IOSR Journal of Computer Engineering (IOSR-JCE)
e-ISSN: 2278-0661,p-ISSN: 2278-8727, Volume 22, Issue 5, Ser. III (Sep. – Oct. 2020), PP 27-34
www.iosrjournals.org

A Novel approach: Design Issues and Challenges in Hierarchical Routing Protocols for Wireless Sensor Networks.

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Abstract:
A Wireless sensor network (WSN) consists of many devices like sensor nodes, a power unit, processing and storage element etc. A normal routing protocols cannot be used in WSNs because of the internal characteristics of WSNs that distinguishes it from other wireless networks. Recent years it has been observed a lot of advancement in wireless communication technology. Implementation of efficient system in a multidisciplinary research such as WSNs is becoming very difficult task.Cluster-based routing provides certain advantages like scalability, increased network lifetime and efficient data aggregation. Routing protocols are classified into four groups: Data centric and flat architecture, Hierarchical, Location based and finally Quality of Service (QoS) based protocols. In this paper we discuss the design issues in hierarchical routing protocols for WSNs by considering its various dimensions and metrics such as Energy consumption, Scalability, Addressing, Robustness, Topology, Mobility, Power Usage, Traffic and QoS. This paper presents a comparative study for different hierarchical routing protocols for WSNs, which are analyzed and compared based on performance parameters, and finally summarizes the problems of routing protocols along with their limitations.

Keywords: *Wireless Sensor Networks, Routing protocols, Efficient System, Performance parameters, Cluster Network, Quality of Service, Scalability.*

Date of Submission: 28-10-2020 Date of Acceptance: 09-11-2020

I. Introduction

Wireless sensor network (WSN) is a hot research topic and one of the emerging technology. In last couple of decades a significant advances have been developed [20]in different parameters of wireless communication. The lower layer of sensor protocol stack mainly addresses the needs of simple but robust modulation, transmission, and receiving techniques which has been designed for different network scenarios and applications. But at higher layers, efficient communication protocols have been developed to address various networking issues[21]. The development of WSNs largely depends on the availability of low-cost and low-power hardware and software platforms for sensor mote networks[22]. With the micro-electro mechanical system (MEMS) technology, the cost and the size of a sensor node has been significantly decreased. In this paper, first a briefdiscuss on the hardware sensor architecture and its design objectives[4] has been given. And previous works on hierarchical routing protocols[10, 22, 11,12,13] for WSN and then compared by considering the performance metrics. A comprehensive survey of various routing protocols and review of hierarchicalrouting protocols[22] for sensor networks is presented in last section.

II. Hardware Architecture Of Sensor Node For Wsn

Energy efficient routing protocols has a great role in extending the time of the WSNs by making routing decisions based on the battery constraints. Wireless sensor networks consist of large number of sensor nodes and all nodes are configured as a dynamic topology. Each sensor node has limited battery resources so it must be recharged or replaced whenever it is required. Network life time is mainly depends on the batteries of sensor nodes, which intern introduced the need of energy efficient routing protocols. Schematic representation of sensor node hardware architecture is given in the Figure 1. A sensor node consists of Sensing unit, Processing unit, Transmission unit. Sensing unit consists of a sensors and ADC (Analog to Digital Converter). Processing unit receives the transformed signal or information from ADC. Processing is carried out by the processor module and storage unit is used to help in processing of the task and stores the result. Transmission unit consists of a transceiver module, used for communicating with other sensors or the sink in WSN. Mobilizer, Position Finding unit and Power unit are optional components of sensor nodes.

Generally, majority of the power is consumed by wireless transmission unit. The transmission module has four states: Send, Receive, Idle and Sleep [20]. Sending and receiving signals take about two third of sensor node energy consumption. Efficient routing algorithms are required to reduce the energy consumption, increase

the lifespan of WSNs and also improve the quality of data transmission.Other group of routing protocols focuses on finding the shortest path from the source to destination node without considering the energy consumed in transferring the data packet.

