A Survey on
Hierarchical Routing Technique in WSN

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Abstract: This paper gives detailed survey of hierarchical routing techniques in wireless sensor networks. Routing algorithm provides reliable path from source node to destination node. In Wireless Sensor Networks Energy efficiency is main constraint. For improving life time and energy consumption various routing algorithms have been proposed, such as location based routing, hierarchical routing and data centric routing. Hierarchical routing includes tree based routing, cluster based routing, chain based protocol, and grid based routing. And also compare the hierarchical routing techniques.

I. INTRODUCTION

Like living organisms, various electronic systems rely on data from the real world around it, and the network which provides this type of data is known as Wireless Sensor Networks (WSN). WSN is formed by very small nodes deployed in the area of which parameters like physical or environmental conditions, such as temperature, vibration, pressure, sound or motion collectively are to be measured.

The node measures relative parameters from the surrounding environment and then transforms these physical parameters into electronics signals that can be processed and further transmitted towards destination to monitor parameters to be measured in that area. Generally in many applications the nodes once deployed are inaccessible therefore wireless network needed to form therefore the name wireless sensor network (WSN) [1]. WSNs can contain hundreds of these sensor nodes, and these sensors can communicate either directly to the base station (BS) as well as among each other. As number of sensors increases for sensing it is possible to cover larger geographical area with greater accuracy.

In Wireless sensors to increase the lifetime of networks minimum energy should be used for that delay free processing of data is required. Minimum energy is used by proper grouping of nodes in the clusters. Clustering is design technique to control the network energy consumption. Clusters make a group of nodes as one and decrease the number of nodes for communication. In each cluster one node is selected as a cluster head (CH) on basis of some criteria. Cluster head receive data from nodes and transfer to base station. This technique reduces energy consumption. Several protocols have been described in this paper, which increases the network life time by usage of cluster based approach [2].

II. DIFFERENT TYPES OF ROUTING TECHNIQUES

In WSN there are two routing techniques Network operations based and Network structure based routing as shown in Fig.1 In which network structure based routing is divided into three categories as location based, data centric and hierarchical on the basis of the structure of the network. And QoS based protocols are present on the basis of operations of network.

By considering routing protocols how Hierarchical, Data Centric, Location based routings are employed into wireless sensor networks is explained. Though the division of a network in hierarchical manner is commonly considered as network classification parameter, we will discuss it as technique used in routing protocols and also study some hierarchical routing protocols.

Data centric Routing

It is query based routing technique in which, sensors from node sense the data and send it to the sink node, meanwhile intermediate nodes perform some form of aggregation on the data and send the aggregated data toward the base station. This process requires less energy because of less transmission of data required by means of aggregation from the sources to the sink.

Hierarchical Routing

By dividing arrangements of nodes into clusters energy consumption is reduced in hierarchical routing. Each cluster has a node which can selected as the cluster head. There are various protocols for hierarchical routings which differs in selection of cluster head and behaviour of nodes in inter and intra cluster domain.

