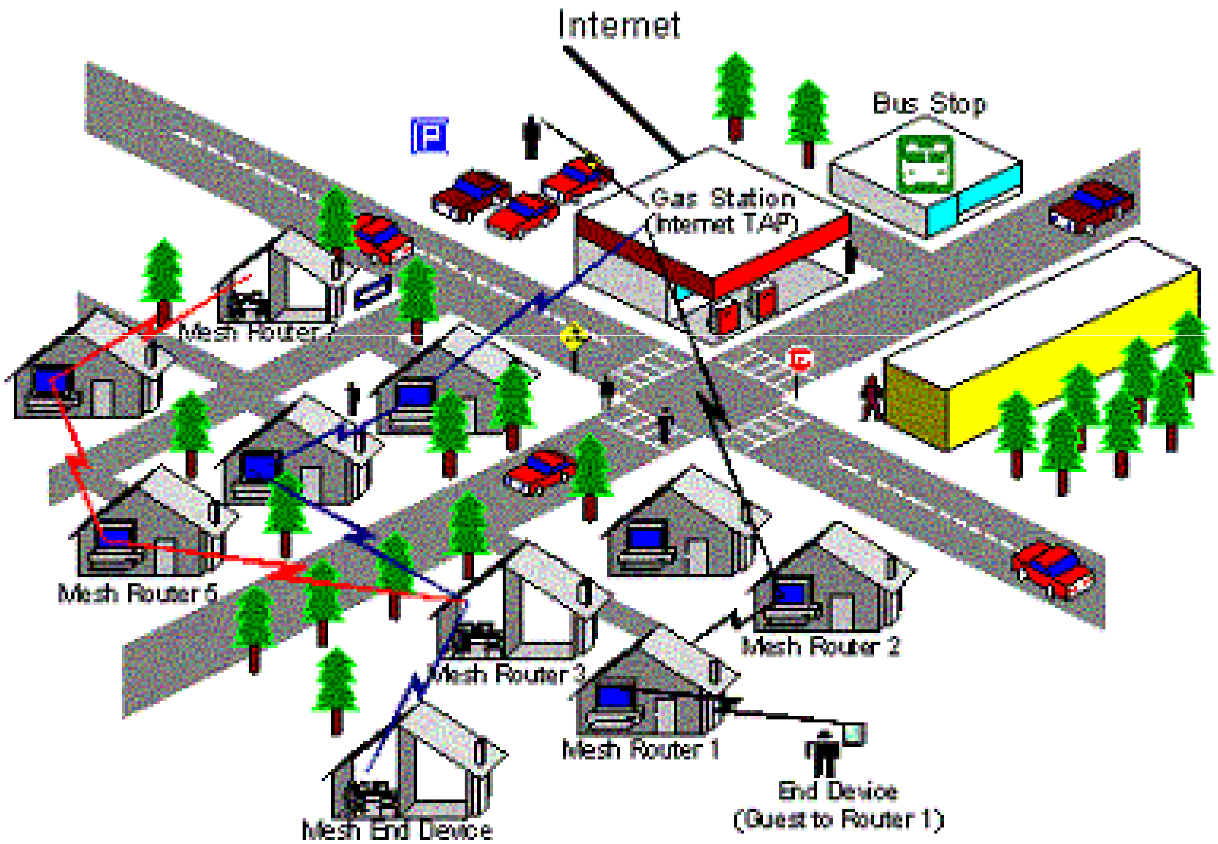
Routing Metrics

Wireless Mesh Networks



Multi-hop Wireless Networks

	Stationary Nodes	Mobile Nodes
Motivating scenario	Community wireless networks (Mesh Networks)	Battlefield networks
Key challenge	Improving Network Capacity	Handling mobility, limited power.

What do you think are good routing metrics?

Potential Ideas (and their cons)

- Product of per-link delivery ratios
- Throughput of a path's bottleneck link
- End-to-end delay

Potential Ideas (and their cons)

- Product of per-link delivery ratios
  - A perfect 2-hop route is viewed as better than a 1-hop route with 10% loss ratio
- Throughput of a path's bottleneck link
  - Same as above
- End-to-end delay
  - Changes with network load as queue lengths vary … can cause oscillations

