CHAPTER 3

POWER AWARE AND ENERGY EFFICIENT MULTICAST ROUTING PROTOCOLS

QoS metrics used by the routing protocols of wired network is oblivious to power awareness and energy efficiency as they do not consider any energy related parameters. The multicast routing protocols [46, 47, 50, 51, 53, 56] do not necessarily compute the power aware or energy efficient paths rather they select paths with minimum hop count or delay. These protocols may result in a rapid depletion of the battery power in the nodes of wireless mobile network along the most heavily used paths in the network. Consequently, such protocols are to be modified to yield power aware and energy efficient routing protocols in mobile network environments to provide scalability.

The solution to this problem can be provided using two categories of protocols. First category of protocols is based on minimum-power routing, which identifies the path to minimize the total energy consumption of a number of packets whereas the other category of protocols are based on attempting to distribute the forwarding load over different path to increase the network lifetime. The disadvantage of the first category of protocols is that they repeatedly select the least-power cost paths between source and destination pairs. As a result, nodes along these paths tend to depart soon by rapidly exhausting their battery energy causing network partitioning. Hence, it is ascertained that, developing power aware and energy efficient protocols that increases the network lifetime has become indispensable in order to provide scalability in multicast routing. Moreover, power-awareness and energy factors are identified as additional parameters that are relevant to mobile ad hoc routing protocol.
The subsequent sections of the chapter describe the rationale and details of the two proposed protocols namely, PASMRP and ROMRP to address the power and energy issues in multicast routing in mobile ad hoc networks in order to increase scalability. The proposed protocols are compared with the MAODV protocol for packet delivery ratio and control overhead parameters. The proposed protocols are based on MAODV and hence MAODV is used for performance comparisons.

3.1 **Power Aware Scalable Multicast Routing Protocol (PASMRP)**

Current research work in the field of mobile ad hoc networks concentrates more on the mobility issues rather than the provisioning of QoS. Though there is a few QoS aware multicast routing protocols exist, they stress upon only basic QoS parameters and not on power and energy issues. Existing power efficient or aware multicast routing protocols [72-74] deal with incremental or decremental power based routing. On these protocols less attention has been given to the scalability factor of the mobile ad hoc networks. A multicast routing protocol is said to be **scalable**, if it can function properly with the increase in the number of multicast sessions or the increase in the number of multicast sources or receivers in a multicast session. The protocol should also extend the duration of the ongoing multicast sessions if the network lifetime is extended.

When the number of multicast request is high, the importance of each multicast session needs to be addressed so that if resource constraints are severe, low profile multicast can be dropped and can prolong the operation of high profile multicast. In MANETs, the existing multicast routing protocols do not address the concept of service level differentiation to provide QoS. Also, the existing multicast routing protocols [72, 73] have taken less effort to increase the lifetime of the mobile ad hoc network.

Due to these issues, there is a need to propose a new protocol namely, **Power Aware Scalable Multicast Routing Protocol (PASMRP)** that is QoS enabled, scalable and provides a longer network lifetime with less control overhead.

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3.1.1 Overview of the Protocol

The main objective of PASMRP is to accommodate as many multicast sessions as possible with the required QoS thereby increasing the scalability of the multicast routing protocol and also increases the network lifetime through fair routing in MANET. The goal accomplishment of PASMRP is explained with the following example. Consider the mobile ad hoc network in Figure 3.1. Node A acts as the source for the multicast session (M1S). Node D is one of the receivers for the multicast session (M1S). Let the multicast route takes the path A → B → C → D, and the cost metrics for the path is computed as 100. The multicast session M1S begins its operation. Later, Node F initiates a new multicast session (M2S) and it floods the Multicast session invitation-Route Request (RREQ) packets. Let node C responds to the M2S invitation through Node B. Node F, on receiving the Route Reply (RREP) packets from Node C through Node B, sends Route Confirm (RCONF) packets through the reverse path B-C and begins its operation.

![Diagram](image-url)  

**Figure 3.1 Overview of PASMRP operations**

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But if node B has less power and is not capable of handling two multicast session M1S and M2S simultaneously, either it simply terminates the later M2S packet forwarding or accept both sessions and drains out of power soon Most multicast routing protocols take this decision and hence they cannot provide a scalable multicast.

In the present work, scalability is achieved for the above scenario through the concept of Class of Service (COS) and alternate path routing or rerouting. When node B receives the second multicast request M2S, it can consider the rerouting of the ongoing transmissions M1S through it. Now node B needs to recognize the importance of the two multicast sessions. Here the concept of COS is used for every multicast session by assigning a priority based on the type of application and QoS requirements.

The proposed protocol assumes the multicast requests with three different classes of priority level namely, Class A, Class B and Class C. The Class A multicast session is assigned high priority that has very stringent QoS requirements in terms of delay, bandwidth and the minimum number of receivers. High profile multicast sessions such as real-time applications are grouped into service type Class A. The Class C multicast session is treated as low priority service as that of normal best effort service. Low profile multicast sessions such as chatting are grouped as Class C. The Class B multicast session is assigned medium priority that is in-between the Class A and Class C services. Multicast sessions with moderate QoS requirements such as file and off-line multimedia content transfer are classified as Class B. The multicast source assigns the priority for the session and it is assumed to be genuine. Now node B can compare the priorities of the two multicast sessions (the ongoing one and the new request) and can decide, which multicast session it can reroute (if the alternate path has a compromisable QoS provisions) or it can reject the low priority multicast request.

