Routing in Wireless Mesh Networks

ECSE6962

Meng Fang

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Outline

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- Basic Terms
- Design of Routing Metrics
  - Basic Idea and Goals
  - Specific metrics design (HOP, RTT, PktPair, ETX, WCETT)
- Comparison of Routing Metrics
  - Test Bed
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- Conclusion and Future work

Back Ground

What is the Characteristics of Static Wireless networks?

- A kind of self-configuring ad-hoc network
- Most of the nodes are either stationary or minimally mobile.
- The network do not rely on batteries
- Compliant with 802.11 standards

Example

Wireless community mesh network that provides connectivity to homes and businesses in rural, suburban, or metropolitan areas at broadband speeds.

Motivation of Multi Radio Routing Algorithm design

Static Wireless networks are facing problems

- Throughput of individual flows decrease rapidly as node density and the number of hops increases.
- Reduction in total capacity due to interference between multiple simultaneous transmissions

More possibility of implementation

- 802.11 radios are off-the shelf commodity parts with rapidly diminishing prices.
- Directional antennas, improved MACs, and channel switching technologies

Some Basic Terms

Basic Routing Protocols

- DSR: Dynamic Source Routing
- LQSR: Link Quality Source Routing
- MR-LQSR: Multi-Radio Link-Quality Source Routing

Others

- NIC: Network interface cards
- Self-Interference: Route instability because of load-dependent metric

Design of Routing Metrics
-Basic Idea and Goals

- Basic Idea

  Consider the quality of links together with the length of routing path

- Goals

  Exploit the available spectrum as efficiently as possible and extract the highest bandwidth possible from existing technology.

Design of Routing Metrics -Hop Count (HOP)

- ## Algorithm Description

  This metric provides minimum hop-count routing. Link quality for this metric is a binary concept; either the link exists or it doesn't.

- ## Advantage

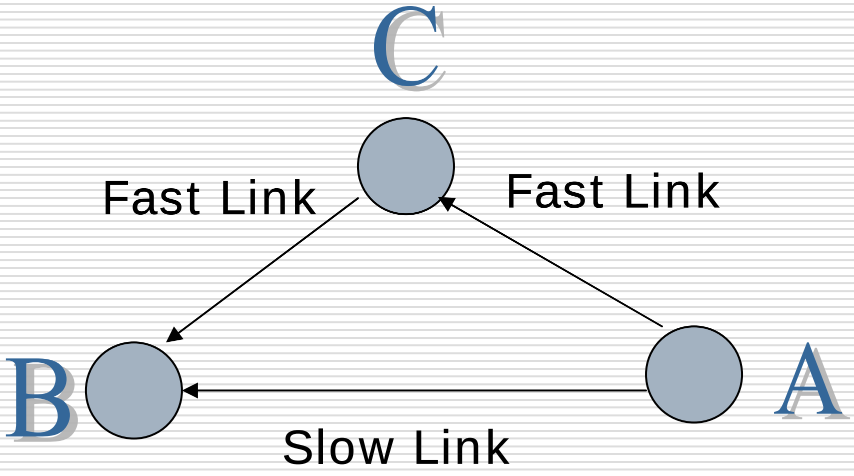
  Simplicity: Once the topology is known, it is easy to compute and minimize the hop count between a source and a destination.

- ## Disadvantage

  It does not take packet loss or data rate into account.