A High-Throughput Path Metric for Multi-Hop Wireless Routing

D. S.J. Couto, D. Aguayo, J. Bicket, R. Morris

Hop Count Metric

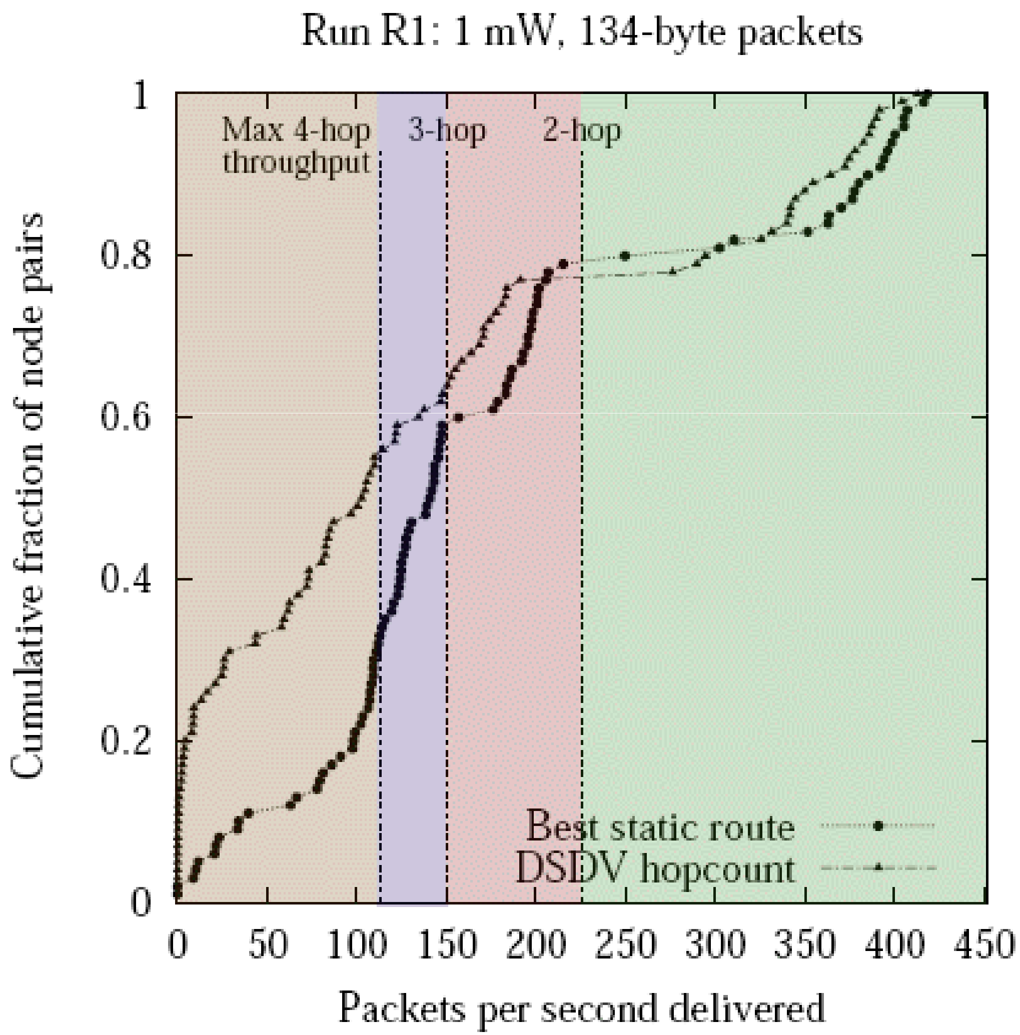
Hop Count Metric

- Maximizes the distance traveled by each hop
  - Minimizes signal strength -> Maximizes the loss ratio
  - Uses a higher TxPower -> Interference
- Possibly many shortest routes
- Avoid lossy links?

Hop Count vs. "Optimal"

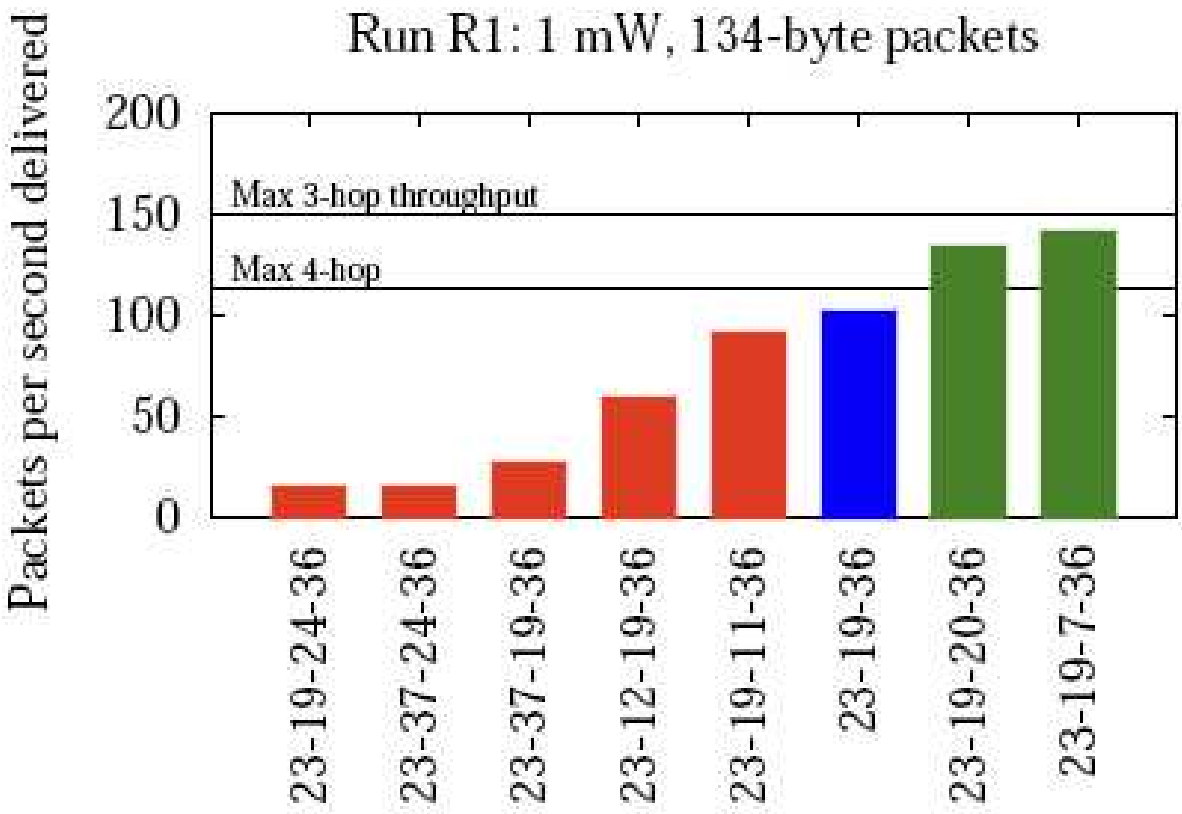
x axis:

throughput

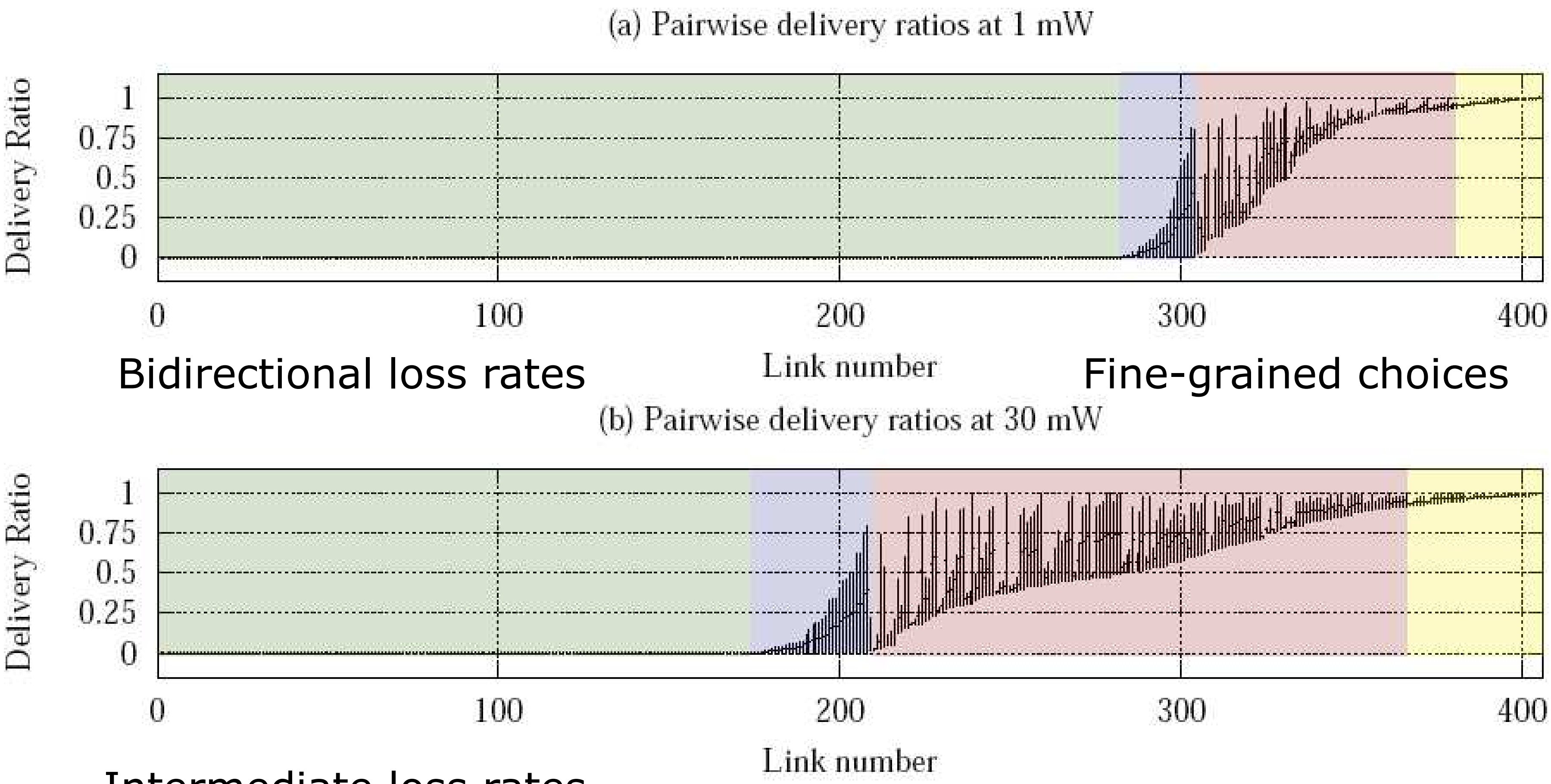


y axis: fraction of pairs with less throughput

Hop Count Route Selection



Motivation for a Better Routing Metric



Bidirectional loss rates

Fine-grained choices

Intermediate loss rates

ETX

- The predicted number of data transmissions required to send a packet over a link
- The ETX of a path is the sum of the ETX values of the links over that path
- Examples:
  - ETX of a 3-hop route with perfect links is 3
  - ETX of a 1-hop route with 50% loss is 2

ETX continued…

- Expected probability that a transmission is successfully received and acknowledged is $d_f \times d_r$
  - d_f is forward delivery ratio
  - d_r is reverse delivery ratio
- Each attempt to transmit a packet is a Bernoulli trial, so…

$$\mathrm{ETX} = \frac{1}{d_f \times d_r}$$

Hooray for ETX!

- Based on delivery ratios, which affect throughput
- Detects and handles asymmetry by incorporating loss ratios in each direction
- Uses precise link loss measurements to make fine-grained decisions between routes
  - Assumes you can measure these ratios precisely
- Penalizes routes with more hops, which have lower throughput due to inter-hop interference
  - Assumes loss rates are equal over links
- Tends to minimize spectrum use, which should maximize overall system capacity (reduce power too)
  - Each node spends less time retransmitting data

Acquiring ETX values

- Measured by broadcasting dedicated link probe packets with an average period τ (jittered by $\pm 0.1\tau$)
- Delivery ratio:
  - *count(t-w,t)* is the # of probes received during window *w*
  - w/τ is the # of probes that should have been received
- Each probe contains this information

$$r(t) = \frac{\mathrm{count}(t - w, t)}{w/\tau}$$

Implementation and such…

- Modified DSDV and DSR
- τ = 1 packet per second, w = 10 sec
- Multiple queues (different priorities)
  - Loss-ratio probes, protocol packets, data packets

Pros and cons?

Conclusions

- Pros
  - ETX performs better or comparable to Hop Count Metric
    - Accounts for bi-directional loss rates
  - Can easily be incorporated into routing protocols

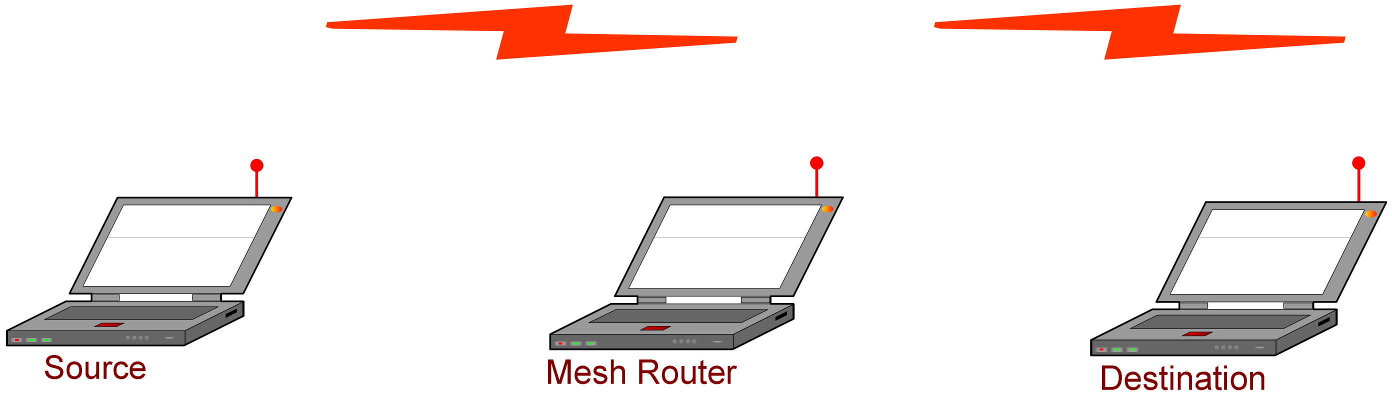
- Cons
  - May not be best metric for all networks
    - Mobility
    - Power-limited
    - Adaptive rate (multi-rate)
    - Interference
  - Predications of loss ratios not always accurate and incur overhead
  - Does not explicitly incorporate the interaction between routing changes and ETX change ➔ oscillation and select sub-optimal paths

