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

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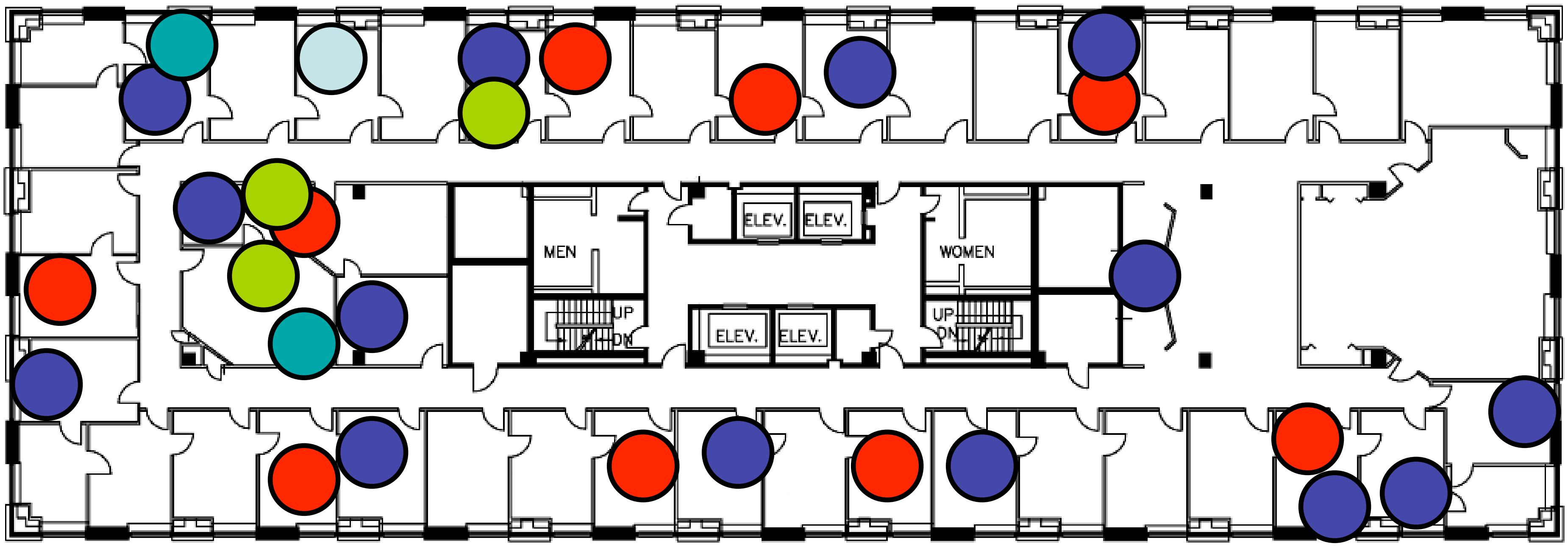
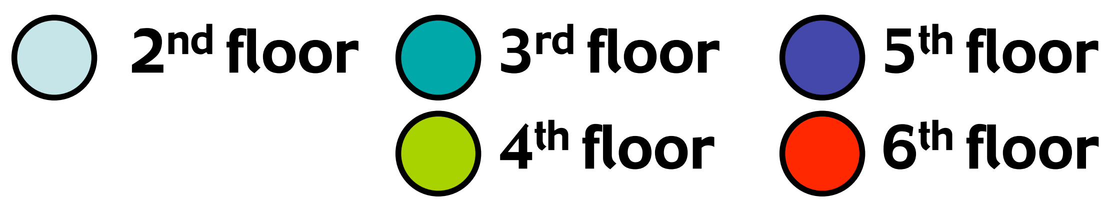
http://pdos.lcs.mit.edu/grid

