An Efficient Route Discovery Mechanism for Mobile Ad Hoc Networks

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Summary
Many Energy Efficient routing protocols and Energy saving protocols for ad hoc networks have been proposed to date. The 'life time of the network' has become important criterion. Many protocols are proposed for effective routing based on remaining energy. At the same time many protocols are proposed for saving energy at the nodes which maximizes the network life time. One of such recently proposed energy saving protocol is Energy Saving Dynamic Source Routing (ESDSR). ESDSR mostly concentrates on increasing network life time by integrating the advantages of transmission power control approach and load sharing approach. But it does not consider the more likeliness of the node to be exhausted because of number of existed routes through it, in route discovery process. This may result in selecting the route more likely to be exhausted. This contradicts the 'increment in life time of the network' and also may affect other existing routes. In this paper we propose a new route discovery mechanism which considers the presence of the node in other routes and its effect on its lifetime. Our proposed protocol ensures route with maximum life time and also maximizes its life span.

Key words:
Ad hoc network; Energy Efficient; Energy saving; routing protocol.

1. Introduction

An ad hoc network is a group of wireless mobile devices (nodes) that communicate with each other in a collaborative way, over multi-hop wireless links, without any stationary infrastructure or centralized management. Examples of ad hoc networks include: disaster situations such as earthquake and flooding, where the rescue teams need to coordinate themselves without the availability of fixed networks, soldiers in battlefield exchanging tactical information, and entrepreneurs in a meeting sharing business information. Many routing protocols have been proposed for ad hoc networks. The mechanisms they adopt are traditionally categorized as table-driven and on-demand. On-demand routing protocols query a route when there is a real need (demand) for it. In contrast, table-driven routing protocols maintain routing information for all network destinations independently of the traffic to such destinations.

The features of Source routing, effective route discovery and route maintenance made the Dynamic Source Routing (DSR) protocol to be widely accepted. Most ad hoc mobile devices today operate on batteries and hence, power consumption becomes an important issue. In DSR, there is less consideration of power consumption and network life time. This reason made the energy efficient routing and energy saving protocols to be proposed and studied extensively in recent years. One of such Energy saving protocol is ESDSR. In ESDSR, the nodes which has a 'tendency' to 'die out' very soon are avoided during the route discovery phase. The 'tendency' of the node to 'die out' is expressed quantitatively as the ratio of the remaining battery energy and the current transmit power of the node. But there may arise some cases where a node with higher rate of depletion may be selected since this protocol does not consider traffic through the node. This leads to quick die out of the node also affecting other routes through the node. We propose an Efficient route discovery mechanism for ESDSR, which helps in selecting a route with maximum life and also maximizes its life span further by reducing the power consumption. Section 2 gives a brief review of some of the Energy Efficient Routing Protocols and Energy saving protocols. Section 3 describes our proposed route discovery mechanism. Section 4 gives an algorithm for our proposed route discovery mechanism.

2. Review of Energy efficient Routing Protocols

The task of finding and maintaining routes is nontrivial in mobile ad hoc networks since host mobility causes frequent unpredictable topological changes. A path that was considered to be optimal at a given instant might not work at all a few moments later. The lifetime of MANET depends mainly on each mobile node's battery capacity. With this constraint, routing algorithms must provide energy-efficient route discovery and maintenance mechanisms. Even when all the traffic is routed through minimum energy paths to the destination, it may not maximize the lifetime of the network. The reason is that some nodes may constitute several routes at the same time, quickly running down batteries and shortening the lifetime of the network. In this context, several energy efficient routing protocols proposed to date.

2.1 Minimum Total Transmission Power Routing (MTPR):

This protocol was proposed in [1] and used the transmission power $P(n_i,n_j)$ between hosts n_i and n_j as a metric to obtain the route with the minimum total power.

The total power for route '*l*',

Manuscript received Sepember 5, 2008
Manuscript revised October 20, 2008

$$P_i = \sum_{i=0}^{D-1} P(n_i, n_{i+1})$$

for all node $n_i \in$ route, where n_0 and n_D are the source and destination nodes, respectively. The desired route k can be obtained from

$$P_k = \min_{l \in A} p_l$$

where A is the set containing all possible routes.

The total transmission power is an important metric because it concerns the lifetime of mobile hosts. However, it has a critical disadvantage. Although this metric can reduce the total power consumption of the overall network, it does not reflect directly on the lifetime of each host.

