Probabilistic and Link Based Energy Efficient Routing in MANET

M.Ilango[#1], A.V.Senthil Kumar[#2]
[1]Research scholar, Hindusthan College of Arts and Science College, Coimbatore.
[2]Director, Hindusthan College of Arts and Science College, Coimbatore.

Abstract- *Mobile Ad hoc NETwork (MANET) plays a major role in providing effective communication services for infrastructure less application through efficient routing. For this reason, many energy efficient routing algorithms are being developed as a promising solution. However, while developing efficient routing, redundant rebroadcasting poses significant problems. Therefore, effective routing without any redundant rebroadcasting is inherently necessary whenever a user transmits the packet on the channel. In this work to attain effective routing mechanism in Mobile Ad hoc NETwork without any redundant rebroadcasting, a method called, Probabilistic and Link based Energy Efficient Routing (PLEER) is presented. The Probabilistic Re-broadcasting mechanism in PLEER method reduces high channel contention causing redundant and average energy per packet by combining both neighbor coverage and probabilistic methods. The PLEER method therefore selects the best path in a network while transmitting the packet reducing the average energy per packet and end to end delay. Link based Energy Efficient Routing provides less redundant rebroadcast by means of avoiding network collision and contention which in turn increase the packet delivery ratio and network lifetime. Simulation results demonstrate that compared to other energy efficient routing, PLEER is an efficient method for reducing the average energy per packet and end to end delay in MANET. Extensive simulations show that PLEER outperforms other existing scheme in terms of successful data delivery and improve network lifetime in various scenarios.*

Keywords - *Mobile Ad hoc Network, Routing, Probabilistic Re-broadcasting, Routing overhead, Packet delivery ratio*

I. INTRODUCTION

In MANET, every mobile node works as both a transmitter and a receiver via bidirectional wireless links which does not require a fixed network infrastructure. Efficient designing of a routing protocol is one of the most required tasks in Mobile Ad Hoc Networks. Reliable Minimum Energy Cost Routing (RMECR) [1] identified an efficient routing by reducing the total energy required for end-to-end packet traversal using expected transmission count of data. Optimization of energy consumption was made in [3] by applying Maximum Independent Set (MIS) resulting in minimum congestion even for sparse networks.

As a result of various research works, MANET are possessing several good and effective routing protocols. Store Carry and Forward (SCF) [4] was investigated to provide a tradeoff between energy and delay in order to achieve maximum energy savings. However, the computational cost increased with the increase in redundancy. In [5] to reduce redundancy, global network information was used by applying adaptive forwarding strategy. This in turn resulted in the improvement of cost related to data delivery with respect to the destination nodes.

The convergent of internet have resulted in the optimal usage of energy during data transmission between nodes. In [6], energy efficient content based routing was followed by applying publish/subscribe middleware system in a distributed manner to optimize the energy variance. Though energy optimization was achieved, but at the cost of network performance. In [7], a routing approach based on the concept of grid was designed with the aid of grid supervisor node to ascertain the network performance. However, with multipath availability, network lifetime gets compromised. To improve the network lifetime, in [8], residual energy of the nodes were preserved by balancing the consumed energy.

In this work, we have introduced a Probabilistic and Link based Energy Efficient Routing method. Here, the mobile nodes calculate their forwarding probability for respective data packet based on the rebroadcast probability mechanism in a dynamic manner. This calculation is performed using exponential function which depends on neighbor coverage and the probabilistic method.

The rest of this paper is organized as follows. Section II introduces the most related work. In Section III, we briefly explain our network models, including the proposed Probabilistic and Link based Energy Efficient Routing method. The impact of PLEER method on the system performance and the simulations are conducted is in Section IV. We finally conclude this paper in Section v.

II.RELATED WORKS

In this section, we discuss related work on energy efficient routing mechanisms in MANET. Multi-hop propagation of data packets is a promising technique for improving routing efficiency and increasing the network lifetime of the nodes in the network. In [9], multi-hop beaconing forwarding strategies were applied to minimize the rate of collision and therefore improve the packet delivery ratio in Vehicular Ad Hoc Network (VANET). An analysis framework for routing performance in Delay Tolerant Networks (DTN) was presented in [10] using coloring process.

