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A Brief Study of Power Efficient Hierarchical Routing Protocols in Wireless Sensor Networks

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***Abstract* - Field of wireless sensor network is among one of the most emerging and fast growing fields in today's scientific world. WSN is collaborated from a large number of low cost and minute homogenous sensor nodes connected by a wireless network. These sensor nodes are spread out in sensor field located far from the users. Increasing lifetime of WSN is one among the most critical issues. Sensor nodes are constrained in values of energy, memory and processing capacity.**
So to overcome such problems, a number of protocols have been proposed for the purpose of data routing in sensor network. Such protocols can be classified into three main groups: data centric, location based and hierarchical. In this paper, we present a brief survey of "Hierarchical Protocols" in which nodes are clustered in various forms to perform data aggregation and multi hop communication. By carrying out the above process, the number of transmitted messages to the base station are reduced, which will be a boon to system scalability and energy efficiency. This paper on the whole focuses on the energy efficient hierarchical cluster based available routing for WSN.

***Index Terms* - *Wireless Sensor Network; hierarchical clustering; cluster head; LEACH; PEGASIS; HEED*.**

I. INTRODUCTION

Wireless sensor network (WSN) is considered as one of the most significant technology for the twenty-first century [1]. In the last ten years, it has got remarkable attention from both academia and industry all over the globe. A WSN typically made of a large number of low-power, low-cost, and multifunctional wireless sensor nodes with sensing ability, wireless communications and computation capability [2, 3]. The sensor nodes communicate over small distance via a wireless medium and cooperate with each other to accomplish a common mission, for example, military surveillance, environment inspection and industrial process control [4]. The viewpoint behind WSNs is that, while the ability of each individual sensor node is limited, the collective power of the whole network is adequate for the required mission. Once set out, the wireless sensor nodes will automatically arrange themselves into a communication network according to the opted distribution algorithm. Since sensor nodes are battery-powered and are expected to function without attendance for a fairly long period of time. In most of the cases it is very difficult and sometimes impossible to change or recharge batteries for the sensor nodes [5]. A typical sensor node is made of four building blocks: power unit, communication unit, processing unit and sensing unit as shown in figure 1.

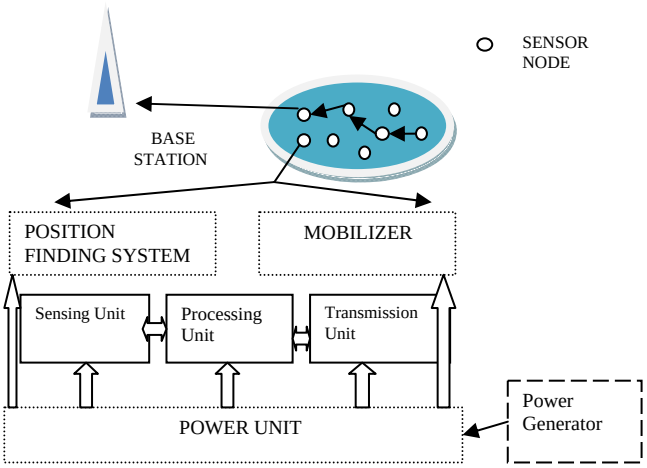

FIGURE1. The components of a sensor node (SOURCE [6])

Management of resources is required to increase the lifetime of the wireless sensor network. Quality of routing protocol depends upon the actual data signal successfully received by Base station from sensors nodes deployed in the network. Various routing protocols have been proposed for wireless sensor network. Primarily there are three types of routing protocols.

1) Flat routing protocols
2) Hierarchical routing protocols
3) Location based routing protocols

Maximum energy efficient routing protocols are being provided by category Hierarchical routing protocols. Number of hierarchical routing protocol has been proposed [8, 9]: LEACH (low energy adaptive clustering hierarchy, PEGASIS (Power-Efficient Gathering in Sensor Information Systems), HEED (Hybrid, Energy-Efficient Distributed Clustering).

II. HIERARCHICAL ROUTING PROTOCOLS

Clustering algorithms for traditional wireless ad hoc networks are not suitable for WSNs. A few special features of WSNs are as follows:

- Sensor nodes are been deployed densely.
- Sensor nodes are prone to failure.
- There are a large number of sensors nodes in a WSN, and are limited in computational capacities, storage memory and power.
- The topology of a WSN may change frequently because a sensor node may alternate between the active and sleep states.

