Abstract—Energy must be significantly conserved in Mobile Ad hoc Networks (MANETs) by employing energy models. Majority of the energy models address only the hidden terminal issue, but result in higher power consumption due to increased collisions during packet transfer. The existing energy models for MANET are based on OLSR protocol and DE (Differential Evolution) – OLSR protocol with features like QoS (Quality of Service) optimization, accuracy of energy states, distributed clustering, and energy-efficient clustering. An energy model is proposed for MANET involving an Energy-efficient Optimized Link State Routing (EE-OLSR) protocol and a path maintenance scheme. The EE-OLSR energy model is based on a progressive search for the most energy-efficient path. This model reduces the routing overhead and path setup delay, and enhances the network lifetime. The path maintenance scheme uses a flooding mechanism to decrease the control message overhead and enhance the packet delivery. The beacon messages from the primary root nodes track the destination’s location. The path maintenance based EE-OLSR model consumes lesser energy compared to the existing energy models, with respect to nodal speed, packet size, average connection arrival rate, number of nodes, grid size and packet inter-arrival time.

Index Terms—Adjacent Cluster (AC), Cluster Head (CH), Immediate Neighbor (IN), Mobile Ad hoc Network (MANET), Optimized Link State Routing (OLSR), and Topology Control (TC).

I. INTRODUCTION

Mobile ad hoc network (MANET) is a self-configuring network of interconnected mobile devices. The energy consumed by the devices in the MANET is an important aspect which is handled by designing various energy-efficient routing protocols. The conventional minimum energy routing protocols involve transmission of signal packets to decrease the hidden terminal issue, as a consequence of using asymmetric transmission powers from different neighboring nodes. The signal packets consume higher power due to increased collisions during the packet transfer.

An energy model is proposed for MANET based on an Energy-efficient Optimized Link State Routing (EE-OLSR) protocol and a path maintenance scheme. The energy consumptions due to various factors are tracked to improve the performance during the path performance. The proposed scheme searches for the most energy-efficient path progressively. This significantly reduces the routing overhead, path setup delay, and enhances the peer-to-peer process.

The path maintenance scheme effectively maintains and repairs the path in case of link failure to reduce the routing overhead. The primary route nodes broadcast beacon messages containing the location of the destination node to their single hop nodes. This method decreases the routing messages by efficiently tracking the mobile destination node.

The remaining part of the paper is organized as follows: Section II involves the works related to the energy models for a MANET. Section III involves the detailed analysis of the path maintenance based Energy-efficient Optimized Link State Routing (EE-OLSR) energy model for MANETs. Section IV involves the comparison of the existing and proposed energy models for a MANET. The paper is concluded in Section V.

II. RELATED WORK

This section gives a brief overview of the existing energy models in a MANET. Toutouh and Alba proposed an energy-efficient routing protocol for Vehicular Ad hoc Networks (VANETs) [1], [2]. A QoS (Quality-of-Service) optimized version of OLSR is used with Differential Evolution (DE). Kunz and Alhalimi proposed an energy model for MANETs based on the accurate state information about available energy levels [3]. The energy levels are utilized as the QoS metrics for the routing decisions. A smart prediction technique is used to increase the accuracy of the energy levels under all traffic loads.

Dimokas, et al., proposed an energy-efficient distributed clustering model for improving the energy conservation in MANETs [4]. The clustering process forms a hierarchical structure over a flat MANET. The distributed clustering model is based on the residual energy of each node and the topological features of the
nodes. Minming, et al., proposed an energy-efficient clustering method for MANETs [5]. Residual energy, neighbor’s topology, relative mobility, and relative location of the nodes in a MANET, determine the capability of a node being a cluster head (CH). The cluster maintenance is performed by Distance Estimation Broadcasting, which estimates the distance between a cluster member and its CH. The least distance leads to lesser energy consumption during data transmission. An Off-Duty Threshold metric is used to restart the clustering operation.

Mian, et al., proposed an energy-efficient protocol for MANETs using IEEE 802.11 MAC (Medium Access Control) protocol [6]. The energy constraints for performing a random walk in the MANET are reduced by using a distributed next hop selection algorithm. Wei, et al., proposed a framework for heterogeneous MANETs known as Device-Energy-Load Aware Relay (DELAR) [7]. A heterogeneous MANET consists of normal nodes and powerful nodes. A cross-layer structured DELAR scheme is used to save energy by power control, a hybrid transmission scheduling, and power-aware routing. The power-aware routing protocol integrates the information regarding device heterogeneity, nodal load, and residual energy, to save energy. The hybrid transmission scheduling is an integration of contention-based and reservation-based MAC schemes. Mini-routing is imposed into the data layer and an asymmetric MAC (A-MAC) method supports the MAC-layer acknowledgments. The end-to-end delay performance is enhanced by a multi-packet transmission technique.

