
Harendra S. Jangwan  
Department of Computer Science & Application, G.B.Pant Engineering College, Ghurdauri, Pauri, Uttrakhand, India.

Ashish Negi  
Department of Computer Science & Application, G.B.Pant Engineering College, Ghurdauri, Pauri, Uttrakhand, India

Abstract

In the past few years, wireless sensor networks (WSNs) have explored different application areas from personal, industry, military, agriculture, environment monitoring to Internet of Things (IoT). The limited battery power of a sensor node becomes a critical issue when it is not possible to replace or recharge its battery. In this paper, we have reported an extensive review on hierarchal routing protocols based on single/multi-hop communication and for homogenous/heterogeneous WSNs as well as a comparison of different existing protocols is done on the basis of some factors that are power consumption, end-to-end delay, load balancing, network stability and scalability. Some factors that influence the design and development of routing protocols for WSNs are also discussed. Further, some advantages and disadvantages of each routing protocol are enlisted.

Keywords: WSN, hierarchal routing protocol, Wireless Sensor Networks.

1. INTRODUCTION

The applications of Wireless sensor networks (WSNs) have increased extensively in the past few decades. A wireless sensor network is a network of large number of sensor nodes deployed in a region to perform a predefined task. The function of each sensor
node is to monitor and collect the data from the surrounding environment and send it to the base station (BS) following a specific protocol. The BS acts as a gateway between the monitored region and the end user or server. Initially, WSNs were used for surveillance inside the battlefield or other military applications [1-3] such as intrusion detection system (IDS), but now they are used excessively in various other areas ranging from earth sensing [4], to industry agriculture and food [5-6], low cost transportation [7-8] and home automation [9], health care. Earth monitoring includes air pollution monitoring, fire detection [10-11], landslide detection, water quality monitoring, flood detection etc. Industrial applications include machine health monitoring, waste water monitoring, data logging, rapid emergency response etc. In health care monitoring, certain wearable devices are equipped with sensor nodes or they can be implanted directly to the human body for overall monitoring known as body area network. 

The deployment of sensor nodes into the region under study can be structured or randomized using mathematical tools such as random graphs. Certain other deployment issues include connectivity and coverage metrics if it is application specific. Several other challenges faced by WSNs are [35-37]: energy efficiency, responsiveness, robustness, self-configuration and adaptation, scalability, heterogeneity, systematic design, security and privacy.

On the other hand, WSNs carries some major unavoidable disadvantages. Firstly, they are adopted over the areas which are almost inaccessible and secondly, their network topology is not known. This makes the sensor nodes resource constrained in nature and as a result, their energy cannot be replenished. Due to these limitations, energy conservation has become an essential and foremost requirement because as a result the working lifetime of the overall network can be increased.

For some of the conventional wireless networking problems, researchers have been working to meet the energy conservation requirements. These are referred to as: finding energy-efficient solutions to WSN problems. Several methods to meet the energy efficiency requirements have been developed so far till today. Some of them include methods such as medium access control, routing, self-organization, bandwidth sharing etc. Simultaneously, all these techniques should consider a balance energy efficiency, accuracy and latency together with hierarchical architectures so that the lifetime of network is prolonged. Although for traditional wireless ad-hoc networks, many algorithms and protocols have been proposed. Sensor networks posses some additional characteristics which make them dissimilar to ad-hoc networks. Sensor networks consist of much higher number of sensor nodes as compared to ad-hoc networks which are densely deployed and are prone to failures [34]. If the sensor nodes are considered as mobile, then for specific applications the topology of a sensor networks changes and that too very frequently. The paradigm used by the sensor nodes in WSNs is mainly a broadcast communication unlike point-to-point communications based most of the
ad-hoc networks. Sensor nodes have three limitations in: memory, power and their capacity of computation and they consist of large amount of overheads and sensor. So, they may not have global identification (IDs). Most of the existing algorithms and protocols are not quite well suited to sensor networks since they have different application requirements and carry certain unique features.

Sensor nodes expend most the energy during communication. The rest of it is consumed during sensing and processing performance. The annihilation of this inefficiency at all layers of protocol stack of communication in WSN is required. Especially at network layer, one needs to devise some novel energy efficient routing schemes that provide consistent data communication among the deployed sensor nodes and external base station to prolong the network lifetime. At network layer, a number of approaches have already been followed by the researchers towards developing energy efficient routing schemes viz. flat routing, hierarchical routing, location-based routing etc. [13] and among these approaches hierarchical routing sounds to be the most attractive as many algorithms have been developed treating this as a base.

1.1 Components of Sensor Node

The diagrammatic representation of a sensor node is done in Fig.1 [12]. A sensor node is comprised of four essential segments: sensing unit, processing unit, transceiver and power unit. Further the division is application-dependent. Some of the components are location finding system, power generator and mobilizer.

![Fig. 1. Components of a sensor node](image)

Sensing units have two usual components or sub-units: Sensors and analog-to-digital converters (ADCs). Based on the observations of occurring phenomenon, the sensors ADC convert those analog signals into digital signals, and then act as input for the processing unit. The processing unit consists of a processor and a small storage unit,
defines the working procedures of sensor nodes to accomplish the special purpose of sensing tasks assigned to them. Transceiver unit is a connection between the node and the network. Power units are the most important components of sensor nodes. These may be supported by power grubbing units, such as solar cells.