• Sensor nodes does not have global identification (ID) due to large amount of overhead and the large number of sensors [6].

A number of research projects in the last few years have explored hierarchical clustering in WSN from different perspectives [10]. Clustering is a protocol that is energy efficient which can be used by the sensors to report their sensed data to the base station. In this section, we describe a sample of layered protocols in which a network is composed of several clusters of sensors. Each cluster is managed by a special node, called cluster head, which is assigned for coordinating the data transmission activities of all sensors in its cluster. As shown in Figure 2, a hierarchical clustering approach breaks the network into clustered layers. Nodes are grouped into clusters with a cluster head that routes the sensed information from the sensor nodes to the other cluster heads or base stations. Sensed data travel from a lower clustered layer to a higher one. Although, it hops from one node to another, but as it hops from one layer to another it covers larger distances. This helps in moving data faster to the base station. Clustering provides optimization capabilities at the cluster heads. Some of the hierarchical protocols are LEACH, PEGASIS, TEEN, APTEEN, HEED [5].

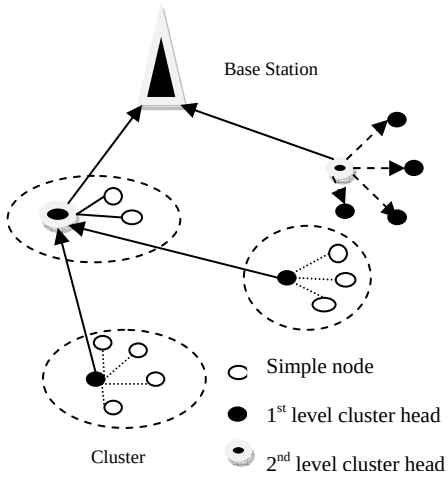

FIGURE.2. CLUSTER-BASED HIERARCHICAL MODEL (SOURCE [7])

III. LEACH (LOW ENERGY ADAPTIVE CLUSTERING HIERARCHY)

LEACH is a cluster-based protocol, which is based on distributed cluster formation. LEACH at random selects a few sensor nodes as cluster-heads and rotates this role to every sensor node which in turn evenly distributes the energy load among the sensors in the network. In LEACH, the cluster-heads aggregate data arriving from sensor nodes that belong to the respective cluster, and then send an aggregated packet to the BS this reduces the amount of information that is been transmitted to the BS shown in figure 3.

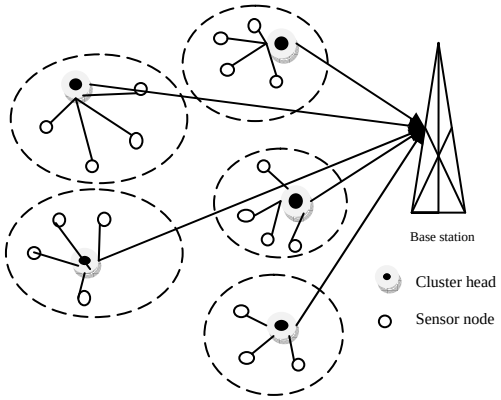

FIGURE 3.LEACH PROTOCOL WITH CH & BS (SOURCE [11])

LEACH Phases:
This protocol is divided into rounds; as shown in Figure 4, each round consists of two phases;
(i)Set-up Phase (ii) Steady Phase

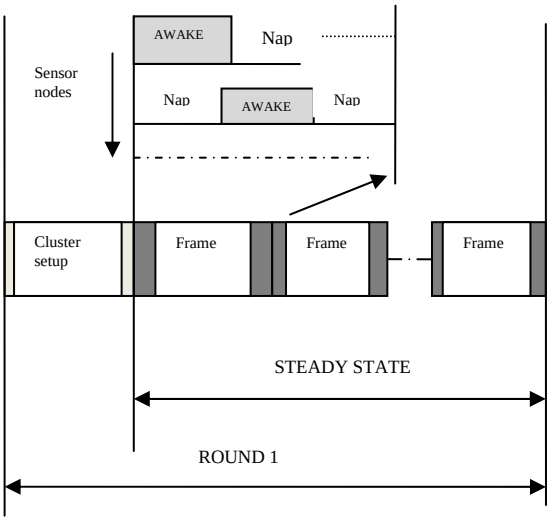

FIGURE 4 LEACH PHASES (SOURCE [17]).

