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An Overview of Cluster-Based Routing Protocols in Wireless Sensor Networks: A Survey

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Abstract: - A Wireless Sensor Network (WSN) comprises numerous small, cost-effective, resource-constrained devices known as sensors, which are strategically placed within or in proximity to a physical area for observation purposes. These sensors, which are connected via wireless networks and the Internet, provide new prospects for a wide range of military and civilian applications, such as environmental monitoring, combat surveillance, and industrial process management. WSN efficiency is mostly determined by the routing protocol used. Routing protocols are widely grouped into network architecture based and operation-based protocols. Energy conservation is a major concern in WSNs, and clustering has emerged as one of the most popular methods for enhancing energy efficiency within these networks. Clustering routing protocols in Wireless Sensor Networks (WSNs) offer several advantages, including improved scalability, optimized energy consumption, and prolonged network lifetime. In this study, we first address WSN system architecture, WSN design and routing challenges, routing protocol categorization, clustering concepts, and finally clustering routing protocols in which their objectives, advantages, and disadvantages are highlighted. Finally, we compare and conclude the study.

Keywords: Wireless sensor networks, Mobile Adhoc Networks, Routing protocol, Clustering, Cluster Head.

I. Introduction

Recent advancements in technology, wireless communications, and digital electronics have made it possible to design and develop multifunctional sensor nodes (or motes), which are compact, smart, low-cost, low power that can communicate wirelessly over short distances [1]. These sensor nodes are equipped with sensing, data processing, and communication capabilities, facilitating the creation of wireless sensor networks (WSNs), which rely on the collaborative efforts of numerous sensor nodes to achieve various tasks. Wireless Sensor Networks (WSNs) were originally introduced for defense applications, they have proven to be highly beneficial in a wide range of fields such as environmental monitoring, health care, agriculture, industrial automation, smart cities, security and surveillance, home automation, among others. Sensor nodes operate with limited resources, such as battery power, memory, computational power, and bandwidth. As a result, a main goal of sensor networks is to extend the network's lifespan by reducing or optimizing the energy consumption of the sensor nodes. This entails using efficient protocols, algorithms, and techniques to properly manage energy consumption, hence increasing the network's operating lifespan.

Wireless Sensor Networks (WSNs) and Mobile Adhoc Networks (MANETs) have some similar characteristics, such as the use of multi-hop communication, in which data travels through intermediary nodes to reach the destination. However, there are several differences between WSNs and MANETs:

1. WSNs interact with the physical environment, resulting in unique traffic characteristics compared to human-driven networks, whereas MANETs support traditional applications with predictable traffic patterns.
2. Data gathered by the sensors is usually based on common phenomenon, and hence data could be redundant in WSN, while this is not the case in MANETs.
3. In WSN, communication is typically from several data sources to a data recipient, rather than between a pair of nodes.
4. While sensors are typically stationary, nodes in MANETs are mobile.
5. WSNs have more stringent network lifetime requirements, and recharging or replacing WSN node batteries is far less feasible than in MANETs. Energy considerations have a greater impact on the system architecture in WSNs compared to MANETs.
6. The number of sensor nodes distributed in the sensing region may be in the range of hundreds of thousands or more than the number of nodes in MANET.

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II. Wireless Sensor Network Architecture

WSN consists of large number of sensor nodes which collaborate and gather information from their surrounding physical environment and send the sensed data to base station (BS). The Fig.1 shows a typical sensor node which consists of the four basic components: a sensing unit, a processing unit, a power unit, and a transmission unit [1][2]. The sensing unit is made up of few sensors and analog to digital converters (ADC). The sensors observe the physical characteristics of the environment and generate analog signals based on the observed phenomenon. The ADCs translates the analog signals into digital signals, which are then fed to the processing unit. The processing unit is often a microcontroller or microprocessor with memory that offers intelligent control to the sensor node. The transmission unit uses a short-range radio to transmit and receive data via a radio channel. The power unit includes a battery that provides power to all system components. Each node may also have two optional components: the Location Finding System and the Mobilizer. The location finding system is utilized to determine the sensor's position. The Mobilizer controls the sensor's mobility from one area to another. And the power generator is used to replenish the sensor energy to increase the lifetime of the sensor, such as solar.

