Energy Efficient Multicast in Wireless Networks

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1 Abstract

We propose a reliable energy efficient multicast protocol and some metrics for ad hoc wireless networks and plan to compare it with a minimum cost spanning tree based protocol.

2 Introduction

Mobile computing is becoming increasingly popular, but faces many challenges as well. For example, the battery power is still limited, causing the mobile clients to disconnect from the network fairly often. So there is a considerable interest in developing energy efficient protocols in wireless networks.

In this paper we consider source-initiated broadcast (one-to-all) and multicast (one-to-many) traffic. Our objective is to form a minimum energy tree rooted at the source, that reaches all the destinations. We consider the energy used for transmission, neglecting the energy associated with reception and signal processing. In this paper, we improve on previous studies on energy efficient multicast by including retransmission energy in the total transmission energy [7]. Current algorithms for energy efficient routing select minimum cost multi hop paths. If the transmission power is fixed, each link has the same cost and the minimum hop path is selected. If the transmission power is varied with distance, the link cost is more for longer hops; the energy efficient routing selects a path with a large number of small distance hops. However a multicast algorithm based on only transmission energy will not capture the effect of link error rate. The link error rate affects retransmission energy leading to total energy for reliable packet delivery. We assume there is no mobility, though the effect of mobility can be included by adjusting transmission power to accommodate the new locations of the nodes. We do not consider the media access control issues so that the node-based algorithms can be developed like the minimum cost spanning tree (MST) algorithms for wired networks. We assume that if the multicast group membership includes nodes in the immediate neighborhood of a transmitting node, a single transmission is sufficient for reaching all these receivers.

Multicast routing algorithms such as CAMP, ODMRP, AMRoute differ in terms of topology, state maintenance, reliance on unicast routing [3,6].The broadcast incremental power (BIP) protocol is a greedy approach which adds a specific node to a tree if the addition of the node results in minimum transmission energy [7]. This requires global network wide information and may not generate a minimum cost tree. This algorithm is similar to Prim's algorithm for the formation of MST.

3 Reliable Energy Efficient Multicast

Most energy efficient protocols use algorithms for computing minimum cost paths with the link metric representing the energy required to transmit a packet over the link. For wireless links, the transmitted power gets attenuated as proportional to $1/(D^k)$. So the transmission power is chosen as proportional to D^k. Typically the energy efficient routing protocol chooses a path with a large number of small distance hops. We intend to see how the link error rate influences reliable multicast in ad hoc networks. Wireless links typically use link layer retransmissions or forward error correcting codes as recovery mechanisms. Additionally TCP uses source initiated retransmission at the transport layer. So the energy cost should include the transmission energy and the retransmission energy. As part of our analysis, we consider two different models [1].

i) End to End Retransmission (EER): individual links do not offer link layer retransmissions. Reliable packet delivery is achieved by source initiated retransmissions.

ii) Hop by Hop retransmission (HHR): individual links offer link layer retransmissions.

Let us consider communication between a sender (S) and a receiver (R) located at a distance D in the EER model. Let N be the total number of hops between S and R. So the total energy is given as $E_{total} = \Sigma E_{i,j} = \Sigma \alpha D^k_{i,j}$ where $D_{i,j}$ is distance between nodes i and j. E_{total} is minimum when all $D_{i,j}$ are same i.e. D/N. Let us assume that each link fails with an independent probability p_{link}.. The probability of a transmission error over the entire path, p, is given by $p = 1 - (1 - p_{link})^N$

The number of transmissions needed for a successful packet delivery between S and D is a geometrically distributed random variable *X*, such that Prob ($X = k$) = $p^{k-1}(1 - p)$. The mean number of packet transmissions for a successful packet delivery is 1/(1 - p). The minimum energy occurs when all the D_{ij} are equal i.e. D/N. So $E_{total} = \alpha(D^k/N^{k-1}) * (1/(1 - p)) = \alpha(D^k/N^{k-1}) * (1/(1 - p_{link})^N)$. This shows that smaller values of *N* do not cause reduction in the transmission energy, but larger values of *N* cause more retransmission energy.

Let us consider the same problem in the HHR model. Here the transmission error on a link indicates the need for retransmission on that link only. This is a better model for multi-hop wireless network. Since the number of transmissions on each link is independent of that on other links and is geometrically distributed, the total energy cost is given by $E_{total} = \sum \alpha D^k_{i,i+1} / (1 - p_{i,i+1})$. The minimum energy occurs when all $D_{i,i+1}$s are equal i.e. D/N. If $p_{i,i+1} = p_{link}$, $E_{total} = \alpha D^k / (N^{k-1} * (1 - p_{link}))$. So the total energy decreases with increasing *N*.

