Chapter 4

Power aware techniques for AODV protocol

4.1 Introduction

During the course of present study, the main objective is design of energy efficient Proactive and Reactive protocols. Existing protocols are selected because simulation software (NS-2) is available for evaluating their performance and the improvement in the protocol can be carried out by introducing relevant information in the header fields. These protocols have reserved bits in the header and relevant information can be easily incorporated in the header.

AODV protocol is selected for design modification and implementation such that it becomes energy efficient to achieve the first objective. Two algorithms are developed during this work:

- Modified AODV protocol (AODVM): Based on ratio of residual energy of node to hop count
- Distributed Energy Efficient AODV Routing protocol (DEEAR): Based on relative measure of residual energy of node as well as network. Route selection for packet transmission is done by considering rebroadcast time which is function of average residual battery power of a network.

The various energy aware techniques developed during the work are presented in the following sections. The concept used to make protocol energy aware is given first followed by development of new version of protocol and experimental analysis of new version of protocol with
4.2 Modified AODV (AODVM) protocol

AODV protocol is modified by considering the ratio of residual energy of node to hop count. AODV protocol belongs to Reactive protocol category. Applications like disaster management where numbers of users are less and there is need to provide emergency services, reactive protocols are preferred. It is very much essential to save power in such applications, so that the network can function for longer duration. After studying various scenarios, AODV is selected as a candidate for further experimentation for achieving objectives 1 and 2 as mentioned in section 1.4.

4.2.1 Concept used for AODVM

The lifetime of the network depends on the route which has smallest residual energy. If this fact is explicitly brought up while deciding the route, it will result in avoiding routes which have node with small energies. While doing this, hop count is also an important factor whose value should be as small as possible.

AODV protocol gets network information by using RREQ and RREP formats before transmitting the packets from source and destination. These formats contain ‘Reserved’ bits that can be defined for future modifications in the protocol.

4.2.2 Development of Modified AODV (AODVM)

In this approach, route selection is done considering minimum remaining energy (Min - RE) and number of hops between source and destination. The routing metric $\alpha$, which is the ratio of Min - RE and hop count, decides the route. Higher value of $\alpha$ indicates efficient route selection.

In order to get minimum remaining energy information ‘Min - RE’ field is introduced in ‘Reserved’ field in RREQ and RREP message formats of original AODV protocol. Protocol modification is as given in Figure 4.1 and Figure 4.2.

This modified AODV is named as AODVM. The node with minimum remaining energy
Operation of the AODVM is as follows:

- In order to find a route to a destination node, a source node floods a RREQ packet to the network. When neighbor nodes receive the RREQ packet, they update the Min-RE value and rebroadcast the packet to the next nodes until the packet arrives at a destination node. If the intermediate node receives a RREQ message, it increases the hop count by one and replaces the value of the Min-RE field with the minimum energy value of the route. In other words, Min-RE contains the least energy value of node on the route. If Min-RE of intermediate node is greater than energy value of Min-RE field, it is unchanged.

- Although intermediate node has route information to the destination node, it keeps forwarding the RREQ message to the destination because it has no information about resid-
ual energy of the other nodes on the route. If the destination node receives the first RREQ message, it triggers the data collection timer and receives all RREQ messages forwarded through other routes until time expires.

- After the destination node completes route information collection, it determines an optimum route and then sends a RREP message to the source node by unicasting. If the source node receives the RREP message, a route is established and data transfer starts. Such route processes are performed periodically. That is, the periodic route discovery will exclude the nodes having low residual energy from the routing path and greatly reduce network partition.

Equation 4.1, gives routing metric used for modified AODV.

\[
\alpha = \frac{\text{Min RE}}{\text{Hop Count}}
\]  

(4.1)

The destination node calculates the value of \( \alpha \) for each route based on minimum residual energy and hop count. A route with the largest value of \( \alpha \) is selected. The proposed protocol collects routes that have relatively large minimum residual energy of nodes and with least hop-count. This is explained by the network illustrated in Figure 4.3. It gives a simple routing example to setup route from source node S to destination node D. The number written on a node represents the value of residual node energy.

In order to understand the operations of the proposed protocol, we consider three different cases for routing protocols for operational comparison.

Case 1 deals with route selection in AODV where selection of route is based on minimum hop count between source and destination. Route selection in AODVEA is represented in Case 2
and Case 3 deals with AODVM.