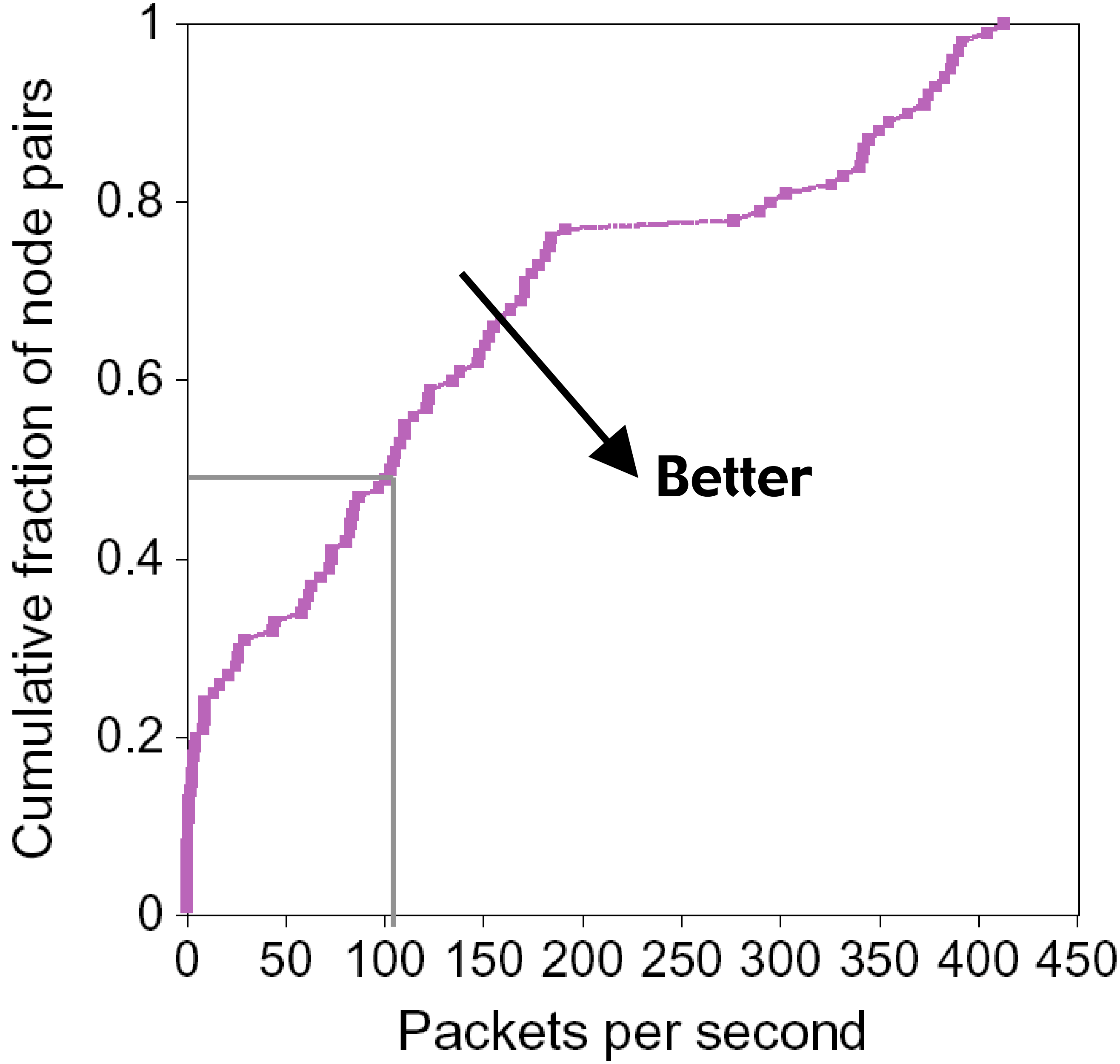
Indoor wireless network



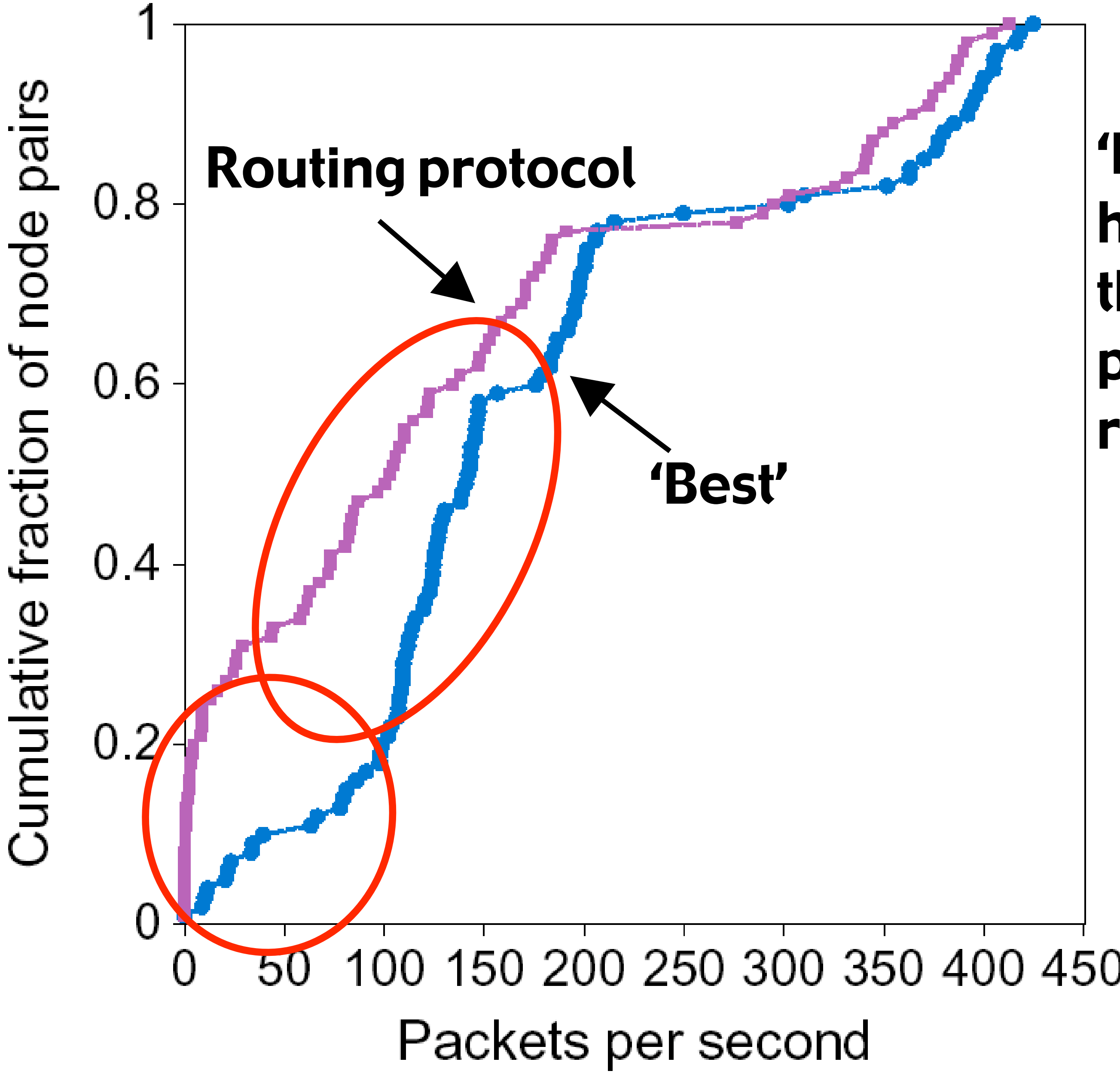
29 PCs with 802.11b radios (fixed transmit power) in 'ad hoc' mode



Testbed UDP throughput



What throughput is possible?



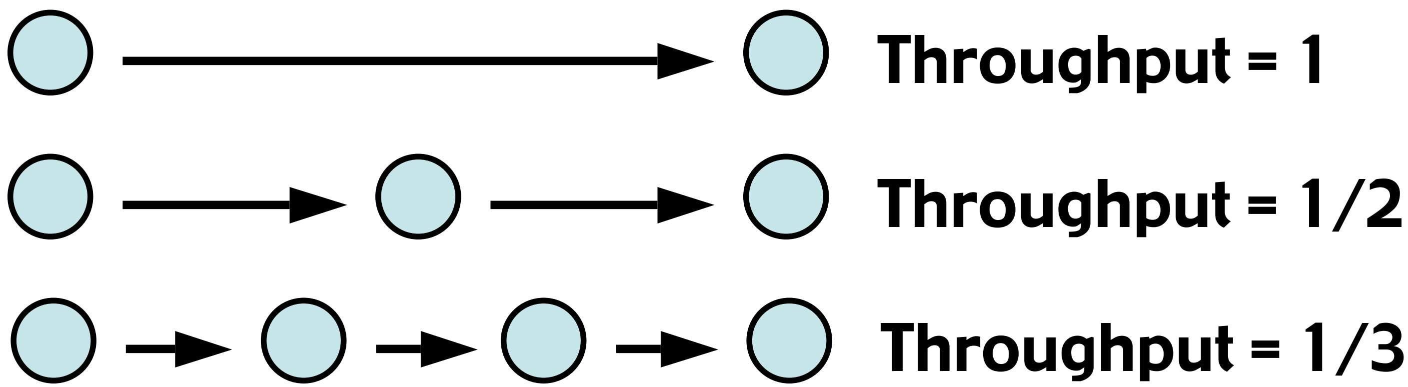
'Best' for each pair is highest measured throughput of 10 promising static routes.