3.1 Set-up Phase:
Set-up phase is further divided into 2 parts:

- Advertisement Phase
- Cluster Set-up Phase

In LEACH clusters are formed by using distributed algorithm where nodes make autonomous decisions without any central control. In the Advertisement Phase, CHs inform their neighbourhood with an advertisement packet to invite them to become CHs. Non-CH nodes pick the advertisement packet which has strongest received signal strength. This is accomplished according to a threshold value, T (n).
The threshold is set as:

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

Where, P is the probability of the node being selected as a cluster-head node, r is the number of rounds passed, G is the set of nodes that have not been cluster-heads in the last 1/p rounds, mod denotes modulo operator. Nodes that are

cluster heads in round r shall not be selected in the next 1/p rounds [13].

Based on all information received within the cluster, the CH create a TDMA schedule, pick a CSMA code randomly, and broadcast the TDMA table to cluster members 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 received, the non-cluster head nodes decide to join the clusters.

3.2Steady Phase:

Steady phase is further divided into 2 parts:

- Schedule Creation
- Data Transmission

The actual data transfer to the BS takes place in steady phase. The time period of the steady state phase is longer than the time period of the setup phase in order to reduce overhead. In steady state phase, the sensor nodes begin sensing and transmitting sensed information to the CHs. The CH node, after receiving all the information, aggregates it before sending it to the base station. After a certain time, which is determined a priori, the network starts back with the setup phase and enters next round of selecting new CHs. Clusters communicates by using different CDMA codes to reduce interference from nodes belonging to other clusters [12].

The significant features of this protocol are:

- Due to clustering in LEACH Protocol, LEACH achieves over a factor of 7x and 8x drop in energy dissipation compared to direct communication and by a factor of 4x and 8x compared to the MTE(minimum transmission energy) routing protocol.
- To achieve balanced energy consumption, it rotates the cluster heads in a randomized fashion.
- Sensors nodes have synchronized clocks so that they know the beginning of a new round.
- Sensors do not need to know distance or location information.

There are a few disadvantages of this protocol such as:

- LEACH uses single-hop routing strategy where each node transmits directly to the cluster-head and the base station. Therefore, it is not applicable for networks deployed in large regions.
- Dynamic clustering brings extra overload on nodes, e.g. head changes, advertisements etc., which may lead to more energy consumption.
- Due to random election of CH, there is possibility that all CHs could 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.

Application field:

- Leach protocol is most suitable for constant monitoring of machinery used for fault detection and diagnosis [6].

IV. PEGASIS (POWER EFFICIENT GATHERING IN SENSOR INFORMATION SYSTEMS)

PEGASIS is an improvement of the LEACH protocol. Instead of making multiple clusters, PEGASIS forms chains of sensor nodes such that each node transmits and receives from a nearest neighbour and only one sensor node is selected from that chain to transmit to the base station. Sensed information is moved from one sensor node to another, then aggregated and is sent to base station [13] shown in figure 5.

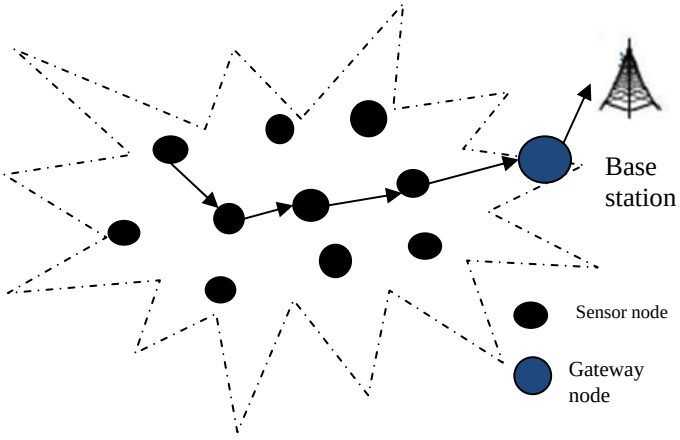

FIGURE 5. PEGASIS PROTOCOL FUNCTIONING

The nodes A0 to A6 are the chain partners for data transmission. A3 is the leader node which will transfer all the data to base station, as shown in figure.6

