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Cost-Effective Lifetime Prediction Based Routing Protocol for Mobile Ad Hoc Network

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Abstract: Mobile Ad hoc Networking (MANET) is the most impressive technology in today's Wireless communications. Cost reduction and proper utilization of battery power becomes the primary concerns for various type of routing. Cost effective lifetime prediction based routing protocol for wireless network gives an optimum path based on both cost and the lifetime of the mobile network. This paper represents an improvement algorithm for the routing protocol of Mobile Ad Hoc Network. Due to the limited battery power of mobile devices, recent research in mobile ad hoc routing is motivated towards selection of a path that maximizes the network lifetime. Another approach for the routing protocol in mobile device to select the minimum path length. This algorithm selects a path that considers both the path cost and the battery power of the mobile network. For the stability of the whole network of the MANET, the most concern thing is that, a low power node/device has to transfer information very earlier for the better improvement of the network. Otherwise the network may damage. The graphical and simulation results of the paper give a clear idea that how can we improve our network stability for the mobile ad hoc network.

Keywords: Mobile Ad Hoc Networks, Lifetime Prediction, Routing Protocol, Wireless Networks, Distributed Systems.

1 Introduction

Ad hoc networks are networks that are designed to dynamically connect remote devices such as cell phones, laptops, and PDAs. These networks are termed "ad hoc" because of their shifting network topologies. Whereas WLANs use a fixed network infrastructure, ad hoc networks maintain random network configurations, relying on a master-slave system connected by wireless links to enable devices to communicate. As devices move about in an unpredictable fashion, these networks must be reconfigured on the fly to handle the dynamic topology. Figure 1 shows a simple mobile ad hoc network.

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 [1]-[5]. 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 for ad hoc network, 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. We must consider both the life time of the battery of the mobile devices and the distance that the routes takes.

Mobile Ad Hoc Network (MANET) is an autonomous system with mobile hosts connected by wireless links and work independent of any common central control. Routing in MANETs has been the subject of intense research efforts over the past few years; these efforts have resulted in numerous proposals for routing protocols. Typically in mobile ad hoc networks, it is assumed that all the devices that make up the network are cooperative in particular they are willing to act as intermediate nodes in a routing path by forwarding data for other network nodes. These hosts are self-adaptive in that if there are changes in the network they also have to change their won routing tables to reflect the changes of the network.

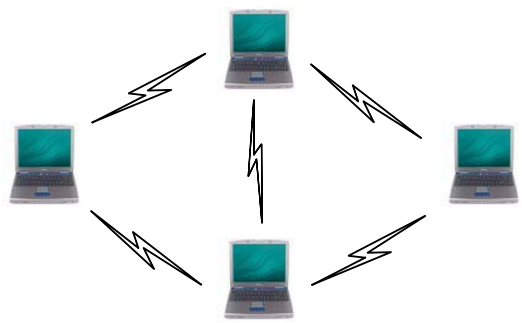

Fig 1: A Simple Mobile Ad Hoc Network

The limitation of finite energy supply of wireless devices raises concerns about the traditional belief that nodes in ad hoc network will always relay packets for each other. Energy efficiency is a key objective in many routing protocols. An energy efficient routing protocol ensures that a packet from a source node to a destination gets routed along the most energy efficient path possible via intermediate nodes. Failure of some nodes in the network might result in lack of connectivity between nodes that are still alive. Hence we should consider the proper utilization of the limited power of a node of wireless network.

Selection of the least power cost route may possess a harmful impact on the network stability. Thus it is better to use a routing solution that avoids using nodes having small amount of remaining battery energy.

The remainder of this paper is organized as follows. In next section we discuss the problem of routing in mobile networks and provide the metrics we used for performance evaluation. Section 3 contains review of some recent related research works. Section 4 describes the Dijkstra algorithm with proposed necessary modification. Section 5 describes the rationale and details of the proposed cost-effective lifetime based algorithm. Section 6 elaborates on the simulation environment, the implementation and experimental results comparing Cost Effective Lifetime Prediction (CELP) with Lifetime Prediction Routing (LPR), Demand Source Routing (DSR) and power-aware routing. At last, Section 7 concludes this paper.

