Clustering Based Routing Protocols for Wireless Sensor Networks: A Survey

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Abstract- Due to the wide range of application of Wireless Sensor Networks (WSN)[1] the past few years have witnessed the potential use of it and also become a hot research area now a days. One the main degradation of WSN is that sensor nodes are battery powered and deployed in harsh environment so it is not possible to recharge or replace the batteries all the time the node fails or dead. WSN are used in various applications like environment monitoring, health care, military, industrial control units and in various other environments. Routing protocols developed for various other adhoc networks such as MANET, VANET etc can't apply directly in WSN due to energy constrains of nodes. It is proved that sensor nodes require much energy to transmit data rather than sensing thus routing protocol developed for WSN should be efficient so that the network lifetime can be prolonged. In this paper, a survey on various Clustering routing protocols has been done indicating their merits and de-merits.

Index Terms- Wireless sensor networks, Hierarchical, Routing, LEACH.

I. INTRODUCTION

Due to recent technological advancement and availability of low cost sensors made WSN an affordable one. Sensors are tiny devices that Sense physical quantities and convert them in to electrical signals. The word wireless denotes that the communication takes place through a wireless medium were as network signifies that these sensors can communicate among themselves. Thus a WSN consist of hundreds of sensor nodes that can sense data and communicate among them or to the sink (external base station). **Figure1** [3] shows the structural view of a sensor network. It mainly consists of four components:

- Sensor Unit
- Central Processing Unit (CPU)
- Power Unit
- Communication Unit

All are assigned with different tasks. The sensor unit consists of sensor and an Analog to Digital Converter (ADC), the sensor unit sense the data and returns the sensed analog data to ADC which is been converted into digital data and informs the CPU what data is been sensed. Communication unit receives the sensed data and transmit the data to rest of the sensors in the network. CPU controls the power, process, compute next hop to the sink, etc. Power unit's main task is to supply power to sensor unit, processing unit and communication unit. Each node may consist of two optional components namely Location finding system and Mobilizer.

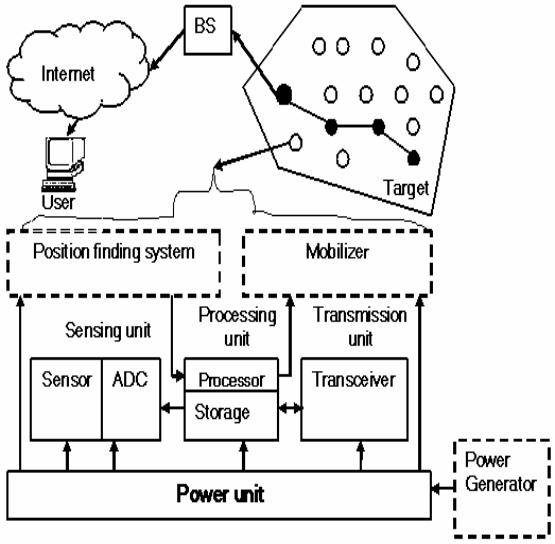

Figure 1: Structural view of sensor network [3]

Routing protocols for WSNs can be classified [4] mainly into two categories depending on the Network Structure:

- Flat Routing Protocol
- Clustering/Hierarchical Routing Protocol

Flat routing is effective only to small-scale networks and not suitable for large-scale networks. On the other hand in Clustering routing protocol nodes are in cluster formations. Each cluster consists of two types of node:

Cluster Head: Every cluster would have a leader, often referred to as the Cluster Head (CH). CH is just one of the sensor with richer resources.CH may be elected by the sensors in the cluster or pre-assigned by the network designer. One cluster consists of only one CH at a time.

Member Nodes: These are the remaining nodes in the cluster with lower resources. Once the CH fails these remaining member nodes in the cluster may get the chance to become the CH.

Mainly two types of communication are performed in clustering protocols:

- INTER-CLUSTER: The communication which takes among the clusters.
- INTRA-CLUSTER:The communication among the nodes present in the clusters.

The remaining of the paper is organized as follows: section 2 outlines the advantages of Clustering routing protocol. Section 3 provides an overview of various Clustering routing protocols. Section 4 summarizes the clustering protocols. Finally, section 5 concludes the paper.

II. ADVANTAGES OF CLUSTERING ROUTING PROTOCOL

Routing in WSN consist various challenging issues such as power supply, scalability, processing capability, transmission bandwidth, global address, frequent topology changes, data aggregation, data redundancy, etc.

