Power-aware Source Routing Protocol for Mobile Ad Hoc Networks

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Abstract. *Ad hoc wireless networks are power constrained since nodes operate with limited battery energy. To maximize the lifetime of these networks (defined by the condition that a fixed percentage of the nodes in the network "die out" due to lack of energy), network-related transactions through each mobile node must be controlled such that the power dissipation rates of all nodes are nearly the same. Assuming that all nodes start with a finite amount of battery capacity and that the energy dissipation per bit of data and control packet transmission or reception is known, this paper presents a new source-initiated (on-demand) routing protocol for mobile ad hoc networks that increases the network lifetime. Simulation results show that the proposed power-aware source routing protocol has a higher performance than other source initiated routing protocols in terms of the network lifetime.*

Categories and Subject Descriptor

C.2.2 [Computer-Systems Organization]:Network Protocols

General Terms

Algorithms

1 Introduction

A Mobile ad hoc Network (MANET) is composed of a group of mobile wireless nodes that form a network independently of any centralized administration, while forwarding packets to each other in a multi-hop fashion. Since those mobile devices are battery-operated and extending the battery lifetime has become an important objective, researchers and practitioners have recently started to consider power-aware design of network protocols for the Ad hoc networking environment. As each mobile node in a MANET performs the routing function for establishing communication among different nodes the "death" of even a few of the nodes due to energy exhaustion might cause disruption of service in the entire network.

In a conventional routing algorithm, which is unaware of energy budget, connections between two nodes are established between nodes through the shortest path routes. This algorithm may however result in a quick depletion of the battery energy of the nodes along the most heavily used routes in the network. The main focus of this paper is to design a power-aware routing protocol that balances the traffic load inside the network so as to increase the battery lifetime of the nodes and hence the overall useful life of the ad hoc network.

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The paper[1] is structured as follows. Section 2 gives a brief classification of the broad domain of ad hoc routing protocols. Section 3 contains review of some research in low power ad hoc routing protocols. Section 4 describes the rationale and details of the proposed Power-aware Source Routing (PSR) algorithm. Section 5 elaborates on the simulation environment, the implementation and the experimental results comparing PSR with DSR, another popular ad hoc routing technique.

2 MANET Routing Protocols

Routing protocols in ad hoc networks are categorized in two groups: *Proactive (Table Driven)* and *Reactive (On-Demand)* routing.

2.1 Proactive (Table-Driven) Routing Protocols

These routing protocols are similar to and come as a natural extension of those for the wired networks. In proactive routing, each node has one or more tables that contain the latest information of the routes to any node in the network. Each row has the next hop for reaching a node/subnet and the cost of this route. Various table-driven protocols differ in the way the information about a change in topology is propagated through all nodes in the network. Several proactive routing protocols are addressed in [1], [2] and [6].

2.2 Reactive (On-Demand) Protocols

Reactive routing is also known as on-demand routing. These protocols take a lazy approach to routing. They do not maintain or constantly update their route tables with the latest route topology. Examples of reactive routing protocols are the dynamic source Routing (DSR) [3][6], ad hoc on-demand distance vector routing (AODV) [4] and temporally ordered routing algorithm (TORA)[5].

Our power-aware source routing algorithm belongs to this category of routing algorithms. Since our approach is an enhancement over DSR, a brief description of DSR is warranted.

DSR is one of the more generally accepted reactive routing protocols. In DSR, when a node wishes to establish a route, it issues a route request (RREQ) to all of its neighbors. Each neighbor broadcasts this RREQ, adding its own address in the header of the packet. When the RREQ is received by the destination or by a node with a route to the destination, a route reply (RREP) is generated and sent back to the sender along with the addresses accumulated in the RREQ header. Since this process may consume a lot of bandwidth, DSR provides each node with a route cache to be used aggressively to reduce the number of control messages that must be sent. If a node has a cache entry for the destination, when a route request for that destination is received at the node, it will use the cached copy rather than

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forwarding the request to the network. In addition, each node promiscuously listens to other control messages (RREQs and RREPs) for additional routing data to add to its cache.

3 Low Power Routing Protocols

The main focus of research on routing protocols in MANETs has been network performance. There has been some study on power-aware routing protocols for MANETs. Presented below is a brief review of some of them.

