

Energy-Efficient Routing Protocol in Wireless Sensor Network

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Abstract - Routing in Wireless Sensor Network (WSN) is an important area of research due to its rapidly increasing application in monitoring various kinds of environment by sensing physical phenomenon. Energy consumption is one of the major criteria for most of the routing protocols because 70% of the total energy is consumed in data transmission in WSN. This paper introduces an energy efficient clustering algorithm for WSN based on Low Energy Adaptive Clustering Hierarchy (LEACH) which will remove some of the drawbacks of LEACH. It utilizes the remaining energy of the current Cluster Head (CH) to make the routing process more efficient. Another level of aggregation is added which not only saves energy by eliminating redundancy and reducing number of data transmission but also distribute the work load evenly by utilizing the energy of the least overloaded CHs.

Keywords - Data Aggregation, Energy-efficient, Global Aggregator, Local Aggregator, Remaining energy, Wireless Sensor Network, Zone.

1 INTRODUCTION

Recent advancement in wireless communication and electronics has enabled the development of low cost, low power multifunctional miniature devices for use in remote sensing application. Such sensors can be widely deployed for commercial, civil and military applications such as surveillance, vehicle tracking, climate and habitat monitoring intelligence, medical and acoustic data gathering. WSN is composed of a large number of sensor nodes which consist of sensing, data processing and communication capabilities. Usually sensor nodes are scattered in the sensing field. They coordinate among themselves to get information about the physical environment. The information is routed to the Base Station (BS) either directly or through other sensor nodes. The BS is either fixed or mobile node which is capable to connect the network to the internet where user can access and process the data. Routing in WSN is very challenging due to the inherent characteristics that distinguish this network from other wireless networks or cellular networks. The most important constraint on WSN is the limited battery power or sensor nodes. Limited computational power and memory size is another constraint (that affects the amount of data that can be stored in individual nodes). Second, sensor nodes are randomly deployed over a region without any infrastructure and prior knowledge of topology. So it is upto the node to identify its connectivity. Third, the routing protocol must be fault tolerant. If some sensor nodes fail the protocol must accommodate itself accordingly. Fourth, it must be scalable enough to respond and operate with large number of sensors. Fifth, some real time sensor application is very time critical. So data should be delivered

within a certain period of time otherwise this will become useless. Considering these challenges many routing protocol have been already proposed for WSN. They can be classified into flat, hierarchical, location-based network routing protocol[1]. In Flat routing all nodes are typically assigned equal roles or functionality. SPIN [2] (Sensor Protocol for Information via Negotiation) and DD [3] (Directed Diffusion) fall in this category. In Hierarchical routing the network is divided into clusters to achieve efficiency. LEACH [4], TEEN, APTEEN are well known hierarchical protocols. In Location-based routing actual position of a node is used to find the optimal routing path. GAF[5] (Geographic Adaptive Fidelity) and GEAR[6] (Geographic and Energy-Aware Routing) are example of this protocol.

In addition to the above the routing protocols can be classified into 3 categories namely proactive, reactive and hybrid protocols [9] depending on how the source finds a route to the destination. In proactive all routes are computed before they are really needed, while in reactive protocols route are computed on demand. Hybrid protocols use a combination of these two ideas.

In sensor network energy is mainly consumed for three purposes - data transmission, signal processing and hardware operation. It is said that 70% of the energy [9] is consumed in data transmission only. So to maximize the network lifetime data transmission is optimized by using energy-efficient routing protocols. As the energy required is proportional to the square of the distance between the communicating parties multi-hop routing needs less energy in compare to direct communication. But maintenance of the network topology is an extra overhead in multi-hop

routing. So if sensor nodes are close enough to the BS direct communication is the best choice due to its simplicity and less overhead. But in most cases sensor nodes are randomly scattered. So multi-hop routing cannot be avoided.

The main objective of the paper is to propose an energy-efficient hierarchical routing protocol which will eliminate redundant data transmission, utilize resource more efficiently thereby increasing the lifetime of the WSN.

The rest of the paper is organized as follows: section 2 gives an overview of clustering protocol LEACH. Section 3 describes the proposed protocol and finally conclusion is drawn in section 4 with the scope of future research.

2 RELATED WORK

In WSN hierarchical structure of sensor nodes are formed by clustering method. This method increase the lifetime of network by efficient use of energy. Within a cluster, data aggregation and fusion are performed at CH to reduce the amount of data transmitting to the BS. Clusters are formed based on the remaining energy of sensor nodes and their proximity to the CH. Members of each cluster transmits data to the corresponding CH. The CH forwards these data along with its own data to the BS after performing data aggregation and fusion. LEACH is one of the first hierarchical routing protocols for WSN.

