CHAPTER – 6
MULTIHOP ENERGY EFFICIENT CLUSTERING AND DATA
AGGREGATION PROTOCOL

6.1 INTRODUCTION
Wireless sensor networks (WSNs) have emerged as an important new class of computation that embeds computing in the physical world and to date; most of the work has focused on homogeneous WSNs, where all of the nodes in the network are of the same type. However the continued advances in miniaturization of processors and low-power communications have enabled the development of a wide variety of nodes. When more than one type of node is integrated into a WSN, it is called heterogeneous. While many of the existing civilian and military applications of heterogeneous wireless sensor networks (H-WSNs) do not differ substantially from their homogeneous counterparts, there are compelling reasons to incorporate heterogeneity into the network. These include:

- Improving the scalability of WSNs
- Addressing the problem of non uniform energy drainage
- Reducing energy requirements without sacrificing performance.
• Taking advantage of the multiple levels of fidelity available in different nodes
• Balancing the cost and functionality of the network
• Supporting new and higher-bandwidth applications [75]

6.2 M-ECCDA Protocol

M-ECCDA (Multihop Energy Efficient Clustering and Data Aggregation Protocol for Heterogeneous WSNs) main aim is to maintain the energy consumption of the network efficiently. It saves the energy of the system with the introduction of the multiple hop short distance communication for normal cluster heads. M-ECCDA consists of three types of sensor nodes (i.e. normal, advanced and super) which are randomly deployed in a sensing region.

Let \( m \) be the fraction of normal nodes among total nodes \( N \) nodes, and \( m_0 \) is the fraction of super nodes which are equipped with \( \beta \) times more energy. \( N \times m \times (1 - m_0) \) nodes are advanced nodes and equipped with \( \alpha \) times more energy as compared to normal nodes [47]. Let the initial energy of the normal node is \( E_0 \). Then initial energy each of the advanced and super nodes are \( E_0 \times (1 + \alpha) \) and \( E_0 \times (1 + \beta) \) where \( \alpha, \beta \) means that advanced and super nodes have \( \alpha, \beta \) times more energy than the normal nodes. Heterogeneous network total initial energy will be:

\[
E_{\text{total}} = N. (1 - m). E_0 + N. m. (1 - m_0). (1 + \alpha). E_0 + N. m. m_0. E_0. (1 + \beta)
\]

\[
= N. E_0. (1 + m. (\alpha + m_0. (\beta - \alpha))) \quad 6.1
\]
Thus due to heterogeneous nodes system has \((1 + m \cdot (\alpha + m_0 \cdot (\beta - \alpha)))\) more energy and epoch of this new system is \(\left(\frac{1}{p_{opt}}\right) \times \left(1 + m \times (\alpha + m_0 (\beta - \alpha))\right)\).

The weighed probability for the various nodes are given by equations (6.2 – 6.4) [47].

\[
p_i = \begin{cases} 
\frac{p_{opt}}{1 + m \cdot (\alpha + m_0 (\beta - \alpha))} & \text{6.2} \\
\frac{p_{opt} \cdot (1+\alpha)}{1 + m \cdot (\alpha + m_0 (\beta - \alpha))} & \text{6.3} \\
\frac{p_{opt} \cdot (1+\beta)}{1 + m \cdot (\alpha + m_0 (\beta - \alpha))} & \text{6.4}
\end{cases}
\]

Threshold for cluster head selection for normal, advanced, super nodes can be calculated by putting above values in equation 6.5.

\[
T(s_i) = \begin{cases} 
\frac{p_i}{1 - p_i \left( r \mod \frac{1}{p_i} \right)} \times \frac{E_{residual}}{E_{init}} & \text{If } s_i \in G \\
\frac{p_i}{1 - p_i \left( r \mod \frac{1}{p_i} \right)} & \text{If } s_i \in G' \\
\frac{p_i}{1 - p_i \left( r \mod \frac{1}{p_i} \right)} & \text{If } s_i \in G'' \\
0 & \text{otherwise}
\end{cases}
\]

Where \(G, G', G''\) represents set of normal, advanced and super nodes that are not selected as cluster heads within the last \(1/p_i\) rounds of the epoch, depending upon whether \(s_i\) represents a normal, advanced or super node. The cluster head

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threshold for normal nodes are further multiplied by the ratio of residual and initial energy of the normal node because they have less energy than advanced and super nodes hence they should become the cluster head only when they have sufficient remaining energy to perform this duty.

