A Comparative Study of Hierarchical Routing Protocols in Wireless Sensor Network

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Abstract:
The paper gives a concise interpretation about various Hierarchical Routing Protocols of WSN.In this paper we analyzed hierarchical routing protocols into two types namely as hierarchical Cluster-Based routing Protocols which includes LEACH, LEACH-C and EEE LEACH and Chain-Based Protocols named as PEGASIS, H-PEGASIS, MH-PEAGSIS and EEPB-PEGASIS.A comparison study of Cluster Based and Chain based routing protocols performed separately based on some performance metrices. And additional the Chain Based protocol and Cluster Based protocols compare with each other on the basis of transmission delay, residual energy of nodes and throughput parameters using MATLAB environment. Main concern in wireless sensor network deploying nodes which have minimum energy consumption and have longer network lifetime due to limited battery life of mobile nodes. This paper reviews and analyzed Chain Based protocols has best performance over Hierarchical Cluster Based protocols in terms of energy efficient, longer network life time and minimum transmission delays.

Keywords
WSN, hierarchical Cluster Based Protocols, Chain Based Protocols, energy efficient, throughput, Delay

1. Introduction

One of the major advancements is networks with Wireless Sensors (WSN). The range of wireless, low-size, low-energy, non-rechargeable, low-computational capability, low-speed and low-cost devices known as environmental sensor nodes, connecting to each other for information gathering through wireless connections. One or more nodes served as a sink(s) that are capable of communication with other nodes. Such sensed data is transmitted either directly or through multi hop relaying to a base station. Each node is equipped with a processing, memory, RF transceivers (Omni-directional) and power sources (batteries, solar cells) to accommodate different sensor. WSN's unique features like minimal energy and computing constraints, limited transmission range, no public identification and denser node deployment makes it different from conventional wireless networks and it is useful for variety of applications. WSN is used for nvironmental surveillance so it can be used in extreme conditions. It is used in Military technologies, including battlefield control or object security, health-care applications, intelligent homes and even in everyday human life. Effective routing algorithms must be used for data collection because of the WSN dynamic characteristics and to extend the lifetime of the sensors [1]. Two approaches are used for data gathering, which are flat and hierarchical approaches. When large number of nodes are required flat based routing is used in which each node plays the same role. In this approach BS sends a request to all nodes and only the nodes that matches the query (request) will respond through their first neighbors or through multi hop path. Particularly, when getting closer to the base station. The limitation is that transmitted data is duplicated. The nodes nearest to the base station thus die sooner and result in network partitioning. To counter the drawback of flat networks, it was suggested that hierarchical routing protocols will be used. These protocols are energy efficient and increase the scalability of network. They are often classified as cluster based routing protocols. It is an energy-efficient approach that randomly chooses high-energy nodes for data processing and transmission, although energy efficient nodes are used to sense and distribute information to CH. Hierarchical networks minimize the messages sent by only special data aggregation and transmission nodes, and other data sensing nodes [2]. There have been several hierarchical routing protocols that can be classified into four classes:

- chain-based routing protocols
- tree-based protocols
- cluster-based routing protocols
- Hybrid routing protocols.

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Only cluster and chain based routing protocols are taken into account in this article. Cluster based routing protocols are used to lessen the energy utilization and scalability of network. The structure of this network is that it is divided in clusters each with a cluster head node each gather detected information from other cluster nodes and transfers aggregated information to the BS (base station). How to pick the CH and how to manage the clusters is the main problem with these protocols. Once the network is partitioned into clusters, the information transmission is isolated into two stages: **Inter and intra cluster communication**. Single hop intra cluster and multi hop inter cluster are base of data transmission mode because the base station is a long way from the sensing area. In single hop each node in the network send their sensed data directly to BS but in multi hop intermediate nodes are used to transmit the data to base station. In Chain based routing protocols a chain is constructed among nodes instead of clusters.

Section 2 analyze overview of hierarchical routing protocols, section 2 studies Hierarchical Cluster-Based routing protocols, section 3 reviews Chain Based routing protocols, section 4 contain performance comparison of Hierarchical Protocols, section 5 reviews implementation environment, section 6 contains Discussion and Results, section 7 contains conclusion and section 8 consists of references.