Since power balanced fair routing is performed, it helps the nodes to survive for longer duration thereby increase the overall network lifetime. With longer
network lifetime and prioritized multicast sessions, longer multicast lifetime of high priority sessions and more multicast requests can be realized

3.1.2 PASMRP Algorithm

The mobile ad hoc network is modeled as an undirected connected network $G = (V, E)$, where $V$ represents the set of nodes and $E$ the set of links between pairs of nodes. A link from node $i$ to node $j$ is said to be present, if node $j$ lies within the Transmission range ($Trange$) of node $i$, i.e., $link(i, j) = 1$, if $dist(i, j) \leq Trange(i)$. It is assumed that all nodes in $V$ have uniform $Trange$ and use omni-directional antennas. The congestion control and packet losses are implemented in the same way as it is in the MAODV protocol. The general algorithm is given below.

In the algorithm, let $N, N \subseteq V$ denotes the multicast tree member nodes with $S$ as source node and $D, D \subseteq V$, the set of receivers. It is assumed that each node has a uniform power supply of $P_{\text{max}}$ and consumes 0.01% of $P_{\text{max}}$ per packet of transmission. Since the power consumption for packet reception and processing is very meager when compared to packet transmission, it is neglected for accounting. Let $P_{\text{available}}$ denotes the current power available in a node and $P_{\text{threshold}}$ denotes the power required to support ongoing multicast transmissions. A node is said to be power constraint, if its $P_{\text{available}} < P_{\text{threshold}}$. Let $M_{\text{reqSource}}, M_{\text{reqPriority}}$ denotes the source node ID and the priority of the requested multicast sessions respectively. $M_{\text{ongoing}}$ represents the ongoing multicast sessions on a node. Let $M_{\text{selected}}$ denotes the selected multicast session for rerouting or termination.
PASMRP Algorithm;

RouteRequest (M_{reqSource}, M_{reqPriority})
{
    For each node n in N, N ⊆ V
    if (P_{available} < P_{threshold})
    {
        // check M_{req priority} with M_{ongoing} Priorities
        if (M_{reqPriority} > M_{ongoingPriority})
        {
            // Find M_{ongoing} with least priority and minimum receivers
            From all M_{ongoing},
            M_{selected} = M_{ongoing} with min(M_{ongoingPriority})
            if (M_{selected} (found)
            {
                // try rerouting ongoing multicast
                route_exist = Reroute (M_{selectedParent}, M_{selectedSource},
                                       M_{selectedReceiver set}, M_{selectedPriority})
                // Accept requested multicast
                Update and Forward RouteRequest (M_{reqSource},
                                                M_{reqPriority})
                if ( !route_exist)
                    Terminate (M_{selected})
            }
            else
                discard RouteRequest(M_{reqSource}, M_{reqPriority})
        }
        else
            discard RouteRequest(M_{reqSource}, M_{reqPriority})
    }
}

3.1.3 Protocol Operations

PASMRP is a source-initiated tree based multicast routing protocol in which
a source tree is constructed to support multiple sources and receivers. The protocol
uses the concept of COS when deciding upon the entry point in the multicast tree
where a new multicast member node is to join. Before admitting a new request, each
node checks its power availability, priorities of the ongoing and the requested multicast sessions, and then the admission control is done The protocol has two phases of operation namely, *Tree Initialization Phase* and *Tree Maintenance Phase* These phases are explained below

**Tree Initialization Phase**

The source node initiates the multicast tree construction phase. Joining a multicast session is a three-step process: flooding RREQ packets by the source, replies along the (better QoS) path by the receivers, and path setup by the source. The tree initialization phase is illustrated in Figure 3.2.

For creating the multicast tree, initially, the multicast source node S broadcasts a Route-Request (RREQ) packet in the network to inform all potential receivers. The RREQ packet holds the multicast source ID (M_{reqSource}) and the multicast priority (M_{reqPriority}) information. When an intermediate node, say I1 (among I1, I2, I5) receives the RREQ packet, it checks whether it has enough power (P_{available}) to handle the multicast session. If it has sufficient power, i.e., $P_{available} > P_{threshold}$, then it appends its ID and increments the hop count along with the QoS information to the RREQ packet and rebroadcasts it to I2 and I3. Table 3.1 shows the structure RREQ packet received at node I3. If the power availability in I1 is insufficient, it compares the priorities of the ongoing multicast sessions (M_{ongoingPriority}) with the priority contained in the RREQ packet (M_{reqPriority}). If the RREQ priority is greater than the ongoing priorities, then the node tries to reroute the lowest priority multicast transmission (M_{selected}) having the least number of multicast members. If rerouting is successful, the node accepts and rebroadcasts the RREQ packet, otherwise, it simply discards the RREQ packet.

After receiving RREQ packets through different paths as shown in Figure 3.2, each of the interested receivers, say R3 (among R1, R2, and R3), responds back by sending a Route-Reply (RREP) packet through the path (R3→I5→I4→I3→I1→S) having less hop count, more power in the intermediate nodes and having a shorter...
This approach is followed in the same order in deciding the best path. After receiving a number of RREP packets from different receivers, the source node S sends Route-Acknowledgement (RACK) packets to all receivers R1, R2 and R3 through the reverse paths (S→I1→I3→I4→I5→R3 for receiver R3) in order to establish the multicast tree.

