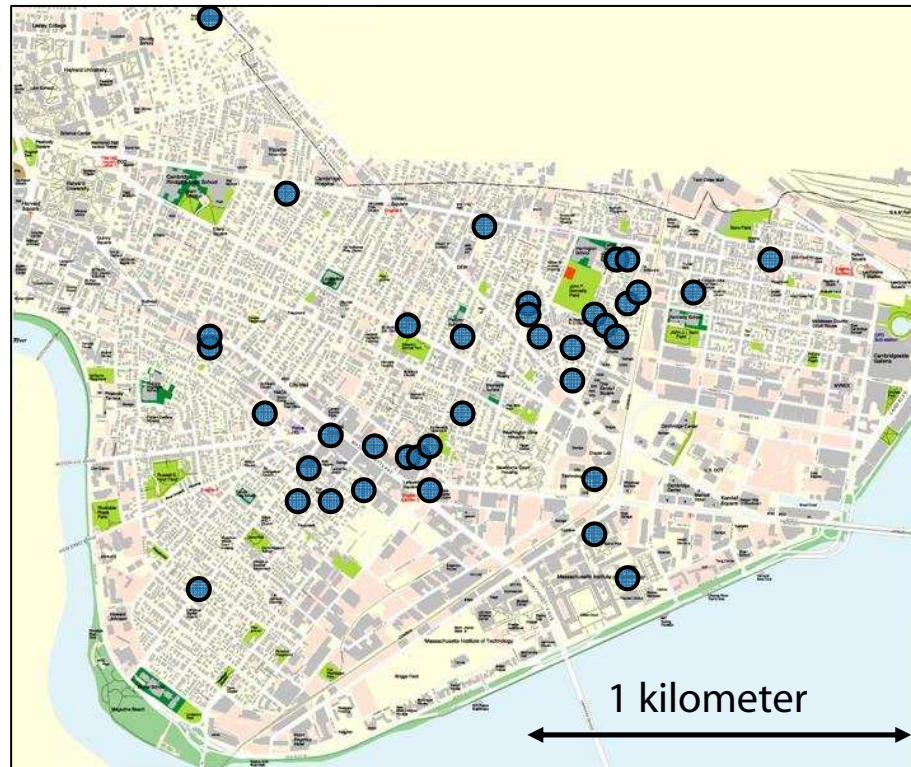


Opportunistic Routing in Multi-hop Wireless Networks

Sanjit Biswas and Robert Morris
MIT CSAIL

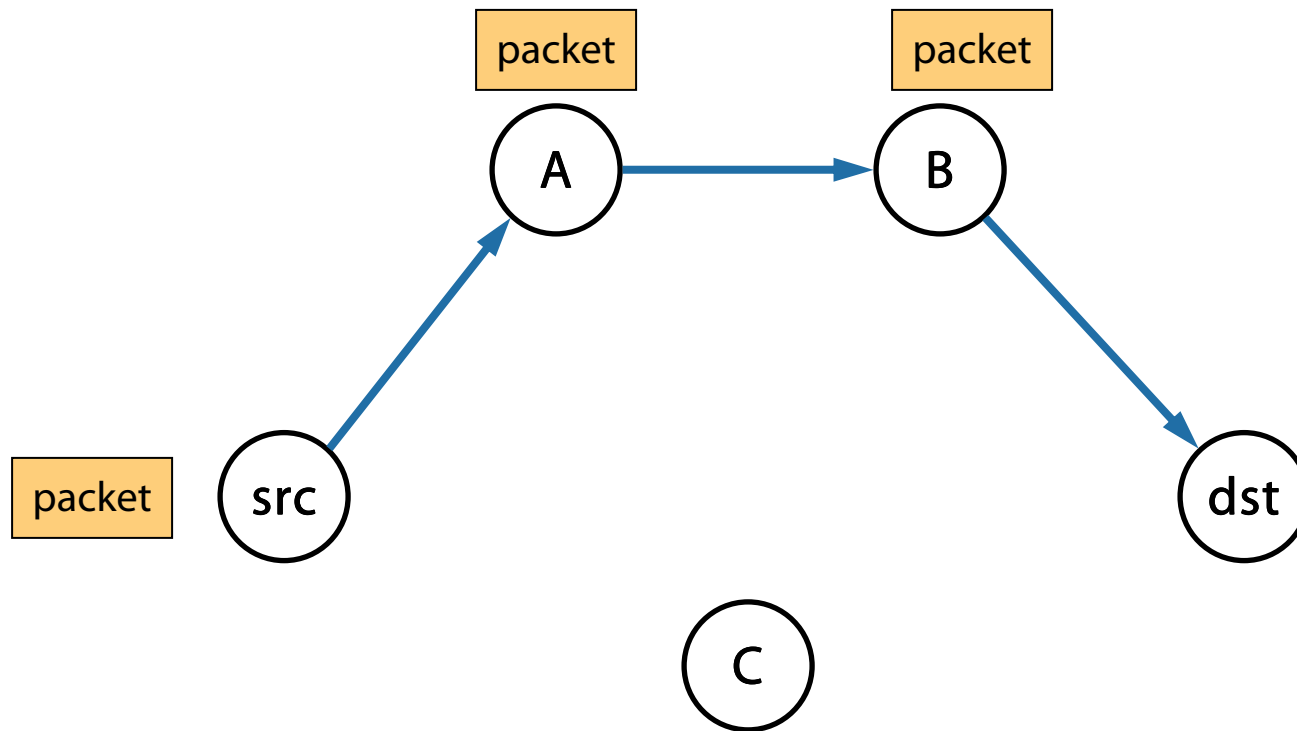
