Chapter

Energy Saving Hierarchical Routing Protocol in WSN

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Abstract

The area of Wireless Sensor Networks (WSN) bring a new era of connected on-demand embedding systems which are mostly resource constrained. Despite of having design and operational challenges in real-time, WSN is currently being deployed for wide range of applications where traditional networking systems are most of time unfeasible. The prime focus of the study is to realize the significance of energy efficient routing in WSN. The core motivation is derived by addressing energy problems of WSN. An extensive analysis drawn from reviewing literatures, clearly shows that very few studies incorporated optimization towards modeling the routing schema. This chapter introduces a methodology consisting of three different types of analytical modeling where two of them focus on energy efficient clustering and another one is integrated to attain higher degree of security during data aggregation. The chapter basically provides an insight into the background of the problem which is related with the energy and security in WSN and also further provides preliminary information regarding the research overview. Further the study performs a thorough investigation on existing literatures to extract the open research problem. It basically highlights the gap which still exists and does not meet the requirements of proper energy and security demands. Literature survey on hierarchical protocols of WSN and their basic characteristics towards energy conservation is performed.

Keywords: energy, hierarchical, QoS, routing protocol, WSN (wireless sensor network)

1. Introduction

1.1 Preamble

In the era of Wireless Sensor network-(WSN), an energy-aware mechanism especially routing protocols, are the major concerns in the research area. This chapter presents a brief discussion about the major power consumption factors that causes the node to run out of their energy due to which WSN becomes non-functional. In addition, this chapter also discusses various existing hierarchical routing mechanisms introduced for energy saving goal in WSN.

Factors Associated to Energy Consumption in WSN This section demonstrates the fundamental characteristics and necessary aspects of WSN in order to understand the cause, factor, and requirements for designing energy saving routing mechanism. The literature review is the research method used in this chapter which is a more relevant method than ever.

1.2 Background of WSN

Before discussing about the energy consumption related factors, it is essential to explain about the background of WSN. The concept of WSN is not new, and since the last 10 decades, it has got lots of popularity among the researchers. However, WSN has the vast potential of sensor network to facilitate real-time and automated services with very less human interaction property. The deployment of WSNs, have attracted various working field of real-time applications such as in (i) Military application: for target localization and for tracking war event, (ii) Medical application: for healthcare monitoring and real-time medical data sharing for diagnosing, (iii) Industrial applications: for monitoring robotic system, the security system, and surveillance system, (iv) Environmental application: for monitoring the environmental factor and events, like this there are many more internal and external application where the concept of WSN are used. There are different technical issues for different applications that the researchers are still working for developing an efficient solution [1, 2].

These technical issues arise due to the constraint nature of WSN that includes many limited properties such as, low-cost and limited battery-operated sensors nodes, limited connectivity & coverage range and less processing and limited transmission capacity. The Routing mechanisms in WSNs are responsible for constructing the paths among the targeted nodes and also to perform multihop communication between nodes in a network for which WSN requires an effective and feasible technique to perform energy efficient routing operation for reliable communication, transmission & data processing [3].

- Energy Utilization: Energy utilization in WSN is defined as a total difference between the initial power and the final power. The following is the numerical expression that can be used to define energy-utilization mathematically:

$$\begin{aligned} &\tau \text{ consumption} = \eta \\ &\tau \text{ consumption} = \sigma + \gamma + \mu \\ &\text{₤ utilization} = \tau \text{ consumption-}\tau \text{ consumption} \end{aligned} \tag{1}$$

The above Eq. (1) illustrates the mathematical definition of ₤ utilization-(energy-consumption) where ι consumption is the initial energy depletion factor, and τ consumption is the total energy depletion factor. The ι consumption is calculated using η (residual energy before performing any operation), and τ consumption is calculated using the addition of total energy consumed in operation of σ (sensing), γ (data forwarding & receiving) and μ (data processing).

2. Analysis of power depletion by sensor nodes

In WSN a single sensor node consists of four components: fixed limited battery, a sensing module, wireless module and data processing module. The energy consumed in data processing and sensing operation is quite low whereas the maximum energy is absorbed in the communication layer of the wireless module.

In the wireless communication operation, the sensor node responsible for data forwarding and data receiving which takes very high energy for communication process in the sensor nodes deployed in the network. **Figure 1** displays the energy consumption ratio with various sensors states [4, 5].

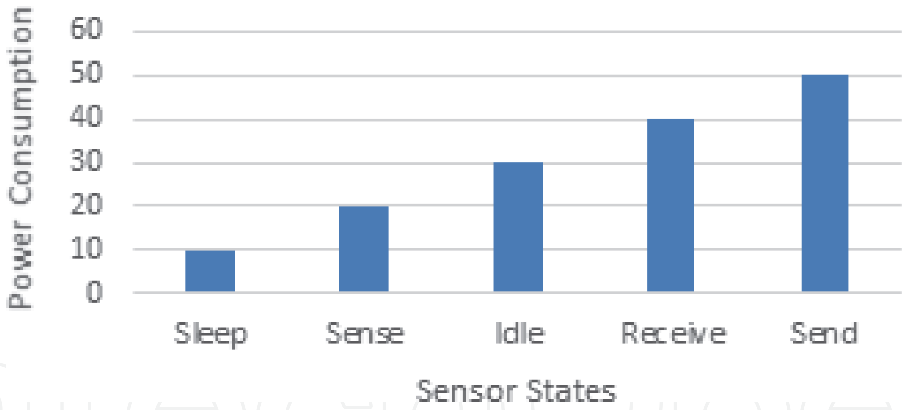

Figure 1.
Power consumption by sensor node in different states.