2. Overview of Hierarchical Routing Protocol

This section reviews WSN's Hierarchical Routing Protocols, which includes arranging clusters in the form of a hierarchy while sending information to the base station from the sensor nodes. By employing multi-hop communication for a particular cluster and thereby conducting data aggregation and fusion in a way that decreases the amount of data transported to the sink through the network, hierarchical routing effectively reduces energy consumption. Several hierarchical routing strategies have been introduced and can be divided into four classes: chain-based protocols for routing, tree-based protocols for routing, cluster-based protocols for routing, and protocols for hybrid routing.

2.1 Hierarchal Cluster Based Routing Protocols:

In the Hierarchical cluster-based protocol, the entire network is organized into clusters, where the cluster has a CH node which is responsible for collecting sensed data from sensor nodes in the cluster and sending the accumulated data to the sink node. Depending on the network size and the hop count between the sensor nodes and the BS, the transmission of data divided into single-hop or multi-hop networks. In single-hop, sensor nodes direct their sensed information to the sink instead of using middle nodes. However, in multi-hop, sensor nodes transmit their data to BS by means of middle nodes. In homogeneous sensor networks, each node has the same computational, storage, communication and energy power abilities. In fact, all nodes utilize power at equivalent rates. In heterogeneous networks, all the nodes have not same abilities. There are some costly sensors which are designed with more efficient and less power devices and thus are responsible for the processing and transmitting of data to the sink, while other cheaper sensors are responsible for detecting and collecting information about the environment. The following cluster-based routing protocols in a single or multi-hop, homogeneous and heterogeneous network are reviewed in this paper.

2.2 LEACH

LEACH is a cluster-based routing protocols that contains distributed formation of clusters. In LEACH few sensor nodes randomly select as a cluster heads also in each round during data transmission new cluster head is selected randomly to manage the energy load amongst the nodes in the network. In LEACH, CH collects data received from non-CH nodes which linked to the relevant cluster, perform aggregation functions on data packets and send to the BS thus lessen the redundant information and sent to the BS. To lessen inter-cluster and intra-cluster interference, LEACH uses TDMA/code-division multiple access (CDMA). The LEACH works in two steps, the setup phase and the steady state phase. In setup phase the clusters are constructed and Cluster Heads are elected. In each data transmission round cluster heads rotate dynamically to adjust the energy dissemination of nodes.CH selection in LEACH is done by using following threshold:

$$T(n) = \left\{ \frac{\mathrm{P}}{1 - \mathrm{P}(\mathrm{rmod}\left(\frac{1}{\mathrm{p}}\right))}, if\ n \in G, \qquad O\ otherwise \right\} \tag{1}$$

In setup phase, every node generated an arbitrary number from 0 to 1, if the value is lesser than specified threshold value then node will be a CH for a given round' r', 'P' denoted the percentage of CHs and 'G' denoted the set of nodes that belongs to 'n' and are not selected as a Ch. Steady state process begins with real transmission of data to the BS, at this point CHs node receive data from nodes, fuses data and aggregates it directly to the base station. Steady State process describes how data

transmission begins, sensor nodes start sending and receiving data to the CHs nodes, while CHs getting all the data perform aggregation and diffusion on the data and transmit it to the BS. Steady State has longer period of time than the setup phase order to decrease excessive congestion. In order to minimize obstruction from nodes that are part of different clusters, clusters interact with each other by different CDMA codes.

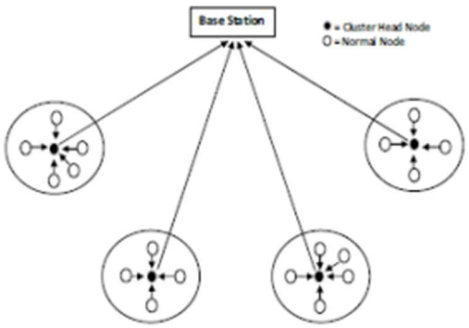

Figure.1 LEACH Structure

2.3 LEACH-C

The new LEACH type, the LEACH-C, is used to pick cluster heads according to their location knowledge with a central clustering algorithm. This enhanced the performance of LEACH by determining the good clusters which requires lower energy to send and receive data. In LEACH-C the number of cluster heads in each round equivalent to a pre decided optimum value. LEACH-C has the same steady phase as comparison to LEACH, but in setup phase base station receives information of each node about their location and current energy level in the network. On the basis of these information base station will decide clusters, CHs and other sensor nodes in a network and as well as in each cluster. After the selection of CHs and clusters, the BS propagates cluster header ID message for every node. When an ID of a cluster head corresponds with its particular ID, Node is a head of the cluster; else the node specifies its TDMA slot to transmit data and go to sleep till its data transmission begins.

