Chapter 4

Energy Balanced Fixed Clustering protocol for WSNs

4.1 Introduction

The primary goal in the design of routing protocol for WSN is to maximize network lifetime by minimizing energy consumption in the sensor nodes, since sensor nodes have limited power, memory and computation. In general, sensor nodes are battery powered and they are randomly deployed to operate in inaccessible terrains. In such applications it is not possible to recharge or replace the batteries. In the literature, several energy-efficient routing protocols for WSNs have been proposed. All aim at extending the network lifetime by reducing the communication overhead. Clustering the sensor nodes have proven to be an effective and energy efficient way to extend the lifetime of WSNs. One of the major challenging issues of a clustering protocol is selecting an optimal group of sensor nodes as CH to partition the network. In this chapter, an Energy Balanced Fixed Clustering (EBFC) protocol is proposed and evaluated. The protocol creates a fixed number of clusters and maintains them till the end of network lifetime. An energy load has been distributed evenly among the CH nodes by periodically rotating the role of CHs. In EBFC protocol, CHs and next-heads (CH_{NXT}) have been selected, based on the residual energy and location of the nodes in the network. The CH_{NXT} are the CH for the next round selected by the current round CHs in advance. This helps in reducing the communication overhead incurred due to negotiation during the selection of CH for the next round.

4.2 LEACH protocol

LEACH [1] is a TDMA-based MAC protocol which is integrated with clustering and a simple routing for WSNs with homogeneous nodes. LEACH is self-organizing, adaptive clustering protocol proposed for periodical data gathering applications. LEACH randomly selects a few sensor nodes as CHs and rotates this role to distribute the energy load among the sensors in the network. The CH node receives the data from all the member nodes, compresses the received data and transmits an aggregated data packet to the BS. This reduces the communication overhead by limiting the amount of information that must be transmitted to the BS. LEACH is a hierarchical routing protocol, which includes distributed cluster formation, and the operations of LEACH are divided into rounds: *set-up phase* and *steady-state phase.*

4.2.1 Set-up phase

In the set-up phase, the clusters are created and CHs are selected for each cluster. The CH is selected based on a certain probability. During this phase, a predetermined number of nodes, p, elected themselves as CHs. Each node generates a random number, r, between 0 to 1. The nodes become a CH for the current round, if this random number is less than a threshold value, $T(n)$. The threshold value is computed using the equation 3.1, by considering the desired percentage of nodes to become a CH, the current round and the set of nodes, G, that have not been selected as a CH in the last $(1/P)$ rounds.

All the selected CH nodes create a cluster by inviting the nodes by means of sending an advertisement message. After receiving the advertisement message, each node decides whether to join a cluster or not based on the signal strength of the advertisement message. Finally, all the CH nodes create a TDMA schedule based on the number of member nodes in the cluster telling when they can transmit data.

4.2.2 Steady-state phase

During this phase, the sensor nodes collect the data from the surrounding environment and transmit them to the CHs during their TDMA time slots. These time slots are broadcasted to all the member nodes of the cluster by CH during the beginning of the steady-state phase. The CH node, after receiving all the data, aggregates it before sending it to the BS. Each CH transmits this data directly to the BS. After a certain time, which is determined a priori, the network goes back into the setup phase again and enters another round of selecting new CHs. Each CH communicates using different CDMA (code division multiple access) codes to reduce interference from nodes belonging to other clusters.

LEACH is able to increase the network lifetime, but has some drawbacks linked to the assumptions used:

- LEACH uses a single-hop communication to transmit to BS, i.e. CHs directly send data to BS. It is not realistic to use single-hop communication in WSNs applications where the nodes are deployed in large regions.

- LEACH can not ensure real load balancing in case of sensor nodes with different amounts of initial energy. Since CHs are elected based on probabilities without energy considerations, there may be possibility of electing the lower energy nodes as CHs for same number of rounds as other sensor nodes with higher initial energy. This leads to the quick failure of nodes.