Figure 3.2 Tree initialization phase in PASMRP

Table 3.1 Structure of RREQ message at node I3

<table>
<thead>
<tr>
<th>Multicast Source ID</th>
<th>Multicast Source ID</th>
<th>Multicast Source ID</th>
<th>Path from Source</th>
<th>Immediate Parent ID</th>
<th>QoS details (D,P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1001</td>
<td>S</td>
<td>1</td>
<td>S→I1</td>
<td>11</td>
<td>refer NNT</td>
</tr>
</tbody>
</table>
Tree Maintenance Phase

Due to movement of nodes, links between nodes break frequently. The tree maintenance is done using a hard state approach; i.e., separate route repair mechanisms are executed to repair the route. PASMRP uses a local and fast route-repair mechanism. Each node maintains a two hop local network topology information table called Neighbour-to-Neighbour Table (NNT) instead of the conventional Neighbour Table (NT). The NNT maintains the following information:

A node's neighbour node ID (immediate / two hop neighbour), next hop node ID to reach the neighbour (for immediate neighbour, the next hop is null), and the QoS details such as distance (D) and power for the path (P). The structure of NNT maintained by the node S with reference to Figure 3.3 is shown in Table 3.2.

Table 3.2 The NNT maintained by node S

<table>
<thead>
<tr>
<th>Neighbour node ID</th>
<th>Next hop</th>
<th>Hop count</th>
<th>Distance</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>I1</td>
<td>Null</td>
<td>1</td>
<td>dist(S, I1)</td>
<td>P(I1)</td>
</tr>
<tr>
<td>I2</td>
<td>I1</td>
<td>2</td>
<td>dist(S, I1) + dist(I1, I2)</td>
<td>Min(P(I1), P(I2))</td>
</tr>
<tr>
<td>I3</td>
<td>I1</td>
<td>2</td>
<td>dist(S, I1) + dist(I1, I3)</td>
<td>Min(P(I1), P(I3))</td>
</tr>
</tbody>
</table>

On receiving each beacon from the neighbours, a node updates the corresponding entry in the NNT. Since there may exist many paths between a node and its two hop neighbour, the problem of maintaining the NNT will be very difficult. Hence, during the updation of NNT, it is ensured that only three best paths are maintained for a node-neighbour pair and other paths are discarded. Thus, the NNT is kept up-to-date by means of the periodic beacon packets. The advantage of using NNT over NT is that, it helps a node to select its best forwarding node (having the better QoS provisions at the two hop level) towards the destination node.
The tree maintenance phase is illustrated in Figure 3.3. If receiver R3 moves from position A to B, link I5→R3 breaks. When a link break occurs, it is the responsibility of the downstream node (R3) to search for its upstream parent/super-parent node (I5). On detecting a link breakage, the downstream node R3 can refer its NNT and find out a best alternate path (R3→I6→I5) to connect to the parent/super-parent node I5 immediately. This fast rerouting avoids the delay in the conventional Route Repair mechanisms, i.e., the Route Error (RERR→RREQ→RREP→RACK) propagation (a four-way messaging) procedure and hence makes the protocol robust. Since NNT maintains two-hop neighbour information, only a maximum of two consecutive link breakages can be locally repaired. Longer link breakages follow the same conventional route repair mechanism.
3.1.4 Simulation Environment

The objective of the simulation is to study the effectiveness of the proposed protocol in a variety of environments with respect to various parameters. The protocol was implemented in C++ and the simulation was carried out using a simulator developed in C++. Once the code was written and debugged, the parameters of the simulations were determined for a variety of network densities, multicast group sizes with varying class of services. The simulations were conducted to assess the performance of the protocol and the results were compared with MAODV. MAODV is identified as the baseline protocol for performance comparison, since PASMRP is an on-demand tree-based protocol similar to MAODV.

Simulation Parameters

The simulation models a dynamic mobile ad hoc network consisting of 50 nodes. Random waypoint mobility model [75] was adopted for the node mobility and the node move at random speeds of maximum 2 meters per second within a 600m x 600m rectangular area. In a random waypoint model a point in the terrain is randomly selected and the node travels to that point at the assigned speed. Once the node arrives at the point another point is selected and travel continues to the new point at the same speed. Each node has a uniform transmission range of 150m and uniform battery power supply of 100W. It is assumed that, each packet transmission consumes 0.01mW of battery power and the power required for internal computations and reception of packets is negligibly small. The multicast source and receiver nodes were randomly selected.

The simulation has been run over 10 scenarios with different topology information. In each scenario, the number of multicast sessions requested were varied in terms of 5, 10, 15, 20, ..., 50. The maximum number of receivers for each multicast session was fixed at 10. Multiple experiments are conducted for different scenarios and the collected data were averaged over these runs. In each run, the
sender and receiver was initiated at the beginning of the simulation. The sender generates a fixed size packet at a rate of every 5 seconds for roughly about 10 minutes. The packets generated by the nodes were tagged with three different classes of priorities. The priorities of the packets were assigned uniformly for the entire multicast session. The distribution of priorities for the entire network was also made uniform.

Similar experiment was repeated with all the initial conditions for another network consisting of 40 nodes to study the performance accurately with the change in network size. To focus the experimental results, only the network topology and the number of multicast groups were varied while other simulation parameters were kept fixed.

3.1.5 Simulation Results and Discussion

The protocol was tested in the simulated environment to investigate the performances under varying network conditions. To analyze and compare the performances of PASMRP with MAODV, the number of multicast sessions survived against the requested, the control overhead and the class-wise multicast session survived were considered as the metrics. The various performance metrics and the comparison results are discussed hereunder.

Performance Metrics

**Multicast sessions survived** This is the total number of multicast sessions survived successfully till the end of simulation. A Multicast session is said to be surviving, if the multicast source has a predetermined minimum number of valid receivers throughout the multicast lifetime. The multicast sessions survived is always less than or equal to multicast sessions requested. In other words, a multicast session is said to be failed, if multicast source does not have the predetermined minimum number of receivers and hence the multicast session is terminated.
Multicast Overhead It is the total number of control packets transmitted by all the multicast group nodes in a multicast session to carry out the tree construction and maintenance.

Class-wise multicast sessions survived: This is the total number of multicast sessions survived till the end of simulation on each class of priority.

