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A Review on Cluster-based Routing for Wireless Sensor Network

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Abstract - *Recently, the use of distributed sensing applications is a major trend glared at the emergence of low-power embedded systems and wireless networking. These technologies directed to the implementation of wireless sensor networks (WSN). Although WSN has offered unique opportunities to set the foundation for using ubiquitous and pervasive computing, it suffered from several issues and challenges such as frequently changing network topology and congestion issues which affect not only network bandwidth usage but also performance. In this paper, we survey the energy-efficient hierarchical routing protocols, developed from conventional LEACH routing protocol. The focus of this study is how these extended protocols work to increase the lifetime and the quality of WSNs. Furthermore, this paper also highlights some issues and challenges of the LEACH protocol and its variants. Additionally, this paper explores how these issues are tackled by extended versions of LEACH. We compare the features and performance issues of the selected hierarchical routing protocols.*

***Key Words*: WSN, Clustering, Routing, QoS, LEACH.**

1. INTRODUCTION

Wireless Sensor Network (WSNs) is a group of sensor nodes that can sense the physical phenomenon of any environment like humidity, temperature, pressure, speed, and others. Also, they can communicate together to send their sensed data to a specific gateway to achieve a monitor of a specific environment. Figure 1 shows the architecture of WSN.

Fig -1: WSN architecture

WSNs attract the attention of many researchers. As WSNs promises lots of benefits in terms of range, cost, and flexibility As shown in Figure 2, WSNs are used for numerous applications such as traffic and video control, habitat monitoring, security, agriculture, medical and health care, industrial automation, entertainment, transportation, smart grid, control systems, military reconnaissance, disaster management [1]. Since plentiful sensors are usually deployed in remote and inaccessible places, the deployment and maintenance should be easy and scalable.

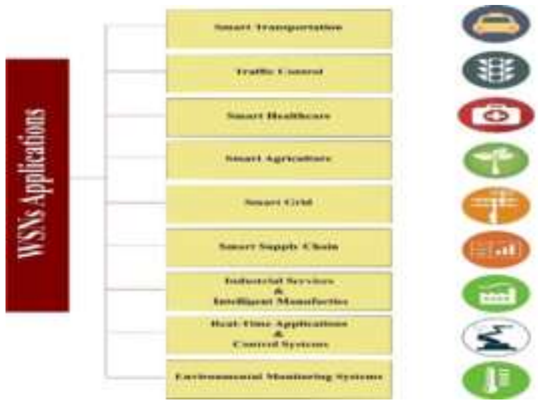

Fig -2: A set of smart applications dependent on WSN.

The future Internet, designed as an "Internet of Things," (IoT) is foreseen to be "a world-wide network of interconnected objects uniquely addressable, based on standard communication protocols". Recently, due to the growth of an IoT technology, Ericsson and Cisco forecast estimate the connected devices (i.e. Tablet, cell phones, etc.) such as smart city, intelligent transportation, environmental monitoring, and home automation will reach approximately 50 billion devices in 2020 [REF], and the data produced by these devices will reach 500 zettabytes as shown in Figure 3. Nowadays, IoT is relied upon to have an important life-care and business processes to add personal satisfaction and to develop the world's economy.

WSNs are Things (sensor nodes) connected without a wire to gather some data. IoT is a WSN embedded in a Physical object (Thing) that are addressed by IP address to be able to communicate over the Internet to perform specific functions for applications. Thus, WSN is like the eyes and ears of the IoT. The IoT in a broad sense is like a brain. With the emerging technology of IoT, the number of applications of WSN increases every day.

In general, WSN composed of nodes and sink (Base station) as shown in Figure 4. Nodes are small devices that collect and transmit data about the surrounding environment. WSN nodes consist of several functional modules: sensing unit, processing unit, storage unit, Transceiver unit, power unit, power generator, Location finding system, and Mobilize, as in Figure 5. Sink (base station) controls communication between nodes and collects data from all nodes about the environment. Thus, data travel from the nodes to the sink using a wired or wireless channel [2] [3].

Fig -3: Future IoT devices statistics

Fig -4: WSN Configuration.

Fig -5: A node functional modules.

There are a lot of challenges faces the WSNs such as (i) power consumption: nodes depend on batteries and in most applications it's very difficult to recharge the battery again. (ii) Limited storage unit. (iii) The nature of the wireless channel. (iv) Congestion: due to poor possibilities of nodes and natural of the wireless channel, data may conflict in any position in the network lead to congestion, which leads to losing a lot of data.

Routing is one of the critical issues in WSNs. The routing protocol is the process to select a suitable path for the data to travel from source to destination [4]. The process encounters several difficulties while selecting the route, which depends upon, type of network, channel characteristics, and performance metrics. In WSN, routing protocols are applied at the network layer in the OSI model.

Routing protocols can be divided into two categories: flat routing protocols (FRP) and hierarchical or clustering routing protocols (CRP). FRP distributes routing information between routers that are connected without any organization or segmentation structure. It enables the delivery of packets among routes through any available path without considering network hierarchy, distribution, and composition. In CRP, each cluster consists of a cluster head (CH) and other member nodes (MNs). The CHs are responsible for data aggregation, information dissemination, and network management, while MNs are responsible for events sensing and information collecting in their surroundings.

The CRP outperforms the FRP in the following

- Maximize scalability, load balancing, fault tolerance, and robustness.
- Minimizing load and delay time.
- Reducing the routing table size.
- Conserving communication bandwidth.
- Prolonging the battery life of sensor nodes.
- Reducing the rate of power consumption.
- Preventing medium access collision.

Hierarchical or CRPs are better than FRPs, so this paper focuses on the CRP. A routing protocol for WSN should be characterized by less computational complexity, efficient power consumption, increase the network lifetime, and low latency for data dissemination from the Sensor Node (SN) to the sink node. A cluster routing protocol for WSN is characterized by performing cluster formation, application dependency, secure communication, synchronization, and data aggregation. LEACH (Low-Energy Adaptive Clustering Hierarchy) protocol is a dynamic, self-organizing, adaptive clustering protocol. The LEACH network is made up of nodes, some of which is called CH that collects data from their surrounding nodes and passes it on to the sink.

The main objective of this paper is presenting different CRP protocols, and compare them to find the best protocols, which achieve the QoS requirements. The rest of this paper is organized as follows: In section 2, the challenges and open areas are explored. In section 3, clustering routing protocols categories are outlined. Section 4 reviews the LEACH protocol. Section 5 surveys the improvement of LEACH protocols at last, in section 5, the paper is concluded.

2. The challenges and open areas

Recently, due to the nature of WSN, Routing protocols have faced several issues and challenges [4] [5] [6]. These challenges, as shown in Figure 6, are discussed in the following sub-sections.

