Types of Cluster - Based Routing Protocols in Wireless Sensor Networks: A Survey.

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Abstract

Wireless sensor networks consist of several nodes, the nodes are used to sense the data and send it to the base station. Wireless sensor networks are classified according to the network structure into three categories; flat network structure, location based network structure and hierarchical (cluster -based) network structure. The hierarchical network structure is classified into three categories which are block cluster- based routing protocols; grid cluster -based routing protocols and chain cluster based routing protocols. The structure of the network has impact on energy efficiency, delivery delay, scalability, cluster head selection, data aggregation and network lifetime. In this paper we will discuss the different types of hierarchical network considering many examples for each type.

1. Introduction:

Wireless sensor network (WSN) consists of a large number of nodes and one and more base stations. Sensors usually consist of a transmitter, a receiver, a microcontroller, an electronic circuit, and a power supply. The power source is usually a battery. These nodes are small in size and can perform several functions namely event sensing, data processing and data transmission [1]. The ability of a single sensor node is usually limited, making it unable to collect the data, so inorder to accumulate a large amount of data, hundreds or thousands of sensors are deployed which act as a collective. The sensors are operated by a non-rechargeable battery and cannot be replaced [2].

Therefore, the design of the network structure in a suitable way is import ant and should consider the energy efficiency, delivery delay, scalability, cluster head selection, data aggregation and network lifetime [3]. The network structure is divided in terms of design to flat network structure, hierarchical (cluster- based) network structure, location- based network structure [4].

In this paper we will talk about many cluster based routing protocols for WSN considering different categories and emphasis their point of strength and weaknesses. Many routing metrics are considered including energy efficiency, delivery delay, scalability, cluster head selection, data aggregation and network lifetime.

2. Background:

In this section, the general structure and benefits of the hierarchical network structure clarified in addition to clarifying the clustering objectives.

2.1 Hierarchical (cluster- based) Network Structure:

In hierarchical network protocols, the nodes are divided into groups that have a cluster head, the cluster head communicates with the higher level.

Cluster-based routing protocols are the most efficient in wireless networks in terms of network scalability, increased energy efficiency and low data re-transmission [5].

The cluster head works to collect data and reduce the excess packets and works to reduce energy consumption by scheduling activities in the cluster.

Hence, there are several advantages of using the hierarchical network such as reducing the size of the routing table saved on different nodes. Moreover, using the cluster head help in extending the life of the battery in the sensor and increasing the life of the network [4].

2.2 Clustering objective:

The nodes are collected in WSN to achieve a set of goals.

The main objectives to be achieved in wireless networks design are [3]:

1. Energy Efficiency: routing protocols must heap network alive for as long as possible, as sensor holding is known to derive its energy from the battery. This battery cannot be replaced or recharged, so when building network protocols, the power should be utilized in an efficient way.
2. Scalability: the number of sensors in the network is composed of hundreds or thousands, and therefore the network protocols are designed to be able to accommodate the sizes of different networks.
3. Delivery Delay: is the time it takes to transfer data from its source to the base station. Routing protocols try to reduce this time as possible.
4. Network Lifetime: protocols should increase the network lifetime, this is achieved by saving power within the network.
5. Data Aggregation: collecting data with each other, holding sensor close to each other sends data to the cluster head to which the group belongs and the group head is responsible for sending data to the base station, thus saving power.

Hence, aforementioned objectives must be considered in the design of routing protocols.

3. **Hierarchical Routing Protocols**:

The hierarchy is classified into several categories depending on how the cluster head is selected and how the data is routed within the network. Routing protocols differ from each other in terms of power consumption, scalability and delay delivery. In this section, different categories of hierarchical protocol and protocols belonging to each category are compared to each other.

3.1 Block Cluster Routing Protocol:

This category contains many protocols, some of the most common ones are LEACH, HEED, TEEN.

