ENERGY-EFFICIENT FLOODING IN MOBILE AD-HOC NETWORKS

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ABSTRACT

One of the most energy-intensive operations in mobile ad-hoc networks is the network-wide dissemination of information, known as flooding. Although highly inefficient, it is widely employed by routing protocols to distribute link/node state information or route-discovery requests. Among the schemes introduced to limit this inefficiency and improve network scalability, Multi-Point Relaying (MPR) stands out as one of the most versatile, applicable to both proactive and reactive routing approaches. However, its original design, focused on fixed-power, broadcast-mode, omni-directional transmission, precludes it from benefiting variable-power or unicast/directional-antenna transmission environments. We propose a family of MPR-based protocols for such environments, and present a realistic evaluation of their energy-conserving capabilities based on simulation models that employ the same code base used in actual network nodes and accurate radio models based on the specifications of existing transceivers.

1. INTRODUCTION

Future Army operations will increasingly rely on networked data acquisition and communication on the battlefield. Among other requirements for versatility and survivability, mobile communication devices for the battlefield must be lightweight, inexpensive, and easy to maintain. A major obstacle in meeting these requirements are the devices' power sources, and since major improvements in battery technology are not expected in the near future (Linden 1995), energy-efficient operation becomes paramount in constraining their dimensions and replenishment needs. This is just as important for the soldiers in minimizing their load, as it is for unattended systems, such as sensors and robots, that must remain operational without recharging for prolonged time periods. Although, many routing protocols that minimize the energy consumed for multi-hop packet delivery have been designed, most of them surprisingly rely on flooding as a mechanism for disseminating or discovering network state information. Flooding, although simple and effective, can be quite inefficient particularly in dynamic environments such as the battlefield.

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1.1. MULTI-POINT RELAYING

A more efficient dissemination mechanism has been offered by Multi-Point Relaying (MPR) (Qayyum, et al. 2002), as part of the Optimized Link-State Routing Protocol (Clausen, et al. 2001). In MPR flood packets are retransmitted only by nodes that are designated as relays, selected to limit redundant retransmissions. Ideally, such transmissions should be minimized by selecting the nodes of the connected dominating set of the network graph as relays. However, identifying this set is a difficult task, requiring global knowledge of the network graph and being computationally an NP-complete problem. To circumvent these problems, MPR operates only with the network state of a node's 2-hop neighborhood and employs a heuristic algorithm based on a greedy strategy of preferentially selecting the most connected nodes for relays. This strategy is based on the assumption that flood packets are transmitted: (1) via omni-directional broadcast and (2) at a single power level; which makes it incompatible with unicast/directional-antenna transmission and unable to effectively exploit the energy-conserving potential of variable-power transmission.

1.2. SIMULATION MODELS

The simulation models used in this study employ the networking protocols used in actual network nodes developed for programs such as JTRS and FCS Communications, the difference being that the simulated nodes exchange packets via OPNET radio models, which have also been designed following the exact specifications of the real transceivers. Another difference is that although the link-layer protocols are capable of estimating the transmission power required to close a link based on the power of received packets, the simulated nodes are provided with the exact instantaneous link transmission power to simplify this study. All simulation results presented in this paper are averaged over 3, 300-second trials of random-waypoint node laydowns.

2. RELAY-SELECTION ALGORTIHMS

We propose a family of relay-selection algorithms, applicable to both unicast and broadcast transmission that account for the variable energy required to reach different nodes. For unicast transmission environments, we propose two protocols: MPR-SU (Selective Unicast) and MPR-ME (Minimum Energy). Our brief protocol description follows Fig. 1, where all lines represent existing connections. The thick arrows show the minimum-energy spanning tree constructed by the Least Unicast Cost algorithm (Weiselthier, et al. 2000) that superimposes the minimum-cost paths from the source (node 1) to each destination, along which tree MPR-ME transmits flood packets. The thin arrows represent the superfluous transmissions that would be performed when classical MPR is applied (recall that MPR selects as relays the most connected nodes that reach all 2-hop neighbors, e.g. nodes 2 and 3). Finally, MPR-SU is a unicast- but not energy-aware extension of MPR that additionally removes any overlapping transmissions; in the figure, the dotted arrows show transmission that are preformed "in reverse" by MPR-SU, i.e. 2→6 instead of MPR-ME's 3→6. All three protocols adjust the transmission power for flood packets to reach the "farthest" selected relay.

