transmits to the base station is justified since data transmission to the base station is an energy-intensive task, and utilizing the cluster head closest to the base station to frequently perform this task will render heavy depletion of energy resources for the nodes closer to the base station. Thus, by randomizing the cluster head transmissions to the base station, BCDCP distributes the burden of routing evenly among all cluster heads. Schedule creation is the last major issue related to the setup phase. 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 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

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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.

iii) 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*.

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

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

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 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.

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

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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.

b) 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.

3. ADVANTAGES AND DISADVANTAGES

Advantages of a Hierarchical Architecture

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

Disadvantages of a Hierarchical Architecture

reach the cluster head, thereby saving on their available energy resources.

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. Two types of routing architectures can be viewed in Table 2.

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.

ISSN 2320-6802

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Table 2: Comparison between Hierarchical and Flat Routing[10]

Hierarchical routing	**Flat routing**
Reservation-based scheduling	Contention-based scheduling
Collisions avoided	Collision overhead present
Reduced duty cycle due to periodic sleeping	Variable duty cycle by controlling sleep time of nodes
Data aggregation by cluster head	Nodes on multi hop path aggregates incoming data from neighbors
Simple but not-optimal routing	Routing can be made optimal but with an added complexity
Requires global and local synchronization	Requires global and local synchronization
Overhead of cluster formation throughout the network	Routes formed only in regions that have data for transmission
Lower latency as multiple hop network formed by cluster heads always available	Latency in waking up intermediate nodes and setting up the multipath
Energy dissipation is uniform	Energy dissipation depends on traffic patterns
Energy dissipation cannot be controlled	Energy dissipation adapts to traffic patterns
Fair channel allocation	Fairness not guaranteed
Overhead of cluster formation throughout the network	Routes formed only in regions that have data for transmission
Lower latency as multiple hop network formed by cluster heads always available	Latency in waking up intermediate nodes and setting up the multipath

Energy dissipation is uniform	Energy dissipation depends on traffic patterns
Energy dissipation cannot be controlled	Energy dissipation adapts to traffic patterns
Fair channel allocation	Fairness not guaranteed

4. PROPOSED METHODOLOGY

Step 1: Initially, base station deploys the nodes in Network area with constant energy E.
Step 2: Base Station sends a START message to all the nodes in the sensor field, to acquire information about their routing table.
Step 2: After receiving the "START" message, each node broadcasts the hello message "HELLO". Each node receiving hello message "HELLO" sends "REPLY" message containing its ID. When a node gets reply, it will note down the ID of the node from where the reply has been acknowledged. In this way each node will have their individual routing table.
Step 3: After receiving the information about their neighbors the nodes, for which the base station is within their range, sends a STATUS message to the base station. This STATUS includes ID, routing table, and Energy of the node. Base station sends an acknowledge (ACK) to all sending nodes.
Step 4: After acquiring acknowledge ACK, the nodes declare itself as parent node and broadcast to all its neighboring nodes.
Step5: the node receiving the parent node's message will check their status whether it is parent node or not, if it is not a parent node then it will become a child node of the parent, from where it has received the parent node message first.
Step6: parent nodes send the STATUS to its grand-parent or direct to Base Station.
Step7: The nodes which are directly sending the STATUS to Base Station, becomes the Cluster Head for the current round. Steps 5-7are repeated until single node is alive.
Step8: For second round the nodes directly communication with Base Station and having max. Energy becomes the Cluster Head.
STEP9: Cluster Head will receive data from nodes that comes in its cluster area.
Step10: After collecting data, Cluster Head sends the aggregated data to the Base Station.
Steps 9-10 are repeated until system is alive.
Each node, during its allocated transmission time, sends to the cluster head quantitative data concerning the sensed events. Each cluster head receives the data from its cluster nodes. The base station collects all the messages transmitted to it.

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