Wang, et al., an energy-efficient location service protocol is proposed for MANETs [8]. The efficiency of the location service protocol depends on the accuracy of position information of the destination node. The location service protocol is based on hierarchical hashing. The distance traversed by the query packets and location update is optimized by this protocol, which reduces the energy consumption. Tavli and Heinzelman proposed an energy-efficient real-time multicast routing protocol for MANETs [9]. The real-time multicasting architecture is known Multicasting through Time Reservation using Adaptive Control for Energy Efficiency (MC-TRACE). The architecture is an integrated cross-layer design between network layer functionality and MAC layer functionality. A passive mesh is used to enclose an active multicast tree in a MANET. Frequent sleeping periods and less redundant data receptions increase the energy efficiency.

Nand and Sharma proposed a probability based broadcasting for AODV (Ad hoc On-demand Distance Vector) routing protocol in MANETs [10]. This broadcasting scheme improves the network lifetime, by decreasing the energy consumption. The probability of rebroadcast is dynamically computed using threshold random delay and a node’s remaining energy. The energy information of nodes is estimated from the route request packet of AODV routing protocol. The total amount of energy consumed to receive a control message during a broadcast operation is greater than the amount of energy depleted to transmit the message [11].

De Pellegrini, et al., proposed optimal monotone forwarding schemes in delay-tolerant MANETs with multiple node classes [12]. Altman, et al., proposed optimal monotone forwarding methods in delay-tolerant MANETs [13]. The tradeoff between delay and energy consumption is modeled as an optimal control problem. The energy-delay tradeoff is modeled as an optimization problem on the basis of a fluidic approximation. The forwarding scheme provides a time-constrained delivery of a message under total energy expenditure constraints.

Yu, et al, proposed a key management scheme in tactical MANETs based on hierarchical identities [14]. The dynamic node selection process is modeled as a stochastic problem and the nodes are selected using a private key generator (PKG) under the security constraints and energy states. The conditions are addressed by a security model, energy model, and cost model. Yi, et al., proposed a multipath optimized link state routing (MP-OLSR) for increasing the load balancing and energy efficiency in MANET [15]. Gallina, et al, proposed a probabilistic energy-aware model for MANETs [16]. The model is based on Segala’s probabilistic automata combined with schedulers to determine the choices among the target probability distributions. An energy-aware preorder semantics is used to compare the energy consumption of different networks.

Díaz-Bañez, et al., analyses the problems in min-energy broadcast for MANETs [17]. For a given set of stations, the min-energy transmission range assignment is computed. Jin-Hee, et al, surveys the various trust management systems for MANETs [18]. A trust system must be asymmetrical and balance reliability, scalability, fault tolerance, and energy consumption.

Jinhua and Xin proposed a model and protocol for energy-efficient routing over MANETs [19]. This model enhances the energy efficiency by decreasing the routing setup time and routing overhead. An energy-efficient routing method known as Progressive Energy Efficient Routing (PEER) is proposed to enhance the performance during the path discovery process. Urgaonkar and Neely proposed a cell-divided model of a delay-tolerant MANET for analyzing the minimum energy function and network capacity region [20].

III. PATH MAINTENANCE BASED EE-OLSR MODEL

A. Architecture of EE-OLSR Energy Model

The flow of the Energy-Efficient-OLSR (EE-OLSR) energy model is given in Fig. 1. The major functions of the energy model are neighbor sensing and route maintenance. EE-OLSR protocol has an advantage of high
mobility and low bandwidth. The nodes periodically exchange the topology information to determine the routes from any source to any destination.

The transmission of the control messages in the network is limited by a multipoint relay (MPR) technique, involving the tracking of the information about the neighbors and topological information about the network. Each node maintains a routing table based on the information on neighbors and the topology of the network. The computation of the routing table is based on Dijkstra’s algorithm. The routing table is updated whenever a variation occurs in the network.

B. Path maintenance scheme

An effective route maintenance scheme is proposed based on quad-oriented forwarding algorithm. This is performed to enhance the data packet delivery ratio while decreasing the number of routing overhead messages through single hop neighbor beaconing of the primary route nodes.