<http://pdos.csail.mit.edu/roofnet/>

ExOR: a new approach to routing in multi-hop wireless networks



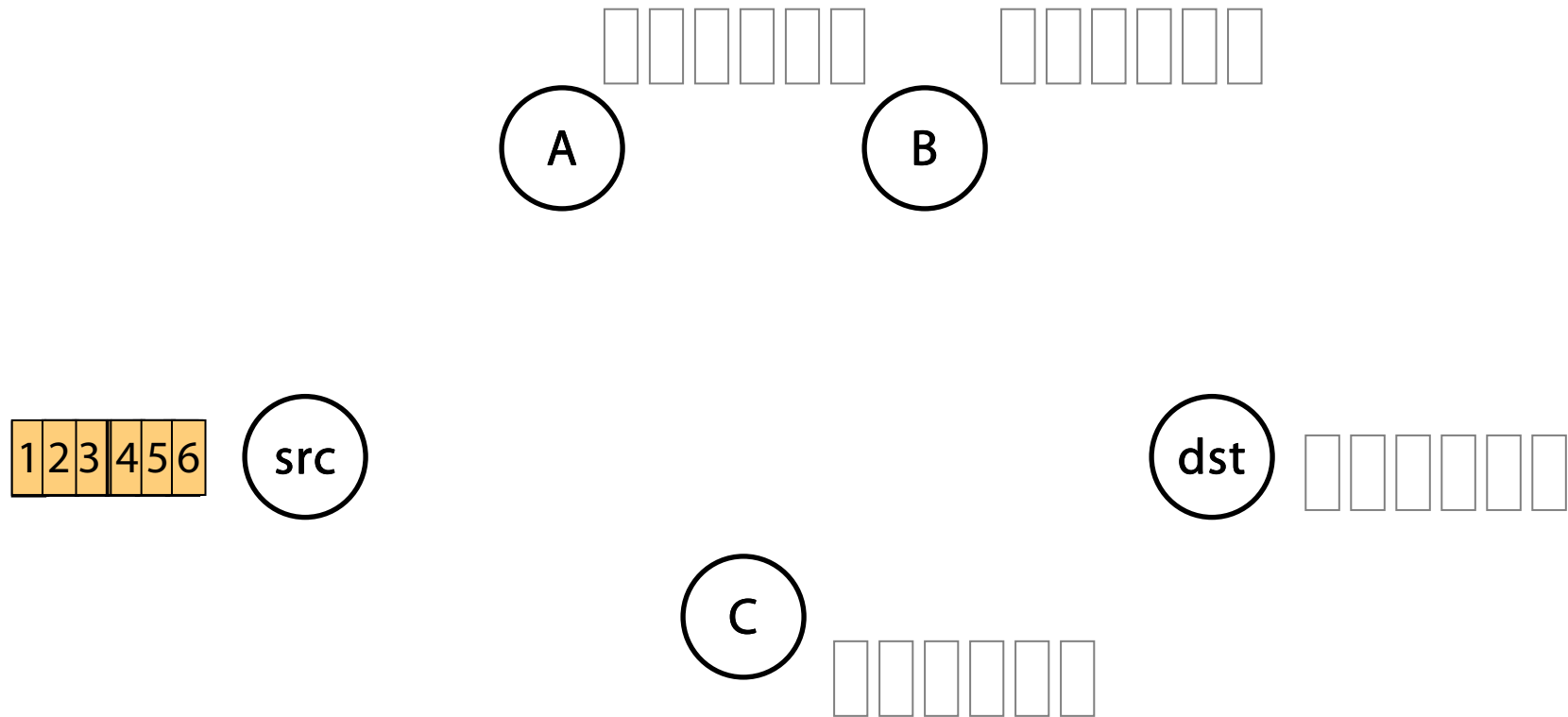
- Dense 802.11-based mesh
- Goal is high-throughput and capacity

