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A Survey on Energy-Efficient Hierarchical Routing Techniques in Wireless Sensor Networks

Chidananda T., Ashwini B. P.
Siddaganga Institute of Technology, Tumkur Karnataka, India

***Abstract* - The recent advances in technology has led to the development of low-cost , very small, battery powered, wireless communication capability devices called sensor nodes. Sensor nodes of these networks have limited energy, limited bandwidth and limited computing power, in which energy is a major problem. Hence, there is a need to design energy-efficient routing techniques to route the data efficiently in the wireless sensor networks (WSN). The routing techniques are mainly classified into three categories namely flat or data-centric routing, hierarchical routing, and location-based routing and among all these, hierarchical routing is the most energy efficient technique. Hierarchical routing, in which, a network is divided into clusters, electing cluster head (CH) to each cluster which collects data from their cluster members and transmits the aggregated data to the base station (BS). Hence, this technique is energy efficient which increases lifetime of the network with decreasing the energy consumption and bandwidth usage. Here, in this paper we are surveying the high energy-efficient hierarchical routing protocols which maximize the network longevity.**

***Keywords* - Clustering, Energy Efficient, Routing Protocols, WSN.**

I. Introduction

Wireless sensor networks can be seen as a combination of sensor nodes, base station and gateway. Various applications[1] are drawn by wireless sensor networks in the area of monitoring, environmental or earth monitoring(which includes the monitoring of forest fire detection ,air pollution and landslide detection), industrial monitoring,(which includes machine health monitoring, data logging, industrial sense and control application), water or waste monitoring(which includes the monitoring of agriculture and greenhouse), structural monitoring, passive localization, tracking, and smart home monitoring, etc. The architecture of a sensor node is shown in the figure 1[2]. Sensor node is a hardware device that produces a response whenever there is a change or occurrences of event in the physical environment like temperature, pressure, movement, etc. The components of a sensor node are transceiver (transmitter and receiver), microcontroller, ADC (analog-to-digital converters), power source and external memory (shown in figure 1).

The recent advances in analog and integrated digital electronics have led to the development of small, less expensive, low-powered nodes called micro-sensor nodes [3-7]. The sensor nodes are equipped with the components which are having high sensing, data processing, communication, and power capabilities, and how each components work is as follows. First, the sensing unit may consist of one or more sensors and ADCs. Sensors sense the physical data of the surroundings to be monitored and ADC takes analog signal as input, converts it into the signal which is processed by processing unit. The processing unit, which normally consists of a microprocessor or microcontroller, helps in processing or controlling an incoming signal. The communication unit has a short-range radio for data transmission and reception on radio channel. The power unit feeds power to all the components of a sensor node using stored energy such as alkaline batteries, coin-type batteries, etc. built into it or from harvesting energy (solar power).

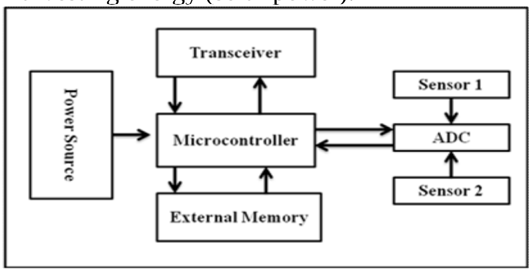

Fig.1. The components of a sensor node

Sensor nodes are deployed in two ways, either manually by users or randomly by dropping from helicopters/airplanes. The sensor nodes coordinate among themselves in measuring the physical environmental conditions and pass the acquired data to the BS. The BS, which is either a fixed or mobile in nature, communicates with WSN through internet/communication infrastructure. These sensed data is transmitted via radio either directly or through gateway to the BS. Since, the sensor nodes are small in size, low cost, battery powered or low powered can be easily initialized or installed in a large number if the application demands. This special features of sensor node have enabled people to start a research on the sensor management, sensor activity, collaborative processing among the sensor nodes (to reduce the bandwidth), deployment of sensor nodes (in either deterministically or statistically) and transmission of data. By this, people have found a way of connecting these distributed sensor nodes naturally using the wireless link in an ad hoc fashion. The arrangement of these distributed sensor nodes in the sensor networks must have significant impact on the efficiency of WSN applications such as tracking an object, disaster management, military applications, civil applications, and so on. In most of the WSNs, hundreds or thousands of sensors have to be deployed if a wider area to be covered. Hence, the sensor network consists of huge number of sensor nodes to monitor the events occurred in the desired regions. However, sensor nodes' main aim is to sense the events occurred near them, they may generate redundant information about the same event to the sink causing unnecessary energy consumption and reduction in networks lifetime.