Routing in Multi-Radio, Multi-Hop Wireless Mesh Networks

Richard Draves, Jitendra Padhye, and Brian Zill

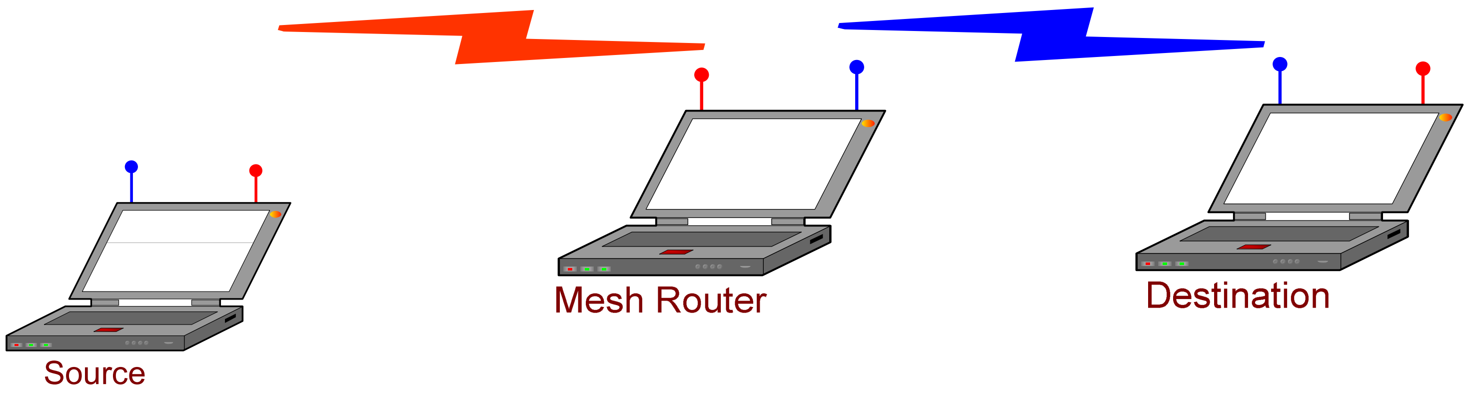
Microsoft Research

Multi-Hop Networks with Single Radio



With a single radio, a node can not transmit and receive simultaneously.

Multi-Hop Networks with Multiple Radios

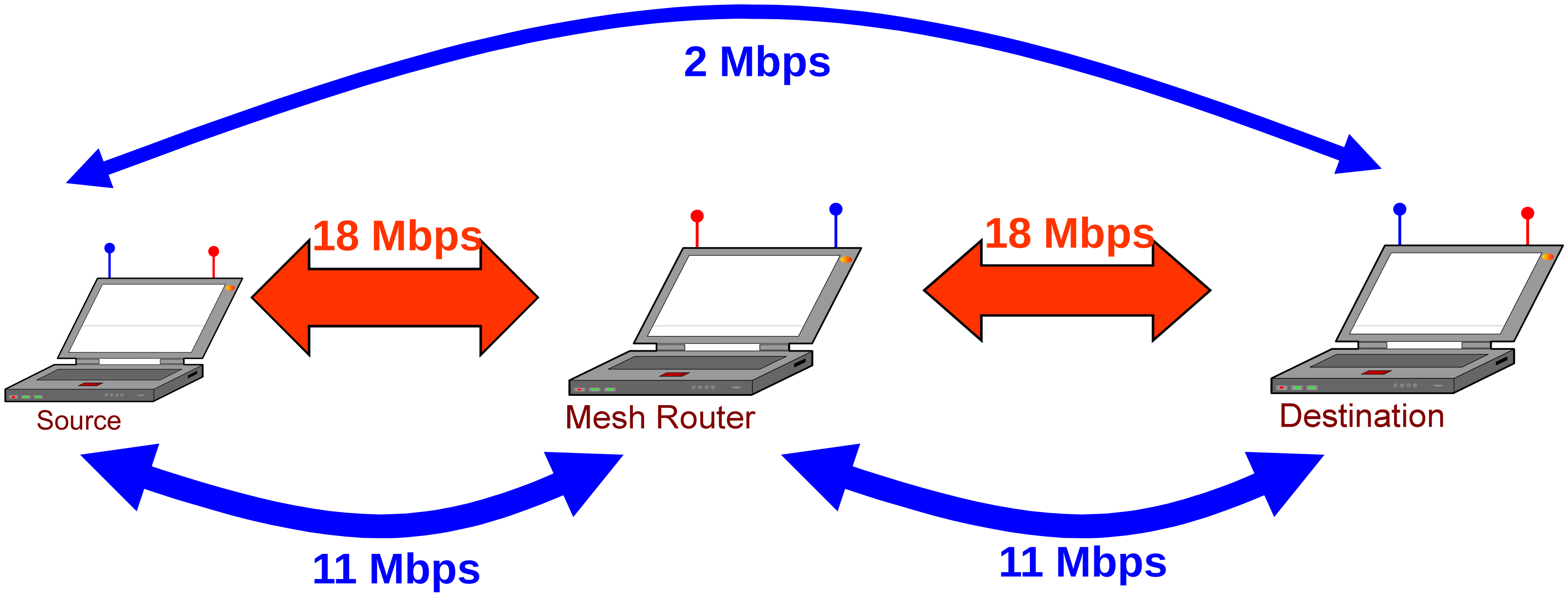


With two radios tuned to non-interfering channels, a node can transmit and receive simultaneously.

Other Advantages of Multiple Radios

- Increased robustness due to frequency diversity
  - e.g. 2.4GHz (802.11b) and 5GHz (802.11a) have different fading characteristics
- Possible tradeoff between range and data rate
  - Can be helpful during early deployment

Existing Routing Metrics are Inadequate



Shortest path: 2 Mbps

Path with fastest links: 9 Mbps

Best path: 11 Mbps

Components of a Routing Metric

- Link Metric: Assign a weight to each link

WCETT: Prefer high-bandwidth, low-loss links

- Path Metric: Combine metrics of links on path

WCETT: Prefer short, channel-diverse paths

Is ETX a good enough link metric?