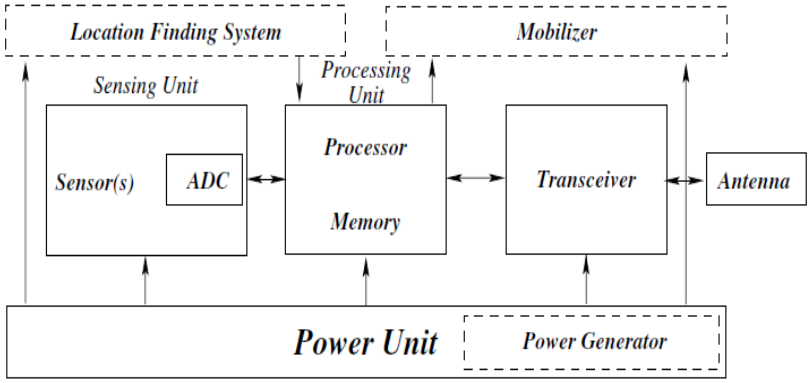

Figure 1: General hardware architecture of a sensor node.

Sensor nodes are used to monitor physical environmental condition, compute and process and transmit this information to main network. The area covered by Wireless sensor nodes is called region of interest (ROI). These sensors can communicate to each other and also to afew external Base station [4]. WSN consists of hundreds and thousands of sensor nodes which communicates using radio signals. A simple sensor monitors only physical phenomenon where as a complex sensor is required to have a track of multiple processes.

The capability of a sensor node is limited which makes them inadequate in gathering valuable information from a particular domain [5]. The sensor nodes in WSNs perform the task of collecting raw data from deployed region along with data storage, some local data processing and routing [6]. The processed information is then transmitted to the base station. Therefore, the sensor nodes consume energy and energy constraints has become a main design goal for WSN [7]. To achieve high energy efficiency, extended lifetime and scalability objectives, the designer has widely adopted the cluster formation methods in medium and large-scale WSN environments.

The nodes are grouped as aclusters in hierarchical network and the local interactions between cluster members are controlled through a cluster head as shown in Figure 2. Based on this architecture, many hierarchical routing protocols have been developed to address the scalability, energy consumption and also other challenges of WSNs.The cluster heads can also form another layer of clusters among themselves before reaching the sink.

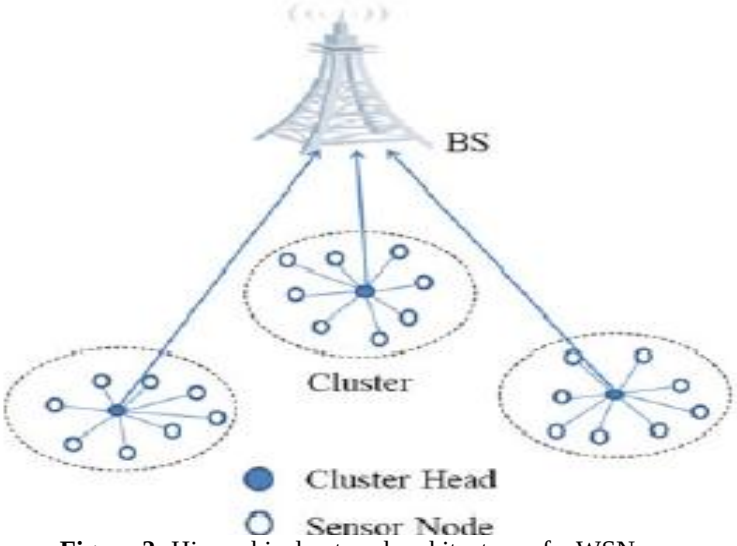

Figure 2: Hierarchical networkarchitecture of a WSN

III. Wireless Sensor Network Design Objectives

The following design objectives are considered in the design of sensor network [4]as the sensor networks are application specific:

i.Small size and Low cost[4]**:**Sensor nodes are normally deployed in a harsh and/or hostile environment in large numbers. Reducing the node size can make node deployment easier. It will also minimizes the power consumption and cost of sensornodes[20].