There are other sub units also, which are application dependent. The knowledge of accurate location is required by most of the sensing tasks and routing techniques in sensor networks. Thus, it is a common phenomenon that location finding system exists in a sensor node. When some certain assigned tasks are required to be carried out, sometimes a mobilizer is needed to move sensor nodes. A matchbox-size module should be able to fit all these subunits. The required size of these sub-units may be smaller than even a centimeter cube. This makes them very light in weight so that they can remain suspended in air. Apart from size, sensor nodes carry some other severe delimiting factors. These nodes should operate in high volumetric densities. Also, they should have low production cost. Being dispensable and autonomous is also important. They should be energy-efficient and must function while consuming extremely low power.

1.2 Wireless Sensor Network

A Wireless Sensor Network (WSN) is a network with collection of sensor nodes which are interconnected by wireless medium or wireless communication channels [1]. The data is collected from the surrounding area by each sensor node which is actually acting as a small device, as illustrated earlier. It also communicates with other sensors nodes or with the base station (BS) and carries out simple computations as well.

![Fig. 2. Communication Architecture of WSN](image)

The sensor nodes are generally deployed in a specific region to monitor and detect real time environmental activities and are capable of data collection and transmission to the BS/sink. Data can be directed back to the sink by multi hop architecture as shown in Fig.2 [1]. The BS/sink may connect to the end user or task manager node via Internet or
satellite. The design of the sensor network as described by Fig. 2 is influenced by many factors, including fault tolerance, scalability, production costs, operating environment, sensor network topology, transmission media and power-consumption [1].

1.3 Protocol Stack

The protocol stacks used by the sink and sensor nodes are given in Fig. 3 [1]. The protocol stack is composed of the physical layer, data link layer, network layer, transport layer, application layer, power management plane, mobility management plane, and task management plane. The physical layer addresses the needs of simple but robust modulation, transmission, and receiving techniques. Most of the time, the network environment is noisy and sensor nodes need to be mobile, the medium access controls (MAC) protocol is responsible for minimizing collision with neighboring nodes. The network layer provides a mechanism for routing the data forwarded by the transport layer.

The transport layer controls the flow of data according to specific sensor networks application. Depending on the sensing tasks, different application specific software can be designed and built for the application layer. Additionally, the power management, mobility management, and task management planes supervise the power, sensor movement and sensing task distribution among deployed nodes. These planes defines procedures for coordination of the sensing task among sensor nodes and reduce overall power consumption. The power management plane oversees how a sensor node utilizes its power.

For instance, during the low energy level of sensor node, it transmits a message to adjoining nodes that it is low in power and cannot contribute in routing data packets. The remaining energy is held for sensing. The mobile nodes in the sensor field are identified and further registered by the mobile management plane, which helps the
sensor nodes in maintaining a track of their adjoining sensor nodes. Therefore few sensor nodes accomplish their assignment less than others relying upon their energy level.

2. FACTORS INFLUENCING ROUTING PROTOCOLS IN WSNs

Routing protocol design is affected by numerous challenging elements. Some of the most influencing factors are as follows:

(a) Fault Tolerance: Fault tolerance can be defined as the ability to sustain sensor network functionalities without any interruption due to sensor node failures [38-40]. It becomes the issue of fault tolerance when the failure of a component affects the overall functioning of the system. There is always a chance of failure of sensor nodes. The overall task of the sensor network should not be affected by this. There can be several causes of failure or blocking of sensor nodes. These may vary from lack of power to some environmental interventions or some physical damages. The modeling of the reliability \( R(t) \) or fault tolerance of a sensor node is done using the Poisson distribution [38]. The probability of a sensor node failure is in the time interval \((0, t)\) is calculated as: 
\[
R_k(t) = \exp(-\lambda_k t)
\]
where \( \lambda_k \) is the failure rate of sensor node \( k \) and \( t \) is the time period.

(b) Scalability: Usually, to study a phenomenon, the number of sensor nodes deployed in a region may be of the order of hundreds or thousands. But just in case, depending on the application, the order may be of millions. Also, the new developed schemes must be able to deal with this amount of nodes. Apart from the number, the density is also concerned. The effective utilization of the high density of the sensor networks should also be taken into account. In a region, the density of the scattered sensor nodes can range from a few to few hundreds. The region can be less than 10 m in diameter [41]. The density of sensor nodes in a region, \( \mu \), can be calculated [42] as: 
\[
\mu(R) = \frac{(N \pi R^2)}{A}
\]
where \( N \) is the number of scattered sensor nodes in region \( A \) and \( R \) is the radio transmission range. \( \mu(R) \) gives the number of nodes within the transmission radius of each node in the region \( A \).

(c) Production Costs: It is obvious that the overall cost of the network system is affected by the cost of a single sensor node. So, this becomes a very important factor to justify the whole cost of the network. The sensor network is not justified in terms of production cost if it becomes more expensive as compared to the deployment of traditional sensors. Therefore, the cost of all the sensor nodes should be minimum. For example, the cost of a Bluetooth radio system is allowed to be less than US $10 [43] according to the state-of-the-art technology and the cost of a Pico node should to be less than US $1 [44]. For a feasible sensor network, the cost of a sensor node should be kept much less than US $1. The known low-cost device, a
Bluetooth radio, is even 10 times more costly than the targeted price for a sensor node.

(d) Sensor Network Topology: In a sensor field, deployment of several sensor nodes is done throughout. This is done within tens of feet with respect to each other [45]. The highest possible node density may be 20 nodes per cubic meter [46]. The topology maintenance is required to be carefully handled with this dense deployment of such a high number of nodes. The issues related to topology maintenance and change can be examined in three phases:

i. Pre-deployment and deployment phase: There are two ways of deploying the sensor nodes in a sensor field: throwing them in as a mass or placing one by one into the region. These include as dropping them from a plane, delivered in an artillery shell, rocket, or missile. They can be placed one by one manually or with the help of a robot.

ii. Post-deployment phase: After deployment, topology changes are due to change in sensor nodes position, reachability (due to jamming, noise, moving obstacles, etc.), available energy, malfunctioning, and task details [47- 48].

iii. Re-deployment of additional nodes phase: Additional sensor nodes can be redeployed at any time to replace malfunctioning nodes or due to changes in task dynamics.