Location based Routing

In location-based routing, data is sent in the form of hops from one node to another till it reaches base station. The source node adds the destination address at the starting of every data packet which is required to identify the destination of the packet. Location-based routing uses the location information of the node for higher efficiency and scalability, and it is done with the help of GPS module.
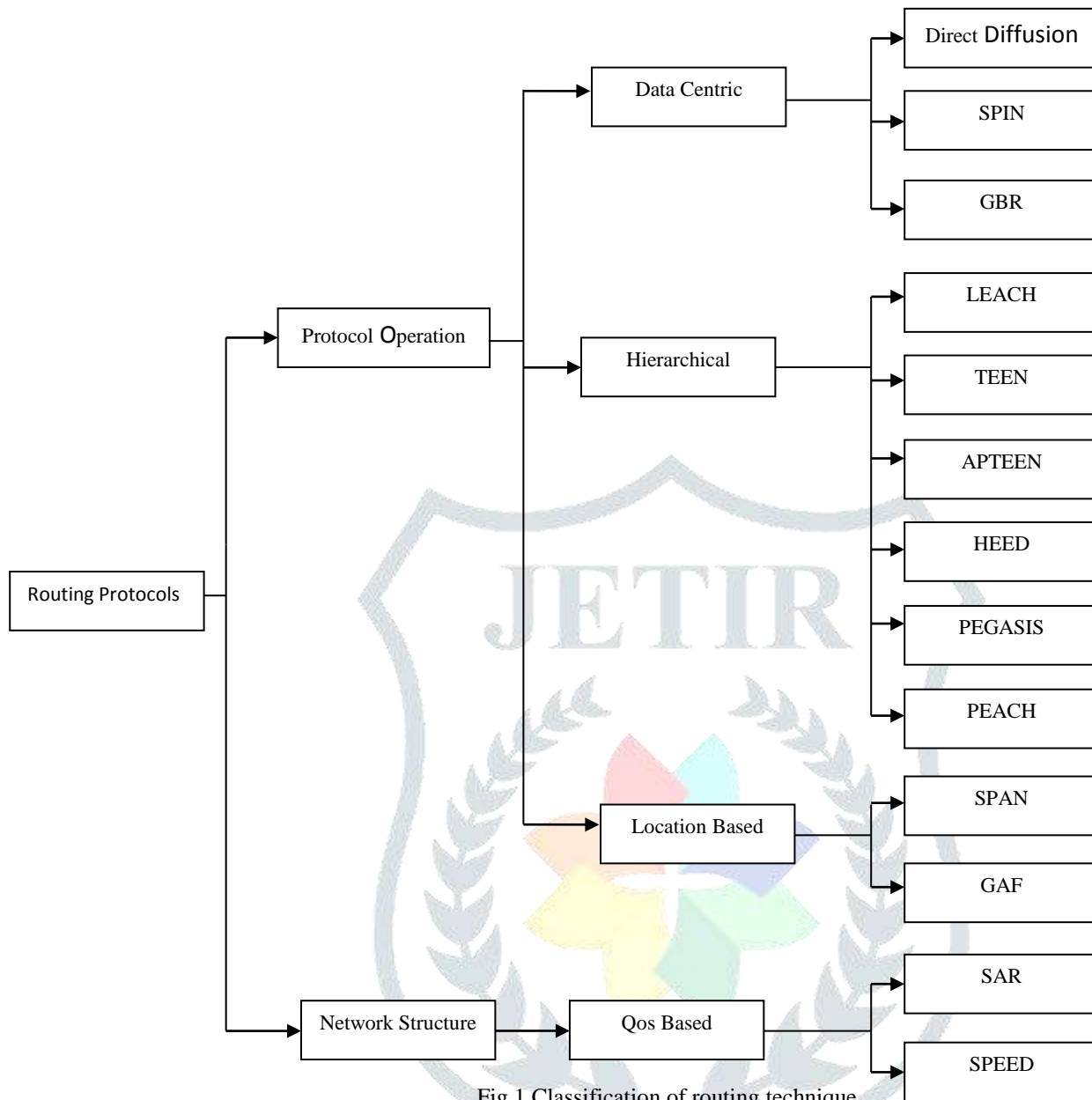
Fig.1 Classification of routing technique

III. HIERARCHICAL ROUTING

Hierarchical routing originally implemented in wire line networks. In this technique nodes having higher residual energy are used to process and transfer the information from lower level to higher in hierarchy, while nodes having low energy are used to perform the sensing in the target area. It improves the lifetime, scalability of network. It reduces the traffic on network [3].

Hierarchical routing improves energy-efficiency and scalability in WSNs. In order to reduce transmitted energy per data frame, data aggregation and fusion is done within a cluster itself before transmitting it to the base station.
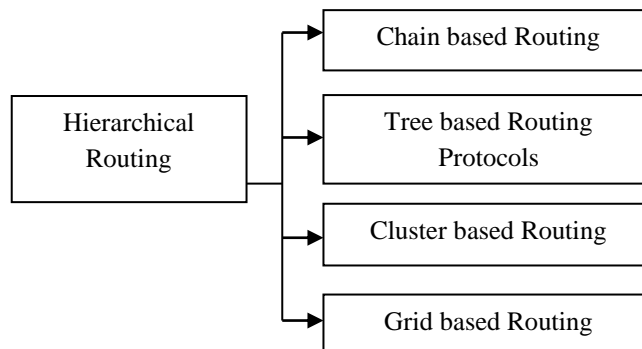