Talk outline

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

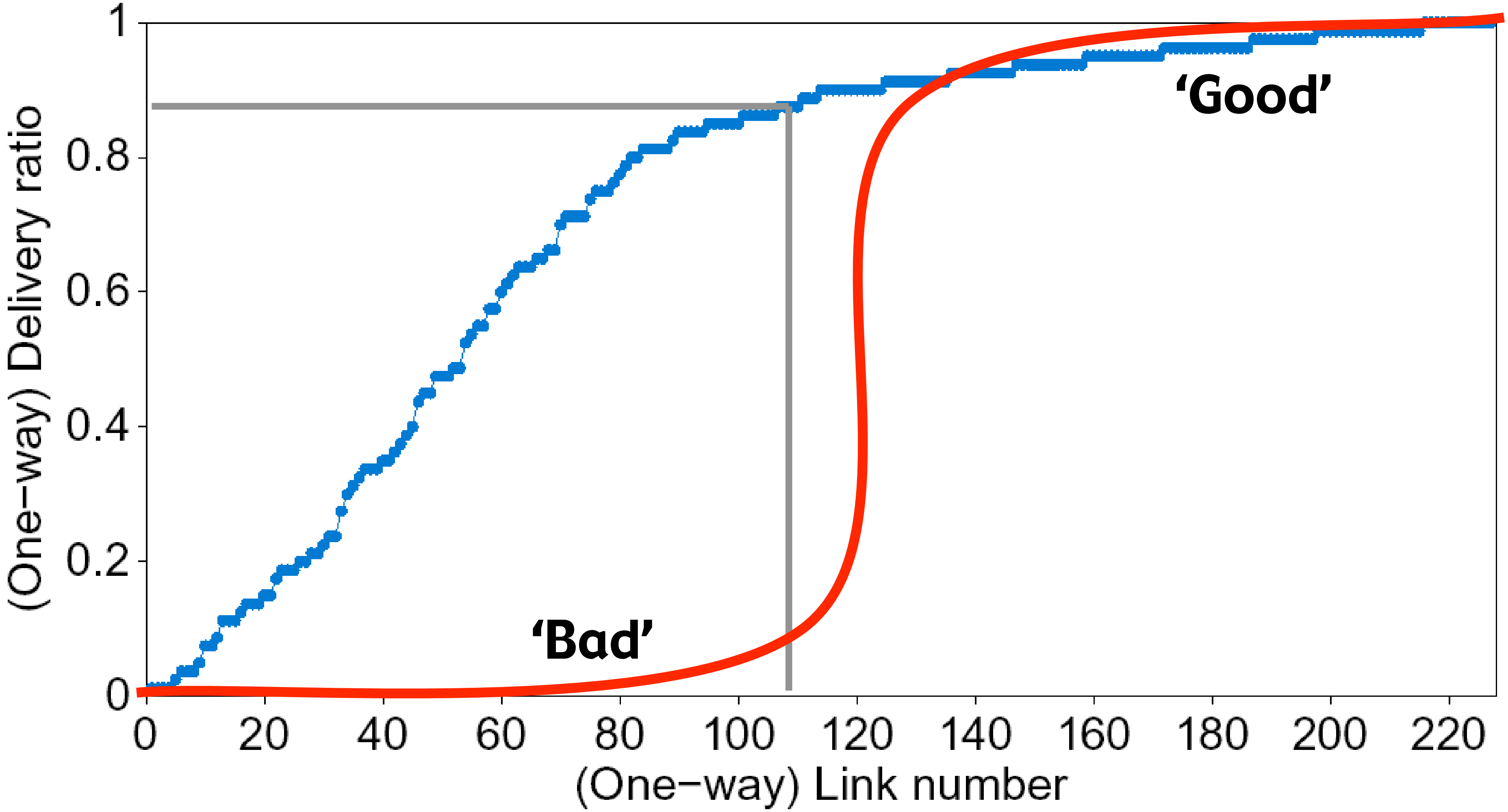
Challenge: more hops, less throughput

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



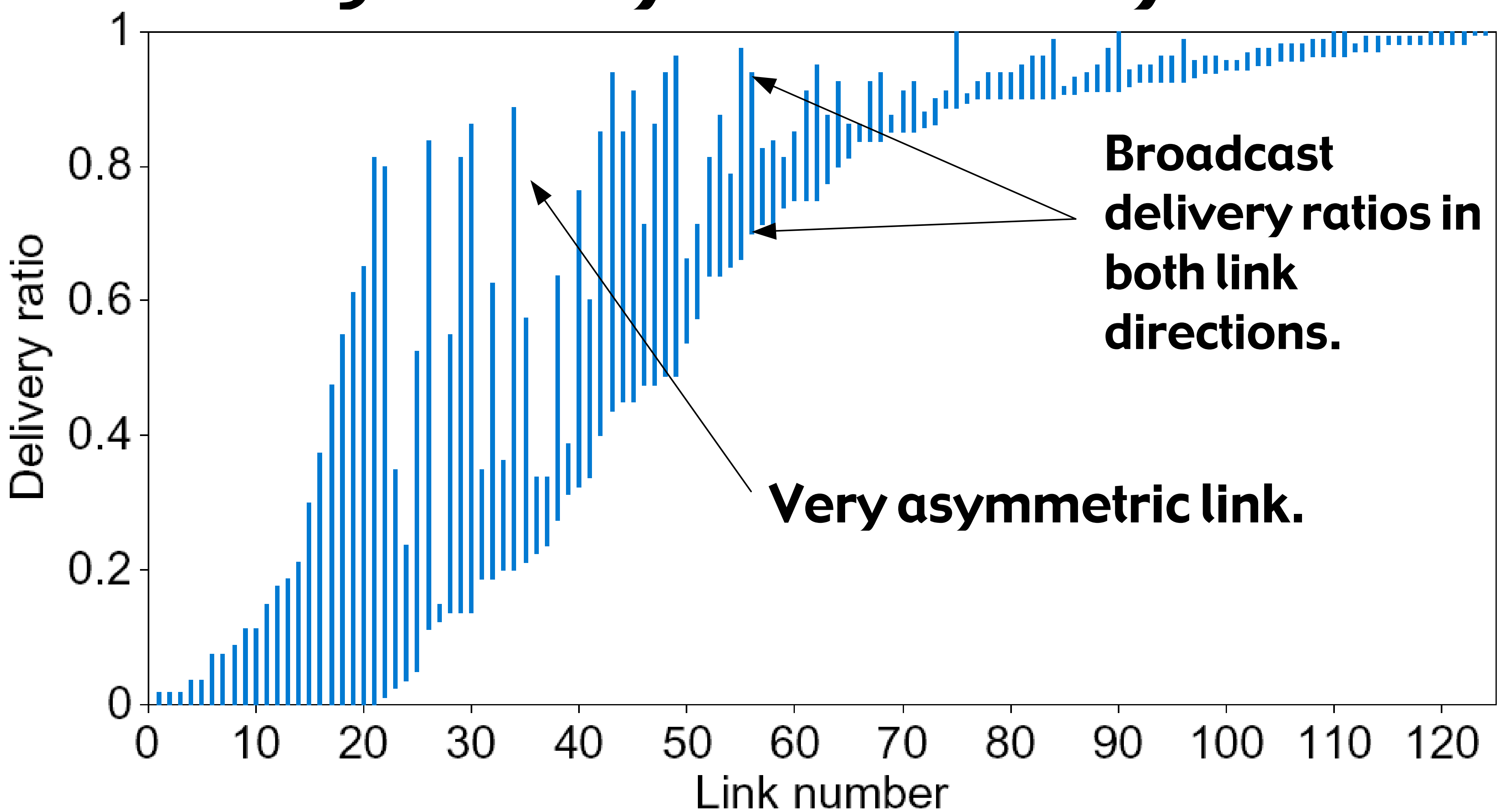
Challenge: many links are lossy

One-hop broadcast delivery ratios



Smooth link distribution complicates link classification.

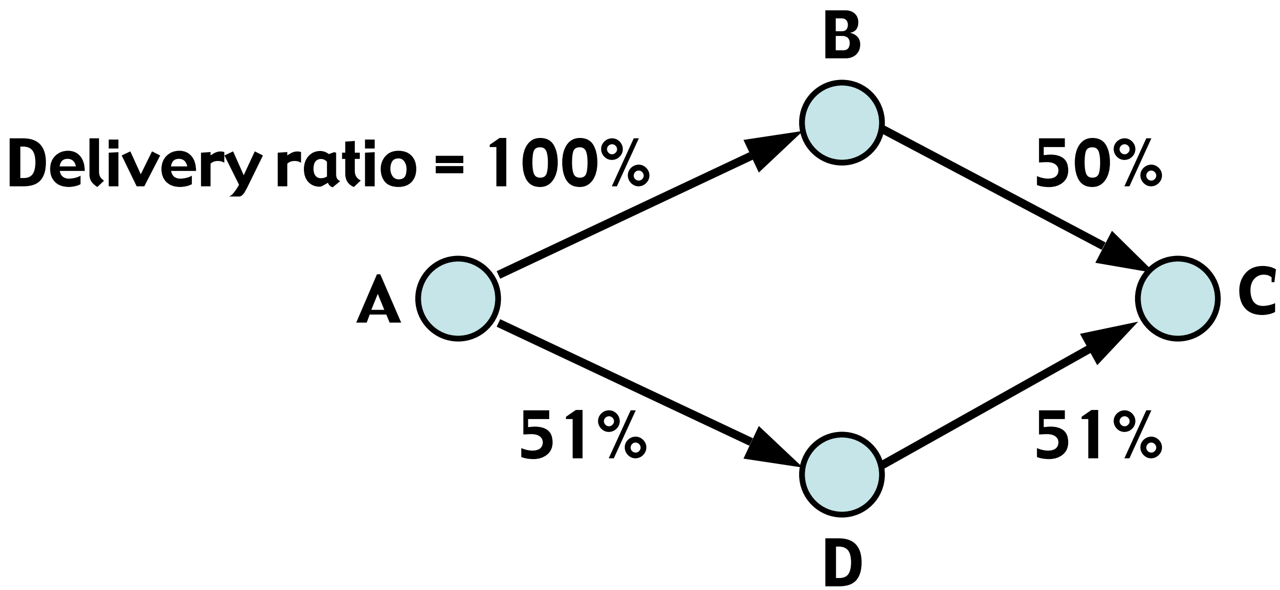
Challenge: many links are asymmetric



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

A straw-man route metric

Maximize bottleneck throughput

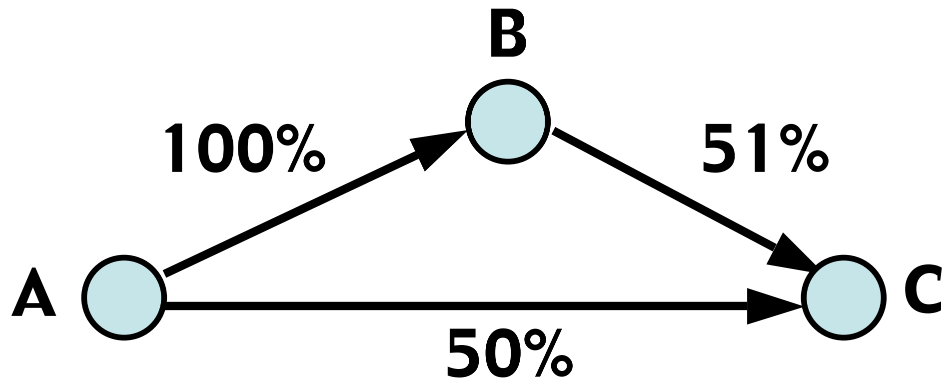


Bottleneck throughput:
- A-B-C = 50%
- A-D-C = <u>51%</u>

Actual throughput:
- A-B-C : ABBABBABB = <u>33%</u>
- 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%

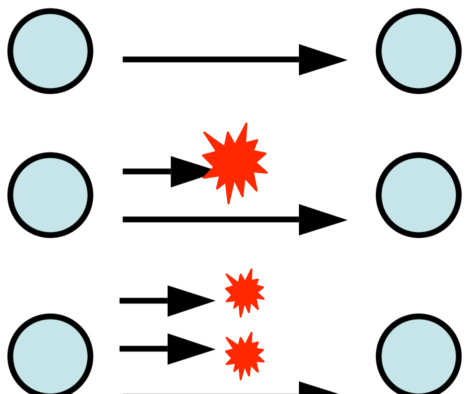
New metric: ETX

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} □ r_{rev})