One of the most critical issues for Internet Service Providers (ISPs) is the consumption of the substantial power. It has been reported that the Information and Communication Technology consumes 2% to 10% of the world total electricity consumption. With the objective of reducing the power, energy efficient routing based on hop-by-hop [11] was introduced that addressed the problem of both energy consumption and traffic delay. In [12], energy-based efficient routing algorithm was designed based on multipath choice mechanism resulting in significant saving of multiple types of sensors.

Many researchers have also applied ACO algorithm to solve the routing problem in mobile ad hoc networks. Both the foraging behavior of the ant colony and trail using behavior was applied in [13] to minimize the communication overhead and energy consumption during routing in wireless sensor networks. An energy efficient buffer aware routing protocol was designed in [14] by modifying the spectral cluster algorithm to improve the delivery cost and node survival ratio.

In [15], an energy efficient spectrum sensing based on the Markov model was designed in Cognitive Radio Sensor Network (CRSN). With the Markov model-based mathematical modeling, energy consumption during routing was reduced. However, network lifetime remained unsolved. To address the issues related to network lifetime, in [16], Centralized Energy Efficient Distance (CEED) based routing protocol was designed to not only improve the network lifetime but also to increase the stability period.

Multi-hop selection algorithm was investigated in [17] to reduce the energy consumption and end to end delay for multi-hop body area networks. However, the computational complexity involved during the design of multi-hop selection was not concerned. In [18], a minimal increase network coding (MINC) algorithm was designed to minimize the computational complexity for dynamic networks. A review of energy efficient routing protocols was discussed in [19]. A Max-Min energy scheme to enhance the network lifetime and packet delivery ratio was presented in [20].

To address the solution to attain effective routing in mobile ad hoc network, in this paper, we propose a Probabilistic Re-broadcasting mechanism to reduce high channel contention causing redundant and routing overhead in the network by balancing energy consumption of each mobile node with the consideration about the network lifetime. Different from the classical energy efficient routing algorithm working with the residual energy to achieve energy efficiency and network lifetime, the reported algorithm here is constructed according to the link estimation that determines the minimum total energy cost between the source and destination nodes to achieve maximum lifetime of the whole network and packet delivery ratio.

III.THE PROPOSED PROBABILISTIC AND LINK BASED ENERGY EFFICIENT ROUTING

In this work, we have introduced a Probabilistic Re-broadcasting mechanism. Here, the mobile nodes calculate their forwarding probability for respective data packet and this calculation is performed via probability function which depends on the neighbor coverage and the probabilistic methods.

Let us model the MANET as a graph '$G = (V, E)$', where '$V = \{S_1, S_2, \dots, S_n\}$' represents the set of mobile nodes and '$E = (\{m, n\} | \, Dis\,(m, n) \leq R)$' is the set of edges that represents the mobile link between the nodes in the network. Here '$Dis\,(m, n)$' corresponds to the distance between the mobile node 'S_m' and node 'S_n' respectively, with 'R' representing the transmission radius.

We further consider the structure of MANET comprising of larger number of mobile nodes, where each mobile nodes in the network moves randomly. For example, node 'S' in figure 1 is the source node, node 'D' in figure 1 is the destination node with two neighboring nodes 'S_i' and 'S_j' in between the source node and destination node respectively. The following subsections provide an overview and the design details of the proposed Probabilistic Re-broadcasting mechanism.

A. Probabilistic Re-broadcasting mechanism

The Probabilistic Re-broadcasting mechanism in PLEER method minimizes the mobile nodes for high channel contention during routing and average energy per packet by combining both neighbor coverage and probabilistic methods. Figure 1 show the Probabilistic Re-broadcasting followed to attain effective routing mechanism based on the neighbor node coverage and the probabilistic methods.

