Comparison of Routing Metrics for Static Multi-Hop Wireless Networks

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Multi-hop Wireless Networks

	Static	Mobile
Motivating scenario	Community wireless networks ("Mesh Networks")	Battlefield networks
Key challenge	Improving network capacity	Handling mobility, node failures, limited power.

Routing in Multi-hop Wireless Networks

- Mobile networks:
  - Minimum-hop routing ("shortest path")
  - DSR, AODV, TORA ….
- Static networks:
  - Minimum-hop routing tends to choose long, lossy wireless links
  - Taking more hops on better-quality links can improve throughput

    [*De Couto et. al., HOTNETS 2003*]

Link-quality Based Routing

- Metrics to measure wireless link quality:
  - Signal-to-Noise ratio
  - Packet loss rate
  - Round trip time
  - Bandwidth
  - …

Our paper: experimental comparison of performance of three metrics in a 23 node, indoor testbed.

Contributions of our paper

- Design and implementation of a routing protocol that incorporates notion of link quality
  - Link Quality Source Routing (LQSR)
  - Operates at layer "2.5"

- Detailed, "side-by-side" experimental comparison of three link quality metrics:
  - Per-hop Round Tip Time (RTT) *[Adya et al 2004]*
  - Per-hop Packet Pair (PktPair)
  - Expected Transmissions (ETX) *[De Couto et al 2003]*

Summary of Results

- ETX provides best performance
- Performance of RTT and PktPair suffers due to self-interference
- PktPair suffers from self-interference only on multi-hop paths

Outline of the rest of the talk

- LQSR architecture (brief)
- Description of three link quality metrics
- Experimental results
- Conclusion

LQSR Architecture

- Source-routed, link-state protocol
  - Derived from DSR
- Each node measures the quality of links to its neighbors
- This information propagates throughout the mesh
- Source selects route with best cumulative metric
- Packets are source-routed using this route

Link Quality Metrics

- Per-hop Round Trip Time (RTT)
  - Per-hop Packet-Pair (PktPair)
  - Expected transmissions (ETX)
  - Minimum-hop routing (HOP)
    - Binary link quality

Metric 1: Per-hop RTT

- Node periodically pings each of its neighbors
  - Unicast probe/probe-reply pair
- RTT samples are averaged using TCP-like low-pass filter
- Path with least sum of RTTs is selected

Metric 1: Per-hop RTT

- Advantages
  - Easy to implement
  - Accounts for link load and bandwidth
  - Also accounts for link loss rate
    - 802.11 retransmits lost packets up to 7 times
    - Lossy links will have higher RTT
- *Disadvantages*
  - Expensive
  - **Self-interference due to queuing**

Metric 2: Per-hop Packet-Pair

- Node periodically sends two back-to-back probes to each neighbor
  - First probe is small, second is large
- Neighbor measures delay between the arrival of the two probes; reports back to the sender
- Sender averages delay samples using low-pass filter
- Path with least sum of delays is selected

Metric 2: Per-hop Packet-Pair

- *Advantages*
  - Self-interference due to queuing is not a problem
  - Implicitly takes load, bandwidth and loss rate into account
- *Disadvantages*
  - More expensive than RTT

Metric 3: Expected Transmissions

- **Estimate number of times a packet has to be retransmitted on each hop**
- Each node periodically broadcasts a probe
  - 802.11 does not retransmit broadcast packets
- Probe carries information about probes received from neighbors
- Node can calculate loss rate on forward (P_f) and reverse (P_r) link to each neighbor