3.1 Minimum Power Routing

Reference [9] proposes a routing algorithm based on minimizing the amount of power (or energy per bit) required to get a packet from source to destination. More precisely, the problem is stated as:

$$Minimize \sum_{i \in path} P(i, i+1) \qquad (1)$$

where *P(i,i+1)* denotes the power expended for transmitting (and receiving) between two consecutive nodes, i and i+1(a.k.a. link cost), in the route. *P.*

This link cost can be defined for two cases:

- When the transmit power is fixed
- When the transmit power is varied dynamically as a function of the distance between the transmitter and intended receiver.

For the first case, energy for each operation (receive, transmit, broadcast, discard, etc.) on a packet is given by [7]:

$$E(packet) = b \times packet\_size + c \qquad (2)$$

where b and c are the appropriate coefficients for each operation. Coefficient b denotes the packet size-dependent energy consumption whereas c is a fixed cost that accounts for acquiring the channel and for MAC layer control negotiation. Route selection depends on the packet size; hence in case of variable packet size transmission many routes should be selected.

The second case is more involved. Reference [8] proposes a local routing algorithm for this case. The authors assume that the power needed for transmission and reception is a linear function of d^a where d is distance between the two neighboring nodes and a is a parameter that depends on the physical environment. They make use of the GPS position information to transmit packets with the minimum required transmit energy. The key requirement of this technique is that the relative positions of nodes are available to all nodes. However, this information may not be easy readily available. The GPS-based routing algorithm has two drawbacks. One is that GPS cannot provide the nodes much information about the physical environment and the second is the power dissipation overhead of the GPS device is additional.

3.2 Battery-Cost-Aware Routing

The main disadvantage of the problem formulation of the previous approach (1) is that it always selects the least-power cost routes. As a result, nodes along these routes tend to "die" soon because of the battery energy exhaustion. This is doubly harmful since the nodes that die early are precisely the ones that are needed most to maintain the network connectivity (and hence useful service life). Therefore, it is better to use a higher power cost route if it avoids using nodes that have a small amount of remaining battery energy. This observation has given rise to a number of "*battery cost-aware routing*" algorithms as described next.

1. Minimum battery cost routing algorithm that minimizes the total cost of the route. It minimizes the summation of inverse of remaining battery capacity for all nodes on the routing path [10].
2. Min-Max battery cost routing algorithm is a modification of minimum battery cost routing. This metric always tries to avoid the route with nodes having the least battery capacity among all nodes in all possible routes. Thereby, it results in fair use of the battery of each node [9][10].
3. Conditional Max-Min battery capacity routing algorithm proposed in [10]. This algorithm chooses the route with minimal total transmission power if all nodes in the route have remaining battery capacities higher than a threshold; otherwise routes including nodes with the lowest remaining battery capacities are avoided. Several experiments have been done in [10] to compare different battery cost-aware routing in terms of the network lifetime. The result showed that the first node in "Shortest Path routing" metric died sooner than all the battery-cost-aware routing but most of the other nodes had longer expiration time. In that result Minimum battery cost routing showed better performance than Min-Max routing in terms of expiration time of all nodes. Conditional Max-Min routing showed different behavior that depended on the value of chosen threshold.

4 Power-Aware Source Routing

4.1 Cost Function

The objective of Power-aware Source Routing (PSR) is to extend the useful service life of a MANET. This is highly desirable in the network since death of certain nodes leads to a possibility of network partitions, rendering other live nodes unreachable. Power-aware source routing solves the problem of finding a route p at route discovery time t such that the following cost function is minimized:

$$C(p,t) = \sum_{i \in p} C_i(t) \qquad (3)$$

$$\text{where } C_i(t) = r_i \cdot \left(\frac{F_i}{R_i(t)} \right)^a \qquad (4)$$

r_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

a : a positive weighting factor

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, in PSR, both the node mobility and the node energy depletion may cause a path to become invalid. Since the route discovery and route maintenance in PSR are more complicated compared to their counterparts in DSR, these two steps will be described in detail. Also, since PSR is derived from DSR, the PSR description will often be contrasted with that of DSR.

