Energy Efficient Routing to Improve Lifetime in MANET: A Clustering Approach

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***Abstract*—**The energy aware routing in Mobile Ad Hoc Network (MANET) is now a critical issue due to limited battery power of mobile devices. A cluster based energy efficient routing for MANET is proposed here to improve the network lifetime. The clusters of the nodes in the network are obtained by assigning priority for each of the nodes. Using this priority, a cluster head (CH) is selected after successive iterations. Based on this clustering, a routing method is proposed in order to select the best possible energy efficient paths bypassing link breakages for data delivery. It includes the amount of residual energy and the data packet size under consideration for obtaining improved network lifetime. The experimental results show the effectiveness of the proposed scheme as compared to the existing routing protocols in terms of several performance metrics.

***Index Terms*—**MANET, energy aware, clustering, lifetime, routing

I. Introduction

Mobile Ad Hoc Network (MANET) is a collection of two or more wireless device/node(s) that can dynamically form a network to exchange information without using any existing fixed infrastructure [1]. All nodes in such a network act as a router or host and the connectivity between them may vary with time due to inclusion and exclusion of the nodes. MANETs have distinct advantages over traditional networks as they can easily be set up and dismantled.

In MANETs, the mobile nodes have restricted amount of battery power and therefore, the energy source of such communicating devices heavily rely on rechargeable battery [2]. Hence, the reservation of energy becomes an essential requirement for accomplishing efficient operations in MANET. Due to dynamic nature of the nodes, the mobility exhausts the remaining energy to a great extent [3]. Additionally, lesser energy dissipation in the network prolongs the lifetime of the nodes and henceforth, the network lifetime [4] also. The link breakage between the nodes leads to an unnecessary wastage of energy.

This energy requirement affects the network throughput as it is necessary to obtain higher throughput by prolonging the lifetime of the nodes in terms of their residual energy. So, it motivates to propose an approach for prolonging the lifetime of the network by reducing energy expenditure for routing. In order to increase network lifetime, the mobile nodes can be grouped into clusters which is a possible way for obtaining better stability and scalability [5]. The Cluster Head (CH) selection is an important criterion to be considered as the CH would be the co-coordinator in this architecture. It decreases routing overhead by updating the routing tables after topological changes. The responsibility of the CH is to manage the nodes of its own cluster and to communicate with other clusters and utilizes minimum transmission power by avoiding flooding of packets [6].

A cluster based routing in MANET is proposed here to obtain an improved network lifetime in the network. In order to obtain clusters of the nodes, the max heap clustering is used by assigning priority for each of the nodes. Such priority is defined in terms of the metrics like average power transmission, mobility factor. Using this priority, a CH is selected after successive iterations. A threshold value in terms of the number of ordinary nodes under such CH is defined such that unnecessary election of a node as CH would not lead to wastage of energy in the network. Now, a routing protocol is devised in order to select the best possible energy efficient paths bypassing link breakages for data delivery. The residual energy for each of the nodes is obtained from both of the initial and consumed energy of the node depending on the packet size. This amount of residual energy is compared with a threshold value for obtaining an efficient routing path. The experimental results show the effectiveness of the proposed scheme as compared to the existing routing protocols in terms of several performance metrics.

This paper is organized as follows: Section II discusses a literature review related to the proposed work. Section III concentrates on system model. The approach proposed for the work addressed in this paper is described in section IV. Various experimental results are shown in section V. Finally, the work is concluded in section VI with the direction of future scope.

II. Literature Review

Since recent years numerous clustered based routing protocols have been proposed and used in MANETs in order to reduce energy consumption [7]. These energy efficient routing protocols are used to improve the

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lifetime of the nodes and ultimately, it increases the network lifetime. There are two basic groups of these routing strategies such as proactive and reactive [8]. The first category maintains up-to-date routing information in routing tables at each network node, whereas the later one creates routes only when desired by the source node and it is maintained until the route is no longer needed or the destination is not at all accessible. Adhoc On Demand Distance Vector (AODV) [9] is such a reactive routing protocol which is preferably used due to its topological adaptability and to obtain higher network lifetime compared to proactive ones. In [10], the CH is selected depending on the node degree. However, it requires precise knowledge of the network status as the links change dynamically. This work may provide better throughput, however not preferred in energy saving. Another work in [11] requires introduction of an extra mobile node to work as a backup. However, this procedure requires sufficient amount of energy to be reserved for the network which would significantly affect the network lifetime by exhaustion of energy and hence increases the routing overhead. The work addressed in [12] needs much more energy in the process of maintaining a neighbours list. The EAER protocol proposed in [13] discovers an energy efficient route. However, it suffers from huge energy dissipation for making backward entry to downstream node and forwarding data packets to neighbouring nodes.