$$ETX = \frac{1}{(1 - P_f) * (1 - P_r)}$$

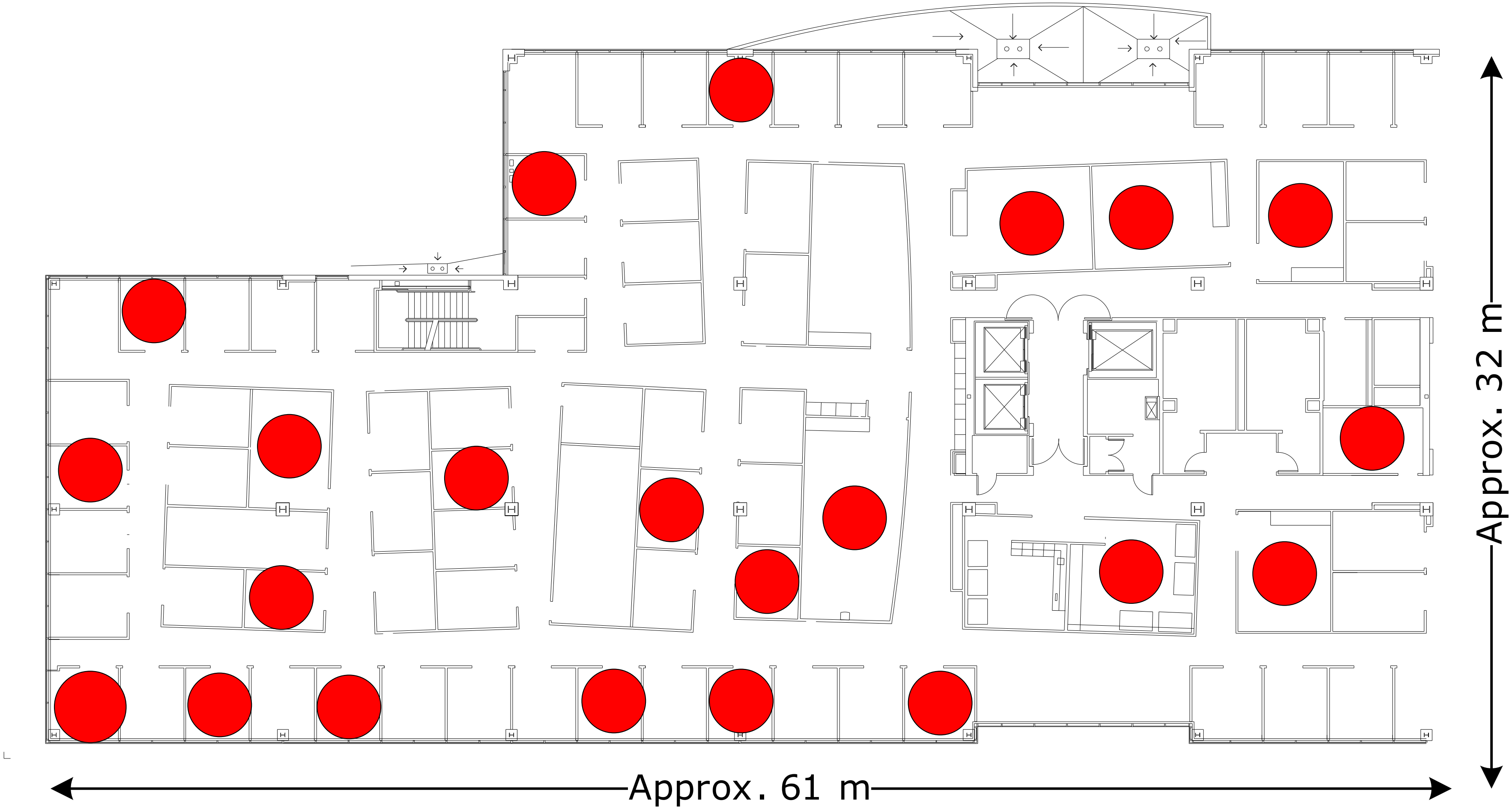
- **Select the path with least total ETX**

Metric 3: Expected Transmissions

- *Advantages*
  - Low overhead
  - Explicitly takes loss rate into account

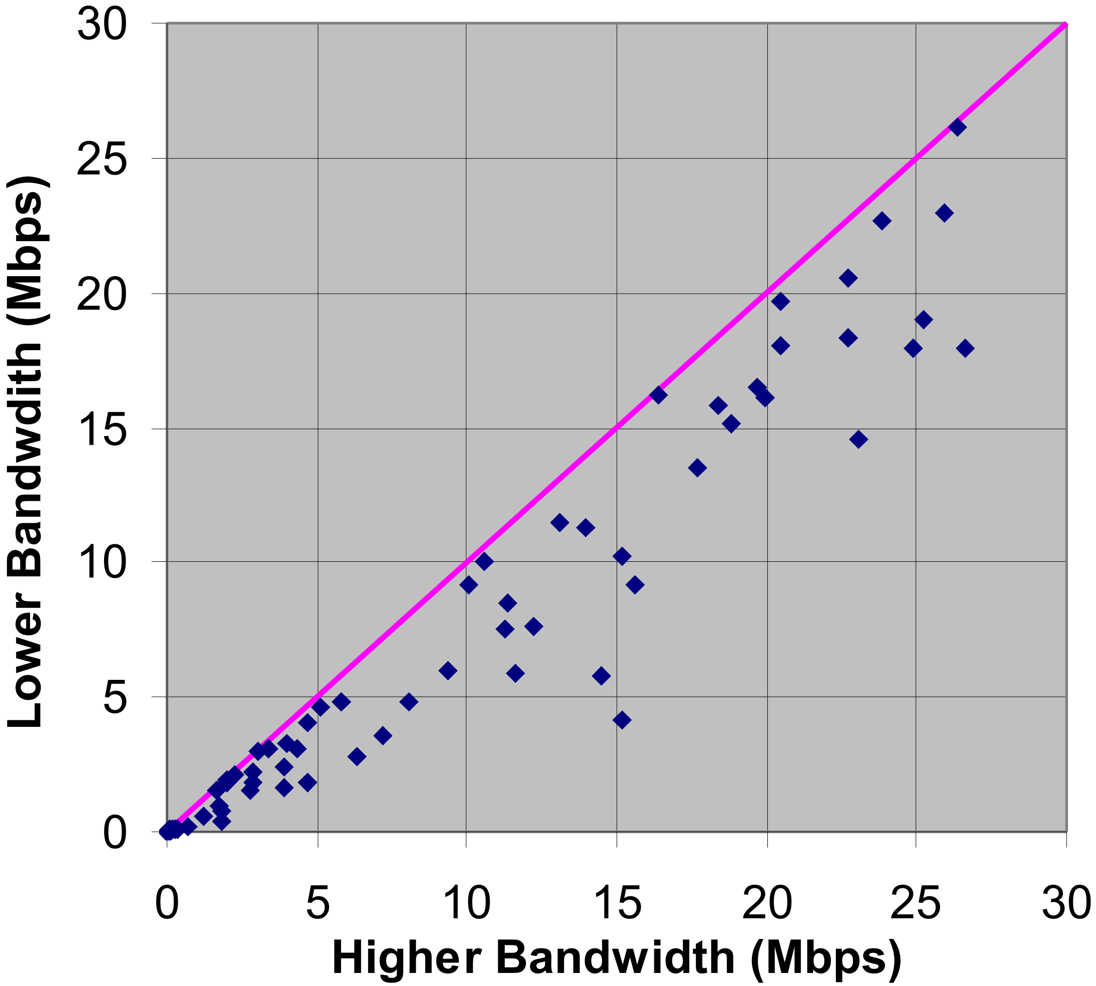
- *Disadvantages*
  - Loss rate of broadcast probe packets is not the same as loss rate of data packets
    - Probe packets are smaller than data packets
    - Broadcast packets are sent at lower data rate
  - Does not take data rate or link load into account