ii.Low powerconsumption[4]: Sensor nodes are powered by battery and it is often very difficult to charge or recharge. It is very much required to reduce the power consumption of sensor nodes so that the lifetime of the sensor nodes, as well as the whole network isprolonged.

iii.Scalability: As the number sensor nodes in sensor networks varies from few hundreds to thousands, network protocols designed for sensor networks should be scalable to different networksizes.

iv.Reliability: Network protocols designed for sensor networks must provide error control and correction mechanisms for reliable data transmission or delivery over noisy and time-varying wireless channels.

v.Self-configurability: Once a sensor network is deployed, sensor nodes should be able to dynamically monitor themselves into a communication network and reconfigure their connectivity in the event of any topology changes and node failures.

vi.Adaptability: In sensor networks, a node may fail, join, or move, which would result in changes in node density and network topology. Thus, network protocols designed for sensor networks should be adaptive to such density and topologychanges.

vii. Channelutilization: Sensor networks have limited bandwidth resources.The communicationprotocolsdesignedforsensornetworksshould efficiently make use of the bandwidth to improve channel utilization.

viii. Faulttolerance [20]**:**Sensornodesaresubjected to failures due to harsh deployment environments and unattended operations. Thus, sensor nodes should be fault tolerant and havetheabilitiesofself-testing,self-calibrating,self-repairing, andself-recovering.

ix. Security:A sensor network should have effective security mechanisms to prevent the data information in the network or a sensor node from unauthorized access or maliciousattacks.

x. QoSsupport: In sensor networks, different applications may have different QoS requirements in terms of delivery latency and packet loss. Thus, network protocol design should consider the QoS requirements of specific applications.

IV. Challenges And Design Issues In Hierarchical Routing Protocol

In WSNs, clustering architecture plays an important role. Clustering improves bandwidth utilization, reduces the useful energy consumption and it also reduces the wasteful energy consumption as a result of reduced overhead [2]. The challenges have become a subjects of research interest and few are listed below [3].

***Network Lifetime*:** The energy constraints on sensor nodes significantly affect the network lifetime for sensor nodes in a wireless network. Clustering methods effectively helps in reducing energy usage in intra-cluster and inter-cluster communication, which intern increasing network and sensor node lifetime.

***Limited Energy*:** Sensor nodes in WSNs are operated by small size batteries, so their energy storage has a limit. This limited energy must be used efficiently, and must be taken into consideration.The overall energy consumed in the network can considerably reduce by applying proper energy efficient hardware and software protocols to manage limited battery life efficiently.

Limited Capabilities: The abilities of sensor nodes like processing, communication range, storage and memory are get limited by a small amount of stored energy and small physical size of sensor nodes. It is possible to make efficient use of shared resources within a geometrical structure by applying good clustering algorithm.

***Cost of Clustering*:**As we know, Clustering plays an essential role, but at some cost. Certain resources like processing tasks and communications are required in creating and maintaining the clustering topology.

***Cluster Formation and Selection of Cluster Heads*:** The physical dimension of a cluster or the number of sensor nodes within a cluster plays a key role in the functioningof a cluster. Therefore, the designers have to examine the cluster formation in a network while designing a particular application.

***Scalability*:** The coverage range is limited in WSNs. This leads to the deployment of thousands of sensor nodes where a relatively larger area has to be covered. Therefore, the routing protocols in such frame work must be capable of handling a large amount of sensor nodes.

***Data Aggregation*:** The larger wireless sensor networks are often densely populated. In such scenario, there is always a possibility that multiple nodes senses similarinformation. Data aggregation is a process which differentiates useful data from sensed data.

***Synchronization*:** Energy usage can be minimized by permitting sensor nodes to repeatedly schedule sleep interludes through particular slotted transmission scheme such as TDMA (Time Division Multiple Access). To have a proper setup and maintainable transmission schedule, such schemes require certain synchronization mechanisms. Thus, synchronization and scheduling will have a great impact on overall performance of WSNs.