2 Metrics

We encounter two conflicting goals: on the one side, in order to optimize cost, least cost or shortest-hop routing should be used, while on the other side, use of shortest-hop route means that nodes with higher degree might die soon since they are used in most cases.

An interesting property of using least-cost routing is that packet delay does not increase. The cost of forwarding messages could be defined and determined in various ways taking into account factors such as cost of energy used to forward messages, hop count, delay, link quality as well as other factors.

Another metrics used is the lifetime of nodes, which is a function of the remaining battery energy. As in [1], lifetime of a node is predicted based on the residual battery capacity and the rate of energy discharge.

Our routing algorithm is a reactive routing protocol, which only takes action and starts computing routing paths when a network initiates a session. It uses a DSR-like route discovery protocol and channels all information regarding cost and lifetime to the destination node. The destination node computes the cost and lifetime of each path and sends this information back to the source.

3 Related work

Some researchers have tried energy efficient broadcast / multicast algorithm [6] [7]. One major approach for energy conservation is to route a communication session along the route which requires the lowest total energy consumption [8][9]. This optimization problem is referred to as Minimum-Energy Routing [10]. While the minimum-energy unicast routing problem can be solved in polynomial time by shortest-path algorithms, it remains open whether the minimum-energy broadcast routing problem can be solved in polynomial time, despite the NP-hardness of its general graph version. Recently three greedy heuristics were proposed in [11] MST (Minimum Spanning Tree), SPT (Shortest-Path Tree), and BIP (Broadcasting Incremental Power). They have been evaluated through simulations in [12],

It has recently been recognized that medium access control (MAC) schemes can significantly increase the energy efficiently of mobile batteries [13]. If mobile device A transmits data to another mobile device B, neighboring mobiles do not listen to the data from mobile A since listening causes unnecessary mobile power consumption. Another energy efficient MAC scheme has been proposed in [14].

The main disadvantage of power aware routing [15] techniques is that it always selects the least power cost routes. As a result, there is a large possibility of selecting a node, which has a very little lifetime; hence it would die early. So the network will get disconnected and the network lifetime will be adversely affected. Besides, in these techniques a particular node may become a victim because of its position at such a place that makes it selected frequently and hence die early. This is doubly harmful since the node that die early is precisely the one that is needed most to maintain the network connectivity.

Therefore, it will be better to use a higher power cost route if this routing solution avoids using nodes that have a small lifetime. Keeping it in mind, [1] proposes a lifetime prediction based routing algorithm. Lifetime prediction routing is an on demand source routing protocol that uses battery lifetime prediction. The objective of this routing protocol is to extend the service life of with dynamic topology. This protocol favors the path whose lifetime is maximum. The authors calculated the lifetime of a route with the following equation.

$$\underset{\pi}{Max}\, T_{\pi}(t) = \underset{i\varepsilon\pi}{Min}(T_i(t))$$

Where:
$T_\pi(t)$: lifetime of path π
$T_i(t)$: predicted lifetime of node i in path π

In this algorithm lifetime of a path is predicted by the minimum lifetime of all nodes along the path. That path is selected which has maximum value of calculated minimum lifetimes. The main objective of LPR is to minimize the variance in the remaining energies of all the nodes and thereby prolong the network lifetime.

Although, LPR increases the stability of the network, this technique has totally overlooked the cost of routing.

To achieve best performance we propose a routing algorithm that combines the best features of the two above-mentioned techniques.

4 Development of Algorithm

Virtually all packet-switching networks and all internets base their routing on some form of least-cost criterion. Most least-cost routing algorithms in use are variations of one of two common algorithms, known as Dijkstra's Algorithm and the Bellman-Ford algorithm. To implement our project proposal, we have used Dijkstra's Algorithm and modified it where necessary.