Based on these performance metrics a number of graphs were plotted to explain the experimental results. Figures 3 4 (b) and 3 4 (c) compare the number of multicast sessions survived with respect to the number of multicast sessions requested for the network of 40 and 50 nodes respectively with a power supply of 100W. From the Figures 3 4 (a), 3 4 (b) and (c), it is inferred that both PASMRP and MAODV perform similarly till the nodes have enough power to handle the requested multicast sessions. Both the protocols give similar performance till the number of multicast sessions requested increases up to about 25 sessions. Once the power in the nodes begins to exhaust and becomes critical, the protocols start to behave differently. From the graphs, it is evident that when the power becomes critical the number of multicast sessions survived in PASMRP is greater than the MAODV. This is because MAODV continues to handle the multicast sessions in the same path and due to that, the member nodes disappear out of power soon and thereby decreasing the number of multicast receivers in each multicast session and make the corresponding multicast session invalid.

On the other hand, PASMRP tries to reroute the ongoing or the requested multicast sessions in an alternate path having better power supply. The alternate path selection is carried out based on the priority of the multicast data and the alternate path is quickly found with the help of NNT. PASMRP avoids the node failure due to power supply by distributing the load to other nodes uniformly in the network. Hence, PASMRP prevents the disconnection of source-receiver pairs thereby making the multicast session to survive for long duration. Since PASMRP prevents node failure due to power within a short duration, it achieves longer network.
lifetime thereby increasing the number of multicast sessions survived. Therefore, PASMRP scales better than the MAODV protocol.
The number of multicast sessions survived was around 80% against the number of multicast sessions requested from 5 to 25 when there was enough power availability in the network for both PASMRP and MAODV. For the given network topology with the initial conditions, the performance of PASMRP gives the best result in terms of the survived multicast sessions than the MAODV when the number of requested multicast session is about 50. In MAODV, the number of sessions survived is drastically reduced when the number of session grows. Therefore, PASMRP yields better results by distributing the power among the number of surviving multicast sessions thereby increasing the throughput and network lifetime.

PASMRP incorporates an alternate path rerouting for increasing the number of multicast sessions. However, in the presence of NNT and fast reroute mechanism, the PASMRP reduces the overhead compared to the conventional route repair procedure in MAODV. Figures 3.5 (a), (b) and (c), present the corresponding overheads involved in both the protocols. The control overhead is initially more in PASMRP compared to MAODV by about 70%. This is due to neighbor information exchange to construct the NNT. When the number of multicast session increases, the control overhead in MAODV also increases drastically as there are control messages required for tree maintenance caused due to node mobility. However in PASMRP, when the number of multicast session increases the control
overhead does not increase proportionally as route failures due to power and associated overheads are avoided by alternate path rerouting. It is inferred that though the control overhead increases proportional to the number of multicast request, PASMRP outperforms than MAODV by an approximate of 50% less in control overhead when the number of multicast request reaches 40 to 50. Therefore, PASMRP requires less control packets when more multicast sessions are required compared to MAODV.

Figure 3.5 (a) Multicast overhead of PASMRP for 40 and 50 nodes

Figure 3.5 (b) Multicast overhead of PASMRP for 40 nodes
Figure 3.5 (c) Multicast overhead of PASMRP for 50 nodes

PASMRP is a QoS aware protocol in which the service level differentiation is employed. The multicast sessions from the source have been classified into Class A, Class B and Class C service classes with decreasing level of priorities. PASMRP ensured higher delivery ratio for high priority data considering the QoS requirements. Figure 3.6 presents the class-wise multicast sessions survived against the multicast sessions requested. It is inferred that Class A multicast sessions survive more than Class B and Class C. Also the number of Class B sessions survives more than Class C. However, there exist failures in multicast session irrespective of their service class due to node mobility which can not be prevented. Normally, a multicast session failure can occur on the following situations: (i) Isolation of multicast source, (ii) Presence of inadequate receivers due to network partition and (iii) Absence of lower class multicast sessions in a power constrained node.

Figure 3.7 shows the ratios of the requested and survived multicast sessions based on their service classes. It is inferred that the high priority multicast sessions always survive more than those of low priority multicast sessions.
After analyzing the importance of scalability and its ignorance in the existing multicast routing protocols in mobile ad hoc networks, a scalable multicast routing protocol with lifetime extension, enhanced QoS has been developed. PASMRP ensures that the high priority multicast sessions always survived more than the low priority multicast sessions. Also PASMRP has less control overhead than MAODV.
The comparison of PASMRP and MAODV has also been presented in Table 3.3 to better explain the features of PASMRP.

Table 3.3 Comparison of MAODV and PASMRP

<table>
<thead>
<tr>
<th>Criteria</th>
<th>MAODV</th>
<th>PASMRP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tree Initialization</td>
<td>Receiver</td>
<td>Source</td>
</tr>
<tr>
<td>Tree Maintenance</td>
<td>Hard state</td>
<td>Hard state with Fast Rerouting</td>
</tr>
<tr>
<td>Scalability</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Network Lifetime</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Protocol Overhead</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Packet Delivery Ratio</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>QoS</td>
<td>Not considered</td>
<td>Aware</td>
</tr>
<tr>
<td>Service differentiation</td>
<td>Not addressed</td>
<td>Addressed</td>
</tr>
</tbody>
</table>

3.2 Robust On-demand Multicast Routing Protocol (ROMRP)

In mobile ad hoc networks, energy efficiency is an important metric like other performance metrics such as packet delivery ratio, control overhead, delay, etc., since it affects overall performance and lifetime of the network. Energy efficiency is achieved in multicast routing protocols using two different methods. The first set of protocols constructs a tree or mesh with least cost links corresponding to the transmission power requirement while the second set of protocols aims at maximizing the sleep mode operation supported by lower level protocols.