Now let us define the graph for computing the minimum cost paths. The nodes of the graph represent the communicating nodes and a link l_{ij} represents the direct hop between nodes *i* and *j*. A link is assumed to exist between nodes *i* and *j* provided that node *j* lies within the transmission range of node i. This transmission range corresponds to the maximum transmission range of the sender. Let E_{ij} represent the total energy associated with the reliable transmission of a packet over link l_{ij} and p_{ij} be the link error probability. Now the goal of the multicast algorithm is to compute the minimum cost path from a source to several destinations such that the sum of transmission energy costs over the links is minimized. In the first approach, a minimum cost path from the source to the destinations is established by using Dijkstra's shortest path algorithm. In the second approach, a minimum cost spanning tree is established by using Prim's algorithm. HHR approach is suitable for extending the BIP approach to the case of link errors. Here we present suitable metrics which can be used with these approaches [5].

4 Metrics for Energy Efficient Multicast

a. *Minimize energy consumed/broadcast*: This reflects our intuition about conserving energy. Suppose that some multicast packet *j* goes through intermediate nodes $n_1, n_2, .., n_k$ where n_1 is the source and $n_2, .., n_k$ are the intermediate nodes that retransmit the packet. Let *T(a)* be the energy consumed by the node a in transmitting one packet. Then the energy consumed for all transmissions for packet *j* is, $e_j = \Sigma_i T(n_i)$: i goes from1 through *k*

The goal of the metric is to minimize e_j for all multicast packets *j*

b. *Maximize Time to Network Partition*: In our context of multicast, as soon as the first node dies, the network is considered to be partitioned. This metric is important for mission critical applications i.e. battlefield applications. However optimizing this metric is difficult if we are interested in maintaining low delay and high throughput at the same time. Given a network, some nodes are used in more multicast trees than other nodes. These nodes are likely candidates for partitioning the network. A multicast procedure must divide the work going through these critical nodes to maximize the life of the network. It is similar to load balancing problem where tasks are sent to one of the many available servers with the goal of minimizing response time. This turns out to be an NP-complete problem.

c. *Minimize Variance in Node Power levels*: The idea behind the metric is that all nodes are equally important and all nodes remain running together for as long as possible. The goal therefore is to optimize the worst case power depletion. For this metric we have to choose a multicast tree to achieve a global load balancing of work. This is similar to load sharing in distributed systems where the objective is to minimize response time and keep the same level of incomplete work in all other nodes. The difficulty with this metric is the unknown execution time of future arrivals. A scheme which performs reasonably well is the Join the Shortest Queue(JSQ). This can be used by a multicast procedure where each node sends data through a neighbor with the least amount of data to be transmitted.

d. *Minimize Cost/packet*: This metric is useful for maximizing the life of all nodes in the network. This allows us to choose paths such that nodes with depleted energy are not intermediate nodes on the multicast trees.

5 Planned Work

We plan to use Dijkstra's shortest path algorithm for multicast where each link of the graph represents the total cost of transmission and retransmission. We intend to study how the total energy requirements of multicast vary versus the maximum link error rate for reliable Dijkstra's shortest path algorithm, unreliable Dijkstra's shortest path algorithm, reliable minimum cost spanning tree based algorithm, unreliable minimum cost spanning tree based algorithm. We then evaluate how the metrics discussed above vary as a function of the maximum link error rate for these algorithms.

Dijkstra's shortest path algorithm:

Input: G = (V,E) (a weighted directed graph) and s (the source vertex)

Output: for each vertex *w*, *d(w,s)* is the length of the shortest path from *s* to *w* (all lengths are non-negative)

```
begin
  for all vertices w do
      w.mark = false
      d(w,s) = ∝
      while there exists an unmarked vertex do
      let w be an unmarked vertex such that d(w,s) is minimal;
          w.mark = true;
          for all z adjacent to w such that z is unmarked do
            if d(w,s) + length(w,z) < d(z,s) then
                d(z,s) = d(w,s) + length(w,s);
end
```

Let us illustrate the algorithm for the following network in Figure 1.

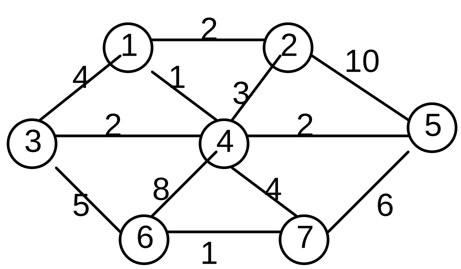

Figure 1: example network

Let us assume that the source is node 1. The nodes adjacent to node 1 are node 2 and node 4. In the first iteration their distances are updated to 2 and 1. Node 4 is selected and marked known. Nodes 3, 5, 6 and 7 are adjacent to node 4 and their distances need to be updated to 3, 3, 9 and 5 respectively. Next node 2 is selected. Node 4 is adjacent, but already known; so no work is performed on it. Node 5 is adjacent, but the distance is not updated because the cost of going through node 2 is 10 + 2 = 12 and a path of length 3 is known earlier. Next node 5 is selected at cost 3. Node 7 is only adjacent node, but it is not updated because the cost of going through node 5 is 3 + 6 = 9 and a path of length 5 is already known. Next node 3 is selected and the distance for node 6 is updated to 3 + 5 = 8. Next node 7 is selected and the distance for node 6 is updated to 5 + 1 = 6. Finally node 6 is selected.

6 References

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