Dijkstra's algorithm can be stated as follows- Find the shortest paths from a given source node to all other nodes, by developing the paths in order of increasing path length. The algorithm proceeds in stage, the shortest paths to the k nodes closest to (least cost away from) the source node have been determined; these nodes are in a set T. At stage (k+1), the node not in T that has the shortest path from the source node is added to T. As each node is added to T, its path from the source is defined. The algorithm can be formally described as follows.

N = Set of nodes in the network.
s = Source node.
T = Set of nodes so far incorporated by the algorithm.

W(i,j)= link cost from node i to node j; w(i,j)=0; w(i,j)=∞, if the two nodes are not directly connected; w(i,j)≥0 if the two nodes are directly connected.

L(n)= cost of the least cost path from node *s* to node *n* that is currently known to the algorithm; at termination, this it's the cost of the least-cost path in the graph from *s* to *n*.

The algorithm has three steps; step2 and 3 are repeated until T=N. That is step 2 and 3 are repeated until final paths have been assigned to all node in the network. The steps are as follows:

Step 1: [Initialization]
T = {s} i.e. the set of nodes so far incorporated consists of only the source node.
L(n) = w(i,j) for n ≠ s i.e. the initial path cost to neighboring nodes are simply the link cost.

Step 2: [Get Next Node]
Find the neighboring node not in T that has the least-cost path from node s and incorporate that node into T: also incorporate the edge that is incident on that node and a node in T that contributes to the path. This can be expressed as-

$$\text{Find } x \notin T \text{ such that } L(n) = \min_{j \notin T} L(j)$$

Step 3: [Update Least-Cost Path]

$$L(n) = \min[L(n), L(x) + w(x,n)] \text{ for all } n \notin M$$

If the latter term is the minimum, the path from s to n is now the path from s to x concatenated with the edge from x to n.

The algorithm terminates when all nodes have been added to T. At termination, the value L(x) associated with each node x is the cost (length) of the least-cost path from s to x. In addition, T defines the least-cost path from s to each other node.

On iteration of the step 2 and step 3 adds one new node to T and defines the least-cost path from s to that node. That path passes only through nodes that are in T. To see this, let us consider this following line of reasoning:

After K iterations, there are K nodes in T, and the least-cost path from s to each of these nodes has been defined. Let us now consider all possible paths from s to nodes not in T. Among those paths, there is one of least cost that passes exclusively through nodes in T, ending with a direct link from some node in T to a node not in T. This node is added to T and the associated path is defined as the least cost path from that node.

4.1 Modified developed algorithm

1. During the time of finding the shortest-path (least-cost path) the main calculation involves the steps 2 and 3, that is
2. Find $x \notin T$ such that $L(n) = \min_{j \notin T} L(j)$
3. $L(n) = \min[L(n), L(x) + w(x,n)]$ for all $n \notin M$

We have used these two concepts in three different ways. They are:

Firstly, we have used the algorithm as it is provided to calculate the least-cost path through the network.

Secondly, we have considered the lifetime of the battery of the mobile device as the path weight to implement the concept that the path will consist only with the high powered nodes on the way from the source to the destination. In order to maintain the integrity of the algorithm, we have just negated the battery power that facilitated us with the concept of least-cost path. For example, if x is an integer greater than all other integers in a set, negation of x (i.e. $-x$) will change it to the smallest integer of the set.

Thirdly, to implement our proposed method we have firstly calculated the value of the function composed of literals (i.e. scaling factor ξ, path selecting parameter β and cost of path $\hat{G}$) that we have proposed. We have used the value of this function to compute the desired route.

