A comparison of energy aware routing objectives in a wireless ad hoc network*

Timothy X Brown, Harold N. Gabow

University of Colorado
Boulder, CO 80303-0530
{timxb,hal}@colorado.edu

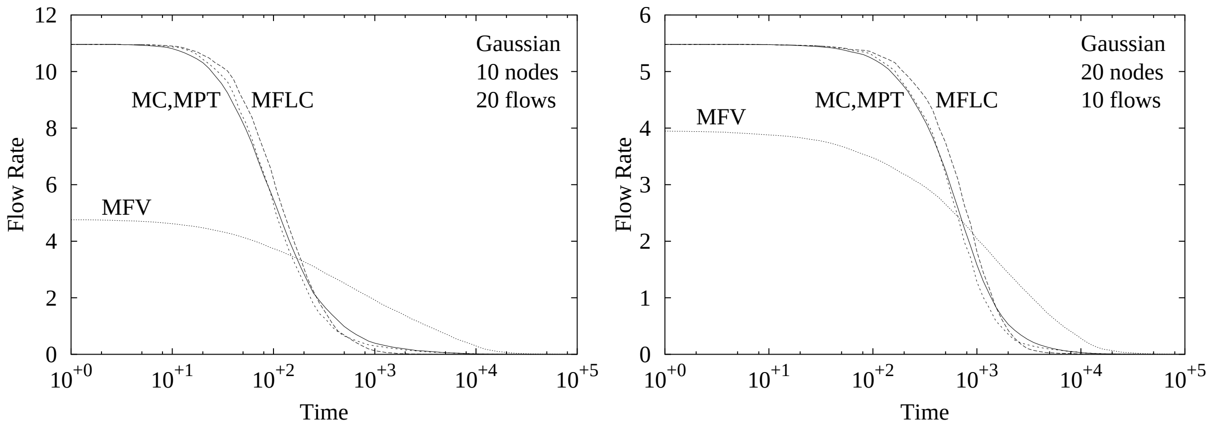
Introduction: Consider a wireless ad hoc network where each node has a limited battery energy supply used mainly for data transmission. One way to conserve energy is for the network to base the routing of packets on transmission and reception energy cost. But, what precisely should be the routing objective? This paper compares four routing objectives (three published already) to clarify the strengths and weaknesses of each.

Model: To keep the comparisons concise we consider stationary nodes with fixed and known flow requirements between them. The nodes can adjust their transmit power as needed to reach other nodes and the power for any node to reach any other node is known. Formally, our wireless ad hoc network is an N node directed graph. The initial energy of each node i is $E_i \geq 0$. The flow from node i to j is $f_{ij} \geq 0$. For the link from node i to j, the send and receive costs are $g^s_{ij} \geq 0, g^r_{ij} \geq 0$.

Nodes start with fixed energy and only spend energy communicating. A node is *exhausted* and can no longer participate in the network communication when it runs out of energy. We focus on the low utilization case where collisions are negligible and every node has sufficient bandwidth to carry any set of flows. A flow is *exhausted* and no longer uses network resources when there is no path containing only unexhausted nodes. A flow can be divided in arbitrary fractions across different paths from a source to destination. A routing is an instance of how the flows are divided across the different paths.

Four Routing Objectives: Minimum cost (MC) routing minimizes the total network power spent at any given time [3]. Dijkstra's method is applied with link costs computed from the sum of transmit and receive link costs. As each node dies, a new routing is computed for the remaining nodes and flows. Maximum partition time (MPT) routing maximizes the time to network partition (i.e. a flow is exhausted) [2]. This is computed via a flow-based linear programming (LP) formulation. An extension of MPT maximizes the time until the first set of flows are exhausted, then minimizes the flows that are exhausted, then continues to find the routing that maximizes the time to the next set of flows are exhausted, and so on [1]. This is denoted the maximum flow-life curve (MFLC) routing and is computed via a path-based LP formulation. Finally, we consider the routing which maximizes the total flow volume (MFV) before the last flow is exhausted. It is readily seen that this is simply the LP: $\max \sum_k \phi_k$ subject to $\sum_k a_{ik}\phi_k \leq E_i \; \forall i$,

*Research supported by the NSF under CAREER Award: NCR-9624791, Grant NCR-9725778 and Grant ANI-0082998.



where a_{ik} is the cost per unit flow to node i on path k and ϕ_k is the total flow volume sent on path k. This is solved using a variation of the algorithm in [1].

Simulation and Discussion: An experiment consists of placing mobiles; assigning flows, initial energies, and pairwise communication costs; then computing routing schedules according to one of the four routing objectives. The output is the flow-life curve, i.e. the flow rate as a function of time. Flow sources and destination are chosen uniform and randomly from the nodes. The flow rate is a uniform random between 0.1 and 1.0 units of flow per unit time. The initial energy is 10000 units for all nodes. For two nodes separated by d the communication cost is $g_t = 1 + d^4$ and $g_r = 1$ units of energy per unit of flow rate. The nodes are placed according to a two-dimensional Gaussian with std. dev. of 2. This produces both outlier and clustered nodes. We considered the flow rich and flow rare cases of 10 nodes with 20 flows and 20 nodes with 10 flows. The results of averaging 1000 experiments are shown above (error bars are less than ± 0.1).

The MFV routing objective is clearly unfair as it ignores flows which are too costly in order to maximize the total data sent. The MC routing objective exhausts most flows sooner than with MFLC and MPT, though enough low-cost flows remain in the tail so the total flow volume is larger. It is more complicated since with each node that dies, a new routing must be computed. The MPT maximizes the time to first partition. But, if a flow source is an outlier node that will die early regardless of the routing, then this objective tells nothing about how to route the other flows. The MFLC maximizes the flow drop time for the larger flow rates. In the above figures, the time to drop to a given flow level is 20–30% longer than with the other objectives over most of the flow rate range. MFV, MPT, and MFLC have a single routing that does not change as nodes die.

This paper provides some insights into the question of what is an energy aware routing protocol. Minimizing the network power (i.e. only power aware) or maximizing the total data volume are unsatisfactory. MFLC, which maximizes the time to exhaustion for most flows, arguably best captures what is intended by energy aware. These results support our efforts in practical energy aware routing protocols.

References

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