Today's paper:

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

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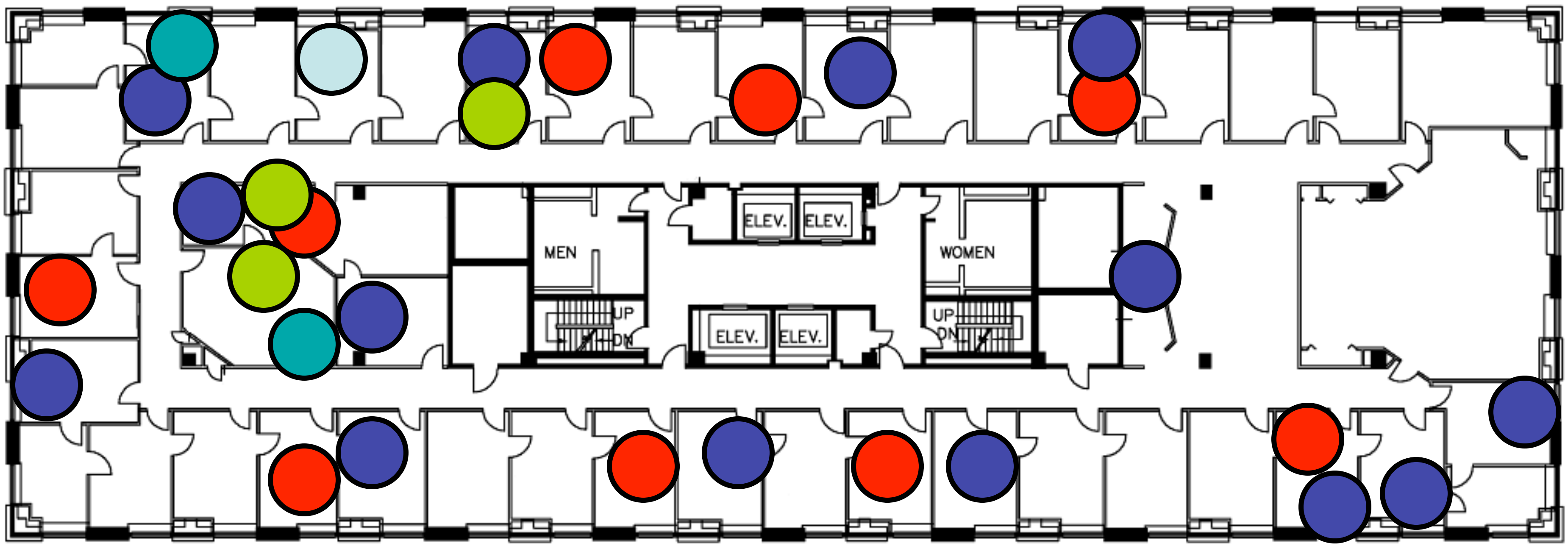
Indoor wireless network

