Chapter 5

Sector Based Multi-hop Clustering protocol for WSN

5.1 Introduction

In hierarchical routing, the sensor nodes are grouped into a set of disjoint clusters. Each cluster has a designated leader called CH. Nodes in each cluster do not transmit their gathered data directly to the BS, but only to their respective CH. Partitioning the network into small clusters and assigning special tasks to CH can greatly contribute to overall system scalability, lifetime, and energy efficiency. Hierarchical routing is an efficient way to lower energy consumption within a cluster by performing data aggregation and fusion to decrease the number of transmitted messages to the BS. But the biggest challenge in hierarchical routing protocol is to provide network survivability and redundancy features.

In the past few years, several cluster-based protocols [1,76–80,89] have been proposed for WSNs to minimize energy consumption. But energy consumption is still high due to redundant data transmission and variable transmission distances between CHs and BS. Also, some of these protocols do not consider the nodes residual energy and each node's distance to BS during clustering process. For these reasons, the protocols could not distribute energy load evenly in the network.

The track-sector clustering (TSC) [90] eliminates the redundant data transmission and minimizes the distance between CHs and the BS. The BS divides the network into concentric circular tracks and triangular sectors just at the beginning of the network setup. The protocol constructs chains within each cluster formed by the intersection of tracks and sectors similar to chain construction in [70]. PEGASIS constructs a longer single chain covering all the nodes in the network. In TSC, smaller chains are constructed within each cluster. TSC reduces the time delay for the data packet to reach the CH node and the chain is re-constructed when the node dies.

The Power Aware Sectoring based Clustering Algorithm (PASCAL) for WSNs is proposed in [91]. The protocol uses the concept of leveling, sectoring for the formation of clusters in the WSN. In the routing algorithm nodes are considered to be static or have a very low mobility with respect to signal propagation. The protocol uses flooding to forward the packets to BS. When an event is detected, packets are flooded from the event occurring node to other nodes in the direction of BS. The node forwards the packet received only if it is from one-hop sector of higher level, otherwise the packet is dropped. The PASCAL uses the concept of mode switching to improve the lifetime of the sensor network.

In this chapter, an energy efficient clustering protocol for WSNs is proposed to maximize the lifetime of the network. The protocol named Sector Based Multi-hop Clustering (SBMC) uses the concept of leveling, sectoring and multi-hop clustering. Dissemination of data from CH to BS is done in such a way that the energy loss in discovering a route is decreased to minimum. The additional computation for the leveling and sectoring are carried out in BS just at the beginning of the network setup. This reduces the energy dissipation among the nodes by eliminating the communication overhead.

5.2 Proposed Network and Radio Energy Model

It is assumed that a WSN composed of N number of sensor nodes, which are randomly deployed in a circular area to collect information periodically. The BS is located at the center of the sensor field and provided with directional antenna. The following assumptions are made on the nature of the WSNs:

a. The BS and nodes in the network are static.

b. Each node has a unique ID and nodes are randomly deployed in a circular area.

c. Sensor nodes are location aware.

d. Each node and BS is capable of controlling transmit power.

e. All the nodes in the network are in the communication range of BS.

f. Intra-cluster communication is single-hop.

The performance of the proposed protocol is evaluated by comparing it with LEACH. The radio energy dissipation model of LEACH [1] is used to evaluate the performance. The energy dissipation model is described in section 4.3.1.

5.3 Proposed SBMC Protocol

Sector Based Multi-hop Clustering is a distributed clustering protocol except the initial round for WSNs. It is used to gather data from randomly deployed sensor nodes and transmit aggregated data to the BS. It is designed to support