Secure Communication: Communication in WSNs is through wireless medium using IEEE 802.15.1 and IEEE 802.15.4 protocols. IEEE defines physical and Medium Access Layer for Low Rate Wireless Personal Area Networks (LR-WPAN). Three frequencies are supported by physical layer, i.e. 2450 MHz, 915 MHz and 868 MHz. An energy efficient and secure inter-cluster as well as intra-cluster communication is one of the most important challenges for clustering protocol design.

***Repair Mechanisms*:** Because of the absence of static structure, the WSNs are frequently subjected to node movement, delay, interference and node demise. A link failure can occur as a result of these situations. Therefore, while focusing on clustering schemes, link recovery and reliable data communication mechanism must be considered.

Security:WSNs operate on remote location and remains unattended which increase their chances of being exposed to malicious intrusion and attacks. All WSNs must be protected from unauthorized access to data. There are some fundamental security requirements to be carried out by WSNs like: Data Authentication, Data confidentiality, Data integrity, Availability and Redundancy. Different types of attacks possible in WSNs are Goal-oriented, Performer-oriented and layer-oriented. Goal-oriented attacks comprise of active and passive attacks.

***Quality of Service*:** QoS in WSNs is very important aspect from an overall network standpoint. The services are prompted depending on the functionalities and applications of the networks. The main focus of most existing clustering routing algorithms is to provide energy efficient network utilization rather than QoS support.

V. Methodology

1. ROUTING PROTOCOLS IN WSN

Routing protocols can be categorized into various groups depending on the network structure, and protocol operations. In this paper two main routing protocols are emphasized. The first group is the traditional protocols that does not take energy consumption into account when making routing decision and the next group is the energy efficient protocols that make routing decisions based on the energy consumed in transferring packets from source to destination node. First category of routing protocols are further classified as data centric routing, hierarchical or clustering based protocols, negotiation-based routing protocols, location-based protocols, multipath routing protocols, query-based routing, QoS-based routing. Energy efficient protocols are further classified based on homogenous and heterogeneous[21] WSNs as given in Figure 3.

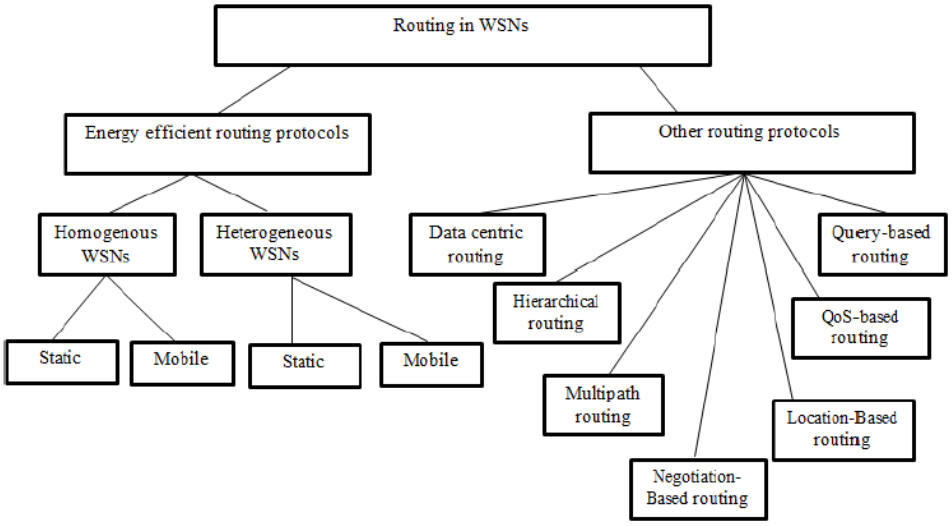

Figure 3: Classification of routing protocol

4.1 Data Centric Routing

Data collection is performed by the intermediate sensors on the path form the source node to the base station in data centric routing [7]. The aggregation performed in data centric routing results in saving energy. Unwanted data form multiple nodes is removed, only summary of data is transmitted like minimum, maximum and average values. Some example protocols for data centric routing are discussed in the following sections.[21, 22]

4.1.1 SPIN:(Sensor Protocols for Information Negotiation)[8] is an adaptive protocol which works in an energy constraint environment by efficiently distributing information in WSNs. The name 'Meta-data' is used to represent the sensor node data. This meta-data negotiations process is used to eliminate transmission of redundant data. The decision of SPIN is mainly based on knowledge of the of the resources available and application-specific knowledge of the data. This makes the sensors efficiently distribute the data with in a limited energy supply.