Nearly 70 percent energy of a WSN is consumed in communication and energy consumed in transmission dominates the total energy consumed for communication. The transmission power grows exponentially with the increase of transmission distance. To reduce energy consumption in a WSN multihop short distance communication is desirable. M-EEDCA introduces three-tier architecture for its normal nodes to save their energy (Figure 6.1). In a round if normal sensor node becomes cluster head, then after collecting the data from its members it aggregates the data and instead of sending the data directly to sink it will try to find an out advanced or super node such that

- Distance between the normal cluster head and advanced or super node is less than the distance between the normal cluster head and the base station.
- And which is not a cluster head in this particular round.

If the normal cluster head is able to find any such advanced or super node who fulfils the above mentioned condition i.e. not a cluster head and distance between normal cluster head and advanced or super node is less than distance, of the normal cluster head from the base station, then normal cluster head sends its data load to this advanced or super node which further sends it to the base station. If a
normal cluster head does not find any such advanced or super node that fulfils the above mentioned two conditions, then it will send the aggregated data of its members directly to the base station itself. Thus by introducing a multihop or three-tier architecture for normal cluster heads, M-ECCDA has reduced the energy consumed in transmission to prolong the network lifetime and stability period.

6.1 Three-tier Sensor Architecture for Normal Cluster head
Moreover, after the cluster-heads election in a round, non-cluster head nodes try to join a close (considering the transmission power) cluster. However in some cases it is not an optimal choice for energy saving because, if a sensor node exists in the base station direction and distance between node and base station is less than distance of node from all nearby clusters (Figure 6.2)

![Cluster-head Selection for Transmission to Base Station](image)

**Figure 6.2 Cluster-head Selection for Transmission to Base Station**

Let consider this figure, where node n1 has to transmit an L-bits message to the base station. The closest cluster-head to n1 is CH1. And, if the node belongs to this cluster, it will spend energy (6.6).

\[ E_3 = L \cdot E_{elec} + L \cdot c_{d2} \cdot d_2^{\chi} \]  

6.6

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Where \( u = 2, \epsilon_{d2} = 10 \, \text{pj} / \text{bit} / \text{m}^2, \) if \( d_2 < d_0 \)
\[ u = 4, \epsilon_{d2} = 0.0013 \, \text{pj} / \text{bit} / \text{m}^4, \] if \( d_2 \geq d_0 \)

But if the node n1 chooses to transfer data to the base station directly, this energy will be (6.7):
\[ E4 = L \cdot E_{elec} + L \cdot \epsilon_{d3} \cdot d_3^3 \]

Here positive coefficients \( u \) and \( v \) represent the energy dissipation radio model used. Clearly \( E4 < E3 \) but in this case lot of uncompressed data is collected at the base station.

To get rid of this problem a sleep state is introduced in M-ECCDA in the following manner. When \( E3 > E4 \) it is not an optimal choice for transmitting data and energy saving, in this case instead of sending the data to the cluster head \( CH1 \) sensor node n1 enters into a sleep state and waits for the next round in which it either itself becomes a cluster head or finds a nearby cluster such that \( E3 < E4 \). Sensor node n1 remains in the sleep state for the maximum 8 rounds, if in these next 8 rounds it either becomes a cluster head or finds a nearby cluster such that \( E3 < E4 \) it wakes up and performs the concerned duty either of a cluster head or the members of a cluster.
If sensor node n1 is neither able to become the members of a cluster such that 
\( E_3 < E_4 \) nor become a cluster head itself in the next 8 rounds, then the sensor 
node wakes up and transmit the data directly to the base station itself. The choice 
of maximum 8 rounds of sleep state is based on the fact that advanced nodes 
rotate the cluster head rotation cycle after every 8th round.