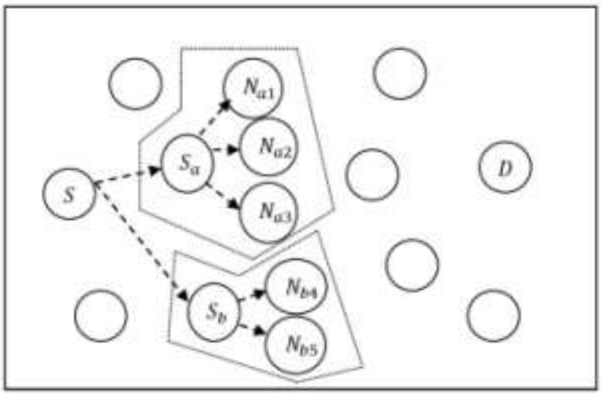

Figure 1: Probabilistic Re-broadcasting mechanism

For example, as shown in Figure 1, a source node 'S' requires a route to destination 'D'. The source node then broadcasts the route request '$RREQ$' message to the nodes in the network.

$$S \rightarrow RREQ \sum_{i=1}^{n}(S_i) \qquad (1)$$

Node 'S_i' and node 'S_j' receives the '$RREQ$' packet and identify its neighbor coverage nodes and sends the route reply message '$RREP$' to the source node.

$$\sum_{i=1}^{n}(S_i) \rightarrow RREP\ (S) \qquad (2)$$

Let us further assume that as shown in the figure 1, the node 'S_i' has neighbor coverage with three nodes 'N_{a1}, N_{a2}, N_{a3}' and node 'S_j' has neighbor coverage with two nodes 'N_{b4}, N_{b5}' respectively. The PLEER selects the neighboring node with maximum neighbor coverage so as to reduce the average end to end delay and is expressed as given below.

$$S \rightarrow MAX\ \sum_{i=1}^{n}\left(S_i(N_i)\right) \qquad (3)$$

Once the neighbour node through which the packets can be transmitted is decided based on the neighbour coverage, probabilistic rebroadcast algorithm is designed. The probabilistic rebroadcast algorithm not only takes into account neighbour coverage but also the number of nodes in determining the probabilistic rebroadcast for a given mobile node.

In this probabilistic rebroadcast algorithm, a mobile node upon reception of an unseen packet initiates a token 't' that records the number of times a mobile node receives similar packets. Such a token is held by each mobile node for each broadcast packet. This process is waited for a random delay 'd' which lies between '0' and 'd_n' seconds. If the token 't' reaches a predefined threshold value 'T', the data packet is dropped. Otherwise, the data packet is rebroadcasted with a rebroadcast probability 'RP'.

In the PLEER , the rebroadcast probability is selected in a dynamic manner. The use of this rebroadcast probability in a dynamic manner enables mobile nodes to make decisions on the rebroadcast probability with respect to number of neighbour nodes. Let us consider a network with area '$Area$', 'n' number of mobile nodes and 'R' representing the transmission radius. The total number of neighbor node 'α' is then computed as given below.

$$\alpha = (n * 1)\ \frac{R^2}{Area} \qquad (4)$$

From the total number of neighbour nodes 'α', the probability function for rebroadcast is evaluated with the aid of exponential function and is expressed as given below.

$$Prob\ Func(T) = e^{-\left(\frac{T}{\alpha}\right)} \qquad (5)$$

From (5), a high rebroadcast probability results in higher redundant rebroadcast whereas a low rebroadcast probability results in lower redundant rebroadcast. In addition, mobiles nodes with higher numbers of neighbours are assigned a high rebroadcast probability while those with lower number of neighbours are assigned a low rebroadcast probability. Figure 2 shows the probabilistic rebroadcast algorithm.

Input: Source node 'S', Destination node 'D', Neighboring Nodes 'NN', random delay 'd', predefined threshold 'T', Data Packet '$DP = DP_1, DP_2, \ldots, DP_n$'
Output: Reduces average end to end delay with minimum average energy per packet
1: **Begin** 2: **For** each Source node 'S' with Data Packet 'DP' 3: Source node broadcasts route request '$RREQ$' message using (1) 4: Neighboring nodes sends '$RREP$' message using (2) 5: Select neighboring node with maximum neighbor coverage using (3) 6: Initiate a token 't' 7: **If** token 't' reaches predefined threshold 'T' 8: Data packet 'DP' is dropped 9: **Else** 10: Data packet 'DP' is rebroadcasted with rebroadcast probability 'RP' using (5) 11: **End if** 12: **End for** 13: **End**

Figure 2: Probabilistic rebroadcast algorithm

As shown in the figure, by applying the probabilistic rebroadcast algorithm, the PLEER reduces high channel contention causing redundant and routing overhead. This is performed in the above algorithm by combining both neighbor coverage and probabilistic methods. In addition with the selection of probability function using exponential value in the PLEER , best paths are selected from the network while transmitting the packet which reduces average end to end delay and average energy per packet.