Design of Routing Metrics -Hop Count (HOP) (Cont')

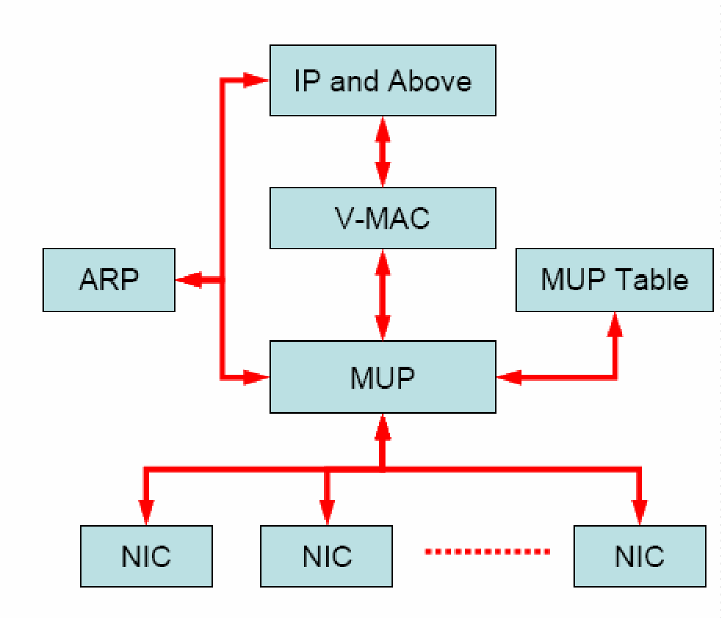
A two-hop path over reliable or fast links can exhibit better performance than a one-hop path over a lossy or slow link



Design of Routing Metrics -Per-hop Round Trip Time (RTT)

- High-level Architecture of **MUP**

RTT is designed for Multi-Radio Unification Protocol (MUP). MUP is implemented at the link layer. To hide the complexity of multiple network interfaces from applications and from the upper layers of the protocol stack, MUP exposes a single *virtual MAC address* in place of the multiple physical MAC addresses used by the wireless Network Interface Cards.



Design of Routing Metrics -Per-hop Round Trip Time (RTT)(Cont')

- components of MUP

  -neighbor discovery and classification

  An ARP request is broadcast over all the interfaces. Once the originating host receives any of the ARP responses, it can begin communicating using the interface on which the response was received. And a MUP Neighbor Table will be made, which is periodically updated.

Field	*Description (for each neighbor N)*
Neighbor	IP address of the neighbor host
Status	Indicates whether N is known to be MUP-capable
MAC list	MAC addresses associated with N
Quality list	Channel quality values for each MAC address of N
Channel	Current preferred channel to communicate with N
Selection time	Last time a channel selection decision was made
Packet time	Last time a packet was sent or received from N
Probe time list	List of times for unacknowledged probe messages

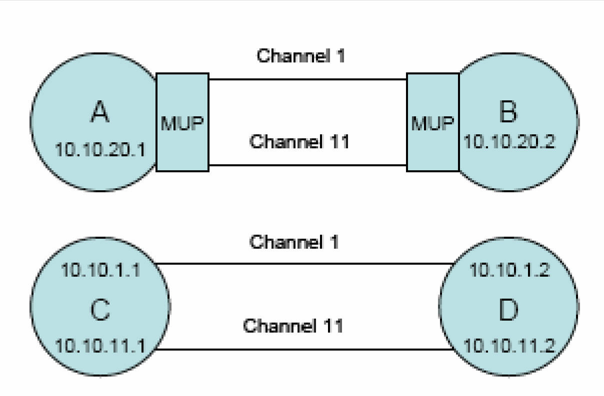
Design of Routing Metrics
-Per-hop Round Trip Time (RTT)(Cont')