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Fig -6: Challenges of the WSN Routing protocols.

2.1 Massive and random node deployment:

Sensor node deployment in WSNs is application dependent and can be either manual or random which finally affects the performance of the routing protocol. In most applications, sensor nodes can be scattered randomly in an intended area or dropped massively over an inaccessible or hostile region.

Open research area:

- Find a technique to move mobile sensors to the position of hole areas, which have a lower coverage rate [7].
- Use a position optimization scheme to reduce the number of mobile nodes and the average moving distance to cover hole areas [8].
- Clustering nodes for the purpose of balancing the load and prolonging the network lifetime [9].

2.2 Sensor locations:

Another challenge that faces the design of routing protocols is to manage the locations of the sensors. Most of the proposed protocols assume that the sensors either are equipped with global positioning system (GPS) receivers or use some localization techniques to learn about their locations.

Open research area:

- A modification of the gradient descent method that can be used in multi algorithms for node location in wireless sensor networks (WSNs) [10].
- Use a sector-based random routing scheme for protecting the source location privacy [11].

2.3 Limited energy capacity

Since sensor nodes are battery-powered, they have limited energy capacity. Energy poses a big challenge for network designers in hostile environments. Furthermore, when the energy of a sensor reaches a certain threshold, the sensor will become faulty and will not be able to function properly, which will have a major impact on network performance.

Open research area:

- Use of energy harvesting to reload the rechargeable battery by power [12].
- Clustering efficacy is improved by applying compressive sensing (CS) and principal component analysis (PCA) data compression techniques [13].

2.4 Limited hardware resources

Sensor nodes have also limited processing and storage capacities and thus can only perform limited computational functionalities. These hardware constraints present many challenges in software development and network protocol design for sensor networks.

Open research area:

- Use a multi-agent clustering WSN model, i.e., Adaptive Distributed Artificial Intelligence (ADAI) technique with a hierarchical resource allocation strategy to address the issue of resource allocation [14].
- Use the FPGA Based Power Saving Technique for Sensor Nodes [15].

2.5 Network characteristics and unreliable environment

A sensor network usually operates in a dynamic and unreliable environment. The topology of a network is defined by the sensors and the communication links between the sensors change frequently due to sensor addition, deletion, node failures, damages, or energy depletion. Also, the sensor nodes are linked by a wireless medium, which is noisy, error-prone, and time-varying. Therefore, routing paths should consider network topology dynamics due to limited energy and sensor mobility as well as increasing the size of the network to maintain specific application requirements in terms of coverage and connectivity.

Open research area:

- Discussed in detail in sections (3,4, and 5).

2.6 Data Aggregation

Since sensor nodes may generate significant redundant data, similar packets from multiple nodes can be aggregated so that the number of transmissions is reduced. The data aggregation technique has been used to achieve energy efficiency and data transfer optimization in a number of routing protocols.

Open research area:

- Data aggregation approaches based on compressive sensing (CS), which has the merit of low traffic cost [16].

– A Trust Assisted- Energy Efficient Aggregation (TA-EEA) scheme that improves overall aggregation precision with limited constraints in neighbor reliability and aggregation [17].

2.7 Diverse sensing application requirements

Sensor networks have a wide range of diverse applications. No network protocol can meet the requirements of all applications. Therefore, the routing protocols should guarantee data delivery and accuracy so that the sink can gather the required knowledge about the physical phenomenon on time.

Open research area:

– Find protocols help to get rid of redundant data by using intelligent data aggregation and forwarding [18].
– Sensor-cloud (SC), which integrates WSNs and cloud computing to deliver data to users anytime and anywhere [19].

2.8 Scalability

Routing protocols should be able to scale with the network size. Also, the sensors may not necessarily have the same capabilities in terms of energy, processing, sensing, and particularly communication. Hence, communication links between sensors may not be symmetric, that is, a pair of sensors may not be able to have communication in both directions. This should be taken care of in the routing protocols.

Open research area:

– Improve medium access control (MAC) protocols to get scalable [20].
– Improve routing protocols to achieve scalability in the network [21] [51].

3. Clustering routing protocols.

The clustering routing protocol is a technique to manage the relationships between nodes in the network in a special manner, which helps to achieve Qos requirements as save energy, prolong the network lifetime, aggregate similar data, load balancing, and prevent packet loss. The clustering routing protocol can be divided into four main categories as follows: chain-based, tree-based, grid-based and block-based as shown in Figure 7.

3.1 Chain-based clustering routing protocols.

In chain-based topology, connections of the deployed sensor nodes are constructed in one or more chains for data transmission as shown in Figure 7 (a) [22]. In a chain, a leader is selected to perform the task of data collecting, like a sink. Data is delivered along the chain, and ultimately to the leader node. During the process of transmission, data aggregation is performed [23]. The main advantage is simplicity. A topology is easy to implement and maintain. A chain-based routing doesn't need a CH competition and ordinary node (ON) selection. A chain-based routing saves energy in local communication. Data is sent from node to the next node, which is very close to it. So, energy is saved by local communication compared with intra-cluster communication in cluster-based topology [24]. However, a chain may be very long with a large number of hops, which may cause a large transmission delay. It also suffers from an imbalance of energy consumption. In such a topology, data is transmitted in hop-by-hop, so nodes far from the leader nodes have little data to deliver, while the nodes near the leader node suffer from too much data traffic [25]. If a sensor node fails, data transmission has to be terminated by the end of the chain to the failed node. Thus, chain-based topology has less robustness.

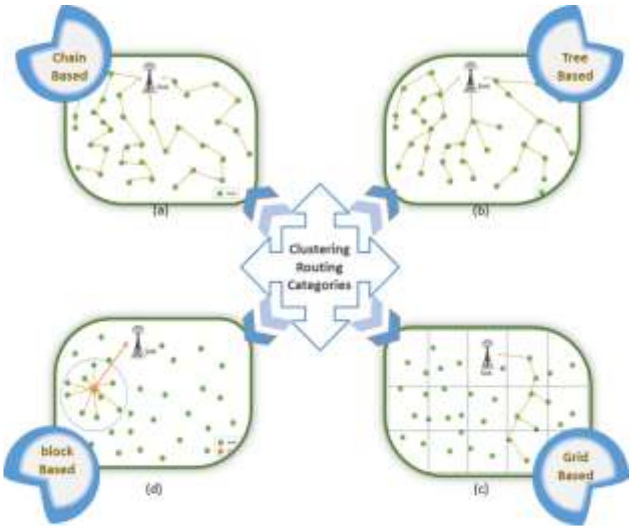

Fig -7: Clustering Routing Categories.