4.1.2 Directed Diffusion[9]: This is a type of data centric routing protocol. Here data's/information's are named using attribute-value pair. A sensor node request data by sending interests for named data. Sensor'sneighbouringnode has to produce data matching to the interest which is drawn down. Each sensor node can interpret, transform, aggregate, cache data and it may also direct interests based on previous information which is present in cache data.

4.1.3 Rumour/Gossiping Routing[10]: Itis a method used for routing a queries. When an event occurs, which consists of a set of sensor readings observed by the node or a query. This request information is directed to the node where the event is observed. This is done by sending a query on a random walk until it finds the event path, instead of flooding the network with the query. When the query occurs, the path of the event all subsequent queries can be directed on the discovered path. The energy required for transmitting information can be reduced by discovering routes rather than flooding the network with queries.

4.1.4 Flooding: It is a simplest routing algorithm. Whenever a node receives a packet, it broadcasts the received packet to all of its neighbors. This process continues until all the nodes in the network receive the packet. As a result, a packet can be *flooded* through the whole network. The flooding can be controlled by limiting the rebroadcast until the packet reaches the destination or the maximum number of hops is reached. The advantages of flooding are in its simplicity. Since a node does not require neighborhood information, and flooding does not require costly topology maintenance and complex route discovery algorithms.

4.2 Hierarchical or Cluster based routing

In Hierarchical routing protocols the nodes are grouped into two types. A high energy node which is used to process and send the information and a low energy nodes are used to sense the data within region of interest (ROI). A cluster is created with a chosen cluster head which is the node with high energy. The proper selection of CH (Cluster Head) contributes to increase the scalability, lifetime and utilization of energy in an efficient manner in WSNs. The number of messages transmitted to base station by data aggregation and fusion process can be reduce by using hierarchical routing protocol. Hierarchical routing can be organized as a two layers routing structure. First layer is used to select the cluster heads and second layer is used to route the data. Few important hierarchical clustering protocols are discussed in the following sections.

4.2.1 LEACH:(Low-Energy Adaptive Clustering Hierarchy)[11] is very popular, commonly used energy-efficient hierarchical clustering algorithm. A group of clusters are created in LEACH, cluster head are chosen on randomized rotation policy to distribute the energy load among the sensors nodes in WSNs. CH forwards the data to the base station. A round policy techniqueis categorised into two phases, the *setup phase* and *steady state phase*. During the setup phase, clusters are formed, CHs are selected, and the cluster communication schedule is determined. In steady state phase, data communication between the cluster members and the CH is performed. Initially, LEACH performs data aggregation or fusion technique to reduce the amount of data that must be transmitted to the base station. It also make data dissemination and routing more scalable and robust. LEACH also changes the cluster head role dynamically such that thehigh-energy consumption in communicating with the sink is spread to all sensor nodes in the network.

4.2.2 TEEN:(Threshold sensitive Energy Efficient sensor Network protocol)[13] is mainly focuses on reactive WSNs which respond immediately to changes in the parameters sensed. These protocols were designed for time critical applications. Here each sensor node senses the data continuously but does not transmit the data. Two types of threshold are set by CH sensors: hard and soft threshold. When the soft threshold is reached by the sensed attribute, the sensor node switched on its transmitter and starts transmission. When hard threshold is reached by the sensed attribute, the sensor node sensing this value switch on the transmitter and transmits the sensed value to its cluster head. Power consumption is reduced in TEEN because of hard threshold method.