Clustering routing protocols try to overcome few of these challenges some of them are listed below:

- **Load Balancing**: Load balancing can be done by even distribution of nodes in the cluster and the data fusion at the cluster head before inter-cluster transmission. CH is responsible for load balancing within the cluster.
- **Fault Tolerance**: In WSN nodes are deployed in harsh environment and thus nodes are usually exposed to risk of malfunction and damage. Tolerating the failure of nodes or CH is necessary in such conditions. Whenever a CH fails re-electing of CH will not be efficient rather than we can assign a backup CH. Rotating the role of CH among the nodes in the cluster is also a solution for CH failure.
- **Data Processing:** Data redundancy can be reduced by aggregating the packets send by various nodes in the cluster to the CH. Thus various redundant data can be removed during this process.
- **Energy Efficient:** Data aggregation at CH reduces data transmission and thus saves energy. Whereas inter-cluster communication helps in less energy consumption.
- **Robust:** WSN like wired network doesn't have any fixed topology thus addition of new node, node mobility, node failure, etc has to be maintained by the individual cluster not by the entire network. CHs rotate among the entire sensors node to avoid single point of failure.
- **Network Lifetime:** Clustering routing protocol helps in energy-efficient routing thus the overall network lifetime is increased.

III. CLUSTERING PROTOCOLS FOR WSN

3.1 ENERGY EFFICIENT HIERARCHICAL CLUSTERING (EEHC):

It is a distributed, randomized clustering algorithm for WSNs. EEHC [5] is based on two stages

Initial: In the initial stage, each node announces itself as a CH with probability *p* to the neighboring nodes within the communication range. These announcements are done by direct communication or by forwarding. These CHs are named as the *volunteer* CHs. The nodes which receives the announcement and is not itself a CH becomes the member of the cluster. The node which doesn't received the announcements within a time interval *t* that is calculated based on the duration for a packet to reach a node becomes a *forced* CH.

Extended: Multi-level clustering is performed in this stage. CHs at the level-1 transmit aggregated data to the level-2 CHs and so on. At the top level CHs transmit the aggregated data to the base station.

3.2 LOW ENERGY ADAPTIVE CLUSTERING HIERARCHY (LEACH):

LEACH [6] [7] is one of most popular clustering algorithm for WSN. It forms the cluster based on the received signal strength and uses the CH nodes as routers to communicate with the sink. Cluster formation in LEACH is done using a distributed algorithm, where each node makes decision without any centralized control.

The operation of LEACH is divided into two phases namely:

Setup Phase: It is an advertisement phase in which nodes uses CSMA MAC protocol to advertise their status, CSMA MAC protocols main task is to prevent two advertisement messages from colliding with each other. Thus, all non-cluster head nodes must keep their receiver ON during the setup phase to receive the message. Initially a node decides to a CH with a probability *p* and broadcasts its decision. Each non-CH node determines its cluster by choosing the CH that can be reached using the least energy. CH is been rotated periodically among the nodes of the cluster to balance load. The rotation is performed by getting each node to choose a random number "T" between 0 and 1. A node becomes the CH for the current round if the number is less than the following threshold:

$$T(n) = \begin{cases} \dfrac{p}{\left(1 - p\left(r - mod\left(\frac{1}{p}\right)\right)\right)} & ,if\ \ n \in G \\ 0 & ,otherwise \end{cases}$$

Where *p* is the desire percentage of the CH nodes in the sensor population, *r* is the current round number, and *G* is the set of nodes that have not been CHs in the last 1/p rounds.

Steady-State Phase: Once the network is divided into clusters, CH uses TDMA schedule for its sensors to send the data. Data sent by the nodes in the cluster is aggregated at the CH and compresses the aggregated data before sending it to the sink. After the compression of data is done it is been send to the sink.
Though LEACH is an energy-efficient routing protocol still it has some drawbacks:

- It is only suitable for small networks and suitable for network deployed in large area.

- TDMA schedule wastes the bandwidth because some nodes might not have data to send.
- Large amount of energy is wasted if the CH is located away from the sink.
- If the CH fails due to some reason between the processes the whole process has to be repeated again which leads to wastage of energy.

3.3 LEACH-CENTRALIZED (LEACH-C):

It is a centralized clustering algorithm developed as an improvement over LEACH. In LEACH-C [8] [9] [10] the nodes in the network sends their location and energy information to the base station. Location information may be sent using some location identifying devices imported on the sensors like GPS etc. On the basis of this information the base station forms clusters, select CH and the members of clusters. In this way the setup phase is completed. The steady-state phase is same as that of LEACH. It is costlier due to the use of location finding devices and less reliable due to single point of failure.

3.4 HYBRID ENERGY-EFFICIENR DISTRIBUTED CLUSTERING (HEED):

It is a distributed clustering algorithm developed as an improvement over LEACH. The enhancement is done in the CH selection method. HEED [11] selects CH on the basis of energy as well as communication cost. In HEED, each node is mapped to exactly one cluster. It is divided into three phases:

Initialization Phase: Each sensor node sets the probability C_{prob} of becoming a CH as follows:

$$CH_{prob} = C_{prob} \cdot \frac{E_{residual}}{E_{max}}$$

Where C_{prob} is the initial percentage of CH required in the network, $E_{residual}$ is the current energy of the node and E_{max} is the maximum energy of the fully charged battery.

