Chapter 6

Energy Efficient Unequal Clustering Protocol

6.1 Introduction

The advances in the MEMS technology made the revolutionary jump in information processing. This enables the development of embedded low cost, low power and small micro-computer with appropriate sensors attached called sensor nodes. The collection of such self-organized sensor nodes forms a WSNs. These are capable of performing sensing, processing and communicating tasks. In reality, WSNs become more popular due to low cost solutions to a wide variety of real-world applications. The reliability of a WSN is restricted, because the sensor nodes have limited power, computation and storage space. Sensor nodes are widely used in disaster management applications such as flood relief, battle field, and forest fire detection. Due to limited and non-rechargeable battery options, the energy resource of the node should be managed wisely. The energy efficiency is the primary design issue, which greatly affect the sensor node lifetime.

The CH nodes must keep their transmitter on all the time to receive data from their member nodes (MNs) [92]. After gathering data, it aggregates the data and transmit it to BS which may be far away. CHs are responsible for many activities, so the energy consumption of CHs is much larger than that of the MNs. If the nodes are left as CHs for longer duration, they deplete their energy quickly and die faster. In order to distribute the energy load evenly among nodes, most of the cluster based routing protocols rotates the role of CH periodically in the network.

In cluster based routing, CH transmits their data to BS directly i.e. single hop or using several hops. In single hop routing, CHs transmit their data to the BS directly which is far away. The CHs farther away from the BS depletes more energy due to longer distances than the CHs near to the BS. In multi-hop networks, the data is routed to the BS via intermediate CHs. This almost balances the energy consumption among the CHs. But the CHs near to the BS have to forward more data packets, which are from the far away CHs. Due to this CHs near to the BS lose more energy in addition to energy expenses involved in intra-cluster task. This imbalance in energy consumption makes the node die prematurely causing the hot spot problems [93]. This hot spot problem can be effectively dealt by unequal clustering algorithms.

The cluster based routing protocol LEACH [1] proposed for the WSNs applications to gather the data periodically. The protocol uses probabilistic approach to elect node as a CH and transmits aggregated data to the BS by single-hop communication. The role of the CH is periodically rotated among nodes to balance the energy consumption. The LEACH protocol is simple and do not require a large communication overhead. However, LEACH do not perform well for heterogeneous networks, since it elects CHs without considering the residual energy of nodes. To overcome these problems, researchers proposed some new protocols like centralized algorithm LEACH-C [1], multi-level clustering algorithm EEMLC [94], an algorithm for heterogeneous networks [85] and multi-hop communication based algorithm LEACH-

M [95]. HEED [78] defines the transmission power to be used for intra-cluster broadcast using the cluster radius. The residual energy of each node defines the initial probability to become tentative CHs. The final CHs are selected based on the intra-cluster communication cost. HEED terminates within a finite number of iterations and achieves fairly distribution of CHs over the network.

The hot spot problems can be managed by unequal clustering algorithms. In order to balance energy consumption due to high inter-cluster traffic, the unequal clustering algorithm proposed based on unequal cluster size (UCS) [73]. The network is divided into different clusters of unequal size. Some high energy nodes are deployed at predetermined locations to take the role of the CH, which balances the energy consumption. In [96], an energy efficient unequal clustering (EEUC) algorithm is proposed and the nodes join the unequal sized clusters. The protocol uses probabilistic approach for the election of CHs. An unequal layered clustering approach for large scale wireless sensor network (ULCA) [97] assumes a BS at the center of the grid and creates layers. The layers closer to the BS are smaller in size giving the inner layers more residual energy for inter-cluster traffic. ULCA has a better network lifetime and the overhead for clustering the network is much lower because of the inherent local join and local broadcast mechanism.

6.2 Proposed Network and Radio energy model

The network of the proposed protocol consist of N sensor nodes randomly deployed over a large geographical area. The deployed sensor nodes periodically monitor the environment and transmit to the nearest CHs. The protocol makes some assumptions about the sensor nodes and the underlying network model:

a. The BS is located far from the sensing field.

b. Sensor nodes and BS are both stationary after deployment.

c. All sensor nodes are homogeneous with a limited stored energy and have the same capabilities.

d. The sensor nodes have the ability to control the transmission power according to the distance to the receiving node.

e. Sensors are capable of operating in an active or a low-power sleep mode.

f. Each node is assigned a unique identifier (ID).

g. The sensor nodes in the network are location-aware.

h. BS aware of positions of all the sensor nodes deployed in the network.

The proposed protocol uses the simple radio model shown in [1] for the computation of communication energy dissipation. Both the free space (d^2 power loss) and the multi-path fading (d^4 power loss) channel models are used, depending on the distance between the transmitter and receiver. The radio energy model used in this protocol is explained in detail in section 4.3.1.