4.2.3 APTEEN:(Adaptive Periodic TEEN) Extension of TEEN is known as APTEEN. It captures periodic data along with reacting to time critical events [14]. In APTEEN, CHs broadcast attributes which consists of: a. Physical parameters which are of interest to the user, b. Hard and soft thresholds, c. Schedule which assigns a

slot to each node, d. Count time is the maximum time period within which the node must send the report. APTEEN relatively combines both reactive and proactive routing policies.

4.2.4 PEGASIS:(Power-Efficient Gathering in Sensor Information Systems)[12]: The aim of the PEGASIS protocol is to provide improvements onLEACH protocol. PEGASIS used to address the overhead caused by the cluster formation in LEACH by constructing chains of nodes instead of clusters. The chain construction is performed according to a greedy algorithm.In greedy algorithm, nodes select their closest neighbors as next hops in the chain. Here each node has a global knowledge of the networks. The chain construction starts from the nodes that are farthest from the sink. As a result, each node only keeps the track of its previous and next neighbour in the chain instead of maintaining complete cluster formation.

4.3 Location-Based Routing Protocols

Here each individual sensor nodes are addressed by means of their location. Distance between the neighbouring nodes are calculated based on their location. Which is used to estimate energy required for transmission of data. Global Positioning System (GPS) can also be used to get the location information of the nodes if the nodes are equipped with small low power GPS receiver. There is a provision in location based routing protocols that, if there is no activity, a node can go to sleep. Which helps in energy conservation in WSNs. Few location-based routing protocols are discussed in the following paragraphs.

4.3.1 GAF: (Geographic Adaptive Fidelity)[15] is an energy aware location-based routing algorithm. It divides the network are into fixed zones by creating a virtual grid. In each zones sensor nodes play different roles and collaborate with each other for specific application. In each zone one sensor node is selected to stay awake for certain period and the rest of the nodes will go to sleep. The node selected is responsible for monitoring and reporting data to base station on behalf of all the nodes in the zone. Power consumption is reduced in GAF by turning off unnecessary nodes in network without affecting routing fidelity.

4.3.2 GEAR:(Geographic and Energy Aware Routing)[16] uses geographic information to propagate queries to appropriate regions. It uses neighbor selection heuristic to restrict the number of neighbor to route the packet towards the destination region. Energy is conserved by GEAR. It keeps an account of estimated cost and learning cost of reaching to destination. Estimated cost is the combination of residual energy and distance from node to destination. Learning cost is refinement of estimated cost incurred for routing around holes in networks. Hole occurs when the node does not have any closer neighbor than itself to the target region. There are two phases in the algorithm: first phase is forwarding packets towards the target region and second is forwarding the packets within the region.

4.4 Multipath routing protocols

Two types of routing paradigms are possible with respect to data transmission between source and base station. First is single path routing where there is a single path from source to base station. Second is multipath routing where there are more than one path from source to base station. All the earlier above discussed approaches for routing are a single path where each source sensor sends its data to the base station via shortest path. Whereas in multipath routing protocols each source sensor has to first find the shortest paths to base station and divide the load equally among these paths. When the primary path fails, a fault tolerance of the protocol is dependent on the number of alternate paths that exist between the source and destination. The alternate paths are kept alive by periodically sending messages on the path. Therefore network reliability is increased.

Authors proposed in [17] an algorithm that routes the data through a path whose nodes have highest residual energy, this path is changed whenever a better path is discovered. Energy depletion of primary path node through continuous use is avoided by changing the paths. Another approach in [18] uses suboptimal paths to increase the lifetime of WSNs. The choice of the path is based on probability of the value of energy consumption of the path. In [19] a multipath routing algorithm was proposed to deliver data in unreliable environment. Network reliability is increased by providing many paths form sources to destination which increases the traffic on the network. Algorithm split the data packets into sub packets and each sub packet is send through one of the available multipath. In this approach original data packets can be reconstructed at the destination node even if some of the sub packets are lost during transit.