3. Energy consumption issues

The energy utilization issue in WSNs is a fundamental problem which is directly associated to its lifetime. Therefore, it becomes the primary goal to be solved while designing WSN architecture. In WSN, the energy supplied to the sensor is usually battery-powered, and the sensor cannot reach to the level of long-term operation without recharging [6]. Also, sensors are typically used in remote or harsh environments, such as battlefields, where it is not possible to charge or replace the battery from all sensor's nodes. Furthermore, sensor network lifetime having a strong dependency on the other intermediate nodes because, as failure of some intermediate sensor nodes lead to significant topology changes and that require re-routing process for communication and data-packets transmission in the network. The following are the main factors that cause complexities while designing energy efficient mechanism in WSN [7]:

- Limited availability of power in the sensor node
- Dynamic topology
- Data collection process
- Data redundancy
- Intermediate node malfunctioning
- Long Coverage
- Packet overhead
- Environmental factor

The following are some steps which have been introduced by several researchers and practitioners for improving WSN lifecycle

- Setting unwanted sensors into sleep mode
- Modifying transmission range so that the sensor node can transmit the data using efficient energy to their neighbor nodes

- Deployment of sensors in a hierarchical network so that cluster heads can be used to aggregate data and reduce the amount of information sent up to the sink
- Efficient Routing optimization mechanism
- Hierarchical Routing strategy, so that data is sent along the shortest path to the target node using the least number of nodes and will conserve energy

3.1 Data exchange and communication process in WSN

This section discusses the process of node communication for data exchange in WSN.

The node communication process in WSN uses radio frequencies as a wireless medium to link themselves among other sensors and follows a routing strategy for performing data exchange communication process in the network. Therefore, routing operations conducts a process of path retrieval where the message is communicated from the source node to the destination node. From the viewpoint of existing research studies, it has been observed that the routing protocol is the primary focus for improving energy consumption and other performance parameters in WSN. However, designing an effective routing protocol is very challenging under the constraints and dynamic topology of the WSN [7, 8].

- **Challenging Task –** Designing an energy efficient mechanism for extending WSN lifetime without compromising network reliability and other QoS parameters.
- **Routing** Protocols **in WSN.**

In WSN, routing protocols are designed on various processes based on the network structure, routing operation, path organization, etc. **Figure 2** demonstrates the routing process based on different formulation strategies [9, 10].

The above **Figure 2** also shows the fundamental consideration for designing routing protocols in WSN to select the appropriate path to exchange data and communicate between the source node and the destination node.

- The routing protocol based on the Path organization includes:

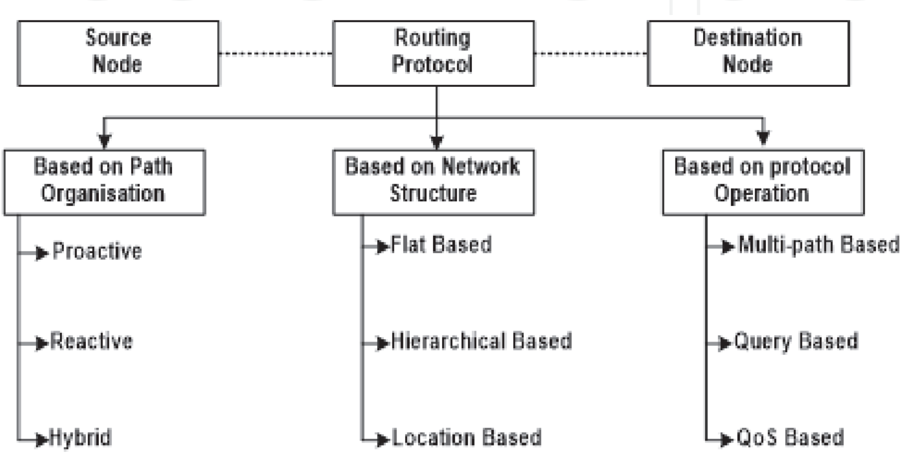

Figure 2.
Fundamental formulation strategies for routing process in WSN.

i. **Proactive routing approach:** In this, the protocols have to maintain a routing information table before initiating the path discovery phase and this is also known as table-driven routing approach.

ii. **Reactive routing approach:** In this protocol, the initialization of the path discovery process for data exchange is based on the requirement of route demand.

iii. **Hybrid routing approach:** In this, both reactive and proactive routing is used in the combined form.

