CHAPTER 5

ANALYSIS OF POWER AWARE MULTI PATH
MULTICAST ADHOC ONDEMAND DISTANCE VECTOR

5.1 INTRODUCTION

In the previous chapter, the PDR, Latency has been investigated for Multiple Path MAODV for MANETs. Both the Multipath algorithms are performing better for VCR Environment. MP-MAODV is a tree based routing algorithm and it selects the multiple paths based on the number of hops and end-to-end delay to the receiver. It is inefficient when the route fails due to exhaustion of batteries at the intermediate nodes, during transmission, which effectively increases the end-to-end delay and route failure. A different strategy proposed in this chapter is to consider the residual battery strength of the nodes as additional parameter for route discovery to reduce the end-to-end delay. Since, power aware is not an issue of one particular layer; the cross-layer design is considered to power aware more effectively.

The organization of the chapter is as follows: The cross-layered approach of routing is compared with layered approach in Section 5.2. The motivations of cross-layer approach are described in Section 5.3. Section 5.4 describes the review of existing power aware routing algorithms. Section 5.5 describes the implementation details of Power Aware MP-MAODV routing algorithm. The performance evaluation is described in Section 5.6. The experiment results and discussions are presented in Section 5.7. Finally, the conclusion of this chapter is given in Section 5.8.
5.2 LAYERED VS CROSS-LAYER APPROACH

Traditional packet-based network architectures assume that communication functions are organized into nested levels of abstraction called protocol layers and that the metadata controlling the packet delivery are organized into protocol headers, one for each protocol layer. Actually, the network functionalities and services are commonly classified and modeled through the well-known Open System Interconnection (OSI) network model. Standardized in 1984, the ISO-OSI model established a 7-layer protocol stack where each layer defined the specifications for a particular network aspect and provided services to the upper layers (Figure 5.1). The main characteristic of the OSI model is the modularity (Kawadia and Kumar 2005). Each layer implements a specific service: the architecture forbids direct communication between non-adjacent layers, while the communication between adjacent layers works by using standard interfaces.

Generally speaking, cross-layer design refers to protocol design done by allowing layers to exchange state information in order to obtain performance gains (Yi et al 2002, Kawadia and Kumar 2005, Chellappa and Pan 2006, Chen et al 2002). The differences between the cross-layer architecture and the layered one are shown in Figure 5.1. The sharing of information enables each layer to have global pictures of the constraints and characteristics of the network. Unlike the wired networks, the wireless channel has several unique characteristics that need to be taken into account when designing wireless networks (Shakkottai et al 2003).

Firstly, different layers are more likely to use the same information in decision making. For example, the link and channel states, locations of the nodes and topology information of the network are commonly used by both the routing and the application or middleware layers in computing routes and making higher-level decisions.
Secondly, in a fast changing ad hoc environment, different layers need to cooperate closely to meet the QoS requirements of the mobile applications. This goal can be better achieved when the routing layer shares the MAC layer information such as channel bandwidth, link quality and the like. In addition, the wireless channel is often affected by factors such as interferences, mobility issues and multi-path fading, etc.

Figure 5.1 The ISO-OSI (left) and the Cross-layer Architecture (right)

This new technique of optimizing the performance by cross-layer interactions aims to achieve gains in overall system performance in wireless networks such as increase in network capacity, energy efficiencies and QoS to
support a wider range of services and the technique may be deployed to support across a variety of wireless devices (Srivastava and Motani 2005, Kliazovich et al 2007).

5.3 MOTIVATIONS

There are four main motivations supporting the adoption of cross-layer design in protocol design for MANETs:

1. the need by protocols to be adaptive to network dynamics,
2. to support the requirements specified by the applications
3. to tackle the energy
4. Security constraints

It is observed that several design challenges in MANETs (security, energy issue, topology control) cut across the layers, and requires joint solutions involving multiple protocol layers.

Adaptivity and Self-Organization: Network protocols for MANETs must be adaptive to many factors to effectively support fair sharing of devices and resources and to hide the system dynamics to the upper layers. The system dynamics include a wide range of communication conditions a wireless node can experience inside a MANET, including changing topology, shared medium contention, varying traffic patterns and distributions. For example, given the current channel state, the MAC protocol may adjust some parameters (for example the length of frame) in order to reduce the energy consumption (Ebert and Wolisz 1999); the routing layer may use the channel state information in the route discovery process, in order to dynamically select the most stable routes (Ebert and Wolisz 1999). Cross-layer architectures have been proposed to guarantee protocols cooperation with sharing of
network status information, while still maintaining separation among the layers (Conti et al 2004).