5 Proposed Model

A network $N=(V,E,\omega)$ consists of a set of nodes $V=\{v_1,\ldots,v_n\}$ that represent mobile devices, a set $E \subseteq V \times V$ of directed edges (v_i, v_j) that connect two nodes, and a weight function $\omega: E \rightarrow R$ (Rational number) for each edge (v_i, v_j) that indicates the cost of transmitting a data packet from node v_i to v_j. Each node has a unique identification number, but it is not a priori known which nodes are currently in the network, nor is edge set E or weight function ω known. A node can not control the direction in which it sends data, and thus data are broadcast to all nodes inside its transmission range. Nodes can move and the edge cost between any two nodes can change over time. Also the lifetime of any node can change over time. However, for the ease of presentation, we assume a static network during the route discovery phase.

5.1 Cost-Effective Lifetime Prediction based routing (CELP)

Our objective is to select a cost effective route, which affects less on the stability of the network. Routing cost and lifetime of nodes are used as the selecting parameters of a path.

In power-aware routing algorithms the selected path of transmission is the most cost-effective whereas in lifetime predictive routing algorithms selects a path with maximum lifetime and hence results stability of the network.

Power-aware routing algorithms suffer from poor stability and lifetime predication based routing algorithms suffer from poor cost effectiveness. Our proposed CLPR algorithm is more stable than that of power-aware routing and also has less cost than that of lifetime prediction routing.

Let us assume the possible lifetime of any node is up to L and the possible transfer cost between any two nodes is up to C. We define a scaling factor ξ as the ratio of the two parameters.

$$\xi = \frac{L}{C}$$

Let there be n paths $(\pi_1, \pi_2, \ldots\pi_n)$ from source to destination. Then lifetime of a path π_i is

$$\tau_i = \underset{j \in i}{Min}\, T_j(t)$$

and the cost of a path π_i is

$$\varsigma_i = \sum_{j=1}^{\pi_{i_m}-1} c_{\pi_{i_{j,j+1}}}(t)$$

where π_{i_m} is number of nodes in path π_i and $c_{j,j+1}$ is the cost between node j and j+1.

Our path selecting parameter β is represented by

$$\beta_i = \frac{\tau_i}{\xi \varsigma_i}$$

The algorithm selects a path, which has the largest β. If more than one path having highest β is found, the path with highest hop count will be selected.

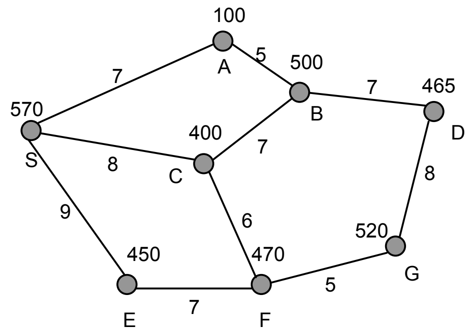

Fig 2: A network with 8 mobile nodes with their battery lifetimes (Network 1).

As an example, consider the scenario shown in figure 2. Here from source (S) to destination (D) there are six paths. They are:

Path 1: S→A→B→D
Path 2: S→A→B→C→F→G→D
Path 3: S→E→F→C→B→D
Path 4: S→E→F→G→D
Path 5: S→C→F→G→D and
Path 6: S→C→B→D.

If we calculate the total cost along each path and select the path with minimum cost among them, as done in cost-effective routing, we get the path 1: S→A→B→D having cost 19 and lifetime 100s. While in LPR the path 4: S→E→F→G→D is chosen having lifetime 450s and cost 29.

For our CELP algorithm let us assume maximum cost (C) between any two nodes is 15 and maximum lifetime (L) of any node is 600. So the scaling factor ξ becomes 40. Hence, using CELP algorithm the selecting parameter β for the path- 1, path- 2, path- 3, path- 4, path- 5 and path- 6 are 0.1316, 0.0658, 0.2778, 0.3879, 0.3704 and 0.4545 respectively. So the selected path is path 6: S→C→B→D having cost 22 and lifetime 400.

As another example, consider the scenario shown in figure 3. Here from source (A) to destination (J) there are twelve paths to reach from source to destination.