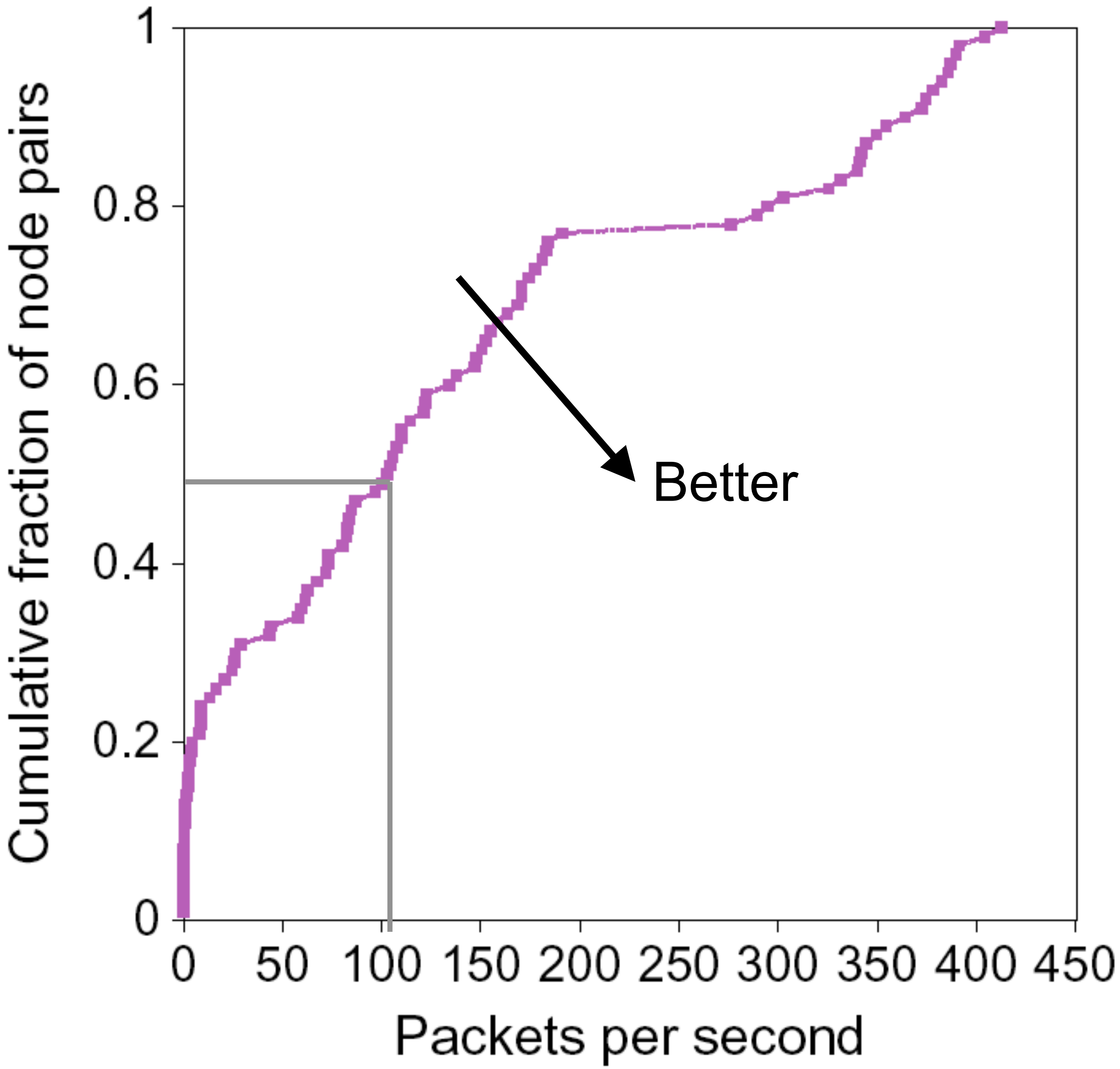


29 PCs with 802.11b radios (fixed transmit power) in ‘ad hoc’ mode

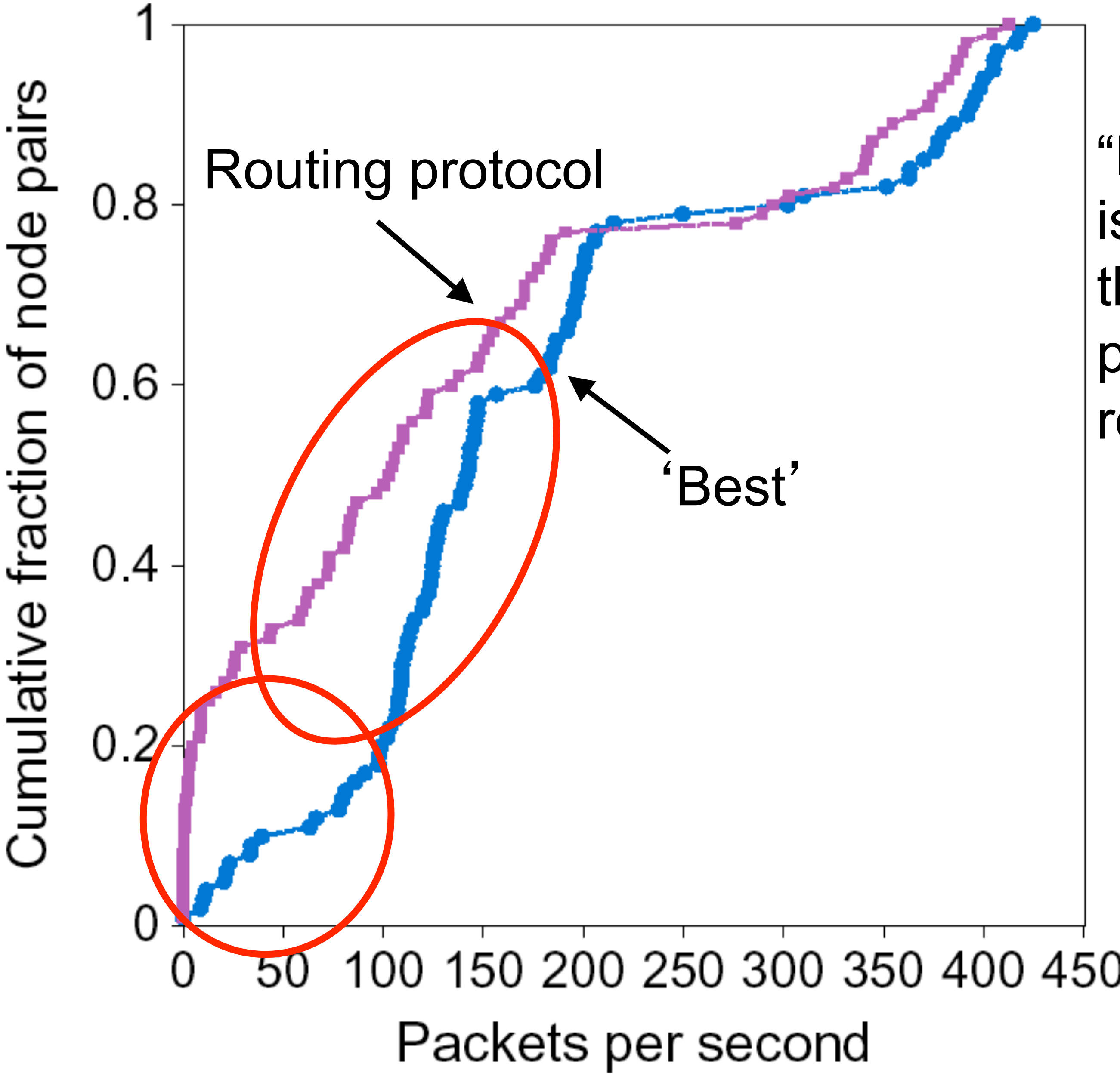
2nd floor   3rd floor   5th floor