Link Metric: Expected Transmission Time (ETT)

- Link loss rate = p
  - Expected number of transmissions

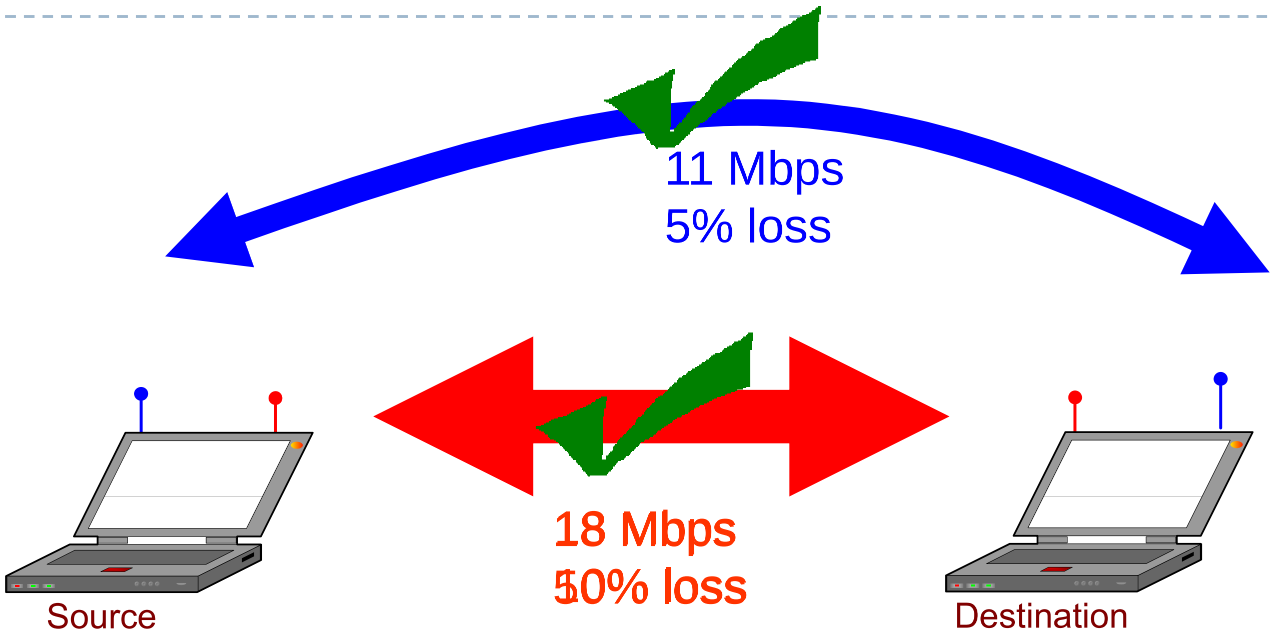
$$\mathrm{ETX} = \frac{1}{1-p}$$

- Packet size = S, Link bandwidth = B
  - Each transmission lasts for S/B

$$\mathrm{ETT} = \left(\frac{S}{B}\right) * \mathrm{ETX}$$

- Lower ETT implies better link

ETT: Illustration



1000 Byte Packet

ETT : 0.77 ms

ETT : 0.89 ms

ETT : 0.49 ms

How to design ETT-based path metric?

Combining Link Metric into Path Metric Proposal 1

- Add ETTs of all links on the path
- Use the sum as path metric

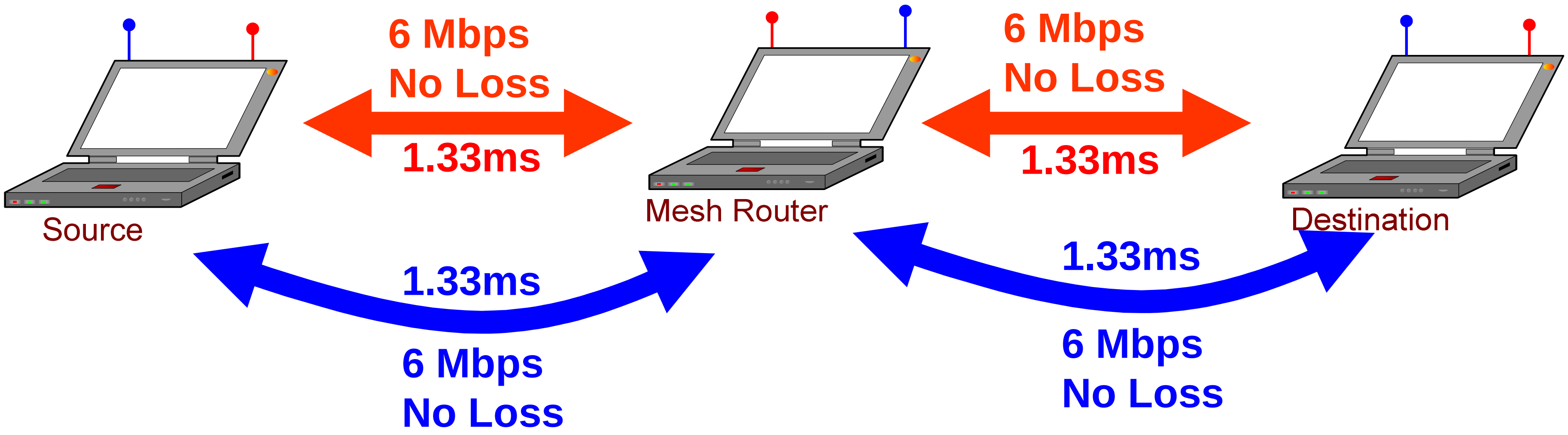
SETT = Sum of ETTs of links on path

(Lower SETT implies better path)

Pro: Favors short paths

Con: Does not favor channel diversity

SETT does not favor channel diversity



Path	Throughput	SETT
Red-Blue	6 Mbps	2.66 ms
Red-Red	3 Mbps	2.66 ms

Impact of Interference

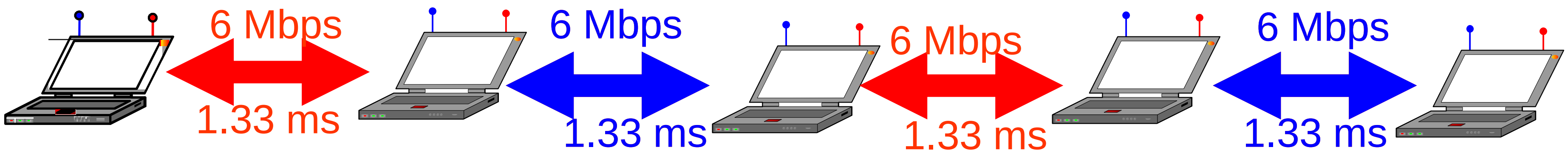
- Interference reduces throughput
- Throughput of a path is lower if many links are on the same channel
  - Path metric should be worse for non-diverse paths
- Assumption: All links that are on the same channel interfere with one another
  - Pessimistic for long paths

Combining Link Metric into Path Metric Proposal 2

- Group links on a path according to channel
  - Links on same channel interfere
- Add ETTs of links in each group
- Find the group with largest sum.
  - This is the "bottleneck" group
  - Too many links, or links with high ETT ("poor quality" links)
- Use this largest sum as the path metric
  - Lower value implies better path

"Bottleneck Group ETT" (BG-ETT)

