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Comparative Study of Hierarchical Routing Protocols in Wireless Sensor Networks

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Abstract— Wireless sensor networks (WSN) comprise a wide variety of applications in every field. Wireless sensor networks consist of small nodes with numerous capabilities such as sensing, computation, and wireless communications. Main area of concern in wireless sensor network is energy. As sensor in wireless sensor networks works on battery and have limited energy, therefore they have a limited lifetime. There comes the idea of hierarchical clustering. Hierarchical clustering of nodes and routing as per clusters contributes in reducing energy consumption and increasing lifetime of a network. This paper presents the study of hierarchical-based routing protocols (HBRP) such as leach and pegasis protocol proposed for wireless sensor networks. Additionally, the paper includes the comparison analysis of both protocols based on some parameter.

Keywords— *WSN;HBRP;LEACH;PEGASIS.*

I. INTRODUCTION

WSN is the collection of hundreds or thousands of tiny sensor nodes. These nodes have numerous capabilities as sensing, computations and communication among each other or with the base station. WSNs are resource constrained distributed systems with low energy, low bandwidth and short communication range[2]. The basic features which make WSNs different from the traditional networks are; self-organizing capabilities, short range communication, multi-hop routing, dense deployment, limitation in energy and memory, and also frequently changing topology due to fading and failures. Wireless communication enables to develop small, low-cost, low power and multi-functional sensing devices. These small sensing devices have the capabilities of sensing, computation, self -organizing and communication known as sensors. Sensor is a tiny device used to sense the ambient condition of its surroundings, gather data, and process it to draw some meaningful information which can be used to recognize the phenomena around its environment. The collection of these homogenous or heterogeneous sensor nodes are called wireless sensor network.

II. COMPONENTS OF WSN

The main components of a general WSN are the sensor nodes and the sink which is also called as base station.

A. Sensor Node

Sensing, processing and communicating data to the required destination are the basic capabilities of every sensor node in wireless sensor network. The basic entities in sensor nodes are sensing unit, power unit, processing unit, communication unit and memory unit to perform these operations.

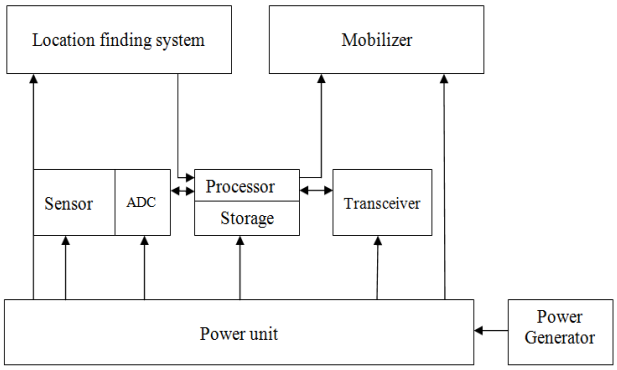

Figure 1 : Component Diagram

1) Sensing Unit

Sensors play an important role in sensor networks by creating a connection between physical world and computation world. Sensor is a hardware device used to measure the change in physical condition of an area of interest and produce response to that change. Sensors sense the environment, collect data and convert it to fundamental data (current or voltage) before sending it for further processing. It converts the analogue data (sensed data from an environment) to digital data and then sends it to the microcontroller for further processing. There are different categories of sensors which are available and can be used depending on the nature of the intended operation. Sensors size and their energy consumptions are the key factors to be considered in selection of sensors.

2) Memory Unit

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This unit of sensor node is used to store both the data and program code. In order to store data packets from neighboring (other) nodes Random Only Memory (ROM) is normally used. And to store the program code, flash memory or Electrically Erasable Programmable Read Only Memory (EEPRM) is used.

3) Power Unit

For computation and data transmission, the corresponding units in sensor node need power (energy). A node consist a power unit responsible to deliver power to all its units. The basic power consumption at node is due to computation and transmission where transmission is the most expensive activity at sensor node in terms of power consumption.