6.3 Proposed unequal clustering protocol

In cluster based routing protocol, communication between member nodes and CH is single-hop, whereas multi-hop communication is used between CHs and BS. The total energy consumption in CHs is due to both intra-cluster and inter-cluster communication. In an even sized clustered network, the energy consumption in CHs is almost same for intra-cluster communication. But the energy consumption is more in CHs closer to the BS; these heads have to

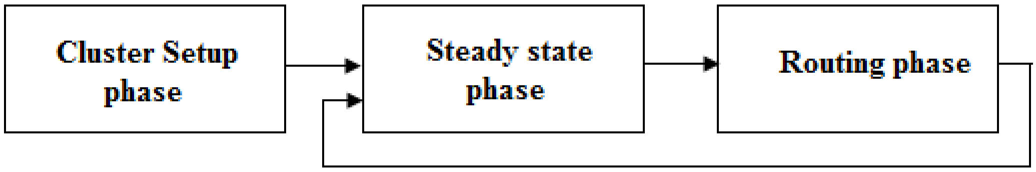


Figure 6.1: Proposed UCBR protocol operations

handle more data from the far away CHs. The CHs closer to BS die faster leads to hot spot problem due to imbalance in energy consumption.

To overcome this problem, a novel Unequal Cluster Based Routing (UCBR) protocol is proposed. The protocol partition the network into cluster of unequal size. The clusters near to the BS are small in size and those far away have larger size. The unequal clustering well balances the energy consumption among the sensor nodes in the network. The UCBR protocol operations divided into cluster setup phase, steady state phase and routing phase shown in Figure 6.1.

6.3.1 Cluster setup phase

During this phase, the BS gathers the node information such as node ID, location information and their initial energy through the *INFORMER* node randomly selected by the algorithm. Based on these information's, the BS wisely organizes the sensor field into number of unequal clusters. The BS creates a sequence table for each cluster; the table contains the sequence number for each node in the cluster. The sequence number specifies the node's order to become a CH. Finally, it is broadcasted into the network. The cluster setup phase is divided into *Information gathering* and *Partition stage*.

6.3.1.1 Information gathering stage

In this stage, BS transmits a message into the network requesting the each node to send their information. The message also contains the BS location information. The nodes in the network can compute distance to the BS and adjust the transmit power accordingly. The algorithm randomly selects few nodes as *INFORMER*. The *INFORMER* nodes gather the information from the neighboring nodes and same is transmitted to the BS. The information includes nodes location, energy level and nodes ID.

6.3.1.2 Partition stage

During this stage, the BS wisely organizes the sensor field into number of unequal clusters. The unequal cluster size approach helps to balance the energy of each CH and maximize the lifetime of the network. In unequal clustered network, the clusters closer to the BS are small in size and the member nodes are less. In order to create clusters of unequal size, BS calculate cluster radius RC_i for each cluster using the maximum cluster radius R_i [98].

$$RC_i = \left[1 - C \bullet \frac{d_{max} - d_i(c_i, BS)}{d_{max} - d_{min}}\right] R_i \qquad (6.1)$$

where d_{max} and d_{min} are the maximum and minimum distances from BS to the clusters, $d(c_i, BS)$ is the distance between the center of the cluster c_i and BS, C is a constant coefficient has the value from 0 to 1, and R_i is the maximum value of cluster radius. The cluster radius can be varied by varying the C values. If the C is increased from 0 to 1, the cluster radius is decreased and BS partition the network into desired number of unequal clusters.

After completion of the network partition, the BS creates a CH sequence table for each cluster. The CH sequence table is intended to reduce the energy consumption during clustering process by eliminating the negotiation among the nodes to select new CH after every round. The sequence table contains the node ID's, cluster ID and the CH sequence numbers. The CH sequence number tells when the node can become CH. The BS considers the nodes position and the distance between the nodes belong to the adjacent clusters while assigning CH sequence number. This ensures the uniform distribution of CHs over the network. Finally, the CH sequence table for all the clusters is broadcasted into the network. Whenever the node depletes it energy and about to die, it transmit a message to co-members of the cluster to update CH sequence table.

6.3.2 Steady state phase

During this phase, nodes in the cluster gets their CH sequence number and the cluster ID from the table and determines their turn to become a CH. If the node's CH sequence number is 1, the node become CH for the first round, if 2, it is CH for second round and so on. In general, if a cluster has n number of nodes and the node with sequence number i becomes a CH for the rounds i, $n+i$, $2n+i$ and so on. The steady state phase has the following stages: *Advertisement stage* and *Schedule creation stage*.