3 EEE LEACH Protocol

Energy Efficient Extended LEACH is an improved method of LEACH which provides multilevel clustering approach in order to expand energy effectiveness by decreasing its radio correspondence distance. In this multilayered clustering methods other than having only one layer of cluster organization between the BS and nodes such as LEACH, it includes two layers for the formation of clusters. First layer involves formation of cluster heads and nodes send their data to corresponding CHs and by utilizing fusion techniques cluster heads aggregate the received information.in the second layer Master Cluster Heads (MCH) are designed. After the arrangement of MCHs, the CHs find the closest MCHs by computing the distance among them and communicate their aggregate information to the individual MCH. In the same manner, the MCHs got information from their closest CHs, accumulated all the obtained data, changed this data into compress form and send it to the base station. At initially, the MCHs and CHs are chosen by utilizing fixed decided fragmentary value for MCHs. Numbers of MCHs in EEE LEACH remain less than the number of CHs to limit the general correspondence distance between the hubs and Base station. EEE LEACH has better performance in terms of network life and more energy effective than LEACH.

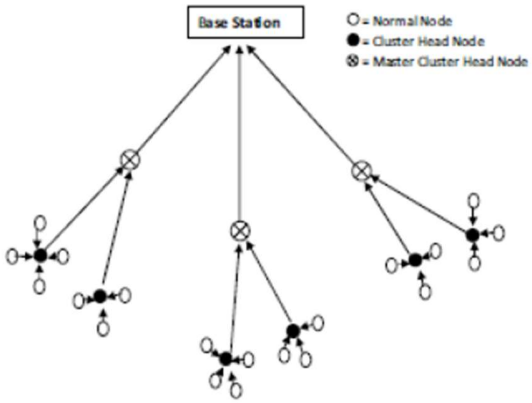

Figure.2 EEE LEACH Structure

3.1 Chain Based Routing Protocols:

In this protocol all nodes are connected in the form of chain rather than clusters. Various algorithms are built in this protocol.

3.2 Power Efficient Gathering in Sensor Information System (PEGASIS):

It is a chain based routing protocol in which a chain is constructed among the nodes. This protocol includes all nodes that sends sensed data to closest neighbors before aggregated data reached to the base station (BS). This protocol enhances the network's life and lessen the use of energy at each round. PEGASIS is identified by:

- The BS is connected to the sensor nodes from a distance.

- Homogeneous capability of sensor nodes.
- Nodes are stationary

3.3 Chain Formation:

In this protocol a chain is constructed by using the greedy algorithms. In each node this algorithm takes into account the physical distance from next hop, ignoring neighbor's energy inducing shorter node life. PEGASIS suggest that sensor nodes have information about the network, location of other nodes is known and nodes are static. PEGASIS network is shown below:

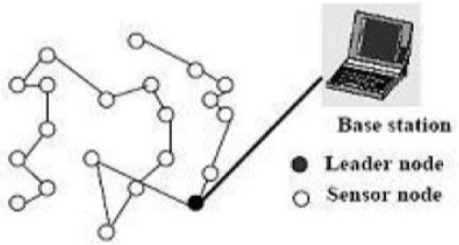

Figure 3 PEASIS network

The advantage of this protocol is that the network randomly starts new chain construction and select a new chain head when chain head die. This protocol has two phases: the selection of the leader and the transfer of data [3].

Leader selection: The chain leader is chosen randomly. Random selection is the benefit because if a chain head is to die the new chain head is selected. After a leader is selected it passes a token message to nodes to start the data gathering process. The movement of a token also consumes energy, but the token size is very limited, so it costs quite little.

Data Transmission: Each node collects or gets information from the closest neighbor in each round fuses its own data to other neighbor of chain until the chain leader reaches at the full chain data. Finally, the leader sends this information to the BS.