Fig.2 Types of hierarchical routing

A. Chain based Routing

In this routing, to connect the sensor nodes various chains are formed. From chain one sensor is constructed as head to perform data transmission. Data delivered along chain and head node automatically. [4]

Main drawback of chain based topology that due to one or more chains increases number of hops and delay occurred. Sector chain based routing protocol proposed in which target network is divided into sectors. It balances number of nodes and arrange in multiple chains.
Chain based routing protocols are:
i. PEGASIS
ii. CCS

i. PEGASIS

It is a chain based power efficient protocol. In this each node selects its closest neighbor as the next hop arrives in the chain. It communicates only with closest neighbor and turns data transmission to base station. Neighbor nodes are finds with usage of signal strength with calculating distance between nodes. In this energy and lifetime reduces per round.

In PEGASIS it is necessary that all Neighbor nodes are joined with each other so less energy consumption of radio signals, this is disadvantages of this protocol that there is necessary that all nodes must be connected to each other. It uses greedy algorithm for chain construction, avoids clustering overhead, reduces power consumption and reduces the cluster head selection burden with usage of chain.

According to simulations [5], the average energy consumed by MH-PEGASIS is lower than the average energy consumed by the hierarchical PEAGASIS, PEAGASIS and LEACH. Compared to LEACH, number of nodes alive is more in MH-PEGASIS than hierarchical PEGASIS than PEGASIS with LEACH having minimum.
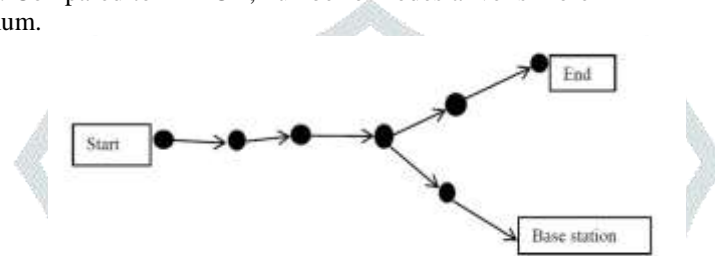

Fig.3 PEGASIS Chain based Protocol

ii. CCS (Concentric Clustering Scheme)

In this routing include the location of base station for less energy consumption and increases life time of network in to concentric circular part say level and each level has assigned a cluster head. According to distance from base station there is assigned a level. The Concentric circular part which is nearest the base station allocates a level 1 and with distance increases level number also increases. In each track multiple chains are formed. At each level cluster head selected and cluster head transfer data to its two neighbor cluster head. Due to communication from CH to CH distances reduced and consume less energy for data transmission.

The concentric clustering scheme is used in enhanced PEGASIS protocol and the data always flow in forward direction towards the base station. Therefore, redundant transmission of the data is avoided and we can save the energy around 35% in comparison with the current PEGASIS protocol.

B. Tree based Routing Protocols

In tree-based routing, hierarchy of sensor nodes forms a tree. Data delivered from leaf nodes to their parent node. Parent nodes after receiving data send to its parent nodes. This process continues up to root node, therefore balancing the energy consumption between the nodes which results in the increased network lifetime [7]. But main drawback of this clustering is that it has too many levels from root to leaf nodes. So it consumes more memory for data transmission.
Various types of tree based clustering are:
i. EADAT
ii. BATR
iii. PEDAP

i. PADAT (Energy-Aware Data Aggregation Tree)

In this algorithm sink node broadcast control message. The sink is considered as the root node in the tree. Sensor node chooses a node which has higher residual energy and shortest path to reach a parent node. If residual power less than it broadcast a help message and changes its status to sleep mode. After receiving help message from parent leaf node find a new parent node if exist. If not any parent node found it goes to danger state. In this routing distance and residual energy to factors are included.

ii. BATR (Balanced Aggregation Tree Routing)

It is a tree-based routing algorithm. It finds an optimum path for transfer of packets from source to destination by means of balanced tree, therefore each node consumes the equal amount of energy. In this assumed that the BS has knowledge about location of all nodes. This routing algorithm starts from base station as root node. Minimum spanning tree is formed which results in minimum energy dissipation cost.

iii. PEDAP (Power-efficient Data Gathering and Aggregation Protocol)

The purpose of PEDAP protocol is to increases network lifetime. The minimum energy cost tree is used for data transmission. This protocol uses 'Prism's minimum spanning tree algorithm [8]. In this algorithm minimum spanning tree is formed resulting weighted undirected graph. Edges which increases spanning of tree for that subset is found which include every vertex, where weight of spanning edges is minimised. The sink is considered as the root of the tree. Minimum weighted edge selected for tree construction, in which one node selected from tree and second which is not in tree.