6.3.2.1 Advertisement stage

Node synchronization is required to ensure the start of node grouping process simultaneously throughout the network. In order to synchronize the process, the BS transmits a beacon signal into the network after each round. When all the CH nodes according to the CH sequence number receive this beacon signal, starts grouping the nodes by broadcasting a CH message into the network. After certain time, nodes determine which CH to join. The decision is based on the signal strength of the advertisement message received. The signal strength is proportional to the distance, so joining the closer CH can save energy and sends join message to the nearest CH.

6.3.2.2 Schedule creation stage

After receiving join messages from member nodes, the CHs creates TDMA schedule based on the number of member nodes. Each node has been assigned a unique time slot and the nodes are allowed to transmit during their time slot. The CH nodes transmit this TDMA schedule to their member nodes. After knowing their TDMA time slots, nodes can turn off their transceiver and can go to sleep mode till their turn. This approach further extends the battery life by reducing the energy consumption in the nodes.

6.3.3 Routing phase

The CH nodes must keep their transceiver on to receive data messages from all the member nodes during this phase. The CH node performs data gathering and aggregation on all the unprocessed data. The CH node collects data from the member nodes during their assigned time slots. The node requires minimum energy to send data to the CH, since the distance between the CH and member node is small.

After completion of data gathering, the CH node performs aggregation of all the received data. The CH nodes transmit the aggregated data to the BS using multi-hop communication. The data is transmitted in the direction of BS, since the CH nodes knows the location of neighboring CHs. The protocol uses multi-hop communication to forward data to the BS via intermediate CHs. This balances the energy consumption in the CH nodes and minimizes the hot spots in the network.

When a data from all the CH nodes reaches the BS, the protocol completes one round of operation. The role of the CH is rotated to balance the energy consumption among the nodes. This is achieved by re-grouping of sensor nodes by the new CH nodes. The BS initiates the next round of operation by transmitting node synchronization signal into the network. All the nodes, which are eligible to become CH based on the CH sequence number starts re-grouping of sensor nodes in distributed way by broadcasting an advertisement message as explained in the section 6.3.2.1 of steady state phase and the

Table 6.1: Simulation parameters for UCBR protocol

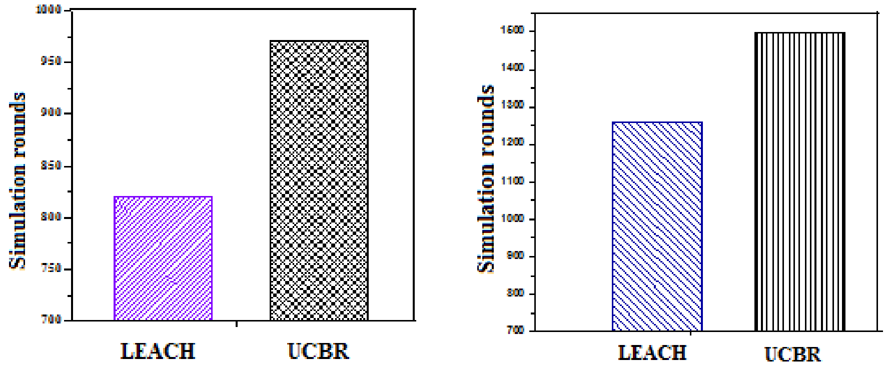
Parameter	Symbol	Value
Simulation area	M × M	100m × 100m
Total number of nodes	N	200
Base station position	(x,y)	(50, 175)
Packet size	P	500 bytes
Propagation delay	T_d	50 μ sec
Transmit/Receive electronic	E_{elec}	50nJ/bit
Amplifier constant	ϵ_{fs}	10pJ/bit/m^2
	ϵ_{mp}	0.00013pJ/bit/m^2
Initial Energy	E_0	0.5J
Energy for Data aggregation	E_{DA}	5nJ

network operation continues.

6.4 Results and Discussions

The performance of the UCBR is evaluated via simulation using NS-2. Each node's energy consumption is calculated from data transmission and aggregation per round. The energy efficiency of UCBR is compared with LEACH. The simulation parameters are given in Table 6.1, in which the parameters of radio model are the same as those in [1]. The performance is evaluated by deploying 200 nodes in 100m × 100m square region.

The CHs in LEACH uses single-hop to reach BS and consume more energy during this process. The communication overhead is more in LEACH, because the nodes make fresh negotiation to select the CH after completion of every round. The node energy depletes quickly and die faster in LEACH than UCBR. From Figure 6.2(a) it is observed that the FND reported during round 820 in LEACH, whereas in UCBR it is reported during round 965. The nodes death



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

Figure 6.2: Network lifetime in terms of FND and LND

rate is delayed in UCBR, Figure 6.2(b) show that the LND is reported during round 1496, but in LEACH it is reported during round 1267.