B. Link based Energy Efficient Routing

Once probabilistic rebroadcasting has been designed, an energy efficient routing has to be provided to improve the packet delivery ratio. The PLEER uses Link based Energy Efficient Routing mechanism with energy cost as the link metric and search for the path with minimum total transmission cost between the source node and the destination node in a continuous manner. As a result, a link based energy efficient routing is ascertained and ensured, selecting the best paths in a continuous manner and maintains the route continuously via link-based energy table (i.e. Table 1).

Table 1: Link-based energy table

Sender node	Receiver node	Energy cost between sender and receiver	Source node	Destination node
p	q	1	S_1	D_1
q	r	4	S_1	D_1
s	r	3	S_2	D_2
u	v	5	S_3	D_3
q	t	2	S_1	D_2

As shown in the table, for each data packet transmission, the PLEER records the following information in the link-based energy table: (a) sender node (b) receiver node (c) energy cost between the sender and the receiver node (d) source node (e) destination node respectively. Figure 3 shows the link-based energy routing followed in the PLEER .

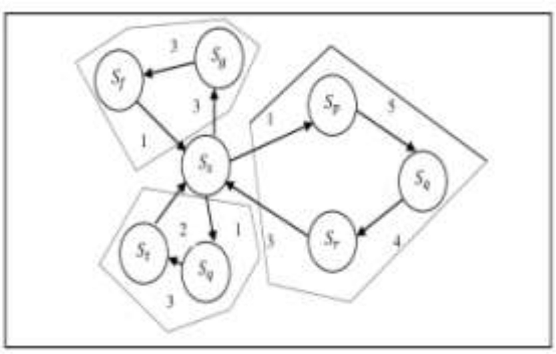

Figure 3: Link-based energy routing

From the Link-based energy table, the PLEER ascertains how a data packet passes through its neighbour nodes using the total link cost (i.e. energy cost). For example, node 'S_s' link energy table is in Table I. With the information obtained from the table, the node 'S_s' obtains the route information for transmitting three data packets. As shown in the figure, node 'S_s' records the route information for three data packets and is expressed below.

$$DP_1(S_1, D_1);\ DP_2(S_2, D_2);\ DP_3(S_3, D_3) \qquad (6)$$

From (6), the first data packet 'DP_1' uses three-hop route '$S_p \rightarrow S_q \rightarrow S_r$' in '$S_s$' neighbourhood and the energy cost is '$13J\ (1J + 5J + 4J + 3J)$'. The second data packet 'DP_2' uses another two-hop route '$S_q \rightarrow S_t$' and the total energy cost is '$6J\ (1J + 2J + 3J)$'. The third data packet 'DP_2' uses two-hop route '$S_g \rightarrow S_f$' and the total energy cost is '$7J\ (3J + 3J + 1J)$'. The link metric in the PLEER is estimated on the basis of minimum energy cost required for routing. Hence, for the above example, a link is established between '$S_s \rightarrow S_q \rightarrow S_t$' and the link estimation (based on the energy cost) for a source mobile node is expressed as given below.

$$L(S) \rightarrow \sum_{i=1}^{n} Min\ (EC\ (N_i) \cup\ S_i) \qquad (7)$$

From (7), a link '$L(S)$' is established where the total energy cost 'EC' between the neighbouring nodes 'N_i' and the source node 'S_i' is minimum. Figure 4 shows the link estimation algorithm.

Input: Source node '$S = S_a, S_b, \ldots, S_r \ldots$', Data Packet '$DP = DP_1, DP_2, \ldots, DP_n$', Neighbouring Node '$N_i$'
Output: Improved packet delivery ratio and network lifetime
1: **Begin** 2: **For** each Source node 'S' with data packet 'DP' 3: Obtain route information 4: Measure link estimation using (7) 5: **End for** 6: **End**

Figure 4: Link estimation algorithm

The link estimation algorithm as given above searches for the energy efficient route based on the link metrics (i.e. total energy cost). The minimum total energy cost between the neighbouring nodes is selected as the route for transmitting the packets. Therefore, the PLEER method provides less redundant rebroadcast by means of link estimation which in turn increases the packet delivery ratio and network lifetime.