Mesh Testbed



23 Laptops running Windows XP.
802.11a cards: mix of Proxim and Netgear.
Diameter: 6-7 hops.

Link bandwidths in the testbed



- **Cards use Autorate**
- **Total node pairs: 23x22/2 = 253**
- **90 pairs have non-zero bandwidth in both directions.**

Bandwidths vary significantly; lot of asymmetry.

Experiments

1. Bulk-transfer TCP Flows

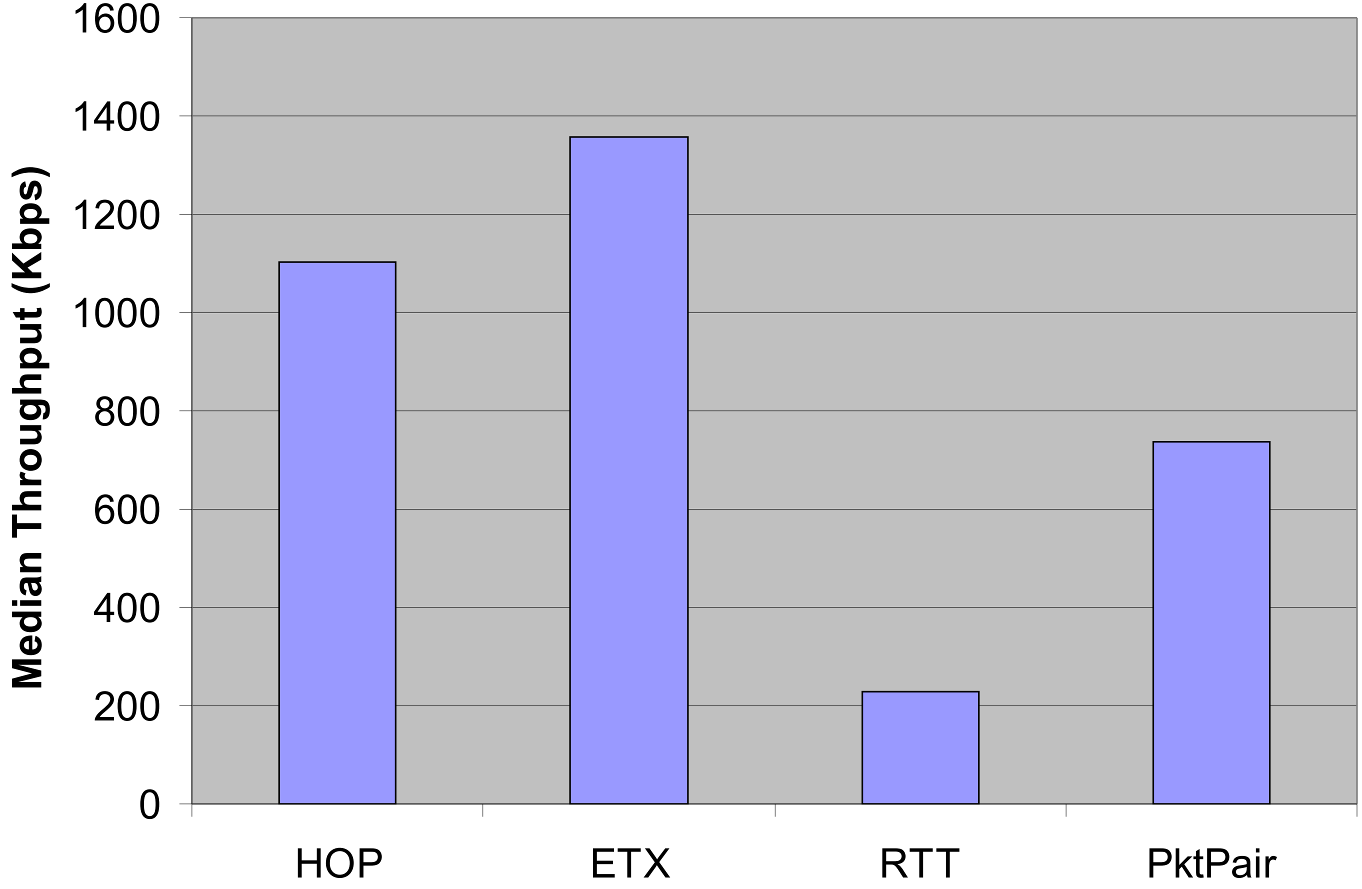
4. Impact of mobility

Experiment 1

- 3-Minute TCP transfer between each node pair
  - 23 x 22 = 506 pairs
  - 1 transfer at a time
  - Long transfers essential for consistent results