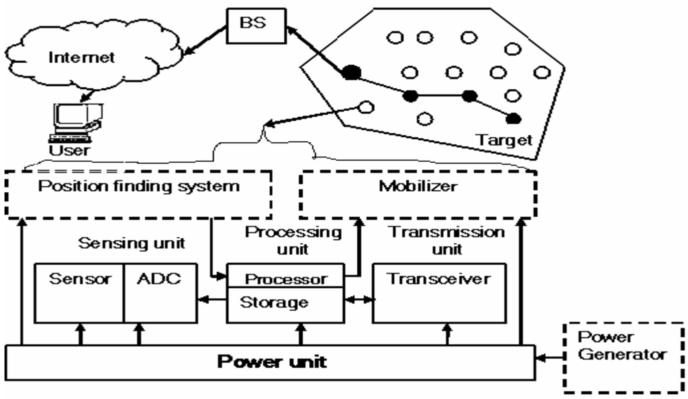

Fig. 1. WSN Architecture [3]

2.1 Design Challenges of WSN

1. Limited computational capabilities
2. Data centric
3. Random deployment
4. Self-organizing
5. Dynamic topology
6. Environmental factors
7. Transmission medium
8. Limited communication range
9. Application-specific quality of service requirements.
10. Connectivity
11. Fault tolerance
12. Scalability [4,5,7]

2.2 Routing Challenges in WSN

Routing protocols are required to extend lifetime of the sensor network by ensuring efficient utilization of energy. Routing in wireless sensor networks is challenging due to various reasons: One reason is that the resources like energy supply, computing power, bandwidth are restricted, and hence optimal resource utilization is vital. Secondly, data may be redundant since data collected by various sensors relies on a common phenomenon and hence data aggregation is required before it is sent to the base station or the destination. Thirdly, sensor networks employ attribute based addressing i.e., data is obtained based on certain attributes. Fourth, WSN involves large number of sensor nodes and hence don't require unique ID since lot of overhead is involved in maintenance of the ID and data is more essential than knowing the ID of the node which sent the data. Fourth, design requirements of WSN changes with application [7]. Fifth, location awareness of sensor nodes is essential since data gathering is based on the position of the node.

III. CLASSIFICATION OF ROUTING PROTOCOLS FOR WSNS

The routing protocols for WSN can be classified into two major categories according to network structure and protocol operation [6][12]. Fig.2 illustrates the classification of routing schemes for WSN.

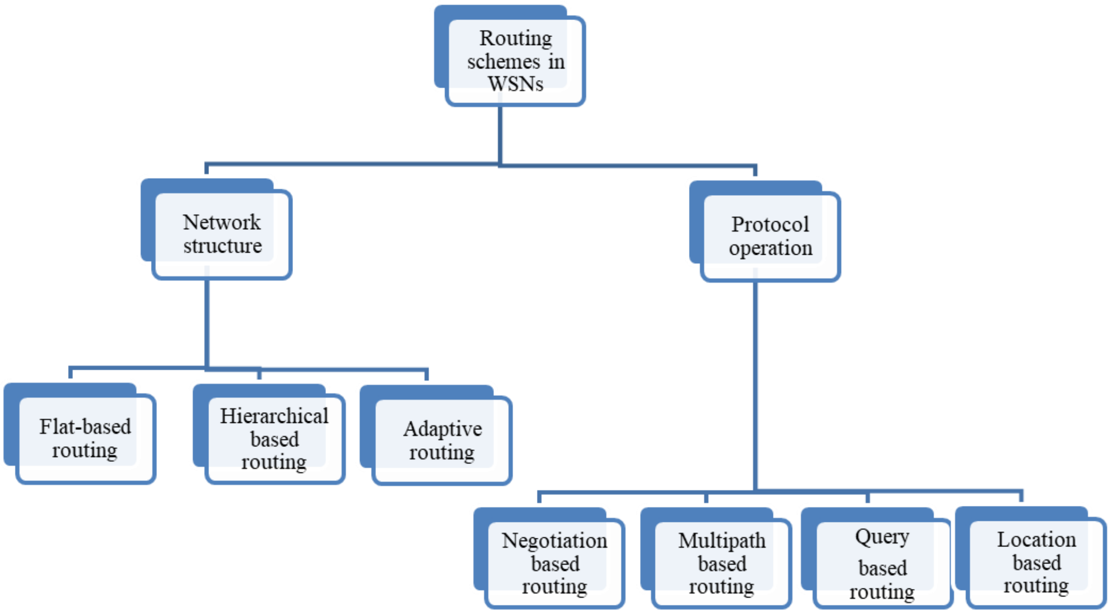

Fig. 2. Classification of Routing schemes in WSN

3.1 Clustering Preliminaries

Clustering

Sensor nodes are grouped into clusters in cluster or hierarchical based routing, and each cluster has a leader known as the Cluster Head (CH). A CH is one of the more resource-rich sensors [11]. Cluster members sense the field, generate data, and transfer it to their respective CHs. The CHs receive the data from the cluster members, aggregates it and delivers to the Base station. [10].