2.2 The minimum battery cost routing (MBCR): This protocol was proposed in [2] which use remaining battery capacity of each host as a metric to describe the lifetime of each host.

$$f_i(c_i^t) = \frac{1}{c_i^t}$$

The battery cost R_j for route i, consisting of D nodes, is

$$R_j = \sum_{i=0}^{D_j-1} f_i\left(c_i^t\right)$$

Therefore, to find a route with the maximum remaining battery capacity, we should select a route i that has the minimum battery cost.

$$R_j = \min \left\{ R_j \mid j \in A \right\}$$

where A is the set containing all possible routes.

The disadvantage of MBCR is that since only the summation of values of battery cost functions is considered, there may be a possibility that a route containing nodes with little remaining battery capacity may still be selected.

2.3 The min-max battery cost routing (MMBCR): This protocol was proposed in [2]. The battery of each host will be used more fairly than in previous schemes.

Battery cost R_j for route j is redefined as

$$R_j = \max_{i \in route\_j} f_i\left(c_i^t\right)$$

Similarly, the desired route i can be obtained from the equation

$$R_j = \min \left\{ R_j \mid j \in A \right\}$$

But the disadvantage is that since the minimum total transmission power is not considered in MMBCR, the power consumption may be more to transmit user traffic from a source to a destination, which actually reduces the lifetime of all nodes.

2.4 The conditional minimum battery cost routing (CMMBCR): The reduction in power consumption and improvement in network lifetime can not be achieved simultaneously in the above said protocols. To achieve these two goals simultaneously, a Conditional Max-Min Battery Capacity Routing (CMMBCR) [3] was proposed. The CMMBCR is a hybrid protocol that tries to arbitrate between the MTPR and MMBCR. A threshold γ was defined which range between 0 and 100. If the battery capacity is more than γ then the CMMBCR works like MTPR which can achieve the power consumption and if the battery capacity is less than γ, then the CMMBCR works as MMBCR to increase the network lifetime.

$$R_j \geq \gamma \quad \text{For any route} \quad j \in A$$

the desired route i can be obtained from the equation

$$R_j = \min \left\{ R_j \mid j \in A \right\}$$

In other words, the CMMBCR scheme chooses a shortest path if all nodes in all possible routes have sufficient battery capacity and when the battery capacity for some nodes goes below a predefined threshold (γ), routes going through these nodes will be avoided, and therefore the time until the first node power-down is extended.

2.5 The maximum residual packet capacity battery cost routing (MRPC): This protocol was proposed in [4]. MRPC is conceptually similar to the MMBCR, but MRPC identifies the capacity of a node not just by the residual battery capacity, but also by the expected energy spent in reliably forwarding a packet over a specific link i.e., MRPC accommodates scenarios where the nodes can adjust their transmission power dynamically (based on the distance between the nodes), and also incorporates the effect of link layer error rates and consequent packet re-transmissions.

$$C_{i,j} = \frac{B_i}{E_{i,j}}$$

Where,

B_i: residual battery capacity at node i.

$E_{i,j}$: transmission energy required by node i to transmit a packet over link (i,j) to node j.

$C_{i,j}$: node-link metric

Accordingly, the "maximal lifetime" associated with route P is seen to be:

$$Life_P = \min_{(i,j) \in P} \left\{ C_{i,j} \right\}$$

The main contribution in [4] is in showing how power aware routing protocols must not only be based on node specific parameters (e.g. residual battery energy of the node), but must also consider the link specific parameters (e.g. channel characteristics of the link) as well, to increase the operational lifetime of the network. Such a formulation better captures scenarios where link transmission costs also depend on physical distances between nodes and the link error rates. Using a max-min formulation, MRPC selects the path that has the largest packet capacity at the 'critical' node (the one with the smallest residual packet transmission capacity).

2.6 The Conditional maximum residual packet capacity battery cost routing (CMRPC): Ref. [4] also present CMRPC, a conditional variant of MRPC that switches from minimum energy routing to MRPC only when the packet forwarding capacity of nodes falls below a threshold. CMRPC performs minimum energy routing as long as the remaining battery power at the constituent nodes lie above a specified threshold. Beyond this point, CMRPC switches to the MRPC-based max-min path selection algorithm. The CMRPC is conceptually similar to CMMBCR. The CMRPC algorithm differs from CMMBCR in that the cost-functions at all times include the link-specific parameters (e.g. error rates).