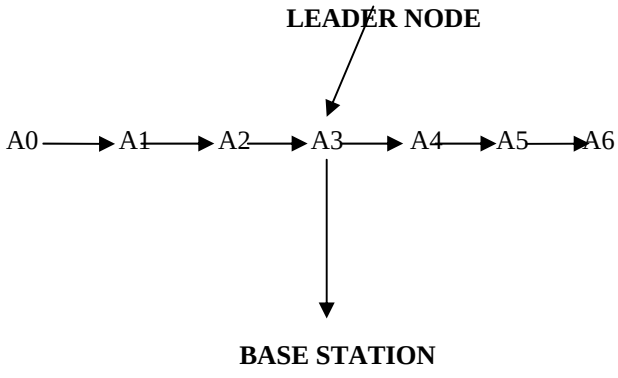

FIGURE6. PEGASIS PROTOCOL

The data is collected and moves from node to node, aggregated and eventually sent to the base station. The chain is constructed in a greedy way. PEGASIS avoids cluster formation as done in leach and uses only one node in a chain to transmit sensed information to the base station instead of using multiple nodes. A sensor node transmits data to its local nearest neighbour. In PEGASIS during the construction phase it assumes that all the sensor nodes have global knowledge about the network, mainly the positions

of the sensors, and knowledge of greedy approach. When a sensor node fails or dies due to low battery power, the chain is constructed using the same greedy approach by ignoring the failed sensor node. During each round, a randomly chosen sensor node from the chain will transmit the aggregated data to the base station, thus reducing per round energy used compared to LEACH.

Simulation results showed that PEGASIS increases network lifetime to double as much increased by LEACH. Such performance gain is achieved by elimination of the overhead caused by dynamic cluster head formation in LEACH. Although the clustering overhead is avoided, but PEGASIS still requires dynamic topology adjustment between sensor nodes. Also the nodes need to know about energy status of its neighbours in order to know where it should route its data. This type of topology adjustment can introduce noteworthy overhead especially for highly utilized networks [5]. So, there exists a problem of time delay in PEGASIS protocol which should be improved [14]. The significant features of this protocol are:

- PEGASIS is greedy chain protocol which leads to lessen the overhead caused due to many cluster heads.
- When a sensor node dies, chain is reconstructed to bypass the dead node.
- Head node receives all the aggregated data and sends to the base station.

There are few disadvantages of this protocol such as:

- PEGASIS assumes that each sensor node is capable of communicating 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 equal 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

Application Field:

- This protocol is most suited for surveillance application such as motion detection and knowing its charactertics.

V. HEED (HYBRID ENERGY-EFFICIENT DISTRIBUTED CLUSTERING)

Another enhanced and very popular energy-efficient protocol is HEED (Hybrid Energy-Efficient Distributed Clustering) [16]. HEED is a hierarchical, distributed, clustering protocol in which a single-hop communication pattern is maintained within each cluster, whereas multi-hop communication is carried out among cluster heads and the base station shown in figure 7. The CH nodes are chosen based on two basic parameters that are residual energy and intra cluster communication. Residual energy of each sensor node is used to probabilistically select the initial set of CHs. On the other hand, intra cluster communication reflects the node degree or node's closeness to the neighbour node and is used by the sensor nodes in deciding to join a cluster or not. Thus in HEED the cluster head nodes are not selected randomly. Only sensors that have a high residual energy are expected to become cluster head nodes. This also reduces the probability of two nodes within same transmission range to become cluster head. Unlike LEACH, this means that CH nodes are well distributed in the network.

In HEED, each node is connected to exactly one cluster and can directly communicate with its CH. Energy consumption is not assumed to be uniform for all the nodes [15].