(e) Environment: Usually, the sensor nodes work in an unattended manner under the sensor field. The deployment of the sensor nodes is done very close to the area under observation. These areas may be remote geographic areas or out of reach. Their environment can be the interior of large machinery, beneath the ocean, in biologically or chemically contaminated field, in a battle field beyond the enemy lines, and in a home or large building.

(f) Transmission Media: The communicating nodes in a multi-hop sensor network are linked by wireless medium. The medium of formation of these links can be a radio, an infrared or an optical media. The transmission medium selected must be global, i.e., it is applicable worldwide. Currently, the major part of hardware for sensor nodes is based on RF circuit design. The $\mu$-AMPS wireless sensor node uses a Bluetooth-compatible 2.4 GHz transceiver with an integrated frequency synthesizer. The low-power sensor device uses a single-channel RF transceiver operating at 916 MHz. The Wireless Integrated Network Sensors (WINS) architecture also uses radio links for communication. Another possible mode of communication in sensor networks is by infrared communication. It is license free and robust to interference from electrical devices. Infrared based transceivers are cheaper and easier to build. Another interesting development is that of the Smart Dust mote, which is an autonomous sensing, computing, and communication...
system that uses the optical medium for transmission. Both infrared and optical require a line of sight between the sender and receiver.

(g) **Power Consumption:** The wireless sensor node, being a microelectronic device, can only be equipped with a limited power source (< 0.5Ah, 1.2 V). In some of the applications, the replacement of the power source becomes an impossible task. The lifetime of a sensor node thus depends primarily on the lifetime of battery used. Each node of a multi hop ad-hoc sensor network participates in the system with two roles: data originator and data router. The requirement of rerouting of data packets as well reorganization of the network arises with the malfunctioning of some nodes. These are some significant topological changes within the network. So, the consumption and conservation of power management add up to importance. In the mean time, the focus of many researchers is on the design of two things: power-aware protocols and algorithms for sensor networks. In a sensor field, mainly there are three functions of a sensor node: detecting events, quick data processing, transmit data. Therefore, the consumption of power has three domains, namely: sensing, data processing and communication.

### 3. ROUTING TECHNIQUES IN WSNs

The general classification of existing routing techniques can be done as: flat routing, hierarchal routing and location-based routing.

- **Flat routing:** Each node assumes the same task in network and the sensor nodes team up to carry out the sensing task. The BS keeps waiting for information from the sensor situated selected areas after it sent queries to those certain areas.

- **Hierarchal routing:** Cluster based or hierarchical routing is advantageous in relation to energy-efficiency as well as scalability. Nodes lower in energy can be utilized to sense data close to target whereas with higher energy for processing and sending the information. The forming of clusters and appointing unique tasks to cluster heads can enormously contribute to the whole network scalability and energy efficiency.

- **Location-based routing:** In location based routing, addressing of sensor nodes is done tending to their location. The separation between neighbor nodes can be found on the premise of strength of incoming signals. If the sensor nodes are outfitted with a little low-power GPS receiver, their location may be accessible straight forward by corresponding with a satellite utilizing GPS.

Out of all these, hierarchical clustering protocols are widely used to improve overall network scalability as well as to increase the lifetime of network by enhancing energy...
3.1 Cluster based routing protocols in WSNs:
Routing Protocols can typically be classified in three categories as: Block, Grid and Chain.

Fig. 4 Basic taxonomy of routing protocols in WSN
3.1.1 Block cluster based routing protocols:

1. **LEACH**

One of the oldest hierarchal protocols, LEACH (Low-Energy Adaptive Clustering Hierarchy) is a simple TDMA (Time-Division Multiple Access)-based routing protocol used in WSNs. Proposed by Heinzelman et.al.[14] in the year 2000. This cluster based protocol emerged as an energy efficient communication protocol for wireless micro-sensor networks that utilizes randomized rotation of local cluster base stations known as cluster heads to uniformly distribute the energy load among sensor nodes in the network.

The key features of LEACH are:

- Localized coordination and control for cluster-set up and operation
- Randomized rotation of the cluster heads and the corresponding clusters
- Local compression to reduce global communication

LEACH is considered to be a self-organizing protocol in which the sensor nodes organize themselves to form clusters and one node is chosen as a cluster head (CH). The CH acts as a local Base Station (BS) in a way that data is transmitted by each sensor node to its corresponding cluster head. The cluster head position is rotated among different sensor nodes within the cluster to ensure that just a single node does not die out due to loss of its whole energy. The rotation is done in a random manner. The CHs also compress the data received by it from the other nodes before sending it to the base station to ensure less energy dissipation in the network. The optimal number of CHs to be elected depends on the network topology or computation cost.