1) Quad-oriented forwarding

The flow of the quad-oriented forwarding algorithm is given in Fig. 2. The location of each node in the MANET is recognized via GPS (Global Positioning System). The location of the primary route node is identified using a beacon message from the single hop neighbor node.

Node A comprises of information about its location \((x_A, y_A)\). Node A broadcasts its location related details using a beacon message. On receiving the information from node A, the nodes B and C store them in their respective routing tables. Four directions are considered along the diagonal of each four quadrants I, II, III, and IV. Here, node B locates the direction in quadrant III from node A and node A sets the position of the direction in quadrant I from node B. Similarly, node C locates the direction in quadrant IV from node A and node A determines the direction in quadrant II from node C. Quad directions are preferred because of lesser routing overhead and higher packet delivery ratio compared to other orientation variants.
ALGORITHM I – Path maintenance algorithm

**Messages:** Beacon (Mb), Request (Mrq), Reply (Mrp), and Error (Me)

**Input:** \( N = \) number of nodes, Node \( X_n \), where \( n = 1, 2 \ldots N \), \((x_d, y_d)\) \rightarrow destination location information, \( t_{\text{WAIT,Mrp}}\) \rightarrow \text{wait time of Mrp}

**Output:** Destination node \((X_d)\) and determination of primary route

```
begin
for each \( X_n \)
    if \((X_n)\) does not have \((x_d, y_d)\) 
        Process 1:
        Flood Mrq
        if \((X_n)\) is \( X_d \)
            Send Mrp
            Send Mb to single hop neighbor from primary route
            Establish primary route
            Transmit data
            Stop
        else
            goto Process 1
        end if-else
    end Process 1
else
    quad-oriented forwarding of Mrq
    Process 2:
    if \((X_n)\) is \( X_d \)
        Send Mrp
        Establish primary route
        Transmit data
        Stop
    else
        if \( t_{\text{WAIT,Mrp}} > 1 \)
            goto Process 1
        else
            goto Process 2
        end if-else
    end Process 2
end if-else
end for
```

Fig. 2. Quad-oriented forwarding scheme.
2) Path maintenance algorithm

This scheme uses four message types namely, beacon (\(M_b\)), request (\(M_rq\)), reply (\(M_rp\)), and error (\(M_e\)). Only the primary route nodes can transmit \(M_b\) to single hop neighbor nodes by specifying the hop limit of \(M_b\) to unity. \(M_{eq}\) and \(M_{ep}\) are used in the path discovery process, while \(M_e\) are used in the path maintenance process. The basic flow of the path maintenance algorithm is given in ALGORITHM I.

a) Local routing table

The local routing table in the path maintenance scheme is updated when it receives \(M_{eq}\), \(M_{ep}\), and \(M_e\). An example local routing table is given in TABLE I.

<table>
<thead>
<tr>
<th>IDd</th>
<th>Od</th>
<th>X_{n+1}</th>
<th>d</th>
<th>nh</th>
<th>ns</th>
<th>tl</th>
<th>State</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>II</td>
<td>24</td>
<td>123</td>
<td>5</td>
<td></td>
<td>264</td>
<td>VALID</td>
</tr>
<tr>
<td>43</td>
<td>IV</td>
<td>62</td>
<td>168</td>
<td>7</td>
<td></td>
<td>156</td>
<td>INVALID</td>
</tr>
<tr>
<td>82</td>
<td>I</td>
<td>43</td>
<td>75</td>
<td>6</td>
<td></td>
<td>221</td>
<td>VALID</td>
</tr>
</tbody>
</table>

The following describes the fields given in TABLE I:
- \(ID_d\): Destination node ID determined using the direction values from 1 to 4
- \(Od\): Orientation to destination
- \(X_{n+1}\): Next node
- \(d\): The distance between two neighbor nodes from under the nodal transmission range
- \(nh\): The number of hops to the destination node
- \(ns\): Automatic sequential numbers to update the route information
- \(tl\): Lifetime of the route details

An INVALID state is obtained when \(tl\) is zero and the respective routing table entry is deleted.

b) Path maintenance

The working of path maintenance in a MANET is shown in Fig. 3. When a multi-hop node moves to a single hop node, the multi-hop node becomes a single hop node. On the other hand a single hop node moving away from the primary route node by more than two hops becomes a multi-hop node. A difference between single hop nodes and multi-hop nodes is the reception of the \(M_b\) from one of the primary route nodes.