IV. Simulations and Performance Evaluation

In this paper, we evaluate the performance of the proposed PLEER method and compared it with the existing Reliable Minimum Energy Cost Routing (RMECR).

A .Simulation Setup

Simulations have been performed by the NS-2 simulator version 2.35 on the Linux Fedora 13 [2].

The simulation parameters that are used for the simulation run are listed in Table 2.

Table 2: Factors used in the simulation

Simulation factor	Value
Protocol	AODV
Node density	5, 10, 15, 20, 25, 30, 35
Simulation time	100s
Pause time	10s
Mobility model	Random Way Point
Transmission range	300m
Network area	1000m * 1000m
Data packets	9 – 63
Packet size	7 MB – 49 MB

In one simulation iteration, the source node requests the routing path and transmits 9 data packets and the size of each packet ranges from 7MB to 49MB. This process is iterated 7 times and is terminated when all node route are identified. The initial energy of each node is uniformly distributed between 10 J and 100 J.

B. Performance Evaluation

The purpose of the simulations presented in this subsection is to study the effects of different network density on the performance of the two methods, PLEER and RMECR [2]. The number of nodes is 5, 10, 15, 20, 25, 30 and 35. The simulation parameters used to conduct experiment are as given below.

1. Energy per packet

Energy per packet is measured using the energy consumed by a single mobile node (for a packet) with respect to the total mobile nodes (all packets) in MANET. The energy per packet is mathematically formulated as given below.

$$EPP = \frac{Energy_{DP}}{Total_{DP}} \quad (8)$$

From (8), the energy per packet 'EPP' for efficient routing is obtained by the ratio of energy consumed for single data packet '$Energy_{DP}$' and total energy consumed for all the data packets '$Total_{DP}$' in the network. The consumption of energy per packet is measured in terms of Joules. Energy consumption for single sensor node using CS-FRS was observed to be 5.5J, 6.3J using ECD-WSN and 6.8J using ESCA-ESN. Therefore, the energy consumption using the two methods is as given below.

Table 3 represents the energy per packet efficiency using NS simulator and comparison is made with RMECR [1]. The data packets considered for experimentation ranges between 9 and 63. To better perceive the efficacy of the proposed PLEER method, substantial experimental results are illustrated in Figure 5. The PLEER method is compared against the existing RMECR [1].

Table 3: Tabulation for energy per packet

Data Packets (DP)	Energy per packet (J)	
	RMECR	PLEER
9	0.16	0.13
18	0.21	0.18
27	0.25	0.22
36	0.28	0.24
45	0.32	0.27
54	0.35	0.30
63	0.28	0.32

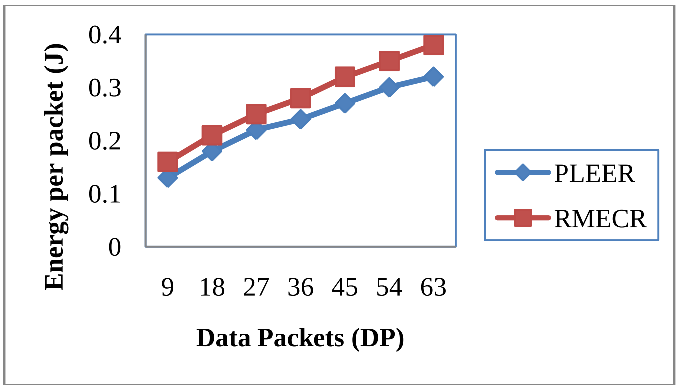

Figure 5: Energy per packet

Figure 5 shows the results of the energy per packet vs. the data packets for the two methods. The metric is increased as the size of data packets grows. The two methods achieve different energy per packet percentages with increasing size of data packets. Apparently, this figure shows that PLEER method significantly achieve lower energy per packet than Reliable Minimum Energy Cost Routing (RMECR) [1]. This is because to achieve significant routing the source node in the PLEER method according to the neighbor coverage having higher number of mobile nodes to send the data packets, which significantly reduce the number of the rebroadcast. This in turn reduces the energy per packet rate compared to RMECR. Therefore, improvement of about 17.71% is observed using PLEER method when compared to RMECR.