In sensor networks, energy consumption may happen by three tasks namely data sensing, data processing and data communication. Among these, communication consumes more energy than any other tasks. As we know these sensor nodes are more energy constrained posed many challenges in the design and management of sensor networks, these challenges really motivated the people to invent the energy-efficient routing protocols to route data efficiently to the sink. To increase the lifetime of the network, we need to have a good route setup from source nodes to the destination node. Here, the routing in WSN is challenging and different from the traditional networks like internet and ad hoc networks for the following reasons. First, an addressing scheme will not be ideal for the WSNs, since it consists of hundreds of thousands of sensor nodes, we cannot assign classical-IP addresses to each sensor nodes unlike nodes in the internet. Second, in sensor networks the information is required to be passed to single point location from multiple nodes in the network makes challenging. Third, the acquired information will be consisting redundant data consumes more amount of power and bandwidth makes routing challenging. In addition to all these, sensor nodes are constrained in energy, processing, less memory and transmission capacity. WSNs show some unique characteristics such as ease of deploying nodes densely, unreliability of sensor nodes, severe energy consumption and storage constraints which poses many challenges in the development of WSNs [3]. All such problems need to be reduced or even overcome by designing energy efficient protocols based on the applications and the architecture. In this paper, few most popular energy-efficient hierarchical routing protocols are discussed. The paper is organized in a way that section 2 explains clustering techniques in WSNs. In section 3, various hierarchical routing techniques [2] [8] [21] are discussed, section 4 has the comparison of various protocols and section 5 is the conclusion of the paper.

II. Hierarchical Routing In WSNs

The propagation technique in WSNs is through routing or flooding. Successful routing in WSN depends on the energy-efficient and reliable transfer of data across individual physical links, which prolongs the network lifetime. Routing in sensor networks is mainly classified into two types namely based on the network structure and based on the protocol operation [2] [8] [19] [20] [22]. Based on the network structure, routing in sensor networks can be classified as flat routing, hierarchical routing, and location-based routing. Based on the protocol operation, routing can be classified as negotiation-based, multipath-based, query-based, QOS-based, and coherent-based routing. Flat routing can be also called as data-centric routing ,where BS sends queries to a particular location and it will be acknowledged by the nodes in that location. In location-based routing, data is sent to the desired region based on the position information of nodes. Position information of nodes can be identified via satellite or from a GPS (Global Position System). The last type of routing based on the network structure is hierarchical routing. In hierarchical routing, sensor network is divided into segments called clusters, these clusters consists of cluster members and their cluster heads (CHs) (the CHs may be normal nodes or gateway nodes), CHs may help in data gathering from their respective members, processing, routing data to the higher level nodes and then finally to the BS. Hierarchical routing [9] is also called as cluster-based routing. This paper surveys energy efficient hierarchical routing protocols for wireless sensor networks which are designed to increase the lifetime of a network.

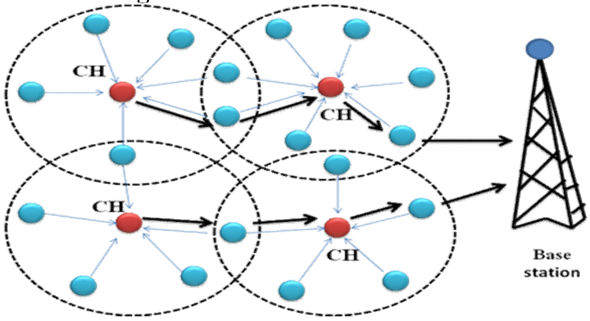

Fig.2. Illustration of routing in clustered network

Clustering techniques [10]-[12] were proposed necessarily to reduce the total power consumption and to evenly distribute an energy load among each sensor nodes in the network. In hierarchical routing, whole network is divided into clusters, and each cluster is supervised by cluster heads (CHs). The CHs are again controlled by the BS which is a root in the hierarchy as shown in the figure 2, redrawn from [21]. Inter-cluster and intra-cluster communication would be used to reduce the collision between clusters and cluster members by MAC protocols. Unlike direct/conventional transmission, the amount of bandwidth usage and distance transmission in hierarchical routing is reduced significantly; this saves lot of energy of the nodes.