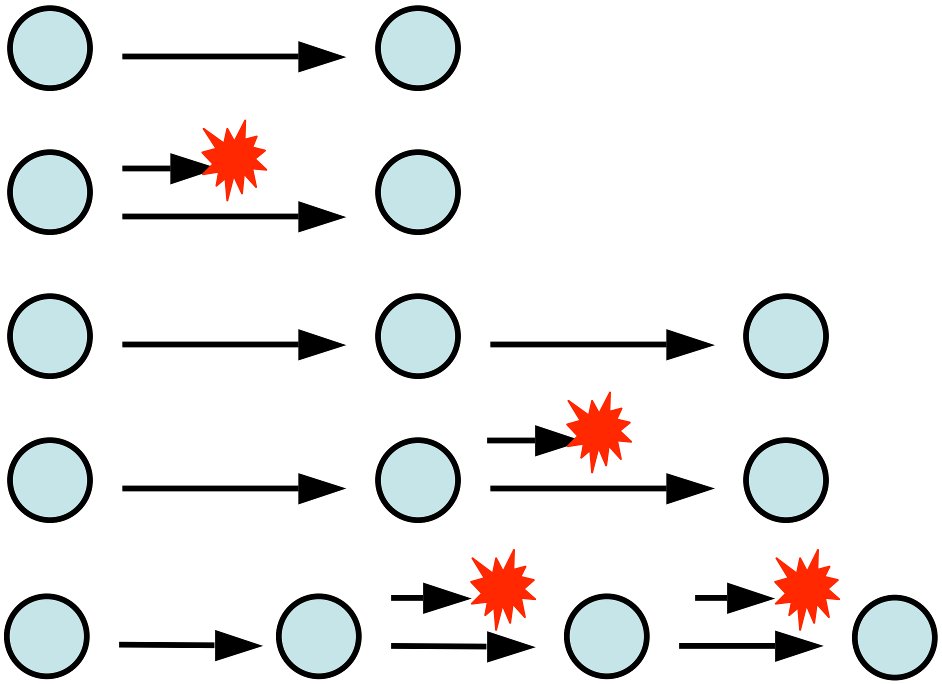
Measuring delivery ratios

- 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_{rev} □ pkts received / 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