A. Low Energy Adaptive Clustering Hierarchy (LEACH) :

LEACH is considered one of the most common protocols in the hierarchal category. This protocol consists of a set of nodes for each node of cluster head that transfers data from the normal nodes to the cluster head. Cluster head which transfers the data to the base station, responsible for long distance data transmission. It collects data from the normal contract and deletes duplicates. In LEACH, the cluster head is selected randomly [8].

The LEACH protocol can be divided into two phases:

1. Set up phase: during which the clusters are organized.
2. Steady state phase: Is the data transfer stage to the base station.

The set up phase includes the announcement phase and the creation of the schedule; a cluster head is chosen based on a certain threshold and the cluster head then sends a signal known to the rest of the nodes. Each node joins the group head based on the signal strength. After configuring groups each cluster head builds the schedule time and sends it to the members and the data is exchanged based on it.

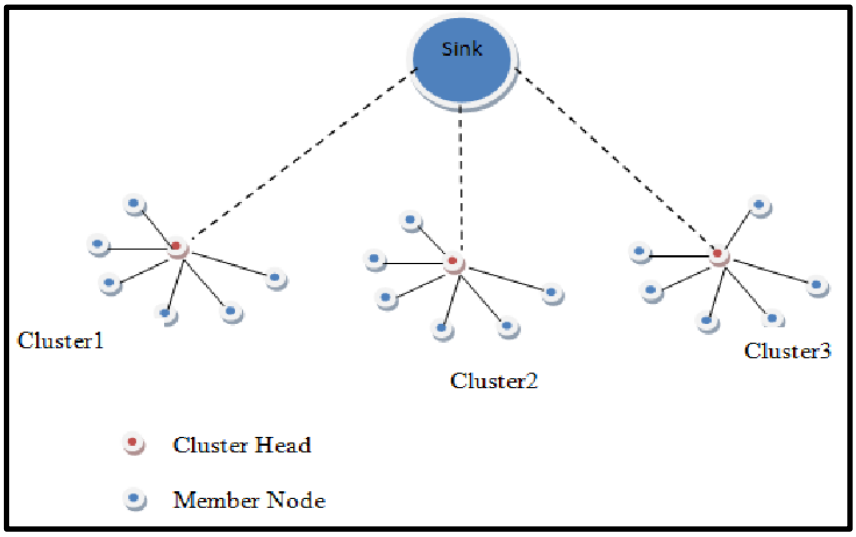

Figure 1: LEACH Protocols[8].

The advantage of this protocol is that it improves network life. Using TDMA works to prevent collisions during data transfer. In addition, the schedule gives members the opportunity to open and close the connection with the cluster head, depending on the allotted time, which avoids excessive energy.

However, this protocol has long-range communication that is directly between the head of the block and the basestation which consumes considerable energy [9].

B. Hybrid Energy-Efficient Distributed Clustering (HEED) :

This protocol is an improvement of the LEACH protocol, it does not use the random way to choose the cluster head, but the choice is based on two basic parameters which are the sensor node's residual energy and the intra cluster communication cost.

The operation of HEED can be divided into 3 phases: Initialization phase, Repetition phase and Finalization phase.

In the *initialization phase*, each and every sensor node sets the probability CHprob, of becoming a cluster head based on the residual and maximum energy [10].

CH prob = Cprob *(Eres/Emax).

Where: CH prob =initial fraction of CHs among all sensors.
Eres =Current energy in the sensor.
Emax =maximum energy.

In the *repetition phase*, each sensor node finds the cluster head that belongs to it in order to send its information to that cluster head.

In the *finalization phase*, each node sends its data to the head of the block, and then the head of the block sends the collected data to the base station.

This protocol improves network life time. Moreover, the cluster head selection in heed protocol is well distributed across the network and the communication cost is minimized.

However, the disadvantage of this protocol is that some cluster heads, especially ones near the base station, may die earlier because these cluster heads have more work load, performing of clustering in each round imposes significant overhead in the network. This overhead causes noticeable energy dissipation which results in decreasing the network lifetime. HEED suffers from a consequent overhead since it needs several iterations to form clusters. At each iteration, a lot of packets are broadcast [11].