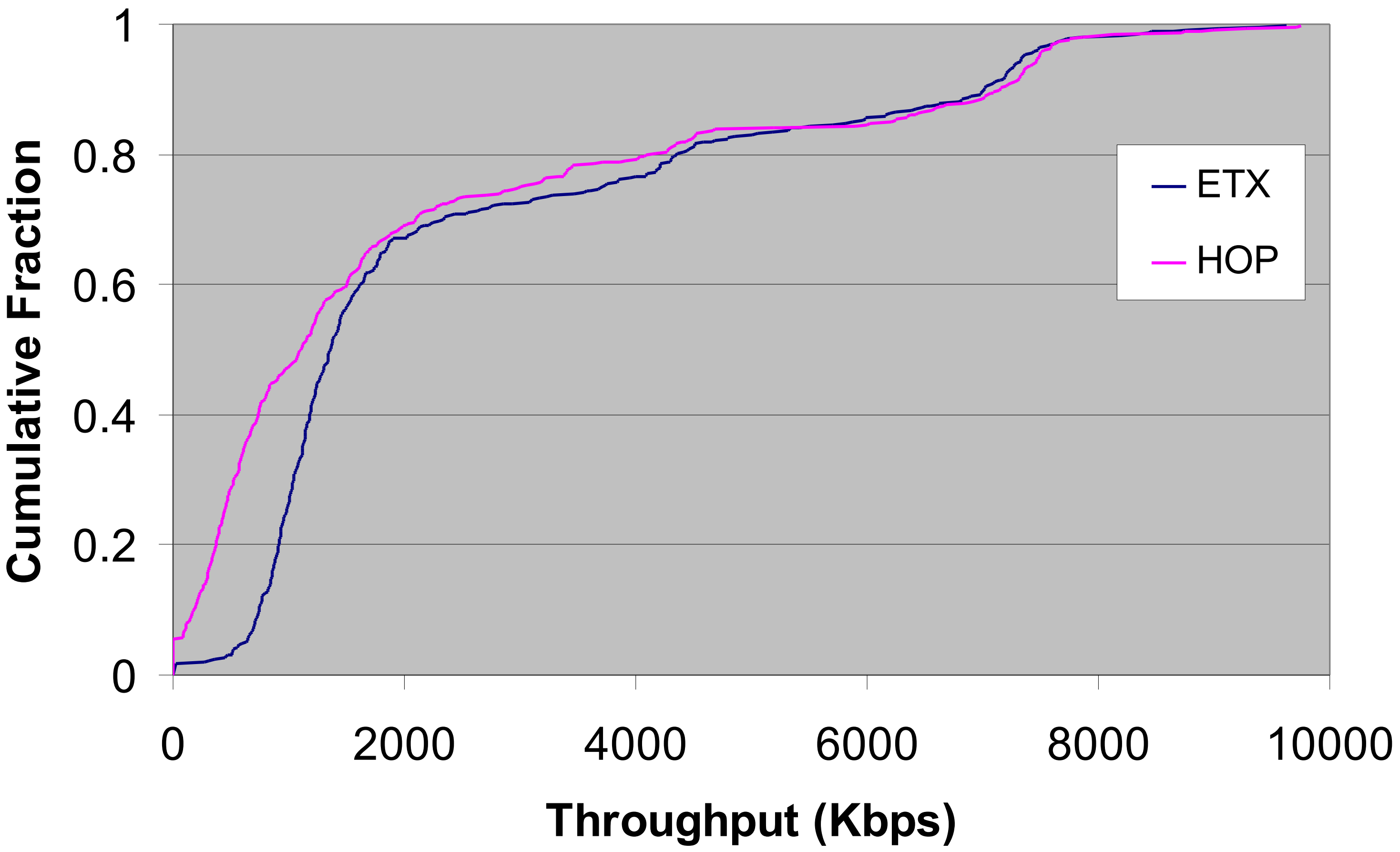
- For each transfer, record:
  - Throughput
  - Number of paths
    - Path may change during transfer
  - Average path length
    - Weighted by fraction of packets along each path