- **The routing protocol based on the protocol operation includes:**

i. **Multi-path-based routing approach:** Multi-path protocol for routing operation is an alternate process in which protocol selects multi-path to deliver data from source to destination. This is mainly designed to overcome the limitation of single route data transmission in order to achieve more reliability and load balancing.

ii. **Query-based routing approach:** Here, the target node broadcasts a query message between the nodes. After receiving the query message, the node replies to the target node with a query matching message. After matching the query from both side nodes, then it initiates a data exchange process between them.

iii. **QoS based routing approach:** In this protocol, the routing is selected on the basis of QoS parameters such that the network must ensure the efficient load balance between energy consumption and data quality (bandwidth, delay, reliability, etc.)

- **The routing protocol based on the Network Structure includes:**

i. **Flat based routing approach:** In this routing approach each node has a similar role in which sharing of data packets is performed through several intermediate nodes.

ii. **Hierarchical based routing approach:** In this approach, routing is performed in an efficient way to utilize low energy as much as possible to increase the lifetime of WSN. In this, the nodes with higher energy are prioritized to form a cluster that are responsible for data forwarding and processing, whereas the nodes with lower energy are selected as a normal node to sense events and collect raw data.

iii. **Location-based routing approach:** In this approach, routes are initialized based on the estimation of sensor location. Also, in order to preserve node energy, some nodes are switched into sleep mode when no events and activities are found at the location of such nodes.

The above Sections 1 and 2, briefly introduced the background of WSN and its fundamental problem (energy consumption) and further introduced the routing process involved in WSN. The proposed system focuses on hierarchical routing protocols to make the WSN active longer. The next section presents an extensive analysis of the existing hierarchical routing protocol.

3.2 An extensive analysis of conventional hierarchal routing protocols

In WSN the nodes are deployed densely, and some of them are placed too tightly which cause data redundancy when transmitting collected data to the base station. Therefore, the hierarchal routing protocol uses a clustering approach in order to lower the energy consumption by avoiding redundancy factor in the data transmission process. The clustering mechanism involves a cluster of nodes and cluster head selected according to node residual energy to forward the aggregated data from the clusters without processing redundant data. The following are some of the existing hierarchical routing protocols discussed [11, 12]:

3.2.1 LEACH – (low energy adaptive clustering hierarchy)

LEACH is introduced as the first hierarchical routing protocol that uses TDMA (Time Division Multiple Access) to implement the energy efficient routing process in the WSN. The LEACH protocol enables a clustering mechanism that forms a set of nodes based on received signal strength. This set of nodes is also referred to as a cluster, where each node of the clusters is devoted towards the extra opportunistic node called as Cluster-Head (CH). The CH acts as a local data center for all the clusters and uses TDMA and CDMA scheduling to transmit aggregated data to the base station (BS) without intra-frame and inter-frame cluster collisions [13–15].

- A salient characteristic of LEACH
    - Clustering based Protocol
    - Self-orienting cluster configuration
    - Adaptive and randomized cluster configuration
    - Localized controls for cluster organization and data transfer operations
    - Low-power data access
    - Data aggregation
    - Local compression to minimize overall communication

The operation involved in LEACH protocol is segregated into rounds where each round contains two phases to perform cluster-formation, CH formation, and data transmission in power efficient way.

The following are the two phases which is involved in the LEACH operation.

- Setup Phase
- Steady Phase

i. Setup Phase

This is the initial phase of the LEACH protocol, in this phase, a grouping of nodes and CHs are formed. The nodes are organized themselves into different groups and these groups with its member nodes is termed as clusters. Initially, each node in the cluster chooses itself to become a CH with a certain probability, and as a

CH node, it must contain higher energy than a non-CH node. In the LEACH protocol, the CH selection mechanism is constructed in such a way that CH can randomly change over time to balance the energy dissipation of the nodes and thereby cluster nodes gets an opportunity to become CH in next cycle.

- Formation of CH- The nodes in the cluster uses a random function to choose a number between 0 and 1. If the number found to be less than subsequent threshold value $\nu(\mathrm{x})$, then the node becomes the CH of the current cycle.

$$\upsilon(x) = \begin{Bmatrix} \theta/1 - \theta * (r \bmod 1/\theta) : fx \in Y \\ 0 : \textbf{\textit{Otherwise}} \end{Bmatrix} \tag{2}$$

The above Eq. (2) demonstrates the computation of threshold value, where r is the number of cycle that has completed, x indicates the overall nodes in the network, θ indicates the percentage of the CH, and Y is the non-CH node. Here in this, each node can generate a random number between 0 and 1 and the node becomes CH when its number is found to be less than $\nu(\varkappa)$, otherwise it will not become CH. Once the CH is selected using the Eq. (2), the CHs-node uses a non-aggressive Carrier-Sense-Multiple-Access (CSMA)-transmission protocol to broadcast the notification message to inform all the other nodes which have played a role for selecting CH in the current cycle. Now based on received signal strength (RSS) of the broadcast notification message, all the non-CH nodes identify that which cluster it belongs to. After each node verified to which cluster it belongs to, then the nodes must have notified to CH that it is a member of its cluster. Therefore the CH plays a role of local data-center to control the transmission of the data packets in its cluster. The CH then initiates TDMA to construct the schedule, then forwards this schedule to all nodes presented in the cluster to ensure that there are no conflicts between data and message transmissions. In order to save power, it also allows each node to put their radio components in a sleep mode outside of their data transmission job. Therefore, the setup phase is complete when all nodes in the cluster are aware of the TDMA schedule, and the steady phase begins.