A LEACH

The main idea of LEACH (Low Energy Adaptive Clustering Hierarchy) is to form clusters of sensor nodes based on the received signal strength and use local CHs as routers to the BS. In the cluster formation phase, each sensor node generates a random number between 0 and 1. The node becomes the CH for the current round if the number is less than following threshold:

$$T(n) = \frac{p}{1 - p \left(r \bmod \frac{1}{p} \right)} \text{ if } n \in G$$

Where p is the desired percentage of CHs (e.g. 0.05), r is the current round and G is the set of nodes that have not been cluster heads in the last 1/p rounds.

After the cluster formation CH asks its members to send data based on a TDMA schedule. In steady phase CH will aggregate and send the data to the sink. Periodic reclustering is done to alleviate the deterioration of cluster quality.

LEACH is completely distributed and requires no global knowledge of the network.

The remaining energy of the CHs is not considered by LEACH and it assumes uniform energy consumption for CHs which is not realistic. Let us consider a scenario[7] in which most of the sensor nodes are grouped together around one or two cluster-heads. It is shown that cluster-heads A and B have more nodes close to them than the other cluster-heads. LEACH's cluster formation algorithm will end up by assigning more cluster member nodes to both A and B. This could make cluster head nodes A and B quickly running out of energy.

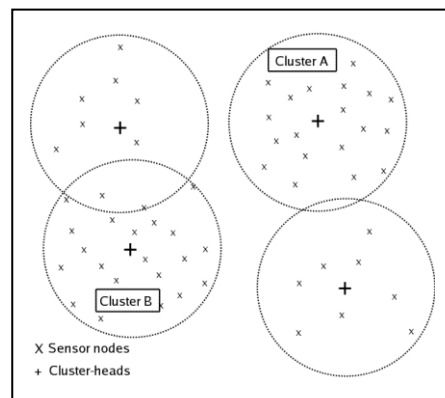


Fig. 1. A Sensor Network

B LEACH-C

LEACH – Centralized[4] is identical to the LEACH protocol as far as forming clusters at the beginning of each round. However, instead of nodes randomly self-selecting as a CH, a centralized algorithm is executed by the BS in LEACH-C. The BS collects the location information and remaining energy levels from the nodes and then broadcasts them its decision about which nodes will become the CHs for that round.

The overall performance of LEACH-C[8] is better than LEACH since it moves the responsibility of cluster formation to the BS.

However, LEACH-C is sensitive to the sink location. Once the energy consumed for communicating with the BS becomes higher than the energy consumed for cluster formation, LEACH-C no longer provides good performance. BS may be located far from the network in most WSN application so the dependence on the BS location is a major disadvantage of LEACH-C.

C DSC

DSC[8] (Dynamic /Static Clustering) protocol is an extension of LEACH-C. In this scheme each node gets its content location using a Global Positioning System (GPS) and sends the location information and energy status to the sink. The sink will then determine the number of CHs based on the collected information and broadcasts the clustering result to each node. Each CH will determine a TDMA schedule for its cluster members similar to LEACH. Compared with LEACH-C the number of messages received at the BS for DSC is significantly reduced. However, it suffers from similar problems that LEACH-C has.

The proposed algorithm Z-LEACH added some features to LEACH to solve the above mentioned drawbacks of this routing protocol.

3 Z-LEACH

The proposed algorithm adds some features that LEACH does not consider such as:

1. Use the remaining energy of the present CH to select the next CH.
2. Use the least overloaded cluster head to add another level of aggregation.

The assumptions used to facilitate the design of the proposed clustering protocol are:

Assumption 1: All the sensor nodes are static and homogeneous in physical characteristics i.e. having identical sensing, computing and communicating ability. Initial battery powers of the nodes are identical at deployment.

Assumption 2: The current CHs will not drain out completely during next CH selection process.

Assumption 3: All nodes can transmit with enough power to reach the BS if needed. So the algorithm is not applicable to networks deployed in large region.

Assumption 4: Sensor nodes always have some data to send and nodes located close to each other have correlated data.

Working of the protocol:

Like LEACH initially some sensor nodes will be selected as the CHs by the BS and accordingly clusters will be formed. Since the CH directly communicates with the BS so it runs out of energy sooner than the other members of the cluster. To maximize the network lifetime periodic cluster head rotation and reclustering are performed.