Node \(X_1\) transmits the location details of the destination node to its neighboring node \(X_2\). The location information is broadcast in an \(M_b\) every second to the neighboring nodes of node \(X_1\) by making TTL value equal to unity. Further the nodes \(X_2, X_3, X_4, X_5\) broadcast the beacon messages to their neighboring nodes containing the address and location details of the destination node. The single hop neighbor nodes from the primary route nodes create the routing tables with the routing information.

The aim of beacon messages is to determine the position of the destination node as soon as the path failure occurs along the primary route nodes. When a path failure occurs, a local repair procedure is executed as shown in ALGORITHM II.

In case of a link failure, an \(M_{eq}\) is broadcast to determine the destination node by setting TTL equal to two. When the destination node is not detected, a \(M_e\) is transmitted back to all active nodes that are a part of the disconnected link. The nodes that receive the \(M_e\) remove the route of the broken link for further communications. Suppose the source receives \(M_e\), it should reinitiate the route discovery process.

When a node along the primary path observes a link failure, the node sends an \(M_{eq}\) towards the direction of the destination. This path maintenance scheme would considerably decrease the routing message overhead.

3) Packet forwarding

When a source node determines the location of the destination node, a node from the routing table is chosen toward the destination direction. For a case of multiple nodes being chosen, the source nodes opts the node of the highest \(n_s\) and lowest \(n_h\). If there are still multiple nodes, the node with longer \(d\) is chosen. The local repair process is executed when there is no appropriate node for packet forwarding. The packet forwarding process with respect to quad directions is given in Fig. 4.
Fig. 3. Flow of path maintenance scheme.
The source node $S$ chooses a forwarding packet from the node in its transmission range.

Initially, node $S$ chooses nodes $A$ and $B$ possessing the same direction in quadrant I.

Next, if nodes $A$ and $B$ have similar $n_h$ and $n_s$, the source node compares the value of $d$ for nodes $A$ and $B$.

Finally, node $A$ is selected for forwarding the packet as it has a larger $d$ than node $B$.

### 4) Control routing overhead

Two new messages are used to find an alternative route to aid in case of link failures. The two messages are a control message and a control-ACK (Acknowledgement) message. There is no periodical update in the determined alternate node until the occurrence of a communication failure. This can lead to problems when the nodes are in high speed motion. So to avoid this, the primary nodes send a beacon message comprising of destination node’s location to their single hop neighbor nodes every second. This message transmission stops when the single hop neighbors move far away from the primary nodes.

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**ALGORITHM II – Local repair procedure**

<table>
<thead>
<tr>
<th>Messages:</th>
<th>Request ($M_{rq}$), Reply ($M_{rp}$), and Error ($M_e$)</th>
</tr>
</thead>
</table>
| **Input:** | $N =$ number of nodes, Node $X_n$, where $n = 1, 2$...
|           | $O_d$ → orientation to destination, $t_r$ → repair time, $X_s$ → Source node |
| **Output:** | Local repair by route reconfiguration |

**begin**

```
for each $X_n$
    Detect link failure
    Notify link failure to $X_i$
    if (Any alternative route)
        **Process 1:**
        Reconfigure the path
        Transmit data
        Stop
    end Process 1
    else
        Send $M_{rq}$ to $O_d$
        if ($t_r >= 0.15$)
            **Process 2:**
            Send $M_e$ to $X_i$
            Flood $M_{rq}$ for path reconfiguration
            Stop
        end Process 2
        else
            if ($M_{rp}$ is being received)
                goto **Process 1**
            else
                goto **Process 2**
            end if-else
        end if-else
    end if-else
end for
```

**end**

---

- The source node $S$ chooses a forwarding packet from the node in its transmission range.
- Initially, node $S$ chooses nodes $A$ and $B$ possessing the same direction in quadrant I.
- Next, if nodes $A$ and $B$ have similar $n_h$ and $n_s$, the source node compares the value of $d$ for nodes $A$ and $B$.
- Finally, node $A$ is selected for forwarding the packet as it has a larger $d$ than node $B$. 
IV. PERFORMANCE ANALYSIS

The path maintenance based EE-OLSR energy model is modeled in a network of 150 nodes arranged with a density of 94 nodes per square kilometer. The existing energy models considered for the survey analysis are DE-OLSR [1], [2], Energy-efficient proactive routing [3], Energy-efficient distributed clustering method [4], Random Walk with Distribution Selection algorithm (RW-DS) [6], DELAR [7], MC-TRACE [9], hierarchical identity based key management method [14], and PEER [19].

