Power-Aware Routing in Mobile Ad Hoc Networks

Introduction

- 5 power aware metrics for shortest-*cost* routing will be presented
- Compared to the traditional shortest-*hop* routing, shortest-*cost* routing
  - Reduces the cost/packet
  - Increases the mean time to node failure
  - Maintains similar delay

Intuitive Ideas

- Route packets through nodes that have sufficient remaining power
- Route packets through lightly-loaded nodes is also energy-conserving because the energy expended in contention is minimized

Survey of Metrics Used in Routing

- The most common metric used is *shortest-hop* routing as (implicitly) in DSR and AODV (there is no explicit metric in these protocols)
- *Shortest-delay* is an equivalent metric in such protocols.

- *Link-Availability* metric as in (alpha,t) clustering algorithm

- Some of these metrics have a negative impact on node and network lifetime by inadvertently overusing the energy resources of a small set of nodes in favor of others (e.g. a hexagon mesh)

- Arguments have been made against path optimization in ad-hoc networks (because of the overhead), but here is a counter argument:

"Minimize the cost for the frequent case (data) packets over the infrequent case (control packets)."

Of course, this works only if the control packets are indeed infrequent (e.g. 10% of traffic)

Metrics for Power-Aware Routing

1. Minimum Energy Consumed per Packet*
   - At low loads, similar to shortest path
   - At high loads, route around congested nodes
   - Has same drawback as shortest path routing in that there could be wide variations of power draining from nodes→low network lifetime.

2. Maximize Time to Network Partition
    - Usually not possible while maintaining low delay and high throughput because
        - Must find min-cut so as to distribute the paths through these nodes→this could be mapped to load-balancing problem that is known to be NP-complete.
        - Proper load balancing requires too much additional control packet overhead (in order to exchange enough information to be able to achieve load balancing) e.g. nodes in different partitions need to co-ordinate the choice of routes through the min-cut set.
        - The min-cut set might change frequently over time.

3. Minimize Variance in Node Power Levels
   - Assuming all nodes are equally important, this metric ensures that all nodes remain alive as long as possible
   - This is also an NP-complete algorithm since it is similar to the bin-packing problem (unless all packets are equal in size, in which case there is a trivial round-robin solution).
   - Join the Shortest Queue (JSQ) is an approximate algorithm to solve this problem (a node sends its traffic to the neighbor that has the shortest backlog in their queue)

4. Minimize Cost/Packet*
   - We now know (from 1.) that the use of "energy/packet" alone as a cost may result in wide variations of node power consumption
   - Associate a cost f_i(x_i) with node i, where x_i is the total energy expended by node i thus far. c_j=sum f_i(x_i)
   - Intuitively, f_i(x_i) indicates a node's reluctance to forward packets (ie. It is highly reluctant if the cost is high, or, equivalently, if the expended energy so far is high).
   - Thus, choose f_i(x_i) monotonically increasing in x_i.
   - The routing starts like shortest path routing, then the routes start to get longer (hops-wise) as the metric kicks-in to route around nodes that are reluctant to route (because they expended their energy during the shortest path mode).

5. Minimize Maximum Node Cost

- Let $C_i(t)$ denote the cost of routing a packet through node i at time t. Let $C'(t)$ denote the maximum of $C_i(t)$. Then,

$$\text{Minimize } C'(t); \text{ for all } t>0$$

- Doesn’t seem to be implementable

What protocols best implement these metrics?

- Any protocol that finds shortest paths can be used to determine optimal routes based on the first and fourth metrics.
  - To implement the first metric, simply associate an edge weight with each edge in the network. This weight reflects the value T(a; b).
  - For the forth metric (cost/packet), associate node weights fi with each node and compute the shortest path as usual.
  - Have not implemented the other three metrics.

Observations from Simulations

- Larger networks have higher cost savings
- Cost savings are best at moderate network loads and negligible at very low or at very high loads
- Denser networks exhibit more cost savings in general
- The cost function used dramatically affects the amount of cost savings.