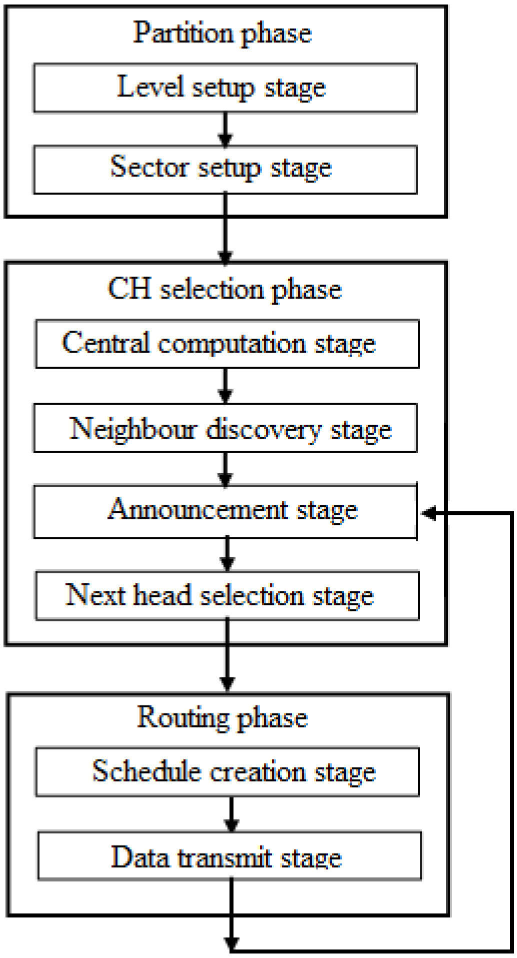


Figure 5.1: SBMC protocol operations

applications where periodic monitoring is required. A WSN is usually composed of a large number of sensor nodes in a given geographical region and the BS is located at the center of the sensor field. Partitioning the network into clusters would minimize the energy required for the data dissemination using multi-hop communication. The protocol functions are divided into three phases: *Partition phase*, *Cluster head selection phase* and *Routing phase*. The various operations in each phase are shown in Figure 5.1.

5.3.1 Partition Phase

During this phase, BS wisely organizes the network into unequal clusters by dividing the sensor field into circular tracks called levels and triangular sectors. The BS calculates the optimal number of clusters and creates the required number of levels and sectors. The cluster is an area under curved strip formed by the intersection of circular tracks and a triangular sector. The clusters nearer to the BS have smaller size than those farthest from the BS. The CHs near the BS have more data traffic from the lower layers and is able to handle the data for long time. This phase is not repetitive and carried out just at the beginning of the protocol operation. Partition phase consists of two stages: *level* and *sector setup stage*.

5.3.1.1 Level setup stage

During this stage, the BS divides the network into concentric circular tracks by transmitting signals at different power levels. The number of levels to be formed is determined initially by the BS. This depends on parameters such as number of sensor nodes, the node distribution and position of the BS. When the protocol operation begins, the BS broadcasts a *Level_ID_Packet_1 (LIP_1)* into the network to create first level with minimum power. All the nodes which receive this packet set their level to 1. Next the BS increases its signal power to create the second level and broadcast an *LIP_2* packet into the network. This time nodes that have not set their level ID previously will set their level to 2, and the nodes that have already set their level will simply ignore the packet. This process continues till the BS sends packets corresponding to all the levels. The level nearest to the BS is top level and the one farthest from it is lower level.

5.3.1.2 Sector setup stage

After completion of circular track setup, the BS divides the network into triangular sectors using directional antenna in clockwise or anti clock wise direction. The BS broadcasts a *Sector_ID_Packet_1 (SIP_1)* into the network for sector 1 in a particular direction. All the nodes who receive this packet set their sector ID to 1. Next, the BS moves its antenna direction by sector angle (θ).

The sector angle depends on the number of clusters and number of levels. The BS broadcasts *SIP_2* packet into the network. The nodes which have not set their sector ID previously will set the sector ID as 2. The nodes which already set their sector ID will simply discard this packet. This process of sectoring continues till the BS sends packets corresponding to desired number of sectors.

