Multipath routing in wireless mesh networks

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Outline

- Why multipath?
- Paper position
- Related work
- Mesh multipath analysis
- Traffic Assignment
- Simulation results
- Summary

Why multipath?

- Multipath
  - Use more than a single loop-free path, when available
  - Need to support more than traditional min-hop routing metrics
- Use in Mesh networks
  - Multipath on mesh backhaul
  - Multipath for end nodes in multiple associations

Why multipath?

- Reliability
  - By using multiple paths, the s,t-reliability is increased.
  - If using two-copy (or N-copy or FEC-enhanced) routing, individual packets are more reliable.
- Delay
  - Using parallel paths can reduce delay if for no other reason than serialization.
  - Increased s,t-reliability may reduce the frequency of path discovery in on-demand protocols.

Kinds of multipath

- Non-disjoint: use any loop-free paths.
- Node disjoint (or just disjoint): Except for source (s) and sink (t), a node appear on at most one path. Same as Link disjoint using node splitting.
- Link disjoint: A given edge does not appear in more than one path.
- Zone disjoint: For a wireless medium, paths do not share interference zones.
- “maximal”: A possibly non-disjoint path that maximizes a disjoint characteristic among possible paths.

Paper Position

- Use non-disjoint paths
  - Many papers on multipath in wireless networks try to achieve some sort of maximal disjoint paths. Often, they do not consider the cost of maintaining such paths.
  - Our position is that this is an unnecessary criterion. Using multiple non-disjoint paths of similar quality should improve reliability.
- Use a “fuzzy” next-hop selection
  - Spread traffic over multiple next-hops without strict optimality.
  - Keep alternate paths “alive” in an on-demand sense.

Related Work

- Kleinrock (1964)
  - A “fixed” (single path) routing can minimize delay under optimal capacity allocation in a static routing configuration.
  - An “alternate” (multipath) routing scheme can perform better with sub-optimal allocation or with dynamic routing.
- Cantor & Gerla (1974), Gallager (1977)
  - Not limited to disjoint paths to minimize delay.

Related Work 2

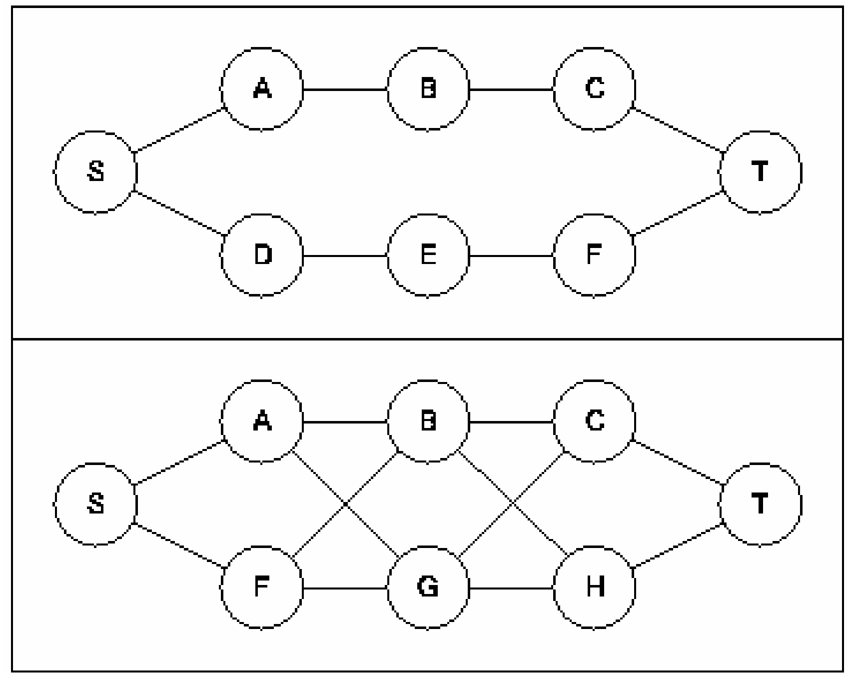
- Chiou & Li (1987, 1988)
  - Use node disjoint paths in two-copy routing to “minimize probability of losing both copies.”
  - Position not argued in papers, but clearly depends heavily on link and node failure rates.
  - Assumptions of paper – independent failures without memory – do not support analysis of this statement.
  - Use source routing.
  - Lee & Gerla (2001) show DSR-like protocol (SMR) performs worse trying to maintain two disjoint paths than letting both paths fail before new path discovery.