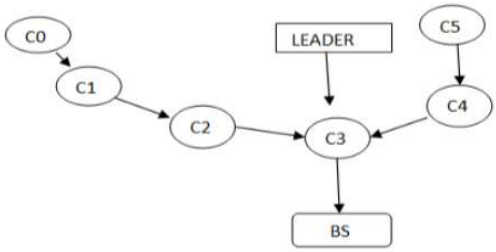

Figure .4 Data Transmission in PEGASIS

In the above fig c3 is selected as chain leader, sending token to all chain nodes. All nodes start transmitting their data after they receive the token. Two end node C0 and C5 will start the communication and send their data to C1 and C4 and they fused their received data with C2 and C3. C2 then essentially fuses the data with C1 and moves them to C3. Chain leader C3 would then merge his C2 and C4 data and give it to BS.

4. H-PEGASIS (Hierarchical PEASIS):

The PEGASIS Protocol is extended, with the goal of minimizing transmitting delays to the BS. In this protocol the organization of nodes in a chain that belong to the same cluster makes it possible to boost and monitor energy dissipation and to reduce the cluster head's load. In fact, nodes only interact with their neighbors, not directly with the energy saver cluster heads. The sum of data shared between nodes and their cluster heads is minimized by data aggregation at each node in the chain, which has the benefit of retaining the energy budget of the nodes. Each node transmits its data to its neighbor in this protocol. They aggregates their received data with others' and pass it to their neighbor until the data are sent by the cluster head directly to the Base Station. Nodes build a chain together to form a hierarchical tree in the hierarchical PEGASIS.

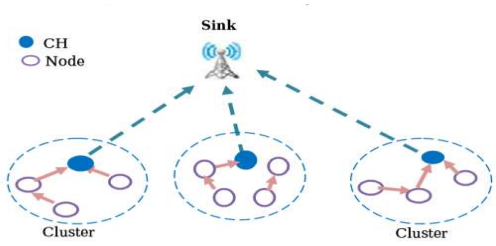

Figure .5 hierarchical cluster routing on chain base

This protocol operates in rounds. The initialization and the transmission process are two steps for each round. But it is important to know no of CH nodes before initialization. This number is referred to as K that is fixed and unchanged for all the rounds. The optimum percentage of the CH number should be estimated to be between 5% and 15% of the total number of nodes. Especially if the CH number is very high, a significant number of nodes will be committed to expensive energy resource consumption activities. In fact, if the number of CHs is very small, the clusters that are to be handled could

be bigger in size, allowing the overload they have to bear to easily reduce CH batteries. At the beginning of each round new CHs are selected on the basis of the probability Pi(t) the starting at time point t determined as follows:[4]

$$Pi(t) = \begin{cases} \dfrac{K}{\text{Nbr of CHs not yet elected CH}} & \text{(Energy homogeneous nodes)} \\ \dfrac{\text{Residual energy}}{\text{Total energy}} & \text{(Energy heterogeneous nodes)} \end{cases}$$

Every node "I" generates a random number between 0 and 1, when the number is less than Pi (t), this will render CH during this round. The initialization method consist of three sub stages: announcement, cluster organization and final neighbor search. In the initialization phase CH is checked if it is available then announce new head for next round but if it is not exist then wait to announce new head.After new CH is announced membership request is sent to the new cluster head and after that transmission Phase is started.