4.5 Query-based routing

In this type of routing the destination nodes propagates a query for data (sensing task) from a node through the network. The node that holds the data matching to the query and send back the data to the initiator of the query. These queries are described in high level languages or natural languages. Directed diffusion algorithm is an example of query based routing techniques.

4.6 Negotiation-Based Routing Protocols

These protocols uses a high level data descriptors to eliminate the redundant data transmission through negotiations. Communication decisions are made on the available resources. The main goal of the negotiation based protocols is to suppress the transfer of duplicate data to the base stations or to the next node by sending a series of negotiation messages before beginning the transfer of the data. SPIN protocol is an example of negotiation based protocols.

4.7 QoS-based Routing

In these types of protocols a balance between data quality and energy consumedis proposed. The network has to satisfy certain QoS metrics such as energy consumed, delay, bandwidth etc., when delivering data to the base stations.

VI. Results And Discussion

In this section, it has been explained the comparison between some of the popular hierarchical routing protocols like LEACH, HEED, EECS, EEHC, LEACH-VF, PEACH, CCM, PANEL, TTDD, GAF, SLGC, HGMR, CCS, PEGASIS, and TSC in WSNsbased on important metrics/constraints like cluster stability, scalability, mobility, energy efficiency,data aggregation, and delivery delay in Table 1.

The following points are observed from this comparative study:

- **Cluster Stability:**Cluster based routing protocols provide better cluster stability than others.
- **Scalability:**Very few protocol (e.g., HGMR) provides very high scalability and other providesmoderate to low scalability.
- **Mobility:**Majority of the protocols provide no mobility (e.g., EECS, EEHC) while few protocols provide limited mobility (e.g., HEED, CCM).
- **Energy efficiency:**Cluster based protocols provides better efficiency than others.
- **Data Aggregation:**Most of the grid based protocols does not support data aggregation.
- **Delay:**The delivery delay varies from very low (e.g., SLGC) to very high (e.g., TTDD, PEGASIS).

Table 1: Comparison between different hierarchical routing protocols in WSNs.

Protocol Name	Cluster Stability	Scalability	Energy Efficiency	Mobility	DATA Aggregation	Delivery Delay
LEACH	Moderate	Very Low	Very Low	Limited	Yes	Low
HEED	High	Moderate	Moderate	Limited	Yes	Moderate
EECS	High	Low	Moderate	No	Yes	Low
EEHC	High	Moderate	High	No	Yes	Low
LEACH-VF	High	Very Low	Moderate	Limited	Yes	Low
PEACH	High	Moderate	Very High	Yes	Yes	Moderate
CCM	High	Very Low	Low	Limited	Yes	Low
PANEL	Low	Low	Moderate	No	No	Moderate
TTDD	Very High	Low	Very Low	Yes	No	Very High
GAF	Moderate	High	Moderate	Limited	No	Low
SLGC	Moderate	Very Low	Moderate	No	No	Very low
HGMR	High	Very High	Low	No	No	Moderate
CCS	Low	Low	Low	No	No	High
PEGASISI	Low	Very Low	Low	No	Yes	Very High
TSC	Moderate	Moderate	Moderate	No	Yes	Moderate

VII. Conclusion

Wireless sensor networks attracted the researchers from many years and find their application in an extensively broad spectrum like: environmental monitoring, security surveillance, and military applications etc. Routing in wireless sensor networks is main area of research. In this paper, it has been presented a review of the important hierarchical routing protocols for sensor networks. Energy Efficiency and QoS are the main challenges in wireless sensor network. Advanced routing protocols such as PEGASIS and ECHERP can be further analysed, simulated and enhanced by considering performance metric as per application. In research work, it has been focused on certain merits and limitations of some popular network structure based hierarchical routing protocols and presented in the form of table. In future, the information provided in this paper can be used by researchers willing to devise their own hierarchical routing protocol.

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Mrs. Kalpavi CY, et. al. "A Novel approach: Design Issues and Challenges in Hierarchical Routing Protocols for Wireless Sensor Networks." *IOSR Journal of Computer Engineering (IOSR-JCE)*, 22(5), 2020, pp. 27-34.