Related Work 3

- Nasipuri, Castaeda & Das (2001)
  - Look at frequency of path discovery (inverse of s,t-connectedness lifetime).
  - Protocol 1 maintains two disjoint paths.
  - Protocol 2 maintains a primary path and a disjoint secondary path. Nodes along secondary path maintain their own disjoint secondary path. Results in a "mesh" path of k+1 links (k=hop count).
  - Find that rate of path discovery is lower for Protocol 2. In fact, rate *decreases* as path length increases.

Analysis

- Consider two sample networks
  - First is “disjoint”
  - Second is “mesh”
  - Consider 4-hop (shown) and 5-hop versions.



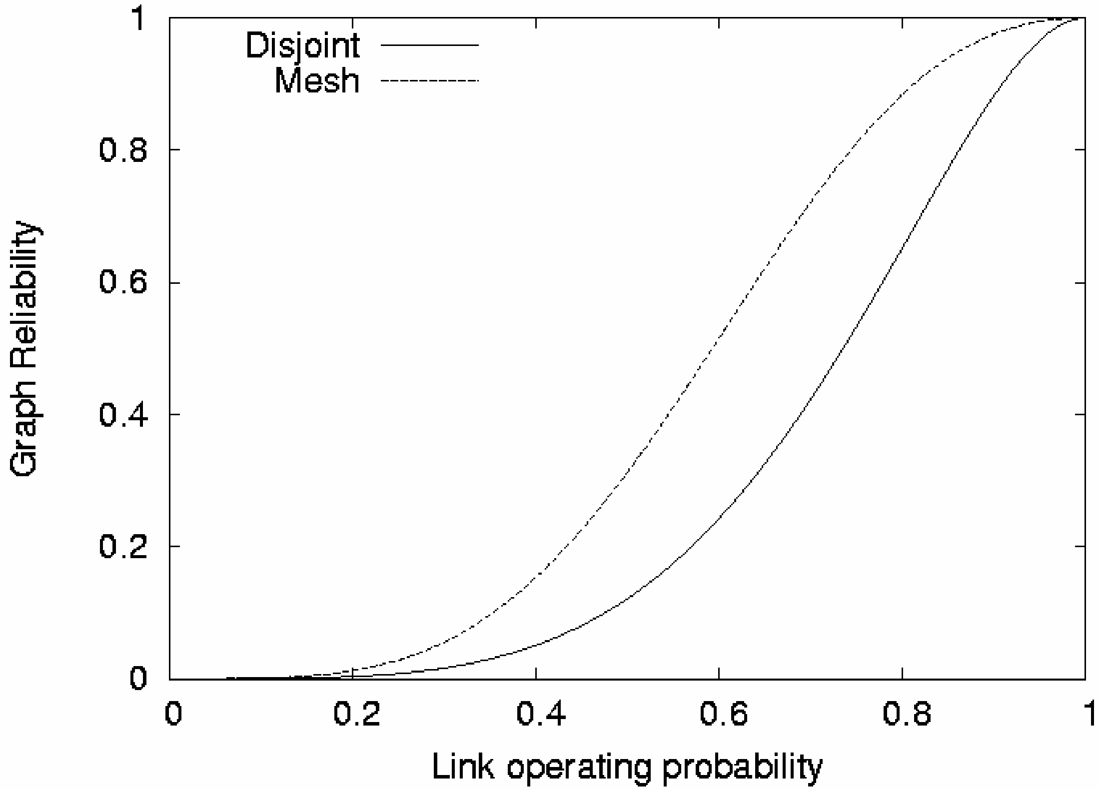
Reliability

$$\text{Rel(disj)} = 2p^4 - p^8 \quad (1)$$

$$\text{Rel(mesh)} = 2p^4 - p^8 + (6p^4 - 12p^6 - 8p^7 + 15p^8 + 12p^9 - 20p^{10} + 8p^{11} - p^{12}) \quad (2)$$

- Compute reliability polynomial
  - Probability that the network is operating (s,t-connected) given a link operation probability *p*.
  - Because *p* • *1*, the Mesh equation will have a higher operation probability.