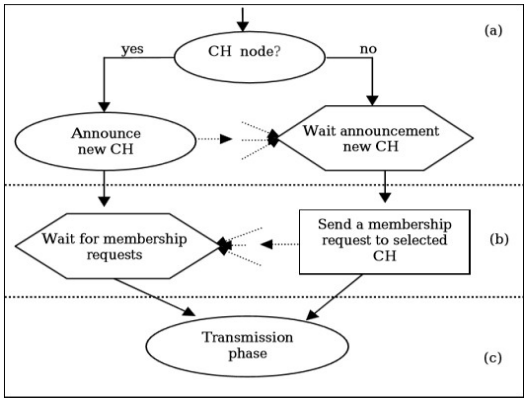

Figure. 6 Sub phases of initialization phase

5. Multi HOP PEGASIS (MH-PEGASIS):

Major drawback of hierarchical PEGASIS was that in this protocol CHs far from BS require powerful signals that increase their energy consumption to interact with BS. Two overcome this problem MH-PEASIS is used, an enhanced technique that uses multi-hop routing between the CH (interclusters) to reach the BS efficiently.Other protocols consume greater energy than the MH-PEGASIS. Multihop correspondence between cluster head and base station with data processing at CHs decreases the number of network routing packets and thus increases the network's lifetime.[3] It contains rounds and each round contain of two stages: invitation and transmission, similar to hierarchical protocol. Three invitation stages are similar to hierarchical PEGASIS, but the last sub phase is known as the search of neighbor phase at the CH level. The degree of a CH is defined according to its distance with regard to BS. It has three circles for this, and center is BS. First circle is level 1, with radius x nearest to the BS than level 2, whose radius is y and (y>x). Likewise, circle level 2 is closer with radius z (z>y) to circle level 3. Thus, the node with a distance of less than or equal to x of the BS is in level 1, the node of the distance d is such that "x≤d≤y" the node is in level 2, and the remainder is in level 3 [5].

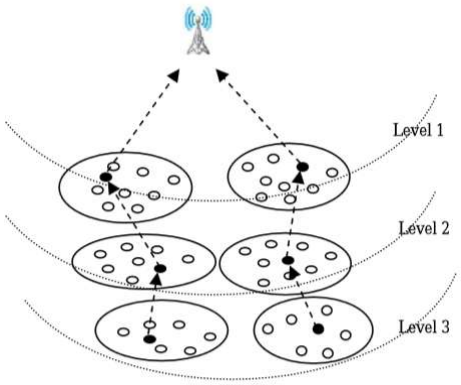

Figure .7 MH-PEGASIS routing

6. Energy Efficient PEGASIS based algorithm (EEPB):

It is an improved protocol over the PEGASIS protocol. EEPB protocols[12] solves the problems of PEASIS protocol by reducing long links of chain due to the long distance between nodes that occurs due to the greedy algorithm used in PEGASIS protocol resulting in high energy consumption and rapid death of the node. This protocol overcome this problem by launching a distance threshold that will be applied to the average formatted chain distance to reduce the long link initialization problem.

$$D_{average} = \sum_{p=1}^{h} \left(\frac{D_p}{h}\right)$$

Where:

Davg: is the distance average of the chain.
H: is the hop no
Dp: is the distance of every segment in the formed chain, where (p=1, 2, 3 …h).
Creating a LL (Long link) problem will be high if the distance between an end node in a formed chain and a new requested node to join with that formed chain of nodes is longer than Dthreshold.
Dthreshold= α * Daverage

Dthreshold: is the threshold distance. α: is a user-defined constant. Leader node is selected in EEPB according to two factors: The node's residual energy with the distance between the node and the base station. When chain is established transmission stage starts with the processing and collection of data from each node in way until before it meets the lead node responsible for transmitting these data to the base station. As a consequence, power between nodes will be saved and balanced.

Table 1. Comparison of Hierarchical Routing Protocols on various performance metrices[13][7] [14]

Hierarchical Cluster-Based Routing Protocols			
Performance metrices	**LEACH**	**LEACH-C**	**EEE LEACH**
Energy Consumption	Nodes autonomously select as a CHs in each round based on the given threshold, so randomly selection of CHs requires minimum energy.	Since its used centralized algorithm, so every node directs its present location and energy level information to BS, then it selects CH and how to form clusters need to broadcast message to all the nodes, so it requires more energy cost	More energy efficient protocol by reducing communication distance between MCHs, CHs and BS
Mobility of node	Fixed BS	Fixed BS	Fixed BS
Scalability	Not scalable for larger networks because of direct transmission of data of CHs and BS due to single hop routing.	Suitable for large network has fixed BS location, if the position of sink changes and nodes are located at distant location then not suitable for large networks.	More suitable for large size networks
Load Balancing	Random CHs selection balance the load among nodes of a cluster.	Better and balance cluster formation based on CHs location and energy level.	Two layers formation divided the energy load between MCHs and CHs.
Overhead	TDMA or CDMA used to minimize inter cluster and intra cluster interference, contains less control packets hence reduce overhead	More control packets need to be broadcast between sensor nodes, CHs and BS, hence increase overhead in the network	Less overhead than LEACH-C by providing multi-hop communication
Data transmission	Single Hop	Single Hop	Multi-hop
Lifetime of Network	Good	Moderate	Very good