Repetition Phase: This is an iterative phase in which each node repeats the same process until it find a CH to which it can transmit with least cost. If any node finds no such CH, the elects itself to be a CH and sends the announcement message to its neighbors. Initially sensor node become *tentative* CH, it changes its status later if it finds a lower cost CH. The sensor node becomes permanent CH if its CH_{prob} has reached 1.

Finalization Phase: In this phase nodes either picks the least cost CH or itself becomes a CH.

Though it is an improvement over LEACH still it has some disadvantages like more CH are generated than expected and it is not aware of heterogeneity.

3.5 THERSHOLD SENSITIVE ENERGY-EFFICIENT SENSOR NETWORK PROTOCOL (TEEN):

TEEN [12] is a clustering routing protocol, which groups nodes into cluster with each led by a CH. Once the cluster is formed CH broadcast two types of threshold values to the nodes in the cluster namely *hard threshold value* and *soft threshold value*. The parameters in the attribute set of the node reaches its *hard threshold value*, the node switches on its transmitter and sends its data if the sensed attribute is greater than the *head threshold*, and the current value of the sensed attribute differs from sensed value by an amount equal to or greater than the *soft threshold*.

The main drawback of TEEN is that if the threshold values are not reached, the node will never communicate. And not even come to know if the entire nodes are alive or dead.

3.6 ADAPTIVE PERIODIC THRESHOLD SENSITIVE ENERGY EFFICIENT SENSOR NETWORK PROTOCOL (APTEEN):

APTEEN is an improvement over TEEN. APTEEN [13] is a clustering routing protocol that allows its nodes to send the sensed data periodically and react to any sudden changes in the value of the sensed data by reporting it to the CHs. Architecture of APTEEN is similar to that of TEEN.

APTEEN supports three types of queries namely:

Historic Query: To analyze past data value.

One Time Query: To view the whole network.

Persistent Query: To monitor an event for a period of time.

APTEEN guarantees energy efficiency and larger number of sensor alive.

3.7 ENERGY EFFICIENT INTER-CLUSTER COORDINATION PROTOCOL (EEICCP):

EEICCP [14] is a clustering routing protocol. In existing protocols CH send data directly to the sink, it is found that direct transmission dissipates lots of energy. EEICCP proposes a multi hop approach for the CHs to transmit data. It consists of two phases:

Election Phase: In this phase layers of clusters have been formed so there is always one cluster coordinator for every lowest cluster. The division of cluster is done from top to bottom. EEICCP starts the election phase in which CH are elected on the basis of received signal strength (RSS). Number of clusters is fixed. Then the CHs elects the cluster coordinator, cluster id is assigned to both CH as well as the coordinator. The id is transmitted to each node in the cluster by advertisement message.

Transmission Phase: In this phase data is collected by the CH of the cluster which has data to send and in next iteration the data is passed to the base station with the help of the cluster coordinators. The path for data transmission is set with the help of the cluster coordinators ids.

EEICCP [14] shows remarkable improvement over LEACH and HCR protocol in terms of reliability and stability.

IV. COMPARISSION OF ROUTING PROTOCOLS

ROUTING PROTOCOLS	CLUSTER STABILITY	ENERGY EFFICIENCY	NODE DEPLOYMENT (RANDOM/UNIFORM)	MULTIPATH	SCALABILITY
EEHC	MEDIUM	POOR	RANDOM	NO	LIMITED
LEACH	MEDIUM	POOR	RANDOM	NO	LIMITED
LEACH-C	MEDIUM	MEDIUM	RANDOM	NO	LIMITED
HEED	HIGH	MEDIUM	RANDOM	YES	LIMITED
TEEN	HIGH	VERY HIGH	RANDOM	NO	GOOD
APTEEN	HIGH	HIGH	RANDOM	NO	GOOD
EEICCP	MEDIUM	HIGH	RANDOM	YES	LIMITED

Table 1: Comparison of clustering based routing protocols in wireless sensor networks

CONCLUSION

Routing in sensor networks is a new area of research, with a limited, but rapidly growing set of research results. In this paper, we presented a comprehensive survey of clustering based routing techniques in wireless sensor networks which have been presented in the section 3. They have the common objective of trying to extend the lifetime of the sensor network, while not compromising data delivery. Although many of these routing techniques look promising, there are still many challenges that need to be solved in the sensor networks. We highlighted those challenges and pinpoint future research directions in this regard.

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