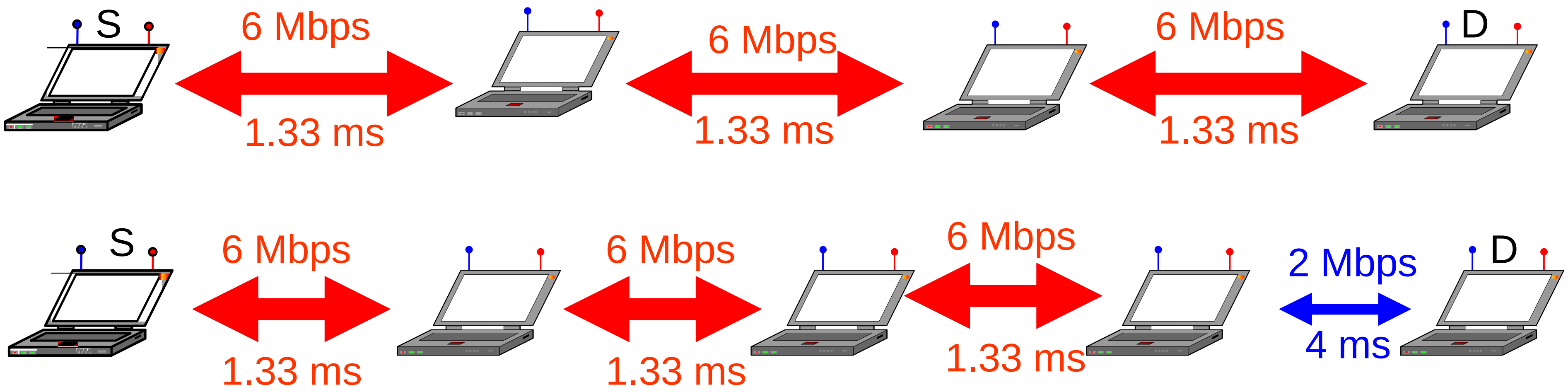
BG-ETT Example



Path	Throughput	Blue Sum	Red Sum	BG-ETT
All Red	1.5 Mbps	0	5.33 ms	5.33 ms
1 Blue	2 Mbps	1.33 ms	4 ms	4 ms
Red-Blue	3 Mbps	2.66 ms	2.66 ms	2.66 ms

BG-ETT favors high-throughput, channel-diverse paths.

BG-ETT does not favor short paths



Path	Throughput	Blue Sum	Red Sum	BG-ETT
3-Hop	2 Mbps	0	4 ms	4 ms
4-Hop	2 Mbps	4 ms	4 ms	4 ms

Path Metric: Putting it all together

- SETT favors short paths
- BG-ETT favors channel diverse paths

Weighted Cumulative ETT (WCETT)

$$WCETT = (1-\beta) * SETT + \beta * BG\text{-}ETT$$

β is a tunable parameter

Higher value: More preference to channel diversity
Lower value: More preference to shorter paths

Any limitation on WCETT as path metric?

How to measure loss rate and bandwidth?

- Loss rate measured using broadcast probes
  - Similar to ETX
  - Updated every second

- Bandwidth estimated using periodic packet-pairs
  - Updated every 5 minutes

Outline of the talk

- Design of WCETT
- Experimental results
- Conclusion

Mesh Testbed

23 nodes running Windows XP.
Two 802.11a/b/g cards per node: Proxim and NetGear (Autorate)
Diameter: 6-7 hops.

Experiment Setting

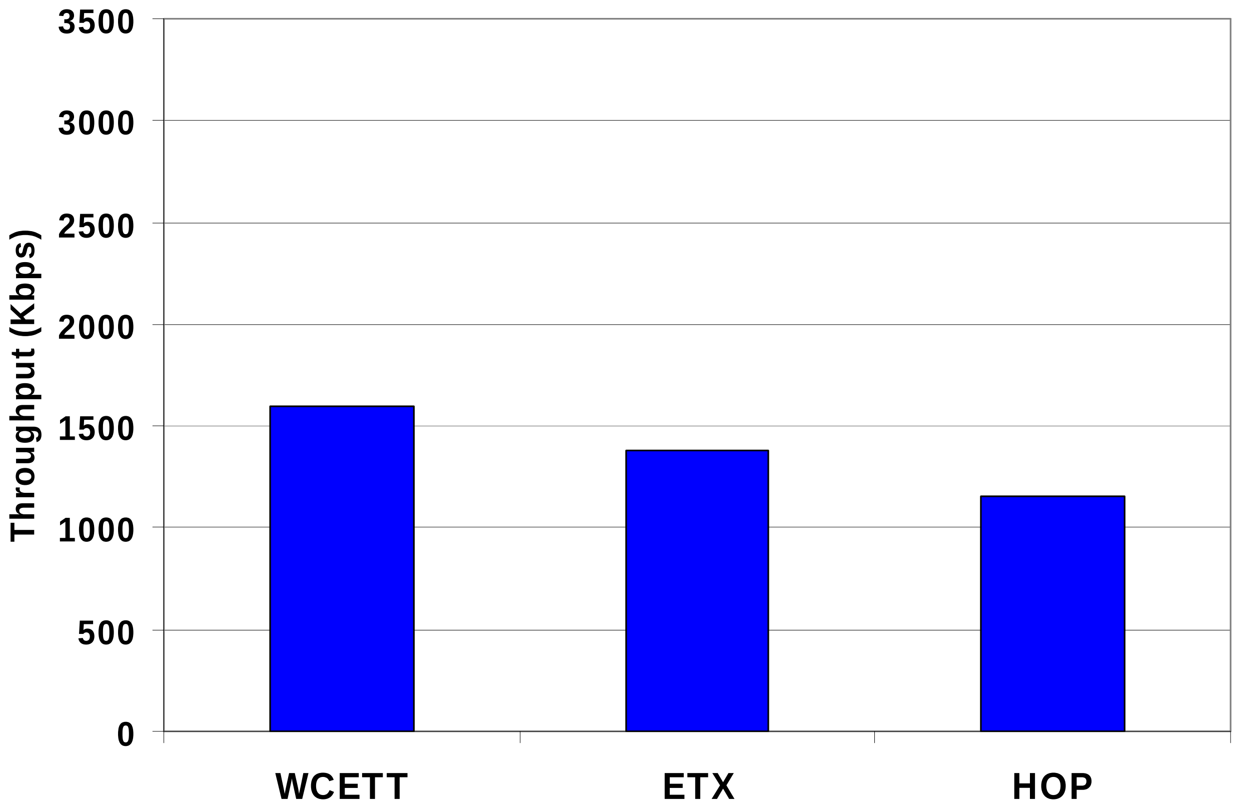
- 2-Minute TCP transfer between 100 randomly selected node pairs (Out of 23x22 = 506)
- Only one transfer active at a time
- Performance metric:
  - **Median throughput of 100 transfers**