Hozgur, korpe et.al.[8], demonstrated while LEACH and DTE is not as much optimal but PEGASIS provides a considerable improvement. Compared to PEGASIS, first node lifetime of PEDAP-PA improved about 400%, but lifetime for the last node remains same. Whereas in PEDAP lifetime of the last node increased about 125%, while lifetime for the first node does not changes.

C. Cluster based Routing

Cluster based routing is a hierarchical routing technique. In this cluster are formed with portioning network in to group of nodes. One node selected as cluster head on basis of residual energy. There are various types of clustering protocols as

i. LEACH
ii. HEED
iii. TEEN
iv. APTEEN, etc.

i. LEACH (Low Energy Adaptive Cluster Hierarchy)

Heinzelman et al. [9], demonstrated a hierarchical clustering technique for sensor networks, named as Low Energy Adaptive Clustering Hierarchy (LEACH). In this whole network is divided into clusters, and for aggregation and transfer of data few sensor nodes are selected as cluster heads (CHs) randomly and this role is rotated to each node so that energy is distributed evenly among the sensors in the network. Data arriving from nodes that belong to the respective cluster is compressed by cluster head, and send it in the form of data packets to the BS, so information that must be transmitted to the BS reduces and hence energy is reduced. Collection of data is centralized and periodically performed, hence this protocol performs well if there is a need for continuous monitoring by the sensor network. Collision between clusters is avoided with code-division multiple access (CDMA)/time division multiple access (TDMA) MAC protocol. Sometimes all the data may not need immediately. Therefore by periodic data transmissions energy is wasted and may drain power source of the sensor nodes. After a certain amount of time, function of cluster head rotated randomly therefore the uniform distribution of dissipation of energy is obtained. It is experimentally found that only 5 percent of the nodes needed to act as CH's [10]. Threshold value calculated as:

$$T(n) = \frac{\text{p}}{1 - \text{p} * \left(r * mod\frac{1}{\text{p}}\right)} \quad \forall \, n = G$$
$$T(n) = 0 \qquad otherwise$$

Communication energy is reduced by 8x in LEACH, and also time duration to death of first node increases by 8x whereas last node death duration increased by 3x compared to direct transmission and minimum-transmission-energy routing.

ii. HEED (Hybrid Energy-Efficient Distributed Routing Protocol)

HEED improves lifetime of network by distributed energy consumption. HEED in which cluster head is selected on the basis of factors two factors as residual energy of sensors and communicate cost during transmission of data between sensor nodes. Cluster head selected more than once in cluster. Therefore more energy required for transmission Selection of probability on basis of

CHprob=Cprob*Eresidual\Emax

Eresidual is current energy of nodes. Emax is maximum energy. HEED protocol improves lifetime of network as compare to LEACH protocol [11].

iii. TEEN (Threshold-sensitive Energy Efficient Protocols)

TEEN used for time specific applications. In time specific applications rapidly change possible as temperature change during a day. This protocol forms the clusters firstly and then each cluster head (CH) transmit two threshold values to group nodes. The core idea of TEEN protocol is that the cluster head is selected periodically, probability and randomly [12]. In cluster head selection during TEEN it is not guaranteed that member nodes must belong to similar cluster head so there is high energy consumption. For less energy consumption TEEN uses the multipath and Multi-hop network.

iv. APTEEN (Adaptive Periodic Threshold Sensitive Energy Efficient Sensor Network Protocol)

It is advancement of TEEN protocol. TEEN is depending on fixed threshold values, so not suitable for periodic reports for real time applications. To provide periodic information APTEEN is used. It is a hybrid approach because it sends data with both critical time and periodic time with hierarchical clustering approach [13]. It provides a TDMA based structure for cluster formation. In this cluster heads broadcast threshold values, physical parameters, timing limit. APTEEN consume less memory. Main disadvantage of TEEN and APTEEN is more levels of cluster formation and overhead of threshold values.