- LEACH uses the probabilistic method to elect the CHs. It is possible that the elected CHs may be concentrated in one part of the network and some nodes that do not have any CHs in their vicinity.
- The idea of dynamic clustering increases communication overhead to form the clusters, which is more expensive in terms of energy expenditure.

Due to these drawbacks, we have considered the LEACH protocol to evaluate the performance of the proposed protocol.

4.3 Proposed network model

In the proposed protocol, the sensor nodes periodically turn on their sensors and transmitters, sense the surrounding environment and transmit the data to the CH. The CHs perform data aggregation and send it to the BS using multi-hop communication via intermediate CHs. The network consists of N sensor nodes, randomly deployed in the two-dimensional space of $M \times M$ area. The network is portioned into clusters and some high energy nodes are selected as CHs, responsible for delivering the data to the BS. The WSN architecture for the proposed protocol is shown in Figure 4.1. Each cluster has a CH, a next head and a number of member nodes. All the member nodes transmit their data to the corresponding CH, then the CH performs data aggregation and finally transmits to the BS. Since data transmission to the BS is more expensive in terms of energy, the role of CHs is rotated to balance energy consumption among CH nodes and extend the network lifetime. The following are the assumptions considered for the proposed protocol.

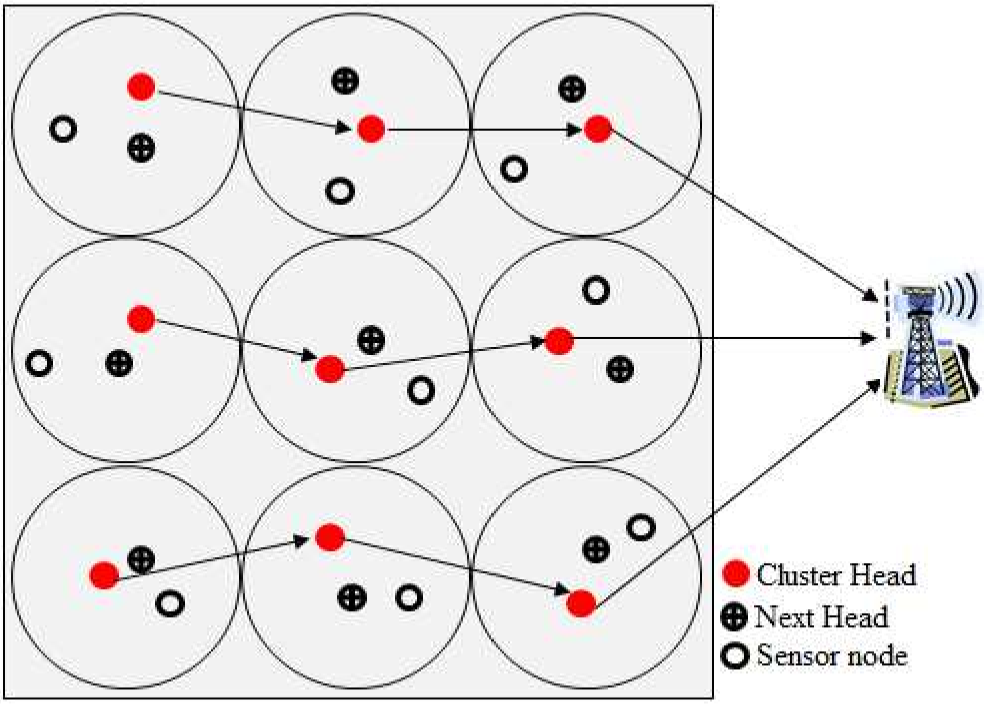


Figure 4.1: Proposed Network Architecture

a. The sensor nodes are homogeneous and they are uniformly distributed in a square field.

b. Both nodes and BS are static after deployment.

c. The BS is located outside the sensor fields.

d. All sensor nodes have the ability to reach BS directly.

e. Nodes are location-aware, which can be determined using GPS or localization techniques.

f. All sensor nodes are assigned a unique identifier (ID).