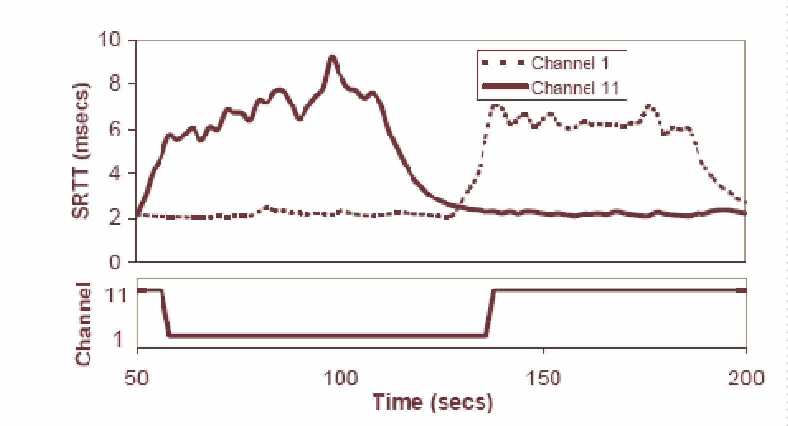
- components of MUP-Path Selection

  MUP selects the NIC with the best channel quality, which is estimated by sending the probe messages over each channel and measure the round-trip time (RTT) of the probes. A weighted average value called Smoothed RTT is introduced to estimate the quality of a link.

$$SRTT = \alpha * RTT_{new} + (1-\alpha) * SRTT$$

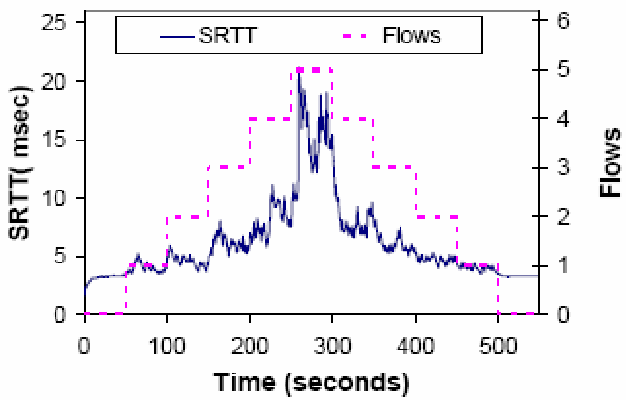
Design of Routing Metrics -Per-hop Round Trip Time (RTT)(Cont')



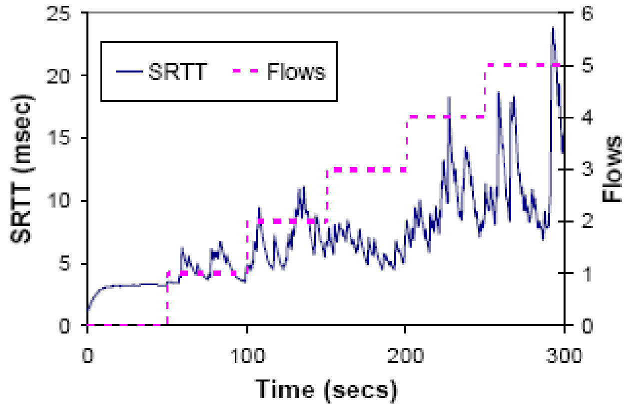


A and B are MUP enable while C and D are Legacy nodes. A and B switch their communication channel whenever the contention of the previous channel increases, which can be reflected by the increase of SRTT Value.

Design of Routing Metrics -Per-hop Round Trip Time (RTT)(Cont')



CBR traffic, $\alpha = 0.1$



Web traffic, $\alpha = 0.1$

The above pictures show that whenever the traffic increase, the SRTT increase correspondingly. It means that SRTT is a reasonable measure of load.

Design of Routing Metrics
-Per-hop Round Trip Time (RTT)(Cont')

Advantages

- The RTT metric is designed to avoid highly loaded or lossy links.

Disadvantages

- Self interference
- Overhead of measuring the round trip time.
- The metric doesn't take link data rate into account.
- It requires that every pair of neighboring nodes probe each other.

Design of Routing Metrics
-Per-hop Packet Pair Delay (PktPair)

- Algorithm Description

It is designed to correct the problem of distortion of RTT measurement due to queuing delays.

A node sends two probe packets back-to-back to each neighbor every 2 seconds. The first probe packet is small, and the next one is large. The neighbor calculates the delay between the receipt of the first and the second packets. It then reports this delay back to the sending node.