4) Processing Unit

Sensor node has a microcontroller which consist a processing unit, memory, converters (analogue to digital, ATD) timer and Universal Asynchronous Receive and Transmit (UART) interfaces to do the processing tasks. This unit is responsible for data acquisition, processing incoming and outgoing information, implementing and adjusting routing information considering the performance conditions of the transmission.

5) Communication unit

Senor nodes use radio frequencies or optical communication in order to achieve networking. This task is managed by radio units in sensor nodes that use electromagnetic spectrum to convey the information to their destinations. Usually each sensor node transfers the data to other node or sinks directly or via multi hop routing.

B. Base Station (Sink)

The sink (some time cluster head) is an interface between the external (management center) world and computational world (sensor network). It is normally a resourceful node having unconstrained computational capabilities and energy supply. There can be single or multiple base stations in a network. Practically, the use of multiple base stations decreases network delay and performs better using robust data gathering. Base station in a network can also be stationary or dynamic. The dynamic base stations can influence the routing protocols greatly because of its changing position which will be not clear to all the nodes in a network.

III. APPLICATION OF WSN

Some of the vast applications and the benefits that WSNs bring are:

- **Environmental Monitoring:** watershed management, forest fire prediction or irrigation management. It helps to preserve and maintain the natural resources.
- **Structural Health and Industrial Monitoring:** machinery failure detection. It reduces the maintenance costs and prevents from catastrophic failures.
- **Civil Structure Monitoring:** health monitoring of large civil structures, like bridges or skyscrapers. It prevents from human catastrophes.
- **Medical Health-care:** telemedicine, remote health monitoring. Allows doctors in remote and rural areas to consult with specialists in urban areas, remote handling of medical equipment etc.

IV. CLASSIFICATION OF ROUTING PROTOCOLS IN WSN

Different routing protocols are designed to fulfill the shortcomings of the recourse constraint nature of the WSNs. These routing protocols can be subdivided into two broad categories, network architecture based routing protocols and operation based routing protocols [3].

A. Architecture based routing protocol classification

Protocols are divided according to the structure of network. The protocols included into this category are further divided into three subcategories according to their functionalities. These protocols are:

- Flat-based routing
- Hierarchical-based routing
- Location-based routing

B. Operation Based Routing Protocol Classification

WSNs applications are categorized according to their functionalities. Hence routing protocols are classified according to their operations to meet these functionalities. Protocols classified to their operations are:

- Multipath routing protocols
- Query based routing
- Negotiation based routing
- QoS based routing
- Coherent routing

V. HIERARCHICAL-BASED ROUTING

When network scalability and efficient communication is needed, hierarchical-based routing is the best match. It is also called cluster based routing. Hierarchical-based routing is energy efficient method in which high energy nodes are randomly selected for processing and sending data while low energy nodes are used for sensing and send information to the cluster heads. This property of hierarchical-based routing contributes greatly to the network scalability, lifetime and minimum energy. The main aim of hierarchical routing is to efficiently maintain the energy consumption of sensor nodes by involving them in multi-hop communication within a particular cluster and by performing data aggregation and fusion in order to decrease the number of transmitted messages to the sink. Cluster formation is typically based on

the energy reserve of sensors. LEACH is one of the first hierarchical routing approaches for sensors networks.