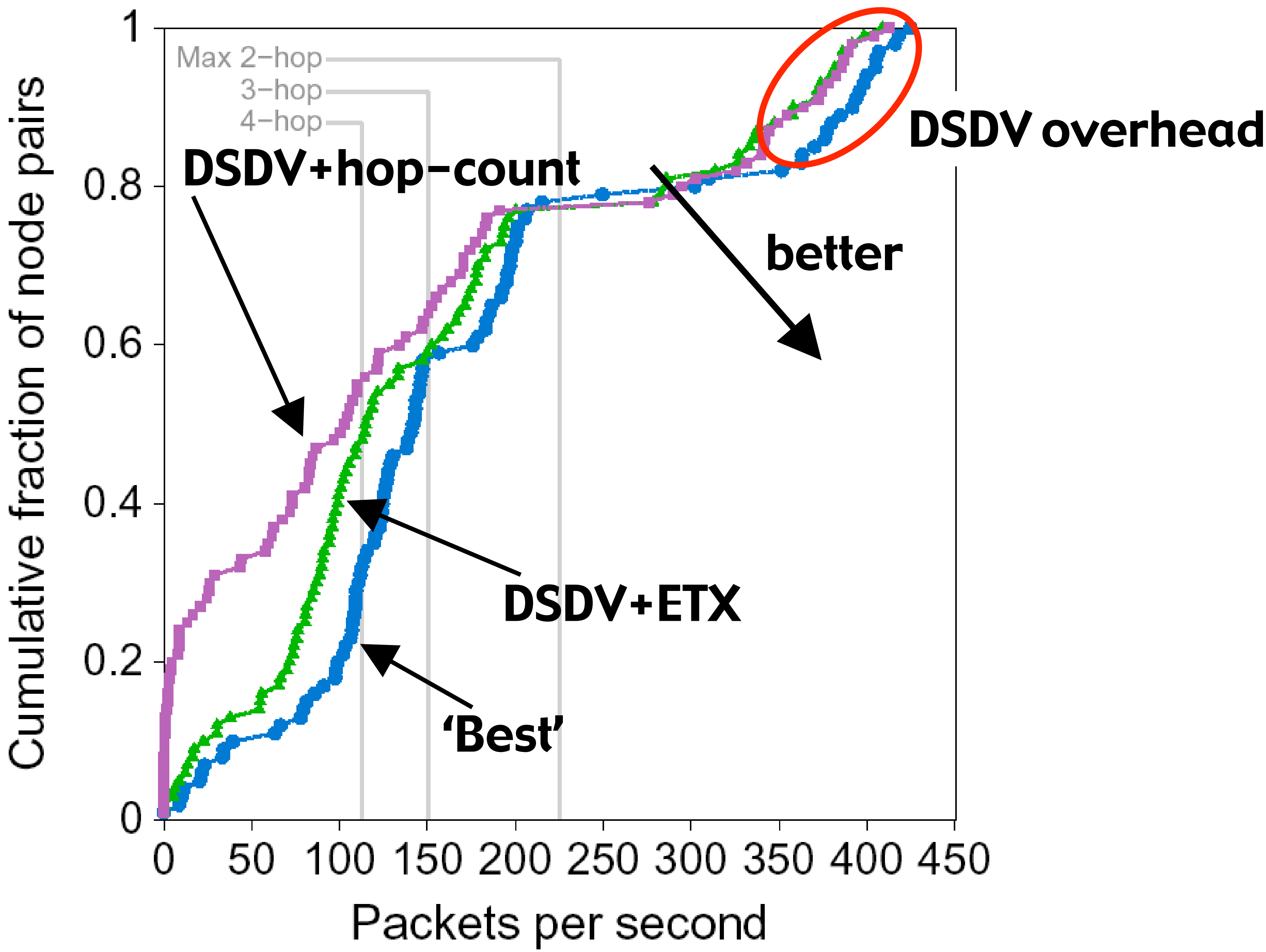
ETX caveats

- 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

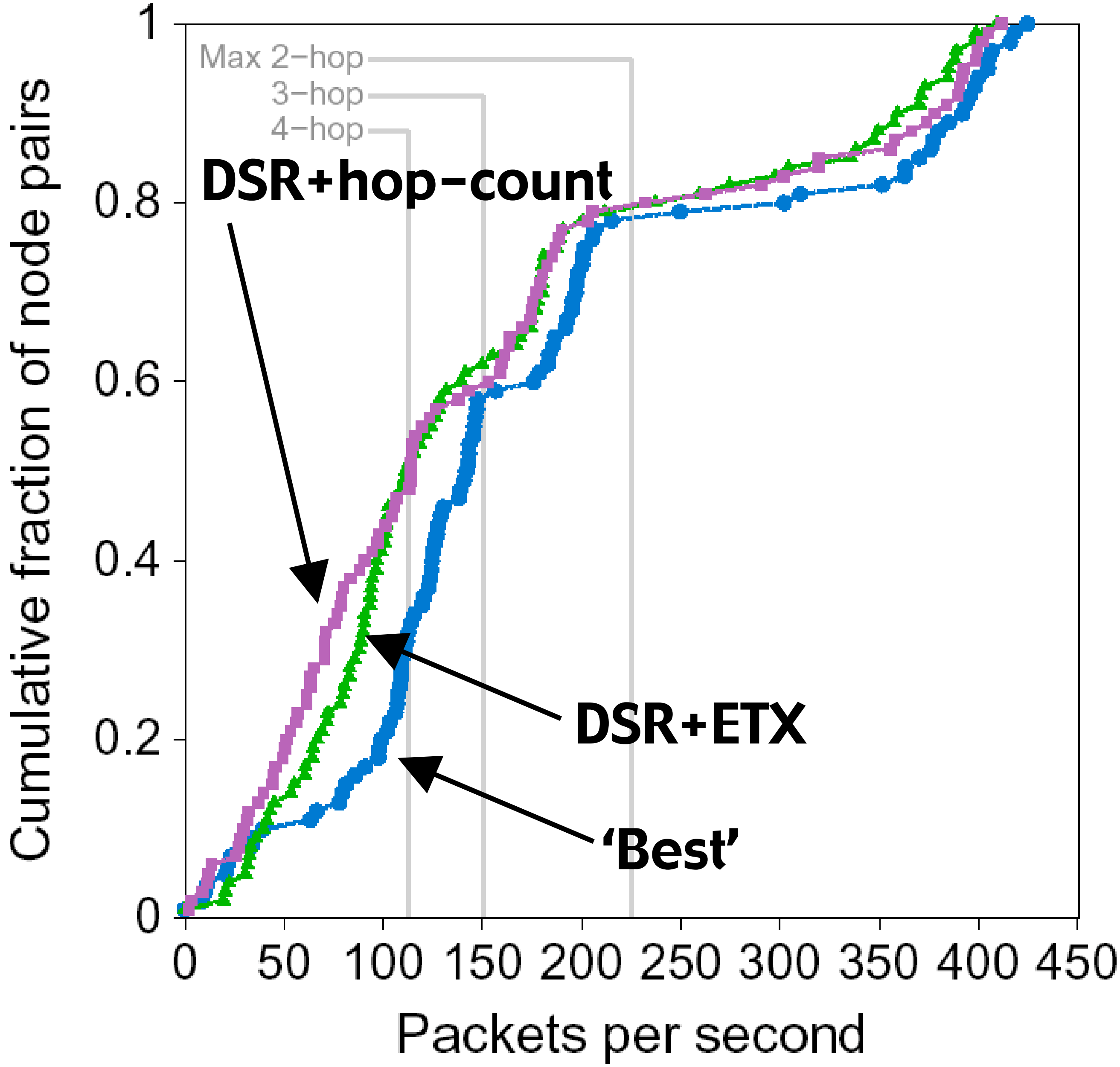
Evaluation Setup

- 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

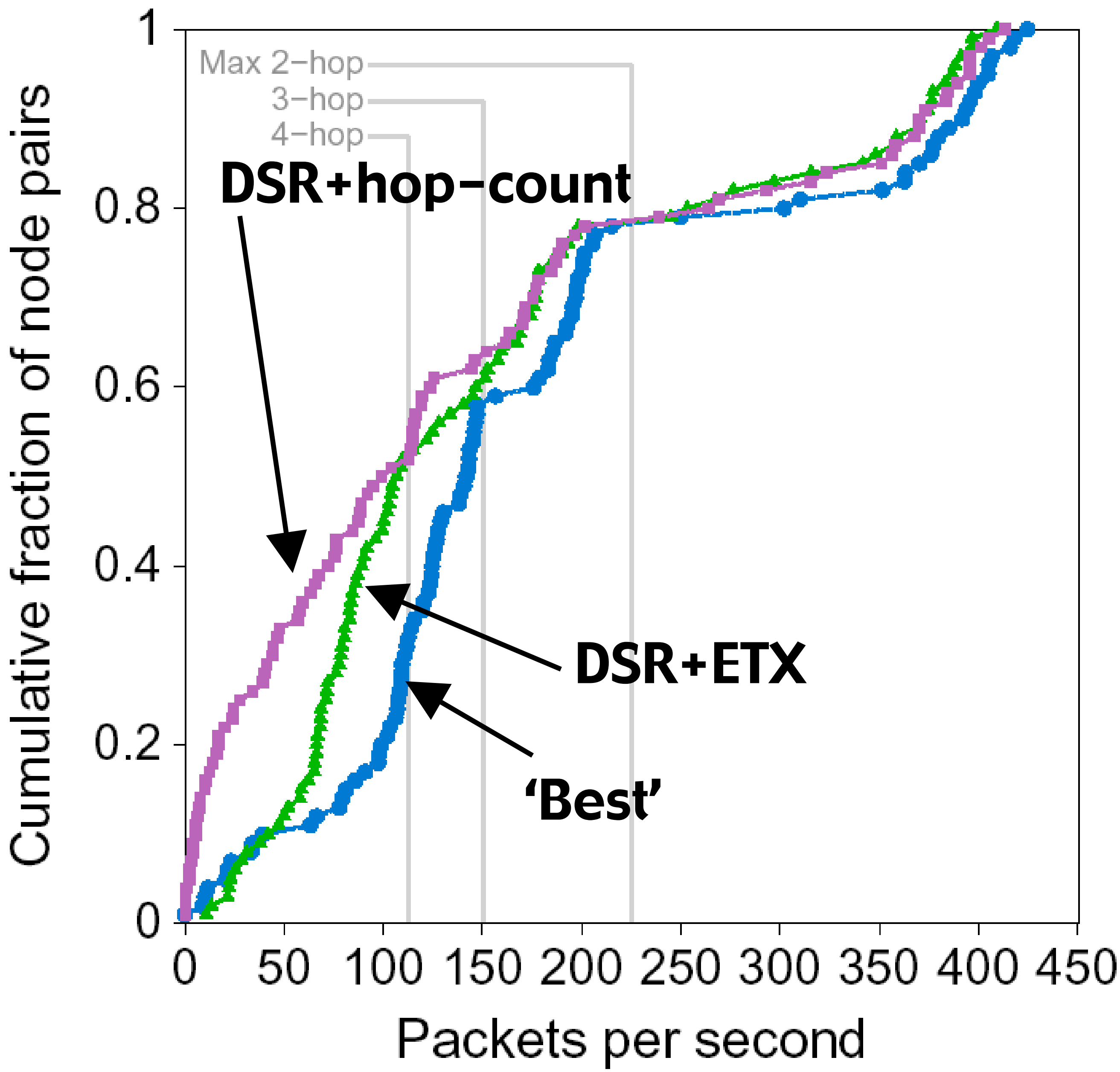


DSR with ETX



Cumulative fraction of node pairs
Packets per second
Max 2-hop
3-hop
4-hop
DSR+hop-count
DSR+ETX
'Best'
0
0.2
0.4
0.6
0.8
1
0
50
100
150
200
250
300
350
400
450

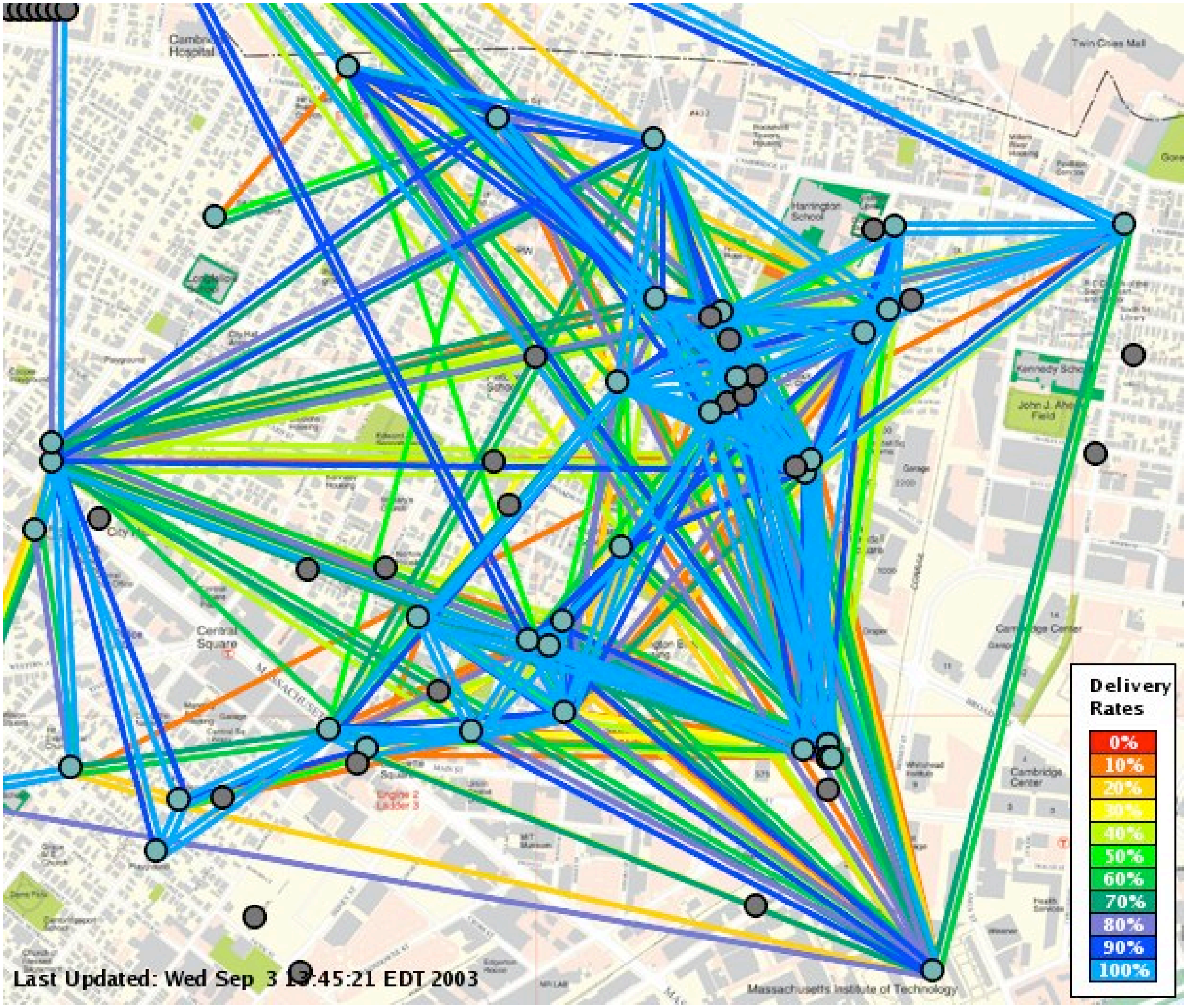
DSR with ETX (no TX feedback)