### 6.3 SIMULATION AND RESULTS

The performance of M-EECDA is compared with EECDA. For evaluation 
100 x 100 square meters region with 100 sensor nodes has been used as shown in 
Figure 6.3. The normal nodes are denoted by using the symbol (o), advanced 
notes with (+), super nodes by (*) and the base station by (x). The various 
assumptions make about the nodes and sensing region are given below.

- Sensors are deployed randomly in the region.

- The base station and sensors become stationary after deployment and base 
  station is located in middle of the sensing region.

- Sensors are location unaware i.e. they do not have any information about 
  their location.

- Sensors continuously sense the region and they always have the data to 
  send the base station.

- Battery of the sensors cannot be changed or recharged as the nodes are 
  densely deployed in a harsh environment.
• In the sensing region, there are three types of sensor nodes i.e. super, advanced and normal nodes. Super and advanced nodes have more energy than the normal nodes.

6.3.1 PERFORMANCE METRICS

The performance metrics used for evaluating the protocols are:

(i) Network Lifetime: This is the time interval between the network operation start until the death of the last node.

(ii) Stability Period: This is the time interval between the network operation start until the death of the first node.

(iii) Number of Alive Nodes per round: This will measure the number of live nodes in each round.

(iv) Number of cluster heads per round: This will reflect the number of cluster heads formed in each round.

(v) Numbers of packets send to base station: This will measure the total number of packets which are sent to base station.

6.3.2 RADIO DISSIPATION ENERGY MODEL

Radio energy model as described in [18] is used for this protocol (Figure 4.1). Free space and the multipath fading channel both the models are used depending upon the distance between the receiver and transmitter. When distance is less than a particular threshold value, then free space model used otherwise multipath loss
model is considered. The amount of energy required to transmit $L$ bit packet over a distance $d'$ is given by equation (6.8).

$$E_{Tx}(L, d') = \begin{cases} L \times E_{elec} + L \times \varepsilon_{fs} \times d^2 & \text{if } (d < d_0) \\ L \times E_{elec} + L \times \varepsilon_{mp} \times d^2 & \text{if } (d \geq d_0) \end{cases}$$  \hspace{1cm} 6.8$$

$E_{elec}$ is the electricity dissipated to run the transmitter or receiver circuitry. The parameters $\varepsilon_{mp}$ and $\varepsilon_{fs}$ is the amount of energy dissipated per bit in the radio frequency amplifier according to the distance $d_0$ which is given by the equation (6.9).

$$d_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}}$$  \hspace{1cm} 6.9$$

For receiving an $L$ bit message the energy expends by radio is given by

$$E_{Rx}(L) = L \times E_{elec}$$  \hspace{1cm} 6.10$$

The various parameters of the radio model are given in TABLE 6.1

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_{elec}$</td>
<td>5 nJ/bit</td>
</tr>
<tr>
<td>$\varepsilon_{fs}$</td>
<td>10 pJ/bit/m$^2$</td>
</tr>
<tr>
<td>$\varepsilon_{mp}$</td>
<td>0.0013 pJ/bit/m$^4$</td>
</tr>
<tr>
<td>$E_0$</td>
<td>0.5 J</td>
</tr>
<tr>
<td>$E_{DA}$</td>
<td>5 nJ/bit/message</td>
</tr>
<tr>
<td>Message Size</td>
<td>4000 bits</td>
</tr>
<tr>
<td>$P_{opt}$</td>
<td>0.1</td>
</tr>
<tr>
<td>d₀</td>
<td>70m</td>
</tr>
<tr>
<td>------</td>
<td>-----</td>
</tr>
</tbody>
</table>

Table 6.1 Radio Parameters of M-EECDA

Figure 6.3 Sensing Region of M-EECDA

(o – Normal, + - Advance, * - Super Node, x - BS)

6.3.3 PERFORMANCE EVALUATION
The performance of M-EECDA is evaluated by introducing the following cases of heterogeneity.