4th floor   6th floor

Testbed UDP throughput

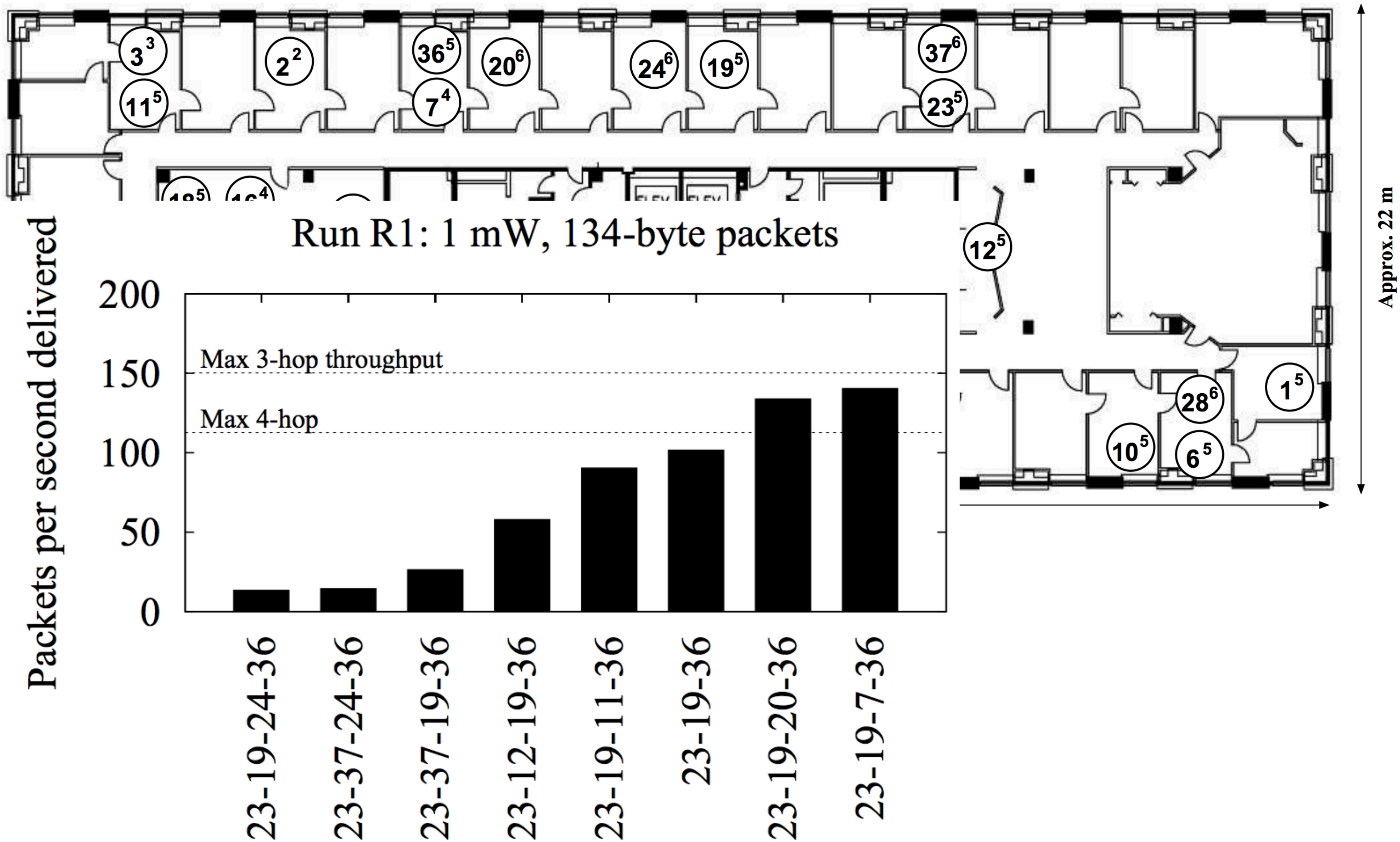


What throughput is possible?



"Best" for each pair is highest measured throughput of 10 promising static routes.