Power-Efficient Gathering in Sensor Information System Protocol (PEGASIS) [22] is a famous chain-based clustering protocol, which uses a greedy algorithm to organize the network sensors to form a chain, starting from the farthest node, to ensure that the node away from the sink has close neighbors. The BS computes this chain and broadcasts it to all the nodes. In each round, only one node takes the role to be the leader in transmitting to the BS. This role is rotated between all nodes in the network except among nodes with relatively distant neighbors along the chain. This chain guarantees that any node can receive from and transmit to close neighbors. This makes the distant transmissions as small as possible. Advantages of PEGASIS are unifying consumption of energy between all nodes; reducing overhead by using the chain instead of forming dynamic clusters and decreasing the amount of data transferred. Disadvantages of PEGASIS are that all nodes can communicate directly with the BS, they suffer from delays, they are not scalable as all nodes must have global knowledge of the network to run the greedy algorithm and they are not suitable for time-varying topologies.

Threshold Sensitive Energy Efficient Sensor Network Protocol (TEEN) [23] is the first protocol developed for reactive networks and it combines the hierarchical technique with the data-centric approach. First, the formulation of clusters and their cluster heads is done. Then, cluster heads broadcast two critical values to their members, Hard-Threshold (HT), and Soft-Threshold (ST). HT is the absolute value of the sensed attribute. As if sensing the value of any node reaches the HT value, it must transmit this value to its CH. ST is the amount of change of sensed attribute, which enables the node to send the sensed value. TEEN has advantages such as (i) using HT makes the node transmit only when the sensed attribute is in the range of interest, (ii) using ST makes the node transmit when there is an amount of change in the sensed value, (iii) reducing the number of transmissions and energy and (iv) being suitable for time-critical applications. However, the drawbacks are found when identifying the value of any node that does not reach HT or ST. In that case, this node does not send any value. This makes the BS unable to know. If this node is alive or dead, and unable to know if the CHs are not in the range of communicating with each other, and thus the data may be lost.

3.2 Tree-based clustering routing protocols.

In tree-based routing, a logical tree is constructed with all sensor nodes as shown in Figure 7 (b). Data is delivered from leaf nodes to their parent ones severally. In turn, the parent nodes send the received data to their parent nodes towards to root nodes. Data aggregation is possibly performed in each node [26]. Similar to chain-based topology, tree-topology is simple and doesn't need CH competition and ON selection. Energy consumption is decreased due to data transmission between neighbor nodes, which saves much energy [27]. If a sensor node fails, the relative whole sub-tree is unable to work and new tree construction is needed that causes low robustness [28]. In tree-based topology, power consumption is uneven across the network. This is similar to chain-based topology, the nodes closer to the BS perform more load in forwarding packets. In large-scale tree-based networks, too many levels are constructed from one root to relative leaves. Thus, it will result in large latency and energy consumption for data transmission [29].

Aggregation Tree Construction in Sensor Networks (EADAT) protocol is based on an energy-aware distributed heuristic. The algorithm is initiated by the sink which broadcasts a control message having five fields: ID, parent, power, status, and hops count. To maintain the tree, a residual power threshold (Pth) is associated with each sensor [26].

3.3 Grid-based clustering routing protocol.

In a grid-based topology, the network is divided into various grids by the geographic approach as shown in Figure 7 (c). Thus, grid-based routing generally belongs to location-aware routing. The distinct characteristic of the type of routing is that the routing operation is performed without any routing table [30]. Once the position of the destination is achieved by the source, all routing operations are locally performed [31]. In grid-based networks, grids are regularly constructed by geographic locations and CH competition and ON selection can be left out [32]. So the hierarchical structure is simple compared with cluster-based routing. Grid-based protocols can provide efficient data delivery in WSNs, in that each node only maintains a simple forwarder candidate set for it to transmit data. This is different from traditional cluster-based topology, in which many more delay candidates can be selected [33]. However, data transmission is performed along with the grids, and energy efficiency depends on balancing the geographic distribution versus occurrence of traffic. Generally, the transmission, routing is fixed. Thus, any dependence on performance with traffic load thwarting the negligence of distance may occur in overload [34] [35].

Position-based Aggregator Node Election Protocol (PANEL) [36] is a grid-based protocol, which partitioned the network area into geographical clusters before the deployment of the network. Each sensor node is aware of its geographical position P and distinguishes geographical information about its cluster by knowing the coordinates of the lower-left corner of its cluster. The operation of the PANEL is divided into epochs. In each epoch, the computing of reference points in each cluster is done first, and then these reference points are used to compute the aggregator points. In PANEL, each node acts as an aggregator node in equal chances, so it ensures the load balancing and saves energy, and it supports the asynchronous application. The drawbacks of the PANEL are that it cannot be applied to the dynamic WSN applications because clusters are predetermined before deployment, and it uses special hardware and software like the GPS to find the geographical position of the nodes.

3.4 Block-based clustering routing protocols.

Block-based topology is an up-to-date structure, in which some sensor nodes are designated in a specific area and act as high-tier nodes. Generally, such nodes perform the task of data collection from ONs and data transmission to the sink. The size of the area can be adjusted according to the load balancing requirements as shown in Figure 7 (d) [37]. Only a specific area must be determined and it is easy to determine which nodes act as high-tier tasks. Energy consumption is decreased compared with that in some clustering routing in WSNs because data exchange is performed in local regions. This can avoid long-distance communication and decrease large energy dissipation. In such topology, generally a mobile sink moves. This prevents traffic load from being distributed in a small space [38]. Therefore, it facilitates load balancing in the network. In a large-region network, a large area of a specific region is needed. Data dissemination around the specific region results in large latency and energy consumption for data transmission. Such a topology is generally used in mobile networks that contain high technology and difficult manufacturing. This can result in a larger cost of network construction compared with that in static WSNs.

Protocols examples are discussed in detail in the next section. Most of the other subsequent protocols are improvements of LEACH. So the next sections explain in brief LEACH protocol and its subsequent protocols.

4. Low-Energy Adaptive Clustering Hierarchy (LEACH) protocol 2000

LEACH protocol [37] [38] is an adaptive, self-organization clustering protocol where nodes organize themselves into clusters. Each cluster contains only one CH node and many of MNs nodes. In each cluster, MNs nodes send their data to its CH node which aggregates the data and sends it to BS as shown in Figure 8.

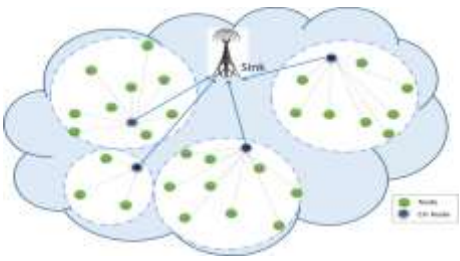

Fig -8: Organization of LEACH protocol.