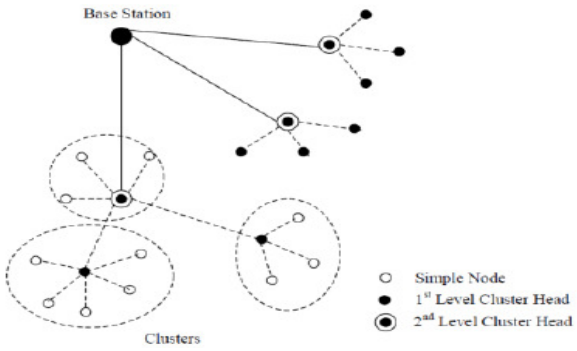

Figure 2: Hierarchical clustering

A. Leach protocol

LEACH arranges the nodes in the network into small clusters and chooses one of them as the cluster-head. Node senses its target and then sends the relevant information to its cluster-head [6].Then the cluster head aggregates and compresses the information received from all the nodes and sends it to the base station. The nodes chosen as the cluster head drain out more energy as compared to the other nodes as it is required to send data to the base station which may be far located. Hence LEACH uses random rotation of the nodes required to be the cluster-heads to evenly distribute energy consumption in the network. TDMA/CDMA MAC is used to reduce inter-cluster and intra-cluster collisions. This protocol is used were a constant monitoring by the sensor nodes are required as data collection is centralized (at the base station) and is performed periodically [5].

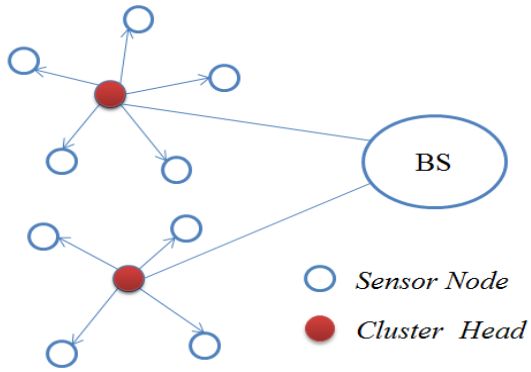

Figure 3: Leach Protocol

1) Operation

LEACH operations can be divided into two phases:-

a) Setup phase

In the setup phase, the clusters are formed and a cluster-head (CH) is chosen for each cluster. During the setup phase, a predetermined fraction of nodes, p, choose themselves as cluster-heads. This is done according to a threshold value, T (n). The threshold value depends upon the desired percentage to become a cluster-head- p, the current round r, and\ the set of nodes that have not become the cluster-head in the last 1/p rounds, which is denoted by G. The formulae are as follows [1].

$$T(n) = \frac{p}{1-p}[r \bmod(1/p)],\ n \in G = 0, \text{otherwise}$$

Every node wanting to be the cluster-head chooses a value, between 0 and 1. If this random number is less than the threshold value, T (n), then the node becomes the cluster-head for the current round. Then each elected CH broadcasts an advertisement message to the rest of the nodes in the network to invite them to join their clusters. Based upon the strength of the advertisement signal, the non-cluster head nodes decide to join the clusters. The non-cluster head nodes then informs their respective cluster-heads that they will be under their cluster by sending an acknowledgement message. After receiving the acknowledgement message, depending upon the number of nodes under their cluster and the type of information required by the system (in which the WSN is setup), the cluster-heads creates a TDMA schedule and assigns each node a time slot in which it can transmit the sensed data. The TDMA schedule is broadcasted to all the cluster-members. If the size of any cluster becomes too large, the cluster-head may choose another cluster- head for its cluster. The cluster-head chosen for the current round cannot again become the cluster-head until all the other nodes in the network have not become the cluster-head.

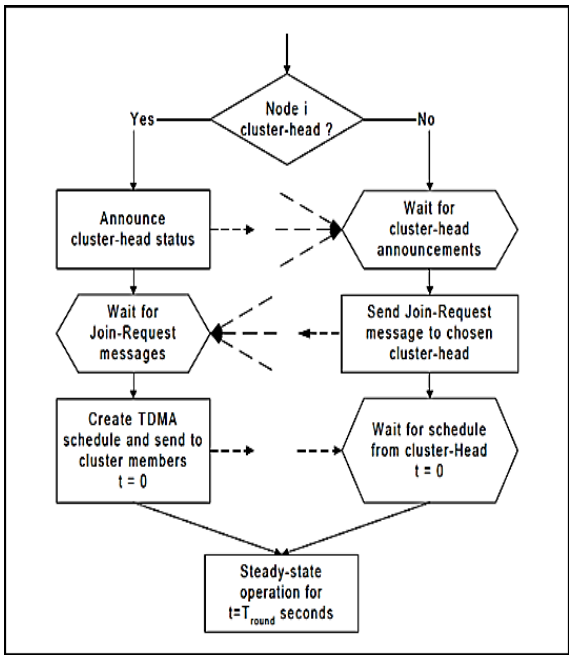

Figure 4: Set up phase

b) Steady phase

During the steady phase, the sensor nodes i.e. the non-cluster head nodes starts sensing data and sends it to their cluster-