Example: 23 → 36 Paths

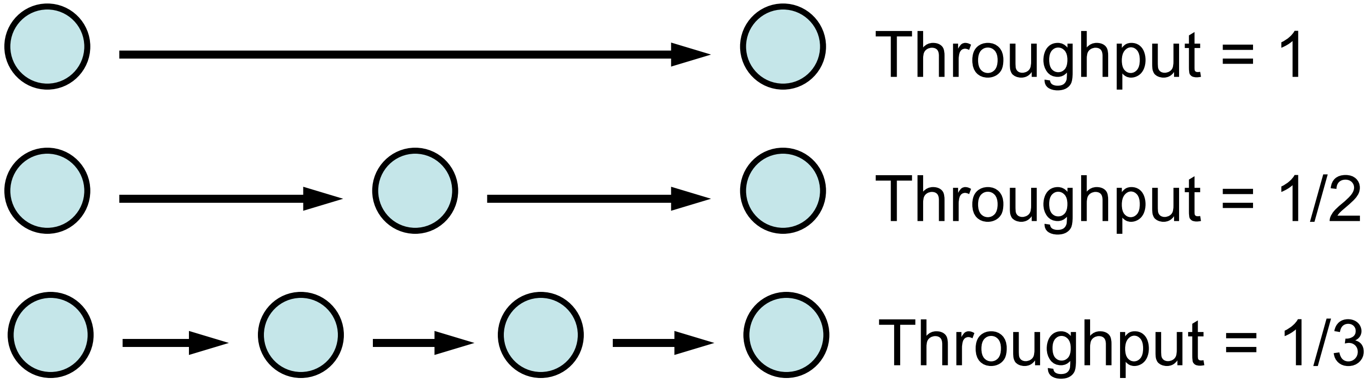


Outline

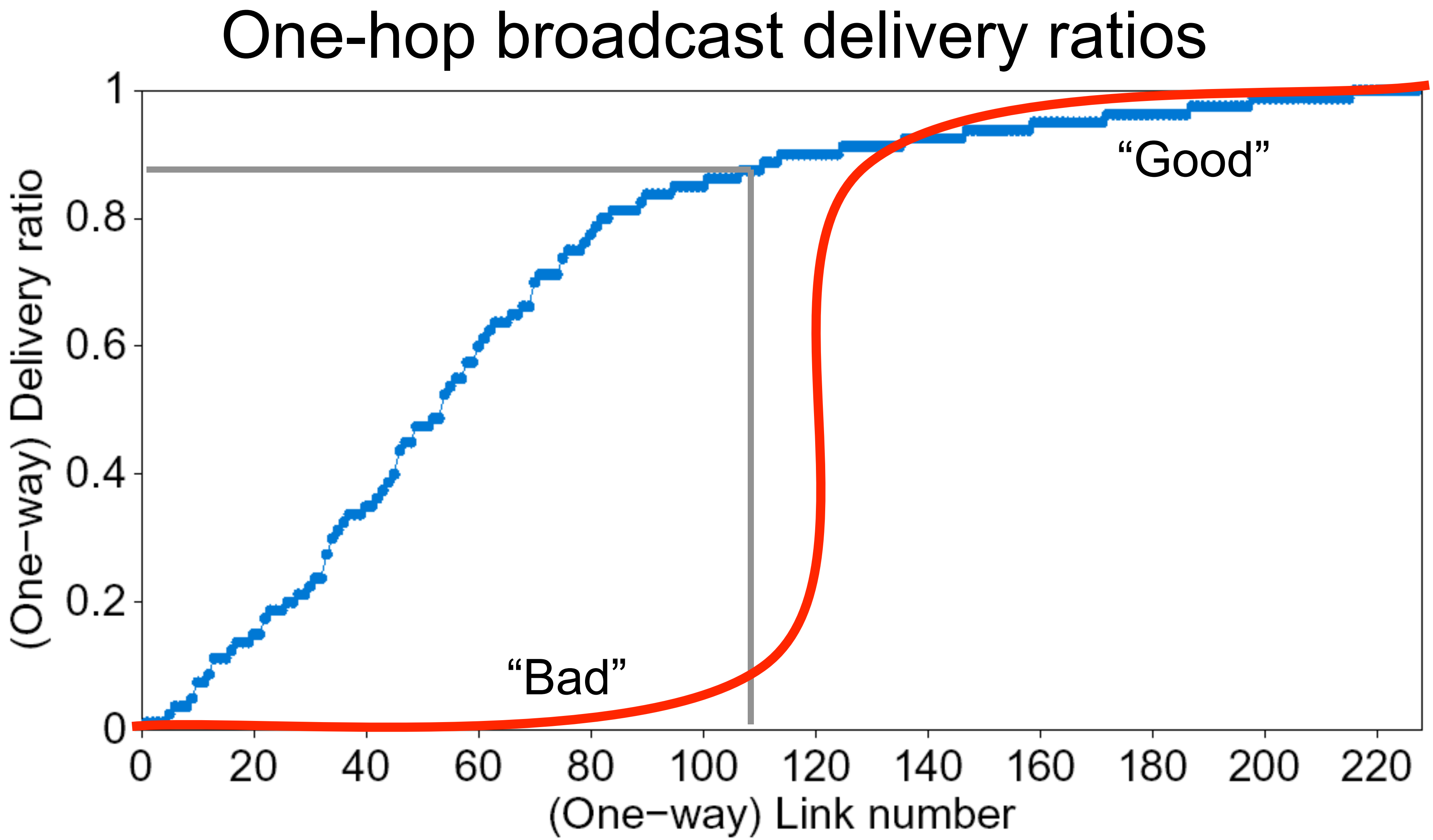
- Testbed throughput problems
- Wireless routing challenges
- A new high-throughput metric (ETX)
- Evaluation