Baseline (Single Radio)
NetGear on 802.11a (Channel 36), Proxim OFF

Two Radio
NetGear on 802.11a (Chan 36), Proxim on 802.11g (Chan 10)

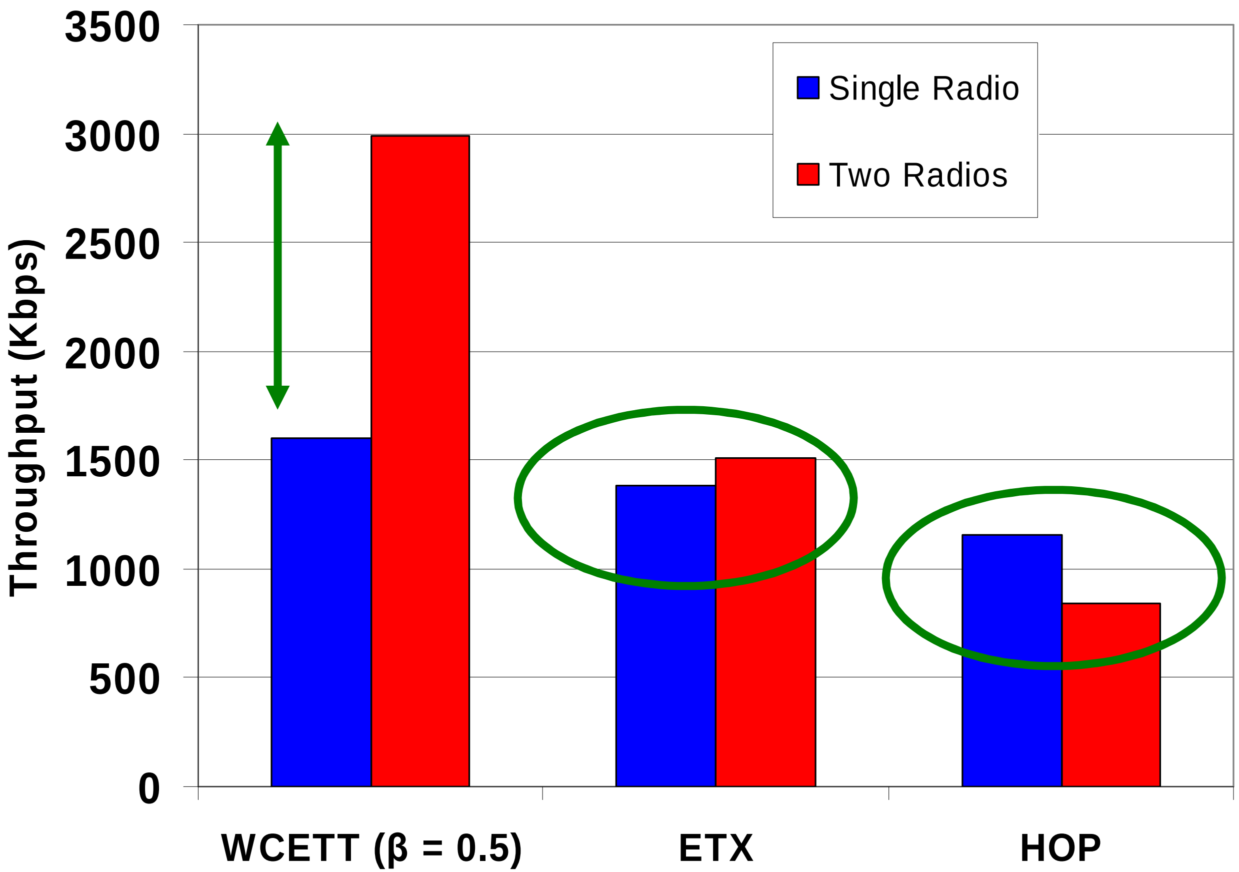
(802.11g radios have longer range, lower bandwidth)

Median Throughput (Baseline, single radio)



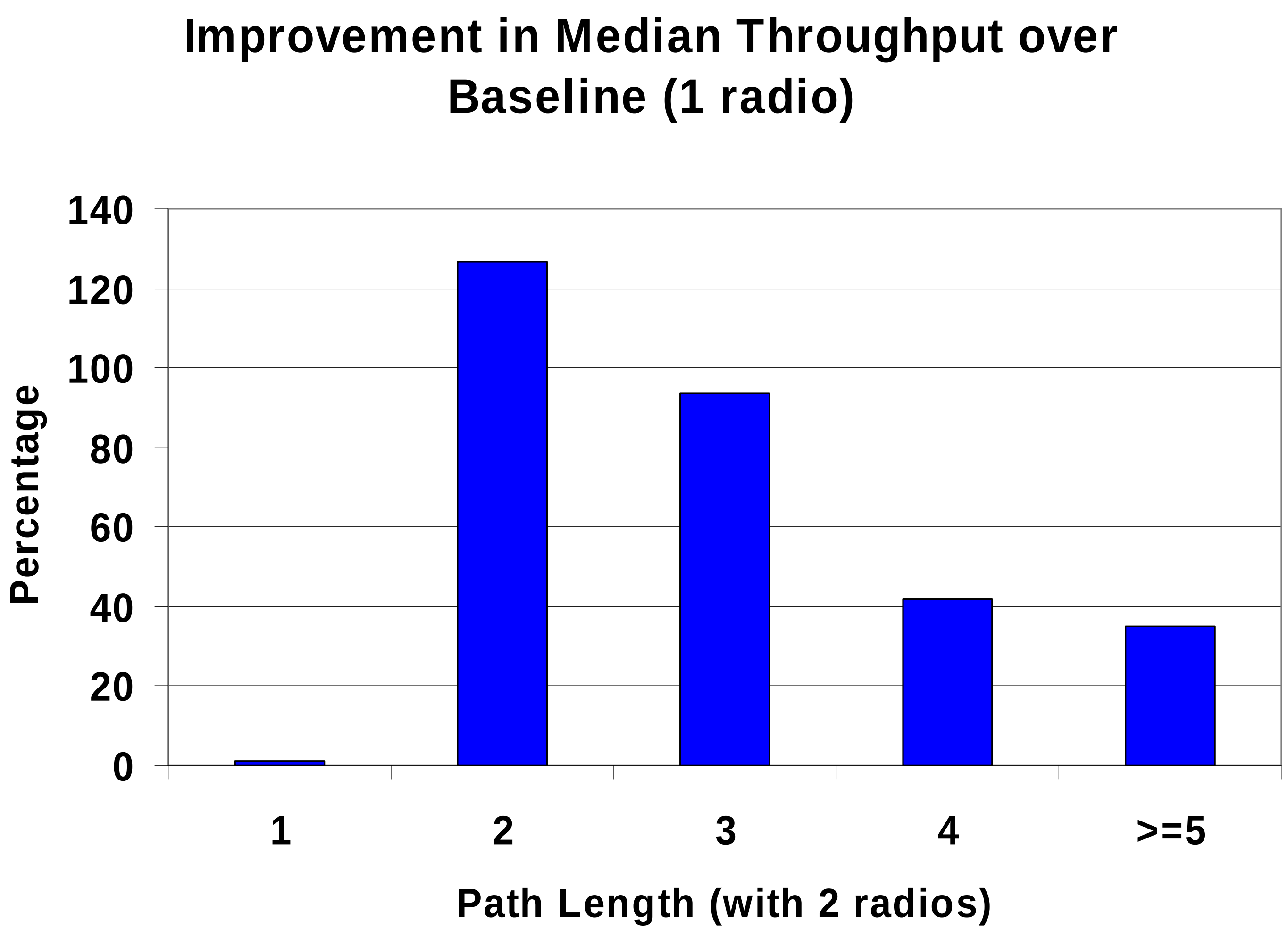
WCETT provides performance gain even with one radio.