Some of the clustering algorithms used in various energy efficient routing procedures are introduced with respect to various aspects. The Least cluster change algorithm [14] based on lowestID/highest connectivity increases the cluster stability. However, re-clustering for single node increases the overhead. In the k-highest connectivity algorithm depending on highest degree, the re-clustering is less due to low rate of CH change. However, the upper limit of the number of cluster is not defined. Hence, the throughput decreases with the increase in the number of nodes. Another clustering algorithm known as Lowest ID algorithm selects the CH depending on only ID. In this method, some nodes are lost due to continuous power drainage for serving as CHs over a longer period of time.

Several clustering techniques focused primarily on k-means clustering algorithm [15]. However, our proposed work in this paper uses Max Heap clustering [16] rather than k-means as we need to specify the value of k under various topographies. Additionally, if the value of such k is very small, then there is a chance of putting dissimilar objects into same group and if it is large then more similar objects will be placed into different groups which decreases the network throughput and further exhaust the lifetime of the nodes. Furthermore, the routes require periodic updates in AODV and they are often easy to break in case of topology variations [17]. So, the routing method proposed in this paper is focussed on finding a route with minimized energy expenditure by measuring residual energy of the nodes which will be apparent from the subsequent discussions.

III. System Model

In this section, the modelling about network, energy and cluster for the proposed work are introduced as follows:

A. Network Model

A network comprising of ‘n’ number wireless nodes is considered here, in which each of these nodes represent individual mobile terminals characterized by their mobility and associated energy consumption for data transmission. This network can be viewed as a graph $G\ (V, E)$, where V and E denote the set of vertices and the set of edges respectively. A vertex in G represents a mobile terminal i.e., $n \in V$ and the connectivity between two nodes are considered as an edge in G. The degree of connectivity for each node and the distance between one-hop neighbours in G are denoted by $|D|$ and $Dist$ respectively.

The mobility (M_o) of each node represents the movement of nodes, and how their location, velocity and acceleration change over time. In order to measure such M_o, the difference between average speed (A_{vs}) of the nodes in final and initial location is estimated in $'t'$ time units. This can be presented as follows:

$$A_{vs} = \frac{Dist}{t} \tag{1}$$

$$M_o = A_{vs}\ (final) - A_{vs}\ (initial) \tag{2}$$

B. Energy Model

We have assumed that I_e denote the initial energy of a mobile node which poses before it takes part in the routing process. This I_e is basically the battery power of the node. This node requires an energy to transmit and receive data packets to/from other nodes in the network. These are denoted by T_e and R_e respectively and these can be obtained by the following:

$$T_e = (Transmitted\ power * Packet\ size)\ /\ 2 \times 10^6 \tag{3}$$

$$R_e = (Receiving\ power * Packet\ size)\ /\ 2 \times 10^6 \tag{4}$$

In both (3) and (4), $Packet\ size$ denotes the size of the packet for data transmission and receive and the denominator is as per [18].

The consumed energy (C_e) by the node is the sum of T_e and R_e. The residual energy (R_{es}) is obtained as the remaining energy after transmitting and receiving data by the node. So, the parameters C_e and R_{es} can be presented as follows:

$$C_e = T_e + R_e \tag{5}$$

$$R_{es} = I_e - C_e \tag{6}$$

The average transmission power (P_{av}) is the transmission power utilized by nodes to transmit data to intermediate nodes. As the force per unit time is constant, so the power can be measured in terms of the average distance which can be expressed in our work as follows:

$$P_{av} = \frac{\sum Dist}{|D|} \quad (7)$$

C. Cluster Model

The nodes in the network are grouped into a set of clusters according to the construction procedure of max-heap. In each cluster, there is a CH which performs inter-cluster and intra-cluster communication. Except the CH in a cluster, the ordinary nodes exist as immediate neighbour of CH and can act as CH when required. This selection of CH can be obtained by the minimum value of the weight (W_t) associated with the nodes in a specific cluster. This weight (W_t) parameter is represented by the following.