**QoS and Applications Requirements:** QoS is a guarantee by the network to provide performance for a flow in terms of bandwidth, delay, packet loss probability, etc. Wireless channel fluctuations, self-contention, limited bandwidth and dynamic topology make the QoS appear a strong issue for MANETs (Shakkottai et al 2003). It appears clear that the QoS requirements can not be met in MANETs unless they are supported across all the layers of the network. For these reasons, many recent works investigate the joint optimization of physical layer power allocation, MAC layer link scheduling and network layer flow assignment (Yoo et al 2004, Kawadia and Kumar 2005).

**Energy Conservation:** Energy efficiency is a limiting factor in the successful deployment of MANETs, because nodes are expected to rely on portable, limited power sources. Moreover, energy conservation is extremely challenging in multi-hop environments, where the mobile nodes should also consume energy to route packets for other nodes and to guarantee the connectivity of the network. At the network layer, the route selection process should be performed by minimizing the total power needed to forward the packet (Royer 2004); if the network layer may have access to energy information; battery-level metrics can be used in the routing process.

**Security:** Since nodes in MANETs communicate each other via open and shared broadcast channel, they are more vulnerable to security attacks. Moreover, the support for multi-hop communication implies that the network has to rely on individual solutions from each mobile node, resulting vulnerable to infiltration, eavesdropping, interference and denial of service attacks.
5.4 REVIEW OF EXISTING CROSS LAYER ROUTING ALGORITHMS

Energy Constrained Multicast Routing Protocol (ECMRP) (Yuan and Zhang 2008) has a better delay than MAODV and a more balance in energy consumption. It has a longer network lifetime than MAODV and successfully solves the inconsistent question of energy and delay.

Energy Aware Multicast Ad hoc On demand Distance Vector (EA-MAODV) (Zhou Wei and Shi Xingrong 2006) protocol based on the classifying energy level, considers the remaining battery level of nodes and chooses the route with maximal remaining power in order to increase the operational lifetime of the whole network.

An energy-aware routing scheme (Shah and Rabaey 2002) is proposed that uses sub-optimal paths to provide substantial gains. The scheme does not find a single optimal path and uses it for communication. Rather, it keeps a set of paths and chooses one based on a probabilistic algorithm.

In addition, a node-based energy metric (Tridib Mukherjee et al 2007) that minimizes the overhearing cost of energy consumption on the multicast tree has been proposed. The metric uses self-stabilizing shortest path spanning tree protocol (SS-SPST) to obtain energy-aware SS-SPST and the energy-latency trade off. The improved MAODV has a better packet delivery ratio even in a large multicast group.

The Power-Efficient Preferred Energy Forecast Multicast Protocol (Guo-feng Zhao et al 2008) called PPEF that uses both hops and energy consumption level of each node together for multicast routing.
A Cross-layer design of Energy-aware Multicast Ad hoc On-Demand Distance Vector (CEMAODV) (Bing Li et al 2008) routing protocol adopts cross-layer mechanism and energy-aware metric to modify AODV routing protocol to reduce the energy consumption of the route to construct a source-based tree.

5.5 POWER AWARE MULTI PATH MULTICAST ADHOC ON DEMAND DISTANCE VECTOR

5.5.1 Scheme

However, the Multipath multicast routing protocol MP-MAODV, use hop count as a metric to represent the distance between nodes, the end-to-end distance may be short but the lifetime of the network is shortened by inefficient consumption of battery energy. In order to utilize the battery effectively a different strategy has been proposed for route selection and route maintenance. The route selection process has been designed to select multiple node-disjoint routes based on link quality, hop count, end-to-end delay and residual battery capacity.