Reliability 2



$$\text{Rel(disj)} = 2p^4 - p^8 \quad (1)$$

$$\text{Rel(mesh)} = 2p^4 - p^8 + (6p^4 - 12p^6 - 8p^7 + 15p^8 + 12p^9 - 20p^{10} + 8p^{11} - p^{12}) \quad (2)$$

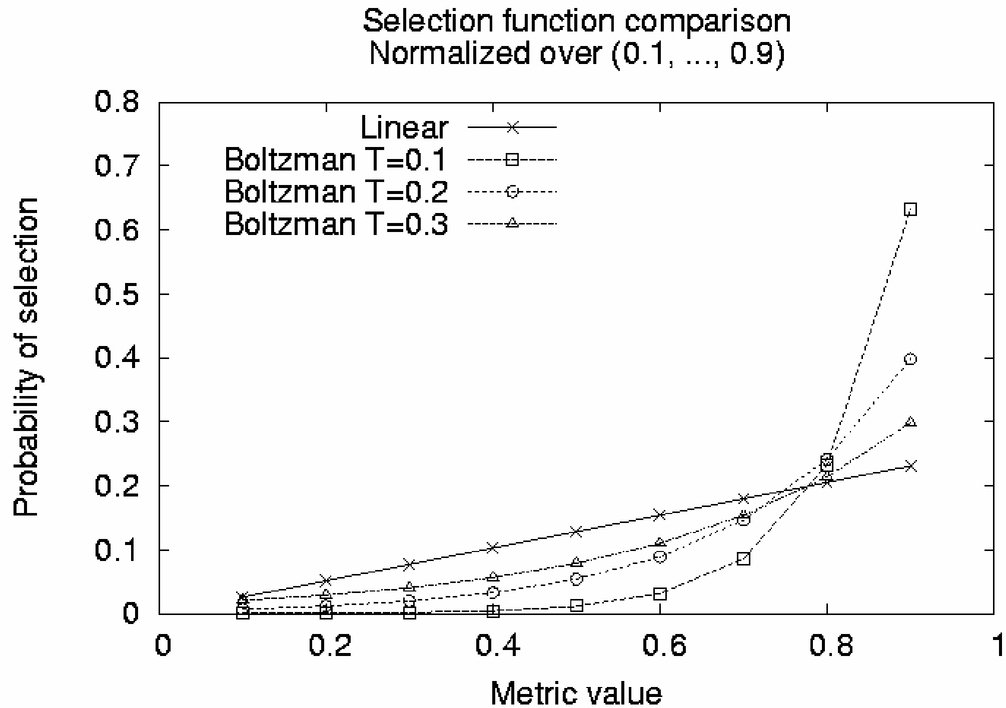
Route lifetime

- Extending Nasipuri et al. (2001)
  - Use an exponential model for link lifetime
  - Compute the mean s,t-connectedness life
  - • = 1 / mean operating life
  - Mean disjoint lifetime = 3/(8•)
  - Mean disjoint lifetime = 44/(77•) = 1.56x longer
    - 3 hop = 1.29x longer
    - 4 hop = 1.56x longer
    - 5 hop = 1.81x longer

Traffic Assignment

- Min-cost
  - Choose multipaths of minimal cost and round-robin assign traffic (or hash, etc.).
- Proportional
  - Pick a metric (or composite metric) and assign traffic in proportion to metric.
- Boltzmann
  - A metric that favors the “better” paths, but still sends some traffic along the “not as good” paths and avoids the “bad paths”. We propose a method to compute composite metrics using geometric means.