CHs are elected within a cluster with certain probability at different time intervals. The node with higher energy will have higher chances of being cluster head. Once the CHs are chosen, they broadcast their position or status to other sensor nodes within the network. Each sensor node then calculates the amount of energy required to communicate data to the CHs and chooses the one with minimum. In this way the clusters are formed. The CHs then create schedule for its sensor nodes to transmit the data and the nodes remain turned off until their turn for transmitting data comes. This saves a large amount of energy dissipated by each sensor node. After collecting data from each node within the cluster, the CH aggregates it and sends it to the BS.
2. HEED

The basic assumption in HEED (Hybrid Energy-Efficient Distributed clustering) is that each sensor node is capable of controlling its transmission power level but they are location unaware. Proposed by Younis & Fahmy [15] in 2004, this technique was developed as a distributed and energy efficient cluster formation. HEED employs a combination of two different parameters for CH selection i.e. residual energy of each node and node degree. A node can be selected as a CH depending on its residual energy together with some probability. The cluster formation occurs when the other nodes in the network choose their respective CHs maintaining minimum cost of communication. The main objective of HEED is to prolong network lifetime as well as supporting scalable data aggregation. Initially the proposed algorithms were able to build only two-level hierarchy.

![Cluster Based Routing protocols in WSNs](image)

**Fig. 5** Cluster based routing schemes in WSNs
3. **SEP**

The SEP (Stable Election Protocol for clustered heterogeneous WSNs) was proposed in the year 2004 by Smaragdakis et.al. [16]. This technique is an improvement over LEACH and considers two levels of heterogeneity of sensor nodes namely normal and advance nodes. Advance nodes are high in energy and have much more probability of becoming CHs as compared to normal nodes. The global knowledge of node energy is not required in every round. Also, the protocol is scalable due to the fact that it does not need the position of nodes within the sensor field.

4. **DWEHC**

As a modification of HEED, the DWEHC (Distributed Weight-based Energy-efficient Hierarchal Clustering scheme) for wireless sensor networks was proposed by Ding et.al. [17] in 2005. The objective of this technique was to balance the cluster size and have minimum energy topology within the cluster. As an approach of being energy efficient protocol, this technique also focused on enhancing the lifetime as well as scalability of the WSN. In order to achieve this goal, clustering is done based on some neighborhood and weight of each node. Each node calculates its weight depending on its residual energy and its distance from the neighboring nodes. Maximum weight node becomes the CH. Clusters are formed depending on minimum energy path to the CH. The data is transmitted to the neighboring parent node until it reaches the respective CH. Simulation results demonstrate that in DWEHC, the clusters are well balanced and energy consumption was far much lower than previously existing energy efficient protocols such as HEED.

5. **UCS**

UCS (Unequal Clustering Size) emerged as the first clustering protocol, which employed unequal sized cluster formation. In this approach, all clusters do not contain the same number of nodes. The algorithm was proposed by Soro & Heinzelman [18] in 2005 with the aim of prolonging lifetime of WSNs.

The main idea behind unequal sized clustering is to balance the energy load among the clusters. The network is divided into heterogeneous clusters and the energy dissipation of each CH is uniform. More unbalanced energy consumption by member nodes among the clusters results in more balanced energy consumption among the CHs. This approach was especially beneficial when the networks collecting large amount of data are considered and can also be applied to prolong the lifetime of both homogeneous and heterogeneous networks. The residual energy of the CH decides the number of member nodes within its cluster.
6. **EECS**

EECS (Energy-Efficient Clustering Scheme) was proposed by Ye et al. [19] in 2005 for WSNs applying periodical data gathering. It is a single-hop routing protocol with a different approach for cluster head selection and cluster formation. This scheme also focuses on balancing energy load and prolonging network lifetime. CHs are selected through comparisons of residual energy of a sensor node with the neighboring ones. CHs are distributed uniformly across the network. Cluster formation is based on minimum energy consumption by the member within the cluster using distance metric as well as CH communication with the BS.

7. **TEEN**

The hierarchal protocol TEEN (Threshold-sensitive Energy Efficient sensor Network protocol) was proposed by Manjeshwar et al. [20] for reactive networks. Reactive networks are those in which the sensor nodes adapt themselves according to the changes in the environment.

This protocol tries to reduce the number of transmissions in order to increase energy efficiency of the network. Data is transmitted only when the sensed data value falls into a specific range of interest. In each cluster, the CH sets two two attributes: Hard and soft threshold for its member nodes. Data is transmitted only when it is greater than the hard threshold value and the difference between the old value and new value is greater than the soft threshold value. In this way some transmissions are eliminated which saves energy of sensor nodes within the network.

8. **BCDCP**

Proposed by Muruganathan [21] in 2005, BCDCP (Base Station controlled Dynamic Clustering Protocol) utilizes CH to CH transmission for routing data to BS. The BS controls the formation of balanced cluster, rotation of CH role randomly where CHs are distributed uniformly throughout the network and setting up data transmission paths.

As this scheme is BS controlled which is high in energy and can perform complex computational tasks, the sensor nodes employed becomes relatively simple and cost effective. In this scheme, the BS receives the energy status of all the sensor nodes, calculates the average energy and chooses those nodes as CHs who have their current energies higher than the average energy of sensor nodes in the network. Cluster formation is done by applying iterative splitting algorithm in which the network is split into sub-clusters, which again are split down into clusters until the required number of clusters is formed. Routing paths are selected using minimum spanning tree algorithm. Routing process is multi-hop but random selection of CH for transmitting the data to BS is done so that the nearest CH to BS does not deplete in its energy.
9. CCM

Tang et al. [22] proposed the technique of CCM (Chain Cluster-based Mixed routing) in the year 2010. CCM uses the advantages of LEACH and PEGASIS. The main advantage of LEACH considered here is its short transmission delay, whereas that of PEGASIS is its low energy consumption. This technique divides the network into chains. The nodes in each chain transmit their data to their CH in the first stage. In the second stage, CHs of chains form a cluster themselves and their new CH is formed to which the fused data is transferred. The two stages of data transmission are namely chain routing and cluster routing.