2.7 Power aware Source routing Protocol (PSR): A Power-aware source routing (PSR) was proposed in [5] to extend the network lifetime of a MANET which is a new source-initiated (on-demand) routing protocol for mobile ad hoc networks.

It finds a route π at route discovery time t such that the following cost function is minimized:

$$C(\pi,t)=\sum_{i\in\pi}C_i(t)$$

where,

$$C_i(t)=\rho_i\left\{\frac{F_i}{R_i(t)}\right\}^{\alpha}$$

ρ_i : transmit power of node i
F_i : full-charge battery capacity of node i.
R_i : remaining battery capacity of node i at time t

The PSR is derived from DSR. The difference is that in DSR, because the route selection is done based on a shortest path finding algorithm (i.e., those with the minimum number of hops), only mobility of the nodes may cause a selected path to become invalid. In contrast, both the node mobility and the node energy depletion may cause a path to become invalid in PSR.

2.7 Energy Saving Dynamic Source Routing (ESDSR): In ESDSR [9] the energy level and the transmit power level of a node are taken into account while making routing decision. Here the source node finds a route R(t) at time t such that the following cost function is maximized:

$$C(R,t)=\max\left(R_j(t)\right)$$

$$R_i(t)=\min\left\{\frac{E_i}{P_{ti}}\right\}$$

where, $R_j(t)$ is the minimum energy to transmit power ratio for the path j, Ei is remaining energy of node i on the discovered path and Pti is the transmit power of node i on the discovered path. $R_j(t)$ is also called as 'minimum expected life'.

On Route Reply, this protocol estimates its expected life using (E_i / P_{ti}). It replaces the value recorded in the route reply if the calculated value is less than the recorded value. It repeats the same process for other Route Reply from other routes. The source then selects the path which has higher 'minimum expected life' instead of choosing the shortest path.

In this protocol, link by link power adjustment is accomplished. The advantage is that almost 70% of energy can be saved if we use controlled transmit power instead of fixed transmit power [9].

Although network lifetime increases using this protocol, since packets are not sent via minimum hop, the average number of hop will increase. Hence delay may be higher in ESDSR in compare to DSR.

Including extra information in the packet header changes packet structure and increases packet size. Modifying the IEEE 802.11 MAC layer protocol will cost a change in the network card and firmware.

3. Our proposed Route Discovery mechanism

The objective of our proposed route discovery mechanism is to select a route which last for a long time and thus avoiding network failure because of extinction of nodes. This mechanism also extends the useful service life of a MANET. This is highly desirable since extinction of certain nodes leads to a possibility of network partitions, rendering other live nodes unreachable.

Since our route discovery mechanism is derived from the route discovery mechanism of ESDSR, the basic operation of ESDSR is described briefly below.

3.1 ESDSR

The Energy Saving Dynamic Source Routing (ESDSR) protocol is an enhancement of Dynamic Source Routing (DSR) protocol. The routing decision is made in ESDSR based on the ratio of remaining energy of the node to the transmitting power. The cost function is defined as

$$C(R,t)=\max\left(R_j(t)\right)$$

$$R_i(t)=\min\left\{\frac{E_i}{P_{ti}}\right\} \quad (1)$$

Where $R_j(t)$ is the minimum value of the ratio of remaining energy to the transmit power for the path j.

The path which has maximum R_j is selected as the route and the route is used for sending data. The process can be better illustrated using figure 1.

Consider a simple four node network as shown in figure 1. Assume node 1 is the source and node 4 is the destination. Node 2 and node 3 are intermediate nodes with remaining energy E_2 and E_3 and transmit powers P_{t2} and P_{t3} respectively. In the route discovery phase the source node 1 broadcast the route request. The intermediate nodes 2 and 3 forward every route request that it receives adding their own IDs to the route in the route request. The destination node 4 accepts each route request, reverses the route and sends route reply. The intermediate nodes 2 and 3 that receive route reply calculate the ratio of their remaining energy to their transmitting power which is termed as 'expected life'. If the calculated value is less than the value in the route reply it replaces. The source node 1 receives the route replies from nodes 2 and 3, and selects the path which has maximum 'minimum expected life'. This means that the nodes that are more likely to die out in each path are considered and the time required for their exhaustion are compared. The path containing the node which lasts for a long time is selected as the route. For example, assume the values E_2 / P_{t2} is 0.3 and E_3 / P_{t3} is 0.1. Here node 3 is more likely to die out than node 2. Hence the path 1-2-4 is selected. This increases the lifetime of the network.