2. Average end to end delay

In MANET, increase in packet transmission also increases the traffic and congestion which leads to increase in end to end delay. Average end to end delay is referred as the time needed to transfer a data packet between a source mobile node and a destination node with respect to the data packet size.

$$D = \frac{Time\ (DN - SN)}{DP_{size}} \quad (9)$$

As listed in table 4, the PLEER method measures the average end to end delay during routing which is measured in terms of milliseconds (ms). The average end to end delay using PLEER method offer comparable values than the state-of-the-art methods.

Table 4: Tabulation for average end to end delay

Size of data packets (MB)	Average end to end delay (ms)	
	RMECR	PLEER
7	3.74	2.92
14	4.05	3.14
21	4.28	3.19
28	4.59	3.25
35	4.74	3.40
42	4.90	3.47
49	5.05	3.52

We measure the average end to end delay of all the packets with the packet size range in between 7MB and 49MB and calculate the variance of the average end to end delay when the simulation ends. For performance comparison, the configuration of energy distribution is not changed but fixed regardless of the method used. The average end to end delay using our method PLEER offer comparable values than the state-of-the-art methods.

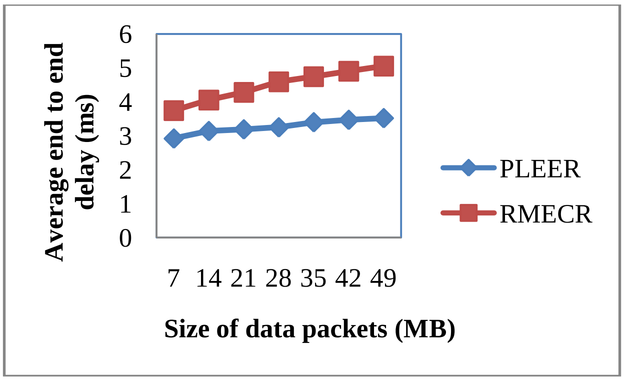

Figure 6: Measure of average end to end delay

The result for the variance of the average end to end delay of all the nodes in the network is shown in Figure 6. The metric is increased as the data packet size grows. However, the variance of the average end to end delay of the nodes under the PLEER method is smaller than that under the typical RMECR method. The simulation result shows that the nodes under the PLEER method with the packets ranging from 7MB to 49MB reduces average end to end delay during routing by applying the probabilistic rebroadcast algorithm. This is due to that the rebroadcast algorithm in PLEER method not only consider the neighbour coverage but also the node density while obtaining the probabilistic rebroadcast for a given mobile node. This in turn improves or reduces the average end to end delay during routing using PLEER method by 36.65ms compared to RMECR.

3. *Packet delivery ratio*

Packet delivery ratio measures the ratio of number of delivered data packet to the destination end. The packet delivery ratio is calculated by dividing the number of data packets received by the destination to the number of data packets sent. The packet delivery ratio is given as below.

$$PDR = \frac{DP_r}{DP_s} * 100 \quad (10)$$

From (10), 'PDR' represents the packet delivery ratio, measured using the data packet received 'DP_r' to the data packets sent 'DP_s' in terms of percentage (%). In table 5 we further compare the packet delivery ratio in MANET using the PLEER method. The experiments were conducted using seven test cases with 9 – 63 data packet that measures the packet delivery ratio in terms of percentage (%).

Table 5: Tabulation for packet delivery ratio

Data Packets (DP)	Packet delivery ratio (%)	
	RMECR	PLEER
9	90.21	96.35
18	89.32	95.18
27	86.12	92.14
36	83.38	89.38
45	80.29	86.21
54	76.14	83.25
63	74.21	80.14

Figure 7 given below shows the packet delivery ratio for PLEER method, RMECR [2] with respect to increasing number of packets in the range of 9 to 63. The packet delivery ratio is much affected by the increasing mobility speed in MANET and is as shown in figure 7.