Design of Routing Metrics

-Per-hop Packet Pair Delay (PktPair) (Cont')

Advantages

- The primary advantage of this metric over RTT (MUP) is that it isn't affected by queuing delays at the sending node, since both packets in a pair will be delayed equally.

Disadvantages

- Even greater overheads over RRT
- The metric is not completely immune to the phenomenon of self interference.

Design of Routing Metrics -Expected Transmission Count (ETX)

- Let *p* denote the probability that the packet transmission from *x* to *y* is *not* successful:

$$p = 1 - (1 - p_f) * (1 - p_r)$$

Where P*f* and P*r* denote underlying packet loss probability in both the forward and reverse directions respectively.

- Let the probability that the packet will be successfully delivered from x to y after k attempts be denoted by s(k)

$$s(k) = p^{k-1} * (1 - p)$$

Design of Routing Metrics
-Expected Transmission Count (ETX) (cont')

- Finally, the expected number of transmissions required to successfully deliver a packet from *x* to *y* is denoted by ETX:

$$\mathrm{ETX} = \sum_{k=1}^{\infty} k * s(k) = \frac{1}{1-p}$$

- The path metric is the sum of the ETX values for each link in the path. The routing protocol selects the path with minimum path metric.

Design of Routing Metrics -Weighted Cumulative ETT (WCETT)

- This is a metric Developed from ETX

Limitation of ETX

- ETX only considers loss rates on the links and not their data rate.
- In an attempt to minimize global resource usage, ETX is designed to give preference to shorter paths over longer paths, as long as loss rates on the shorter paths are not significantly higher.

Design of Routing Metrics
-Weighted Cumulative ETT (WCETT) (Cont')

Assumptions

- All nodes in the network are stationary.
- Each node is equipped with one or more 802.11 radios.
- If a node has multiple radios, they are tuned to different, non-interfering channels.

Goals

- Take both the loss rate and the data rate of a link into account.
- It should be an increasing path metric.
- The path metric should explicitly account for the reduction in throughput due to interference among links that operate on the same channel.

Design of Routing Metrics
-Weighted Cumulative ETT (WCETT) (Cont')

How to Compute the path Metric?

- Attempt 1

$$\mathrm{WCETT} = \sum_{i=1}^{n} \mathrm{ETT}_i$$

Where ETTi is expected transmission time of a packet on the link i.

However, we also want WCETT to consider the impact of channel diversity, so

Design of Routing Metrics
-Weighted Cumulative ETT (WCETT) (Cont')

- Attempt 2

$$X_j = \sum_{\text{Hop i is on channel j}} ETT_i \quad 1 \leq j \leq k$$

Thus, *Xj* is the sum of transmission times of hops on channel *j*.

$$WCETT = \max_{1 \leq j \leq k} X_j$$

However, this is not an increasing metric as more hops are added to the path.

Design of Routing Metrics

-Weighted Cumulative ETT (WCETT) (Cont')