C. Threshold Sensitive Energy Efficient Sensor Network Protocol (TEEN):

The TEEN protocol is a combination of a hierarchical approach and a central data approach, which is used to limit the number of transmissions from the normal nodes of the cluster head, and the cluster head sends data to the cluster head at the next level.

In this type, the cluster head sends to its members the following hard threshold and soft threshold.

Hard threshold denotes the minimum value for an attribute beyond which the node should turn on its transmitter and send data to cluster head [8].

Soft threshold refers to the small change in value of attribute for which the node should turn its transmitter on and transmit the sensed value to the cluster head [11].

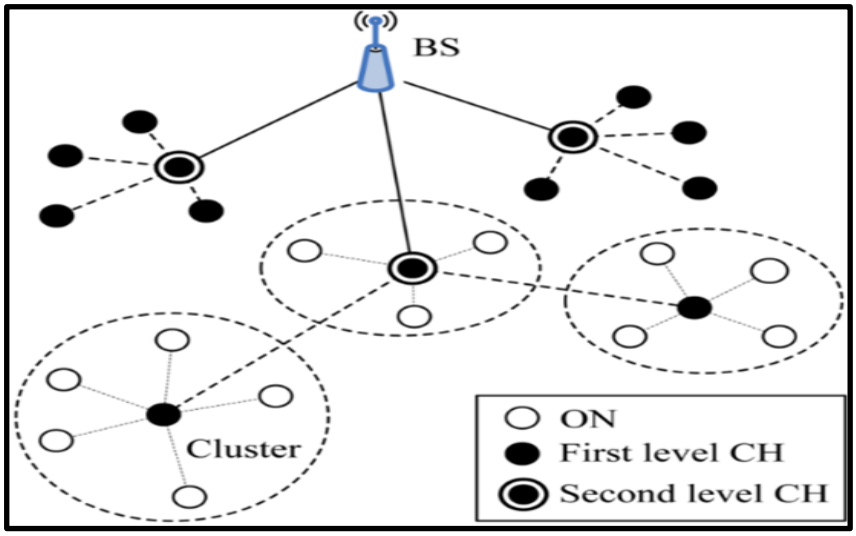

Figure 2 : TEEN Protocols[12].

This protocol is useful for applications where the users can control a trade-off between energy efficiency, data accuracy, and response time dynamically. Message transmission consumes more energy than data sensing, so the energy consumption in this scheme is less [12].

Table 1, summarizes the differences between the discussed block clusters-based routing protocols:

Table 1: Comparison between block clusters-based routing protocols.

Protocol Name	Energy Efficiency	scalability	Delivery Delay	Selection Cluster Head	Data Aggregation	Network Life time
LEACH	Low	Low	Low	Random	Yes	Low
HEED	Medium	High	Low	Selection	Yes	Medium
TEEN	High	Medium	Low	Selection	Yes	High

The HEED and TEEN protocol are better than the LEACH protocol in terms of energy efficiency, because both work to select the cluster head based on the remaining energy while the LEACH protocol selects cluster head randomly. As for the network lifetime, the better the use of energy, the longer the network lifetime.

3.2 **Chain Cluster-Based Routing Protocol** :

In chain routing, a set of nodes are connected to each other as a series, the cluster head is selected to collect the data inside. Each node sends its data to the next node until the data reaches the cluster head, and the cluster head sends the data to the base station [6].

In general, the advantages of this type are that the choice of the cluster head does not require competition, since the node closest to the base station is the cluster head. Moreover, in this category the energy is saved because each node sends data to the next node directly, so it reserves energy of different nodes compared to the block cluster based routing protocols.
Disadvantages of this type is the large delay, because each node sends data to the next node and therefore requiring time for the data to reach the base station. Moreover, if a node fails the data transfer fails in the whole chain. Also, the cluster head consumes more power than the remote nodes because it sends data frequently [7].