Once the route formation is completed the source node sends the data packet through the route. Every node records its transmit power in the data packet and sends it to the next hop. When the next node receives the data packet at power P_{recv}, it reads the transmit power P_t and calculates the transmit power for the previous node using the formula

$$P_{req} = P_t - P_{recv} \quad (2)$$

For successful reception of the packet and to overcome the fluctuations in the channel a threshold power and margin value are added to the P_{req} calculated. The node records the value in ACK packet and sends it. The transmitting node, after receiving the ACK packet reads P_{req} and stores it in a power table. The node uses the transmit power stored in the table to send next data packet. This means that the packet is transmitted only with required power, reducing the energy consumption at each node and thus increases lifetime of the route.

3.2 Our Proposed route discovery mechanism

The ESDSR does not consider the rate of depletion of the node and the minimum power required to send the packet at each node to form a route. This may lead to the selection of route with lesser lifetime. We propose a new route discovery mechanism which considers the number of already existed routes through the node and the minimum power required instead of transmission power. The cost function may be defined as

$$C(R,t) = \max\left(R_j(t)\right)$$

$$R_i(t) = \min\left[\frac{E_i}{P_{req-i} + \sum P_{r-i}}\right] \quad (3)$$

Where E_i is the remaining energy capacity, P_{req-i} is the minimum required power for the node i to transmit packet to the next node in the corresponding hop, P_{r-i} is the minimum required power for the node for other routes through it.

Every node maintains a power table as shown in Fig. 3, which records number of other routes through that node and minimum required transmit power (P_r) for the next hop in the corresponding route. P_r is the minimum required transmit power learnt from its next node through ACK packet during data transmission in the corresponding route. The table is updated by discarding the routes from which no packet is received in a threshold timeout.

The route discovery mechanism can be illustrated using figure 2. Node 1 is the source node and node 6 is the destination node. The source initiates the route discovery by broadcasting the route request packet. Here the source node records its transmit power value in the route request packet. The nodes 2 and 4 in the transmission range of node 1 receive the route request at different receiving powers (P_{recv}). The nodes 2 and 4 read the transmit power (P_t) recorded in the packet and calculate the minimum required transmit power P_{req} for the node 1 to send a packet to them using (2).

The nodes store the calculated P_{req} in their route request table. Then the nodes replace the transmit power in the RREQ packet with their transmit power values and rebroadcast the route request. The nodes 3 and 5 receiving route request from the nodes 2 and 4 respectively repeats the same process. Finally the destination node 6 also calculates the P_{req} of the previous node in the path mentioned in each route request. The destination node records the calculated P_{req} in the reply packet and sends route reply to the source node 1 by reversing the path. Consider the route reply through the path 6-5-4-1. The node 6 records the P_{req} of node 5 in the reply packet and sends it. The node 5 receiving the route reply reads the P_{req}. All the P_r values are read from the power table and the cost function (R_j) is calculated using (3). The calculated value is recorded in the reply packet. Then the node replaces the P_{req} in the packet with the value stored in the table for the corresponding previous node i.e., node 5 records the P_{req} of node 4 and sends the route reply. The node 4 repeats the same process and compares its cost function (R_j) to that in the packet. If it is less than that of the value stored in the packet, it replaces it. Finally the source node selects the path with maximum cost R_j recorded in the route replies. And the remaining paths are stored in a cache in the order of their cost functions for future use. This ensures selecting an optimum path with maximum life time. The link by link power adjustment is done while transmitting data packets through the route in a similar way followed by ESDSR protocol. The power table is updated each time the node receives the packet from its neighbor. Our proposed route discovery mechanism helps in selecting the efficient route with maximum lifetime and then reduces the energy consumption at each node. Consider a simple four node network as in the figure 1 where node 1 is the source and node 4 is the destination. Assume all the nodes have equal remaining energy and take it as unity. Assume that no node is in other route. Hence

$$\sum P_{r-i} = 0 \text{ for all nodes.}$$

Let the transmit powers, P_{t2} be 0.3 and P_{t3} be 0.4. And the minimum powers required, $P_{req-2-4}$ be 0.25 and $P_{req-3-4}$ be 0.2. According to equation 1, for the path 1-2-4 the Rj is equal to 1/0.3 = 3.33 and for the path 1-3-4 the R_j is equal to 1/0.4 = 2.5. Since R_j of the path 1-2-4 is greater than R_j of the path 1-3-4, ESDSR selects the path 1-2-4 having maximum R_j as the route. But the node 3 requires lesser transmission power to node 4 ($P_{req-3-4}$ = 0.2) than node 2 ($P_{req-2-4}$ = 0.25) i.e., $P_{req-3-4} < P_{req-2-4}$. Then the energy consumption per packet will be more in path 1-2-4 than in path 1-3-4. Thus the path 1-3-4 will be having more lifetime than the selected path 1-2-4. The above mentioned disadvantage can be overcome using our proposed mechanism. According to the equation 3, for the path 1-2-4 R_j is equal to 1/(0.25 + 0) =4 and for the path 1-3-4