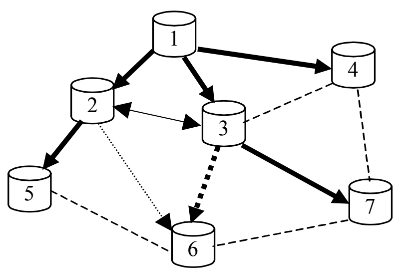

Figure 1. Two-hop neighborhood illustration

It should be noted that the proposed protocols differ in the relay-notification overhead they generate. Once a node has identified its 2-hop multicast tree it must inform its 1-hop neighbors whether and if so, where to forward the flood packets that it sends them. MPR features the lowest overhead, since it only switches relay status on or off, whereas MPR-SU and MPR-ME need to specify a list of the 2-hop nodes associated with each relay. Ideally, the trade-off between notification overhead and relay-tree optimality should be controlled to achieve maximal efficiency, which remains a problem for future work.

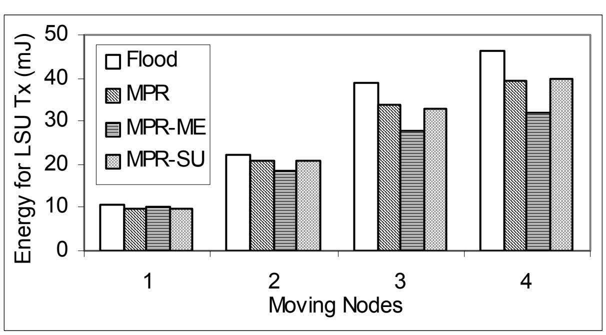

Figure 2. Energy for LSU Dissemination, Unicast

In Fig. 2 we present the energy expenditure for dissemination of Link-State Updates (LSUs) for a 24-node random network with a varying number of moving nodes (speed 2 m/s), i.e., varying update intensity. MPR-ME achieves appreciable energy savings in the range of 8-31% with a notably increasing trend as flooding intensifies. MPR-ME clearly outperforms classical MPR, except for 1 moving node, where LSU volume is so low that its reduction is insufficient to compensate for the additional overhead generated by MPR-ME. MPR-SU's poor performance across all trials is also a result of its higher overhead not being compensated by a commensurate flood reduction due to its over-simplistic heuristic. All three protocols display no deterioration of user packet delivery, indicating no loss of routing information.

In broadcast mode, constructing a minimum-energy spanning tree becomes NP-hard, thus we employ the Broadcast Incremental Power (BIP) heuristic algorithm that provides near-optimal solutions (Weiselthier, et al. 2000). To make a fair comparison, we also enhance MPR with the ability to reduce transmission power to the level necessary to reach the farthest relay (MPR-EA). Even so, MPR-BIP clearly outperforms it, resulting in energy savings of 26-33%, without any detrimental side effects.

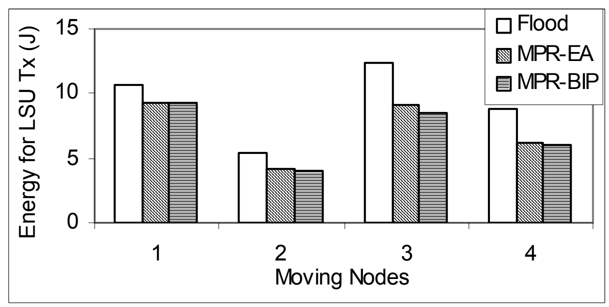

Figure 3. Energy for LSU Dissemination, Broadcast

3. CONCLUSIONS AND FUTURE WORK

In this paper, we present a family of energy-conserving flooding protocols capable of supporting both reactive and proactive routing approaches, as well as network applications that rely on network-wide information dissemination. Based on realistic simulation models, these protocols show significant energy-conserving potential. Future work will focus on methods for balancing the protocols' overhead and relay-tree optimality to further enhance their efficiency.

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