Generally tree-based multicast routing protocols are more efficient in terms of efficient usage of resources than mesh-based protocols. More specifically, shared-tree protocols are more efficient and scalable than source-based tree protocols. One of the important aspects of energy efficient protocol is to balance energy.
consumption among all nodes so as to increase the network lifetime [76-78]. For example, in shared multicast trees, the root node of the tree consumes more battery energy than any other node in the tree and stops working earlier than other nodes. This leads to network partitioning and increase in control message overhead in order to resume multicast. Excessive control message and associated energy exhaustion further reduces the overall network lifetime. Power exhaustion of group leader could be prevented by effectively changing the group leader when the energy level reaches to a lower bound threshold value. This procedure avoids flooding of control messages and network partitioning while increasing the network lifetime.

3.2.1 Motivation

In recent years, there has been tremendous research interest in the design of energy aware broadcast/multicast routing protocols for ad hoc networks. Most of this work has focused on minimizing the total energy consumption [70, 72, 73, 76-79]. The problem of finding minimum-energy broadcast tree and multicast tree was proved as NP-hard [74]. Wieselthier et al., [70] first considered minimum-energy multicast tree and proposed greedy heuristics based on Prim’s and Dijkstra’s algorithms. Among the heuristic algorithms, the most efficient one is known as Broadcast Incremental Power (BIP) and Multicast Incremental Power (MIP) for the minimum energy multicast tree problem. Online multicast protocol to maximize the network capacity using energy consumption is also proposed [80].

However, in many practical applications of mobile ad hoc networks, the performance measure of interest is not only to optimize the overall energy consumption but also to maximize the lifetime of the network which in turn maximize the lifetime of ongoing multicast session. Most of the multicast routing protocols [76-79, 81, 82], provide an effective tree maintenance procedure to repair the route failure due to battery power exhaustion of tree nodes in order to increase the lifetime of the ongoing multicast sessions. However, power exhaustion in group leader leads to adverse effects like splitting the network in disjoint groups. Instead of solving this situation using conventional tree maintenance procedures, a group
leader migration is proposed, if the leader reaches a predefined threshold power value in order to preserve the ongoing multicast session.

In this research, a Robust On-demand Multicast Routing Protocol (ROMRP) is proposed and developed based on MAODV to address the problems when the multicast group leader fails due to battery power exhaustion. In ROMRP, group leader's power level is monitored and if the power level reaches the predefined threshold value, then the group leader identifies another node which can last for longer time than the group leader. Then the responsibility of the current group leader is given away to the newly identified group leader node. ROMRP uses lightweight approach for the entire process of identifying the new leader and leader migration. Both the operations are performed by the existing group leader itself.

ROMRP is an on-demand shared-tree protocol, wherein the first node that joins/initiates the multicast session becomes the multicast group leader or the root node of the tree. Then the group leader is responsible for tree construction, maintenance and distribution of the multicast data to the group members. The group leader has to keep on updating the multicast members by sending the multicast group sequence number periodically. As a result, the leader may drain out the battery energy earlier than the other nodes in the multicast tree. If the group leader is fully relinquished of its battery power, there is a need for change in leadership which is similar to creation of a new multicast group. This may lead to the following adverse situations:

(i) Loss of data packets and increased overhead due to error messages

During the reformation of multicast tree, the data packets destined to the multicast group are dropped if the multicast leader is not available. In this situation, either the sender should wait for some time until a new group leader is selected or it should become the group leader in order to send the data packets. When the group leader is not available in a multicast group, the data sent to the leader is simply dropped. This results in generation of Router Error (RERR) messages. In addition to that, the
selection of a new group leader involves transmission of RREQ for ROUTE REQUEST RETRIES message which increases the number of control messages in the ad hoc network.

(ii) Network partitioning and non-availability of the multicast group If group leader is relinquished due to power depletion, the members who are connected to the leader are separated into two or more disjoint groups with same multicast group address This is defined as network partitioning. The group leader is the one who manages multicast tree and multicast sequence number The absence of the group leader makes the whole multicast group becomes unavailable until a new leader is selected.

(iii) Inefficient group leader selection The selection of group leader in normal case happens without any reservation A node, which initiates the route repair procedure for the leader, becomes the group leader and may happen to be a weaker one in terms of energy This situation may once again lead to the possibility of the group leader failure.

The above mentioned limitations due to energy exhaustion of group leader could be solved by effective group leader migration, thereby avoiding the control messages and associated energy utilized for control packets This will certainly decrease total energy consumption and increase network lifetime The subsections will describe the ROMRP protocol operations and simulation results.

3.2.2 Overview of the Protocol

The main objective of the ROMRP is to provide an energy efficient on-demand multicast routing protocol to avoid the above said limitations. ROMRP uses a new approach to preserve the multicast session by migrating the multicast group leader to another node when the energy level of the leader goes below certain
threshold value. The energy level calculation and control information for change of leader have been carried out using group hello control packet.

The group leader selection is broadly classified into static and dynamic selection approaches [83]. Static selection usually chooses the first node of the multicast group as the group leader and remains fixed irrespective of changes in the network topology. Dynamic core selection can be further classified into explicit and implicit methods. In explicit group selection method all members of multicast group compute their weight functions and exchange the weights among themselves so as to select the node with the minimum weight as the group leader. On the other hand, an implicit core selection method requires the leader, to monitor the network regularly for the desired metric (power, hop position, etc.) and makes a decision based on a threshold, which may be either fixed or computed dynamically.