Advantages and Objectives of Clustering

1. Scalability
2. Data Aggregation
3. Efficient Energy Consumption.
4. Robustness
5. Load Balancing
6. Fault-Tolerant
7. Increase in the lifetime of the Network [8],[9].

3.2 Characteristics of Clustering

WSN clustering protocols have been compared based on some clustering characteristics, including cluster and cluster-head properties. Fig. 3 illustrates the taxonomy of clustering properties.

Cluster Properties

1. The number of Clusters: The number of created clusters can be fixed or variable [10].
2. Cluster Sizes: The size of each cluster can be same or different. Clustering with varying cluster sizes can result in more uniform energy use.
3. Intra-Cluster Communication: The CH and sensor nodes can communicate using either a single hop or multiple hops.
4. Inter-cluster communication: Some WSN applications assume direct connection between the CH and the BS [10], while others assume multi-hop communication.

Cluster Head Properties

1. Existence: A cluster may contain at least one CH or none at all.

2. Type of node: Sensor networks can be homogeneous or heterogeneous. In a homogenous network, all sensor nodes have identical capabilities and resources. In a heterogeneous network, each sensor node possesses different skills capabilities and resources.
3. Mobility: The CHs may be mobile or stationary [10]. CHs can travel for shorter distances to improve network performance [11].
4. Role: A CH can merely serve as a relay for traffic generated by sensor nodes in its cluster, or it can aggregate information acquired from sensor nodes in its cluster. Sometimes, a CH works as a base station that takes actions based on the identified phenomenon [11].