III. Energy Efficient Hierarchical Routing In WSNs

A. Low Energy Adaptive Clustering Hierarchy (LEACH)

LEACH [13] was the very first and most popular hierarchical clustering algorithm for WSNs. As the name implies it is based on the cluster formation in which the nodes are distributed known as distributed cluster formation. LEACH uses some sensor nodes to select as cluster heads (CHs) randomly and makes every node to take turns to become CHs by a randomized rotation technique, thereby evenly distributes energy load among all the nodes in the network. CH node compresses the data gathered from its respective cluster members and sends the aggregated data/packet to the BS in order to reduce the

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amount of information that has to be transmitted. While in transmission of data there may be a chance of collisions due to the external disturbance inside a network. Normally, collision happens in two ways called inter-cluster collision and intra-cluster collision. Thus, LEACH uses TDMA/CDMA MAC protocols [23] to reduce these kinds of collisions. This protocol is most ideal when an application needs constant monitoring by the sensor network. In LEACH, data collection is centralized and can be performed periodically.

After a given interval of time, LEACH rotates the role of CHs randomly, so that the energy dissipation among all the sensor nodes is uniform. Based on simulation results, it's found that only 5% of the nodes have to act as CHs which will consume more energy. The operation of LEACH is divided into two phases namely the set-up phase and the steady-state phase. In the set-up phase, it performs cluster formation and CHs can be selected in it. In the steady-state phase, an actual data transmission takes place in the network to the BS. Often the duration of the later phase is always longer than that of the former phase. During the set-up phase, each node chooses a random number between 0 and 1, compares r with the threshold value T(n), if the value of a random number is less than the threshold value it becomes a cluster head for the current round and the threshold value formula is given by,

$$T(n) = \begin{cases} \frac{P}{1-P\left(r \bmod \frac{1}{P}\right)}, & \text{if } n \in G \\ 0, & \text{otherwise} \end{cases} \quad (1)$$

Where G is the set of nodes are selected as CHs in the last (1/p) rounds, r is the round number and p is the desired percentage of CHs. After the election of CHs, it broadcasts a message to all the remaining nodes in the cluster that it is the new CH. Other members, after receiving an advertisement message decide themselves to which cluster head they intend to report to. In set-up phase, CH node broadcasts a TDMA schedule to each its member nodes in the cluster to when they can transmit. During the steady-state phase, the member nodes start transmitting the sensed data to the CH node, after receiving all the data, CH aggregates the data that and transmits to the BS. After a given interval of time, the network goes back to the same process. Although, the LEACH has provided everything to increase the lifetime of the network, still there are problems associated with it based on its assumptions like it does not applicable to networks deployed in large regions, CHs will be concentrated on only part of the network (if they distributed non-uniformly), dynamic clustering brings extra overhead (head changes, advertisements etc), CHs consume more amount of energy (they take charge of transmission on behalf of all nodes).

B. Power-Efficient Gathering in Sensor Information System (PEGASIS)

PEGASIS [14] was proposed as an enhancement of LEACH protocol. PEGASIS is an optimal chain-based protocol. Unlike LEACH, it uses a chain-based approach to increase the energy efficiency of the sensor network. Each node in a chain receives data from and transmits data to a closest neighbor, amongst only one node is responsible for transmitting the aggregated data to the BS. Nodes will take turns of being the leader in the chain for the transmission of data to the sink node. Due to uniform distribution of load obvious increase in lifetime was observed. The chain formation can either be done through the BS or nodes themselves. If the nodes organize a chain themselves, they must be aware of their position information. Construction of chain is using greedy approach shown in the figure 3, redrawn from [14].

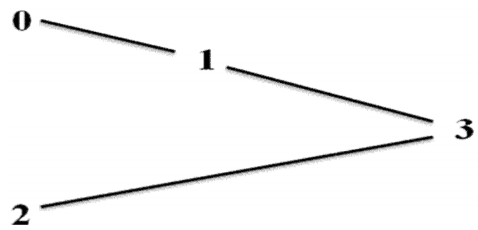

Fig.3. The greedy approach

In the simulations of [14], it was observed that greedy approach worked well with different size of networks. Data gathering is achieved by each node receiving data from its neighboring nodes, aggregating data with its own data and transmitting the aggregated data to the next neighbor node in the chain and so on till the BS. The nodes will take turns to become the leader in the chain is based on the usage of imodN (where i indicates the round number and that N indicates the number of nodes) and the leader will always be in a random position. For a leader node to collect the data from neighbor nodes in the chain it uses the token passing approach as shown in figure 4, redrawn from [14] and the cost of using the tokens is always less because the tokens are small in size.