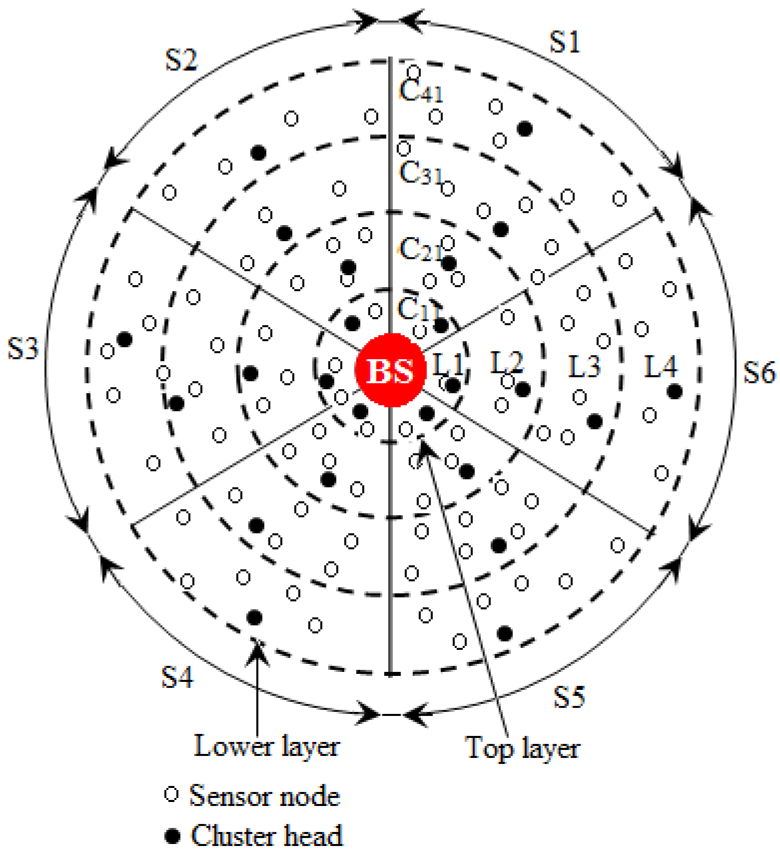


Figure 5.2: Clustered network of SBMC

At the end of the partition phase, the sensor network is organized into circular tracks and sectors creating the required number of clusters. The clustered network of the proposed protocol is given in Figure 5.2. The network consists of four circular tracks, the first track level ID is $L1$, $L2$ is the second level ID and so on (i.e. $L1$ through $L4$). Similarly, $S1$ is the ID of first sector, $S2$ is the second sector ID and so on (i.e. $S1$ through $S6$). The area's covered by the intersection of circular track and sector are considered as clusters. Each cluster in the network is identified by level ID and sector ID (i.e $C_{i,j}$). In $C_{i,j}$, i is the level ID and j is the sector ID. For example, the cluster ID $C_{3,2}$ is the ID of the cluster that belongs to third circular track and second sector.

5.3.2 Cluster head selection phase

CH is responsible for gathering all the sensed data from the member nodes, aggregating data and transmitting the aggregated data to the BS. The protocol employs centralized CH selection for the first round and distributed CH selection for the rest of the rounds. This phase consists of: *Central computation stage*, *Neighbor discovery stage*, *Announcement stage* and *Next head selection stage*.

5.3.2.1 Central computation stage

During this stage, the BS collects the information from the sensor nodes. Based on the information received, the BS computes the center of each cluster, selects the CH for the first round and broadcasts this information into the network.

The BS broadcasts a *REQ* packet into the network requesting the all nodes to send information. The information includes level ID, sector ID, node ID, energy level and location of sensor nodes. Upon receiving *REQ* message, all the nodes in the network send their information to the BS. Based on the level, sector and location information, the BS creates the distance table separately for each cluster. The distance table has distance entries, i.e. the distance between the nodes and cluster center. In addition, the BS also selects the CH for the initial round by taking energy, number of neighbor's and closeness to the center of the cluster into account. Next the BS broadcast *CH_TAB_CENT* message sector by sector into the network. The *CH_TAB_CENT* has CH IDs for the first round, distance table with nodes coordinates and the x-y coordinate of the center of all clusters in that sector.

5.3.2.2 Neighbor discovery stage

During this stage, each node in the cluster extracts their cluster center and initial CH ID. If the node is not a CH, it will wait for a CH announcement. The node creates and maintains a neighbor table by extracting the information in the distance table. When any of the nodes energy falls below some threshold value, the node tells its neighbor to update their neighbor table by sending *UP_TABLE* message. All the neighbors of this node update the neighbor table by deleting that node.

5.3.2.3 Announcement stage

In this stage, the nodes selected as CH by the BS broadcast a *CH_ADV* message to the member nodes of the cluster. The *CH_ADV* message has the node ID and its location information. On hearing this, node clustering is initiated by the farthest node in the cluster. The farthest nodes send *JOIN_CH* message to the immediate neighbors in the direction of CH. The *JOIN_CH* message has nodes ID and residual energy. These immediate neighbors add their ID and residual energy level to the received *JOIN_CH* message and forward to the next neighbor's. This process continues till CH receives messages from all the member nodes of the cluster.

5.3.2.4 Next head selection stage

The main aim of the protocol is to maximize the network lifetime by reducing the number of transmissions. This is achieved by the selection of CHs for the next round by the current round CHs. This do not require any negotiation among sensor nodes to elect the new CHs.