As results shown by Manjeshwar, Agrawal et al. [13], the performance evaluation is done between LEACH, TEEN, APTEEN with respect to energy consumption, number of nodes alive over time and total data signals received at the BS respectively. With respect to longevity and energy consumption, the performance of APTEEN lies between TEEN and LEACH. TEEN transmits time critical data, to overcome this periodic transmission is incorporated in APTEEN. As only threshold value change is transmitted in APTEEN it performs better than LEACH.

D. Grid based Routing

In a grid-based routing by the geographic approach network is divided into various grids. It is a greedy algorithm which uses traffic splitting and dynamic range based cluster head to minimize the intra cluster communication cost. It also optimize inter cluster communication cost among cluster heads [14] in this routing performed without routing table. Various routing protocols are as:

i. PANEL
ii. TTDD
iii. HGMR

i. PANEL(Position-Based Aggregator Node Election Protocol)

In PANEL geographical position information of the nodes is obtained through GPS. PANEL assumed sensor nodes constructed in a limited area and this area divided in to geographic clusters. It used in inter cluster communications. Reference point is computed according to position of clusters. The node which is the nearest to the reference point is considered as CH, therefore both synchronous and asynchronous applications are satisfied. PANEL ensures load balances and each node has given same chance to become aggregator [15].

ii. TTDD (Two-Tier Data Dissemination)

This routing technique provides efficient and scalable data delivery to multiple mobile sinks. Grid based structure allows to mobile sinks continuously receive data in local area [16]. In this approach each source node with sink node makes a rectangular grid around itself and it becomes a crossing point of this grid. To form grid location enabled sensor nodes are required. When sink node require data, it send query message within a grid cell and the source nodes responds to these queries by forwarding data to the sink through same path.

iii. HGMR (Hierarchical Geographic Multicast Routing)

HGMR is the combination of both HRPM (Hierarchical Rendezvous Point Multicast) and GMR (Geographic Multicast Routing) protocols, in which HRPM is reduces the encoding overhead while GMR improves the forwarding efficiency respectively. In HRPM, the network is partitioned into multiple cells hierarchically using the mobile geographic tagging idea. It provides energy efficiency and scalability to large networks [16].

As HGMR is combination of HRPM and GMR; HGMR less number of transmissions than GMR, but an encoding overhead similar to HRPM if the network size increases. PDR of HGMR is much higher than GMR but very close to HRPM. Finally, HGMR performs better than other two protocols even non-uniform distribution of group member.

E. Advantages of clustering

i. Clustering reduce overhead for data transmission between network topology.
ii. Consume less memory during routing between sensor nodes.
iii. It provides bandwidth reusability and reduces collisions of channels.
iv. Network stability increases due to less usage of energy by clusters.
v. Only Cluster heads of several nodes and gateway nodes maintain routing in network.

F. Analysis of Hierarchical Routing Techniques

Table 1. Chain based Routing Techniques

Various Parameters	PEGASIS	CCS
Power Usage	High	Low
Scalability	Good	Low
No. of cluster groups	Single	Multiple
Selection of Cluster head	Based on distance from BS	Based on Distance from BS
Traffic	Low	High
QoS	Low	Low
Energy efficiency	High	Very low
Algorithm Complexity	High	Moderate

Table 2. Cluster based Routing Techniques

Various Parameters	LEACH	HEED	TEEN	APTEEN
Power Usage	High	Low	High	Moderate
Scalability	Good	Good	Good	Good
No. of cluster groups	Multiple	Multiple	Multiple	Multiple
Selection of Cluster head	Based on probabilistic approach	Based on residual energy	Based on attribute	Based on attributes and time limit
Traffic	High	High	Low	Low
QoS	Low	Low	Moderate	Moderate
Energy efficiency	Poor	Poor	High	High
Algorithm Complexity	Low	Low	High	High