4.2 Route Discovery

In DSR, activity begins with the source node flooding the network with RREQ packets when it has data to send. An intermediate node broadcasts the RREQ unless:

- It gets a path to the destination from its cache, or
- It has previously broadcast the same RREQ packet. (This fact is known from the sequence number of the RREQ and the sender ID.)

Consequently, intermediate nodes forward only the first received RREQ packet. The destination node only replies to the first arrived RREQ since that packet tends to take the shortest path.

In PSR, all nodes except the destination calculate their link cost, C_{ij} (cf. equation 4) and add it to the path cost in the header of the RREQ packet (cf. equation 3). When an intermediate node receives a RREQ packet, it starts a timer (T_r) and keeps the cost in the header of that packet as *Min-Cost*. If additional RREQs arrive with same destination and sequence number, the cost of the newly arrived RREQ packet is compared to the *Min-Cost*. If the new packet has a lower cost, *Min-Cost* is changed to this new value and the new RREQ packet is forwarded. Otherwise, the new RREQ packet is dropped.

In PSR, the destination waits for a threshold number (T_r) of seconds after the first RREQ packet arrives. During that time, the destination examines the cost of the route of every arrived RREQ packet. When the timer (T_r) expires, the destination node selects the route with the minimum cost and replies. Subsequently, it will drop any received RREQs. The reply also contains the cost of the selected path appended to it. Every node that hears this route reply adds this route along with its cost to its route cache table. Although this scheme can somewhat increase the latency of the data transfer, it results in a significant power saving as will be shown later.

4.3 Route Maintenance

Route maintenance is needed for two reasons:

- **Mobility**: Connections between some nodes on the path are lost due to their movement,
- **Energy Depletion**: The energy resources of some nodes on the path may be depleting too quickly.

In the first case, a new RREQ is sent out and the entry in the route cache corresponding to the node that has moved out of range is purged. In the second case, there are two possible approaches: semi-global and local.

- Semi-global Approach: The source node periodically polls the remaining energy levels of all nodes in the path and purges the corresponding entry in its route cache when the path cost increases by a fixed percentage. Notice that this results in very high overhead because it generates extra traffic.
- Local Approach: Each intermediate node in the path monitors the decrease in its remaining energy level (and hence increase in its link cost) from the time of route discovery as a result of forwarding packets along this route. When this link cost increase goes beyond a threshold level, the node sends a route error back to the source as if the route was rendered invalid. This route error message forces the source to initiate route discovery again. This decision is only dependent on the remaining battery capacity of the current node and hence is a local decision.

PSR adopts the local approach because this approach minimizes control traffic. Furthermore, it assumes that all transmit power levels (ρ_{ij}) are constant. This enables PSR to separate the effect of mobility from that of energy depletion during route maintenance. More precisely, node *i* generates a route error at time *t* when the following condition is met:

$$C_i(t) - C_i(t_0) \geq d \qquad (5)$$

$$\text{t : current time}$$

$$\text{t}_0 \text{ : route discovery time}$$

This metric appears to be a good way of capturing the dynamics of the node usage in MANETs. As the remaining energy level of a node decreases, the link cost of the node increases. This forces new routing decisions in the network by invalidating its own cache entries to various destinations. However, if a path was recently added to the cache table, the node will not force a new decision (route finding step) unless the node's remaining energy is depleted by a certain normalized amount due to messages passing through that path. The effect of δ on the performance of PSR is studied in detail in section 5.

It should be noted that the protocol provisions for reuse of invalidated paths. When a node *i* has data to send, it looks up its route cache and chooses the route, if found, irrespective of whether the route was invalidated or not. Thus, we avoid redundant route discoveries in the presence of an existing route. The invalidated cache is purged after a fixed time. The invalid entries are analogous to victim buffers in the cache structure of general-purpose processors.

However, the same does not hold good for relaying data. If a cache entry is invalidated in a node and that node is asked to relay data/reply to the destination of that cache entry, then the node will send a route error back to the source.

5 Experimental Results

We used the event driven simulator ns-2 [11] for our simulations. We also used the wireless extensions provided by CMU [12]. The setup consists of a test bed of 20 nodes confined in a 1000 X 1000 m^2 area. Range of each node is assumed to be 250 m. 100 reliable connections are established at random in the network. The connections are ftp connections with varying lengths of duration. The average duration of the connection is about 20 s. The nodes are randomly selected for data transfer. The total setup is run for 10000 s. The speed of movement is 10 m/s. Random mobility is assumed with a pause time of 4 s.