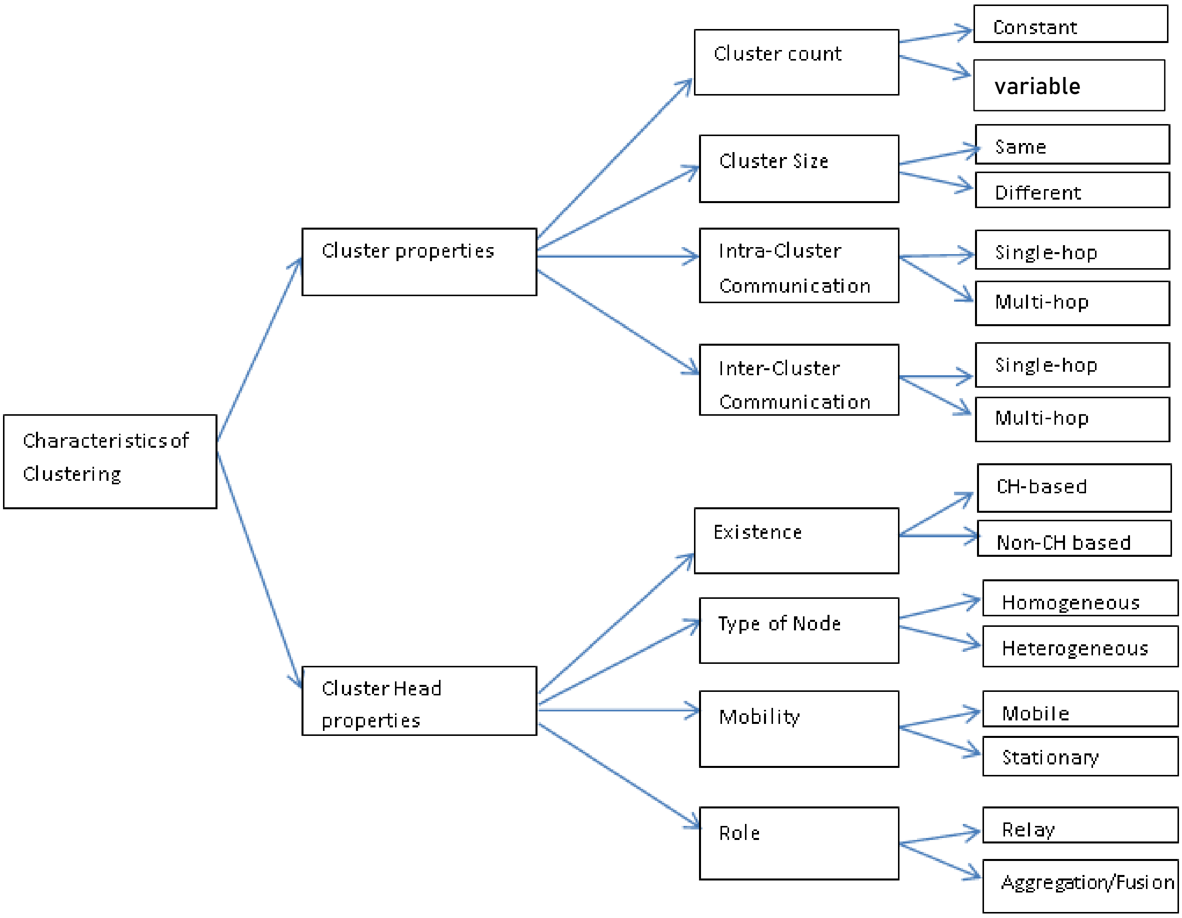

Fig. 3. Taxonomy of clustering characteristics

IV. CLUSTERING PROTOCOLS

4.1 LEACH - Low-Energy Adaptive Clustering Hierarchy

It is the most prevalent cluster-based routing protocol and main objectives of the protocol are:

1. To extend network lifetime by periodic re-clustering.
2. Data aggregation and hence reduction in energy consumption.

The protocol's operation is separated into rounds, each of which consists of two phases-

1. Setup or clustering phase
2. Steady-state or data gathering phase

During the setup phase, clusters are organized and CHs are chosen. During the steady-state phase, sensor nodes sense and send data to the CH, which aggregates it to remove redundancy before sending it to the BS via a single hop. It employs TDMA (Time division multiple access) and CDMA (Code-Division Multiple Access) MAC to minimize intra- and inter-cluster collisions, respectively [12]. The setup phase begins with a round of CH selection. The role of CH is rotated across sensor nodes in order to evenly distribute energy usage over the entire network.

During the setup phase, in order to become a CH, a node selects a random number between 0 and 1. If the random number is less than a threshold value (T(n)), then the node becomes a CH for the current round.

The threshold T(n) of a competing node n is expressed as follows:

$T(n) = 0 \qquad\qquad \text{if } n \notin G$

= P / 1- P (r mod (1/P))   if n ∈ G

where ‘P’ represents the CH probability, the variable 'G' represents the set of nodes that were not chosen to become CHs in the last 1/P rounds., and r is the current round.

Following the selection of the CH, each CH advertises itself to the other nodes in the network. After receiving the advertisement, the non-cluster head nodes choose a cluster to join based on the intensity of the received signal. The nodes then inform their respective CHs of their desire to join their cluster.

Following cluster’s formation, every CH broadcasts the TDMA schedule, which specifies the time slot for each node to send sensed data. Each CH also selects a CDMA code, which is distributed to all cluster members to reduce inter-cluster collisions. During the steady phase, non-cluster head nodes gather information periodically and use their assigned time slots to relay the data acquired to the CH. After a predetermined period of time, the network returns to the setup phase and begins another round of selecting new CHs.

Advantages of LEACH:

1. The rotation of CHs amongst sensor nodes results in balanced energy consumption.
2. CH broadcasts CDMA code/TDMA schedule, which prevents collisions. Based on the assigned time slots, sensor nodes can open/close communication interfaces thereby reducing energy consumption
3. Nodes need not send their information directly to the BS as data is aggregated and sent by the CH to the BS, which reduces the number of transmitted messages and also the energy consumed.
4. Local cluster management eliminates the requirement for global network knowledge.

Drawbacks of LEACH:

1. The protocol’s periodic re-clustering may increase the energy consumption of the nodes.
2. Long-range communication between CH and the BS can consume a lot of energy and hence it is neither a feasible technique, nor is it appropriate for networks deployed in large regions.
3. Random CH selection may result in the selection of a low energy node as the CH. Moreover, the number of CH’s may not be uniformly distributed throughout the network, leading to an increase in CH intensity in a specific area. As a result, certain nodes may not find any CH’s nearby.
4. The protocol assumes that in each election round, all nodes start with the same amount of energy[12].

4.2 PEGASIS – Power-Efficient Gathering in Sensor Information Systems

It is an enhancement of the LEACH protocol. The primary goals of the protocol are:

1. To improve network lifetime by promoting energy efficiency and uniform consumption across the network.
2. To reduce data delays on the way to the BS.