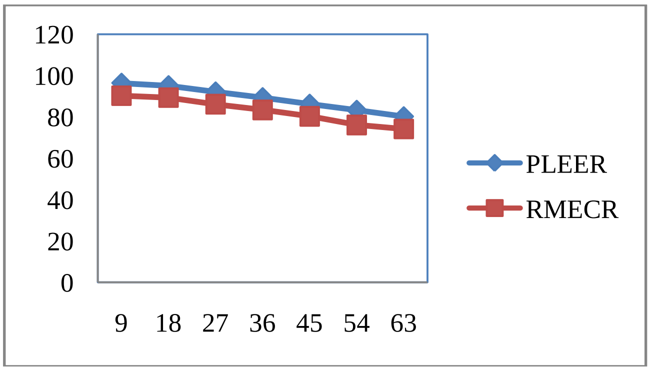

Figure 7: Measure of packet delivery ratio

The packet delivery ratio returned over RMECR decreases gradually as the number of packets gets increased. Due to the increase in the mobility rate, frequent changes occur in the topology, minimizing the network lifetime and henceforth increases the link failure rates. Packets may be dropped due to higher rate of frequent link failure in all the methods. Our proposed PLEER method outperforms the existing RMECR and achieves better performance because of choosing the minimum total transmission cost between the source and destination node. This in turn avoids the overhead for propagating control packets, which significantly minimizes the packet dropping rate over a long period of time. Therefore the packet delivery ratio using PLEER method is improved by 6.94% compared to RMECR.

4. Network lifetime

The network lifetime is mathematically formulated as given below.

$$NL = \left(\frac{S_{addressed}}{Total_S}\right) * 100 \quad (11)$$

From (11), the network lifetime 'NL' is measured using the total number of mobile nodes '$Total_S$' in the network and routing addressed for the mobile node '$S_{addressed}$' in MANET. Higher the network lifetime, more efficient the method is said to be and is measured in terms of percentage (%).Table 6 lists out the network lifetime by PLEER method and RMECR [2].

Table 6: Tabulation for network lifetime

Node density	Network lifetime (%)	
	RMECR	PLEER
5	81.48	91.35
10	77.14	88.34
15	77.39	85.21
20	70.32	81.32
25	68.23	79.14
30	67.14	77.35
35	65.31	75.29

Network lifetime is shows in figure 8 where PLEER method avoids selecting neighbour mobile nodes with minimum coverage and further uses link-based energy routing and prevents the nodes from the premature deaths. Therefore, in the PLEER method even for the higher node density and data packet retransmission scenarios of the high mobility network environment, it improves the network lifetime than RMECR and maintains the network in a more balanced way. Furthermore, the PLEER method shows outstanding and significant improvement for network lifetime because of its judicious choice of neighbor nodes based on the total link cost (i.e. energy cost). This in turn improves the network lifetime using PLEER method by 12.34% compared to RMECR.

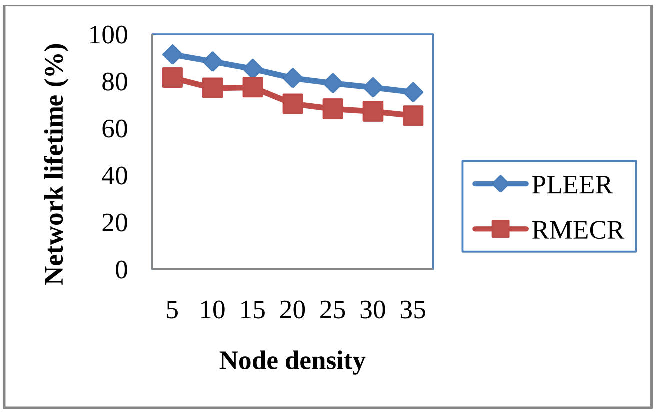

Figure 8: Measure of network lifetime

V. CONCLUSION

In this paper, we presented a Probabilistic and Link based Energy Efficient Routing (PLEER) for MANET and also proposed a Probabilistic Re-broadcasting for consistent efficient routing. In PLEER, routing is performed and data packets are forwarded to the neighbor node based on the neighbor coverage and probabilistic methods with dynamically computed probability called as rebroadcast probability. The rebroadcast probability function is calculated based on the exponential function. Finally, a link based energy efficient routing is investigated via link-based energy table. The performance of the PLEER has been compared against RMECR. Simulation results showed that PLEER method performs better than other representative energy efficient routing in terms of energy per packet, network lifetime, packet delivery ratio, and average end to end delay.

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