The Power Aware Multi Path Multicast Adhoc On Demand Distance Vector (PAMPMAODV) has been designed to combine hop count, end-to-end delay and residual battery capacity metrics to find node-disjoint multiple routes. The physical layer provides information that allows predicting the link conditions. Figure 5.2 shows the cross-layer interaction concept. At the physical layer, residual battery capacity estimation is obtained to predict the lifetime of the node. At the network layer, the routing protocol then makes a decision based on the delay associated with each link. Since the presented approach considered residual battery capacity, it resulted in load balancing, minimal power consumption, minimal packet loss, minimal packet delays and prevents unnecessary control messages.
5.5.2 Determination of Battery Power Threshold

The threshold for the residual battery capacity $R_{th}$ has been calculated based upon the number of total packets to be transferred and the maximum transmitted power used for each packet $T_r$ (Sychip Cheetah WLAN GSPI card Specification 2006)

$$R_{th} = N \times T_r$$

(5.1)

where $N = \text{Number of packets to be transferred by each route}$ and

$$T_r = 32 \text{ mW}, \quad \text{(from Sychip Cheetah WLAN GSPI card Specification 2006)}$$

$N$ is calculated as

$$N = n_d + n_c$$

(5.2)

where $n_d = \text{number of data packets to be transferred by each route}$,

$n_c = \text{number of control packets to be transferred by each route}$

$$n_d = X/\text{Number of assumed routes}$$

(5.3)
where \( X \) = Total number of pending packets to be transferred by the source

Let the Number of assumed routes = 2 and it is assumed that

\[
n_c = 0.10 \times n_d
\]  

(5.4)

By using equations (5.3) and (5.4), equation (5.2) can be written as

\[
N = \frac{X}{2} + 0.1 \times \frac{X}{2}
\]  

(5.5)

5.5.3 Protocol Message Formats

The PAMPMAODV uses six types of control messages (RREQ, RREP, MACT, RREP-S, MACT-S and GRPH) and a data message similar to MP-MAODV. The RREQ and RREP messages have been modified to include the details of link quality and residual battery capacity of intermediate nodes along the path. The GRPH message has been modified to include the details of link quality and residual battery capacity of the neighbour.

5.5.4 Route Selection and Establishment

PAMPMAODV also relies on broadcast based on-demand route discovery similar to MP-MAODV. Figure 5.3 shows the initiating a RREQ. In Figure 5.4, when a source node S1 starts a communication session to group member nodes \{D1, D2, D3 and D4\}, it broadcasts a route request (RREQ) Packet; it is often likely to receive more than one response packet since any node in the multicast tree can responds to the packet. The route discovery process of PAMPMAODV is explained with a scenario showing RREQ transmission by a source node S1 as shown in Figure 5.4.
When a source node **S1** wants to initiate data transmission, it starts sending RREQ which includes number of data packets to be transferred. The neighbour nodes that are in the vicinity of **i1** with one hop distance, receives and processes RREQ. The neighbour nodes **{i1, i2 and i5}** receives the RREQ. The nodes **{D1, D2, D3, D4, i3, i4, i6, i7, i8 and i9}** have not received...
RREQ, since they are out of the radio transmission range of S1. After receiving RREQ, the neighbour nodes \{i1, i2, i5\} check TTL value to verify whether it is greater than TTL_Threshold (set to 1 hop). If so, the neighbour processes the incoming RREQ.

The neighbour nodes \{i1, i2 and i5\} then calculate $R_{th}$ needed to transfer data packets and the Residual Battery (RB) capacity. For reading the battery capacity, using the package in c# as “Microsoft.WindowsMobile.Status;”. This package contains the function for getting battery status is “GetPowerStatus()”. The RB capacities calculated for these nodes \{i1, i2 and i5\} are 50, 60 and 40 units respectively. Using the Equation (5.1) suppose the $R_{th}$ value is 27 units, then all the neighbour nodes append RB into the RREQ and forward it further. If $R_{th}$ value considered is 45 units, then node i5 will not forward RREQ, whereas i1 and i2 will forward RREQ. Let $R_{th}$ be 27 units.
Each intermediate node, which receives RREQ, calculates ‘N’ using equation (5.2) and residual battery capacity $R_{th}$ needed to transfer ‘N’ packets. When the residual battery (RB) capacity is greater than $R_{th}$, then the intermediate node forwards RREQ further. Figure 5.5 shows the processing of RREQ. When an RREQ packet arrives at its any member, the received RREQs are stored in RREQ table.