In this protocol, sensor nodes are expected to have global knowledge of other sensors' locations. Furthermore, they can adjust their power to span arbitrary distances. The nodes' role is to collect and send data to the sink. PEGASIS, unlike other protocols, uses a chain structure for data gathering and dissemination rather than a cluster-based hierarchical network organization. Based on the chain structure, nodes communicate with their nearest neighbors, and each node has the opportunity to be the chain leader for transmitting aggregated data to the BS. The chain begins at the farthest node from the BS and network nodes are gradually added to the chain, starting from the closest neighbor to the end node in a greedy manner.

To determine the closest neighbor, a node uses signal strength to calculate the distance to all of its surrounding nodes and then modifies the signal strength such that only the closest node can be heard. Nodes transmit aggregated data to the sink in turns, with node number i mod N (N represents the number of nodes) transmitting in round 'i'. A node in the chain is chosen to be the chain leader, and it is the chain leader's responsibility to provide the aggregated data to the sink. Data is aggregated along the chain, with each node receiving data from one neighbor, combining it with its own data, and transmitting it to the next neighbor on the chain. The chain leader aggregates the data from right and left sides of the chain and transmits it to the data sink.

Advantages of PEGASIS:

1. It eliminates the overhead of periodic cluster formation, advertisements, and minimizes data transmissions via data aggregation in chain communication.
2. Because each node in the chain can send data per round, energy consumption is evenly spread among them.
3. The multi-hop, chain-based technique among nodes enables network scalability [10].

Drawbacks of PEGASIS:

1. In large-scale networks, it is not feasible for all nodes to have global knowledge of the network topology.
2. The single chain strategy may reduce network reliability [10].
3. Excessive delays may occur for nodes located far away from the sink, requiring significant energy for transmission.
4. A single chain leader method may cause bottlenecks.

4.3 HEED - Hybrid Energy-Efficient Distributed Clustering

It is a popular, hybrid, energy - efficient protocol and has the following objectives:

1. Prolonging the lifespan of the sensor network through energy distribution.
2. Limit the amount of clustering iterations.
3. Minimizing control overhead.
4. Establishing evenly distributed CHs and compact clusters.

HEED chooses CHs on a periodic basis using two parameters: primary parameter, is each node's residual energy, and the second, the intra-cluster communication cost. Each sensor node's clustering process consists of multiple rounds.

A predefined initial percentage of CHs in the network, denoted as C_{prob}, is set and employed to restrict the initial CH announcements. Each node determines the probability CH_{prob} of becoming a Cluster head as follows:

$CH_{prob}= C_{prob}.E_{residual} / E_{max}$,

where $E_{residual}$ is the node’s current residual energy and E_{max} is the node’s maximum or the initial energy. The CH_{prob} value must be above a minimum threshold p_{min}.

A CH is either a tentative CH or a final CH, depending on whether its CH_{prob} is less than or greater than one. In each round of the protocol, any node that has not received communication from a CH nominates itself as a CH with a probability determined by its CH_{prob}.The newly selected CH’s are added to the current set of CH’s. If a sensor node is selected to be a CH, then it broadcasts a message indicating whether it is a tentative CH or a final CH.

A sensor node that receives the list of CHs selects the CH with the minimal cost from this list. Subsequently, each node doubles its CH_{prob} and moves on to the next step. If a node completes the protocol’s execution without opting to be a CH or joining a cluster, it proclaims itself as the final CH. If a tentative CH hears from a lower-cost CH, it can become a normal node later in the iteration process. A node can be chosen as CH at successive clustering intervals if it has higher residual energy at a lower cost.

Advantages of HEED:

1. Energy distribution increases the lifetime of all motes in the network, ensuring the stability of the neighbor set.
2. Multi-hop communication between nodes improves energy efficiency and network scalability.
3. The protocol enhances network longevity by selecting CHs based on two characteristics, rather than randomly.
4. Well-distributed CHs ensure balanced network load and lower communication costs.

Drawbacks of HEED:

1. The protocol's iterative clustering mechanism increases energy consumption and shortens the network's lifetime.
2. The CH selection process incurs lot of overhead resulting in imbalanced energy consumption across the network.

4.4 EEHC- Energy - Efficient Hierarchical Clustering

It is a decentralized, k- hop hierarchical clustering algorithm with the following goals:

1. To Prolong the life span of the network.
2. To enhance network scalability by employing multilayer clustering.

The algorithm arranges the sensors into a hierarchy of levels and CH’s. The CH’s collect information from the sensors within their respective clusters and send an aggregated report to the sink via the CH hierarchy.