Challenge: more hops, less throughput

- Links in route share radio spectrum
- Extra hops reduce throughput

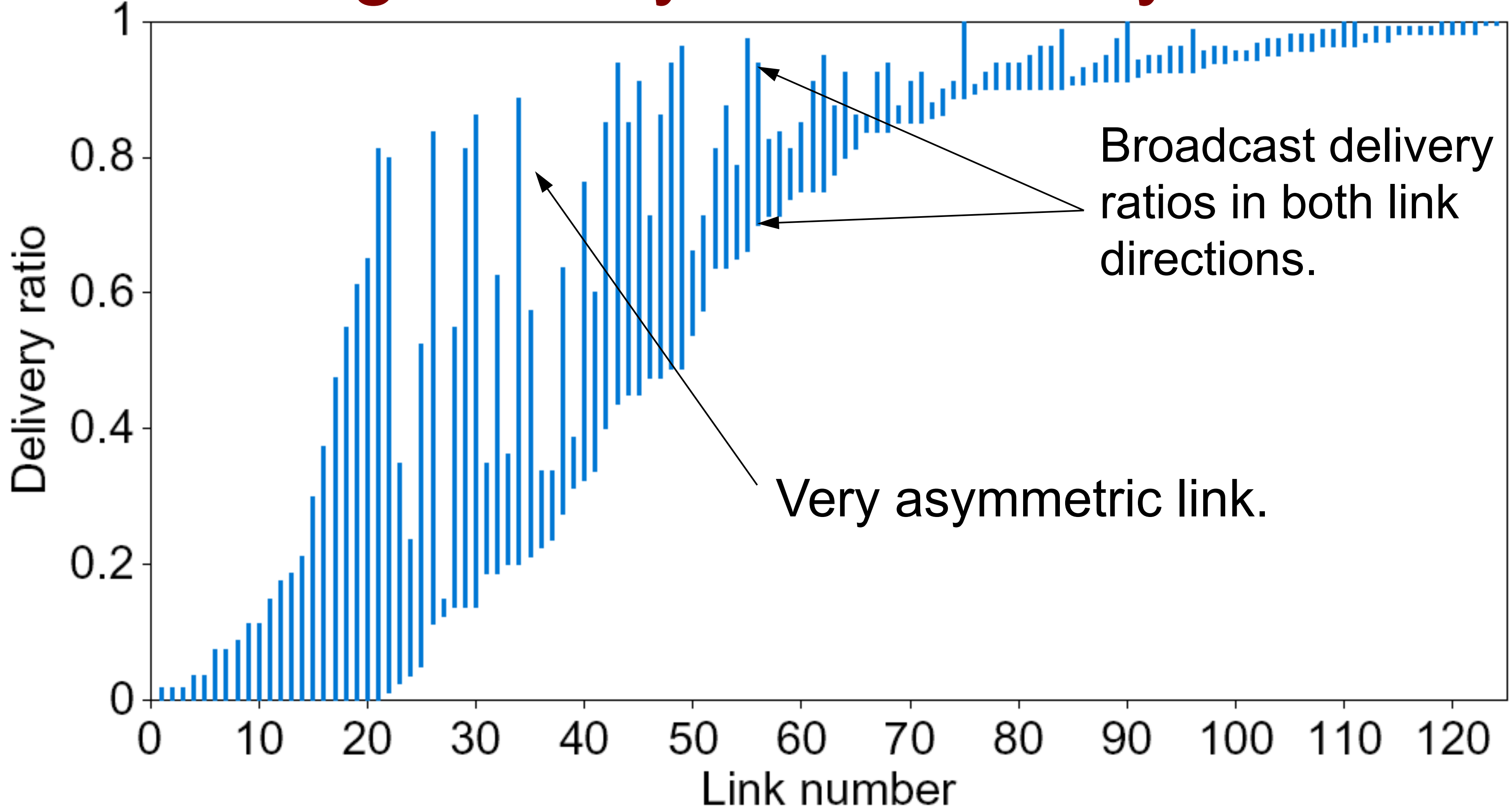


Challenge: many links are lossy



Smooth link distribution complicates link classification.