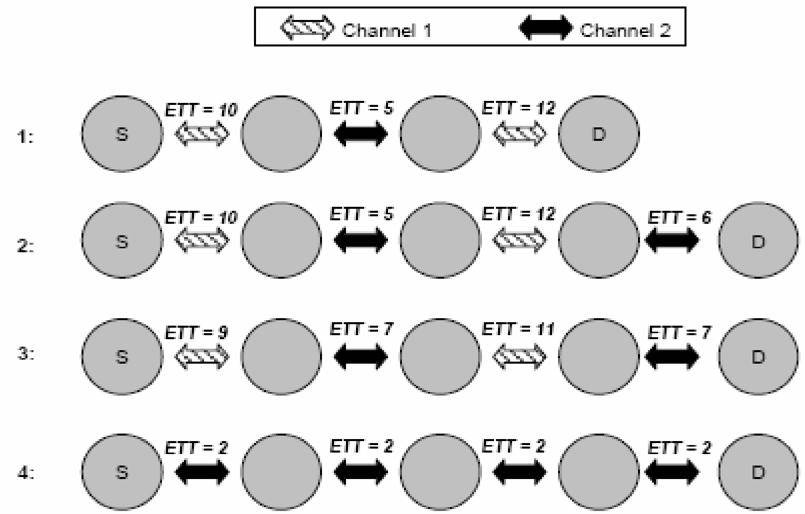
- So we combine the above two

$$\mathrm{WCETT} = (1-\beta) * \sum_{i=1}^{n} \mathrm{ETT}_i + \beta * \max_{1 \le j \le k} X_j$$

where β is a tunable parameter subject to $0 \leqslant \beta \leqslant 1$.

- We can view it as a tradeoff between global good (first term) and selfishness (second term).
- We can also view it as a tradeoff between throughput (first term) and delay (second term).

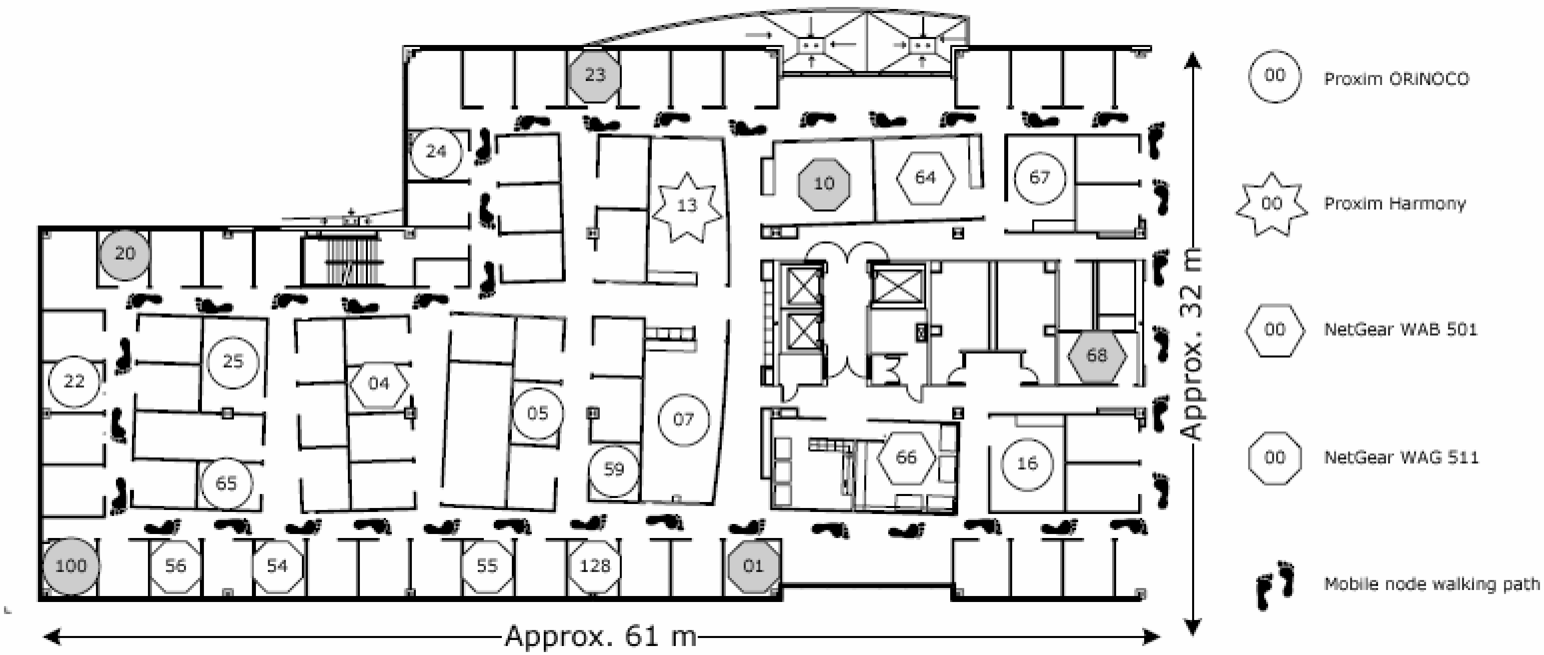
Design of Routing Metrics
-Weighted Cumulative ETT (WCETT) (Cont')