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

What's next: MIT Roofnet

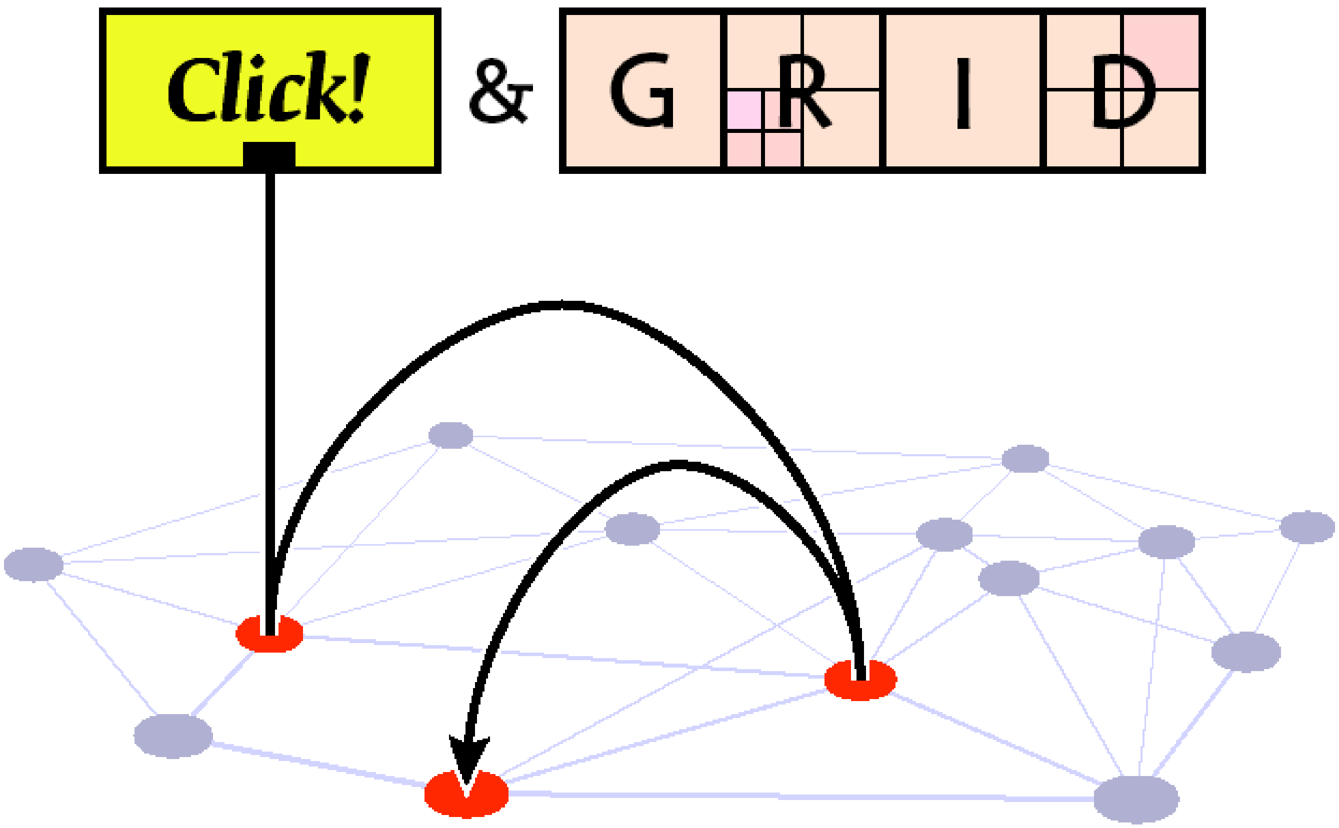


Summary

- 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!

DSDV & DSR implementations:

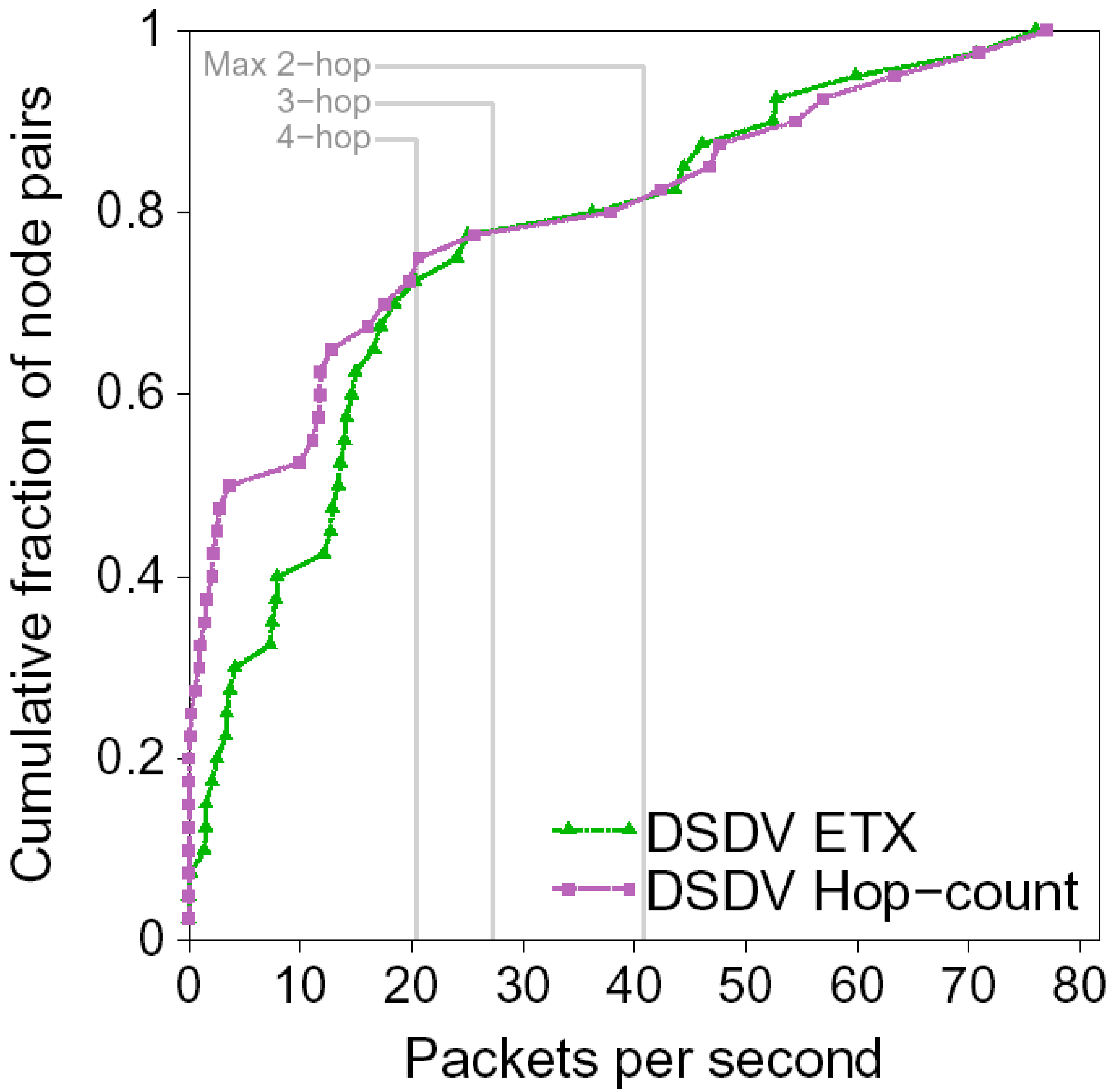
http://pdos.lcs.mit.edu/grid



Roofnet info at poster session

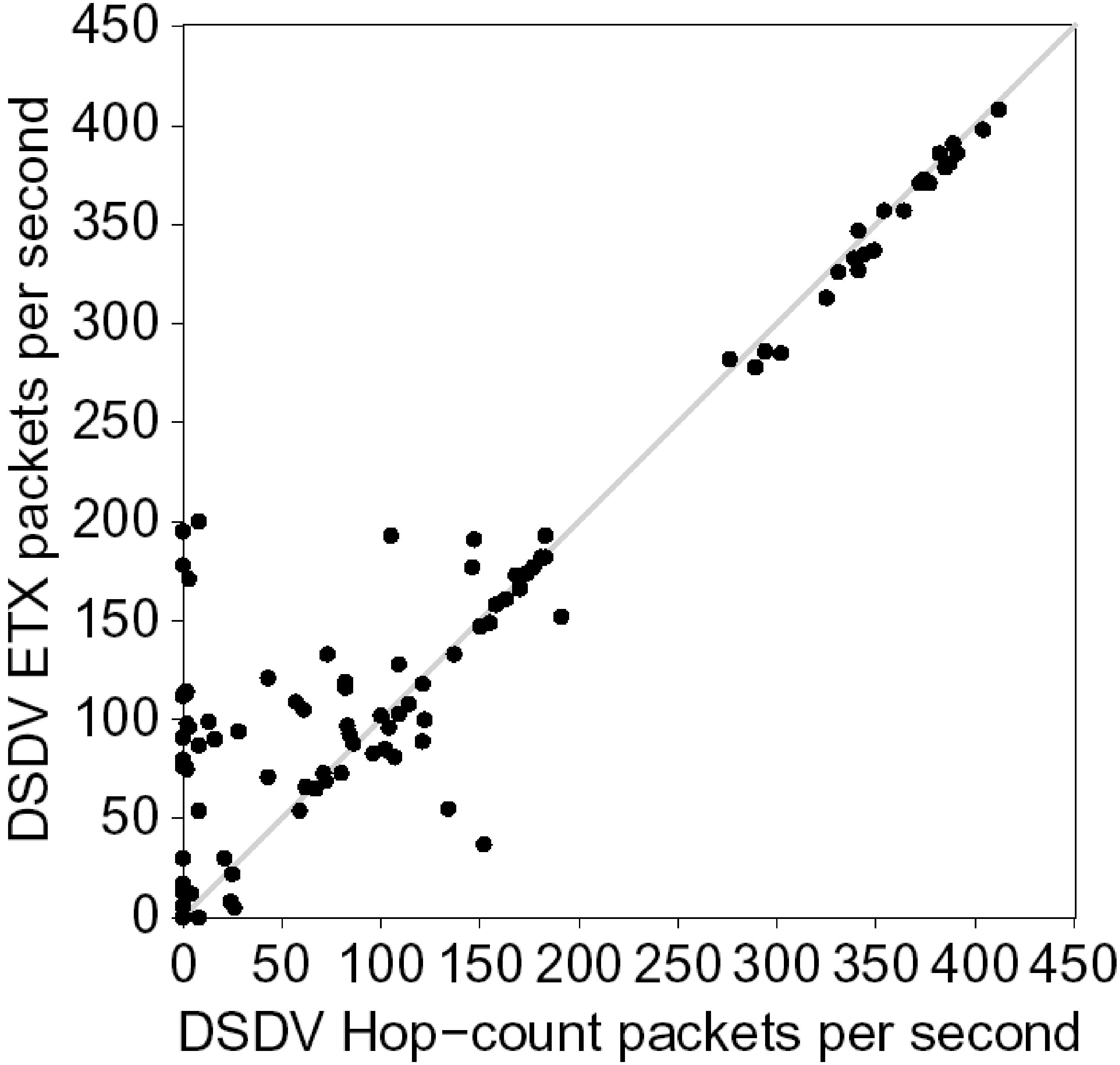
Extra slides follow

Big packets

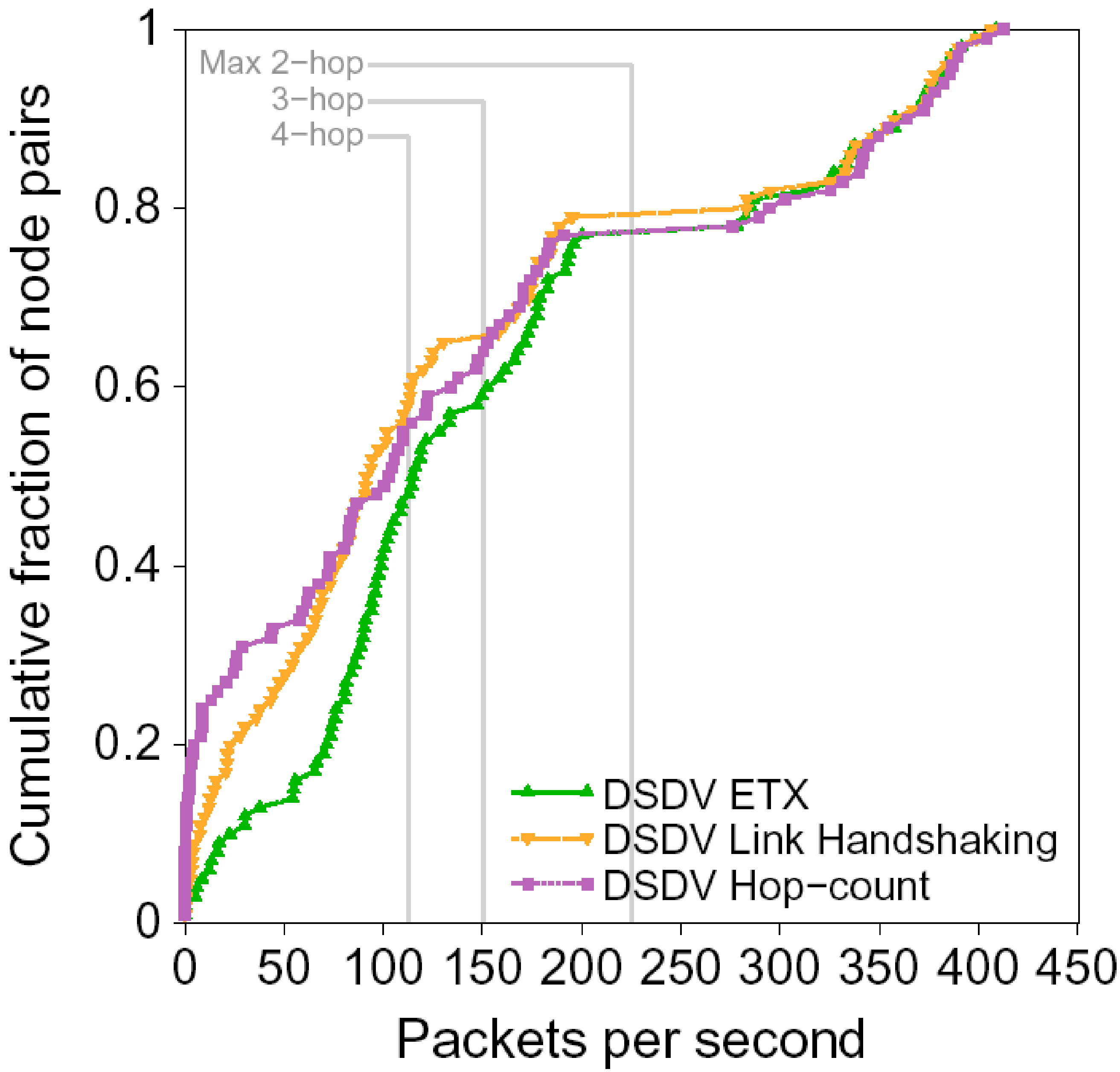


Max 2−hop
3−hop
4−hop
Cumulative fraction of node pairs
Packets per second
DSDV ETX
DSDV Hop−count
0
0.2
0.4
0.6
0.8
1
0
10
20
30
40
50
60
70
80