The route selection for three cases in Figure 4.3 is as follows:

- **Case 1**: AODV select a route with the minimum hop count between source and destination. It selects route S-B-J-D which has least number of hops without considering residual energy of nodes. The hop count is 3 (smallest among other routes).

- **Case 2**: AODVEA selects a route with largest minimum residual energy. Selected route is S-A-K-F-L-H-G-D which has Min-RE as 6. This route has the largest minimum residual energy among remaining routes. It has serious problem in terms of the hop count and hop count is 7.

- **Case 3**: AODVM select a route with the largest value of $\alpha$, i.e. with the longest network lifetime. Route S-C-E-I-D is selected.

As per Equation 4.1, $\alpha$ for all three routes is calculated. Largest value of $\alpha = (5/4) = 1.25$, for the route S-C-E-I-D so this route is selected for data transfer. Case-3 takes care of the drawbacks of Case 1 (where $\alpha = (2/3) = 0.67$) and Case 2 ($\alpha = (6/7) = 0.86$) by considering both residual energy and hop count. This technique should extend network lifetime by using energy efficient nodes for data transfer.

### 4.2.3 Experimental results of AODVM

Simulations are carried out for various speeds starting from 0 (no mobility) to 60 m/sec. The network parameters selected for simulation are given in Table 4.1. The performance of AODVM is compared with AODV and existing power-aware routing algorithm, AODVEA. This newly developed version of protocol gives optimized path considering node’s residual battery power as well as number of hops.

The graphs for lifetime, average delay and energy consumption at 40 m/sec speed are shown in Figure 4.4. The results are summarized in Table 4.2. From Figure 4.4 it can be observed that,

- AODVM gives increased number of nodes alive as compared to other protocols without greatly affecting average delay and energy consumption.
Table 4.1: Simulation setup for AODVM, AODV and AODVEA testing

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Node initial energy</td>
<td>1.000 J</td>
</tr>
<tr>
<td>Receive Power</td>
<td>300 mW</td>
</tr>
<tr>
<td>Transmit Power</td>
<td>600mW</td>
</tr>
<tr>
<td>Topography</td>
<td>670 x 670</td>
</tr>
<tr>
<td>Packet send rate</td>
<td>4</td>
</tr>
<tr>
<td>Number of connections</td>
<td>10</td>
</tr>
<tr>
<td>Pause time</td>
<td>600</td>
</tr>
<tr>
<td>Speed</td>
<td>0 - 80 m/sec</td>
</tr>
<tr>
<td>Application</td>
<td>CBR</td>
</tr>
</tbody>
</table>

Figure 4.4: Comparison of AODV, AODVEA and AODVM for delay, number of nodes alive and energy consumption
Table 4.2: Comparison of AODVM and existing routing protocols AODV, AODVEA

<table>
<thead>
<tr>
<th>Parameters</th>
<th>AODV</th>
<th>AODVEA</th>
<th>AODVM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lifetime</td>
<td>Minimum</td>
<td>Medium</td>
<td>Maximum</td>
</tr>
<tr>
<td>Average Delay</td>
<td>Less</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>Energy consumption</td>
<td>Less</td>
<td>High</td>
<td>Medium</td>
</tr>
</tbody>
</table>

- The proposed algorithm is simple and adds an overhead of a couple of bytes to store the hop count and minimum energy and thus energy consumption is slightly more than AODV.
- AODV has less delay and energy consumption as route discovery process is simple but it suffers from less number of nodes alive.
- AODVEA searches for energy efficient nodes and might consider route with more number of hops. Thus it can results in larger delay and more energy consumption.

As the mobility of the node increases, number of nodes alive count reduces with marginal increase in delay and energy consumption. The advantage is not obvious beyond a speed of 50m/sec.

### 4.3 Distributed Energy Efficient AODV Routing (DEEAR) protocol

Another approach to make AODV energy efficient is based on route selection via intermediate nodes which control the rebroadcast time of the RREQ packet. The rebroadcast time of node is proportional to the ratio of average residual battery power of the entire network to its own residual battery power. An improvement in AODV protocol for node energy awareness is suggested by Distributed Energy Efficient AODV Routing named as DEEAR protocol.

#### 4.3.1 Concept of Distributed Energy Efficient Ad hoc Routing

A relative measure of energy considering residual energies of both, node and network is considered during the development of new version of protocol. Basically, nodes use their residual battery power for the rebroadcast time of RREQ packets. If the time is determined only by the
nodes’ absolute residual battery power, then the retransmission time will increase as time passes by. Therefore, the relative measure needs to be used.