Path	Sum	Max	WCETT ($\beta = 0.9$)	WCETT ($\beta = 0.1$)
1	27	22	22.5	26.5
2	33	22	23.1	31.9
3	34	20	21.4	32.6
4	8	8	8	8

Comparison of Routing Metrics -Test Bed

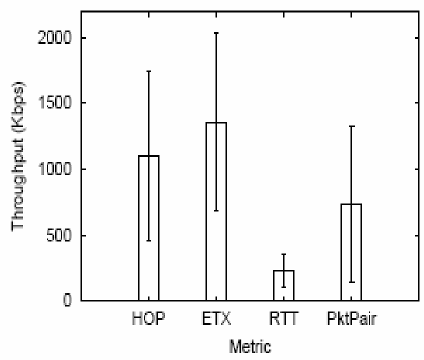
- Test Bed



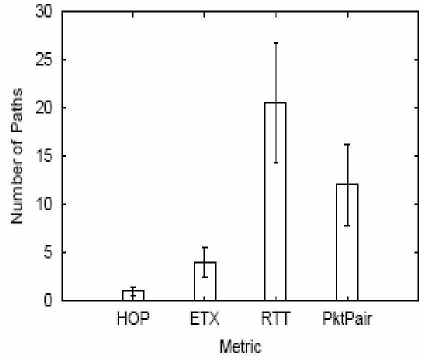
Comparison of Routing Metrics -Test Bed (Cont')

- The 23-node wireless testbed is located on one floor of a fairly typical office building, with the nodes placed in offices, conference rooms and labs.
- The building has rooms with floor-to-ceiling walls and solid wood doors.
- With the exception of one additional laptop, the nodes are located in fixed locations and did not move during testing.
- The nodes are primarily laptop PCs with Intel Pentium II processors with clock rates from 233 to 300 MHz and Windows XP.

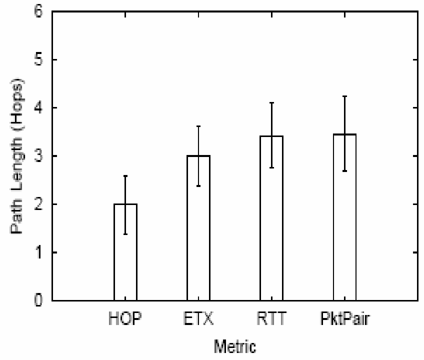
Comparison of Routing Metrics -Impact on Long Lived TCP Flows



All pairs: Median throughput of TCP transfer.



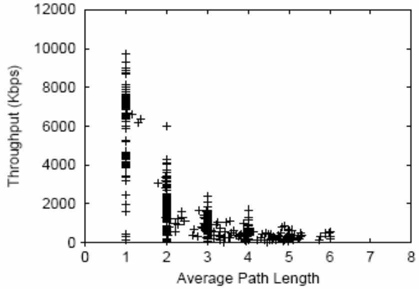
All Pairs: Median number of paths per TCP transfer.



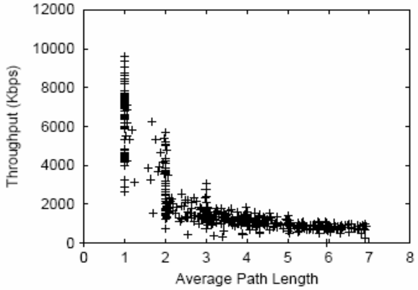
All pairs: Median path length of a TCP transfer.