The operation of LEACH as shown in Figure 9, is broken up into lots of rounds, where each round starts with setup phase then steady-state phase.

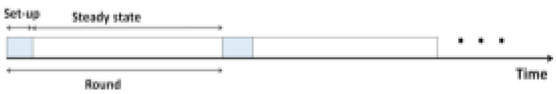

Fig -9: Operation of LEACH protocol.

4.1 Setup phase

In the setup phase clusters are organized in four main steps. Step 1, each node selects a random number between 0 and 1 and compares this number to the threshold number. For any node random number is less than the threshold amount, this node becomes a CH node for this round. The threshold value is given by equation (1).

$$T(n)=\{(P/(1-P*(r \bmod 1/P)) \quad \text{if } n \in G \qquad (1)$$

Where p is the desired percentage of cluster heads, r is the current round; G is set of nodes that have not been cluster heads in the last 1/p rounds. Step 2, the chosen CH nodes for this round broadcast a small advertisement message (ADV) with high power to guarantee that all nodes in the network can receive this message; this is done using CSMA in MAC protocol. Step 3, all remaining non CH nodes trying to join CH nodes to perform clustering. Each node chooses the closest CH which requires minimum communication, energy based on the received signal strength of the (ADV) message, and then sends a short Join-Request message (Join-REQ) to the chosen CH node using CSMA in MAC protocol. Step 4, each CH node creates schedule TDMA and transmits this schedule to MNs nodes in its cluster.

4.2 Steady-state phase.

Data of each cluster is transferred from MNs nodes to CH node using the schedule of TDMA, as each node transmits only in its slot. Afterward, data are aggregated and send from CH to BS. Each cluster communicates using (DS-SS) besides TDMA in MAC protocol to reduce inter-cluster interfaces while eliminating intra-cluster interfaces, as in one cluster all nodes use one spreading code to transmit data to the CH node.

LEACH Protocol doesn't require information about the location of nodes to create clusters. Another advantage, rotating selections of CH lead to equally share tasks of CHs between all nodes, this leads to balance energy consumption, and solve the problem of CH die. Using a TDMA in MAC protocol prevents unnecessary collisions as each node can communicate only in its slots. Aggregated data by CH nodes lead to limit the high amount of traffic and save energy. The protocol can add new nodes or remove die nodes in each round.

The protocol dis-advantage is in the selection of CHs. The random manner causes an imbalance in energy load. Also, it does not depend on residual energy. Single-hop inter-cluster, directly from CHs to the BS makes it not applicable to large-region networks as it leads to long-range communications which lead to energy consumption. Dynamic cluster causes extra overhead.

5. Consecutive of LEACH protocols

The protocols presented in the next sections are the LEACH protocol consecutive.

5.1 LEACH-centralized (LEACH-C) 2000

In LEACH nodes organize themselves to form clusters. LEACH-C uses a central control algorithm to form clusters. Same as LEACH, the operation of LEACH-C consisting of many rounds, where each round starts with setup phase, then steady-state phase which is the same as in LEACH.

In the setup phase clusters are organized. First, all nodes send information about energy level and current location (obtained by GPS receiver or other location-tracking method activated at the beginning of each round) to the base station (BS). Second, BS runs an optimization algorithm such as simulates annealing to find the best CH nodes for this round, which chosen from nodes with energy levels more than average energy. Once cluster head nodes are determined, they are used to form better clusters with less transmission energy for data. Third, BS broadcasts a message containing the IDs of optimal CHs to all nodes in the network. Each node compares its ID with optimal CH IDs if it matches, this node takes the role of CH. Otherwise, it can transmit only in its slot determine by TDMA and sleeps in remaining slots [37].

Using a central control algorithm form better clusters with CH nodes dispreaded through the network. LEACH-C outperforms LEACH by 20% to 40% in terms of the number of data gathering rounds. LEACH-C loses its robustness because of using GPS at the beginning of each round to determine the location of each node. Single-hop inter-cluster, directly from CHs to the BS makes it not applicable to large-region networks as it leads to long-range communications which lead to energy consumption [38].

5.2 Fixed clusters, rotated CH (LEACH-F) 2000

Same as LEACH, LEACH-F consists of a lot of rounds and each round consists of two phases with the same steady-state phase.

In LEACH-F setup phase runs only once in the first round where fixed clusters are organized using a centralized cluster formation algorithm developed for LEACH-C. These created clusters will be fixed for the remaining rounds, only rotation of cluster head role is done at the beginning of each round depending on the rotation schedule of the future CH which determined by the sink.

The main advantage of LEACH is the reduced setup overhead at the beginning of each round. However, any node may be farther from its CH than another CH belongs to another cluster, so it uses a large amount of power to communicate. New nodes cannot be added and died nodes cannot be removed at the beginning of each round. Also, it doesn't handle node mobility. LEACH-F would not be practical in any sort of a dynamic system. LEACH, LEACH-C, and LEACH-F did not solve the problem of fixed round time as CH dies before completing the round which leads to waste energy and information, this problem can be minimized by making a relationship between round time and current energy of CHs [37].

5.3 Two Level LEACH (TL-LEACH) 2005

The idea of TL-LEACH is saving power by reducing the number of nodes that can communicate directly with the base station. In TL-LEACH, each round consists of three phases

5.3.1 Setup phase:

In this phase, each node decides which to be primary CH, secondary CH, or simple node (SN) in each round. Primary and secondary CHs elected for this round advert other nodes with their status using CSMA. Then each secondary CH chooses one of the primaries CH to join with it and send it an advertisement message. Same at each simple node, choose one of secondary CH to join and advertise it. The organization of TL-LEACH is shown in Figure 10.

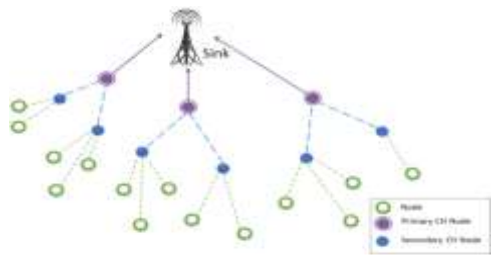

Fig -10: Organization of TL-LEACH protocol.

5.3.2 Schedule phase:

Each primary CH creates a TDMA schedule to assign slots to transmit to secondary CH belongs to it and their simple node. Transmission between nodes belongs to one primary CH is done using unique CDMA code, to avoid collision between groups of nodes belongs to different primary CH.