The following subsections discuss some protocols based on the chain cluster-based routing.

A. Power Efficient Gathering in Sensor Information System (PEGASIS):

PEGASIS is a chain cluster-based hierarchical protocol, in which the nodes are organized into a linear chain to transfer data.

The formation of the chain takes place in two stages*; chain construction* and *gathering data*. *Chain construction* starts from nodes farther to the base station, each node is connected to the next node and this procedure continues until all nodes are included in the chain. It is assumed at this stage that all nodes have knowledge of the network's topology. If the sensor fails or is lost due to battery loss, a new chain is constructed using the same approach but excluding the sensor that fails. In the *gathering data* phase, each node gives its data to the next node, the next node fuses its information with the previous node information until it becomes a single packet and sends it to the next node and so on until the data reaches the cluster, which in turn sends data to the base station [11].

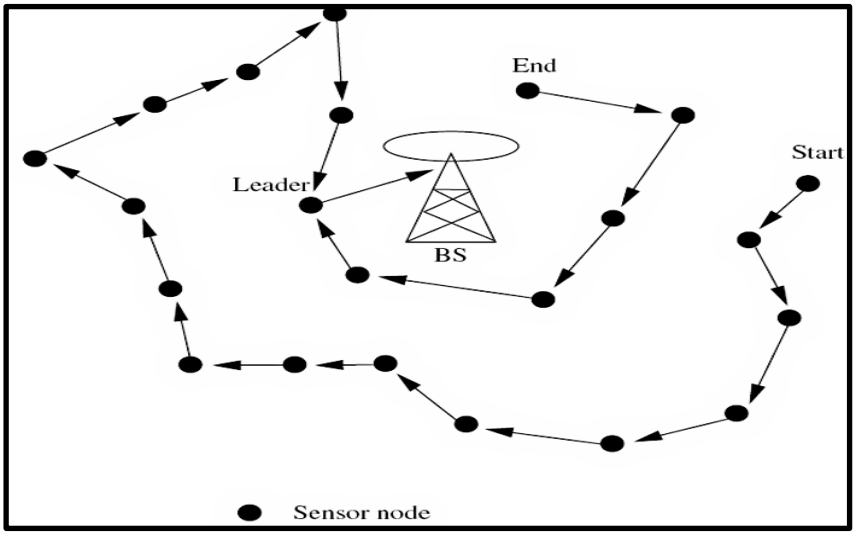

Figure 3: PEGASIS Protocols[11].

This protocol uses less energy because each node sends data to its nearby neighbor and thus increases the life of the network. This protocol doesn’t

result in large overhead on cluster head because the data arrives in a single package. But one disadvantage of this protocol is that it needs long time to transfer data, therefore result in, large delay. Moreover, this protocol is not suitable for large networks; therefore, it has low scalability [13].

B. Concentric Clustering Scheme (CCS) :

CSS is a chain-oriented routing algorithm. This protocol contains multiple chains; the objective of the protocol is to improve energy efficiency.
The entire network is divided into several concentric circular paths representing different groups at different levels [14].
The first track is the closest to the base station and the larger the distance to the base station, the higher the level. Each level elects cluster head within it depending on the residual energy. Within the same path each node sends data to its neighbors until the data reach cluster head and the cluster head sends the data to the cluster head in the next level and so on until the data reach the base station.