- The RTT metric gives the worst performance among the four metrics due to self-interference.
- The PktPair metric performs better than RTT, but worse than both HOP and ETX

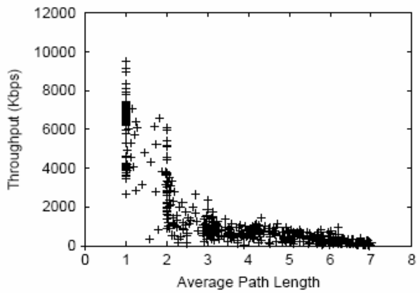
Comparison of Routing Metrics -Impact of Path Length



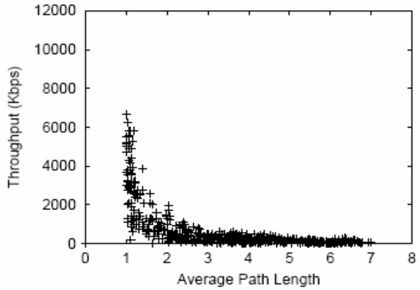
All Pairs: Throughput as a function of path length under HOP. The metric does a poor job of selecting multi-hop paths.



All Pairs: Throughput as a function of path length under ETX. The metric does a better job of selecting multi-hop paths.



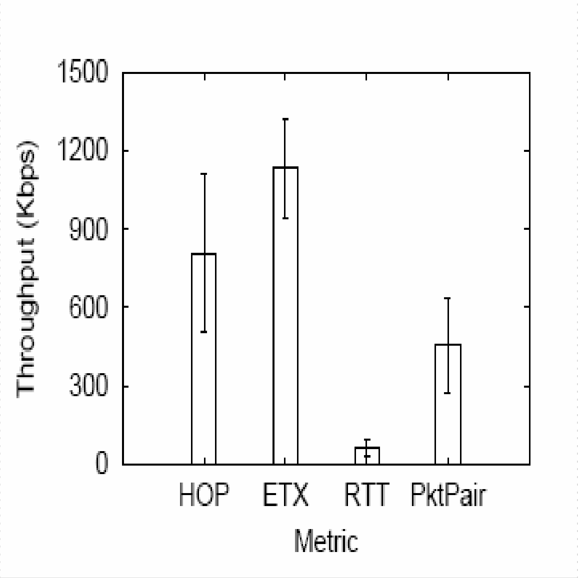
All Pairs: Throughput as a function of path length under PktPair. The metric finds good one-hop paths, but poor multi-hop paths.



All Pairs: Throughput as a function of path length under RTT. The metric does a poor job of selecting even one hop paths.

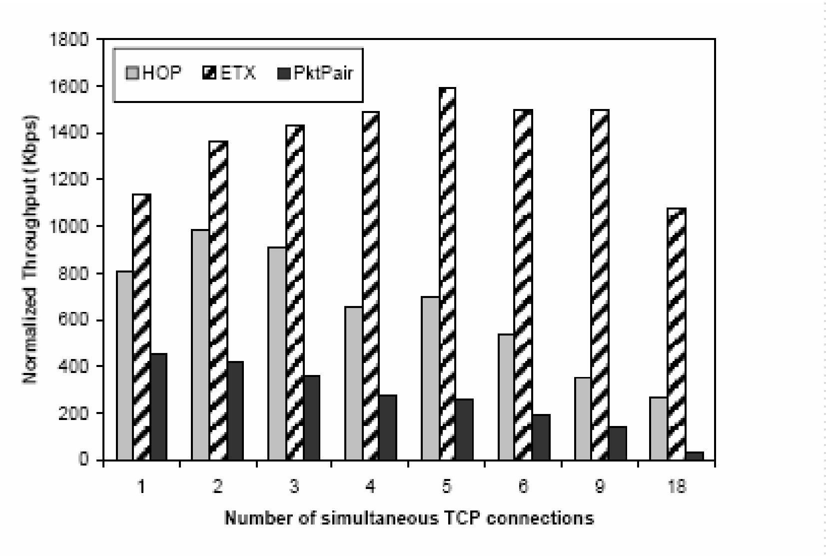
Comparison of Routing Metrics -Variability of TCP Throughput

- The picture shows show the median throughput of the 300 TCP transfers using each metric. Once again RTT performs worst and ETX performs best.