The key parameter of study is the *network lifetime*. We vary the different parameters and study their effects on this metric. The network lifetime can be defined in many ways:

1. It may be defined as the time taken for K% of the nodes in a network to die
2. It might be the time taken for the first node to die;
3. It can also be the time for all nodes in the network to die.

For analysis here, the first definition is adopted. Network lifetime of DSR and PSR are compared for the given scenario. Figure 1 shows the time instances at which a certain number of nodes have died when simulating PSR and DSR.

As can be seen, the first node in DSR dies about 15% earlier than in the case of PSR. Similarly, in DSR 5 nodes (25% of the nodes) die approximately 30% earlier than PSR. Note that the above experiment and the next one were performed without any cache invalidation policy.

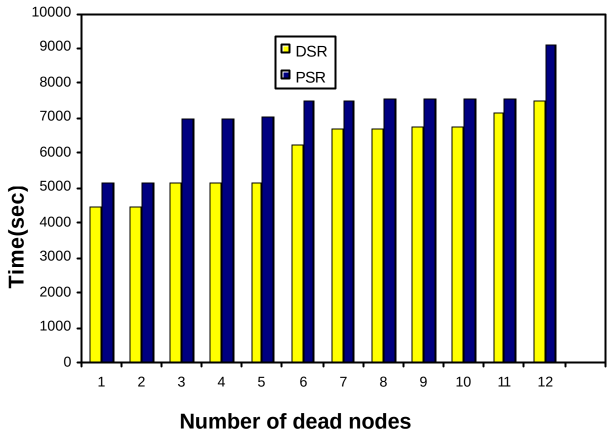

Figure 1: The number of dead nodes in DSR and PSR versus time

Due to the dynamic nature of the path cost function, a discovered path cannot remain valid for a long time. This is because these connections - if maintained for a long period of time may exhaust the energy of some nodes on that path. However, discovered paths are in the cache and can be accessed whenever they are required in DSR and (as implemented in ns-2) only mobility can invalidate these cache entries. Also, cache invalidation is very expensive for the network, since the route is reconstructed by flooding the network. This is handled in PSR as follows. When the path is discovered, every node puts its remaining energy and path cost in the cache entry. Intermediate nodes check for validity of this path by computing the cost difference as in equation (5). Here, δ (the threshold) is a metric that decides how often we invalidate the cache. This threshold affects the performance of PSR. If the threshold is very high, we do cache invalidation very rarely, and might end up over-exercising some nodes in the path. If it is very low, cache invalidation rate is very high and may lead to unnecessary flooding in the network.. The effect of varying this threshold is shown in Figure 2.

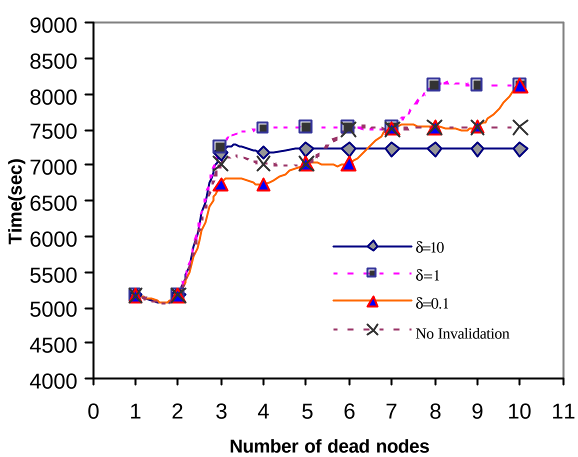

Figure 2: Effect of the threshold, δ, on network lifetime.

6 Conclusion

A new *power-aware* source-initiated (on demand) routing protocol for mobile Adhoc networks that increase the network lifetime was presented in this paper. Simulation results show that the proposed "Power-aware Source Routing" protocol can increase the network lifetime up to 30%. A greedy policy was applied to fetched paths from the cache to make sure no path would be overused and also make sure that each selected path has minimum battery cost among all possible path between two nodes.

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