Initial approach: Traditional routing



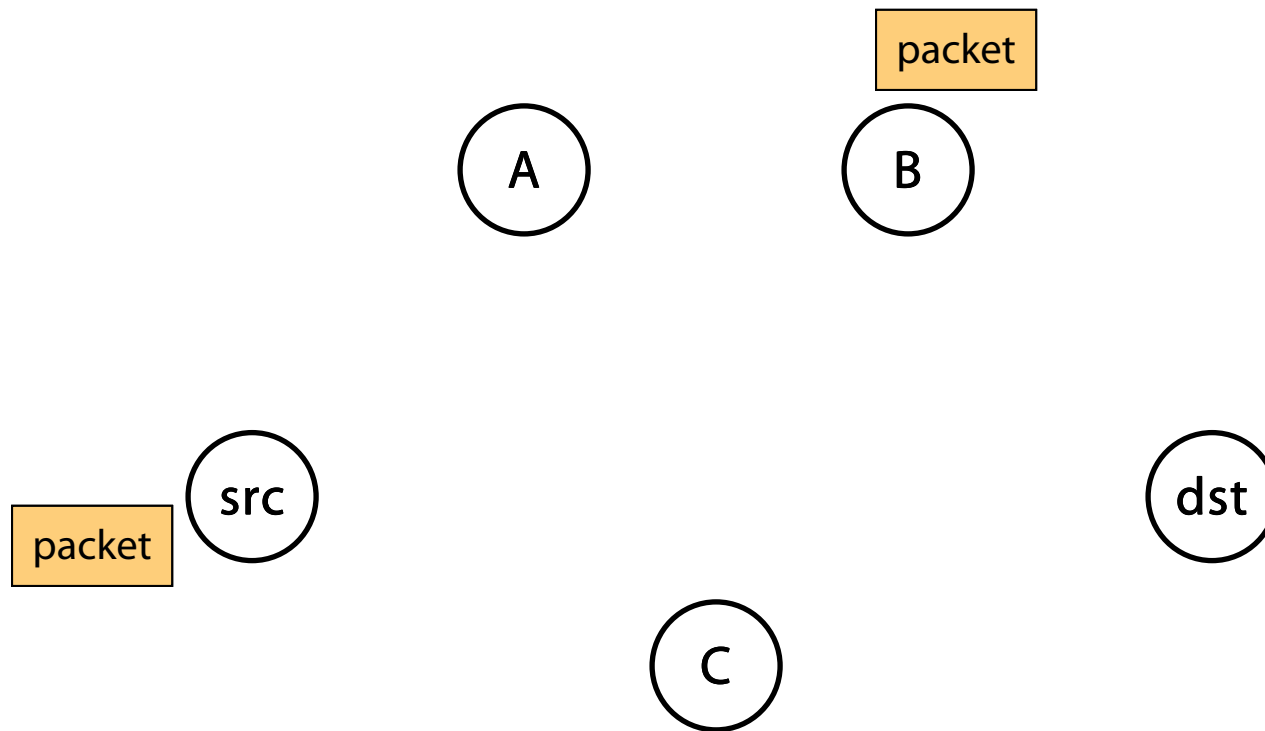
- Identify a route, forward over links
- Abstract radio to look like a wired link