Challenge: many links are asymmetric



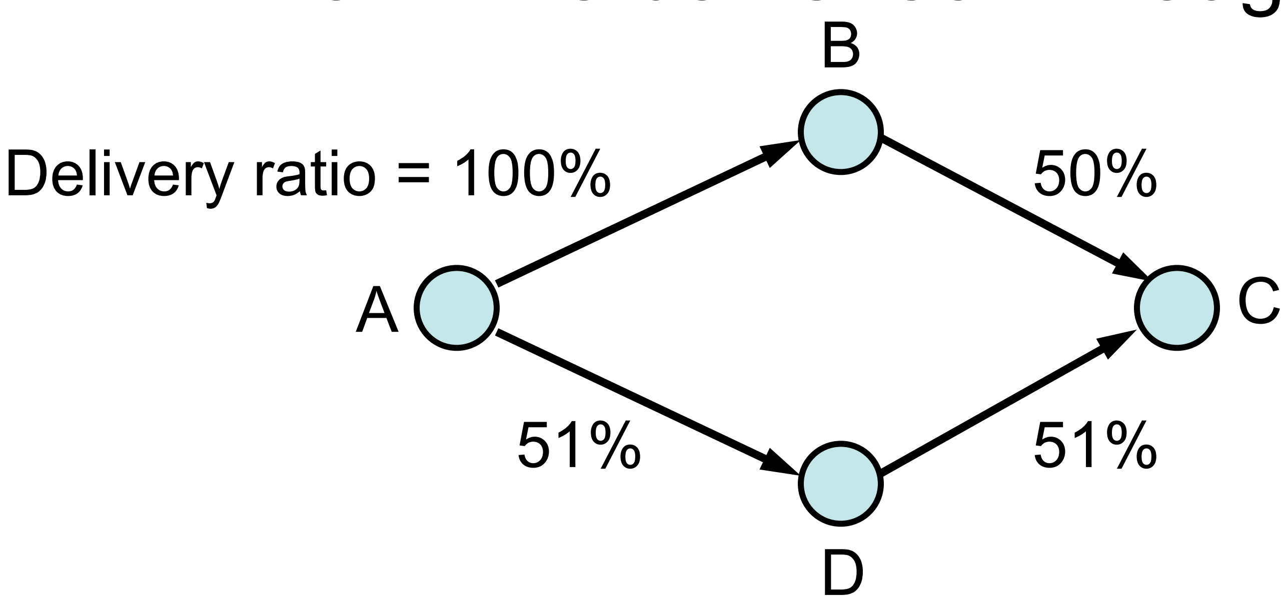
Many links are good in one direction, but lossy in the other.

Summary of Problems

- Longer paths have lower throughput
- Many links are lossy and loss rates are not ”modal”
- Loss rates are often asymmetric

A straw-man route metric

Maximize bottleneck throughput

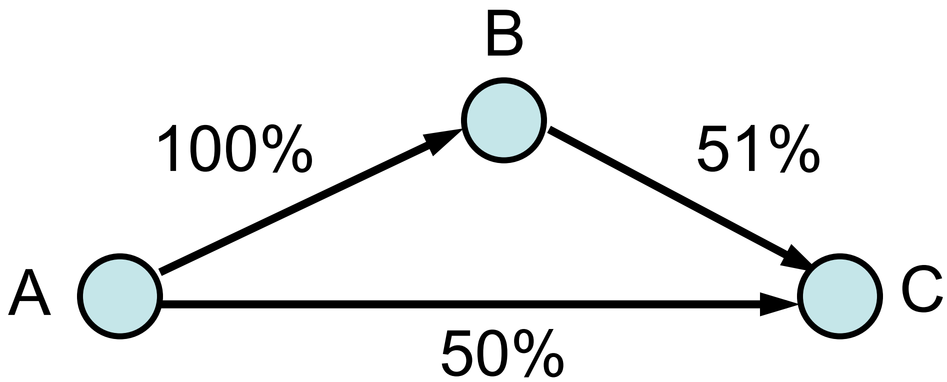


Bottleneck throughput:
- A-B-C = 50%
- A-D-C = 51%

Actual throughput:
- A-B-C : ABBABBABB = 33%
- A-D-C : AADDAADD = 25%

Another straw-man metric

Maximize end-to-end delivery ratio



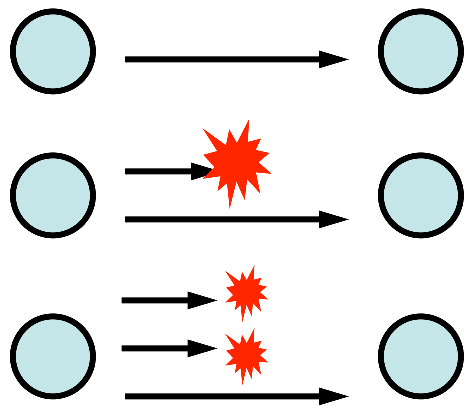
End-to-end delivery ratio:
- A-B-C = 51%
- A-C = 50%

Actual throughput:
- A-B-C : ABBABBABB = 33%
- A-C : AAAAAAAA = 50%

New metric: ETX

Minimize total transmissions per packet (ETX, “Expected Transmission Count”)

Link throughput ≈ 1/ Link ETX



Delivery Ratio	Link ETX	Throughput
100%	1	100%
50%	2	50%
33%	3	33%

Calculating link ETX

Assuming 802.11 link-layer acknowledgments (ACKs) and retransmissions:

P(TX success) = P(Data success) × P(ACK success)

Link ETX = 1 / P(TX success)
= 1 / [P(Data success) × P(ACK success)]

Estimating link ETX:

P(Data success) ≈ measured fwd delivery ratio r_{fwd}

P(ACK success) ≈ measured rev delivery ratio r_{rev}

Link ETX ≈ $1 / (r_{fwd} \times r_{rev})$

Measuring delivery ratios

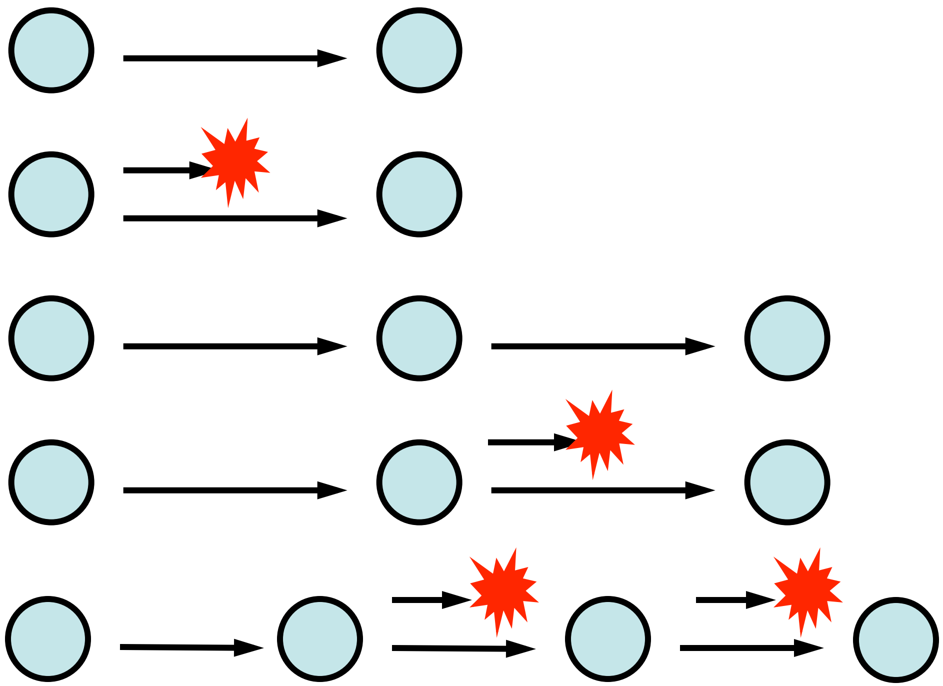
- Each node broadcasts small link probes (134 bytes), once per second
- Nodes remember probes received over past 10 seconds
- Reverse delivery ratios estimated as

$$r_{\text{rev}} \approx \text{pkts received} / \text{pkts sent}$$

- Forward delivery ratios obtained from neighbors (piggybacked on probes)

Route ETX

Route ETX = Sum of link ETXs



Route ETX	Throughput
1	100%
2	50%
2	50%
3	33%
5	20%

ETX Properties

- ETX predicts throughput for short routes (1, 2, and 3 hops)
- ETX quantifies loss
- ETX quantifies asymmetry
- ETX quantifies throughput reduction of longer routes