Chain Bases Routing Protocols				
Performance Metrics	**PEGASIS**	**H-PGASIS**	**EEBP**	**MH-PEGASIS**
Energy consumption	Saves energy because distance between nodes to transmit data are less	Energy consumption is low	Moderate due to long link problem	Energy consumption is lower than other protocols
Mobility of nodes	Fixed BS	Fixed BS or moveable nodes	Fixed BS or moveable nodes	Fixed BS or moveable nodes
Scalability	PEGASIS is not scalable because getting global knowledge of network is not easy.	Low scalability	Low	Not defined
Data transmission	Single hop	Single hop	Single hop	Multi-hop
Overhead	Low	Low	Low	Low
Lifetime of Network	Good	Very good	Good	Very good

7. Implementation Environment

Simulation and execution of routing protocols is the significant[15] work phase, it allows us to know which protocol performed better in according to various metrics. Several modeling settings were studied in detail and simulation software's are presented for measuring network performance. We have chosen the MATLAB in oecause it is simple and easy to construct User interface.

Table 2. Simulation parameters

Sr #	*parameters*	*Values*
1	Protocols	Cluster based; chain Based
2	Network Area	300 x200
3	Number of nodes	200 to 300
4	Size of Packet	2000 bits
5	BS location	Scenario based
6	Node's energy	1.0 J
7	Number of rounds	10 to 10,000

8. Discussions and Results:

6.1 Hierarchical Cluster Based Routing Protocols:

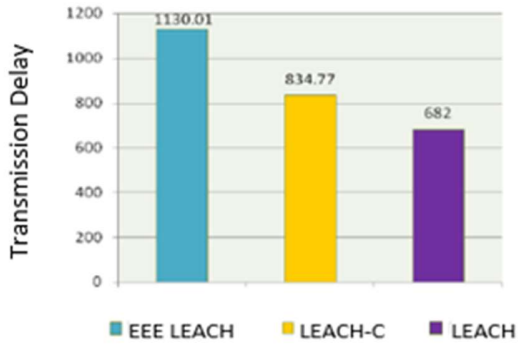

Figure 8. Transmission delay

From figure 8, we can observe that EEE leach protocols requires larger transmission delay because it involves two level of clustering and hence more control packets need to be transmitted between two layers and increased transmission delay, while in LEACH-C[8] due to single hop communication data traveled from sensor node to CHs and then CHs to BS. Less transmission delay than EEE LEACH.LEAC has the least delay among all protocols due to less control packets need to transmit to BS.

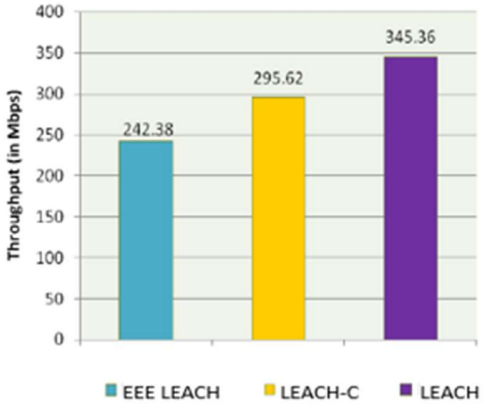

Figure 9. Throughput

Figure 9 shows the comparison of throughput values, EEE LEACH has least throughput because it takes highest transmission time to transmit control packets to BS. LEACH-C transmission time less than EEE LEACH, hence throughput greater than EEE LEACH. LEEACH has the highest throughput among all protocols

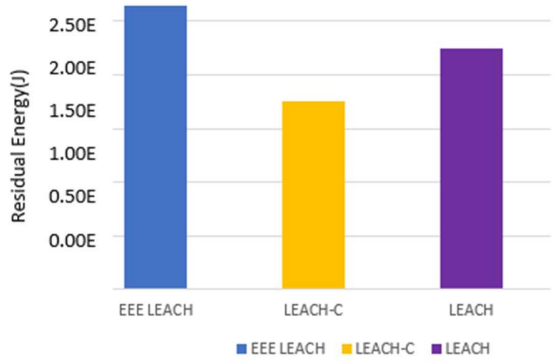

Figure 10. Residual Energy

Above figure 10, shows the comparison of residual energy of nodes with number of rounds, EEE LEACH conserves more energy than LAECH and LEACH-C due to shortest path selection between MCHs and CHs. LEACH-C consumes more energy due to more control packets and messages broadcast between CHs, sensor nodes and BS. LEACH's nodes consume less energy due to less message broadcast and control packets in the network.