In this stage, next head (CH_{NEXT}) is selected by the current CHs, after receiving the *JOIN_CH* message from all the member nodes. The next heads are selected based on the residual energy, location and number of neighbor's.

If more than one node is eligible to become CH_{NEXT}, the node close to the center of the cluster is selected as next head. These next heads take the role of CH for re-clustering of nodes when the new round begins.

5.3.3 Routing phase

During this phase, the CHs creates and distributes the TDMA time slots to all the member nodes to avoid the collision of data from the member nodes. The CH node aggregates data from its member nodes and forward it to the BS. This phase consists of *Schedule creation stage* and *Data transmit stage*.

5.3.3.1 Schedule creation stage

After the completion of node clustering, the CHs know about the member nodes of the cluster. Based on the number of nodes, the CH assigns a unique TDMA time slot to each node in the cluster telling when it can transmit the data. The TDMA technique is used to avoid collision of data from nodes. Once the schedule is created, the CH node broadcasts *TDMA_CHNEXT* message to the member nodes. The *TDMA_CHNEXT* message contains the nodes TDMA time slot and next head ID. After knowing their time slots, member nodes of the cluster turn off their transmitter and can enter into sleep mode till their turn comes. This further minimizes the energy consumption and significantly contributes towards extending the network lifetime.

5.3.3.2 Data transmit stage

After the TDMA schedule is fixed, the data collection begins. The data forwarding is initiated by the nodes far away from the CH. The farthest nodes send their data to the immediate neighbor's and these neighbor's add their data to the received one. This data is forwarded to the next neighbor's in the direction of CH. This process continues till the data from all the member nodes reaches CH. The CH nodes aggregate the received data and rout it to the BS using multi-hop communication through the CHs of the next higher levels. The data transmission is initiated by CHs in the lower level. When CHs in level L_i receive data from the heads in level L_{i+1}, the CHs add their data to the received message if it is from the lower level of the same sector, otherwise the data packet is discarded. This process continues till the data from the CHs of all the levels reaches the BS.

This is the routing phase operation of SBMC protocol. In this protocol the CH nodes must keep their radio on to receive data from all member nodes of the cluster. If these CH nodes are continued as heads for several rounds, the head nodes quickly deplete their energy and die faster. In order to distribute the energy load uniformly among the nodes in the network, the protocol rotates the role of CHs after every round. After a certain time, which is determined a priori, re-clustering of nodes in the network begins. The next head (CH_{NEXT}) in the network becomes CH for this new round. The node re-clustering is initiated by announcing the *CH_ADV* message into the network by the current round CH as described in the section 5.3.2.3.

5.4 Results and Discussions

The prototype of a proposed protocol is built through simulation, which helps in the performance evaluation. The simulation helps research community to check functioning of a protocol in different scenarios, configurations and topologies. The simulation becomes a feasible approach for analysis of the sensor networks.

The performance of the proposed protocol has been evaluated by considering similar parameters and radio model considered in LEACH. The simulation parameters are summarized in Table 5.1 and the simulations were carried out using MATLAB. The sensor nodes lose communication ability when their en-

Table 5.1: Simulation parameters for SBMC protocol

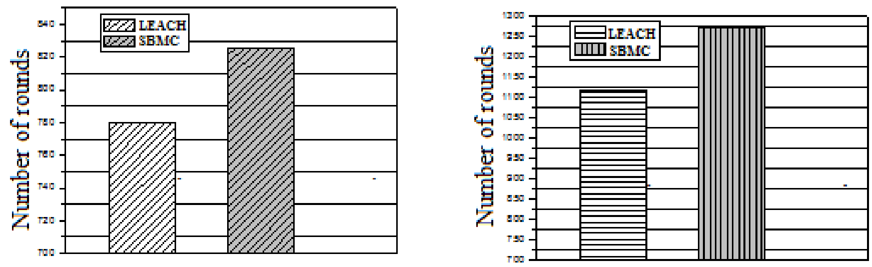
Parameter	Symbol	Value
Simulation area	Circular area of radius 50 meters	
Total number of nodes	N	200
Base station position	(x,y)	(0, 0)
Packet size	P	500 bytes
Number of tracks	T	4
Number of sectors	S	6
Transmit/Receive electronic	E_{elec}	50nJ/bit
Amplifier constant	ϵ_{fs}	10pJ/bit/m^2
	ϵ_{mp}	0.00013/pJ/bit/m^2
Initial Energy	E_0	2J
Energy for Data aggregation	E_{DA}	5nJ

ergy is depleted and are considered as "dead". The data transmissions from sensor nodes were simulated till the death of last node in the network.