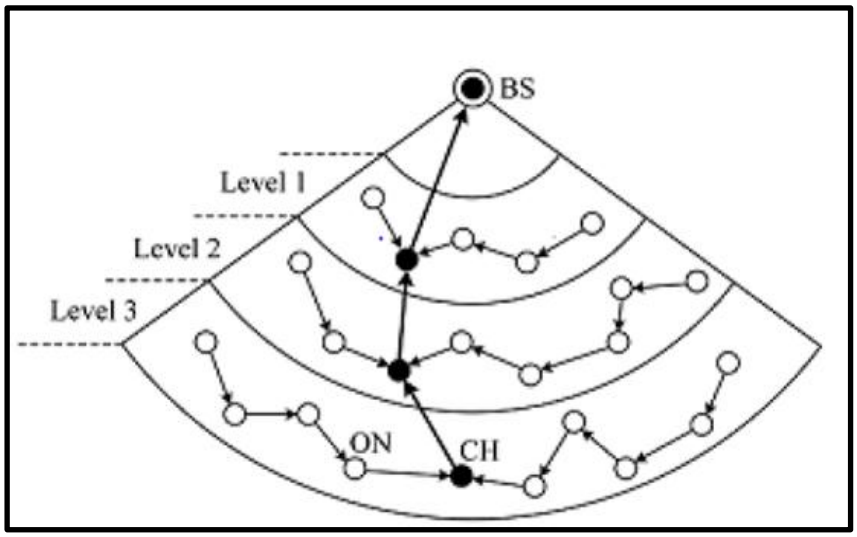

Fig 4: CCS Protocols[15].

This protocol reduces power consumption due to the reduced distance and thus resulting in long networks lifetime . However, there is still the problem of large delay during data transmission [15].

C. Energy Balanced Chain Cluster Routing Protocol (EBCRP) :

EBCRP is a chain-oriented routing algorithm, which is based on dividing the network into rectangular forms. A connection string is created in each rectangle based on the Ladder algorithm [16].
When the cluster head selects the cluster head closest to the base station, and chooses more than one to be the cluster head, for example 3, when the low energy of the first cluster head. The second cluster head to communicate with the base station and remains the number of cluster head

fixed. Thus choosing more than one cluster head will keep the network lifetime longer.

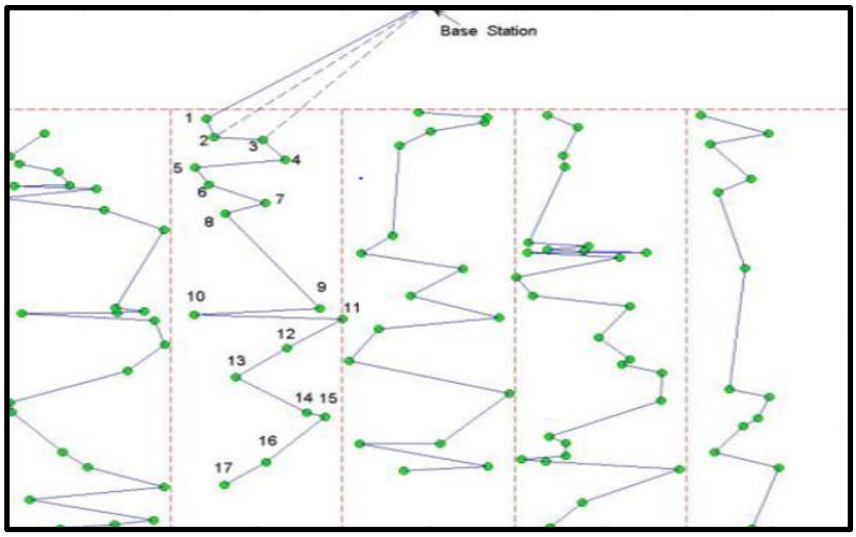

Fig 5: EBCRP Protocols[16].

In general the benefits of this protocol remain the long network lifetime and energy-efficiency.

Table 2, summarizes the differences between the discussed chain cluster-based routing protocols:

Table 2: Comparison between chain clusters-based routing protocols.