In chain routing, the sensor nodes are assumed to be distributed in a two-dimensional location symmetrically. Each node is given a serial number according to its location in 2D coordinate system (x,y). Data is transmitted into the chains by a node to its neighboring node. Every node acts a head node in each chain so that energy consumption is evenly distributed. Also, energy is not consumed for selection of head node in a chain. A token system is employed to transmit data within a chain. Two tokens are generated by the head node and transmitted in the opposite directions i.e. to the first node and the last node. The nodes transmit the data to the neighboring node in the chain towards the head node after fusing it with its own data. This transmission is done in parallel but alternatively. Finally, the head node has all data and it destroys the tokens.

In cluster routing, after all the head nodes are ready with their collected data, all other sensor nodes go to sleep mode. Now, these head nodes form a cluster with a CH. The CH is chosen based on the residual energy of these nodes. Comparison between the nodes is done and the node with higher residual energy advertises for itself. In case of conflict, the node which advertised first is selected. Afterwards, CH assigns TDMA slots to other nodes for data transmission. The CH collects all the data and sends it directly to the BS.

10. LEACH-VF

LEACH-VF (LEACH with Virtual Force), proposed by Awad et al. [23] in 2012, uses the principles of virtual field force to locate the sensor nodes in each cluster. The approach is based on two key issues: sensing coverage and data transmission energy.

Clustering is done similar to the LEACH protocol. In addition to this, every node messages its current location to its CH. In the next phase, the nodes move to their new locations determined by their CHs. Both attractive and repulsive forces are used to move the nodes within the cluster. The attractive forces are used to move nodes towards respective cluster heads so that the energy consumed for transmitting the data is reduced. Repulsive force is used to move the nodes covering the same area, apart from each other in order to cover the maximum area for data sensing. The data transmission phase is also same as in LEACH.
Simulation results show that performance of LEACH-VF as compared to LEACH is better in terms of both area coverage and increasing network lifetime. The only drawback that appears is that the cost of mobility of sensor nodes is not considered.

11. MWBCA

Fan et al [24] proposed MWBCA (The Multi-Weight Based Clustering Algorithm) as a modification of LEACH for reactive networks. Combined weight is computed as score function for nodes to form CHs. This function is a linear combination of the transmission power and the residual energy of the sensor nodes, together with their weight. The combined weight is broadcasted by each sensor nodes to its neighboring sensor nodes and the node with least combined weight among all others is chosen as the CH.

The technique employs alternative turns of nodes to become a CH. This overcomes the nodes from early dying out due to excess energy dissipation of a node. The nodes with low amount of residual energy have low chances of becoming CHs as compared to nodes with higher residual energy.

12. HCTE

Proposed by Azizi et al. [25] in the year 2012, HCTE (Hierarchical Clustering based routing algorithm with applying the Two cluster heads in each cluster for Energy balancing in WSN) is a multi-hop cluster based routing protocol in which each cluster contains two CHs for energy load balancing. The CHs are named as initial and second cluster heads. Both of these CHs have different tasks to perform. This technique has five phases: initial CH announcement, cluster formation, second CH announcement, schedule creation and data transmission.

The initial CHs have high residual energy and its neighboring nodes are more in number. Tasks performed by initial CHs are cluster formation, data gathering form other sensor nodes within the cluster and sending those data to the second CH. The clusters are formed when each sensor node calculates the confidence value of initial CHs using its transmission range. In this manner a node chooses its CH which is high in residual energy as well as close to it. If any node fails to do so, then it chooses the nearest initial CH as its CH.

Again, within each cluster, the node with highest confidence value is chosen as second CH. That is its distance with the BS is least and its residual energy is high. The tasks performed by the second CH is gathering the data from respective initial CH or second CHs of other clusters, sending the data to other second CHs or to the BS(since this is a multi-hop routing). Again using multi-hop routing for data transmission, data is routed to the second CH which has lowest cost. The cost function is calculated on the basis of some parameters such as residual energy and distance to the BS.
3.1.2 Grid Cluster-based Routing Algorithms

1. GAF

To reduce energy consumption in ad hoc networks, GAF (Geographic Adaptive Fidelity) was proposed Xu et al. [26] in the year 2001. Adaptive fidelity is a technique in which redundancy in the network is exploited to conserve energy while maintaining application fidelity. This is a geographic location based clustering algorithm. The nodes are divided into clusters in the form of virtual grids.

This technique uses the process of turning off the nodes, which are equivalent in view of routing. When multiple paths exist in between two nodes, the intermediate nodes are turned off. Because of this behavior of nodes, the routing fidelity is kept constant. Routing fidelity is defined as uninterrupted connectivity between communicating nodes.

Application and system information is used to predict the node duty cycles and the periods of time for which the nodes should be turned off. The movement of nodes depends on communication fidelity. The nodes adapt to adjust routing fidelity according to node deployment density. GPS or other location information system and active node communication is used to determine the node density and redundancy.

2. PANEL

PANEL (Position-based Aggregator Node Election scheme) was proposed by Buttyan et.al. [27] and designed to support supports intra and inter-cluster routing allowing sensor to aggregator, aggregator to aggregator, base station to aggregator and aggregator to base station communications. The aggregators are the nodes that collect data from their respective clusters and then store them after aggregation. This technique can be used for synchronous as well as asynchronous WSNs, where the BS receives data after periodic delays.