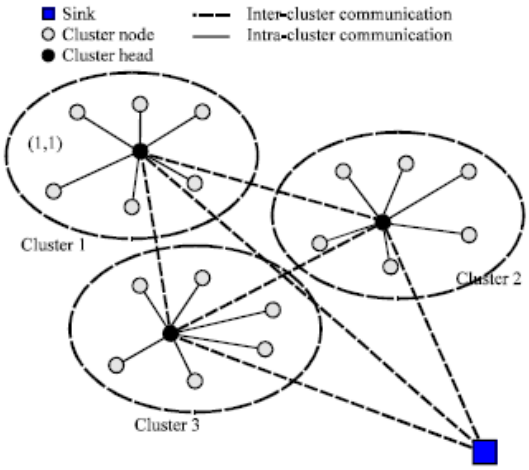

FIGURE7: HEED PROTOCOL FUNCTIONING

HEED was proposed with four primary goals namely,

- Increases network lifetime by distributing energy consumption.
- Terminate the clustering process within a even number of iterations,
- Minimize control overhead.
- Giving well-distributed cluster heads and compact clusters.

In HEED, the clustering process at each sensor node requires several rounds. Every round is lengthy enough to receive messages from any neighbour within the cluster range. The parameter C_{prob} is used to border the initial cluster head announcements and has no direct effect on the final cluster structure. In HEED protocol, each sensor node sets the probability CH_{prob} of becoming a cluster head as follows. Where *E residual* is the approximate current residual energy in this sensor node and E_{max} is the maximum energy analogous to a fully charged battery. The CH_{prob} value must be greater than a minimum threshold value p_{min}. A cluster head is either a unsure CH, if its CH_{prob} is <1, and a final CH, if its CH_{prob} has reached 1.During each round of HEED, every sensor node tries to become cluster head with probability CH_{prob}. The newly elected Cluster head are added to the current set of CHs. A sensor node receiving the CH list selects the CH with the lowest cost of energy consumption. Every node then doubles its CH_{prob} and goes to the next step [7].

The significant features of this protocol are:

- In HEED distribution of energy increases the lifetime of the nodes in the network thus stabilize the neighbouring node.
- Special node capabilities are not required, such as location awareness.
- HEED do not make assumptions about node distribution.
- Nodes automatically update their neighbour sets in the multi-hop network by intermittently sending and receiving messages.
- It even operates precisely even when nodes are not synchronized.
- The nodes only require local neighbourhood information to form the clusters

There are few disadvantages of this protocol such as:

- Higher communication overload is caused by random selection of the cluster heads.
- Election or periodic cluster head rotation needs extra energy to rebuild clusters.

Application Field:

- This protocol is most appropriate to prolong the network lifetime rather than for the entire requirements of WSN.

VI. COMPARATIVE STUDY OF ROUTING PROTOCOLS

Table 1 gives comparison of LEACH, PEGASIS and HEED the power efficient routing protocols for wireless sensor networks. PEGASIS increase network life span two-fold compared to the LEACH protocol. The HEED protocol clustering improves network life span over LEACH clustering because LEACH selects CHs by distributed algorithm, which may result in more rapidly death of some nodes. The final CHs selected in HEED are well distributed across the network and the communication cost is reduced as compared to other routing protocols [6].

PROTOCOL / PARAMETERS	LEACH	PEGASIS	HEED
ROUTING	Cluster based	Chain based	Cluster based
NODE MOBILITY	Fixed base station	Fixed base station	Stationary
DATA AGGREGATION	Yes	No	Yes
ENERGY EFFICIENT	No	Yes	Yes
BALANCED CLUSTERING	Ok	N/A	Good
CLUSTER STABILITY	Moderate	N/A	High
MULTI-HOP	No	No	yes

TABLE1. COMPARISON OF LEACH, PEGASIS AND HEED

VII. CONCLUSION

The existing hierarchical routing strategies in the wireless sensor network and their analogous protocols are been explained. Though the protocols like LEACH, PEGASIS and HEED are proved to be energy proficient than direct transmission. The major pitfalls in these protocols are that nodes are assumed to be static and stationary. The energy efficiency model is untried when the sensor nodes exhibit mobility. Future works may focus on achieving improved energy efficiency in routing mechanism for mobile wireless sensor nodes.

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