In the ROMRP, the group leader selection is initially assigned statically and the migration is carried out using implicit selection method. The group leader energy level is used as a metric based on which the migration is initiated. The tree construction and multicast operations are carried out using receiver initiated approach similar to the MAODV protocol. The first node initiating a multicast group is designated as the group leader which is responsible for maintaining the group sequence number for the group and disseminating group information to all network nodes. The group sequence number is periodically incremented by the group leader and it is used by the receivers to identify the latest group related messages. The group leader will also be designated as the root of the group’s multicast tree.

A node that wants to join to a multicast group will broadcast a RREQ message. Any on-tree node can respond to the RREQ message with a RREP message via the reverse path. Other nodes in the tree will rebroadcast the RREQ message. The intermediate node unicasts the request to the group leader, if there is a path to group leader. As the joining node may receive multiple RREPs, it activates the selected path by sending a Multicast Activation (MACT) message along the
selected path to the multicast tree. The multicast tree constructed with set of receivers is shown in Figure 3.8 (a).

![Multicast Tree Diagrams](image)

Figure 3.8 (a) Multicast tree with original group leader (b) Multicast group leader requests the energy levels of all the In-Tree nodes (c) Multicast group leader with group leader change

The multicast group leader periodically broadcasts a Group Hello message across the network. This message carries a multicast group-id, group sequence number and corresponding group leader IP address. This information is used for disseminating updated group sequence numbers throughout the multicast group and for repairing multicast trees after a previously disconnected portion of the network containing part of the multicast tree becomes reachable once again. When the multicast group leader is fully relinquished of its battery power, there is a change in leadership which is a process similar to creation of a new multicast group. This leads to loss of data packets, increased overhead, network partitioning and non-availability of group leader. This problem leads to unnecessary control packets flown in the network causing battery power exhaustion reducing the network lifetime and overall throughput. ROMRP avoids this situation by group leader migration before it fails due to non-availability of the energy to another node.
3.2.3 Protocol Operations

The protocol operation for group leader migration is carried out by exchanging a set of group hello messages with the current and safe energy levels. In each multicast group, the group leader is assigned a Safe Energy Level (SEL) which is the threshold value set either at the start of a new group or by the way of leadership migration. This energy level will decrease while the multicast session progress due to the packet transmission. Once the Energy Level (EL) of the leader goes below the SEL, the group leader queries its group members about their energy status. The requesting of energy level by the leader is shown in Figure 3.8 (b). The group leader then finds the SEL for the new leader using the energy levels submitted by the group members and finds a new leader. The new leader is selected by considering both the energy level and the distance from the current group leader. A group member with the most energy level and less hop count from the present leader is chosen as the new leader and leader migration takes place. After the core migration, the multicast tree is rooted at the newly selected group leader. This is shown in Figure 3.8 (c).

![Figure 3.9 Sequence of ROMRP operations](image-url)

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The change in leadership is first intimated to the new leader along with the SEL calculated for the new leader. The new leader then informs the group members about the group leadership migration and makes them update their routing tables. The complete operations of the protocol are explained in Figure 3.9. This leads to avoid reconstruction of multicast tree and the associated control packets transmission for reconstruction. This certainly increases the packet delivery ratio and reduces the control overhead. The energy level negotiation between the group leader and other members carried out using group hello packets and hence the control overhead is still decreased.

Energy level negotiation need energy level request, energy level reply, SEL calculation and communication, and new leader update operations. The packet formats for these operations are explained below.

**Energy Level Request**

Whenever a multicast group member takes the responsibility of the group leader, it needs to send periodic GROUP HELLO (GRPH) messages with new sequence number to all the group members. The GRPH message is sent for every GRPH INTERVAL time. Before sending the GRPH, the group leader verifies its energy level to check whether it has reached the threshold energy level. In case the SEL goes below threshold value, group leader sends a modified GROUP HELLO for ENERGY (GRPH_E) packet intimating the group members that the group leader requests for the group member energy levels. The modified GRPH packet format for GRPH_E is shown in Figure 3.10. The E bit is set in the GRPH_E packet.

**Energy Level Reply**

Whenever the multicast group node receives a GRPH_E message, it checks the multicast sequence number of the group to verify that the request is latest or not. If GRPH_E message is the latest packet, the node calculates its residual energy level and the same communicated to the group leader through unicast ROUTE REQUEST.
(RRQ_E) message. The RRQ_E message contains Energy level of the sender with the E bit set to 1. Figure 3.11 shows the packet format of RRQ_E packet.

The E bit set in the RRQ_E packet indicates to the intermediate nodes that the packet carries the energy information of a node. Therefore, the request packet is unicast to the group leader and no ROUTE REPLY is sent back to the sender even if the intermediate node is a member of the group.

<table>
<thead>
<tr>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type</td>
<td>U</td>
<td>O</td>
<td>E</td>
</tr>
<tr>
<td>Group Leader IP address</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multicast Group IP address</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multicast Group Sequence Number</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 3.10 GRPH_E Packet format of ROMRP

<table>
<thead>
<tr>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type</td>
<td>J</td>
<td>R</td>
<td>G</td>
</tr>
<tr>
<td>Other fields as specified for MANODV</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 3.11 RRQ_E Packet format of ROMRP

**Safe Energy Level Calculation**

Safe Energy Level is a threshold Energy Level which is set with the group leader. SEL for a new leader is calculated as follows:

\[
SEL_{NODE} = \min (EL_{NODE} / 2, \min (EL_{NODE1}, EL_{NODE2}, EL_{NODEx})),
\]

where \(EL_{NODE}\) is Energy Level of a group node and \(EL_{NODEx}\) is the Energy Level of group members other than the node for which SEL is being calculated. For a new
node to become group leader, the SEL is defined as the minimum of half of its EL and the minimum of EL value of other group members. The basic idea behind choosing SEL as above is to ensure that the group leader must continue its responsibilities until the least powered member node is present in the multicast group.