In DEEAR, intermediate nodes control the rebroadcast time of the RREQ packet, where rebroadcast time is proportional to the ratio of average residual battery power of the entire network to its own residual battery power i.e. nodes with relatively larger battery energy will rebroadcast RREQ packets earlier. This is possible as continuous update of node power and network average residual power is performed in our scheme. Path consisting of energy efficient nodes is selected for routing. This being On-demand routing protocol, drops duplicate RREQ packets without rebroadcasting them.

If the individual battery power is larger than the average residual battery power of a network, then that node would tend to be selected as a member of the route, which results in fair energy consumption among the nodes. When the residual battery power variation is small, most nodes have a similar retransmission time. In that case, the route with a smaller hop count will be selected. Thus DEEAR compromises between the min-hop path and the fair energy consumption path.

### 4.3.2 Development of Optimum path selection mechanism for DEEAR

The route selection in this method is given as follows:

1. First, the source records its own battery power as ‘P’ field in place of Reserved bits in RREQ of AODV (Figure 3.1), and sets the hop count ‘N’ to 1, and broadcasts the RREQ packet.

2. It is assumed that a node ‘i’ has received an RREQ packet, and its residual battery power is ‘Bi’ and the ‘P’ value of the RREQ packet is ‘Pold’. Then, the average residual battery power of new route is ‘Pnew’ that includes the node ‘i’ is given by,

\[
P_{\text{new}} = \frac{[(P_{\text{old}} \times N) + B_i]}{(N + 1)}
\]

Before the node i rebroadcasts the packet, it updates P to P new and increases the value of N by one. This step is not executed for duplicate RREQ packets.

3. Whenever a node i receives an RREQ packet, it calculates the average residual battery power (‘Enew’) of the network based on previous residual battery power of a network
(‘E_{old}’) and ‘P_{old}’ as follows,

\[ E_{new} = [(1 - \alpha) \times E_{old}] + (\alpha \times P_{old}) \]  \hspace{1cm} (4.3)

Here \( \alpha \) is the weighting factor of the moving average and is set to 0.50 in our simulations.

We assume random position of node \( i \) in the entire route. To consider this random hop issue we have taken into consideration.

4. Based on estimated average power \( E \) and node’s own residual battery power ‘\( B_i \)’ for a node, rebroadcast time ‘\( T \)’ for a node ‘\( i \)’ is given by

\[ T = D \times \frac{E}{B_i} \]  \hspace{1cm} (4.4)

\( D \) is a constant to scale the retransmission time. Referring to equation 4.4, if the residual battery power ‘\( B_i \)’ is smaller than the average network residual power \( E \), then the retransmission time will be longer. If the individual battery power ‘\( B_i \)’ is larger than the average, then the node ‘\( i \)’ would tend to be selected as a member of the route, which results in fair energy consumption among the nodes.

When the residual battery power variation is small, most nodes have a similar retransmission time. In that case, the route with a smaller hop count will be selected.

Residual battery capacity of a node and overall remaining battery capacity of a path in a network are compared and accordingly route for packet transmission is selected considering rebroadcast time and average residual battery power of a network.

### 4.3.3 Experimental results of DEEAR protocol

The performance of DEEAR is compared with existing AODV and power-aware routing algorithm Combination Min Max Battery Combination Routing (CMMBCR). We have used free space model for our simulation purpose as area under consideration is small. The parameters selected for testing proposed protocol are given in Table 4.3. The parameter selected for protocol comparison are, Number of nodes alive, delay, throughput and packet delivery. These are tested for various simulation times in order to check the effectiveness of protocol over time. Energy consumption is tested against MANET area. In addition to time and area, impact of speed variation (1m/s and 25m/s) is checked for above mentioned parameters. The simulation results are shown in Figure 4.5 and Figure 4.6.
Figure 4.5: Comparison of DEEAR protocol with AODV and CMMBCR for nodes alive, delay and PDR
Table 4.3: Simulation Parameters for DEEAR, AODV and CMMBCR protocol testing