Median Throughput



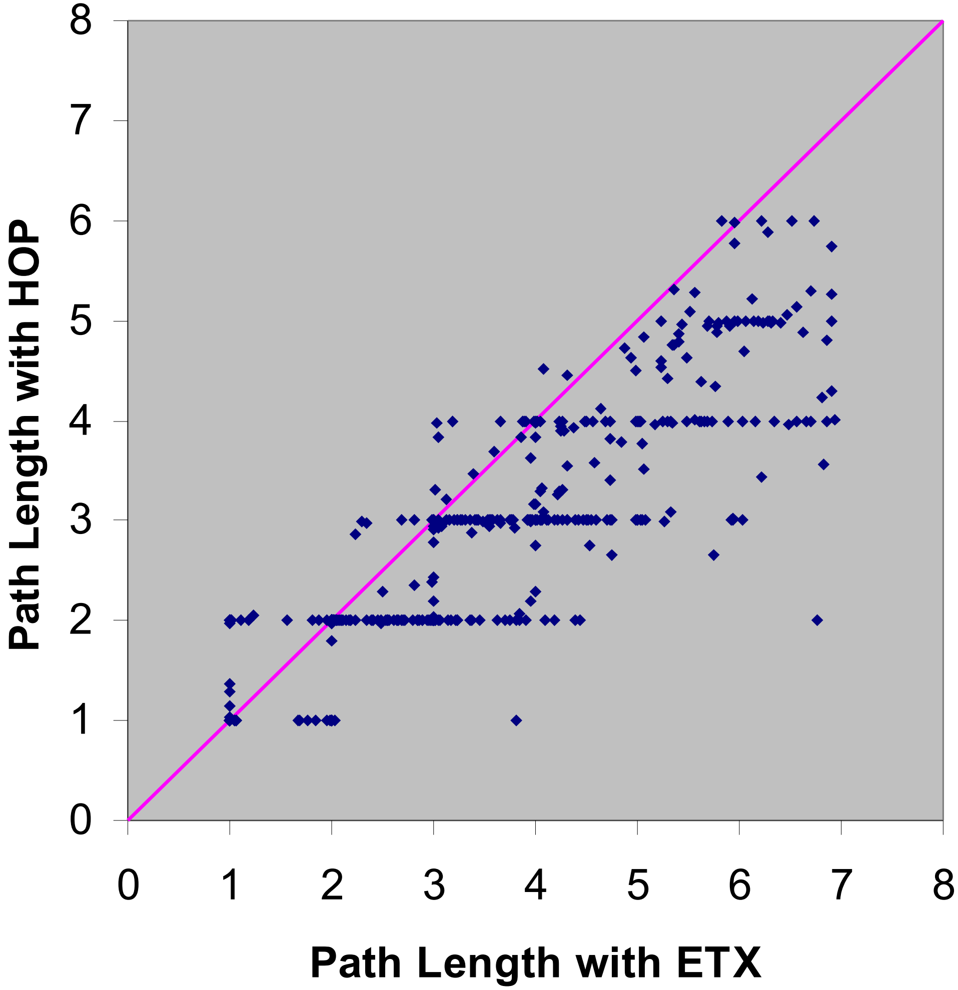
ETX performs best. RTT performs worst.

Why does ETX perform well?



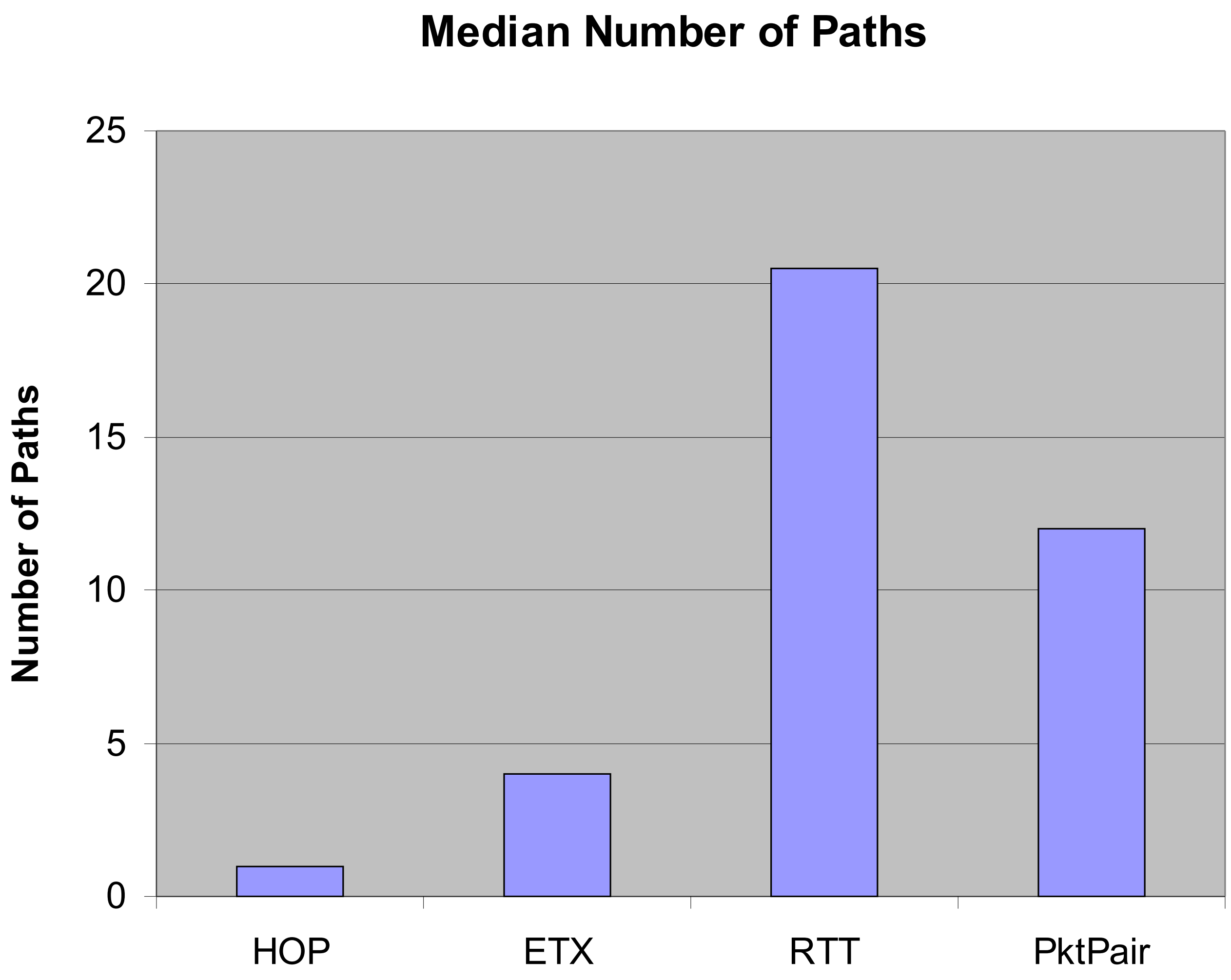
ETX performs better by avoiding low-throughput paths.