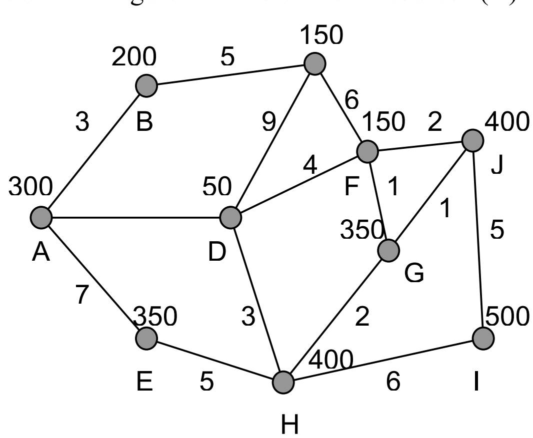

Fig 3: A network with 10 mobile nodes with their battery lifetimes (Network 2).

Those paths are:
Path 1: A→B→C→F→J
Path 2: A→D→F→J
Path 3: A→D→C→F→J
Path 4: A→E→H→I→J
Path 5: A→E→H→D→F→J
Path 6: A→E→H→D→C→F→J
Path 7: A→E→H→G→J
Path 8: A→E→H→G→F→J
Path 9: A→D→H→I→J
Path 10: A→D→H→G→J
Path 11: A→B→C→D→F→J and
Path 12: A→B→C→D→H→I→J.

If we calculate the total cost along each path and select the path with minimum cost among them, as done in cost-effective routing, we get the path-2, having cost 11 and lifetime 50s. While in LPR the route path-4 is chosen having lifetime 350s and cost 23.

So the selected path for our proposed CELP based method is path-7: A→E→H→G→ J having cost 15 and lifetime 350.

Now we will consider another network shown in figure 4. Here we have 13 nodes. Let the Source is A and the destination is M. If we use Cost-Effective Routing then the path will be- path 1: A→B→E→I→M, If we use Lifetime Prediction Routing then the path will be- path 14: A→D→H→G→K→M and if we use our proposed Cost Effective Lifetime Prediction then the path will be- path 15: A→D→H→L→M.

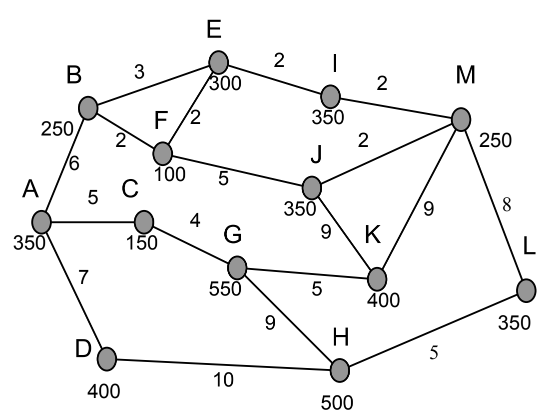

Fig 4: A network with 13 mobile nodes with their battery lifetimes (Network 3).

The paths are:

Path 1: A→B→E→I→M
Path 2: A→B→F→E→I→M
Path 3: A→B→F→J→M
Path 4: A→B→F→J→K→M
Path 5: A→B→F→J→K→G→H→L→M
Path 6: A→C→G→K→J→F→ B →E→I→M
Path 7: A→C→G→K→J→F→E→I→M
Path 8: A→C→G→K→J→M
Path 9: A→C→G→K→M
Path 10: A→C→G→H→L→M
Path 11: A→D→H→G→K→J→F→B →E→I→M
Path 12: A→D→H →G→K→J →F→E→I→M
Path 13: A→D→H →G→K→J→M
Path 14: A→D→H →G→K→M and
Path 15: A→D→H →L→M

Here is a comparison tables for the path-cost and network lifetime for the three methods for the above three networks.