R_j is equal to 1/(0.2 + 0) =5. Our proposed mechanism selects the path 1-3-4 having maximum R_j as the route. As P_{req} is always less than P_t all the cases can be satisfied by considering the equation 3. Thus the effective route can be formed by considering the minimum required transmit power.

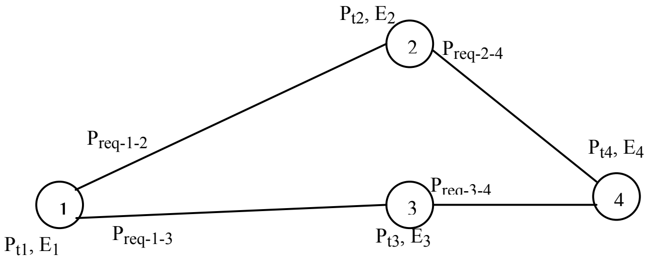

Fig 1. Example network without considering other routes through the nodes.

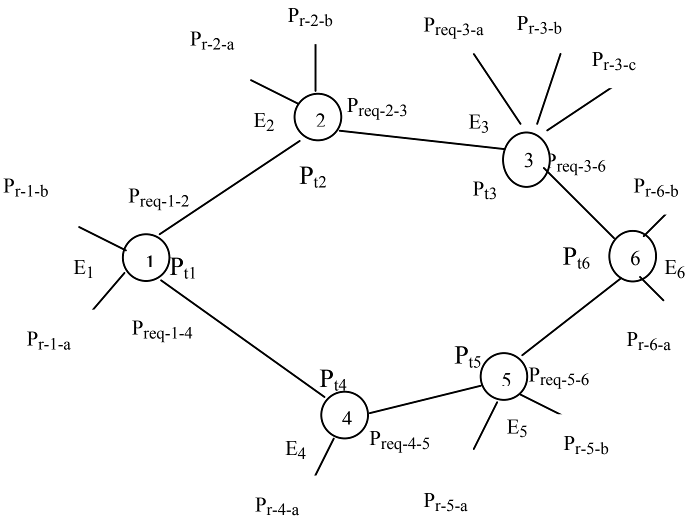

Fig 2. Example network considering the nodes with other routes.

S.No	***Route***	***P_{req} for next hop***	***Time of last received packet***

Fig 3. Power table.

Let us now consider the existence of the other routes through the nodes. For this consider a network as in figure 2 where node 1 is the source node and node 6 is the destination node. The transmit power of i^{th} node is referred as P_{ti} , remaining energy levels as E_i , the corresponding minimum required power for the other routes through the node as P_{r-i-k} and the minimum required power to the next hop as $P_{req-i-j}$. Let the transmit powers of nodes 2,3,4 and 5 be

$$P_{t2}=0.3,\ P_{t3}=0.4,\ P_{t4}=0.5,\ P_{t5}=0.3$$

Let the P_{req} is same for all the hops. For calculation purpose, approximate it to zero. Assume all the nodes have equal remaining energy E_i=1. And let the minimum transmit powers of each node for other routes be

$$\sum P_{r-2}= 0.4,\ \sum P_{r-3}= 0.6,\ \sum P_{r-4}= 0.2,\ \sum P_{r-5}= 0.4$$

According to equation 1, R_j of node 2 is equal to 1/0.3 = 3.33, R_j of node 3 is equal to 1/0.4= 2.5 and hence the minimum R_j of the path 1-2-3-6 is 2.5. Similarly, R_j of node 4 is 1/0.5= 2 and R_j of node 5 is 1/0.3= 3.33. Hence the minimum R_j of the path 1-4-5-6 is 2. ESDSR selects the path 1-2-3-6 having maximum R_j. but the nodes 2 and 3 in the path 1-2-3-6 are included in more other routes than the nodes 4 and 5 in the path 1-4-5-6. Hence the depletion rate of the nodes 2 and 3 will be more compared to that of the nodes 4 and 5. This means the path with lesser lifetime is selected.