Lifetime is an important criterion for evaluation of performance of sensor networks. In the proposed SBMC protocol lifetime is measured using three metrics: number of nodes alive over simulation rounds, FND and LND. The performance of the proposed protocol has been compared with popular centralized LEACH clustering algorithm.

Figure 5.3 shows the network lifetime using the metrics FND and LND. It is observed from Figure 5.3(a) that the FND in LEACH is reported earlier than the proposed SBMC protocol i.e, after 780 rounds, whereas in SBMC it is reported after 826 rounds. The results in Figure 5.3(b) show that LND dies after 1270 rounds, but in LEACH it is reported earlier i.e. after 1115 rounds. Hence the proposed protocol has higher network longevity than the LEACH.

Figure 5.4 shows the number of sensor nodes that are alive after each round. It is observed from the result that the death rate of nodes is higher in



(a) First node dies (b) Last node dies

Figure 5.3: Network lifetime in terms of FND and LND

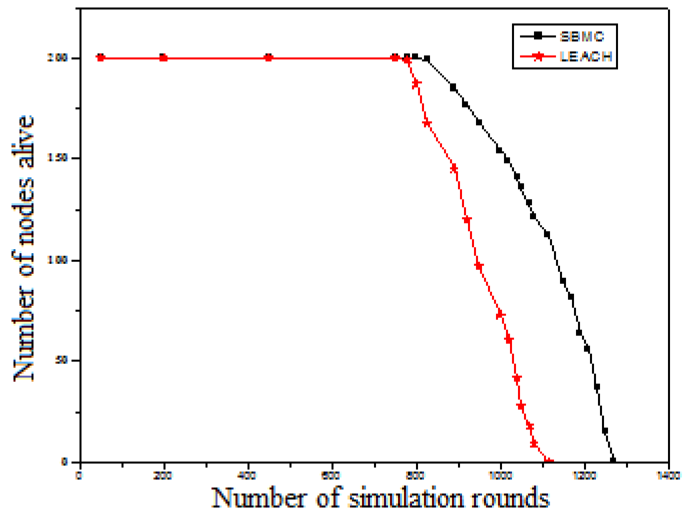


Figure 5.4: Network lifetime

LEACH than SBMC. LEACH uses direct communication to reach BS, which is more expensive for farthest CHs. This results in uneven distribution of energy load and nodes die quicker in LEACH. The proposed protocol uses multi-hop communication, this makes uniform consumption of energy among CHs results in even distribution of energy load. The CHs consume less energy in SBMC and delays the death rate. Due to slower death rate, the proposed SBMC protocol outperforms LEACH and prolongs the network life time by 13%.

5.5 Conclusion

The proposed protocol divides the sensor network into several clusters using the concept of leveling and sectoring. In the proposed protocol, CHs are evenly distributed over the entire network and there is only one CH for each cluster. LEACH uses direct communication to transmit data to the BS, which is more energy expensive. The proposed SBMC uses multi-hop communication for data transmission, which minimizes the energy consumption among the sensor nodes.

In LEACH, CH distribution is not uniform and results in larger variance in energy consumption by the CHs. On the other hand, in SBMC, the CHs are distributed uniformly in all sectors. As a result, energy consumption is balanced among sensor nodes.

The cluster area near to BS in the proposed SBMC protocol is smaller and has lesser member nodes. The farthest clusters have larger area and obviously have more member nodes. So, CHs near to the BS expends less energy for intra-cluster communication and more energy to forward data to from far away CHs. But, farthest CHs spent more energy for intra-cluster communication and less energy for inter-cluster communication. This way the proposed protocol almost uniformly distributes the energy load among all the CHs in the network and thus minimizes the hot-spot problem. It is observed that the proposed protocol maximizes the network lifetime compared to LEACH due to following facts:

- CHs uses multi-hop communication to reach BS in the proposed protocol, but LEACH uses direct single-hop communication.

- SBMC takes care of uniform distribution of CHs in the network, whereas in LEACH more number of CHs may concentrate in one region during some rounds.

- SBMC reduces communication overhead by next head concepts, which do not require any further communication among nodes.
- The energy consumption in member nodes of the proposed protocol is less compared to LEACH, since nodes forward data to the CHs via neighboring nodes.