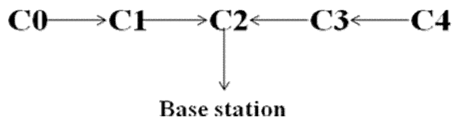

Fig.4. Token passing approach

The data aggregation in chain-based approach takes place at every node, except at the end nodes in the chain. In figure 4, nodes c0 and c4 will not be involved in data aggregation. Each node receives data from neighbor nodes, adds its own data to send it to next node and node should have at least two neighbor nodes to receive and transmit the data.

Having a chance of occurrence of distant neighbor node's failure, which would, causes energy depletion in the chain. In such cases, PEGASIS does increases the performance by not allowing such nodes to become part of the network by setting the predefined threshold value on neighbor nodes. If the node in a chain dies, the chain will again be reconstructed and the threshold value is to be changed to ensure re-election of leader. From all this, the performance of PEGASIS is better over LEACH and we can observe the following aspects of differences from the LEACH.

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First, the distance of transmission of each node to the BS is less when compared to LEACH. Second, amount of receiving the data by a leader is limited to messages, whereas in LEACH, the CH has to receive multiple messages. Third, in PEGASIS, only one node is responsible for transmitting the data and whereas in the LEACH, there would be number of CHs involved in transmitting the data to the BS. Though the performance of PEGASIS is good over LEECH, it still has some problems to be considered. PEGASIS requires dynamic topology adjustments to know the energy status of neighbor nodes that introduces overhead in the network. Involvement of single node in transmission can become a bottleneck in the network. It introduces excessive delay for distant node on the chain. Finally, it affects the protocol functionality if the nodes are mobile. However, PEGASIS outperforms LEACH by eliminating the overhead of dynamic cluster formation, minimizes the distance to transmit by non-heads must transmit, avoids the number of transmitting and receiving messages among the nodes and only one node is responsible for the transmission per round to the sink node.

C. Threshold-sensitive Energy Efficient Protocol (TEEN)

Routing protocols in sensor networks in another way can also be classified into three categories namely, proactive, reactive and hybrid protocols and it depends on how the nodes find a route to the destination. In proactive protocols, for the data to transmit all routes are computed before they are needed. In reactive protocols, routes are computed on request. Hybrid protocol, use up the combination of both reactive and proactive protocols. Here, the TEEN [15] is a reactive protocol specially targeted for reactive networks and to our best knowledge it is the first protocol developed for reactive network. Reactive networks means, nodes will have to respond to the sudden changes in the network such as acoustic changes, temperature changes, magnetic changes, etc. TEEN follows a hierarchical cluster-based approach along with the use of data-centric approach (shown in the figure 5), redrawn from [15]. Each cluster will have a CH which gathers data from its cluster members; it aggregates the data and sends the aggregated packet to the BS or to an upper-level CH node. This protocol forms hierarchy of clusters, uppermost-level cluster nodes reporting directly to the BS. The BS will be the root of the hierarchy, directs the entire network.

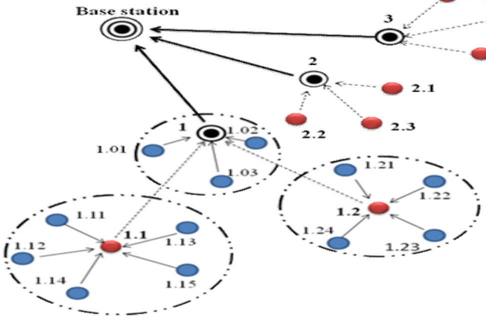

Fig.5. Hierarchical clustering in TEEN and APTEEN

After the network is clustered, each node is given a pair of threshold values; hard threshold and soft threshold for the sensed attribute. Hard threshold value can be meant as an absolute value or minimum possible value of a sensed attribute, if the nodes sense this value, they switch on their transmitter and notify the sensed data to the CHs. Thus, hard threshold value abates the amount of transmission significantly. Hence hard threshold allows the nodes to transmit only when the sensed attribute is beyond an absolute value. Soft threshold is meant as small change in the value of sensed attribute causes the node to switch on its transmitter and notifies its data to the CH. As a result, soft threshold further reduces the number of transmissions when there is no change or little change in the sensed attribute. The sensed attribute is stored in an internal variable called sensed value (SV).