$$W_t = w_1.M_o + w_2.P_{av} \quad (8)$$

In (8), w_1 and w_2 are represented as weight factors and the sum of these weight factors value is equal to 1 i.e., $w_1 + w_2 = 1$. The node with lowest weight $[\min(W_t)]$ is assigned with maximum priority value and is selected as the CH which is placed at the root of the tree. The CHs are defined to associate with a threshold number of nodes so that the CHs do not lose all its energy and become out of order. A node once selected as the CH must be operational for a certain amount of time. Until all the nodes are assigned with their role either as a head or a member, the entire process is iterated. When an intermediate node departs from the cluster or CH gets exhausted, tree balancing is needed.

IV. Proposed Approach

The entire procedure for the approach proposed here is divided into two sequential phases - Phase I and Phase II. In Phase I, a clustering algorithm to the set of nodes present in the chosen network area of size "d" is executed. The CH in a cluster is selected according to the principle discussed earlier. A routing approach is followed in Phase II. In order to obtain an improved output as a result of this routing approach, energy perimeters like T_e, R_e, C_e and R_{es} are taken into consideration. Now, the algorithms for Phase I and Phase II are described next.

A. Phase- I

The input network is initialized with $'n'$ number of nodes. The weights (W_t) for the nodes are obtained using (8). Then, these W_t of the nodes with a priority value (P_r) are associated in such a way that min (W_t) is assigned as max (P_r) in CH creation ( ). Thereafter, the entire cluster formation is initiated using the max-heap creation( ). This approach places the CH based on max (P_r) at the root of the tree. The function cluster creation( ) is called to check whether a CH is adhering to its threshold limit satisfying which the nodes in the tree are assigned to a cluster C_i . This procedure of cluster formation is described by the following algorithm.

Algorithm: Phase-I

CH creation( )
Start
for i = 0 to n // n is the number of nodes
begin
calculate $W_t[1]$, $W_t[2]$, $W_t[3]$..... $W_t[n]$ *//assign the weight of each node, where W_t is the weight*
Assign priority P_r for each node, such that node with lowest weight is assigned the highest priority $P_r[1]$,$P_r[2]$,....$P_r[n]$
end for
Max-heap creation( )
Root <-- $P_r[A]$ // *highest priority node*
Left <-- $P_r[L]$
if (P_r [Left] > P_r[Root])
{
interchange P_r[Left] <--> P_r[Root]
}
Right <-- $P_r[R]$
if (P_r[Right] > P_r[Root])
{
interchange P_r[Right] <--> P_r[Root]
}
Cluster creation( )
while(n)
{
if(Th_value satisfied)
P_r[Root] <-- CH
assign it to cluster C_i
else
Max heap cluster( )
end
}

B. Phase-II

After formation of clusters, Phase-II is initiated by probing the nodes for their I_e and set the packet size for data transmission. This procedure is continued by calculating several parameter values according to (3), (4), (5) and (6). The R_{es} value obtained by (6) must be higher than a certain threshold (0.30% of the highest R_{es}) to be involved in the routing path, failing which the node and the packet will be discarded from the route selection process and will be considered for further passes. This entire routing scheme in Phase-II can be described by the following algorithm.

Algorithm: Phase-II

Routing( )

Begin

Initialize the initial energy and packet size
for i = 1 to n // *n is the number of nodes in a cluster C_i*

For j= 1 to n-i
Calculate T_e and R_e
Calculate C_e
Calculate the R_{es}
if(R_{es}[j] > R_{es}[j+1])&&(Th_value satisfied)
node consider in routing path and packet forwarded
else
discard the node and the packet from route selection process
end if
end for
end for

C. Analysis & Time Complexity

Four cases can be considered to analyse Phase-I. These are summarized in the following Table I.