4.3.1 Radio Energy Dissipation model

The radio hardware energy dissipation model given in [1] is assumed for the proposed protocol shown in Figure 4.2. In this model, the transmitter has power control abilities to dissipate minimal energy to send data to the receiver.

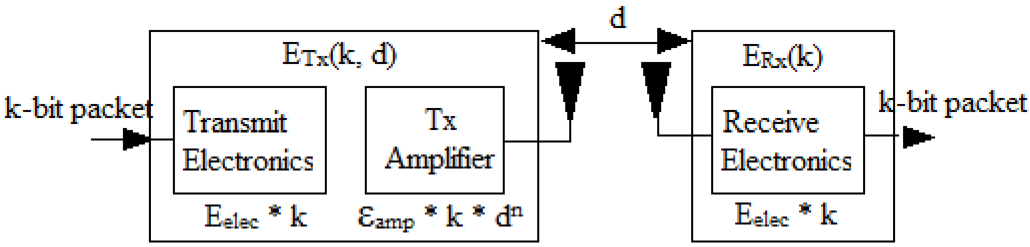


Figure 4.2: Radio Energy dissipation model [1]

Transmitter dissipates the energy to run transmit electronics ($E_{Tx-elec}$) and power amplifier (E_{Tx-amp}). The energy required to transmit a $k-bit$ message to a distance d is given by:

$$E_{Tx}(k,d) = E_{Tx-elec}(k) + E_{Tx-amp}(k,d) \tag{4.1}$$

The transmitter power loss is controlled by appropriately setting the power amplifier based on the distance between the transmitter and receiver. If the distance is less than a threshold d_0, the free space (fs) model is used, otherwise the multi-path (mp) model. The radio energy model for free space (d^2 power loss) and multi-path fading (d^4 power loss) channel is given below:

$$E_{Tx}(k,d) = \begin{cases} kE_{elec} + k\epsilon_{fs}d^2, & d < d_0 \\ kE_{elec} + k\epsilon_{mp}d^4, & d \geq d_0 \end{cases} \tag{4.2}$$

The energy expended by the receiver to run radio electronics to receive this message is given by:

$$E_{Rx}(k) = E_{Rx-elec}(k) = kE_{elec} \tag{4.3}$$

$$d_0 = \sqrt{\frac{\epsilon_{fs}}{\epsilon_{mp}}} \tag{4.4}$$

The electronics energy (E_{elec}), depends on factors such as the digital coding, modulation technique, filtering type, spreading of the signal. The amplifier energy, $\epsilon_{fs}d^2$ or $\epsilon_{mp}d^4$, depends on the distance to the receiver and the acceptable BER (bit error rate). The d_0 is the threshold transmission distance for the amplification circuit.

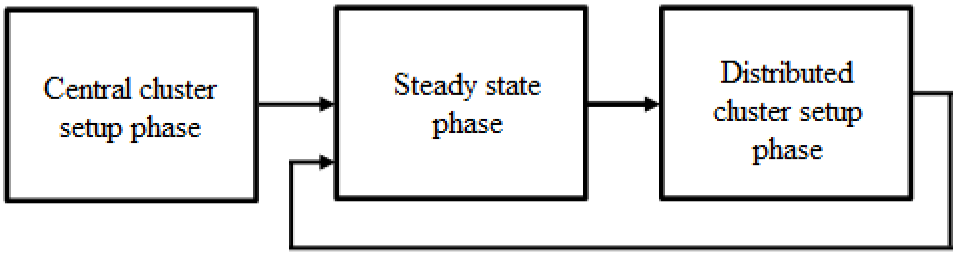


Figure 4.3: EBFC protocol operation

4.4 EBFC Protocol Operation

EBFC is designed for application, where periodic monitoring of WSNs is required. It is used to collect data from randomly deployed sensor nodes and transmit data to a BS located outside the sensor field. EBFC is a clustering protocol, which divides the network into a fixed number of clusters and the same is maintained throughout the lifetime of the network.