Impact on Path Lengths



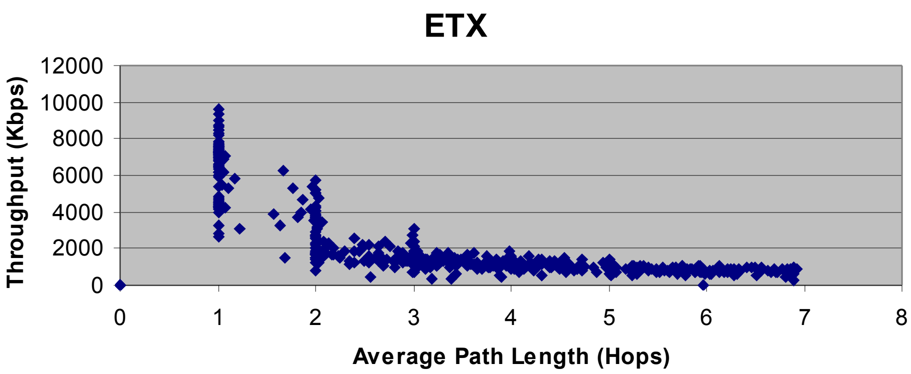
Path length is generally higher under ETX.

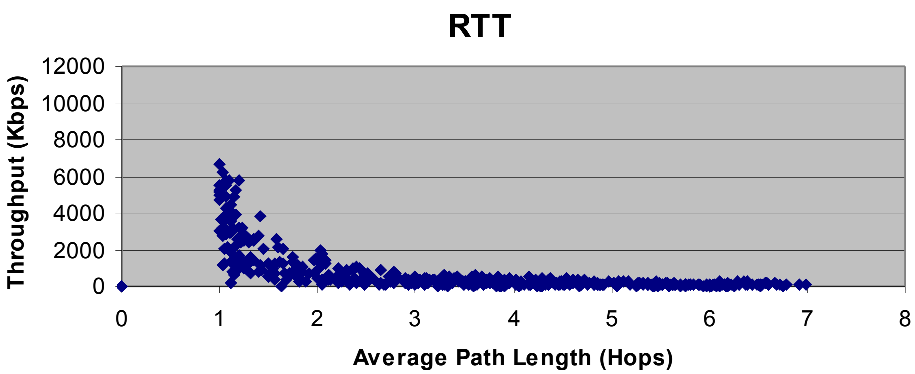
Why does RTT perform so poorly?

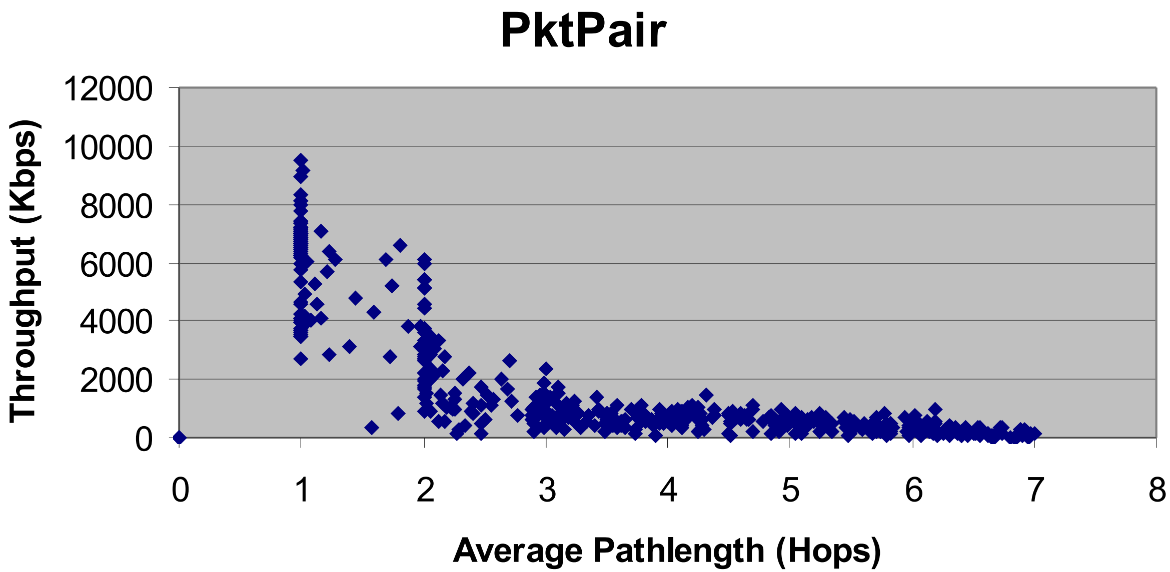


RTT suffers heavily from self-interference

What ails PktPair?