5.3.3 Data transmission phase:

First, all simple nodes send their data to their secondary CH in their slots using their codes. This data are fused by each secondary CH, which sends this fused data to primary CH. Then each primary CH fused this data again and send it to BS [39]. Distributing energy load between sensors reduces energy consumption. Using two levels of communication, lead to reduce the distance of transmission between nodes. However, TL-LEACH suffers from long delay time [37].

5.4 LEACH-energy threshold (LEACH-ET) 2006

LEACH-ET consists of many rounds; each round begins with the setup phase, then the steady-state phase.

5.4.1 Setup phase:

In Setup phase clusters are formulated like LEACH-C protocol. The setup phase requires more energy compared with the steady-state phase. So if the number of frames increased in each round, then the number of rounds will be minimized and this prolongs total lifetime. LEACH-ET enhances energy efficiency by increasing the proportion of steady-state in each round this is done by using an energy threshold [40].

First, BS computes ET (energy threshold) using equation 2:

$$ET=n.\ P.\ ECH \quad (2)$$

Where: n: is the number of bits transmitted by each node, p: is the probability of retransmission in every round, ECH: is energy dissipation rate of the CH per bit, then BS broadcast this value to all nodes. Second, if any CH node energy reaches to ET, it notifies the BS to broadcast RRM (round rotation message) to all nodes.

5.4.2 Steady-state phase.

In practical application, non-CH nodes may not always have data to transmit to the CH node, so sending data depend on probability (P) number. At P=0, if any non-CH node doesn't have data to send to its CH in its slot, then this non-CH node and CH node go to sleep mode in this slot. At P=1, it works like LEACH. At 0<P<1, it works like TEEN and APTEEN. Reducing the time of round rotation in LEACH-ET saves energy. On the other hand, Transmitting control message use a lot of energy. Single-hop inter-cluster, directly from CHs to the BS makes it not applicable to large-region networks as it leads to long-range communications which lead to energy consumption.

5.5 Energy LEACH (E-LEACH) 2007

Same as LEACH expect in the selection of cluster head. In E-LEACH, at first round, all nodes have the same energy and the same probability to become a CH. For the remaining rounds, node energy level changes so the selection of CH depends on the amount of residual energy of each node. Compared with LEACH, residual energy same as LEACH at first, then it enhanced over a period of time. And network lifetime more than LEACH. E-LEACH increases the lifetime of LEACH by 40%. It also handles CH failure. Fixed time round in E-LEACH wastes energy [41].

5.6 Multi-Hop LEACH (MH-LEACH) 2007

This protocol solves the problem of single-hop communication founded in LEACH which leads to consuming a lot of power if the distance is far between CH and BS. MH-LEACH provides inter and intra multi-hop communication to send data. As any CH node selects the optimal path between itself to sink through other CHs. MH-LEACH minimizes energy consumption, especially for the large size network. However, it suffers from hot spots and limited scalability [41].

5.7 Time-based Cluster head selection algorithm LEACH (TB-LEACH). 2008

TB-LEACH works on maximizing the network lifetime by modifying the selection of CH in the LEACH protocol. Same as LEACH, TB-LEACH consists of a lot of rounds and each round consists of two phases. TB-LEACH differs from LEACH in two points: the number of CH selected for each round is fixed which is determined by the counter using a random time interval. At the beginning of each round, each node produces a random timer. If the counter number does not reach the total number of CH for this round and timer of any node is expiring this node broadcasts (CH-ADV) message using CSMA to inform all nodes that it will be a CH. After determining CHs nodes, completion of this phase same as LEACH [42]. TB-LEACH protocol improves the lifetime of LEACH by about 20% to 30%. However, it is not suitable for the large region as all nodes must be in the range of CH advertisement to change counter status.

5.8 Advanced LEACH (ALEACH) 2008

Same as LEACH, the operation of ALEACH consists of a lot of rounds where each round starts with setup phase then steady-state phase. It differs from LEACH in selecting a CH node, as nodes with more energy should be a cluster head for that round. The selection of CH is done using the threshold equation used for LEACH added by an equation containing terms of current energy and initial energy for each node as we can see in equations (3,4,5) [43]. Remaining of the setup phase same as LEACH.

$$T(n)=Gp+CSp \quad (3)$$

$$Gp=k/(N-k(r \bmod N/k)) \quad (4)$$

$$CSp=E\_current/E\_(n\text{-}max) \;\; x \;\; (k/N) \quad (5)$$

Where E_current: is a node current energy, E_(n-max): is a node initial current.

In the steady-state phase, data are processed by using the mobile agent technique. This improves the reliability of data transfer, and ALEACH uses a synchronized clock which makes every node know when each round starts. ALEACH achieves minimum node failure probability. It also increases the time interval before the death of the first node, and the lifetime of CH and overall lifetime. The usage of TDMA/CDMA saves energy. However, it is not suitable for large scale networks.

5.9 LEACH-H 2009

LEACH-H combines the advantage of LEACH and LEACH-C. LEACH-H consists of a lot of rounds.

5.9.1 At first-round:

Each node sends information about its location and remaining energy to BS in the setup phase. BS selects optimal CH nodes, which locate near to the center of any cluster for first and second-round using simulated annealing algorithm and send these selected CH nodes in (BS-CH-INFO) message. All nodes that received (BS-CH-INFO) messages determine their status to start the transmission phase. If any node is chosen as a CH for this round, it waits for data from other nodes. Otherwise, if any node is chosen as an ordinary node, it sends data to its CH in its slot.

5.9.2 The remaining rounds:

CH nodes broadcast their information to the network in the setup phase. They wait for access messages from other nodes. Access message contains the location and remaining energy information, this information is used to choose CH nodes for the next round and send them a message. In transmission phase nodes not chosen as a CH send their data to chosen CH nodes. LEACH-H Combines between centralized and distributed protocol. However, it is using a one-hop transmission, so not suitable for a large area [44].

5.10 Vice-cluster head LEACH (V-LEACH) 2009

In LEACH, CH nodes lose energy and die due to receive, aggregate, and transmission of data. Death of CH leads to loss of the gathered data. V-LEACH solves this problem by adding Vice-CH which takes the role of CH when the CH dies.

Data is not lost if CH nodes die and it always reaches BS. No need to elect a new CH each time a CH dies. Increases the lifetime of the network. Increases overhead at the setup phase. Reserves a node in each round. Still the one-hop communication [45].

5.11 CELL-LEACH 2012

The setup phase is done only in the first round of CELL-LEACH. In setup phase network is divided into cells and each cell has its cell-head. Every 7 near cells compose one cluster, which has one cluster-head as shown in Figure 11.