ii. Steady-State Phase

In this phase, the data transmission operation is executed in different frames. In this frame, the cluster node forwards its data to the CH node according to its transmission schedule. In order to preserve energy, each cluster node uses less power dissipation mechanism based on the RSS value of the CH broadcast notification message. Afterward, the CH receives all data from the cluster nodes and then performs the data aggregation operation and transmits resultant data to the sink node (**Figure 3**).

- Analysis of energy consumption in LEACH

The LEACH protocol considers that cluster nodes start with the same energy and the likelihood function with threshold value v(x) not recognizes the remaining power of each node. Therefore, the LEACH gets good reduction rate in energy utilization comparing to direct communication process and MTE routing protocols. However, LEACH distributes the similar-level power-loads to all nodes of clusters, and this will further result in an imbalance of node after running for a long time. Also, if a node with less energy is selected as the CH, the node may quickly drain its energy. If this happens then, the CH will terminate and lose their connectivity to all nodes belonging to its cluster.

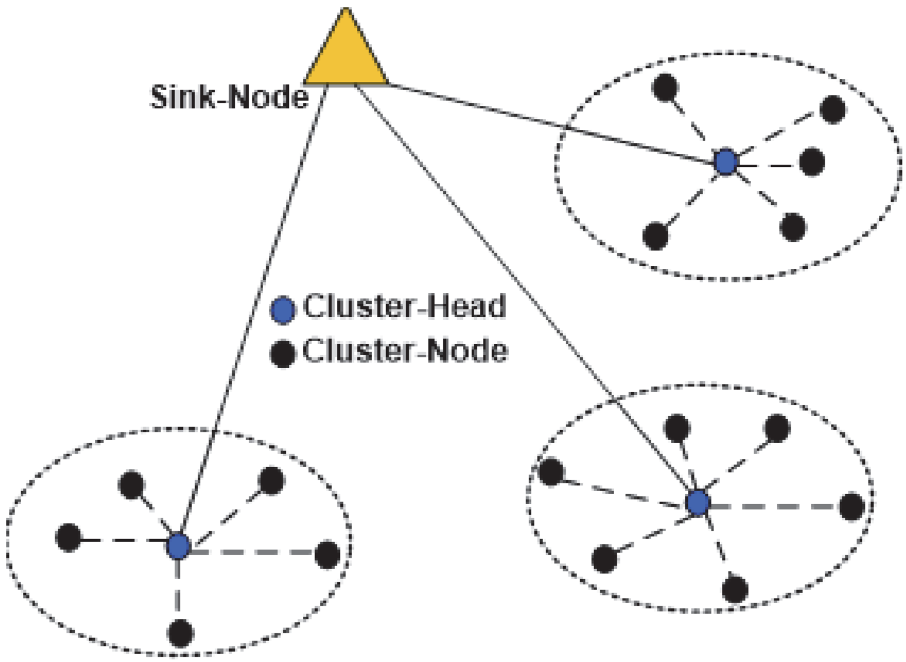

Figure 3.
Clustering mechanisms in LEACH protocol.

- Advantages of LEACH Protocols

  i. LEACH protocol uses a clustering mechanism which enables less communication load between sensors and Sink.

  ii. The CH performs data aggregation which leads to minimizing the redundancy factor and saves energy.

  iii. In this CH uses a scheduling process that allows member nodes to enter into sleep mode. This avoids collision factor and preserves the extra energy consumption.

  iv. LEACH protocol also allows each sensor node in the cluster to become the CH.

  v. Random rotation of CH also enhances network lifetime.

  vi. It also saves energy by following a single hop routing process from the sensor to CH.

  vii. LEACH does not require the location of the nodes to establish as CH.

  viii. LEACH is independent and distributed which does not require control information from the sink node.

  ix. LEACH protocol has one of the big disadvantages is this that if anyhow CH dies then the cluster nodes will become useless their collected data will not reach to the sink node.

- **Radio Energy Model**

This section presents a simple concept of Energy radio model, used by the hierarchal routing protocol such as LEACH, PEGASIS, etc. [16, 17].

The following are the assumptions for Radio Energy Model (REM)

- The REM considers sensor nodes and Sink are all stationary and Sink node is deployed outside from the sensing field.
- It also considers that all nodes are aware of their location.
- All sensor nodes are considered as homogeneous that have the same energy supply.

Figure 4 displays the first order radio model that considers most of the energy is consumed in the communication operation performed by the sensor nodes. Therefore, it demonstrates that the energy needed to forward kbits-packets is computed by Eq. (3) and energy utilized in packet reception can be computed by Eq. (4).