The main advantages of this protocol are, firstly, this scheme is most ideal for time-critical data sensing applications. Second, we know that the power would be consumed more in transmission rather in data sensing, in this technique the data sensing takes place periodically and the transmission is not done regularly like data sensing hence, the power consumption is less here. If the energy consumption is not considered, smaller value of soft threshold gives more accurate results. Some problems with TEEN are; the scheme will not be suitable for applications where they need to get continuous data, because if the thresholds are not reached the nodes will never communicate, never receives any data in the network, and also neither will it know even if the nodes die. Another problem is that, collisions may occur during the transmissions of time-critical data in the clusters; this can be avoided by MAC TDMA scheduling and lastly delay in the network also is a problem, CDMA technique is a solution for this.

D. Adaptive Threshold-sensitive Energy Efficient Protocol (APTEEN)

APTEEN [16] is an enhancement over TEEN and is a hybrid protocol that changes the threshold value used in the TEEN according to the type of application and user requirements. It aims at not only getting the overall view of a network but also time-critical data sensing. In APTEEN, after the network is divided into clusters, the CHs broadcast the following messages; attributes (A), thresholds, schedules and count-time (CT). The attributes indicates the set of physical parameters in which the user is interested. The threshold indicates the pair of threshold values called hard and soft threshold values. Schedule indicates the TDMA schedule, assigning time slots to each node and the last one, count-time indicates the maximum time period between two successive reports sent by a node. A node sensing the surroundings continuously can transmit the data if they reach threshold value and it transmits data only when the value of an attribute changes by an amount equal to or greater than the soft threshold. Count-time is used to set because if the node does not send data for a period of time, it is forced to sense the environment and retransmit. APTEEN allows users to query a network in three types namely; historical query, one-time query, persistent query. Historical query allows users to query about historical data stored at the BS. One-time query allows querying a particular snapshot of a network and persistent query allows querying future events in the network over a time. The main advantages of this scheme are it gives an overall snapshot of a network and performs well by combining both proactive and reactive approaches. Energy consumption can be controlled by setting threshold and count-time values. The main drawback of APTEEN is that, complexities in implementing thresholds and count-time parameters.

However, TEEN gives the best performance, since it decreases the number of transmissions. The main drawbacks of the two approaches are overhead and complexity involved in forming clusters at multiple levels.

E. Power Efficient and Adaptive Clustering Hierarchy (PEACH)

Among all the routing techniques in the WSNs, clustering technique is considered as the high energy-efficient technique. Though, the clustering technique is comparatively good enough to save the energy of the nodes in the network, still it has got some problem in clustering that need to be solved. The existing protocols have the problem of energy consumption on the cluster formation which is to be overcome. To solve this problem, a new protocol called PEACH [17] has been proposed.

In PEACH, cluster formation is performed based on the overheard information. Overhearing means in WSNs is, encountering the conversation between two neighbor nodes. The advantage of PEACH is there is no additional packet transmission overhead. PEACH is designed to eliminate the problems of fixed-level clustering as in the traditional clustering protocols. Eventually, it is more scalable and efficient than other existing protocols. PEACH can also be used on both position-aware and position-unaware WSNs.

F. Hybrid Energy Efficiency Protocol (HEEP)

HEEP [18] is an enhancement to increase the lifetime of the network by decreasing the energy consumption. Actually, it has been developed by combining the two most popular protocols called LEACH and PEGASIS. It takes the existing problems of both the protocols to improve the routing of data by using the features of these protocols. HEEP applies the principles of LEACH called clustering and the chain formation of PEGASIS. The chain construction of PEGASIS is performed within the clustering of LEACH, hence reducing the chain formation. HEEP also eliminates the overhead of CH in LEACH by, in which, data aggregation is performed along chain of nodes rather by a CH node. So that the amount of data exchanged between the CH and its members is reduced and en energy is saved. Figure 2 shows the mechanism of HEEP in which the network is made into clusters and the chain is formed within the clusters.