Radios aren't wires



- Every packet is broadcast
- Reception is probabilistic

ExOR: exploiting probabilistic broadcast

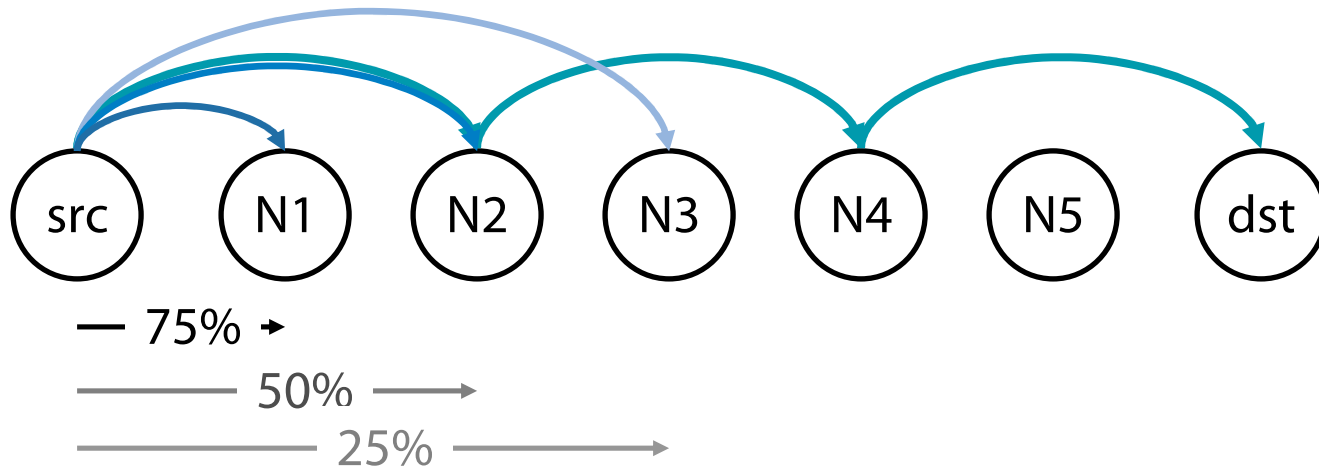


- Decide who forwards after reception
- Goal: only closest receiver should forward
- Challenge: agree efficiently and avoid duplicate transmissions

Outline

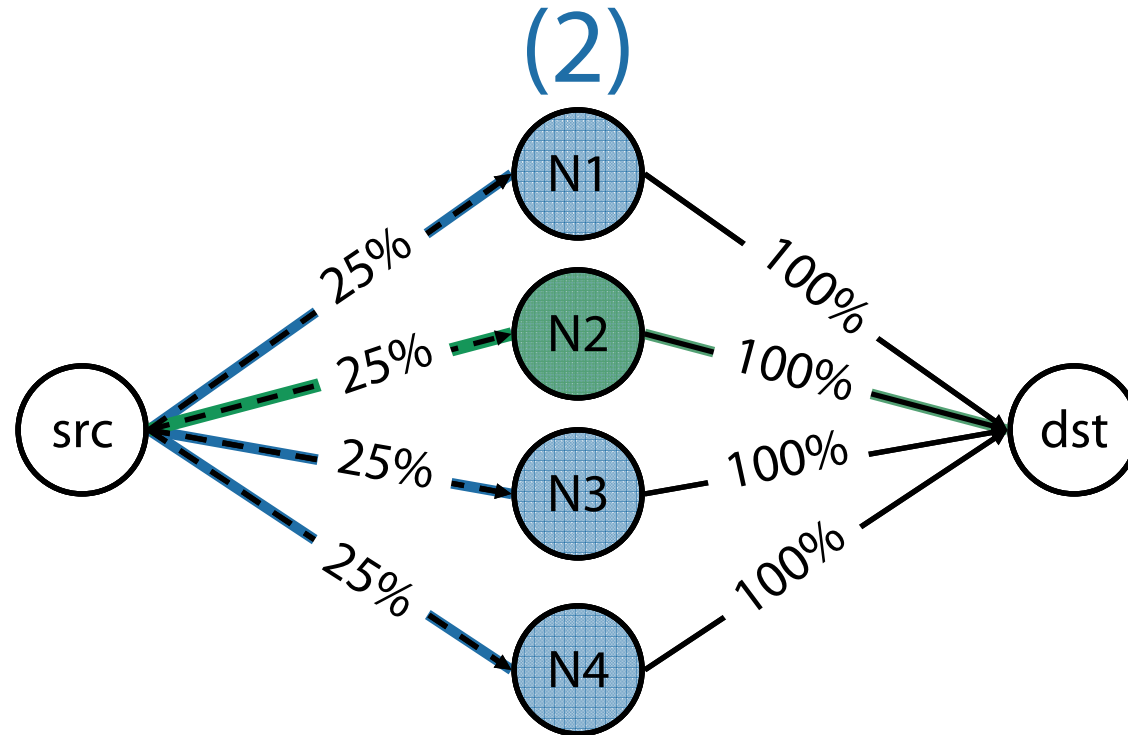
- Introduction
- Why ExOR might increase throughput
- ExOR protocol
- Measurements
- Related Work

Why ExOR might increase throughput (1)