<table>
<thead>
<tr>
<th>Simulation Parameters</th>
<th>Trial 1</th>
<th>Trial 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Node initial energy</td>
<td>1.000 J</td>
<td>1.000 J</td>
</tr>
<tr>
<td>Receive Power</td>
<td>300mW</td>
<td>300mW</td>
</tr>
<tr>
<td>Transmit Power</td>
<td>600mW</td>
<td>600mW</td>
</tr>
<tr>
<td>Topography (square meter)</td>
<td>670 X 670</td>
<td>670 X 670</td>
</tr>
<tr>
<td>Packet Sent Rate (packets/sec)</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Number of connections</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Pause time</td>
<td>600</td>
<td>600</td>
</tr>
<tr>
<td>Speed</td>
<td>1 m/s</td>
<td>25 m/s</td>
</tr>
<tr>
<td>Application</td>
<td>CBR</td>
<td>CBR</td>
</tr>
</tbody>
</table>

Figure 4.6: Comparison of DEEAR protocol with AODV and CMMBCR for throughput, energy consumption
Based on simulation results given in Figure 4.5 and Figure 4.6 following points can be concluded:

1. Number of nodes alive for DEEAR are much larger as compared to AODV and CMM-BCR. Due to speed variation, the number of nodes alive starts reducing after 170 sec and a sudden drop is observed between 175 to 185 sec. With increase in speed, number of nodes alive count decreases. As shown in Figure 4.5(a) and Figure 4.5(b) number of nodes alive count falls from 35 nodes to 15 nodes with speed variation from 1 m/s to 25 m/s.

2. Average delay for DEEAR, shown in Figure 4.5(c) and Figure 4.5(d), is more than AODV and CMMBCR. In initial periods there is sudden increase while later it remains steady. As speed is varied from 1 m/s to 25m/s, delay increases from 40 milliseconds to 60 milliseconds and total delay interval also increases. This indicates that mobility of nodes affects our protocol.

3. Packet delivery ratio for AODV is poor after 80 sec. In case of CMMBCR it is less after 100 sec while for our protocol it extends up to 120 sec. From Figure 4.5(e) and Figure 4.5(f) Packet delivery is almost twice as compared to AODV.

4. Figure 4.6(a) and Figure 4.6(b) show throughput is not as good as AODV but better than CMMBCR. Throughput is relatively fair till speed of 20 m/s and it reduces with greater slope for 25m/s. Thus protocol is not suitable for throughput at higher speeds.

5. From Figure 4.6(c) and Figure 4.6(d), it is observed that energy consumption of both AODV and CMMBCR increases with increase in mobility but in DEEAR protocol it remains almost constant. Overall energy consumption of nodes is much less leading to more alive nodes and in turn more lifetime of the network.

The comparison among protocols is presented in Table 4.4. The performance is satisfactorily tested for speeds from 1 m/s to 25 m/s. From Table 4.4, it is observed that all performance parameters are improved for DEEAR protocol except slight increase in average delay for 25 m/s speed condition. The advantage of the proposed protocol is that partition of the network is successfully delayed due to balance of energy in the network. This can be useful in applications where data delivery is important and the delay is given less preference.
Table 4.4: Comparison of AODV, CMMBCR and DEEAR protocols

<table>
<thead>
<tr>
<th>(Parameters)</th>
<th>AODV</th>
<th>CMMBCR</th>
<th>DEEAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>No of alive nodes</td>
<td>Less</td>
<td>Medium</td>
<td>Maximum</td>
</tr>
<tr>
<td>Energy Consumption</td>
<td>More</td>
<td>Medium</td>
<td>Least</td>
</tr>
<tr>
<td>Average delay</td>
<td>Less</td>
<td>Medium</td>
<td>Maximum</td>
</tr>
<tr>
<td>Throughput</td>
<td>More</td>
<td>Minimum</td>
<td>Medium</td>
</tr>
<tr>
<td>Packet delivery ratio</td>
<td>Less</td>
<td>Medium</td>
<td>Maximum</td>
</tr>
</tbody>
</table>

### 4.4 Summary

In this chapter two new versions of AODV are suggested for energy awareness, they are:

- **AODVM**: Based on parameter $\alpha$, the ratio of residual energy of node to hop count.

- **DEEAR**: Relative measure of residual energy of node as well as network is considered. Rebroadcast time is function of this relative measure. Intermediate node accepts the RREQ with least rebroadcast time.

The simulation results show that AODVM has higher lifetime as compared to AODV and AOD-VEA. DEEAR is superior as far as number of nodes alive, energy consumption and packet delivery ratio parameter are concerned. However slight increase in delay is the price paid for this improvement.