The nodal speed is varied from 1 m/s to 25 m/s. The path maintenance based EE-OLSR energy model is analyzed in terms of energy consumption for a set of nodal speeds, packet sizes, and connection arrival rates. The energy dissipation analysis for a set of nodal speeds is performed per packet, per node and on an average basis. The energy consumption of the system is analyzed for the specified number of nodes and grid size. The path maintenance based EE-OLSR energy model is also analyzed in terms of nodal energy consumption for a given set of packet inter-arrival time, and network lifetime for a given set of nodes.

The total energy consumed during the system modeling by DE-OLSR scheme [1], [2] is 6684.708 J, and by that of the path maintenance based EE-OLSR scheme is 6023.342 J. The amount of energy consumed by the radio to operate the transmitter or receiver ($E_{elec}$) is 50 nJ/bit by Energy-efficient distributed clustering method [4], and 43.23 nJ/bit by the path maintenance based EE-OLSR scheme. The amount of energy required to operate the transmitter amplifier ($E_{amp}$) is 100 pJ/bit per m² by Energy-efficient distributed clustering method [4], and 95.23 pJ/bit per m² by the path maintenance based EE-OLSR scheme.

Fig. 4. Packet forwarding process with respect to quad directions.
A. Energy consumption with respect to various parameters

The energy consumption is analyzed in the various energy models with respect to parameters like nodal speed, packet size, average connection arrival rate, number of nodes, grid size and packet inter-arrival time.

Fig. 5. Energy consumption analysis for a set of nodal speeds, (a) per packet analysis in the path maintenance based EE-OLSR scheme and PEER scheme [19], and (b) average energy consumption per node in the path maintenance based EE-OLSR scheme, DELAR scheme [7], and MC-TRACE scheme [9].

Fig. 6. Energy consumption analysis in the path maintenance based EE-OLSR scheme and PEER scheme [19], (a) for a set of packet sizes, and (b) for a set of average connection arrival rates.
1) Nodal speed
The energy consumption per packet is analyzed in terms of various nodal speeds for the path maintenance based EE-OLSR scheme and PEER scheme [19]. The average energy consumption per node is analyzed in terms of nodal speed for the proposed EE-OLSR scheme, DELAR scheme [7] and MC-TRACE scheme [9]. The comparative analysis is given in Fig. 5.

2) Packet size and connection arrival rate
The energy consumption is analyzed per packet in the path maintenance based EE-OLSR scheme and PEER scheme [19], for a set of packet sizes (bytes) and average connection arrival rates (per hour), and compared in Fig. 6.

3) Number of nodes and grid size
The mean consumed system energy for various numbers of nodes and grid sizes is analyzed in the path maintenance based EE-OLSR scheme and RW-DS scheme [6] and compared in Fig. 7.

4) Packet inter-arrival time
The nodal energy consumption rate is analyzed for a set of packet inter-arrival times in the path maintenance based EE-OLSR scheme and Energy-efficient proactive routing technique [3] and compared in Fig. 8.

![Fig. 8. Comparison of nodal energy consumption rate in the path maintenance based EE-OLSR scheme and energy-efficient proactive routing scheme [3] for various packet inter-arrival times.]

B. Network lifetime
The network lifetime is analyzed for various numbers of nodes in the path maintenance based EE-OLSR scheme and hierarchical identity based key management method [14] and compared in Fig. 9.
V. CONCLUSION

The conventional energy models for a MANET address only the hidden terminal problem, but fail to decrease the energy consumption due to the increased collisions during the packet transfer. The existing energy models for MANET are based on OLSR protocol and DE–OLSR protocol with features like QoS optimization, accuracy of energy states, distributed clustering, and energy-efficient clustering. An energy model for MANET is designed upon an Energy-efficient Optimized Link State Routing (EE-OLSR) protocol and a path maintenance

![Fig. 7. Mean consumed system energy in the path maintenance based EE-OLSR scheme and RW-DS scheme [6], (a) for various numbers of nodes, and (b) for various grid sizes.](image)

![Fig. 9. Comparison of network lifetime in the path maintenance based EE-OLSR scheme and hierarchical identity based key management scheme [3].](image)
scheme. The efficiency of the energy model is enhanced due to a progressive search for the most energy-efficient path. This model reduces the routing overhead and path setup delay, and enhances the network lifetime. The path maintenance scheme is based on quad-oriented forwarding algorithm with single hop beaconing from the primary route nodes. The path maintenance based EE-OLSR model consumes lesser energy compared to the existing energy models, with respect to nodal speed, packet size, average connection arrival rate, number of nodes, grid size and packet inter-arrival time.

REFERENCES