To determine the aggregator nodes, it uses geographic location of nodes and ensures their selection with nearly equal frequency for load balancing. So, the nodes are static but location aware. The BS is mobile and their presence can be occasional. The cluster size is chosen appropriately according to deployment density and maximum power range of sensor nodes so that the connectivity within the cluster can be maintained. Each sensor node is connected to every other sensor node within that cluster. This connectivity is used for intra-cluster routing. A reference point is calculated in each cluster and the node closest to this reference point is elected as aggregator. Position-based routing protocol is used for inter-cluster communications. The CH is selected at each epoch to ensure load balancing. Reliable and persistent data storage is done by delivering the replicated data to the aggregator node of other cluster.
3. TTDD
The approach used in TTDD (Two-Tier Data Dissemination) by Luo et.al. [28] attends multiple mobile BS problem. The sensor nodes are location aware but static and arranged in grids in order to achieve low overhead. The sensor nodes surrounding an area collectively process the signal and one of them becomes source node. The source nodes forward their data to other nodes close to the grid points. The BS is mobile and continuously receives data by flooding queries within the same cell and its location is propagated to all the sensor nodes within the network so that the nodes become aware of the direction for sending data in future. The number of BSs varies from time to time. In this way, TTDD effectively delivers data from multiple sources to multiple BSs with high performance.

4. HGMR
HGMR (Hierarchical Geographic Multicast Routing) was introduced by Koutsonikolas et al. [29] in the year 2007. It is a location based multi-hop routing protocol (multicast) which merges the key design features of previously existing GMR and HRPM techniques in order to overcome the energy inefficiency and scalability issues in large networks. Mobile geographic hashing is used to decompose a multicast group into subgroups. For data transmission, local multicast scheme is applied. The region of deployment is divided into cells and cost over progress optimizing broadcast algorithm to select the next relay nodes at each hop.

5. SLGC
In SLGC algorithm was proposed as a single-hop routing scheme by Delavar et al. [30] in the year 2012. The BS and sensor nodes in the network are static. The heterogeneous nodes are deployed in two-dimensional region. In this grid cluster based scheme, a center of gravity and threshold energy value is calculated for CH selection in every grid. Those sensor nodes are selected as CHs who high energy and less distance with the center of gravity of that grid. The nodes send their data to CHs and then it is directly sent to the BS.

3.1.3 Chain Cluster-based Routing Algorithms
1. PEGASIS
This approach (Power-Efficient GAthering in Sensor Information Systems) was proposed by Lindsey et al. [31] and is a modification of LEACH. A chain of sensor nodes is formed in which each node communicates only with its close neighbors. Data transmission is done from node to node and only a designated node sends it to the BS. The leader node responsible for transmission changes turn by turn. The chain formation is either determined by the BS or the nodes themselves form chains using greedy algorithm, which requires global knowledge of the network. While data gathering, each
node gathers data from its neighbor and further transmits it to next neighboring node after fusing it with its own sensed data. To make the scheme robust, the sensor nodes die out at random locations. This is achieved by changing the data transmission leader in each communication round.

Nodes having distant neighbors will dissipate more energy. To overcome this, such nodes are allowed to form leaders by setting a threshold on distance to neighbors. Simulation results demonstrate that PEGASIS outperforms LEACH in many ways viz. dynamic cluster formation overhead is removed, number of transmissions, distance of transmission of nodes is minimized, and there is single transmission to the BS in each communication round.

2. CCS

As an extension to PEGASIS, CCS (Concentric Clustering Scheme) [32] was proposed by Jung et al. in the year 2007. In this protocol, concentric circles are formed as clusters while the chain is formed according to PEGASIS protocol. The idea is to remove the redundancy issues in PEGASIS and make the network energy efficient, by considering the location of the BS.

Certain level numbers are assigned to each node, which divides the region into concentric circles. The number of levels is determined by the BS depending on node density, location of BS. The lowest level is nearest to BS. Nodes at the same level form a cluster and a chain is formed within each cluster starting from the farthest node to BS. A head node is selected in each cluster or chain. Data transmission within a chain is done in the same manner as in PEGASIS i.e. data is transmitted from the starting node to its neighbor in the chain and the neighbor fuses this data with its own data before transmitting it to its next neighbor until it reaches head node. Each head node receives data from its chain nodes as well as head node of the higher level cluster. Finally, all the collected data is transmitted to BS by the head node of lowest level cluster.

3. TSC

Gautam et.al. [33] presented TSC (Track-Sector Clustering) scheme in the year 2009. The main aim of this scheme is to remove the shortcomings of earlier protocols like LEACH, PEGASIS and CCS viz. to reduce accumulation of larger data at head nodes and distances of these nodes from BS, reverse data flow and bottleneck formation at head nodes. Likewise, CCS, the network is divided into concentric circular tracks. In TSC, the tracks are further divided into triangular sectors. In this way, this approach tries to reduce the redundancy in data transmitted within the whole network as the larger clusters at high level are broken down into smaller clusters. Also, the energy-efficiency is attained by reducing the distances between the head nodes and the BS. The BS is responsible for the computation of tracks and sectors so in this way the energy of sensor nodes is saved. By minimizing the head node to BS distances, the energy dissipation of nodes is also minimized.
Each cluster comprises of a head node. The clusters are formed by the strips obtained by the intersection of circular tracks and the triangles. In this way, the network is partitioned into tracks and sectors, which are static for whole lifetime of the network. The BS is positioned at the center of concentric circles. The number of levels is determined similar to CCS. The head node of first level in a sector is selected randomly. The BS calculates the transmission slope of this head node after determining its location. The nodes at the higher levels having similar transmission slope will form the head node of that particular cluster.

Chains are formed as in PEGASIS. As a node dies out, the chain is again formed leaving that node behind. Data is transmitted via chains to the respective head nodes. Each head node passes it on to the head node of the lower level cluster within same sector. At last, lowest level head node sends it to the BS.