Boltzmann Distribution

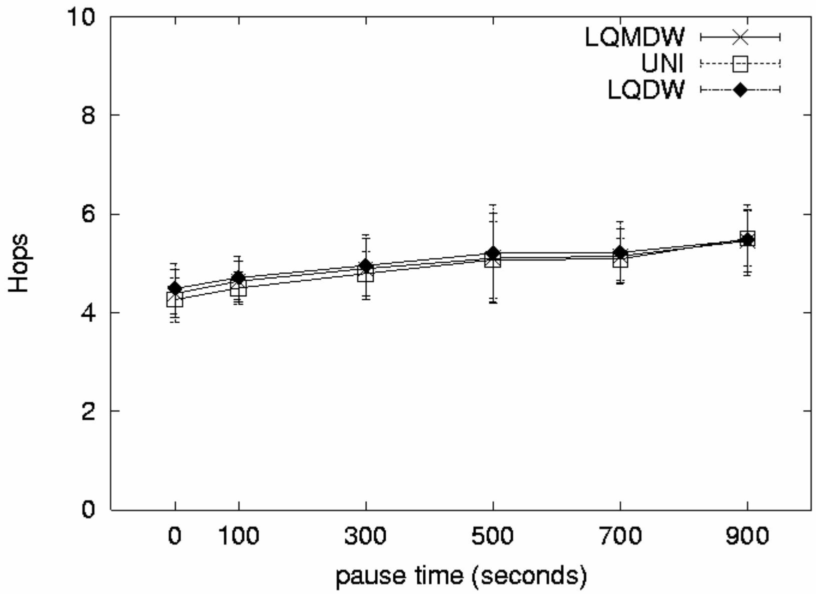


$$b_{i,j} = \frac{\exp(x_{i,j}/T_j)}{\sum_k \exp(x_{k,j}/T_j)}$$

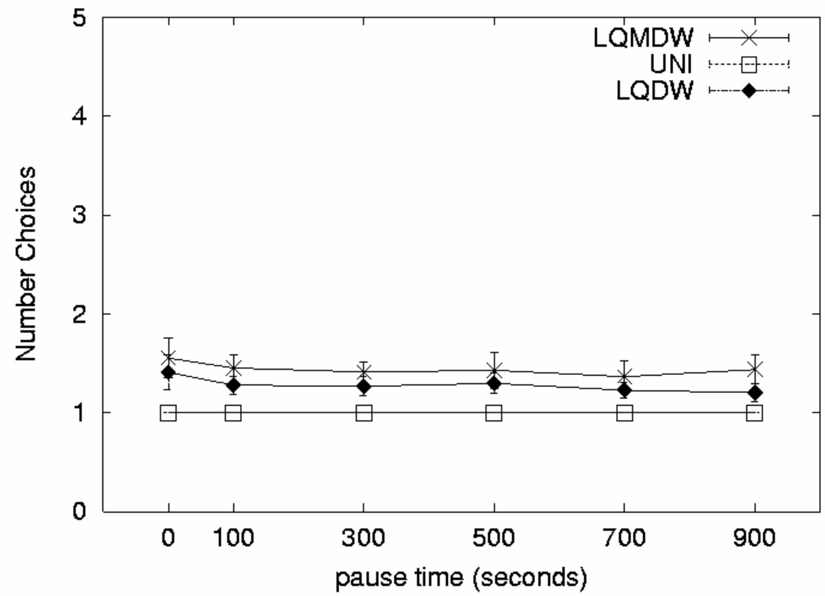
Simulation Results

- Multipath simulations
  - Done as standard ad-hoc mobile node
  - NS2 with 802.11 MAC, 50-nodes and 100-nodes.
  - DOS (Distributed Ordered Sequences) routing protocols – new protocol from PARC.
  - Compare Unipath, min-hop multipath, and unequal cost multipath. Only use hop-count metric in current work. Do not try to maintain a minimum number of multipaths.
  - Use Boltzmann distribution to distribute load over unequal cost multipath.