The RRQ_E messages received by the group leader contain the EL of other nodes and the hop count (the number of hops between the node and the current group leader). The group leader then stores the EL information along with hop count of the nodes to identify the probable new leader. The group leader then ranks the members based on their energy levels with the maximum energy level member set with value 1. The group members are also ranked based on hop count with the lowest hop count member set with value 1. The new group leader is selected with the minimum value of sum of two rank values. This is to ensure that the newly selected leader is not only with maximum energy level but also closer to the previous leader and hence do not increase the routing overhead. The hop count is also used for selecting the new member so as to avoid a far away member becoming the leader of the multicast group.

**Communicating SEL**

Once the group leader selects the new leader for the group, it unicasts a ROUTE REPLY (RREP_E) to the newly selected group leader. The RREP_E packet contains the SEL value for the new leader with L bit set to indicate that it is a group leader migration packet. The packet is intended to the newly chosen group leader. The packet format is shown in Figure 3.12 for RREP_E:

```
<table>
<thead>
<tr>
<th align="center">Type</th>
<th align="center">R</th>
<th align="center">L</th>
<th align="center">Reserved</th>
<th align="center">SEL</th>
<th align="center">Hop Count</th>
</tr>
</thead>
<tbody>
<tr>
<td align="center">0123456789012345678901234567890123456789012345678901</td>
<td align="center"></td>
<td align="center"></td>
<td align="center"></td>
<td align="center"></td>
<td align="center"></td>
</tr>
</tbody>
</table>
```

*Figure 3.12 RREP_E Packet format of ROMRP*
Figure 3.13 GRPH_U Packet format of ROMRP

New Leader Update

The new group leader on receiving the change of leadership intimation through RREP_E updates the GROUP LEADER TABLE for the new leader information and sends GROUP HELLO UPDATE (GRPH_U) packet to all the group members. The GRPH_U packet contains the new group leader's address, the group address and the sequence number with which the other group members update their GROUP LEADER TABLE values. Figure 3.13 shows the packet format of GRPH_U.

Using these control packets, the ROMRP effectively migrates the group leader before it is relinquished out of power in order to preserve the ongoing multicast session.

3.2.4 Simulation Environment

To study the performance of the ROMRP, the protocol has been simulated in a discrete event simulator namely, Network Simulator 2 (NS-2) and was compared with the MAODV protocol for packet delivery ratio, total energy consumption, energy per delivered packet and peak to mean ratio. These parameters were thoroughly analyzed for both the protocols by varying nodes in the network and with varying mobility speeds of the nodes. ROMRP operations are based on MAODV...
and hence the performances have been compared with MAODV itself. The simulation parameters and the performance analysis are discussed below

**Simulation Parameters**

The simulation designs a mobile network of 50 nodes placed randomly in a 1500m x 400m rectangular flat-ground area. The transmission range for the nodes were set to 250 meters and a two-ray ground reflection channel is assumed with a data rate of 2Mbps. Mobile nodes are assumed to move randomly according to the Random Waypoint Mobility model [75]. Two parameters, maximum node speed and pause time, determine the mobility pattern of the mobile nodes. Each node starts moving from a randomly selected initial position to a target point, which is also selected randomly within the simulated area. When a node reaches the target point, it stays there for the pause time and then repeats the movement. For our simulation, node maximum speed is chosen to be 1 meter/second and the pause time is set to zero which means that the nodes are continuously moving at a constant speed and may take diversions at any point of time. In our simulation, senders are assumed to be multicast sources and their corresponding destinations are randomly selected among 50 mobile nodes, where the number of destinations is varied from 10 to 40 to test the effect of the multicast group size on the performance.

The source sends a 256 byte multicast packet every 500 millisecond during the simulation. An omni-directional antenna having unity gain is used by the mobile nodes where the power utilized for transmission is 0.6 watts and for reception it is 0.3 watts. The initial energy of the nodes is set to 100 joules. The transmission power is set as 0.6 watts (joules/second) and the transmission energy consumed per second is 0.6 joules. The number of bits transmitted per second is $2 \times 10^6$ bits and energy consumed is 0.6 joules. Energy consumed for transmitting one bit is $0.3 \times 10^6$ joules and the energy consumed for transmitting one byte is $2.4 \times 10^6$ joules. The size of one packet is 256 bytes and energy consumed for transmitting one packet is $0.614 \times 10^3$ joules.
The experiments were conducted using two scenarios with varying mobility speed of the mobile nodes in order to study the effect of mobility speed. The experimental results were tabulated for both the scenarios and are given in Table 3.4.

Table 3.4 Simulation results of ROMRP for two scenarios

<table>
<thead>
<tr>
<th>Size</th>
<th>MAODV</th>
<th>ROMRP</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.7123</td>
<td>0.7452</td>
<td>98.1021</td>
<td>87.4532</td>
<td>0.0233</td>
<td>0.0196</td>
<td>1.1957</td>
</tr>
<tr>
<td>20</td>
<td>0.7245</td>
<td>0.8782</td>
<td>84.3488</td>
<td>82.4702</td>
<td>0.0155</td>
<td>0.0159</td>
<td>1.1789</td>
</tr>
<tr>
<td>30</td>
<td>0.6923</td>
<td>0.6493</td>
<td>183.2121</td>
<td>87.4832</td>
<td>0.0211</td>
<td>0.0231</td>
<td>1.1701</td>
</tr>
<tr>
<td>40</td>
<td>0.6805</td>
<td>0.5894</td>
<td>273.4124</td>
<td>262.0458</td>
<td>0.0238</td>
<td>0.0233</td>
<td>1.1493</td>
</tr>
</tbody>
</table>