Figure 5.6 shows the scenario of RREQs received by the receiver nodes {D1, D2, D3 and D4}. These received RREQs are stored in the RREQ TABLE of D1 and is shown in Table 5.1. The RREQ TABLE of D2 and is shown in Table 5.2. The RREQ TABLE of D3 and is shown in Table 5.3. The RREQ TABLE of D4 and is shown in Table 5.4. Then the receiver nodes {D1, D2, D3 and D4} wait for RREQ TIMER. First sorting the RREQ table with respect to hop count, then the sorted RREQ TABLE is further sorted based on total RB of the intermediate nodes.

### Table 5.1 RREQ TABLE at Node D1

<table>
<thead>
<tr>
<th>Route number</th>
<th>RREQ route</th>
<th>Hop count</th>
<th>Total RB of the intermediate nodes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>S-i1-D1</td>
<td>2</td>
<td>50</td>
</tr>
<tr>
<td>2</td>
<td>S-i2-D1</td>
<td>2</td>
<td>60</td>
</tr>
</tbody>
</table>

### Table 5.2 RREQ TABLE at Node D2

<table>
<thead>
<tr>
<th>Route number</th>
<th>RREQ route</th>
<th>Hop count</th>
<th>Total RB of the intermediate nodes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>S-i1-D1-i3-D2</td>
<td>4</td>
<td>170</td>
</tr>
<tr>
<td>2</td>
<td>S-i2-D1-i4-D2</td>
<td>4</td>
<td>175</td>
</tr>
<tr>
<td>3</td>
<td>S-i2-D1-i4-i9-i6-D2</td>
<td>6</td>
<td>230</td>
</tr>
</tbody>
</table>
Table 5.3  RREQ TABLE at Node D3

<table>
<thead>
<tr>
<th>Route number</th>
<th>RREQ route</th>
<th>Hop count</th>
<th>Total RB of the intermediate nodes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>S-i1-D1-D3</td>
<td>4</td>
<td>110</td>
</tr>
<tr>
<td>2</td>
<td>S-i2-D3</td>
<td>2</td>
<td>60</td>
</tr>
<tr>
<td>3</td>
<td>S-i5-D4-i7-D3</td>
<td>5</td>
<td>195</td>
</tr>
</tbody>
</table>

Table 5.4  RREQ TABLE at Node D4

<table>
<thead>
<tr>
<th>Route number</th>
<th>RREQ route</th>
<th>Hop count</th>
<th>Total RB of the intermediate nodes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>S-i5-D4</td>
<td>2</td>
<td>40</td>
</tr>
<tr>
<td>2</td>
<td>S-i1-D1-D3-i7-D4</td>
<td>5</td>
<td>215</td>
</tr>
<tr>
<td>3</td>
<td>S-i2-i8-D4</td>
<td>3</td>
<td>85</td>
</tr>
</tbody>
</table>

The receiver nodes \{D1, D2, D3 and D4\} assign rank for each route, based on hop count and total RB of the intermediate nodes. The member generates a RREP packet that contains the node list of the whole route and unicast it back towards the source that originated the RREQ packet along the reverse route. Figure 5.5 shows the processing of RREQ. When an intermediate node receives a RREP, it updates its Multicast Routing Table to add an entry towards member node by using the nodes list of the whole route contained in the RREP.
Figure 5.5 (Continued) Flowchart of RREQ Processing (part-1)

1. Begin
2. Receive a RREQ packet
3. Get TTL value from the RREQ packet
4. If TTL value < TTL threshold value, then:
   - If Member List[i]= my node address?
     - Yes: Store Multiple Request
     - No: Get residual battery capacity of the node
   - No: Residual battery > \( R_{th} \) (threshold)
5. If Yes, go to A
6. If No, go to B

A

B
Figure 5.5 (Continued) Flowchart of RREQ processing (part-2)

A

Get sequence number of received RREQ

Save sequence number in receipt buffer

RREQ already received?

Yes

Discard the RREQ

No

Get the hop count from the RREQ. Append the necessary details to unicast routing table, and add my address and link direction as downstream in multicast routing table

Append my address, residual battery into RREQ. Update TTL=TTL-1 and forward RREQ to neighbouring nodes

End
Figure 5.5 (Continued) Flowchart of RREQ processing (part-3)
Figure 5.5 Flowchart of RREQ processing (part-4)

Figure 5.6 Scenario Showing RREQs Received by Receiver Nodes
Figure 5.7 shows the processing of RREP. If the source node receives one or more RREP messages in this time, it queries the Multicast Routing Table and check if the route is activated to confirm which one is the first arrival. The source node unicasts a MACT to the node which RREP is the first arrival for activating the route and sends packets through the path due to the first path has the shortest latency.