6.2 Chain Based Routing Protocols

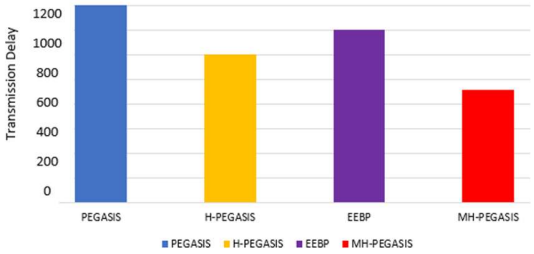

Figure 11. Transmission Delay

Figure 11 shows that PEGASIS[15][16] has higher delay than other protocols due to long distance between communication nodes. H-PEGASIS provides simultaneous transmission of data from top layer to bottom layer in a hierarchy also CDMA based nodes used to avoid collision and interference in communication, so it reduces the delay problem in previous PEGASIS.EEBP has longer delay than H-PEGASIS due to long links also heavy load on one chain because distance between the BS and chain.MH-PEGASIS has no delay due to multi-hop routing 3 level of chain hierarchy between sensor nodes and base station.

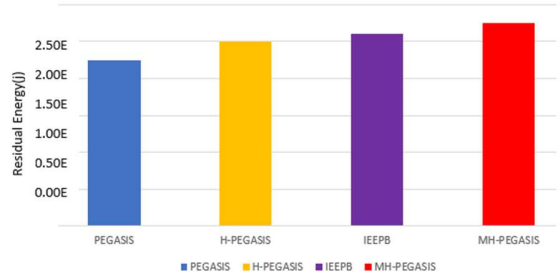

Figure 12. Residual Energy

PEGASIS consumes more energy due to more delay in communication, saves more energy than LEACH due to minimum messages overhead i.e., only two messages received between leader node and BS.H-PEGASIS used energy*delay metric, minimum delay means more energy conserved by each node for next round. EEBP uses distance threshold parameter to forming a chain in closest nodes to avoid lengthy links, thus it saves energy and energy load is balanced among nodes.

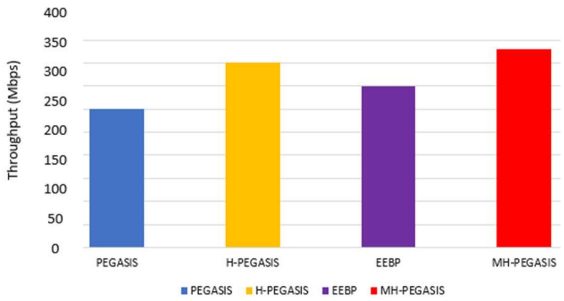

Figure 13. Throughput

Figure 13. shows that PEGASIS has less throughput than other protocol due to long distance between nodes, but it has more throughput than LEACH due to less message overhead. H-PEGASIS has high throughput than PEGASIS due to low delay in transmission packets has high delay than H-PEGASIS, hence highest delay means less transmission of messages in a given time.MH-PEGASIS has no delay thus it has highest throughput among all protocols.

9. Conclusion:

In this paper we studied and analyzed hierarchical routing protocols which further divided into two types Hierarchical Cluster Based routing protocols which include LEACH, LEACH-C and EEE LEACH and chain-based routing protocols include PEGASIS, H-PEGASIS, EEBP and MH-PEGASIS. We review the performance of these 7 protocols on the basis of different evaluation parameters including transmission delay, throughput, energy consumption LEACH performed best in terms of energy conservation and network's lifetime, but it takes more transmission time to send data to base station, which degrades its value of Throughput. On the other hand, LEACH protocol has the highest throughput due to direct data transmission to base station than EEE LEACH and LEACH-C. While LEACH-C protocol behaves normal in terms of throughput, residual energy and transmission delay. In chain base routing protocols, we have concluded that among other protocols MH-PEGASIS is better because it has no delay, data transmission is done through multi hop which allows faster data routing towards base station through cluster head and thus improves network's life time. Overall performance of chain Based routing protocols is highest as compared to Cluster Based Protocols in terms of Delays, Throughput, lifetime of the network, energy efficiency and other discussed parameters.

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