3.2.5 Simulation Results and Discussion

The protocols ROMRP and MAODV were simulated in NS-2 and the experiments were conducted for different multicast group sizes of 10, 20, 30 and 40. Based on the experimental results, the performance analysis between ROMRP and MAODV has been carried out for energy efficiency and general performances. The energy efficiency is evaluated using the metrics Total Energy Consumption (TEC) and the residual energy through Peak to Mean Ratio (PMR). The general performances are evaluated using the Packet Delivery Ratio (PDR) and Energy per Delivered Packet (EDP) parameters. The above parameters have been analysed with varying network size and different mobility pattern. However, the energy efficiency of the new protocol is justified with the varying network size. The analysis of varying the mobility pattern affects both ROMRP and MAODV protocols in a similar manner and hence it is sufficient to consider only varying network size only.
Packet Delivery Ratio

PDR is the ratio between the number of packets actually delivered to the destination and the number of packets expected to be received. The ideal value of PDR is equal to 1 (one) and indicates that all the intended packets were exactly delivered to the destination. Figure 3.14 and Figure 3.15 shows the Packet Delivery Ratio for two different scenarios respectively. In the figures, the PDR of ROMRP is much higher than MAODV for all the multicast group sizes. On an average the ROMRP gives 28.33% and 26.14% improvement in terms of PDR compared to MAODV protocol in two scenarios respectively. The increase in PDR is not uniform in two scenarios i.e., when the group size is 20 and 30 the increase in PDR is marginally high and this may be due to initial placement of nodes in the simulation area and the direction of mobility. However, in all the cases the PDR of ROMRP is certainly more than MAODV. Similar behaviour is exhibited when the experiments were repeated with varying mobility patterns.

![Figure 3.14 Packet delivery ratio of ROMRP with 1 m/s mobility](image_url)
Figure 3.15 Packet delivery ratio of ROMRP with 10 m/s mobility

Total Energy Consumption

TEC is another parameter which is defined as the total energy consumed to construct and transfer data in the multicast tree. This metric represents the energy efficiency of a protocol and ROMRP aims at minimizing the TEC. Figure 3.16 and Figure 3.17 compares the TEC of ROMRP and MAODV for two scenarios. The graph shows that ROMRP consumes lesser energy compared to MAODV. On an average, ROMRP reduces the energy consumption by about 7.13% and 4.58% than MAODV in two different scenarios respectively in all the group sizes. The TEC is always less in ROMRP even there is a change in multicast group size and the network size itself. This is due to prevent the group leader alive without power depletion to avoid network partitioning. The group leader migration does not stop the network partitioning due to node mobility, however, the partitioning owing to group leader power depletion is avoided. Hence the control packet transfer and associated power consumption is reduced.
Figure 3.16 Total energy consumed by ROMRP with 1 m/s mobility

Figure 3.17 Total energy consumed by ROMRP with 10 m/s mobility
Energy per Delivered Packet

EDP is the ratio between the total energy consumption and the total number of delivered packets. EDP can be analyzed to better understand the tradeoff between energy consumption and packet delivery performance. A lesser EDP value suggests that the member nodes efficiently utilize the energy. Figure 3.18 and Figure 3.19 compares the EDP of ROMRP with that of MAODV for two scenarios. This parameter depicts similar behaviour as that of the PDR. However, in any group size the EDP is lesser in ROMRP by 29.68% and 24.45% than MAODV protocol in two different experimental scenarios.

![Graph comparing EDP of ROMRP and MAODV](image)

Figure 3.18 Energy per delivered packet of ROMRP with 1 m/s mobility

Peak-To-Mean ratio

PTM is the ratio between the energy consumption of the most utilized node and the average energy consumption of all other nodes. In an ideal situation, this ratio becomes 1 (one) when the total energy consumption is evenly distributed among the nodes in the network. In practical situations, the ratio is larger than 1 (one) as there are some nodes which are having additional responsibilities in the multicast tree construction and delivery of packets. The smaller value of PTM ratio...
indicates better energy distribution over the entire network, since the difference between energy of heavily used node’s and the average energy consumed by the remaining nodes is less. Figure 3.20 and Figure 3.21 compare the PTM for two scenarios. In the graphs though there is up and down trend in MAODV, on an average the ROMRP has around 1.43% and 2.17% less than MAODV in terms of PTM. To conclude, the ROMRP provides higher energy distribution than MAODV.

**Figure 3.19** Energy per delivered packet of ROMRP with 10 m/s mobility

**Figure 3.20** Peak-to-Mean ratio of ROMRP with 1 m/s mobility
The energy efficiency of multicast routing is generally provided through construction of minimum energy multicast tree and exploiting the sleep mode of the mobile nodes. In this research work a new approach in the shard-tree protocol by group leader migration has been proposed and developed. The protocol uses a centralized method for identifying the new group leader. The ROMRP gives better performance in terms of PDR, TEC, EDP and PTM ratios. Distributed solution for new group leader identification could be an alternative choice. But the increase in efficiency due to distributed solution will be negligibly small as the network size and multicast group size is less than hundred nodes.

3.3 Summary

In this chapter two protocols namely, PASMRP and ROMRP have been developed. PASMRP provides QoS multicast routing along with power awareness and scalability. The scalability is achieved by increasing lifetime of the network, and multicast session through power-based rerouting. ROMRP provides an energy efficient routing by reducing control messages using manager migration. These protocols have been compared with MAODV protocol which is widely referred by the researchers. The protocols outperform in terms of packet delivery ratio and control overhead in addition to QoS and Scalability.