PktPair suffers from self-interference only on multi-hop paths.

Summary

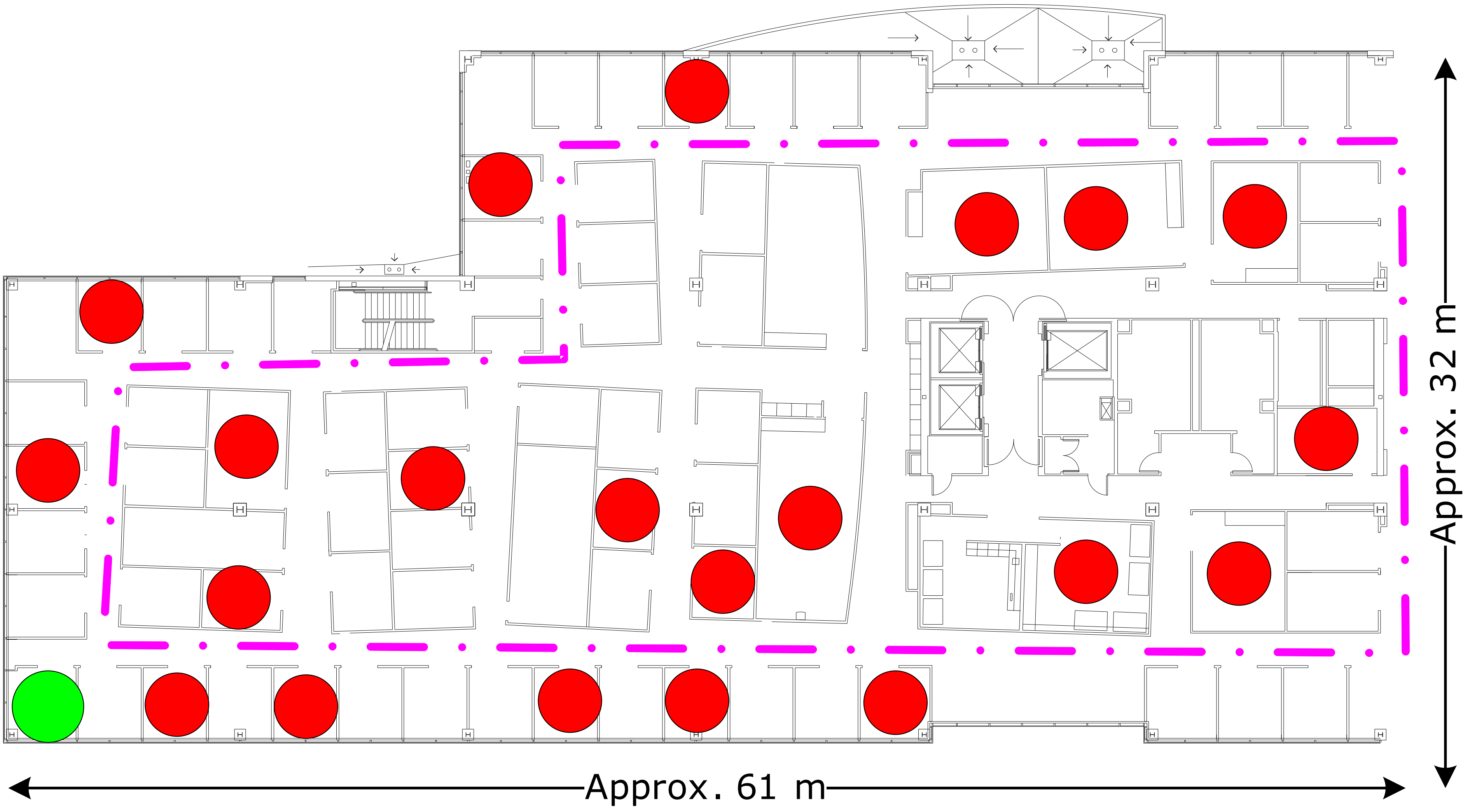
- ETX performs well despite ignoring link bandwidth
- Self-interference is the main reason behind poor performance of RTT and PktPair.