The LEACH protocol uses radio energy model for power dissipation in the communication process. The numerical Eqs. (3) and (4) is demonstrated below to compute energy utilization in transmission and energy utilized in the receiving process.

$$\mathrm{E}_T(\kappa, \partial) = \begin{cases} \kappa \mathrm{E}_{power} + \kappa \varepsilon_{fs} \partial^2, \partial < \partial_0 \\ \kappa \mathrm{E}_{power} + \kappa \varepsilon_{amp} \partial^4, \partial < \partial_0 \end{cases} \tag{3}$$

$$\mathrm{E}_R(\kappa) = \kappa \mathrm{E}_{power} \tag{4}$$

The above Eqs. (3) and (4) illustrates the energy dissipation rate in the communication process of sensor nodes. The ETx(k,∂) is the transmission energy needed for (kbits-packets) over ∂ distance and Epower is the electric power utilized per bit to run the communication module such as transmission circuit and receiver circuit based on modulation and digital coding. fx∂2 and amp∂4 is the amplification power which is based on the significant rate of bit-error. The ∂0 is the square root of dividing power utilization in data aggregation by fx∂2 and amp∂4.

3.2.2 PEGASIS – (power-efficient gathering in sensor information systems)

PEGASIS is introduced as an enhanced version of the hierarchical routing protocol over the LEACH. The PEGASIS protocol follows a chain-based approach where all sensor nodes formulate a chain system, and one leader node is selected randomly to execute data transmission process to sink node. In this, the collected

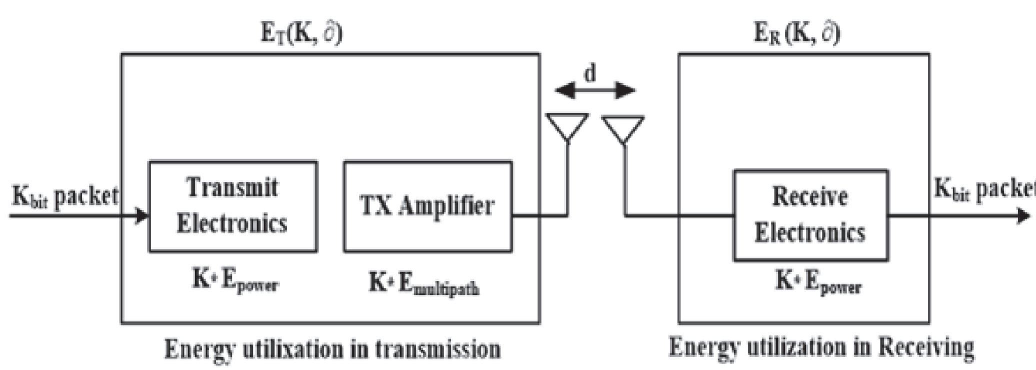

Figure 4.
Energy radio model.

data transfers via a node to node and if any node fails between the chain process, then the node rearranges themselves to bypass the deadly node and reconstruct chain to continue their process. The primary goal of PEGASIS is to receive and transmit data from the nearest neighbor and forward it to sink node with the support of leader node. The PEGASIS protocol involves two phases to achieve chain process which is mentioned as follows [18, 19]:

- Chain formulation
- Data Gathering

i. **Chain Formulation:** The chain structure proceeds in a greedy manner, i.e. from starting nodes to the last node at the sink node and nearest node of the just previous node is selected as a next node, and in the same way all nodes will continue to arrange themselves in this pattern until a suitable chain is formed. Furthermore, the node in the chain is only able to place itself at one location. In each round, a leader node is selected randomly. In the construction phase, the protocol uses a greedy algorithm with considering that all sensor nodes are globally aware of the network condition and sensor location. When the sensor node fails due to power loss, the chain is rebuilt by utilizing the greedy method and by omitting the failure sensor nodes.

ii. **Data Gathering:** The concept of PEGASIS protocol avoids the formation of clusters and CH. It considers that, only a single node as a leader-node instead of multiple nodes in the chain to transmit collected data to the sink node. In this, raw data is collected and carried from one node to another node, then it is aggregated and finally leader node forwards to the sink node.

The above **Figure 5** demonstrates the chain formation and data collection and transmission process. The nodes N1, N2, N3, N4, and N5 have arranged themselves in a chain structure where N3 is randomly chosen as leader node and remaining are the normal participating nodes. The N1 forward its data to N2 then after N2 aggregates the collected data and transmits it to N3. Now, N3 broadcasts token message to N5. The node N5 sends its data to N4 then N4 aggregates collected data and transmits it to N3. The node N3 as leader node collects data from its both neighbor and then it fuses, and aggregates collected data itself and transmits to sink node (SN).