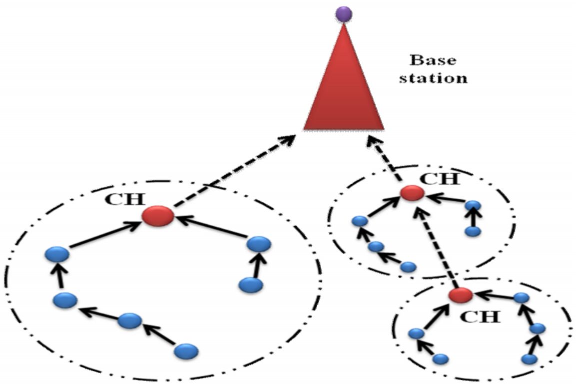

Fig.6. Chaining within clusters in HEEP

Table 1: Comparison of Hierarchical Routing Protocols

Protocols / **Parameters**	**LEACH**	**PEGASIS**	**TEEN & APTEEN**	**PEACH**	**HEEP**
Routing	Cluster based	Chain based	Active threshold	Overheard based	Hybrid (chain & cluster based)
Energy-efficient	NO	YES	YES	YES	YES
Multihop	NO	NO	YES	YES	YES
Cluster(CH) overhead	High	Low	High	Low	Low
Data aggregation	Yes	No	Yes	No	Yes
Number of alive nodes.	Less	Less	More	More	More
Mean residual energy	Low	More	NA	More	NA
Latency average	More	More	NA	NA	Less

As shown in the figure 2, node N0 transmits the acquired data to node N1, N1 adds its own data to the N0's data and sends it to a neighbor node (N2). This process continues until it reaches the CH node and finally CH node transmits the sensed data to the BS. Hence, the number of nodes communicating with the CH reduced and the distance between the CH node and its member nodes is decreased. Thus, this affects the better energy saving and increasing the network lifetime. Also, the problem of latency was introduced in PEGASIS is eliminated in HEEP by forming chain within the clusters which eventually reduces the chain length. As an effect of this, the latency problem of PEGASIS is decreased in HEEP.

IV. Comparative Study of Hierarchical Routing Protocols

Comparison of all six different popular energy efficient hierarchical routing protocols for wireless sensor networks described in this paper are shown in table 1. LEACH was the very first hierarchical routing protocol which reduces energy by 8 times of direct transmission and minimum-transmission-energy routing [13]. PEGASIS increases the network lifetime 2 times compared to LEACH protocol by eliminating the dynamic cluster formation overhead, number of transmissions and receptions among all nodes and uses only one transmission per round to the BS [14]. Simulation results show that both modes (soft and hard modes) of TEEN are more efficient than LEACH in terms of energy consumption and response time [15]. We can say the performance of APTEEN which lies between TEEN and LEACH in terms of energy consumption and lifetime of a network. However, APTEEN overcomes the drawback of both LEACH and TEEN, by setting threshold values and periodic data transmission [16]. As we know the advantages of PEACH protocol, we will compare the functionalities of PEACH with both the location-unaware and location-aware protocols like LEACH and PEGASIS.

LU-PEACH does not require packet transmission overhead (advertisements, announcements, scheduling information, etc) between CH and its nodes unlike in LEACH and LA-PEACH has the advantages like multihop transmission, adaptive clustering over PEGASIS which does not support multihop transmission and adaptive multi-level hierarchical clustering [17]. Simulation results of HEEP (both HEEP_D and HEEP_S) tell us that its performance over existing protocol like LEACH and PEGASIS is better in terms of number of alive nodes over time, percentage of dead nodes in the network, number of data messages received by the BS over time, number of alive nodes per amount of data massages received by the BS, average energy dissipation over the network's lifetime and number of data messages received by the BS over energy dissipation [18].

V. Conclusion

In WSNs, the sensor nodes are battery powered. All the components of sensor nodes like CPU, ADC, sensors, and radio/RF component use the power stored in small batteries. Among all these components, radio component consumes much of the energy of a node, since; it involves communication of data to the targets. Hence, the design of efficient routing techniques is needful to reduce the energy consumption and to increase the lifetime of the network. In this paper we have surveyed the energy-efficient routing protocols for WSNs. Each surveyed protocol in this paper has both the advantages and disadvantages. Enhancing the performance of these protocols is an open problem for future research.

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AUTHOR'S PROFILE

Chidananda T
pursuing his M. Tech in Computer Network and Engineering from the department of Computer Science & Engineering in Siddaganga Institute of Technology, Tumkur under Vishveshvaraya Technological University (VTU), and received his B.E in 2011 from GM Institute of Technology, Davanagere under VTU, Belgaum, Karnataka. His major field of study is on wireless networks.

Ashwini B P
completed B.E in Computer Science and Engineering from Oxford College of Engineering, Bangalore under Vishveshvarya Technological University (VTU). She obtained her M. Tech. in Computer Science and Engineering from RV College of Engineering, Bangalore under VTU, Belgaum, Karnataka. She is currently working as Assistant Professor in Siddaganga Institute of Technology, Tumkur, Karnataka. Her area of interest in research is in energy efficient algorithms for security in wireless sensor networks.