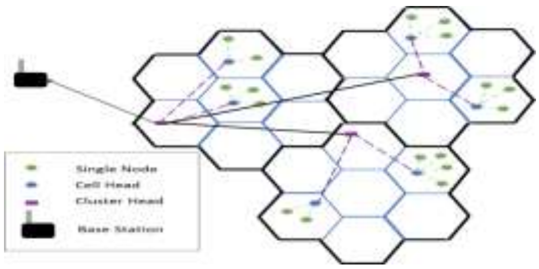

Fig -11: Organization of CELL-LEACH protocol.

At first round: Cell-head and cluster-head are chosen randomly as all the sensors have the same energy. At next rounds: Each old cell-head selects a new cell-head same as each old cluster-head selects a new cluster-head. This is done using factors of EAvg-cell and Eavg-cluster.

To calculate Eavg-cell: after a period of time, all sensors send their remaining energy to their cell-head, and each cell-head calculates Eavg-cell to its cell. And to calculate Eavg-cluster, each cluster-head sends its calculated Eavg-cell to cluster-head to calculate Eavg-cluster. To choose a new cell-head when the remaining energy of the cell-head is less than Eavg-cell, cell-head sends a message of Eavg-cell to cell nodes. If any node of this cell remaining energy is more than an Eavg-cell, it sends its remaining energy to the cell-head. The old cell-head chooses a new cell-head with more energy. Else if there are no messages sent to cell-head this means that no remaining energy of any node in the cell is more than Eavg-cell so the operation of calculating Eavg-cell is done again. Choosing a new cluster-head is the same as Chosen a new cell-head but the new cluster-head is chosen from all nodes in the cluster but with remaining energy more than an Eavg-cluster.

In the transmission phase, all cell nodes collect their data and send it to a cell-head using TDM (Time Division Multiplexing) as each node transmits only in its time and remaining nodes are in sleep mode. Cell-hard aggregate this data and send it to cluster-head using TDM. Cluster-head found the best path between all cluster-head by using table contain each cluster head and their location to send data to BS. CELL-LEACH distributes the load between nodes. It also uses multi hop communication. However, it increases the complexity and control overhead [46].

5.12 A Multi-hop Technique Protocol (MHT-LEACH) 2016

MHT-LEACH same as LEACH in choosing CH nodes, but it creates two-hop communication between CHs and BS for delivering the aggregated data. MHT-LEACH divides CHs nodes into two groups: Firstly, the external group, which contains all CHs, which located at a distance equal to or larger than do, while do parameter represents the threshold distance. Secondly, the internal group that consists of all nodes located at a distance less than do.

In the communication phase, the internal group can send their data directly to BS. On the other side, the external group can follow one of three cases. In the first case, when the CH distance to BS >= do and CH distance to the closest CH the internal group < do, the CH chooses next-CH which has a minimum value from the CH. In the second case, when there is no node in the internal group, and the distance from CH to BS is <= the distance from CH to the nearest CH in the external group, the CH transmits the data directly to the BS. The third case, when there is no node in the internal group, and the distance from CH to BS is > the distance from CH to the nearest CH in the external group, the CH transmits the data to the CH, which has a minimum value from the CH [47].

MHT-LEACH uses the location of the node to avoid overload. It also takes the distance into consideration to find the best path in communication. The internal group may not contain CH nodes. MHT-LEACH does not consider energy in the selection of CH nodes.

5.13 Improved Multi-hope Technique LEACH (IMHT-LEACH) 2017

IMHT-LEACH protocol improves the MHT-LEACH protocol. The MHT-LEACH protocol faces a problem related to the area of deployment, as some of the deployment areas could be relatively large and probably most of the CHs are located upper than do, so the MHT-LEACH requires a lot of energy to transmit the data to the CHs in the internal group. The IMHT-LEACH solves the problem of the large area, by reducing the cost of energy during the data transmission to the BS [48].

The IMHT-LEACH classifies all CHs based on the distance from the BS, whereas the length of every level is do/2. This algorithm proposes four phases to establish a route from the CHs to the BS:

5.13.1 Initial Phase

Same as the setup phase of the LEACH protocol, but it uses the Global Positioning System (GPS). Use GPS divide the network into a number of levels around the BS, so each CH node knows its position, level, and distance from BS.

5.13.2 Announces Phase

CH nodes broadcast announcement messages, which contain their position, and their distance to the BS. Announcement messages help in building a routing table for all nodes.

5.13.3 Routing Phase

Each CH node uses the routing table, which created in the announcement Phase to decide its route to the BS. Routing Phase has three cases for choosing the route to the BS, where each case selects the CH route and computes the amount of energy that will be dissipated, as follows:

Case 1, if the distance between the CH and the BS is less than do/2, the CH sends its data directly to BS. Case 2 occurs when the CH position far from BS within a distance between do/2 and do. In this case, when the distance between the CH and the BS is less than the distance between the CH on the second level with all CHs located on the first level, the CH sends its data directly to BS. Otherwise, the CH sends its data to the CH, which has minimum distance in level 1. Case 3 occurs when the CH position far away from BS with a distance more than do. In this case, when the distance between the CH and the BS is less than the distance between the CH on the upper level with all CHs located on the lower level, the CH sends its data directly to BS. Otherwise, the CH sends its data to the CH, which has minimum distance in level n.

5.13.4 Redundancy Phase

CHs that are located at the same level and have a copy of packets, work on reducing this redundant data before sending it to BS.

IMHT-LEACH uses multi hop communication instead of two-hop communication. Removing redundant data reduces the data sent to BS. The protocol chooses CH based on location and the load is distributed among nodes. However, energy is not considered in CH selection. In large areas, the announcement phase consumes a lot of energy.

5.14 Modified Cluster Head LEACH (H-LEACH) 2017

H-LEACH improve LEACH protocol by improving the CH selection as it uniformly distributes the load among all sensor nodes, minimizing the variations between the energy of sensor nodes, which leads to the dead-spot occurrence, and extending the overall network lifetime. An optimal count of clusters, closer nodes are considered during the election of CH, which reduces the transmission distance and helps to prolong the lifetime of the network [49].

The election of CH is done by:

- First, Threshold T(n) is calculated based on node remaining energy, optimal CHs, average distance and closer nodes to BS.
- Second, compare the generated random number of the node against T(n). If a random number less than T(n) then check node remaining energy is greater than average energy.

Each member node will communicate to cluster head in their TDMA slots. Finally, data transmitted with multi-hop using TDMA (Time Division Multiple Access) to the BS. H-LEACH uses multi-hop communication and distributes load among nodes. It chooses CH upon node remaining energy and distance to BS. The protocol presented a solution for the dead - spot problem. H-LEACH did not take the size of data sent in its consideration while selecting CH.