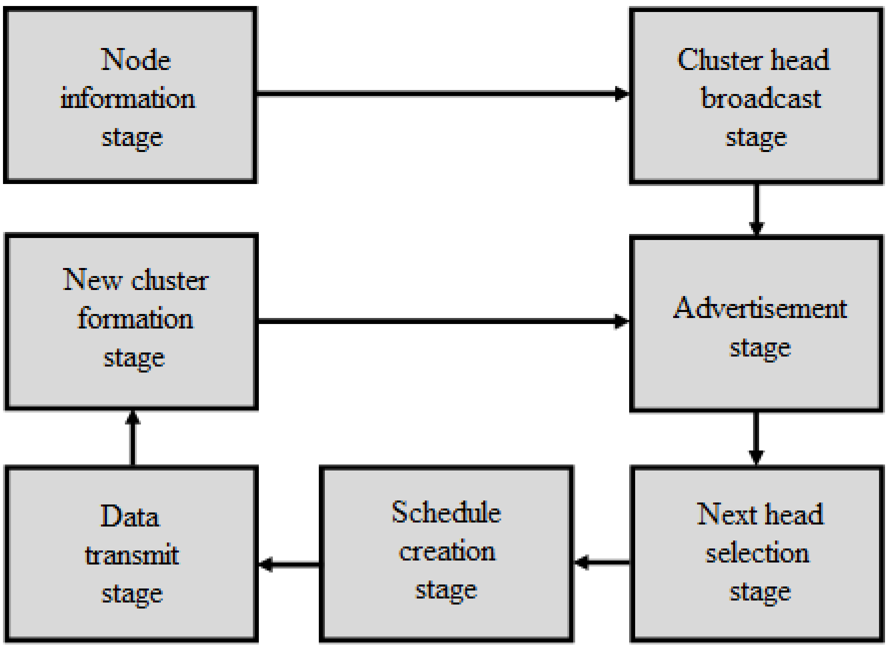


Figure 4.4: EBFC protocol activities

The protocol operation begins with central control mode at BS and proceeds in distributed control mode. The EBFC operates in three phases: *central cluster setup phase*, *steady-state phase*, and *distributed cluster setup phase* shown in Figure 4.3. The central cluster setup phase is executed only once, i.e. at the beginning of the protocol operation; steady state phase and distributed cluster setup phase are executed alternatively in the subsequent rounds. Figure 4.4 describes the various activities of the EBFC protocol.

4.4.1 Central cluster setup phase

During this phase, the BS divides the network into a number of clusters, these clusters are fixed and select CHs based on the energy status and location information received from sensor nodes. The central cluster setup phase consists of three stages: *Node information stage*, *CH broadcast stage*, and *Advertisement stage*.

4.4.1.1 Node information stage

In this stage, BS collects the information from all the nodes in the network. The BS broadcasts an *REQ* message requesting each node to send its location, ID and initial energy. The sensor nodes get their current location either by using GPS receiver or localization techniques. In response to the request from the BS, all the nodes in the network send the *INFO* message, which includes node location, ID, and energy level to the BS.

4.4.1.2 CH broadcast stage

After receiving information from nodes, the BS creates a number of clusters determined priori and fixes the center of each cluster. The BS selects the energy abundant nodes as a CH for each cluster. If more than one node is eligible to become a CH, the node which is nearest to the center of the cluster is selected as CH. Once the clusters and CHs have been determined, the BS broadcasts *CH_ID* message into the network. This message has the IDs of the first round CHs and center of each clusters.

4.4.1.3 Advertisement stage

During this stage, each node extracts the CH ID from the *CH_ID* message. If the node ID matches with received CH ID, the node becomes a CH, otherwise the node waits for the CH advertisement message. The CH node broadcasts (*CH_ADV*) message into the network. The non-CH node decides whether it would like to join the cluster or not, based on the received signal strength of the advertisement signal. All the non-CH nodes join the cluster by sending *JOIN_CH* message signal to the nearest CH. The *JOIN_CH* message contains the member node ID, location information and current energy level.