A. CH Rotation:

Unlike LEACH the CH rotation follows a little different approach as described below:

- The current CH will decide who will be the next CH depending on the remaining energy of the sensor nodes in its cluster.
- All the sensor nodes will send its current energy level along with the data to the CH after certain time interval.
- From this information the current CH will select the sensor node having maximum remaining energy as the new CH.
- The new CH broadcasts its status. Changes in cluster can occur. Some nodes may join this cluster as they come closer to this new CH. On the other hand a few sensor nodes may move to other cluster if the CH of that cluster comes closer to them.
- After this the new CH will broadcast the TDMA schedule to all the members and each member will send data in its own slot.

In this way the remaining energy of the current CH is utilized (to find the next CH) which would have been wasted otherwise. It also eliminates the process of CH selection by the BS which causes poor energy utilization.

B. Zone Formation and Selection of GA:

In LEACH all the cluster members send data to their corresponding CH which will perform aggregation and forward the data directly to the base station. This approach certainly minimizes the redundancy but does not eliminate it.

In some applications like environment monitoring the CHs located nearby will get almost similar data. So they transmit redundant information to the base station which not only wastes bandwidth but also decreases the network lifetime by poor utilization of energy.

The proposed algorithm suggests the use of Global Aggregator (GA) along with the Local Aggregators i.e. the CHs. Instead of directly forwarding data to the BS, the CHs will send data to the GA of the particular **zone** to which it belongs.

A zone is a group of clusters located nearby. The clusters are not homogenous i.e. number of nodes in each cluster may vary. The CH of a cluster which has minimum number of members is selected as the GA since it is not as loaded as the other CHs in its zone. So its energy can be better utilized in this process. All the GAs will aggregate the data obtained from the LAs and then forward it to the BS. So by adding another level of aggregation the process eliminates redundant information, at the same time it saves energy since instead of all the CHs only the GAs will now directly communicate with the BS.

C. Process of Zone formation:

Initially the CHs are selected by the BS. After that clusters are formed. During this all the CHs will broadcast message to communicate among themselves. Depending on the signal strength a CH will be able to identify its neighbours. The CH with its 4 to 5 neighbours will form a zone of clusters. After the formation of zone, head of each zone which is also called Global Aggregator will be selected by the following algorithm which will be executed by all the CHs:

Step 1: If the number of nodes in the cluster is less than a specified threshold then broadcast message M to other CHs in that zone and goto step 2 otherwise exit.

Step 2: Wait for a particular time interval.

Step 3: If no message is obtained from other CHs then announce itself as the GA and return otherwise goto step 4.

Step 4: Compare the remaining energy of itself and that of the sender of the received message.

Step 5: If its remaining energy is greater than that of the sender of the received message then announce itself as the GA and return.

Step 6: If after a certain interval of time GA is not found (in case when number of nodes in no cluster is less than the specified threshold) then the cluster-head having maximum remaining energy and minimum number of nodes will be elected as the Global Aggregator.

Due to dynamic clustering the CHs and even the clusters change periodically for better utilization of energy. Consequently the zone may also change and like the CH rotation the GAs also have to be changed periodically since they will drain out of energy after some time due to their direct communication with the BS. The above algorithm will be executed by all the new CHs for finding the new GA of their zone.

It may be seemed that the process of zone creation, GA selection and their dynamic rotation add extra overhead to the routing process. But all these process require communication among the sensor nodes whose distance is less compare to the distance between the sensor node and the BS. The extra processing performed by the CHs and the GAs will not create much burden since processing does not consume much energy whereas much more energy consumption is saved due to this processing.

The whole process can be summarized into two basic phases : Set-up Phase and Steady-state Phase.

Set-up Phase:

1. Initially Cluster-heads are selected as in LEACH.
2. After cluster formation each CH will broadcast a short message containing its ID (spreading code, as discussed in LEACH) to find its neighbors.
3. Each cluster-head will receive such message from other cluster heads. Depending on the signal strength each cluster-head will find its two neighbors (assuming each zone contains 3 clusters).
4. Now within each zone one of the cluster-heads will be chosen as the global aggregator by the algorithm described above.
5. The selected global aggregator will create a TDMA schedule defining the time slot for each cluster-head in its zone and forward it to them.