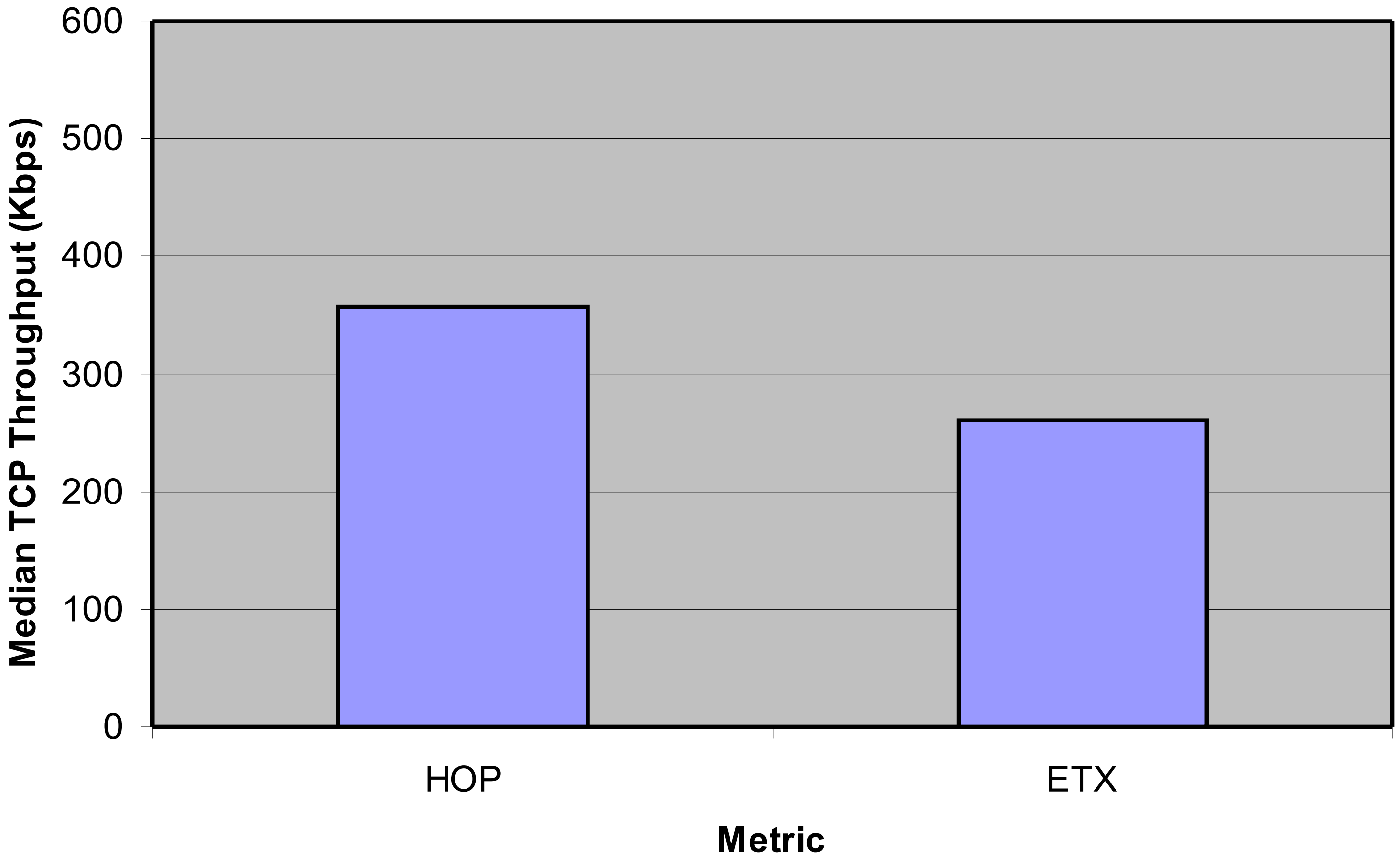
Similar results for multiple simultaneous flows.

Experiment 2

- Walk slowly around network periphery for 15 minutes with a laptop
- Mobile laptop is the sender, a corner node is receiver
- Repeated 1-minute TCP transfers

Testbed Layout





Shortest path routing is best in mobile scenarios?

Conclusions

- ETX metric performs best in static scenarios
- RTT performs worst
- PacketPair suffers from self-interference on multi-hop paths
- Shortest path routing seems to perform best in mobile scenarios
  - Metric-based routing does not converge quickly?

Ongoing/Future work

- Explicitly take link bandwidth into account
- Support for multiple heterogeneous radios per node
  - To appear in MOBICOM 2004
- Detailed study of TCP performance in multi-hop networks
- Repeat study in other testbeds

For more information

http://research.microsoft.com/mesh/

Source code, binaries, tech reports, …

Backup slides

LQSR Architecture

- Implemented in a shim layer between Layer 2 and 3.
- The shim layer acts as a virtual Ethernet adapter
  - Virtual Ethernet addresses
  - Multiplexes heterogeneous physical links
- Advantages:
  - Supports multiple link technologies
  - Supports IPv4, IPv6 etc *unmodified*
  - Preserves the link abstraction
  - Can support any routing protocol

- Architecture:

IPv4	IPv6	IPX
Mesh connectivity Layer with LQSR		
Ethernet	802.11	802.16

- Header Format:

Ethernet	MCL	Payload: TCP/IP, ARP, IPv6…

Web transfers

- Simulated Web transfer using Surge
- One node serves as web server
- Six nodes along periphery act as clients
- Results: ETX reduces latency by 20% for hosts that are more than one hop away from server.

Static Multi-hop Wireless Networks

- Motivating scenario:
  - Community wireless networks ("Mesh Networks")
    - Very little node mobility
    - Energy not a concern
- Main Challenge:
  - Improve Network capacity
- Minimum-hop count routing is inadequate
  - Tends to choose long, lossy wireless links [*De Couto et. al., HOTNETS 2003*]

“Traditional” Multi-hop Wireless Networks

- Envisioned for mobility-intensive scenarios
- Main concerns:
  - Reduce Power consumption
  - Robustness in presence of mobility, link failures
- Routing:
  - Minimum-hop routing (“shortest path”) with various modifications to address power and mobility concerns
  - DSR, AODV, TORA ….