Protocol Name	Energy Efficiency	scalability	Delivery Delay	Selection Cluster Head	Data Aggregation	Network Life time
PEGASIS	Low	Low	High	Selection	Yes	Low
CCS	Medium	Medium	Medium	Selection	Yes	Medium
EBCRP	High	Medium	Medium	Selection	Yes	High

Since all previous protocols select the cluster head depending on the remaining energy, all of them have good energy utilization. These protocols work to collect the data in the cluster head and then send it to the base station; this reduces the transmission of data thus reducing the energy used. The EBCRP protocol is better than CCS in terms of energy efficiency because it selects more than one cluster head for the communication with the base station. The data moves from the cluster head in a rectangular network to the cluster head in the corresponding rectangular grid until it reaches the cluster head closest to the basestation.
The CCS protocol is better than the PEGASIS protocol because the data is transferred from level cluster head to another until reaching the base station.

While the PEGASIS protocol moves data from node to another closer to the cluster head thus consumes more energy.
As for the data transmission time, the PEGASIS protocol requires a high transmission time, so the delay time is greater compared to other protocols using chain cluster.
The network lifetime depends on energy consumption optimally as optimal utilization of energy result longer the network lifetime.

3.3 **Grid Cluster Routing Protocol**:

In this category, the grid is divided into groups based on the distance between the nodes, where the nodes close to each other are in the same group. Network division depends on the geographic location of the nodes.
The advantages of this type of routing are that messages are routed from the source to the base station without a routing table, and the data is connected effectively, delay is low, and scalability is high.
Some protocols based on the grid cluster are discussed in the following sub section.

A. Tow-Tier Data Dissemination (TTDD):

This protocol is a low-power protocol to send data from the source to the base station and depends on geographical direction. The grid is divided into square cells. Each cell has crossing points called the dissemination points in the network. The source, if it has data, calculates the four dissemination points adjacent to it and sends an announcement of the data available to it to the dissemination points using single greedy geographical forwarding.
The source sends an announcement of data to the node closest to it and from the dissemination points, where each node received by the data announcement sends it to the other nodes until the announcement reaches the network dissemination points. Each node received the data dissemination message stores the location source.
When the base station asks for information, the network sinks messages to discover network dissemination points. After discovering the network dissemination points that access the source and access the information.
This protocol is compatible with applications that contain events rather than constant traffic [19].

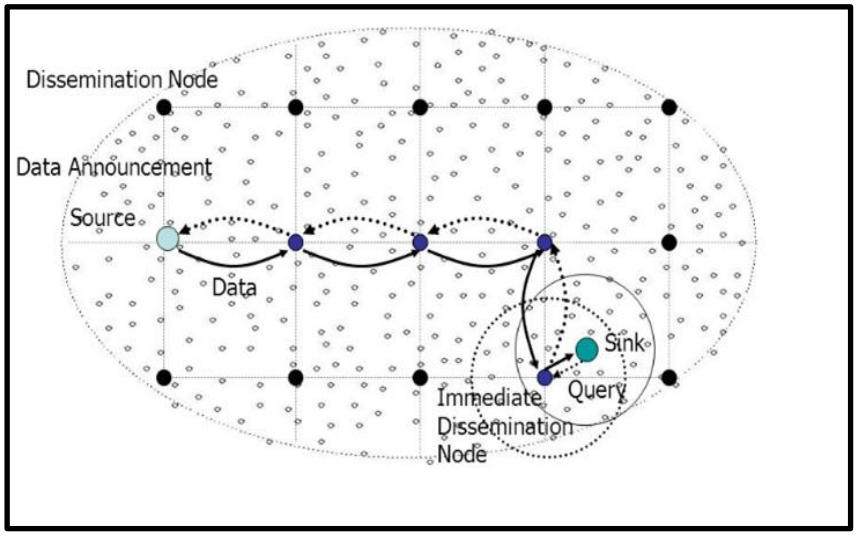

Figure 6: TTDD Protocols[19].

B. Hierarchical

HGMR is a hierarchical network-based protocol that combines the advantages of two protocols which are Hierarchical Rendezvous Point Multicast (HRPM)which is used to reduce the encoding overhead and Geographic Multicast Routing(GMP) is used to improve the forwarding efficiency.