	COST-EFF.	LPR	CELP
Network 1	19	29	22
Network 2	11	23	15
Network 3	13	40	30

Table 1: Path-Costs for different Networks

	COST-EFF.	LPR	CELP
Network 1	450	600	400
Network 2	50	350	350
Network 3	250	400	350

Table 2: Network-Lifetimes for different Networks

The following two charts figure 5 and figure 6 will graphically show the comparisons of path-cost and network lifetime for the existing two protocols and with our proposed one for those three networks.

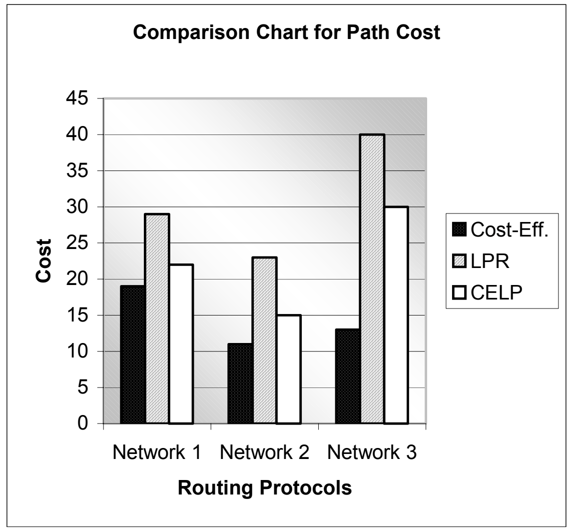

Fig 5: A Comparison of Path Cost for different Routing protocols.

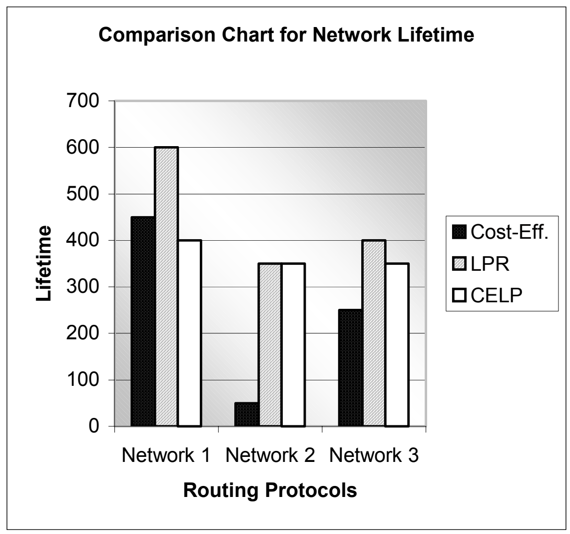

Fig 6: A Comparison of Network lifetime for different Routing protocols.

We find that CELP is better than CLP in cost perspective and also better than cost-effective routing in stability perspective. Although CELP may selects a path with cost little higher than a path with least cost and a path having little less of lifetime than a path having highest lifetime, this is acceptable considering both the stability and the cost-effectiveness of the route.

5 Simulation

In our discrete event driven simulation we used up to 20 nodes. The lifetime of a node may vary between 1 and 500 while the transmission to neighboring nodes may vary between 1 and 20.

Random connections were established where each node has chance to connect with every other nodes. The simulation was run for 2000 time unit. Nodes followed random viewpoint mobility model. Each packet relayed or transmitted has a cost factor and this cost is considered as the cost at the transmitter node.

6 Conclusion

A cost effective lifetime prediction (CELP) based routing protocol for mobile ad hoc networks that increase the network lifetime and performance, was presented in this paper. Simulation results show that the proposed "Cost Effective Lifetime Prediction (CELP)" protocol can increase the network lifetime more than 20%. In the previous works, while they are trying to increase the lifetime of the network, they just considered the battery power of the mobile devised. They didn't consider the distance that the selected route covered. So most of the time, it has chosen the longest path to maximize the network lifetime. Here security may be hampered due to the longest distance from the source to the destination. Our proposed method has cut the distance short while increasing network lifetime.

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