4.4.2 Steady-state phase

In this phase, CHs select the next head and distribute the TDMA schedule, which specifies the time slots allocated for each member of the clusters. Upon gathering data from all the member nodes, the CH transmits fused data to the BS. The steady-state phase is broken into the following stages: *Next head selection stage*, *Schedule creation stage*, and *Data transmit stage*.

4.4.2.1 Next head selection stage

During this stage, each CH selects next head based on the energy level and location information. The node with higher residual energy is selected as the next head of that cluster. After every round, the nodes need not make any fresh negotiation among them to elect new CHs. This results in reduced energy consumption, thereby maximizing the lifetime. The next head takes the role of the CH in the next round thereby reducing communication overhead.

4.4.2.2 Schedule creation stage

In this stage, the CH sets up a TDMA schedule to avoid collisions among data messages. Based on the number of nodes in the cluster, the CH node creates a TDMA schedule telling each node when it can transmit. The TDMA time is divided into a set of slots, the number of slots being equal to the number of nodes in the cluster. Each node is allocated a unique time slot during which it can transmit its data to the CH. Once the TDMA time slot is defined, the CH sends the *TDMA_NXTCH* message to member nodes of the cluster. The message has the TDMA time slot and its next head node ID.

4.4.2.3 Data transmit stage

During this stage, the CH node gathers the information, performs data aggregation and sends the aggregated data to the BS. To minimize energy dissipation, each member node uses power control to set the amount of transmit power based on the received signal strength of the *CH_ADV* message. Furthermore, the transceiver of each member node is turned off until its allocated TDMA time slot.

The CH node must keep its receiver on to receive all the data from the member nodes in the cluster. After receiving all the data, it performs data aggregation by eliminating any redundant data. The resulting data is transmitted to the BS. This stage consumes more energy, as the BS is far away and the data messages are large.

4.4.3 Distributed cluster setup phase

The CHs are responsible for collecting data from member nodes within the cluster, aggregating data and transmitting the aggregated data to the BS. All the CH nodes expends more energy compared member nodes of the cluster. In order to distribute the energy load uniformly among the sensor nodes, the role of the CH rotated periodically. Otherwise, the CH node would quickly deplete its limited energy and die. In the proposed protocol, after certain time interval, which is determined priori, network re-clustering takes place to reduce the energy load among the CH nodes. After the first round, new clusters are formed in distributed mode. The activities in this phase are broken into two stages: *New cluster formation stage*, and *Advertisement stage*.

4.4.3.1 New cluster formation stage

In this stage, next heads which were selected in the previous round become new CHs and CHs of previous become member nodes. The network is re-clustered by new CHs. The idea of selecting the next heads in advance is to minimize the energy consumption by eliminating the negotiation among the sensor nodes. The new CH broadcasts an advertisement message into the network for re-clustering. The advertisement stage explained in section 4.4.1.3 of central cluster setup phase continues. When the advertisement stage is completed, the steady-state phase can begin.

4.5 Results and Discussions

The proposed protocol simulated by deploying 100 nodes in a 100 m X 100 m network area. The sensor nodes are randomly deployed in a sensing field as shown in Figure 4.5. The BS is placed outside the sensor field, and located at (50, 175). The data packet size was fixed at 500 bytes, and packet header