HGMR protocol divides the hierarchy into several cells using mobile geographic hashing [17].Each cell contains an access point. This AP is responsible for managing the location information for the group of nodes it is responsible for. All access points can be managed through a point called rendezvous point. The source gives its data to the access point and the access point gives the member information. The advantages of this protocol are energy efficiency as well as, high scalability [18].

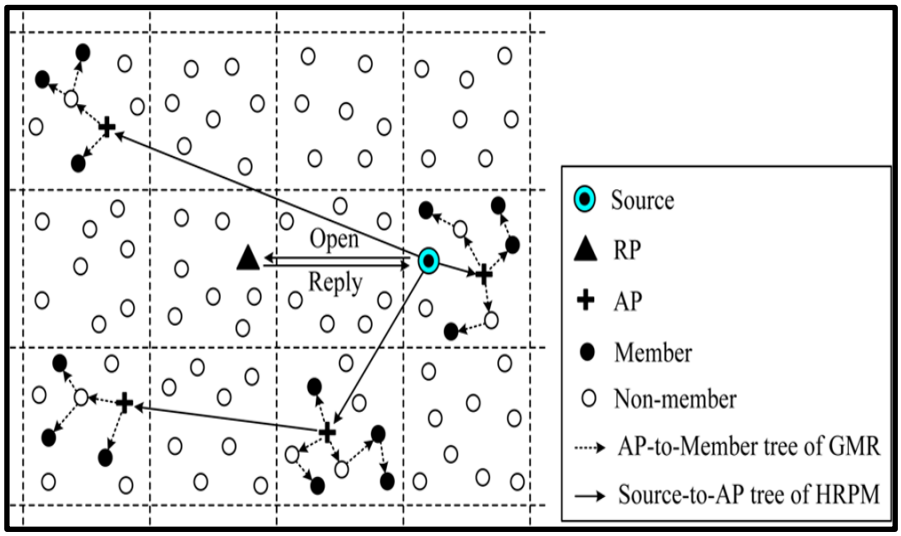

Figure 7: HGMR Protocol [18].

Table 3, a comparison between grid clusters based routing protocols is presented:

Table 3: Comparison between grid clusters-based routing protocols.

Protocol Name	Energy Efficiency	scalability	Delivery Delay	Data Aggregation	Network Life time
TTDD	Low	Moderate	High	Yes	Low
HGMR	Medium	High	Medium	Yes	Medium

The HGMR protocol has better energy efficiency than TTDD protocol, since it is based on the GMR protocol in building the network. Thus in terms of network life, the HGMR protocol gives a longer network lifetime than the TTDD protocol.

In the delivery delay in data transmission, the HGMR protocol needs less time to send data because the data is being propagated in the network while the TTDD protocol needs more time to transmit the data because the data takes path.

Scalability is good for both protocols, but the HGMR protocol has better scalability compared to the TTDD protocol due to its low data traffic.

4. Conclusion:

In this paper, the categories of the cluster-based routing protocols and some existing protocols of each category are presented. This comparison considered many metrics such as energy efficiency, scalability, delivery delay, network lifetime and data aggregation.

Based on the previous comparisons, we note that the grid based protocols achieve high scalability, while the chain based protocols achieve high energy efficiency and the block based protocols achieve low delivery delay.

So we may choose the type of the protocol to be used to route data in the network depending on the properties we want.

For example if we want to design a network that contains a large number of nodes we use the HGMR protocol, but if we want a network that gives a longer lifetime, we may choose the EBRCP protocol.