TABLE I: VARIOUS CASE ANALYSIS OF PHASE-I

Number	Case	Analysis
case-1	A new node arrives in the cluster	The tree is re-balanced according to weight matrix. Its maximum priority can even replace the existing CH.
case-2	A leaf node departs from the cluster	It does not require tree balancing.
case-3	An intermediate node departs from the cluster	Immediate balancing requires to maintain tree structure.
case-4	CH departs from the network	New CH needs to be identify though it has less chance.

Considering such cases with their analysis, the time complexity of the phase-I turns to be O (n log n), where ‘n’ denotes the number of nodes in the network. In Phase-II, it is obvious that the superfluous flooding is reduced by the proposed routing scheme. The time complexity to find such routes in a network is O(d), where ‘d’ denotes the network diameter. Hence, the overall time complexity of the proposed approach is sum of these complexities in two phases i.e., $O\ (n\ log\ n\ +\ d)$.

V. SIMULATION STUDIES

In this section, the performance of proposed approach is evaluated using NS-2.35 simulator. Such performance for our proposed routing protocol is compared with AODV and EAER. In order to execute these experiments, the following simulation environment is considered.

A. Simulation Set-up

The network area of 800m × 800m has been considered for the simulation, where the nodes are randomly deployed to move freely in the network environment and out of which the source nodes generate data packets at constant bit rate (CBR). Various parameter values considered in experiments are given in Table II.

TABLE II: SIMULATION PARAMETERS

Parameter	**Value**
Area	800 x 800
Simulation Time	300 sec
Traffic Type	CBR
Packet Size	512/1024/2048/4096
Antenna Model	Antenna/Omni Antenna
Initial Energy	160J
Transmitting Power	18W
Receiving Power	9 W
Sense Power	3 W
Movement Trace	ON
Threshold matric	0.30%

B. Performance Metrics

In order to measure the effectiveness of our proposed routing method, the following metrics are defined with respect to this work. These are as follows:

- ***Throughput***: Throughput is defined as the rate of successful data delivery to the destination. So, it can be expressed as
  Throughput (bits/Sec) = Number of Received data / Duration of data transmission
- ***Packet Delivery Ratio:*** The packet delivery is the ratio between the total number of packets delivered to the destination and the number of packets sent from the source.
  Packet Delivery Ratio (%) =Number of packets delivered to the destination / Number of packets sent from the source node
- ***End-to-End Delay:*** End-to-End delay is the average time taken for a packet to reach the destination from the source node.
  End to End Delay (ms) = (Delay for each data packet) / Total number of delivered data packets
- ***Network Lifetime:*** Network Lifetime is defined as the time until the first node or last node in the network depletes its energy. So, it is obviously dependent onR_{es}.

C. Experimental Results

In the proposed approach, the routes are obtained by considering R_{es} of the nodes. If the nodes energy level is greater than the threshold value and the packet size is adhering to a threshold size, then only the node is considered for routing; if not then the node is discarded from the route selection process.

The size of the packet to be transferred is considered important while accounting the total amount of routing packets exploited throughout the simulation. Our proposed routing protocol solves the link failure problems and route recovery so that they can adapt to dynamic changes of network topology and hence minimize the routing overhead. This overhead also depends on the packet delivery and end to end delay. Packet delivery ratio for the protocols decreases as the speed increases. This is because, at higher speeds, link breakage may occur more frequently and therefore a packet loss fraction is increased. The packet delivery ratio in our proposed work as shown in Fig. 1 is the highest among the other two existing protocols such as AODV and EAER. Link breakages are less frequent due to a substantially high PDR.

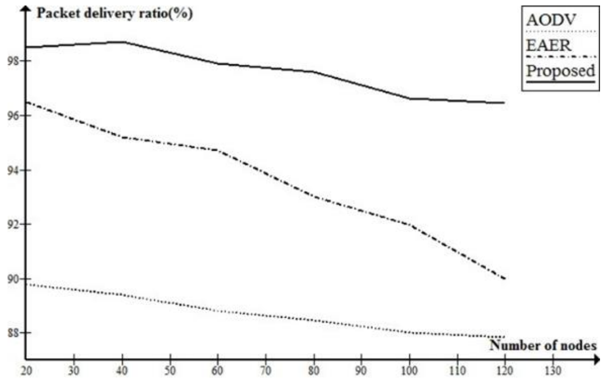

Fig. 1. Packet delivery ration vs. number of nodes.