Simulation Results

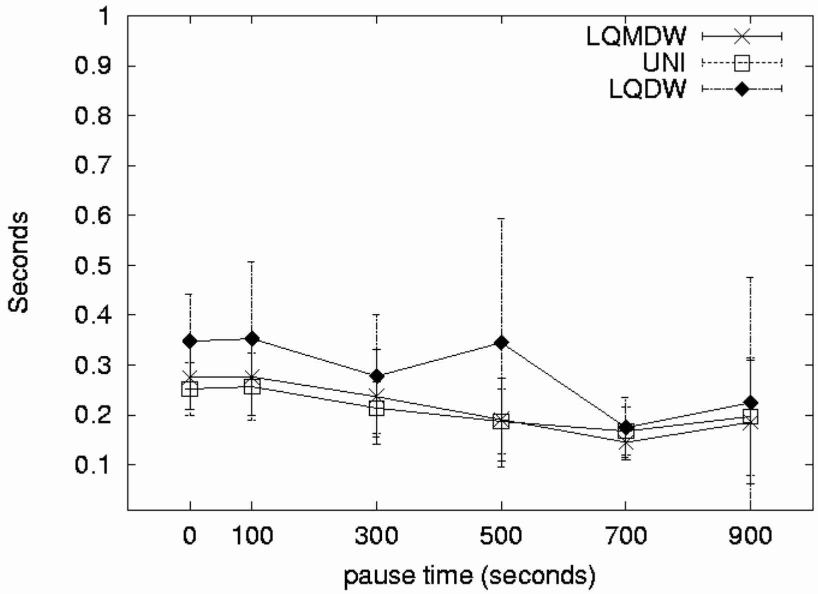


Avg. Path Length

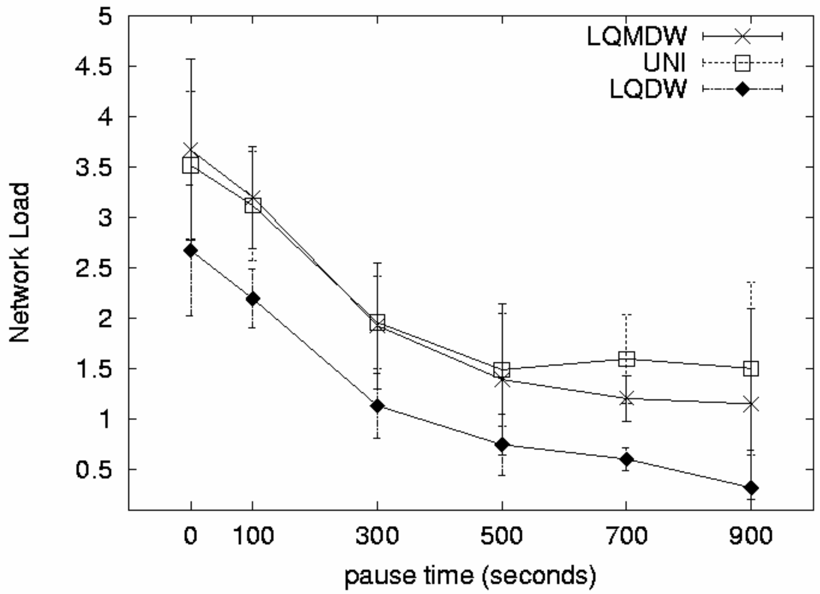


Avg. # of multipaths per hop

Simulation Results 2



Avg. end-to-end latency



Avg. network load
(control/delivered)

Summary

- Exploit the “mesh” in Mesh Networks
  - Do not restrict to disjoint paths
  - Distribute load over unequal cost paths
- Future work
  - Thorough comparison of load sharing.
  - Use different metrics (delay, etc.)
  - How to do a “reliability” metric protocol to solve inclusion/exclusion calculations?
  - Better analysis of on-demand packet delay.
  - Study of preemptive path repair using features of DOS (unicast probes).