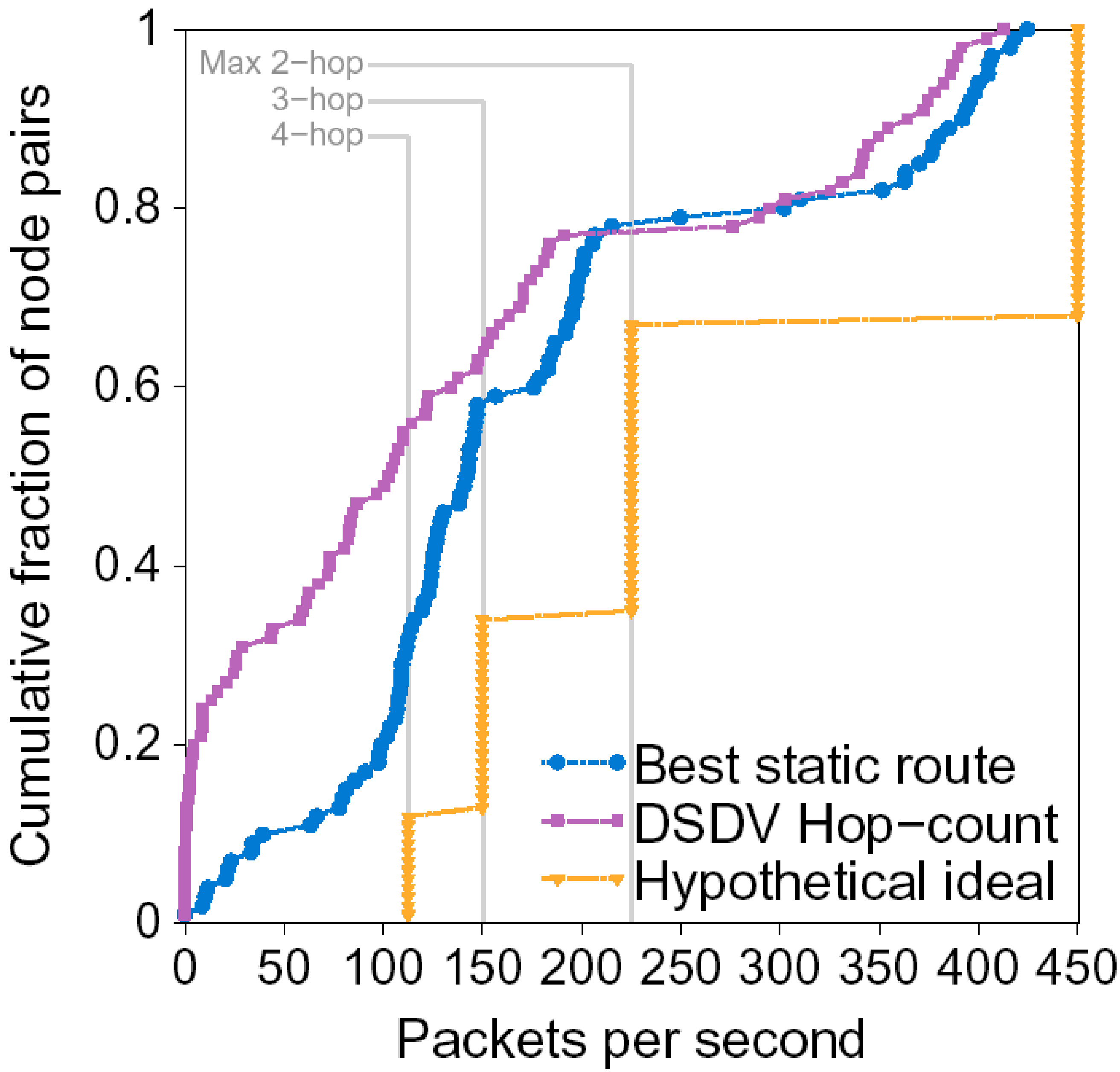
Per-pair DSDV throughputs



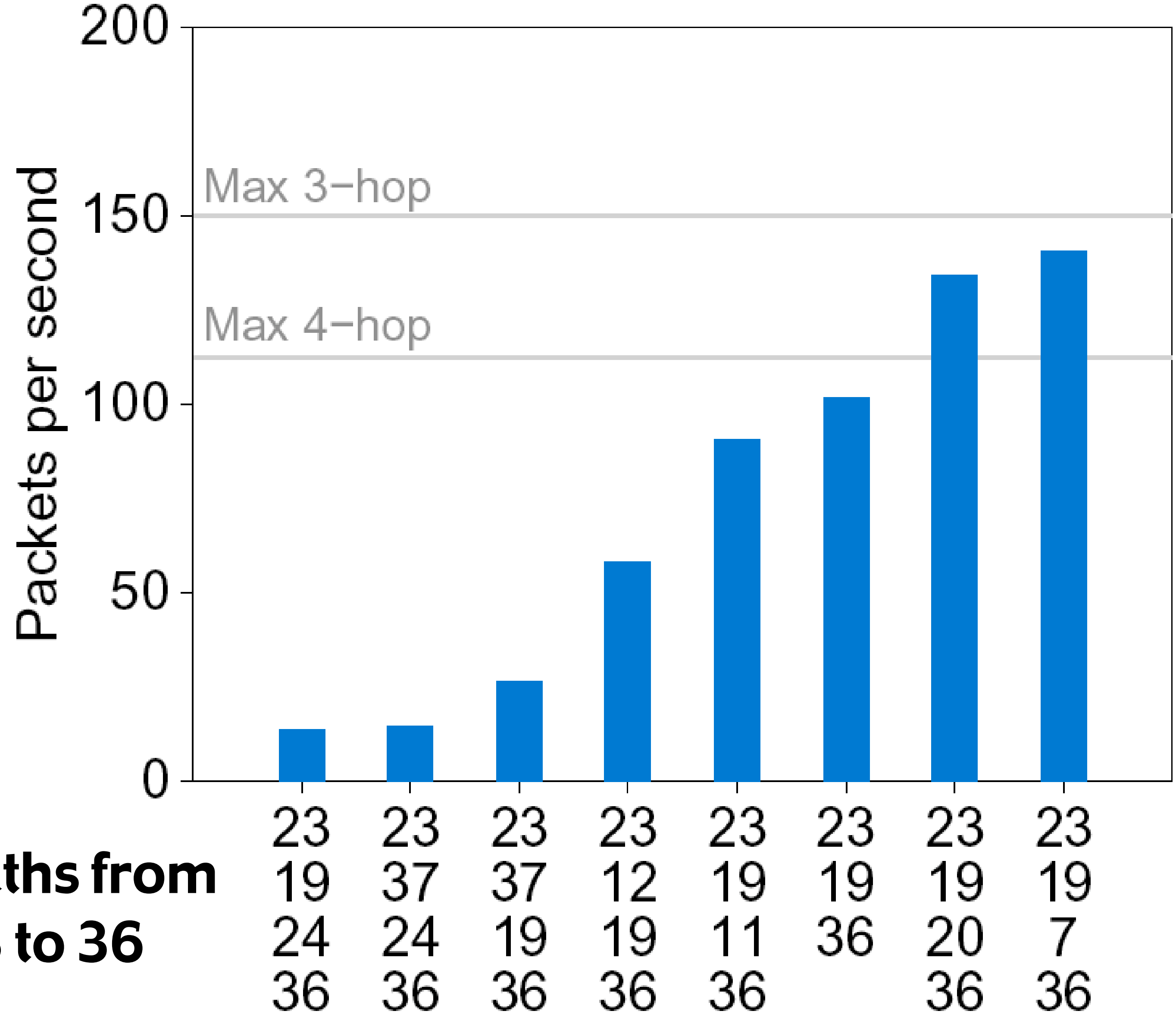
ETX vs. link handshaking



Hop-count penalty



Throughput differs between paths

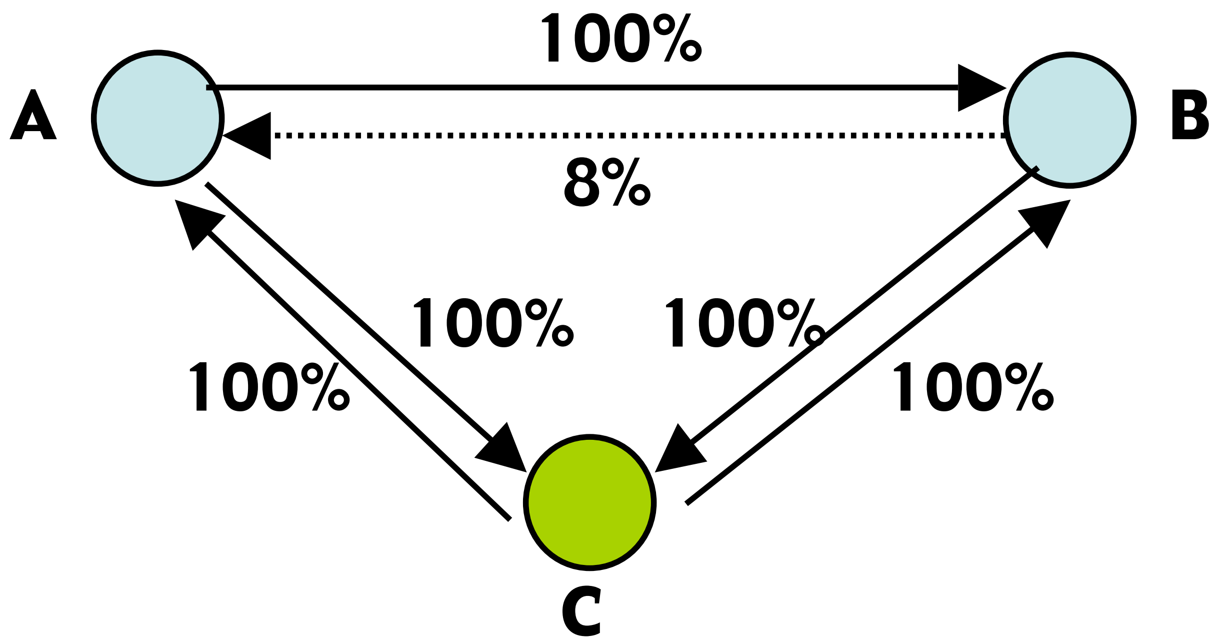


Paths from 23 to 36

Evaluation details

- All experiments:
  - 134-byte (including 802.11 overhead) UDP packets sent for 30 seconds
- DSDV:
  - 90 second warm-up (including ETX)
  - Route table snapshot taken at end of 90s used to route UDP data for next 30s
- DSR:
  - Initiate route request by sending 1 pkt/s for five seconds; followed by UDP data for 30s
  - ETX warms up for 15s before route request

Effect of asymmetry on DSDV



B successfully receives all of A's route ads, and installs a one-hop route to A.

But, throughput of B–A = 0.08

B–C–A = 0.5