References:

1. Muhammad Noman Hayat, Fazlullah Khan, Haroon Khan, Muhammad Yaseen Khan1, Maqbool Shah1, "Review of Cluster-based Energy Routing Protocols for WSNs", *International Journal of Advanced Research in Computer Engineering & Technology (IJARCET) Volume 5, Issue 6, June 2016.*
2. Rohit Goyal and Padmavati Khandnor , "Routing Protocols Based on Sink Mobility in Wireless Sensor Networks", the IEEE WiSPNET 2017 conference.
3. M. MehdiAfsar , Mohammad-H.Tayarani-N , "Clustering in sensor networks", Journal of Network and Computer Applications,2014.
4. R.Devika 1, B.Santhi 2 ,T.Sivasubramanian , Routing Protocol in Wireless Sensor Network , International Journal of Engineering and Technology (IJET), Feb-Mar 2013.
5. Ibrihich OUAFAA , Krit SALAH-DDİNE , Laassiri JALAL , El Hajji SAİD 4 Recent Advances of Hierarchical Routing Protocols for Ad-Hoc and Wireless Sensor Networks, BİLİŞİM TEKNOLOJİLERİ DERGİSİ, MAYIS 2016.
6. Xuxun Liu, Atypical Hierarchical Routing Protocols for Wireless Sensor Networks: A Review, IEEE SENSORS JOURNAL, OCTOBER 2015.
7. Navdeep Kaur, Deepika Sharma and Prabhdeep Singh3 ,Classification of Hierarchical Routing Protocols in Wireless Sensor Network, International Journal of P2P Network Trends and Technology, 2013 .
8. Mamta Verma, Vratika Mittal, Anjali Kushwaha, Survey of Routing Protocols in Wireless Sensor Network (LEACH, TEEN, APTEEN),Journal of Network Communications and Emerging Technologies (JNCET) , September (2017).

9. Asgarali Bouyer and Abdolreza Hatamlou,New Approach for Decreasing Energy in Wireless Sensor Networks with Hybrid LEACH Protocol and Fuzzy C-Me,International Journal of Communication Networks and Distributed Systems , October 2014.
10. G. Anitha1, V. Vijayakumari2, S. Thangavelu3 ,A Comprehensive Study and Analysis of LEACH and HEED Routing Protocols for Wireless Sensor Networks–with Suggestion for Improvements,Indonesian Journal of Electrical Engineering and Computer Science , March 2018.
11. Puneet Gurbani , Hansa Acharya , Prof. Anurag Jain , Hierarchical Cluster Based Energy Efficient Routing Protocol for Wireless Sensor Networks: A Survey,Puneet Gurbani et al, /(IJCSIT) International Journal of Computer Science and Information Technologies, 2016.
12. Mr.Muruganandam.K, Dr.Sibaram Khara,Performing Efficient protocol for reducing energy consumption in wireless sensor Networks, International Journal Of Engineering And Computer Science , July 2017.
13. Parul Bansal, Poonam Kundu, and Prabhjot Kaur , Comparison of LEACH and PEGASIS Hierarchical Routing Protocols in Wireless Sensor Networks Int. J. of Recent Trends in Engineering & Technology, June 2014.
14. S. Jung, Y. Han and T. Chung, "The Concentric Clustering Scheme for Efficient Energy Consumption in the PEGASIS", Proceedings of 9th International conference on Advanced Communication Technology, 2007.
15. Pooja Mishra1 and Sanjiv Sharma2, A Comparative Study of Existing Cluster-Based Routing Protocols in Wireless Sensor Networks, International Journal of Future Generation Communication and Networking Vol. 9, No. 7 (2016).
16. Bao Xi-rong1, Zhang Shi1, Xue Ding-yu1,Qie Zhi-tao2,An Energy-Balanced Chain-Cluster Routing Protocolfor Wireless Sensor Networks,2010 .
17. Nandini G and J. Anitha,Performance Chronicles of Multicast Routing Protocol in Wireless Sensor Network, (IJACSA) International Journal of Advanced Computer Science and Applications,Vol. 8, No. 9, 2017.
18. Dimitrios Koutsonikolas ,Saumitra M. Das , Hierarchical geographic multicast routing for wireless sensor networks ,Wireless Netw (2010).
19. Fan Ye, Haiyun Luo, Jerry Cheng, Songwu Lu, Lixia Zhang ,A TwoTier Data Dissemination Model for Largescale Wireless Sensor Networks.