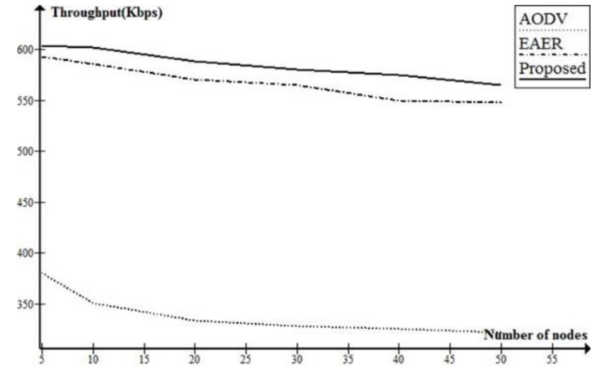

Fig. 2. Throughput vs. number of nodes.

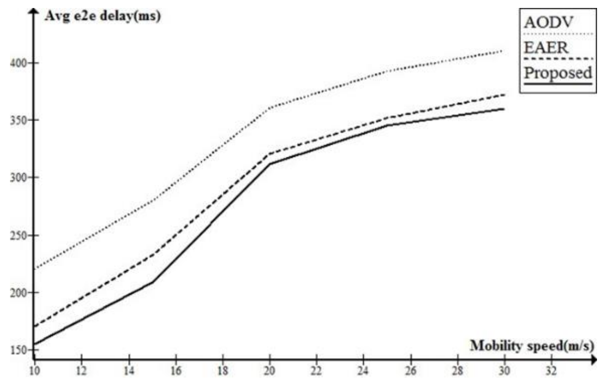

Fig. 3. Average end to end delay vs. mobility.

The throughput ensures the reliability of packet delivery. It is well-known that throughput increases when connectivity is better. As the network lifetime is more, the throughput is naturally increased. Our proposed work as shown in Fig. 2 obtains a higher throughput as compared with both AODV and EAER due to higher PDR and network lifetime. Our proposed work shows minimum average end-to-end delay as compared to EAER and AODV protocols in Fig. 3, as it increases the network lifetime. However, with the increase in mobility, more energy is washed out due to which an increase in delay is observed in all the protocols.

The proposed algorithm exhibits a higher network lifetime compared to other two protocols, which is shown in Fig. 4, as the node with limited residual energy are avoided from continuous usage. The network lifetime is found out to be proportional to the residual energy left in the nodes which eventually varies with the packet size. For larger packet size, the remaining energy is less and hence the lifetime of the network also.

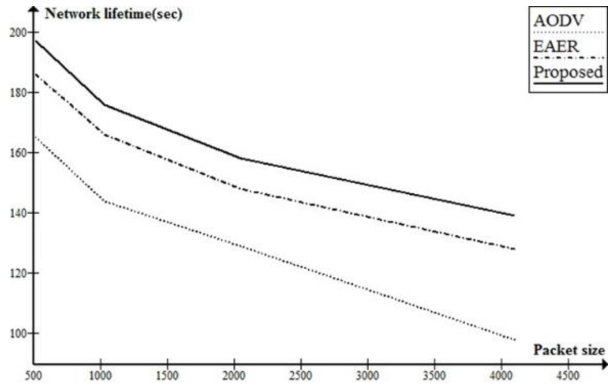

Fig. 4. Network lifetime vs packet size.

VI. Conclusion

In this paper, a cluster based energy efficient routing protocol is proposed for achieving consistent data delivery with reduced energy, increasing the lifetime of the network. In our proposed methodology, the clustering algorithm developed indicates that a node having lowest weight *W* among its 1-hop neighbours in the tree structure consumes minimum battery power and utilizes minimum transmission power to serve its neighbours and is chosen as the CH. This approach ensures the flooding of packets to be avoided at the cluster level which in turn results into higher scalability. The proposed routing protocol conserves the energy in each of the node in the network by forwarding the data packets of smaller size. Hence the lifetime of the network is improved accordingly compared to several existing protocols as observed from the simulation results. Our future work would investigate how this approach leads to a better network resource utilization with optimization of the activities in the nodes towards energy conservation.

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