The intermediate nodes, which received MACT, activate the related entry in Multicast Routing Table, and set multipath flag mpath as 1 and then forward the MACT to next hop until one group member receives MACT. Figure 5.8 shows the processing of MACT. If the RREP received by the source node is not the first arrival, the source node replies MACT-S to the next hop. The intermediate nodes, which received MACT-S, query the Multicast Routing Table and check if the route is activated. If the route is activated, the intermediate nodes discard this MACT-S, if not, it will add an entry to the Multicast routing Table to establish reverse route in Multicast Routing Table and send MACT-S to the next hop until this MACT-S forward to a group member.
Figure 5.7 (Continued) Flowchart for processing RREP
Figure 5.7 (Continued) Flowchart for processing RREP (part2)

- Send MACT
  - Increment the packet sequence number by 1
    - Save new packet sequence number in the sent buffer, set route table valid flag in upstream and mpath value as 1 at mcast routing table
      - Create a MACT packet with set mpath field as
        - Unicasts the MACT packet to neighbouring nodes
          - End
Figure 5.7 Flowchart for processing RREP (part3)
Figure 5.8 Flowchart for Processing MACT
Figure 5.9 (Continued) Flowchart for Processing MACT-S (part 1)
Figure 5.9 (Continued) Flowchart for Processing MACT-S (part 2)

Figure 5.9 shows the processing of MACT-S. The multicast group node received the MACT-S then unicasts a RREP-S to the source node. The intermediate node that received MACT-S adds an entry to the Multicast Routing Table to establish forwarding route and set mpath field as 2, then forwards it to the source node. So this mechanism can guarantee two node disjoint paths and avoided loops. Source node is likely to receive one or more RREP-S messages during this time, but it selects the route with largest sequence number and smallest hops by checking the RREP-S messages as the second path, and adds an entry to the Multicast Routing Table with mpath field as 2. Figure 5.10 shows the processing of RREP-S.
Figure 5.9 (Continued) Flowchart for handling MACT-S (part 3)
Maintaining more than two paths cannot evidently improve route performance. So, the researcher selects only two paths in order to reduce resource consumption and improve calculation efficiency. If the source node does not receive a RREP-S message before timeout, it uses the one path to send data packets. Figure 5.11 shows the processing of Data Packets. The route maintenance is done similar to MP-MAODV, as discussed in Section 4.5.4.
Figure 5.10 Flowchart for Processing RREP-S

1. Begin
2. Receive a RREP-S packet
3. Get Source address from RREP-S packet
4. Source IP address = my IP address?
   - Yes: Get sequence number of RREP-S packet
     - Update unicast routing table, Record next hop toward source in Multicast routing table upstream entry
     - Forward the RREP-S toward source node along the reverse route path
   - No: Get node list of the route path from the RREP-S packet
     - Update unicast routing table, Record next hop toward source in Multicast routing table upstream entry
     - Forward the RREP-S toward source node along the reverse route path
5. RREP-S timer expired?
   - Yes: Multicast Data Packets through the selected paths
   - No: Repeat from Step 3
6. End
5.5.5 Traffic Allocation

Once the source node has selected a set of node-disjoint and power-aware paths to the receivers, it can begin sending data to the destination along the paths. In order to exploit a maximum number of the available routes, route optimality should be considered in such a way to transmit more packets on the most optimal routes, thereby dispersing data load over a maximum number of nodes. The number of routes ‘P=2’ is assigned. Data are spread based upon the probability of that route.
5.6 PERFORMANCE EVALUATION

5.6.1 Experimental Setup

The experimental setup mentioned in Section 3.7.2 has been used for the analysis of the above three routing protocols (MAODV, MP-MAODV, and PAMPMAODV).

5.6.2 Performance Metrics

In addition to the metrics specified in Section 3.7.3, SD of RB capacity of nodes and Control overhead.