According to equation 3, which considers $\sum P_{r-i}$, the R_j of node 2 is 1/0.4=2.5 and the R_j of the node 3 is 1/0.6=1.66. Hence the minimum R_j of the path 1-2-3-6 is 1.66. Similarly R_j of node 4 is 1/0.2 = 5 and R_j of node 5 is 1/0.4=2.5. Hence the minimum R_j of the path 1-4-5-6 is 2.5. Our route discovery mechanism selects the path 1-4-5-6 having maximum R_j. Thus an effective route can be formed by our mechanism which will be having longer life time. All routing packets are transmitted at default power and in order to maintain the normal operation of MAC layer, all MAC layer packets are also transmitted at default power. Our proposed mechanism satisfies the MTPR protocol which considers total transmission power to be the minimum and also satisfies MBCR, MMBCR and CMMBCR that consider the cost function which is the inverse of battery capacity to be the minimum. The protocol MRPC which considers link specific parameters is also satisfied. In our route discovery mechanism, the same energy saving technique of ESDSR is followed. Thus, the proposed mechanism integrates the advantages of the energy efficient protocols and overcomes the individual drawbacks.

4. Algorithm for our proposed route discovered mechanism

Table 1: Route Request Phase

Source Node:

1. Record P_t in RREQ packet.
2. Broadcast RREQ.

Intermediate Node:

1. Observe P_{recv} of the RREQ packet and read P_t recorded in the RREQ packet.
2. Calculate P_{req} and store in RREQ table.
3. Replace P_t in the RREQ packet with its own P_t.
4. Forward the RREQ.

Destination Node:

1. Observe P_{recv} of the forwarded RREQ packet and read P_t recorded in the packet.
2. Calculate P_{req} and record it in the corresponding RREP.
3. Send the RREP by reversing the route in the RREQ.

Table 2: Route Reply Phase

INTERMEDIATE NODE:

1. Read P_{req} recorded in RREP packet.
2. Read the values of P_r from the power table.
3. Calculate R_j.
4. *If already* R_j *recorded in the RREP packet*
   Compare calculated R_j with recorded R_j
   If calculated R_j < *recorded* R_j
   Replace recorded R_j with calculated R_j
   Else
   Record the R_j in the RREP.
5. Replace P_{req} in RREP packet with the P_{req} (stored in RREQ table) of the previous node in the route mentioned in RREP.
6. Forward the RREP.

Source Node:

1. Receive all RREPs for threshold timeout.
2. Compare all the R_j s recorded in the RREPs.
3. Select the route with maximum R_j.

Table 3: Data Transmission Phase

SOURCE NODE:

1. *If the first data packet*
   P_t = default power P_t.
   Else
   Read P_{req} from Power table.
   $P_t = P_{req}$
2. Record P_t in Data packet.
3. Send Data packet through the selected route at power P_t.
4. *If ACK received*
   Read P_{req} in the packet
   If already P_{req} *for the hop exists in Power table*
   Update the table.
   Else
   Add it to the table.

Intermediate Node:

1. Observe P_{recv} of the Data packet.
2. Read P_t recorded in Data packet.
3. Calculate new P_{req}.
4. Record the new P_{req} in ACK packet and send it.
5. *If the first data packet*
   P_t = default power P_t.
   Else
   Read P_{req} from Power table.
   $P_t = P_{req}$
6. Replace P_t in Data packet.
7. Forward the Data packet.
8. *If ACK received*
   Read P_{req} in the packet
   If already P_{req} for the hop exists in Power table
   Update the table.
   Else
   Add it to the table.

Destination Node:

1. Observe P_{recv} of the Data packet.
2. Read P_t recorded in Data packet.
3. Calculate new P_{req}.
4. Record the new P_{req} in ACK packet and send it.

5

In this paper we proposed an Efficient Route discovery for Energy Saving Dynamic Source Routing protocol. It improves the route discovery mechanism of ESDSR to select a better route having greater lifetime. The ESDSR helps in transmit power control of a selected route while our route discovery mechanism helps in both selecting a route with maximum life time and better utilize its lifetime by controlling transmit power. Although the proposed route discovery mechanism increases the lifetime of a network further, the other drawbacks of ESDSR also apply. Since extra information is added to the packet header the packet size may increase and the packet structure may vary. We are investigating new methods to increase the performance of our proposed route discovery mechanism.

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