5.15 Hybrid Clustering LEACH Protocol (HLEACH) 2018

Hybrid Clustering LEACH Protocol (HLEACH) improves the LEACH protocol by using node location and make protocol depend on the area. First, all nodes in the network know their location coordinates. Then the area is divided into many zones as the desired number of clusters. Each zone considered as a cluster and protocol chooses randomly any node of each zone as a CH for this round. A load of the CH role is rotated between all nodes in each zone to distribute the load between nodes.

Dividing an area with fixed clusters with knowing nodes location saves energy, and increases its stability. But it suffers from holes not covered with the node as it causes protocol failed. Also, it's not used energy or distance metric at choosing CH. Besides, it still suffers from one-hop communication, which makes it unsuitable for large areas [50].

5.16 Congestion aware Clustering and Routing (CCR) protocol 2019

CCR protocol is scalable, stable, reliable, efficient, distribute, and fault tolerance protocol.

The operation of the CCR protocol consists of two phases:

5.16.1 Start phase.

At the beginning of each round, the start phase operates. In the first round, the start phase runs the algorithm of the setup phase, but for the remaining round, the start phase runs the algorithm of the small setup phase.

Setup phase, run once at the beginning of the first round, in this phase the network area is divided into levels L and sectors S to create fixed clusters as shown in Figure 12. Dividing a network to levels is performed by the sink, as the sink node sends messages with different powers to cover specific areas. Nodes of level 1 hear all these messages; otherwise, the nodes of the last level can hear one message.

Dividing a network to sectors is done using mathematical equations. The CCR protocol does not use information about the location of the node, but any node can know its distance from another node using the received signal strength of the message.

The intersection of each level and sector creates a cluster. CCR protocol equalizes the number of nodes in sectors of each cluster to achieve an equal distribution of load between nodes. Every node must also know its cluster number, which consists of a level number L followed by sector number S denoted as Cls. Each cluster must have a primary cluster head PCH node and optionally secondary cluster head SCH node. The PCH and SCH nodes are selected in the setup phase depending only on the distance [51].

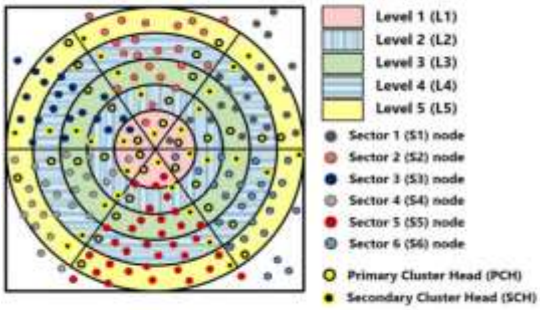

Fig -12: CCR cluster configuration.

The small setup phase runs at the beginning of the remaining rounds. In the small setup phase, dead nodes are removed from clusters, new nodes can be added to clusters, if there is any level have a dead cluster, setup phase merges clusters of this level with the corresponding clusters in the next level together, to avoid hot spots. Also in the small setup phase, the roles of the PCH node and the SCH node are rotated among cluster nodes, so new PCH, and new SCH have chosen by using these equations (6,7).

$$PCH_{new}=n\in| \ \max(n)_{ER} \wedge \max(n)_{SD} \ \wedge \max(n)_{dP} \qquad (6)$$

$$SCH_{new}=n\in| \ \max(n)_{ER} \wedge \max(n)_{SD} \ \wedge \max(n)_{dS} \qquad (7)$$

Where:

- N the set of nodes in the network.
- $\max(n)_{ER}$ node with the maximum remaining energy.
- $\max(n)_{SD}$ node with the maximum data needed to be sent.
- $\max(n)_{dP}$ node with the minimum distance to PCH.
- $\max(n)_{dS}$ node with the minimum distance to SCH.

5.16.2 Communication phase.

The communication phase divided into two types intra cluster routing, and inter-cluster routing.

In intra cluster routing all ordinary nodes of each cluster send their data to their PCH, or SCH node in single-hop communication, by using TDMA and CDMA.

TDMA divides time between nodes. Each node sends data in its specific time slots. The number of slots given to each node depends on the size of data each node wants to send. First, the PCH node must determine the destination node (PCH or SCH) for each node in the cluster. The destination node of the PCH node is itself, and the destination node of SCH is itself. Other nodes specify two distances; the first is the distance to PCH + distance between PCH and Sink. The second is the distance to SCH + distance between SCH and Sink. Each node sends its info message to the PCH node. Each node sends its data to the closer CH with free size in its storage unit that can contain this data. Then aggregate data in PCH, and SCH. After aggregation new space, maybe appear in PCH or SCH; so if there is any remaining data in nodes not be sent yet because there was no space for it before aggregation, it can be sent in this new space.

In inter-cluster routing only the PCH node and the SCH nodes are awake. Each CH node tries to send its data to the sink node. Each sector sends its data to the same sector at the pre-level until the data reach the sink node, so each sector at all levels uses the same CDMA to send the data. Transmission is divided into several periods, according to the size of data that each level needs to send, and the number of PCH and SCH node in level (1). The transmission in each period is done when all the PCH and SCH nodes of the level (1) are full of data [51].

5.17 The Improvised TL-LEACH protocol 2019

The Improvised TL-LEACH protocol is operated in many rounds each consisting of a setup phase and a steady phase.

In the first round, four main steps are identified in the setup phase. The first step is the selection of PCH node, which selection is the same as in LEACH protocol, besides it selected based on maximum energy and minimum distance to BS. The second step is cluster formation in which the chosen cluster head advertises its position with the nearby nodes. Each node selects the closest CH to belong to it. At the end of this step, several clusters are formed with a PCH. The third step is the selection of SCH node, which used to help PCH to minimize the distance required to send data to BS. In this step distances between all nodes in the clusters are calculated. The SCH node is chosen to be nearer to every node in the cluster, to minimize the distance of transmission. The fourth step is that the SCH creates a TDMA schedule and advertises cluster nodes with it. At the least, in the steady-state phase, every node sends their data depending on the TDMA schedule to SCH, which aggregated it and send it again to BS.

The difference in the remaining rounds is done after the selection of PCH, the average energy of each cluster is calculated. The node with minimal distance and maximum energy is declared as SCH. The protocol ensures that the SCH mostly remains near the center of every cluster and also has enough energy to receive the data from other cluster members, aggregate it and transmits it to the PCH. The advantage of this protocol is using distance and energy in its consideration in selecting PCH and SCH. But this protocol is still two-hop count and not suitable for large network areas [52].