head according to the TDMA schedule. The cluster-head node, after receiving data from all the member nodes, aggregates it and then sends it to the base-station after a certain time, which is determined a priori, the network again goes back into the setup phase and new cluster-heads are chosen. Each cluster communicates using different CDMA codes in order to reduce interference from nodes belonging to other clusters.

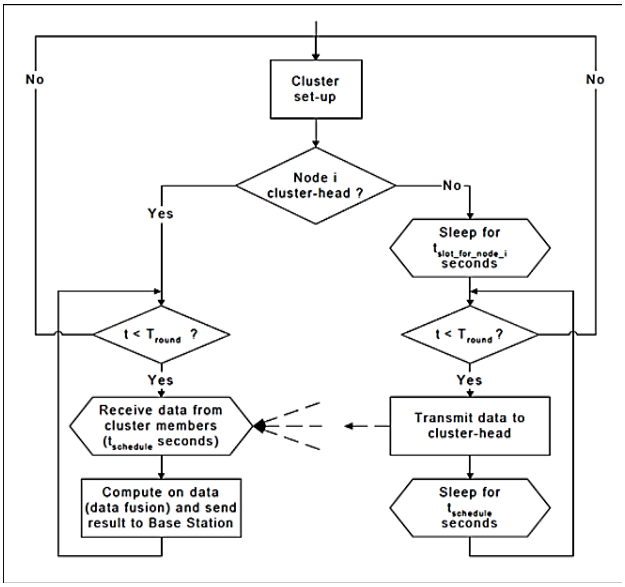

Figure 5: Steady phase

2) Advantages

The major characteristics of this Protocol are as follow:

- It rotates the cluster heads in a randomized fashion to achieve balanced energy consumption,
- Sensors have synchronized clocks so that they know the beginning of a new cycle,
- Sensors do not need to know location or distance information.

3) Drawbacks

There are some drawbacks of this protocol such as:

- LEACH uses single-hop routing where each node can transmit directly to the cluster-head and the sink. Therefore, it is not applicable to networks deployed in large regions.
- The idea of dynamic clustering brings extra overhead, e.g. head changes, advertisements etc., which may decrease the gain in energy consumption.
- Random election of CH, hence there is Possibility that all CHs will be concentrated in same area.
- The protocol assumes that all nodes begin with the same amount of energy capacity in each election round, assuming that being a CH consumes approximately the same amount of energy for each node.

B. Pegasis Protocol

PEGASIS (Power-Efficient Gathering in Sensor Information Systems) is a greedy chain-based power efficient algorithm. Also, PEGASIS is based on LEACH. The key features of PEGASIS are that the BS is fixed at a far distance from the sensor nodes. The sensor nodes are homogeneous and energy constrained with uniform energy. No mobility of sensor nodes [10].PEGASIS is based on two ideas; Chaining, and Data Fusion. In PEGASIS, each node can take turn of being a leader of the chain, where the chain can be constructed using greedy algorithms that are deployed by the sensor nodes. PEGASIS assumes that sensor nodes have a global knowledge of the network, nodes are stationary (no movement of sensor nodes), and nodes have location information about all other nodes. PEGASIS performs data fusion except the end nodes in the chain. PEGASIS outperforms LEACH by eliminating the overhead of dynamic cluster formation, minimizing the sum of distances that non leader-nodes must transmit, limiting the number of transmissions and receives among all nodes, and using only one transmission to the BS per round. PEGASIS has the same problems that LEACH suffers from. Also, PEGASIS does not scale, cannot be applied to sensor network where global knowledge of the network is not easy to get. The protocol, called Power-Efficient Gathering in Sensor Information Systems (PEGASIS), is a near optimal chain-based protocol. The basic idea of the protocol is that in order to extend network lifetime, nodes need only communicate with their closest neighbors and they take turns in communicating with the base-station.When the round of all nodes communicating with the base-station ends, a new round will start and so on. This reduces the power required to transmit data per round as the power draining is spread uniformly over all nodes.