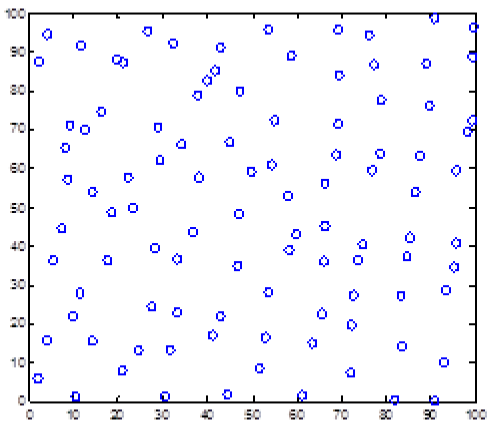


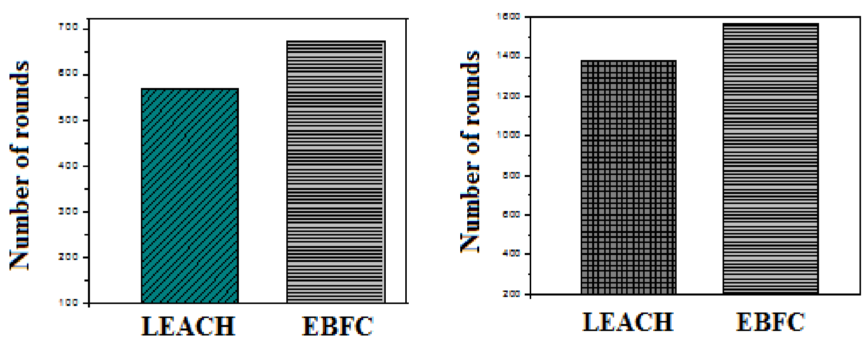
Figure 4.5: Node deployment in EBFC

Table 4.1: Simulation parameters for EBFC protocol

Parameter	**Symbol**	**Value**
Simulation area	M x M	100m x 100m
Total number of nodes	N	100
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

size was set to 25 bytes. The initial energy of the nodes was 2 joule. The parameters used in the simulation are listed in Table 4.1.

The proposed EBFC protocol is simulated using MATLAB. The performance of the protocol is evaluated with the original LEACH algorithm. The results show that the EBFC protocol performs better in terms of power efficiency by improving the lifetime of WSN.



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

Figure 4.6: Network lifetime in terms of FND and LND

The performance of the protocol is evaluated using the metrics: First node dies (FND), Last node dies (LND) and number of nodes alive over simulation rounds. FND refers to the time from the deployment of the network to the death of the first node, whereas LND refers to the time when all the nodes are dead in the network. In Figure 4.6, the first node and last node dead in LEACH is reported earlier than EBFC. Since the sensor nodes in LEACH need to make fresh negotiation to create the cluster after every round, this increases the communication overhead and leads to faster depletion of energy in the nodes. But the proposed protocol uses the idea of selecting the CHs for next round by the present round CHs. This do not require additional communication among sensor nodes to elect new CHs, but the network switches directly to the next heads. This technique considerably reduces energy consumption in the proposed protocol and delays the node death rate compared to LEACH.

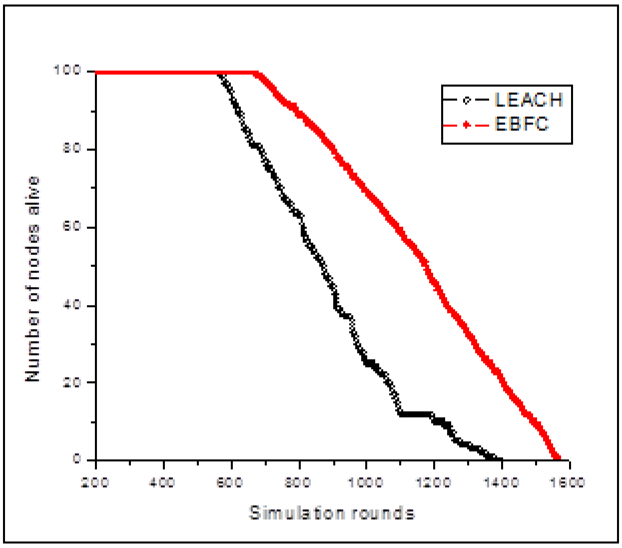
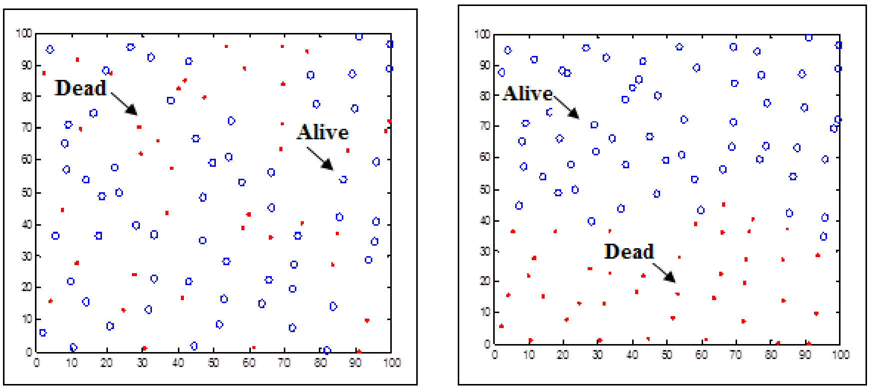