The algorithm uses two-stages of clustering: single-level clustering and multilevel clustering. During the single-level clustering stage, each sensor node has a predetermined probability, denoted as p, of becoming a Cluster Head (CH). It announces its intention to become a CH to neighboring nodes within a communication range of k hops. Any node receiving such an announcement message and not already a CH will join the nearest cluster. Nodes that are neither CHs nor members of a cluster become forced CHs.

If the announcement messages do not reach a node within a predetermined time interval t, the node is considered a "forced" CH, presuming it is not within k hops of all volunteer CHs. The parameters p and k determine how much energy is necessary to transfer the information gathered by the sensors to the processing center. The second stage extends the bottom-up process to multilayer clustering. Assuming there are h levels in the clustering hierarchy, the information gathered at all sensor nodes is initially transmitted to level -1 CHs, which aggregate the information and pass it on to level -2 CHs, and so forth. Finally, the level-h CHs transmit the aggregated report to the BS.

Advantages of EEHC:

1. Improves network lifetime and its stability.
2. The hierarchical architecture enhances the scalability of the sensor network.

Drawbacks of EEHC:

1. In multi-layered clustering, data aggregation causes delays since data is kept in intermediate nodes until other data arrives before being aggregated and transferred to the sink.
2. Optimal p and k parameters determine network energy consumption.

4.5 DWEHC - Distributed Weight-based Energy-Efficient Hierarchical Clustering

It is a distributed clustering algorithm with the following objectives:

1. Creating balanced cluster sizes.
2. Enhancing intra-cluster topologies for optimization.
3. Maximizing network lifetime.
4. Enhancing network scalability.

The algorithm operates under the assumption that the sensor nodes possess location awareness and transmit at consistent, fixed power levels. The cluster radius, defined as the maximum transmission distance from any cluster member node to its Cluster Head (CH), is fixed across the entire network. Following seven iterations on each node, the algorithm produces a multi-hop intra-cluster structure wherein a CH serves as the root node, and member nodes are organized in breadth-first manner. Intra-cluster communication is done using TDMA, while CHs contend for channel access using the 802.11 protocol to transmit data to the sink. After locating its neighbors, each sensor node computes its weight as follows:

$W_{weight(s)} = E_{residual(s)} / E_{initial(s)} \times \sum_{(R - d) / 6R}$

where $E_{residual(s)}$ is the residual energy of node ‘s’, $E_{initial(s)}$ is the initial energy of node ‘s’, R is the cluster range which is fixed for the whole network and d is the distance between node ‘s’ and its neighbor node. The node with the highest weight in the neighborhood becomes a temporary CH, and a temporary CH becomes a real CH only if a certain number of neighbors choose it as their CH.

At this point, neighboring nodes are considered as first-level child members of the Cluster Head (CH). Nodes gradually adjust their membership to decrease energy consumption while reaching a CH. Each node assesses the cost of reaching a CH through its non-CH neighbors, and then decides whether it's more beneficial to remain a first-level member or become a second-level one, accessing the CH via a 2-hop path. This procedure continues until all nodes decide on the best energy-efficient intra cluster structure.

Advantages of DWEHC:

1. The network's scalability is improved by each cluster having a minimum-power architecture and a limited number of child nodes per parent.
2. The method ensures optimal load balance per node, extending the lifespan of a CH.
3. The algorithm balances clusters and uses less energy for intra- and inter-cluster routing compared to HEED.

Drawbacks of DWEHC:

1. Multi-hop intra-cluster communication consumes more energy, making it unsuitable for large-region networks.
2. The iterative method followed during cluster creation results in a higher control message overhead in comparison to other protocols.

4.6 TEEN - Threshold Sensitive Energy Efficient Sensor Network Protocol

TEEN is a clustering communication protocol with the following objectives:

1. It focuses on a reactive network, and allows CHs to restrict when sensors should transmit their data.
2. It dynamically balances data accuracy, energy efficiency, and response time.

TEEN employs hierarchical clustering, organizing sensors into clusters led by a designated cluster head. Sensors within each cluster send their sensed data to the CH, which then forwards the aggregated data to higher-level cluster heads until it reaches the sink [13].

Once the CH’s are determined, each CH broadcasts the following threshold values in addition to the attributes:

- Hard Threshold (HT): This is the threshold value for the sensed attribute beyond which, the sensor node sensing the value must turn on its transmitter and report to its Cluster head.
- Soft Threshold (ST): Once the HT has been crossed, this is a minor change in the value of the sensed attribute that triggers the node to turn on the transmitter and transmit.

In addition, nodes store an internal variable called the current sensed value (SV) of the sensed attribute [15]. The nodes constantly sense their surroundings and communicate the sensed data based on the values of the hard and soft thresholds.