1) Objective

PEGASIS has two main objectives.

- First, increase the lifetime of each node by using collaborative techniques and as a result the network lifetime will be increased.
- Second, allow only local coordination between nodes that are close together so that the bandwidth consumed in communication is reduced.

To locate the closest neighbor node in PEGASIS, each node uses the signal strength to measure the distance to all neighboring nodes and then adjusts the signal strength so that only one node can be heard [4]. The chain in PEGASIS will consist of those nodes that are closest to each other and form a path to the base-station. The aggregated form of the data will be sent to the base-station by any node in the chain and the nodes in the chain will take turns in sending to the base-station. The chain construction is performed in a greedy fashion.

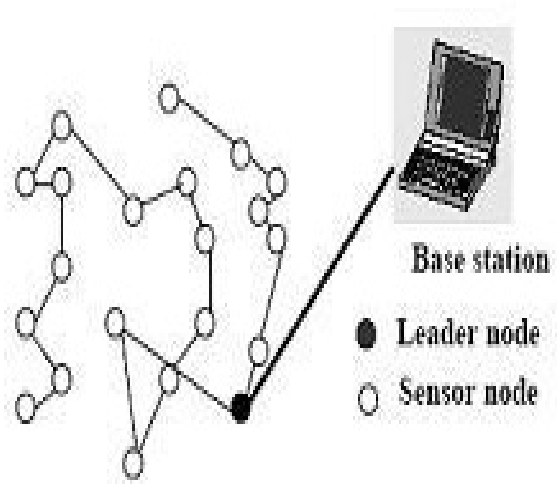

Figure 6: Pegasis Protocol

2) Advantages

The important features of this protocol are as follows:

- PEGASIS avoids cluster formation and uses only one node in a chain to transmit to the BS instead of multiple nodes.
- PEGASIS increase the lifetime of each node by using collaborative techniques.
- PEGASIS reduces the power required to transmit data per round as the power draining is spread uniformly over all nodes.

3) Drawback

PEGASIS assumes that each sensor node is able to communicate with the BS directly. In practical cases, sensor nodes use multi-hop communication to reach the BS.

- PEGASIS assumes that all sensor nodes have the same level of energy and are likely to die at the same time.
- PEGASIS introduces excessive delay for distant nodes on the chain.
- The single leader can become a bottleneck.

VI. COMPARISON OF HIERARCHICAL NETWORK PROTOCOLS

LEACH is one of the fundamental and powerful routing protocols which are designed for hierarchical networks [8]; but LEACH weak points led to the design of other protocols such as PEGASIS. However PEGASIS increases network life time and decreases overhead on CHs, but it needs to keep the information of neighbored nodes and it leads to network overhead.

Table 6.1 illustrates the comparison between LEACH and PEGASIS Protocols

Protocols / Parameters	LEACH	PEGASIS
Routing	Cluster Based	Chain Based
Node Mobility	Fixed BS	Fixed BS
Data Aggregation	YES	NO
Energy Efficient	NO	YES
Balanced Clustering	OK	N/A
Cluster Stability	Moderate	N/A
Multi-hop	NO	YES

Table 1: Comparison of protocols

VII. CONCLUSION

The main objective of hierarchical based routing is to maximize the network lifetime. Therefore in these paper basic concepts of leach and pegasis protocols which come under wireless sensor networks has been discussed. Then comparative analysis of both protocols is shown in the form of table. This Comparison is based on the various parameters of the protocol. By focusing on the drawbacks of these protocols modified version can be suggested to minimize energy consumption.

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