Median Throughput (Two radios)



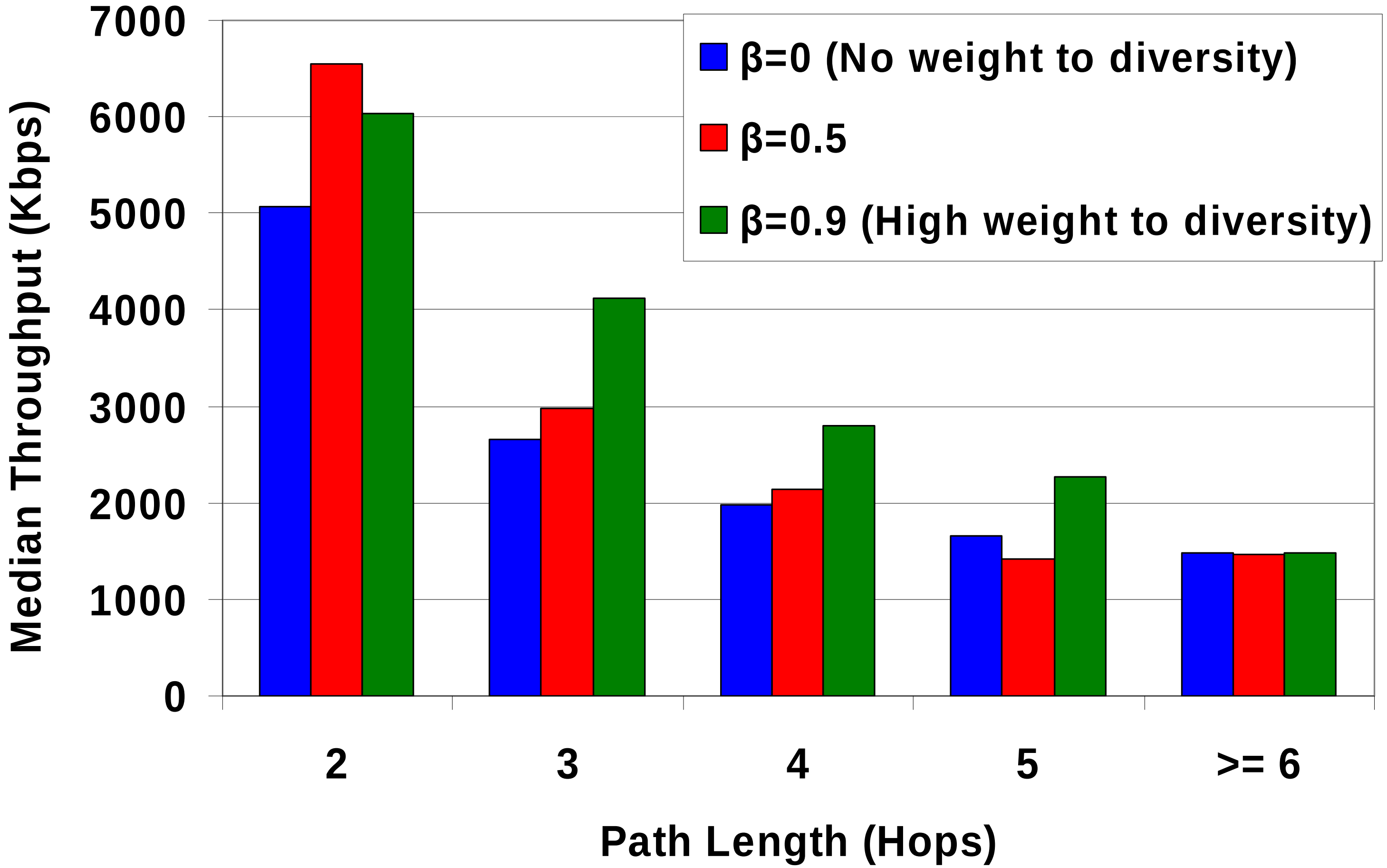
WCETT r Performance of HOP worsens with 2nd radio! r baseline

Do all paths benefit equally with WCETT?



WCETT gains are more prominent for shorter paths

Impact of β value



Channel diversity is important; especially for shorter paths

Conclusions

- Previously proposed routing metrics are inadequate in multi-radio scenario
- WCETT improves performance by judicious use of 2nd radio
  - Benefits are more prominent for shorter paths
- Optimal value of β depends on load
- Passive inference of loss rate and channel bandwidth

How do we further improve upon ETX and WCETT?

Areas for improvement

- Passive measurement of routing metrics
- Existing metrics measure link quality before the changes and cause oscillation and sub-optimal performance
  - Need metrics that take into account of the impact of traffic on link quality
- Existing metrics are selfish and do not lead to globally good performance
- Need to consider backoff overhead
- WCETT assumes that all links on the path interfere
  - Should consider more realistic interference patterns
- Routing metric is not the only factor that affects performance

PER and BER

- Packet Error Rate

$$\mathrm{PER}(t) = 1 - \prod_{i=1}^{n} \left[1 - \mathrm{BER}(t_i)\right]$$