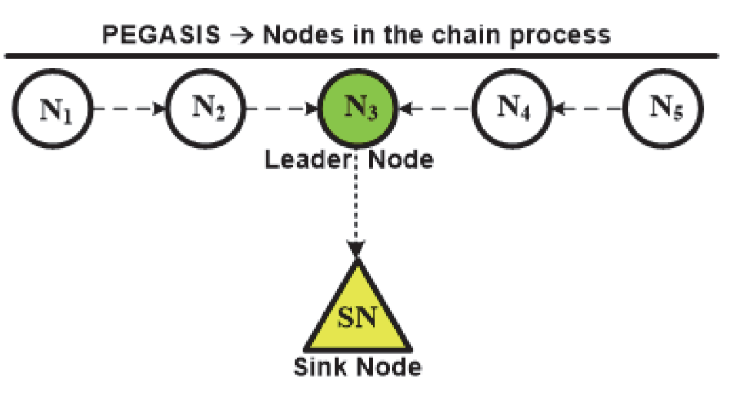

Figure 5.
Chain formation and data processing.

- Advantages of PEGASIS

    i. It uses a greedy mechanism to build chain of nodes that result in a low overhead communication process.

    ii. In this, communication process is not disturbed because when any node fails, the protocol reconstructs the chain and is allowed to continue the data collection and transmission process.

    iii. Only leader node has permission to send data directly to the sink node.

    iv. It decreases energy consumption in communication operation and prolongs the network lifecycle.

- Disadvantages of PEGASIS

    i. PEGASIS considers that each sensor nodes in chain carry an equal level of energy.

    ii. This protocol sometimes results in delay because it takes more time to collect data from the distance node in the chain.

    iii. In this, the single leader-node can also act as a bottleneck for the other nodes.

    iv. Each node in this protocol needs to be aware of network information.

3.2.3 TEEN – (threshold sensitive energy efficient sensor network protocol)

TEEN is a hierarchical clustering protocol that binds sensor nodes and forms a cluster of nodes where each node of the cluster is operated by CH. In this CH collects data from their member node and then forwards it to their higher CH node, the CH aggregates the data and delivers to the sink node. In this scenario, at each cluster varies with the time where the CH broadcast threshold value to its member nodes [20, 21].

- Hard threshold: In this threshold value is broadcasted for the sensed attribute where the role of sensor nodes is to sense and report back its data to their associated CH.

- Soft threshold: In this, a small modification is made in the sensed attributes where it triggers the node to switch transmitter to on mode.

- Later, the sensed attribute value is stored in the internal node memory. Then based on the following condition the sensor node forwards its data in the current cluster round.

    i. The value of the current sensed attribute must be higher than the hard threshold value.

$$S_{current} > H_{cuttoff} \quad (Condition\ 1)$$

ii. The value of the current sensed attribute must vary from the stored sensed value, and its difference value should be equal or greater to the soft threshold value.

$$(S_{current} \neq S_{stored}) \geq S_{cuttoff} \quad (Condition\ 2)$$

Whenever these conditions are met, the hard-cutoff attempts to minimize the burden of transmissions by permitting the sensor nodes to forward data only when the sensed attribute exists in the area of interest.

The above **Figure 6** demonstrates, the time line operation of TEEN protocol where it represents a little variation in the sensed attributes value and allow to sensor nodes to become active form sleep mode in order to forward the data to CH. Therefore, if the value of the sensed attribute does not change or changes minimally, the soft cutoff value will reduce the transmission load of the sensed data. Based on the hard-cutoff value, the node will only transmit the sensed data according to end user requirement and resulting in more energy preservation through making changes relative to earlier data report. When the next cycle initiates, the CH is to be changed, then a new value of parameters broadcasts.

TEEN is very practical for the user interactive applications where a user can dynamically control energy efficiency and perform trade-offs between the data accuracy, reliability and its response time. In this, Clustering formation process uses a layered approach as well as data-centric approach. The key feature of this protocol is that it is ideal for the real-time operated applications. Therefore, TEEN is best considered to be used in the reactive network because it saves power consumption during communication and data transmission. Also a critical drawback of this protocol is that if the threshold is not reached, then user will not be able to obtain any data packets.

- Cluster formation in TEEN

In this protocol, CH basically follows the concept of LEACH. In TEEN, first a cluster is formed; afterwards CH is selected by its member nodes. The CH broadcasts two threshold values to all of its member nodes. This process will continue for each cluster change time. The clustering and data collection process in TEEN is shown in **Figure 7**, where clusters are formed in a hierarchical arrangement, with CH and cluster nodes and data shared to the sink nodes through higher-position CHs.

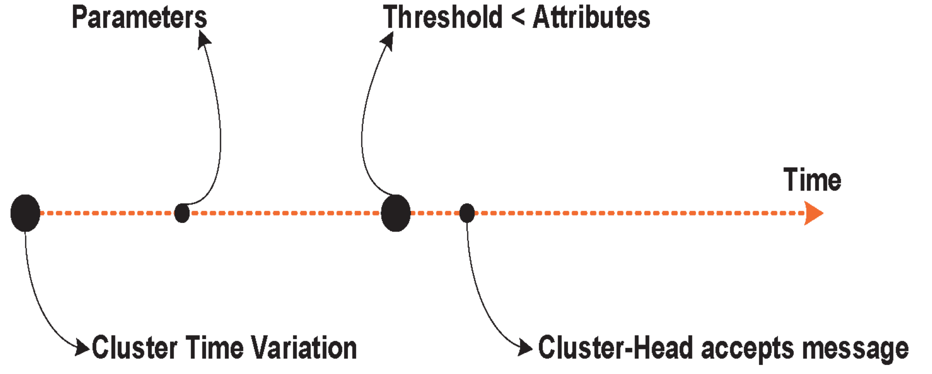

Figure 6.
Operation of TEEN protocol.