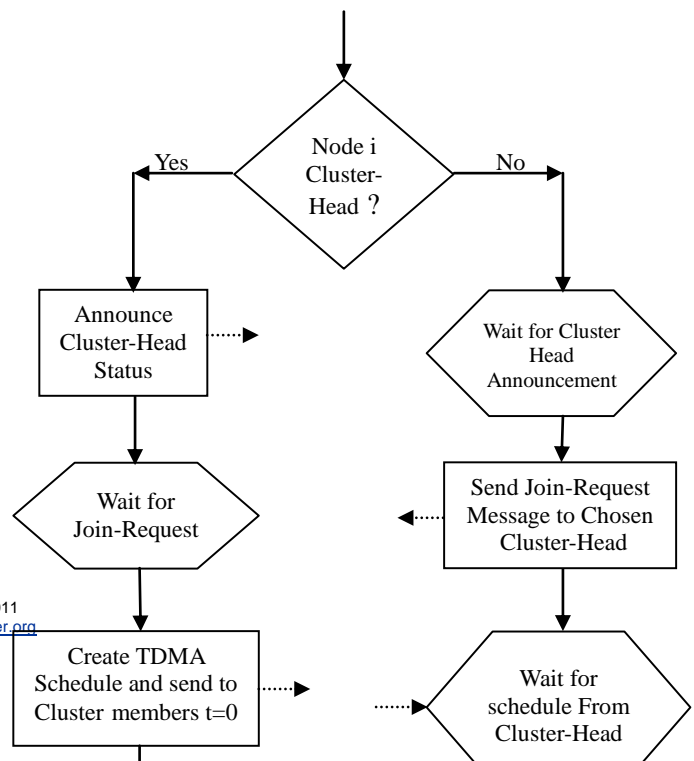


Figure: Flow-graph of the distributed cluster formation algorithm

Steady-state Phase:

1. Like LEACH all the cluster members will send data to their corresponding cluster-heads.
2. Unlike LEACH after aggregation cluster-heads send the result to the global aggregator of the zone to which it belongs.
3. The global aggregator will again aggregate the data and forward the result to the base station.

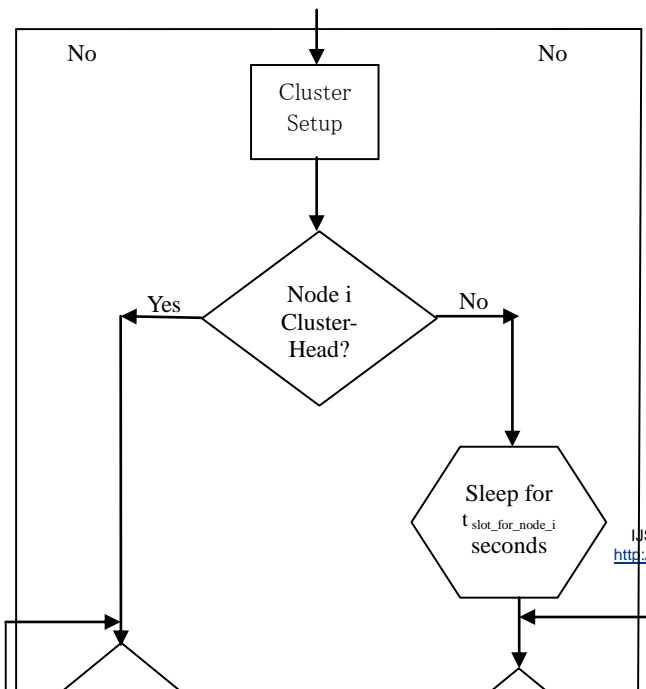


Figure 3-7: Flow-graph of the steady-state operation

4 CONCLUSION & FUTURE WORK

Unlike LEACH where all the CHs directly communicate with the BS, in this algorithm only the GAs directly communicate with the BS. The GA will act as the representative of its zone and it reduces communication with the BS almost by 5 times because instead of 5 separate communication by all the CHs belonging to that zone only one communication by the GA takes place. As data transmission consumes 70% of the total energy[9] and energy consumption is proportional to the square (or even higher) of the distance between the communicating parties so a huge amount of energy is saved due to this second level of aggregation. Moreover the GA will utilize the energy of the least loaded CHs which was previously wastage in LEACH. So the overall energy utilization is better in this proposed algorithm in compare to LEACH.

The concept of GA can be used only if the CHs located nearby have similar type of data to transmit. Otherwise it will not work. There is an extra overhead associated with

dynamic clustering and zone formation and selection of CH and GA. Moreover the threshold used in GA selection algorithm should be chosen properly otherwise it can lead to improper GA selection.

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