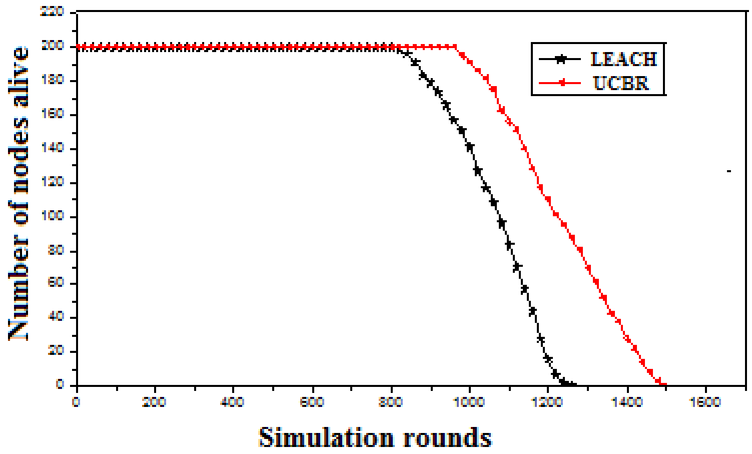


Figure 6.3: Network lifetime

Lifetime is the important criterion for evaluating the performance of WSN and is plotted in Figure 6.3. The lifetime is evaluated by considering the number of nodes alive over a simulation rounds. From the Figure 6.3, UCBR clearly improves the network lifetime over LEACH both the time until the first node dies and the time until the last node dies. From the result, it is observed that the node death rate is slower in proposed protocol. Since the protocol uses the unequal clusters to balance the energy consumption among the sensor nodes. The hot spot problem is effectively dealt by balancing energy consumption in nodes. The clusters near the BS are small in size and have only few member nodes, whereas clusters far away from the BS are larger in size and have many member nodes. The near heads consume more energy to forward data from the far away CHs and less energy for intra-cluster communication. The heads far away from the BS consume more energy for intra-cluster communication. This approach makes the network lifetime longer in the proposed protocol.

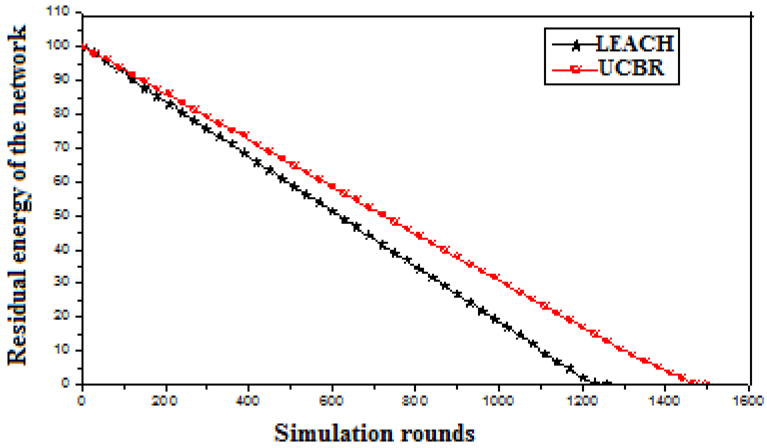


Figure 6.4: Residual energy of the network

The network total residual energy is another metric used to evaluate the performance of the protocol. It is the sum of the residual energy of all the nodes in the network over a simulation round. From Figure 6.4, it can be seen that total energy dissipation in LEACH is high compared to the proposed scheme. So, the proposed clustering algorithm performs better than LEACH and maximizes the network lifetime.

6.5 Conclusion

In this chapter, a novel energy-efficient Unequal Cluster Based Routing protocol for WSNs is presented. The equal size clustering with multi-hop routing approach creates hot spot problems. This is due to large energy consumption in CHs near to the BS due to high data loads from inter CHs in addition to the intra-cluster energy cost. The rotation of the CHs not not only sufficient to balance the energy consumption across the network. The hot spot problem is well addressed by an unequal clustering approach to distribute energy load evenly among CHs.

The UCBR protocol partition the network into clusters of unequal size, the clusters near to the BS is small in size and the farther away clusters larger in size. Obviously, the clusters near to BS have lesser number of member nodes than far away clusters. Due to this, intra-cluster energy cost smaller in the nearer clusters, but more in far away clusters. The CHs of the farther clusters expends more energy for intra-cluster communication than the CHs closer to the BS due to large number of member nodes. The clusters near to BS have less number of nodes and can preserve some energy for the purpose of inter-cluster data forwarding. Simulation results show that the proposed unequal clustering approach improves the network lifetime than LEACH.