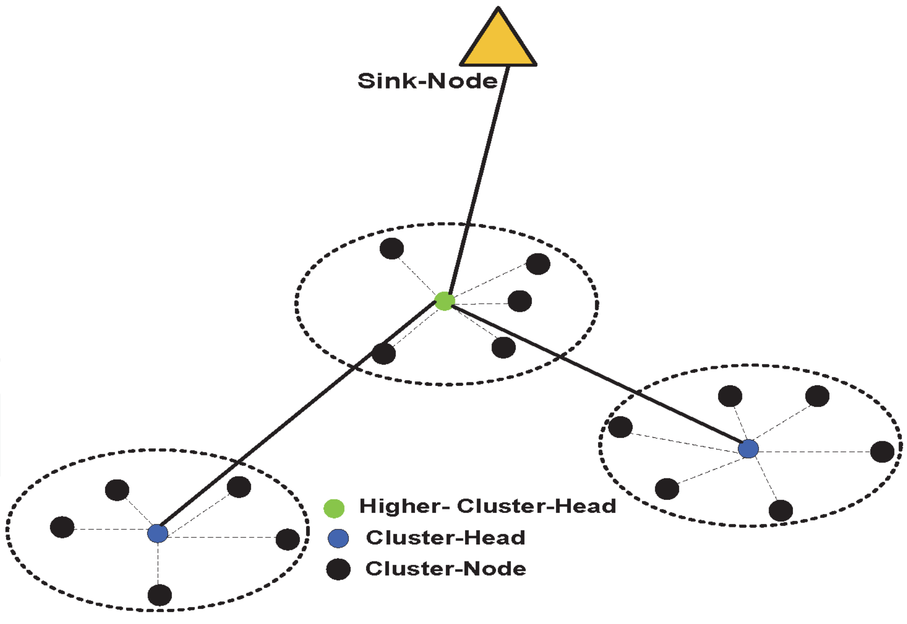

Figure 7.
Clustering process in TEEN.

- **Advantages of TEEN Protocol**

    i. This protocol is most suitable for the time-dependent applications.

    ii. It allows users to dynamically control response times, intrusion identification, and explosion detection, and also allows performing a tradeoff between energy efficiency and data accuracy.

    iii. It also saves the energy through hierarchical clustering mechanism.

- **Disadvantages of TEEN Protocol**

    i. For vdata transmission, process, nodes may have to wait for their time slots allotment.

    ii. If the node has no data to transmit, the time slot assigned to the node may be useless.

    iii. The cluster head always looks for data that causing its receiver transmitter continuously open.

3.2.4 APTEEN – (adaptive threshold sensitive energy efficient sensor network protocol)

APTEEN was introduced as an improved version of TEEN to enhance the performance of the TEEN protocol to support the regular data collection process. The architecture of APTEEN is similar to the architecture of TEEN. APTEEN also follows a hierarchical clustering approach to achieve energy efficient communication between source sensors and receivers (SINK nodes). An enhanced feature of this protocol is that it allows the node to periodically transmit its sensed data, and if any rapid variations are found in the sensed attributes, then the sensor accordingly respond its report to CH. In this version, CH is also responsible for performing data aggregation operations to reduce power consumption in data processing tasks. Once

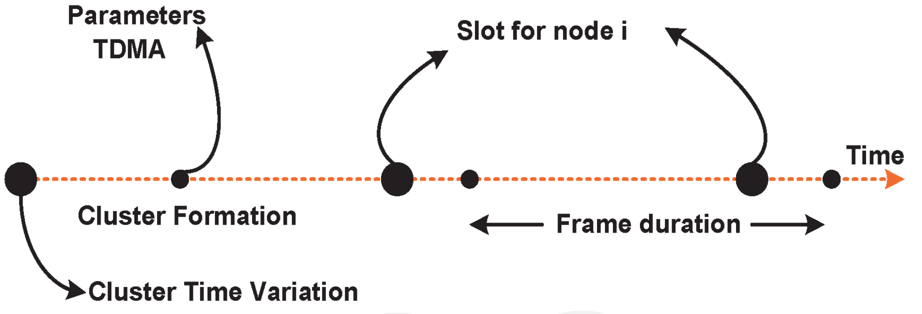

Figure 8.
Operation of APTEEN.

Sink node decides the cluster, the following are the parameters that are broadcasted by the CH (**Figure 8**):

i. Attributes: In this user are curious to get all data related to physical parameters.

ii. Threshold -value: In this there are two threshold value i.e. Hard threshold and soft threshold value which is as same as used in TEEN protocol.

iii. Schedule: In this, TDMA is used to assign a time slot to every sensor node.

iv. Count Time (TC): It is the maximum duration among two consecutive reports forwarded by the sensor nodes.