- **SD of RB capacity of nodes** along each route is calculated to measure the battery energy used for the transmission.

- The **control overhead** is the total number of control packets transmitted by the routing protocol.

The following metrics are analysed in varying scenarios to evaluate the PAMPMAODV protocol:

- Packet delivery ratio
- Latency
- Control overhead and
- SD of the RB capacity of the node.

5.6.3 Results and Discussion

5.6.3.1 Different Traffic

Figure 5.12(a) shows the VCR Implementation results and Figure 5.12(b) shows the NS2 simulation results. The results show the packet delivery ratio of MAODV, MP-MAODV and PAMPMAODV for different traffic. When, the traffic is increased, all the MAODV and the MP-MAODV
and PAMPMAODV’s packet delivery ratio have decreased. However, the MAODV decreased more quickly compared to MP-MAODV and PAMPMAODV. Suppose the source node sends out 10 KB per second, the packet delivery ratio of PAMPMAODV is 88 percent higher than MAODV, also 9.5 percent higher than MP-MAODV.

![Figure 5.12(a) Packet delivery ratio versus traffic (Experimental)](image1)

![Figure 5.12(b) Packet delivery ratio versus traffic (Simulation)](image2)

Figure 5.12(a) shows the VCR Implementation results and Figure 5.12(b) shows the NS2 simulation results. The results illustrate the variation of the average end-to-end delay as a function of data rate for MAODV, MP-MAODV and PAMPMAODV. The performance of PAMPMAODV is 35% to 45% better than that of MAODV and 4% to 20% than MP-MAODV.

![Figure 5.13(a) VCR Implementation results](image3)

![Figure 5.13(b) NS2 simulation results](image4)

Figure 5.13(a) shows the VCR Implementation results and Figure 5.13(b) shows the NS2 simulation results. The results illustrate the variation of the average end-to-end delay as a function of data rate for MAODV, MP-MAODV and PAMPMAODV. The performance of PAMPMAODV is 35% to 45% better than that of MAODV and 4% to 20% than MP-MAODV.

![Figure 5.14(a) VCR Implementation results](image5)

![Figure 5.14(b) NS2 simulation results](image6)

Figure 5.14(a) shows the VCR Implementation results and Figure 5.14(b) shows the NS2 simulation results. The results depict the SD of battery energy used for different traffic like 10, 20, 30, 40, 50 and 60 Packets/sec\(^{-1}\). The SD of the battery energy used in PAMPMAODV has been found to be 4% to 8.5% better than that of MAODV and 1.8% to 3.5% better than that of MP-MAODV for different traffic like 10, 20, 30, 40, 50 and 60 Packets/sec\(^{-1}\). The SD of the battery energy used in PAMPMAODV has been found to be 4% to 8.5% better than that of MAODV and 1.8% to 3.5% better than that of MP-MAODV for different traffic.
5.6.3.2 Different Area

Figure 5.15(a) shows the VCR Implementation results and Figure 5.15(b) shows the NS2 simulation results. The results show that the PDR of PAMPMAODV, MP-MAODV and MAODV are better for small areas up to 1000×1000 m because of tree link breakage and reconstruction is easy. For larger areas PAMPMAODV and MP-MAODV performs better because of
multiple path available in the routing. Suppose the node may move in area of 1500*1500m, the packet delivery ratio of PAMPMAODV is 24 percent higher than MAODV, also 11 percent higher than MP-MAODV.

![Figure 5.15(a) Packet delivery ratio versus area (Experimental)](image)

![Figure 5.15(b) Packet delivery ratio versus area (Simulation)](image)

Figure 5.15(a) shows the VCR Implementation results and Figure 5.15(b) shows the NS2 simulation results. The results show that the latency of PAMPMAODV, MP-MAODV and MAODV are low for small areas up to 1000×1000 m because of tree link breakage and reconstruction is easy.

![Figure 5.16(a) Latency versus area (Experimental)](image)

![Figure 5.16(b) Latency versus area (Simulation)](image)

Figure 5.16(a) shows the VCR Implementation results and Figure 5.16(b) shows the NS2 simulation results. The results show that the latency of PAMPMAODV, MP-MAODV and MAODV are low for small areas up to 1000×1000 m because of tree link breakage and reconstruction is easy.
For larger areas PAMPMAODV and MP-MAODV performs better because of multiple path available in the routing. Suppose the node may move in area of 2000*2000m, the packet delivery ratio of PAMPMAODV is 34 percent higher than MAODV, also 9 percent higher than MP-MAODV.