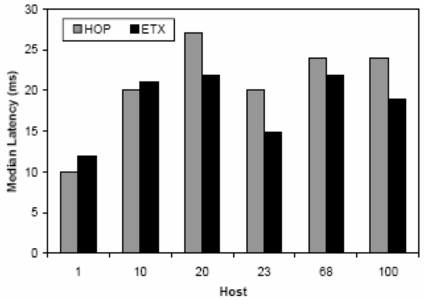


Comparison of Routing Metrics -Multiple Simultaneous TCP Transfers

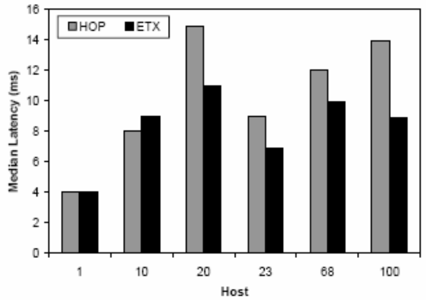
- ETX gives a better performance than other two metrics.
- When the number of simultaneous TCP connections reaches 5, the throughput of ETX has the maximum.



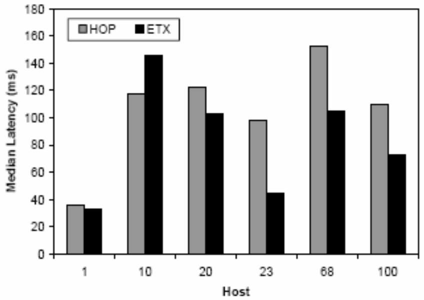
Comparison of Routing Metrics -Web-like TCP Transfers



Median latency for all files fetched



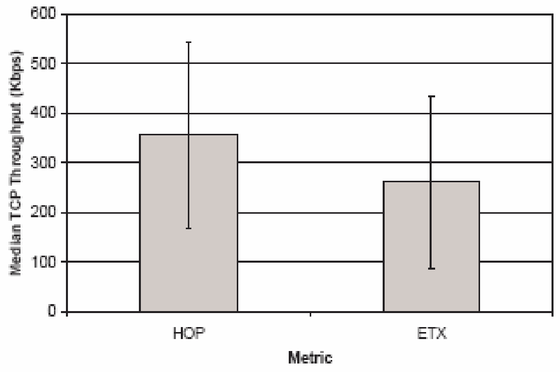
Median latency for files smaller than 1KB



Median latency for files larger than 8KB

- On longer paths, ETX performs better than HOP, but on one-hop paths, the HOP metric sometimes performs better.
- The benefit of ETX is indeed more evident in case of larger transfers. However, ETX also reduces the latency of small transfers by significant proportion.

Comparison of Routing Metrics -A MOBILE SCENARIO



Median Throughput of 45 1-minute TCP transfers with mobile sender using HOP and ETX.

- The median throughput under HOP metric is 36% higher than the median throughput under the ETX metric. It means that in this mobile scenario, HOP performs better over ETX because it reacts more quickly to fast topology change

Conclusion

- The RTT metric is the most sensitive to load; it suffers from self-interference even on one-hop paths and has the worst performance.
- The PktPair metric is not affected by load generated by the probing node, but it is sensitive to other load on the channel.
- The ETX metric has the least sensitivity to load and it performs the best.
- It is hard to make a conclusion about HOP.

Future Work

- Adding more nodes to the testbed
- Further investigating the performance of Metrics in mobile scenarios.
- Whether different radios (e.g. 802.11a & 802.11g) can be used simultaneously.

References

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Thank you!