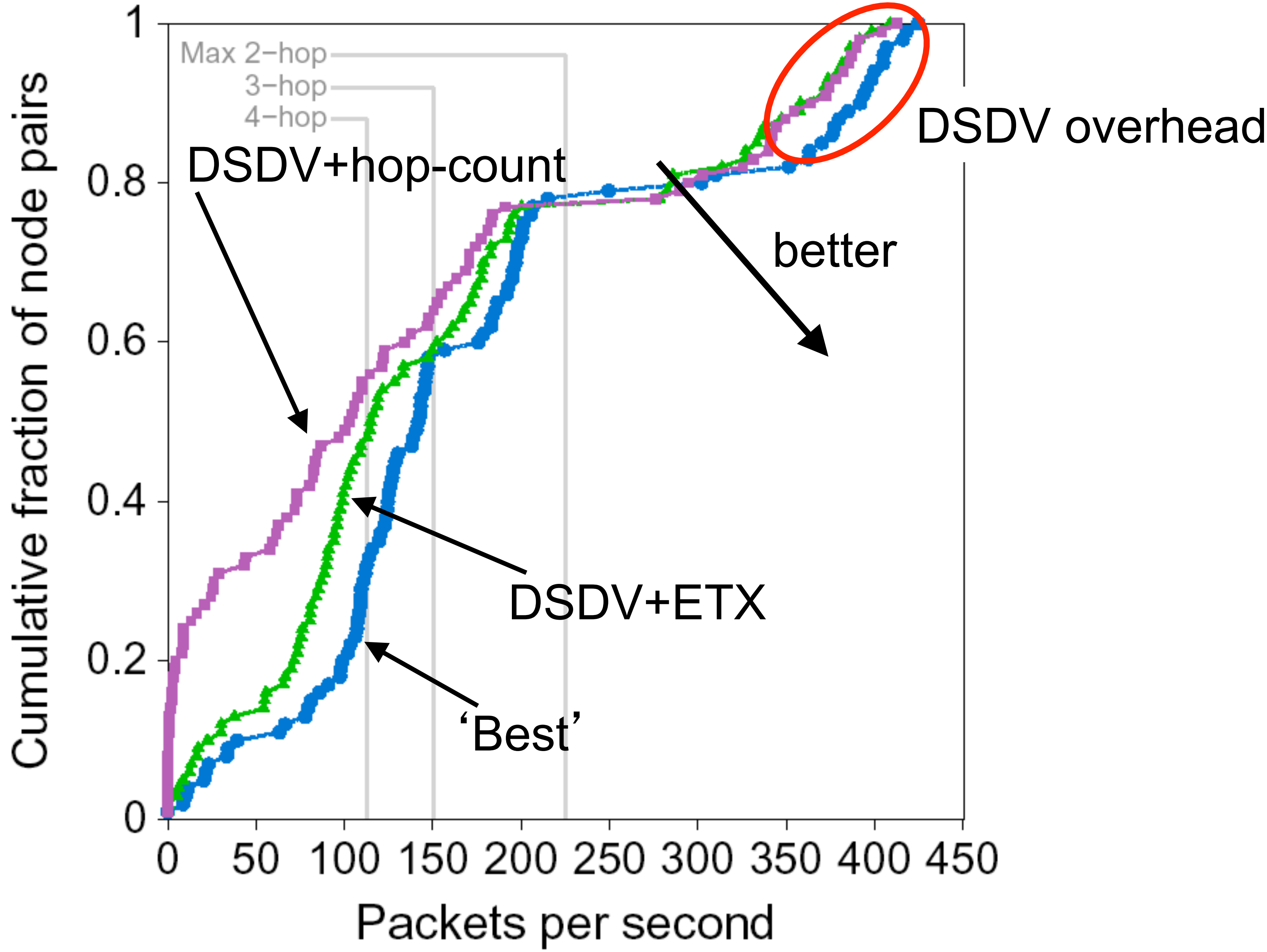
ETX caveats

- ETX link probes are susceptible to MAC unfairness and hidden terminals
  - Route ETX measurements change under load
- ETX estimates are based on measurements of a single link probe size (134 bytes)
  - Under-estimates data loss ratios, over-estimates ACK loss ratios
- ETX assumes all links run at one bit-rate

Evaluation Setup

- Indoor network, 802.11b, “ad hoc” mode
- 1 Mbps, 1 mW, small packets (134 bytes), RTS/CTS disabled
- DSDV + modifications to respect metrics
  - Packets are routed using route table snapshot to avoid route instability under load.
- DSR + modifications to respect metrics

ETX improves DSDV throughput

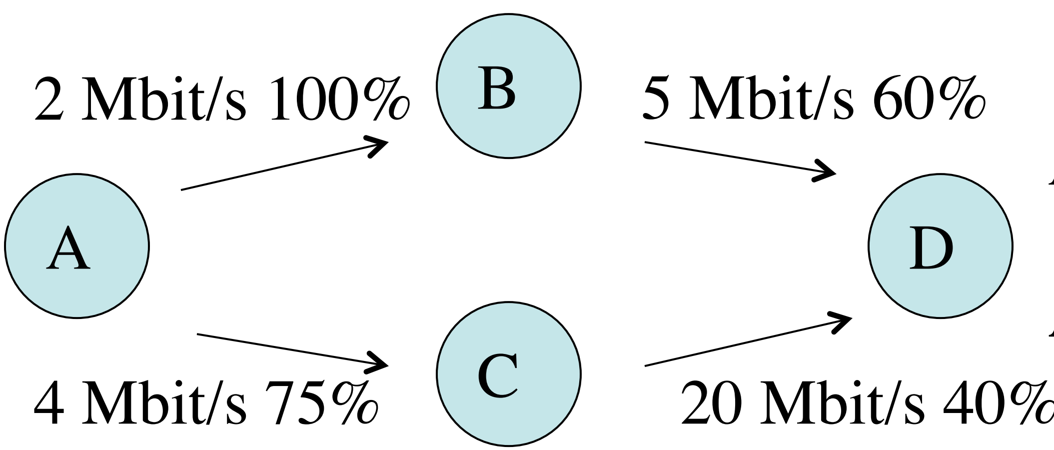


Some related work

- Threshold-based techniques
  - DARPA PRNet, 1970s–80s [Jubin87]: Minimum hop-count, ignore ‘bad’ links (delivery ratio < 5/8 in either direction)
  - Link handshaking [Lundgren02, Chin02]: Nodes exchange neighbor sets to filter out asymmetric links.
  - SNR-based approaches [Hu02]: Mark low-SNR links as ‘bad’, and avoid them
- Mote sensors [Yarvis02]
  - Product of link delivery ratios

From ETX to Expected Transmission Time (ETT)

- Extending to wireless networks with multiple bit rates
- Take into account both the delivery rate and the **time** taken to transmit packet (i.e., time occupied on “air” by packet)



ABD: 10*1+ 4*5/3 = 50/3

ACD: 5*4/3 + 1*5/2 = 55/6

Summary

- ETX is a new route metric for multi-hop wireless networks
- ETX accounts for
  - Throughput reduction of extra hops
  - Lossy and asymmetric links
  - Link-layer acknowledgements
- ETX finds better routes!