A node transmits its sensed data only if the following conditions are met:

- The sensed attribute's current value (CV) exceeds the hard threshold (CV >HT).
- Difference between CV and SV is greater than or equal to the soft threshold. (CV-SV>=ST) [14].

Both the thresholds decrease the number of transmissions by enabling sensor nodes to send only when the sensed attribute falls within the desired range.

Advantages of TEEN:

1. It performs significantly better than LEACH.
2. It is suitable for real time applications.

Drawback of TEEN:

1. The biggest disadvantage of the protocol is that if the thresholds are not met, the sensor nodes will never interact, and the user won’t receive any data from the network and will never be able to determine if the nodes are functioning properly or have died.
2. This scheme may not be suitable for applications that require regular data access.

4.7 APTEEN - Adaptive Periodic TEEN

Adaptive Periodic TEEN (APTEEN) addresses the limitations of TEEN and has the following objective:

1. To combine characteristics of both TEEN (time-critical data) and LEACH (periodic sensed data transfer).

It is a hybrid clustering scheme that allows the sensors to sense data periodically and also report any sudden change in the value of the sensed attribute to their cluster heads [13]. Some applications require not only time-critical information but also want a network that can be queried at regular intervals in order to get an overall picture of the network. This technique requires nodes to communicate data on a periodic basis and also respond to rapid changes in attribute values. It is similar to TEEN.

Once the clusters are formed and CHs are decided, CH broadcasts the following parameters in addition to the sensed attributes, the hard and soft thresholds:

- Schedule: This is a TDMA schedule which assigns a time slot to each sensor.
- Count Time (CT): It is the maximum time interval between two consecutive reports sent by a node.

Nodes continuously sense their environment and transmit according to hard and soft thresholds. In addition to the thresholds, if a node does not communicate data for a duration equal to the CT, it is forced to sense and transmit the data, regardless of the attribute's sensed value.

Advantages of APTEEN:

1. It integrates elements of both proactive and reactive strategies. Through periodic data transmission, it provides users with comprehensive view of the network as in a proactive approach. Simultaneously, it maintains continuous data sensing and promptly reacts to significant changes, ensuring responsiveness to time-sensitive scenarios. Consequently, it exhibits characteristics of a reactive network as well.
2. Energy usage can be controlled by adjusting the count time and threshold parameters.

Drawback of APTEEN:

1. There is additional complexity involved in implementing soft, hard thresholds and the count time.

4.8 EECS - Energy Efficient Clustering Scheme

EECS expands the LEACH algorithm with the following objectives:

1. Clusters are dynamically sized according to their distance from the base station.
2. The competition-based clustering technique partitions the network into clusters and uses single-hop communication between the CH and BS.

In each cluster, candidate nodes contend for the role of CH by broadcasting their residual energy status to all neighboring nodes within a competitive radius. Subsequently, these competing nodes await announcements regarding residual energy from other nodes [10]. If a competing node fails to encounter a node with higher residual energy, it takes over as the CH.

This approach demonstrates that clusters located farther from the BS need more energy for transmission compared to those in closer proximity. This enhancement in energy distribution across the network contributes to prolonging the network's lifespan [16].

Advantages of EECS:

1. EECS uses energy and distance to find a balance between intra-cluster energy consumption and inter-cluster communication load [9].

Drawbacks of EECS:

1. It is not appropriate for large-range networks.
2. It increases control overhead as all nodes compete to become CHs.

4.9 EARP - Energy Aware Routing Protocol

EARP is designed for clustered sensor networks structured on a 3-tier architecture, aiming for the following:

1. It operates by organizing sensors into clusters before network operation.
2. The algorithm uses CH's referred to as gateways, which have less energy constraints than sensors and are assumed to possess knowledge of the sensor nodes' locations.

The nodes employ a TDMA-based MAC protocol to transmit data to the gateway. Gateways manage the sensor states and establish multi-hop routes to collect sensor data. Each node is instructed by the gateway about specific time slots to listen for transmissions from other nodes, and slots which they can utilize for their own transmissions [8]. Communication between the sink occurs solely with the gateways. Sensor nodes can operate in either an active mode or a low-power stand-by mode. Furthermore, sensing and processing functionalities can be turned on and off.

Sensor nodes within a cluster can exist in one of four states: Sensing, Relay, Sensing-Relay, and Inactive. In the Sensing state, nodes observe their environment and consistently generate data [17]. When in the Relay state, nodes don't sense the target but instead forwards the data from other active nodes. In the Sensing-Relay state, nodes simultaneously sense their surroundings and relay messages from other nodes. Finally, in the Inactive state, nodes neither sense nor relay messages from other nodes, which is achieved by disabling the communication circuit.