Case 1: \( m = 0.5, m_0 = 0.4, a = 1, b = 2 \)

Case 2: \( m = 0.5, m_0 = 0.4, a = 1.5, b = 3 \)

![Graph showing rounds for 1st, Half & Last Node Death in M-EECDA & EECDA](image)

**Figure 6.4 Rounds for 1st, Half & Last Node Death in M-EECDA & EECDA**

Case 1: \( m = 0.5, m_0 = 0.4, a = 1, b = 2 \)

In this case there are 30 advanced nodes having one times and 20 super nodes have two times more energy as compared to normal nodes. Figure 6.4 shows that the network lifetime of M-EECDA is more than EECDA because last node dies in M-EECDA at 11445\(^{th}\) round and in EECDA it happens at 5369\(^{th}\) round. It means that the network life of the system is extended by 131\%. First node dies in M-EECDA at 1625\(^{th}\) round and in EECDA it occurs at 1374\(^{th}\) round. Thus the
stability period of the system is increased by 18%. Figure 6.5 shows that no of alive nodes per round are more in M-EECDA than EECDA. Figure 6.6 shows that throughput i.e. total number of messages send to the base station are more in M-EECDA. Figure 6.7 plots the total remaining energy (in joules) per round and it is more in M-EECDA than EECDA.

Figure 6.5 Comparisons of No. of Alive Nodes per Round in
Figure 6.6 Comparisons of Throughput per Round in M-ECCDA & EECDA
Figure 6.7 Comparisons of Total Remaining Energy per Round in M-EECDA & EECDA

Case 2: \( m = 0.5, m_0 = 0.4, a = 1.5, b = 3 \)

In this case there are 30 advanced nodes and 20 super nodes. Advanced nodes have 1.5 times and super nodes have 3 times more energy than normal nodes. Figure 6.8 shows that the network lifetime of M-EECDA is more than EECDA as last node dies in M-EECDA at 11995\(^{th}\) round and in EECDA it occurs at 7125\(^{th}\) round i.e. the network life is extended by 68\%. First node dies in M-EECDA at 1705\(^{th}\) round and in EECDA it happens at 1480\(^{th}\) round. It means that M-EECDA extends the stability period of system by 15\%. Figure 6.9 show that no of alive nodes per round are more in M-EECDA than EECDA. Figure 6.10 shows that throughput i.e. total number of packets send to the base station is more in M-EECDA. Figure 6.11 plots the total remaining energy (in joules) per round and
it is also more in M-EECDA.

Figure 6.8 Rounds for 1st, Half & Last Node Death in M-EECDA & EECDA

Figure 6.9 Comparisons of No of Alive Nodes per Round in M-EECDA & EECDA
Figure 6.10 Comparisons of Throughput per Round in M-EECDA & EECDA

Figure 6.11 Comparisons of Total Remaining Energy per Round in M-EECDA & EECDA
6.4. CHAPTER SUMMARY

This chapter has described M-EEDCA, a multihop clustering protocol for three level heterogeneous sensor networks. The proposed protocol suggests a residual energy based cluster head election scheme for normal nodes because they have less energy. The protocol has also introduced three-tier architecture for normal cluster heads and their data load are taken over by advance and super nodes when they are not performing the duty of a cluster head. When joining to a nearby cluster head is not energy efficient then the protocol has suggested a sleep state for the nodes so that the energy of the network can be saved. Simulation results show that the proposed protocol M-EEDCA has extended the stable region, network life and throughput of the system by 18 %, 131 %, 8 % respectively when (a = 1, b=2). Similarly, when (a = 1.5, b =3) stable region, network life and throughput is improved by 15 %, 68% and 11 % respectively. Next chapter will conclude the thesis with the directions for future research work.