Table 3. Tree based Routing Techniques

Various Parameters	EADAT	BATR	PEDAP
Power Usage	Moderate	High	Moderate
Scalability	Low	Low	Low
No. of cluster groups	Single	Multiple	Multiple
Selection of Cluster head	Depends on root of node	Depends on root of node	Depends on root of node

Traffic	High	High	Moderate
QoS	Low	Moderate	Low
Energy efficiency	Moderate	Low	Moderate
Algorithm Complexity	Low	Moderate	Moderate

Table 4: Classification of Hierarchical Routing Protocols

Routing protocol & Author & Routing technique	Key features & Recent developments
LEACH: Low Energy Adaptive Clustering Hierarchy Heinzelman,2000 Hierarchical Routing	i. Centralized, Hybrid & distributed clustering implemented, which is based on the residual energy in each node. Cluster head selected deterministically or randomly. ii. Two phases, Setup Phase (Cluster formation) and steady phase (data transfer phase). iii. Two types of data transmission techniques implemented single-hop technique and multi-hop technique. iv. **DL-LEACH (Dual-hop Layered-LEACH)**, July-2016:- Multi-hop routing technique is implemented in this protocol which overcomes two-hop transmission distance of LEACH [17]. vi. **LEACH-MAC (LEACH-Medium Access Control), July 2016:-** randomness problem reduced by restricting the number of cluster head advertisements [18].
TEEN: Threshold sensitive Energy Efficient sensor Network A.Manjeshwar & D.P Agrawal, 2001 Hierarchical Routing	i. For cluster head selection two types of threshold technique is used which is soft threshold or hard threshold. System performs better if users don't get threshold value. ii. Data reaches the user in very short time therefore it is suitable for real time applications. iii. Soft threshold can be varied, depending on the criticality of the sensed attribute and the target application. As threshold value reduces we can get more accurate picture of the network, therefore trade-off between accuracy and energy efficiency can be controlled [19].
PEGASIS: Power Efficient Gathering in Sensor Information System Lindsey and Raghavendra ,2002 Hierarchical Routing	i. In PEGASIS, algorithm is based on chain. Each node aggregates data from downstream node and send it to upstream node [20]. ii. Packet delay can be reduced in hierarchical PEGASIS therefore data gathering problem can be solved [21]. iii. During chain building Improved Energy Efficient PEGASIS takes tentative and very complicated threshold value which forms long chain, allowing nodes to dissipate small power in data transfer, which enhances the lifetime of the network by saving energy [22].
HEED: Hybrid Energy Efficient Distributed O.Younis, and S.Fahmy, 2004, Hierarchical Routing	i. As name indicated HEED based on distributed clustering. Considered as improvement over leach. The clustering is done in rounds, and CH is selected on the basis of residual energy in each round. ii. H-HEED(Heterogeneous Hybrid Energy Efficient Distributed), 2010- Specially developed for heterogeneous type of network. iii. RHEED- clustering operation divided into rounds [23].
APTEEN: Adaptive Periodic Threshold–sensitive Energy Efficient sensor Network A.Manjeshwar and	i. Hybrid clustering, limitations of proactive and reactive network has been overcome in this protocol [21]. ii. By sending periodic data it gives continuous monitoring, as well as by sending drastic change in data it makes it compatible to the time critical situation [24]. iii. Limitation is complexity required to implement threshold function and count values [24].

D.P.Agrawal,2009 Hierarchical Routing	

IV. Conclusion

Routing plays an essential role in WSN. The nodes are battery operable and unattended once deployed. In this paper, we studied comparison between various hierarchical routing protocol and previous work and recent development on various routing protocols. A detailed study of different versions of protocols has been done. Although most of these protocols look similar to conventional protocols such as LEACH, GBR, PEGASIS, but there is still many challenges overcome and modifications was done. This paper would be helpful for comparison between various routing protocols for future researchers.

In Hierarchical routing technique nodes are grouped to form clusters and the interactions between the cluster nodes are controlled by cluster-head. In this paper we described various types of hierarchical routing techniques and compare on basis of scalability, energy efficiency, QoS *etc* is done. Also various recent trends in these techniques are explained. Overall this paper will demonstrate complete analysis of the hierarchical routing techniques and superiority over each other.

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