4. PROS AND CONS OF CLUSTER BASED ROUTING TECHNIQUES IN WSNs

Table 1 summarizes the pros and cons of each routing protocol covered in this paper.

<table>
<thead>
<tr>
<th>Protocol</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEACH [49-50]</td>
<td>• Introduced data fusion to reduce the redundant data. • More energy efficient than direct transmission approach. • It uses TDMA schedule to avoid unnecessary collision among CHs.</td>
<td>• The randomness in LEACH may result in large number of CHS from the optimal count. • There is no criterion for optimal CH selection. • CHs directly send data to base station.</td>
</tr>
<tr>
<td>HEED [15, 51]</td>
<td>• It supports uniform and non uniform node distribution. • It provides balanced clusters and uniform distribution of CHs. • HEED improves energy efficiency and network scalability through inter cluster communication in multi hop way.</td>
<td>• Complexity of algorithm increases due to repeated iterations to form clusters. • The cluster head near to BS consumed more power than any other node due to multi hop communication, which may result in quick drain of battery. • Unbalanced energy consumption due to more CHs generated than the expected number of CHs.</td>
</tr>
<tr>
<td>SEP [16, 52]</td>
<td>• It works on hierarchical clusters.</td>
<td>• It has large control message overhead compared to other</td>
</tr>
<tr>
<td><strong>Techniques</strong></td>
<td><strong>Description</strong></td>
<td></td>
</tr>
<tr>
<td>---------------</td>
<td>----------------</td>
<td></td>
</tr>
</tbody>
</table>
| **DWEHC** [17, 53] | - It provides balanced cluster size and intra-cluster communication is performed using TDMA.  
- The nodes in each cluster may vary to balance communication load.  
- UCS is more energy efficient because it uses bi-layered network model and two hops inter cluster communication.  
- It is not suitable for homogeneous network structure and cluster heads are predetermined.  
- There is no discussion on residual energy and CHs are always kept in the center of cluster.  
- It is not suitable for large scale network because it works on two hop inter cluster communication. |
| **UCS** [18, 53] | - Introduced dynamic sizing of clusters that solves the problem of long distance communication between a cluster and the BS.  
- It is a well balanced network in terms of effective energy utilization and communication load.  
- A CH node far away from BS may die quickly due to single hop communication between a CH and BS.  
- It need more global information about the distances between the CHs and BS, which takes a massive overhead.  
- All nodes compete for CH election, which in turn give more overhead complexity. |
| **EECS** [19, 54] | - TEEN introduced clustering technique with a data centric approach.  
- Data transmission is performed less frequently as it operates in reactive mode.  
- It is suitable for time critical applications.  
- It is not suitable for periodic data transmission as if the thresholds are not met, the node does not communicate at all.  
- If the cluster heads are not able to communicate each other, the data packets may lose. |
| **TEEN** [20, 55] | - It works on global distribution of CHs as all the communication channels and CHs are elected by the base station.  
- TDMA schedule is used to avoid unnecessary collision among the cluster members.  
- It is not suitable for large scale networks due to single hop communication and suffers from the problems of scalability and robustness.  
- The complexity of algorithm increases due to the assumption that each node should send the
<table>
<thead>
<tr>
<th>Protocol</th>
<th>Advantage</th>
<th>Disadvantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Efficient Hierarchical Routing Protocols for Homogeneous...</td>
<td>It provides effective energy utilization as the nodes only transmits data when it is necessary.</td>
<td>information about its location and energy level to BS. It is not suitable for continuous data flow model.</td>
</tr>
<tr>
<td>BCDCP [53,56]</td>
<td>It combines the advantages of LEACH and PEGASIS. It is more energy efficient than LEACH. It has less end to end delay as compared to PEGASIS.</td>
<td>Leader node selection criteria in the chain If the CH is far from the sink more energy will be consumed in communication.</td>
</tr>
<tr>
<td>CCM [22, 53]</td>
<td>It works on hierarchical clusters. It provides balanced cluster size and intra-cluster communication is performed using TDMA.</td>
<td>It has large control message overhead compared to other clustering techniques. The total energy consumption may increase due to multi hop intra-cluster communication.</td>
</tr>
<tr>
<td>LEACH-VF [23,57]</td>
<td>It eliminates the problem of overlapped sensing coverage by using repulsive force. It eliminates the problem of sensing holes by using attractive force. The nodes outside the cluster area can be moved to coverage inside the cluster.</td>
<td>Energy distribution and communication load balance is not very good. Poor energy efficiency</td>
</tr>
<tr>
<td>MWBCA [24, 53]</td>
<td>The communication load of CHs is optimized because the selection of CH is based on residual energy, multi weight, number of nodes and time as a CH. The node death rate is lower as compared to LEACH.</td>
<td>Network scalability is very low. It suffers from large latency.</td>
</tr>
<tr>
<td>HCTE [25]</td>
<td>It uses multi hop communication for routing data. It prolongs network lifetime by 35% as compared to LEACH.</td>
<td>Energy consumption is much higher during cluster formation and CHs selection. It is not suitable for large scale WSNs.</td>
</tr>
<tr>
<td>Method</td>
<td>Advantages</td>
<td>Disadvantages</td>
</tr>
<tr>
<td>----------</td>
<td>-----------------------------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------------</td>
</tr>
</tbody>
</table>
| GAF      | - It is fully localized and routing fidelity is controlled through the nodes coordinating the active and sleep periods.  
- It saves energy by keeping off the radio of redundant nodes. | - Residual energy is not considered for effective utilization of energy.  
- It is not suitable for real time application due to large traffic injection and delay is not predictable. |
| PANEL    | - It prolongs network lifetime and maintains a well load balance because each node has equal probability to become a CH.  
- It is suitable for asynchronous applications in WSN. | - Clusters are predefined before deployment of nodes which is not applicable to real world application in WSN.  
- Sometime special conditions are required to know the geographic position of nodes which is always not possible. |
| TTDD     | - It provides a feasible solution for multiple sink and sink mobility in a large scale WSN.  
- It is suitable for event driven applications with irregular data traffic. | - It is not suitable for continuous data flow model.  
- Sensor nodes are stationary and location aware.  
- It suffers from large latency. |
| HGMNR    | - It uses mobile geographic hashing to decompose a multicast group into subgroups of manageable size, which results in encoding efficiency and scalability to large scale networks.  
- HGMR achieves energy efficiency through multicast routing and scalability. | - It may suffer from unbalanced energy consumption because all transmissions are performed by hash function.  
- The routing path may not optimal because data packets are sent from upper APs to lower APs without discovering the fact that lower AP may be closer to the source. |
| SLGC     | - It has higher energy efficiency level as compared to LEACH. | - It is not suitable for large scale WSNs. |
| PEGASIS  | - It provides balanced energy consumption through selecting each node as a leader node once.  
- It works on dynamic cluster formation | - The energy level is not considered in the selection of a leader node.  
- It is assumed that each node is able to communicate with the sink directly.  
- There is only one leader node at a time, which may result in the transmission delay. |
Energy Efficient Hierarchical Routing Protocols for Homogeneous...