Figure 4.7: Network lifetime

The energy efficiency of the two protocols is examined by considering the network lifetime shown in Figure 4.7. In EBFC protocol the sensor nodes can switch directly to next heads without communicating with the BS. Thus, it reduces a large amount of communication overheads and saves a considerable amount of energy. From the result, it is clearly shown that the death rate in EBFC is less than in LEACH. It is observed that the proposed protocol offers a better life span for each node and even the entire network than LEACH.

EBFC clearly improves the network lifetime (i.e. time until the first node dies and the time until 40% nodes die) over LEACH. EBFC adopted the



(a) EBFC (b) LEACH

Figure 4.8: Distribution of dead nodes

fixed clustering mechanism and inter-cluster multi-hop routing schemes, which effectively balance the energy consumption for data transmission between the clusters close to the BS and the clusters far away from the BS. As given in Figure 4.8, the distribution of dead nodes (represented by small dots) of two protocols is quite different. In LEACH, the dead nodes are concentrated in the region far away from the BS; while the dead nodes of the proposed protocol are concentrated little more in the region closer to the BS. Because the CHs near to the BS consume more energy to forward data from farther away CHs to the BS creating hot spot in the network.

4.6 Conclusion

In the proposed protocol the network is divided into fixed number of clusters. The selections of CHs and next heads in advance are weighted by the remaining energy of sensor nodes and the center of the cluster. Simulation results indicate that the proposed protocol effectively balances the energy consumption of the entire network, slow down the death rate of the sensor nodes and hence prolong the network lifetime efficiently. The next head eliminates the negotiation required to form node re-clustering. It is observed that first and last node dies quickly in LEACH shortening the lifetime. Because, in LEACH protocol the node re-clustering after every round is carried out by making fresh negotiation among the sensor nodes. This consumes a node energy. The next head selection concept increases energy conservation in EBFC, which decreases the death rate of sensor nodes, resulting in longer lifetime of the network. In LEACH, CH node directly communicates with the BS, whereas in proposed protocol the CHs communicate with the BS using multi-hop communication. Direct communication consumes more energy and the nodes far away from BS dies quickly in LEACH.

The energy efficiency of the proposed EBFC protocol better, still hot spot problem need to be addressed. The protocol creates the clusters of equal size irrespective of the distance from the BS. The protocol assumes that sensor nodes are deployed uniformly over the sensor field. Therefore, each cluster has almost equal number of nodes. However, the CHs near to the BS are responsible for forwarding data packets from the far away CHs in addition to intra cluster data. So, these CH nodes expend more energy than the far away CHs and dies quickly creating hot spot problem.

The hot spot problem can be eliminated by reducing the energy consumption in the nearest CH. This is possible by distributing the energy load equally among all the CHs in the network. This can be achieved by creating the clusters of unequal size. The clusters near to the BS are small in size compared to the far away clusters and contains fewer number of nodes. This results in almost uniform distribution of energy load among CHs and minimizes the hot spot problem.