5.6.3.2 Different Speed

Figure 5.17(a) shows the VCR Implementation results and Figure 5.17(b) shows the NS2 simulation results. The results show that the PDR of PAMPMAODV is better for node speed up to 15 m sec\(^{-1}\). MAODV and MP-MAODV are not influenced by the node speed and perform better than PAMPMAODV for speed larger than 5 m sec\(^{-1}\). This resulted in more multicast tree partitions for PAMPMAODV, MP-MAODV and MAODV. Notice that the number of packet deliveries was high when the nodes had low mobility. Note also that the multicast tree structure was mostly static and, therefore, the packet delivery ratio was high. At high speeds, the tree links broke down quite often, leading to constant branch reconstructions and larger packet losses.

![Figure 5.17(a) Packet delivery ratio versus node speed (Experimental)](image1)

![Figure 5.17(b) Packet delivery ratio versus node speed (Simulation)](image2)

Figure 5.18(a) shows the VCR Implementation results and Figure 5.18(b) shows the NS2 simulation results. The PAMPMAODV’s latency has been found to be the smallest for any node speed as shown in Figure 5.18(a) and Figure 5.18(b). Figure 5.19(a) and Figure 5.19(b) compares the packet delivery ratio of the protocol PAMPMAODV, MP-MAODV and MAODV.
As the number of receivers is increased the packet delivery ratio remains constant due to the selection of the minimum energy paths in routing packets in PAMPMAODV. Packet delivery ratio in MP-MAODV and MAODV decreases as the number of receivers is increased.

**Figure 5.18(a)** Latency versus node speed (Experimental)

**Figure 5.18(b)** Latency versus node speed (Simulation)

**Figure 5.19(a)** PDR versus Number of Receivers (Experimental)

**Figure 5.19(b)** PDR versus Number of Receivers (Simulation)

Figure 5.20(a) shows the VCR Implementation results and Figure 5.20(b) shows the NS2 simulation results. Although the PAMPMAODV, MP-MAODV has an additional control message, its control overhead is still lower than the MAODV protocol along with the increase of network load. When source node sends out 50 packets per second, the control overhead of
PAMPMAODV is about 20 percent lower than MAODV and 3 percents lower than MP-MAODV protocol, as is shown in Figure 5.20(a) and Figure 5.20(b). Because the power aware backup path provides a better fault-tolerant capability and it can efficiently reduce the control overhead used for frequently route discovery due to link breakage caused by network topology change. The additional control packets can be ignored compared to the increased network load.

![Figure 5.20(a) Control Overhead versus Network Load (Experimental)](image1)

![Figure 5.20(b) Control Overhead versus Network Load (Simulation)](image2)

5.7 CONCLUSION

The PAMPMAODV algorithm has been implemented and simulated for various conditions. The parameters PDR, Latency, control overhead and SD of battery energy used have been studied for different scenarios. The first set of experiments has been performed by varying the network traffic. The performance of the PAMPMAODV compared to MP-MAODV for different traffic have been observed as, an increase of 9 to 28% in PDR and a reduction of 4% to 43% in Latency. The PAMPMAODV performance is better than that of MAODV with a 6% to 20% improvement in packet delivery ratio and 4.5% to 35% reduction in Latency.
The second set of experiments has been performed by varying the different area 100×100, 500×500, 1000×1000, 1500×1500, 2000×2000 and 2500×2500m respectively. The improvement in the PAMPMAODV compared to MP-MAODV for different area has been observed as, a raise of 1% to 12% in PDR, a reduction of 2% to 10% in Latency. The performance of the PAMPMAODV compared to MAODV is observed as, an increase of 1% to 53% in PDR and 5% to 34% in Latency.

Finally the performance of PAMPMAODV has been examined by varying different speed in the network. The improvement in the PAMPMAODV compared to MP-MAODV for different number of node speed is found to be, an increase of up to 24% in PDR, a reduction of 1% to 3% in Latency. The performance of the PAMPMAODV compared to MAODV for different number of node speed is observed as, an increase of 1% to 47% in PDR and 1% to 13% in Latency.