Advantages of EARP:

1. It consistently outperforms in energy-based metrics like network lifetime and other metrics like throughput and end-to-end delay

Drawbacks of EARP:

1. The algorithm limits the minimum transmission range.
2. Multiple gateway deployments are required for extensive sensor coverage.

4.10 EEUC - Energy Efficient Uneven or Unequal Clustering Protocol

It has the following objectives:

1. It solves the hot spot problems in the network.
2. It balances the energy consumption among the sensor nodes in the network by partitioning the whole network into clusters of unequal sizes.

During the Cluster head election process, every node becomes a tentative CH by broadcasting a compete message within a range indicated by its distance to the Base station [9]. The node's competition range reduces as its distance from the BS decreases. Consequently, clusters situated nearer to the BS exhibit smaller sizes, resulting in reduced energy consumption during intra-cluster communication, thereby conserving more energy for inter-cluster processing. Subsequently, tentative CHs within local regions engage in competition to ascend to the status of actual CHs. It operates in three phases: Cluster Setup, Steady State, and Routing.

During the Cluster Setup phase, the BS collects node information such as node ID, location, and energy status. Utilizing this data, it forms clusters of varying sizes and broadcasts this information across the network. In the Steady State phase, nodes within clusters are assigned CH sequence numbers and cluster IDs. Nodes assigned a CH sequence number of 1 become CH for the initial round, while those with subsequent sequence numbers serve as CHs for subsequent rounds. In the Routing phase, CH nodes undertake data collection and aggregation of all received data within their clusters. This aggregated data is then transmitted to the BS through multi-hop communication.

Advantages of EEUC:

1. Unequal clustering mechanism solves the hot spot problems by balancing the energy consumption among CHs.
2. Increased network lifetime compared to LEACH and HEED.

Drawbacks of EEUC:

1. Clustering in each round adds overhead to the network.
2. The routing scheme can create additional hotspots.

V. Comparison

The different clustering routing protocols for WSNs have been compared based on Clustering characteristics and the figure for the same is specified in Fig. 4.

Clustering Routing protocol		**LEACH**	**PEG ASIS**	**HEED**	**EEHC**	**DWEHC**	**TEEN**	**APTEEN**	**EECS**	**EARP**	**EEUC**
Cluster Property	Cluster count	Variable	Variable	Variable	Variable	Variable	Constant	Variable	Variable	Variable	Variable
	Cluster size	Same	Same	Same	Same	Same	Same	Same	Different	Same	Different
	Intra-Cluster Communication	Single-hop	Multi -hop	Single-hop	Multi-hop	Multi-hop	Single-hop	Single-hop	Single-hop	Multi-hop	Single-hop
	Inter-Cluster Communication	Single-hop	Single-hop	Multi-hop	Multi-hop	Single-hop	Multi-hop	Multi-hop	Single-hop	Multi-hop	Multi-hop
Cluster Head Property	Existence	CH based	non- CH base	CH based	CH based	CH based	CH based	CH based	CH based	CH based	CH based
	Type of node	Homogeneous	N/A	Homogene	Homogene	Homogene	Homogene	Homogeneou	Homogene	Homogene	Homogene
	Mobility	Stationary	N/A	Stationary	Stationary	Stationary	Stationary	Stationary	Stationary	Stationary	Stationary
	Role	Relay /Aggregation	N/A	Relay /Aggregati	Relay /Aggregati	Relay /Aggregati	Relay /Aggregati	Relay /Aggregation	Relay /Aggregati	Relay /Aggregati	Relay /Aggregati

Fig. 4. Comparison of different clustering routing protocols in WSNs

VI. Conclusion

Over the last few years, both academics and industry have focused heavily on wireless sensor networks (WSNs). In the near future, WSNs will transform how we live, work, and interact with the physical world. A lot of research has been conducted to study and address many design and application difficulties, and significant breakthroughs have been made in the development and deployment of WSNs, which may be used in a variety of applications. The development of reliable, economical, and scalable routing protocols for WSNs is a difficult issue. Clustering has been intensively pursued by the academic community because clustering routing techniques may effectively address the issues and restrictions of WSNs. As a result, major efforts have been undertaken to develop effective and efficient cluster routing protocols for WSNs. In this research, we offered an overview of a few clustered routing protocols in WSNs, highlighting their objectives, advantages, and drawbacks.

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