- Energy consumption is minimized by optimizing the communication distance.
- It controls the data flow from BS through portioning the network into concentric clusters.

- The energy level is not considered during cluster head selection.
- Communication with neighbor node is done by low radio power but the long chain may cause large transmission delay.

- It is more energy efficient as compared to PEGASIS and CCS.
- It minimized redundant data transmissions by breaking the long chain of nodes into smaller chains.

- Unbalanced node distribution at each level
- The energy level of nodes is not considered during CH selection.

5. COMPARISON TABLE FOR ROUTING TECHNIQUES IN WSNs

Table 2 summarizes the comparison between cluster-based routing schemes based on communication architecture, Network Structure, power efficiency, end-to-end delay, load balance, network scalability and stability.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>LEACH</td>
<td>Single hop</td>
<td>Homogeneous</td>
<td>Very poor</td>
<td>Very small</td>
<td>Medium</td>
<td>Very poor</td>
<td>Medium</td>
</tr>
<tr>
<td>HEED</td>
<td>Multi hop</td>
<td>Homogeneous</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>SEP</td>
<td>Single hop</td>
<td>Heterogeneous</td>
<td>High</td>
<td>Medium</td>
<td>Good</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>DWEHC</td>
<td>Multi hop</td>
<td>Homogeneous</td>
<td>Very high</td>
<td>Medium</td>
<td>Very good</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>UCS</td>
<td>Multi hop</td>
<td>Heterogeneous</td>
<td>Very high</td>
<td>Small</td>
<td>Poor</td>
<td>Poor</td>
<td>High</td>
</tr>
<tr>
<td>EECS</td>
<td>Single hop</td>
<td>Homogeneous</td>
<td>Medium</td>
<td>Small</td>
<td>Medium</td>
<td>Poor</td>
<td>High</td>
</tr>
<tr>
<td>TEEN</td>
<td>Multi hop</td>
<td>homogeneous</td>
<td>Very high</td>
<td>Small</td>
<td>Good</td>
<td>Poor</td>
<td>High</td>
</tr>
<tr>
<td>BCDCP</td>
<td>Multi hop</td>
<td>homogeneous</td>
<td>Very high</td>
<td>Small</td>
<td>Good</td>
<td>Very poor</td>
<td>High</td>
</tr>
<tr>
<td>CCM</td>
<td>Multi hop</td>
<td>homogeneous</td>
<td>Very poor</td>
<td>Small</td>
<td>Medium</td>
<td>Very poor</td>
<td>High</td>
</tr>
<tr>
<td>LEACH-VF</td>
<td>Single hop</td>
<td>homogeneous</td>
<td>Medium</td>
<td>Very small</td>
<td>Medium</td>
<td>Very poor</td>
<td>High</td>
</tr>
<tr>
<td>MWBCA</td>
<td>Multi hop</td>
<td>homogeneous</td>
<td>Medium</td>
<td>Very</td>
<td>High</td>
<td>Very poor</td>
<td>Medium</td>
</tr>
</tbody>
</table>
6. CONCLUSION

Effective power utilization is a major concern in deploying wireless sensor networks because a sensor node is battery operated and it has a fixed lifetime. Studies have observed that most of the power is consumed during data sensing, data routing and data processing. In WSNs, the current trend is to integrate WSNs and internet, so that the real time information can be used to make our day-to-day life as smart as possible. However, due to limited power source, one needs to devise some novel energy efficient routing strategies at network layer. This paper differentiates the different hierarchical routing protocols based on several performance parameters and it is observed that the cluster-based approaches tend to be more energy efficient as compared to other approaches.

REFERENCES


Energy Efficient Hierarchical Routing Protocols for Homogeneous... 1251


[34] C. Perkins, 2000, Ad Hoc Networks, Addison-Wesley, Reading, MA.


integration,” Proceedings of IEEE Southeastcon’93, Charlotte, NC.


[51] Chand, Satish and Singh, Samayveer and Kumar, Bijendra, 2014,