The node continuously observes its surroundings, whose sense value is higher than the hard threshold value. Once the node senses a value that exceeds the threshold value, then it only sends the data when the value of the sensed attribute changes to the total quantity equal to or greater than the defined soft threshold value. If the node fails to send data for the duration set equal to the count time, then the system asks to recollect and resend the data. TDMA is used to set up scheduling in which each node in the cluster is assigned a transmission slot.

- **Advantages of APTEEN**

i. It provides feature of both proactive network and reactive network.

ii. Proving periodic data to user, it demonstrates clear picture of the whole network.

iii. Highly responsive to any reaction on its attributes.

iv. It provides, flexible and scalable feature to the user, so that user can perform modification, set time intervals and attribute threshold values.

v. It allows to control power consumption factor by regulating time count and the threshold values.

- **Disadvantages of APTEEN**

i. In this cluster formation takes place in multi-level, that sometime results in overhead.

ii. The second disadvantage is that it requires additional complexity to threshold-function and time count.

3.2.5 HEED – (hybrid, energy-efficient distributed clustering protocol)

HEED Protocol is introduced as an extension of LEACH feature in order to acquire power balancing feature for cluster selection by utilizing residual energy and node density. It works in multi-hop pattern within inter-cluster communication through adaptive power transmission. The HEED protocol is mainly introduced for achieving following features:

i. Extends network life-span by allocating energy consumption.

ii. The clustering process ends within a constant number of iterations.

iii. Lowering the overhead problem.

iv. Provide a homogeneous distribution of CH and a solid pattern of clusters.

In this protocol the cluster formation processes perform in various cycles. Each cycle takes long duration to get messages from corresponded nodes in the cluster. A probability factor is used to bound the initialization of CH selection at first cycle. In this, every sensor node uses a probability factor to become a CH. The mathematical expression is given as follows:

$$N_{CH-prob} = C_{prob}\left(\frac{P_{Rresidual}}{P_{\max}}\right) \quad (5)$$

The above Eq. (5), NCHprob is the probability of node that wants to be becomes CH, Rresidual is the estimated remaining energy in the senor node and Pmax is the maximum power equivalent to a charged battery source.

In this the Value of NCHprob must be higher than the minimum threshold value Tmin. If NCHprob < 1, then CH is an temporary-CH or if its NCHprob equal to 1, then NCH will become is the final CH. The recent elected CHs will be added to the current CHs set. If the sensor node is elected to be CH, then it broadcasts the message as it becomes temporary CH or a final CH. The node that hearing the CH lists chooses the CH with the minimal cost from the group of CHs. Afterwards, each nodes increase its probability value to become CH in next round. If the sensor node completes cycle of HEED execution without choosing to become a CH or to connect to the cluster, it will declare itself to be the final CH. If a temporary CH node hears from a lower cost CH, it can become a regular node in a later iteration (**Table 1**).

- **Advantage of HEED protocols**

i. This protocol enhances the life of network, thereby stabilizing adjacent nodes.

ii. It does not require any information about the network such as location.

iii. It also does consider the distribution of nodes.

	Leach	Pegasis	Teen	Apteen	Heed
Classification	Hierarchical	Hierarchical	Hierarchical	Hierarchical	Hierarchical
Proactive	Yes	Yes	Yes	Yes	Yes
Energy Conservation	Very Good	Very Good	Good	Good	Yes
Network life time	Good	Very Good	Very Good	better	Good
Data Based	No	Yes	Yes	Yes	Yes
Data Aggregation	Yes	Yes	Yes	Yes	Yes
Location Based	No	No	No	No	No
Qos-Supported	No	No	No	No	No
Multipath	No	No	No	No	No
Optimal Path	No	No	No	No	No
Robustness	better	better	better	better	Better
Scalability	Good	Good	Good	Good	Good
Security	No	No	No	No	No

Table 1.
Comparison Conventional Hierarchal Routing Protocols [22].

iv. In this protocol the sensor nodes node updates its neighbor timely forwarding and receiving messages in the multi-hop network.

v. In HEED the Nodes only need their neighborhood information to built a cluster

- **Disadvantage of HEED Protocols**

i. In this protocol the CH are selected in random patterns that may cause communication overhead problem that leads to exhaust extra energy and affects other QoS parameters.

ii. In addition, another factor affecting network lifetime is the periodic rotation of the CH during the selection process, which results in the exhaustion of additional energy to rebuild the cluster.

4. Summary

This chapter briefly discusses the various power-aware existing hierarchical routing protocols designed for WSN. Initially, this chapter discussed the background of the WSN and the factors associated with energy utilization in sensor nodes. The common goal of all of the above discussed protocols is to extend the life of the WSN by minimizing energy consumption without affecting packet transmission. It is also emphasized that all protocols have some limitations and advantages. The main motivation for this chapter is to analyze the difficulty and issues in existing routing protocol in order to design an effective low-power consumption routing protocol.

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