5.18 The modified LEACH 2019

The modified LEACH routing algorithm aims to minimize energy consumption by minimizing the overhead of selecting the cluster head and cluster formation on each round. The CHs chose and clusters formatted in the first round were done the same as LEACH. After the cluster is fully formed, the cluster head still works until two-third of its total energy is consumed, and the cluster head schedules cluster heads for the next rounds depend on the residual energy of individual nodes. Then re-clustering is done. The re-clustering process helps to regroup alive nodes and to remove dead nodes from the cluster member cache.

At the remaining rounds, the new chosen CH automatically acts as a cluster head until two-third of its total energy is consumed. Hence, the cluster-head scheduling removes the over-head of a cluster-head advertisement message to get members, join request message to the cluster-head and computation for electing cluster-heads. If the scheduled node dies before it serves as a cluster head, the successor scheduled node will serve. The benefit of this protocol uses residual energy as a metric to choose a new CH. Also, every CH chooses CH nodes for the next many rounds, and this helps to save energy and removes the over-head of selecting a new CH. But it's still a one-hop communication as LEACH, and not suitable for large areas [53].

5.19 ENHANCED TWO-LEVEL-LEACH PROTOCOL (ETL-LEACH) 2019

Enhanced two-level-leach protocol (ETL-LEACH) is improved TL-LEACH by making choosing of PCH, and SCH depends on energy. Each SCH node takes information about energy from end nodes and uses this information to create a table. When the energy of SCH decreases and falls below an acceptable threshold, the SCH requests for a role switch use the energy table to select the node with the highest residual energy to take its role. The process is similar to the primary cluster head role switching. This ensures an overall increase in the lifetime of the cluster-based wireless sensor network.

The main advantage of this protocol is using energy in its consideration of selecting a cluster head. But it does not use the distance or location of nodes. Also, it's still two hops count which makes it not suitable for large areas [54]. Comparing between all previous mentioned protocols can be shown in Tables1and compare between block-based clustering protocols in the metrics used to choose CH shown in Table 2.

6. Conclusion

In recent years, clustering routing protocols in WSN have gained tremendous attention leading to unique challenges and design issues when compared to routing in flat routing protocols. Clustering is most suitable for large scale wireless sensor networks and a useful topology management approach to reduce the communication overhead and exploit data aggregation in sensor networks. The big challenges for clustering algorithms are how to manage intra-cluster and inter-cluster transmissions for good packet delivery ratio with minimum energy consumption, and how to format the optimal cluster help to maximize the network lifetime. In this paper, we have discussed the difference between cluster routing categories, and concentrate on block-based cluster routing protocols. There are still some energy-efficient protocols are to be studied in the future.

Table -1: Comparison between different protocols

Protocol	Year	Scalability	Stability	Efficiency	Homogeneous	Self-organization	Control	Location	Hop-count	Aggregation
PEGASIS	2001	Good	Low	High	√	-	-	X	M	√
TEEN	2001	Good	High	V. High	√	-	D	X	1	X
PANEL	2007	Low	Low	High	√	-	D	√	M	√
LEACH	2000	Low	Medium	Low	√	√	D	X	1	√
LEACH-C	2000	Good	Medium	Medium	√	√	C	√	1	√
LEACH-F	2000	Low	High	High	√	√	C	√	1	√
TL-LEACH	2005	Good	Medium	Medium	√	√	D	√	2	√
LEACH-ET	2006	V. Good	-	Medium	√	√	C	√	1	√
E-LEACH	2007	V. Good	Medium	High	X	√	D	√	1	√
MH-LEACH	2007	V. Good	-	V. High	√	√	D	√	M	√

TB-LEACH	2008	Low	Medium	High	√	√	D	X	1	√
ALEACH	2008	Good	-	Medium	X	√	D	X	1	√
LEACH-H	2009	-	-	Medium	√	√	H	√	1	X
V-LEAC H	2009	V. Good	-	V. High	√	√	D	√	1	√
CELL-LEACH	2012	V. Good	-	V. Good	√	√	D	√	M	√
MHT-LEACH	2016	Good	High	High	√	√	D	√	2	√
IMHT-LEACH	2017	V. Good	V. High	V. High	√	√	D	√	M	√
H-LEACH	2017	V. Good	High	V. Good	√	√	D	X	M	X
HLEACH	2018	Low	High	V. Good	√	√	D	√	1	√
CCR	2019	V. Good	V. High	V. Good	√	√	D	X	M	√
Improvised TL-LEACH	2019	V. Good	High	V. Good	√	√	D	√	2	√
Modified LEACH	2019	Low	High	V. Good	√	√	D	X	1	√
ETL-LEACH	2019	Good	High	High	√	√	D	X	2	√

Table 2. Comparison between different protocols

Protocol	Choose CH metrics
LEACH	It depends on a random number. Not chosen before in the last 1/P round.
LEACH-C	Run an optimization algorithm such as simulates annealing to find the best CH nodes for this round, which chosen from nodes with energy levels more than average energy.
LEACH-F	It depends on the rotation schedule of the future CH which determined by the sink.
TL-LEACH	Each node decides which to be primary CH, secondary CH, or simple node (SN) in each round.
LEACH-ET	The CH node energy reaches to energy threshold (ET).
E-LEACH	The selection of CH depends on the amount of residual energy of each node.
MH-LEACH	Same as LEACH.
TB-LEACH	CH selected for each round is fixed which determined by the counter. Each node produces a random timer. If the counter number does not reach the total number of CH for this round and timer of any node is expiring, this node broadcast (CH-ADV) message to inform all nodes that it will be a CH.
ALEACH	The energy of nodes.
LEACH-H	In first and second-round BS use simulated annealing algorithm to choose the best CH. In the remaining rounds, old CH nodes choose CH nodes for the next round.
V-LEACH	Choose CH node and vice-CH node the same as LEACH.
CELL-LEACH	Use average energy to choose Cell-head and cluster-head
MHT-LEACH	Same as LEACH.
IMHT-LEACH	Same as LEACH with taking location in its consideration.
H-LEACH	Choose CH based on node remaining energy, optimal CHs, average distance and closer nodes to BS.
CCR	Not chosen before in the last 1/P round. Remaining Energy. The amount of free space of the storage unit in each node. The amount of data that each node wants to send. The distance from each node to the PCH node of the cluster in [the previous level and the same sector]. The distance from each node to the SCH node of the cluster in [the previous level and the same sector].
Improvised TL-LEACH	Not chosen before in the last 1/P round. Remaining Energy. The distance between each node and SCH The distance between PCH and BS

Modified LEACH	Not chosen before in the last 1/P round. Remaining Energy.
HLEACH	Not chosen before in the last 1/P round.
ETL-LEACH	Remaining Energy.

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