- Best traditional route over 50% hops: $3^{(1/0.5)} = 6$ tx
- Throughput $\cong 1/\# \text{ transmissions}$
- ExOR exploits lucky long receptions: 4 transmissions
- Assumes probability falls off gradually with distance

Why ExOR might increase throughput

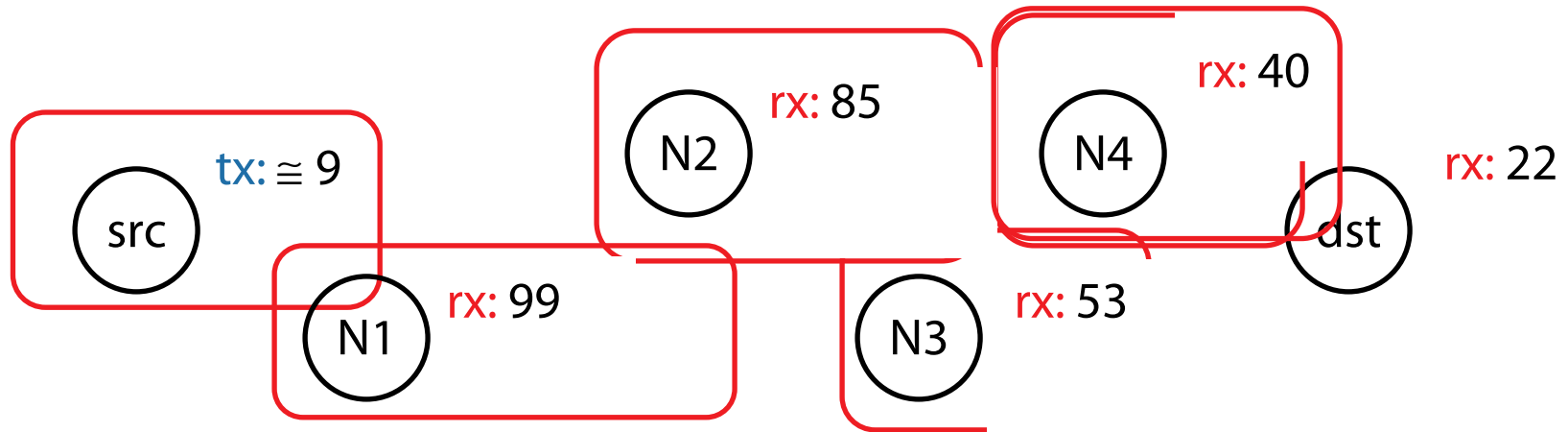


- Traditional routing: $1/0.25 + 1 = 5$ tx
- ExOR: $1/(1 - (1 - 0.25)^4) + 1 = 2.5$ transmissions
- Assumes independent losses

Outline

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ExOR batching

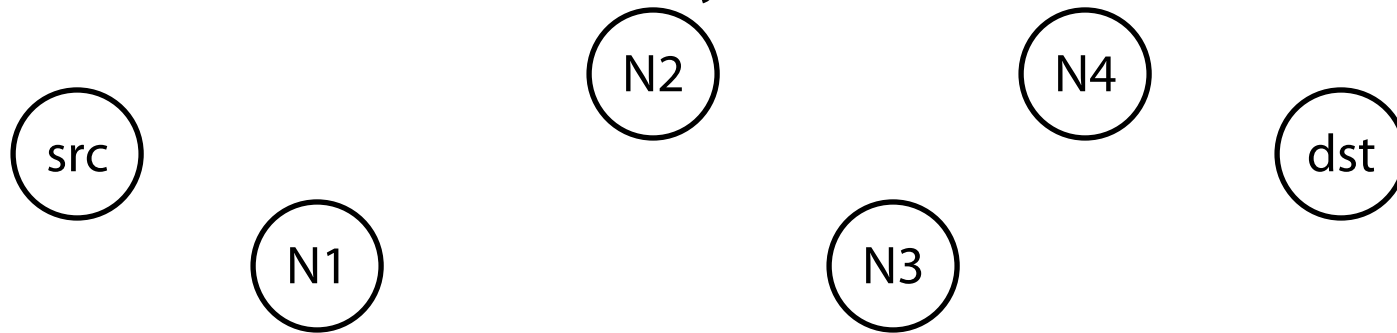


- Challenge: finding the closest node to have rx'd
- Send batches of packets for efficiency
- Node closest to the dst sends first
 - Other nodes listen, send remaining packets in turn
- Repeat schedule until dst has whole batch

Reliable summaries

tx: {2, 4, 10 ... 97, 98}

summary: {1, 2, 6, ... 97, 98, 99}

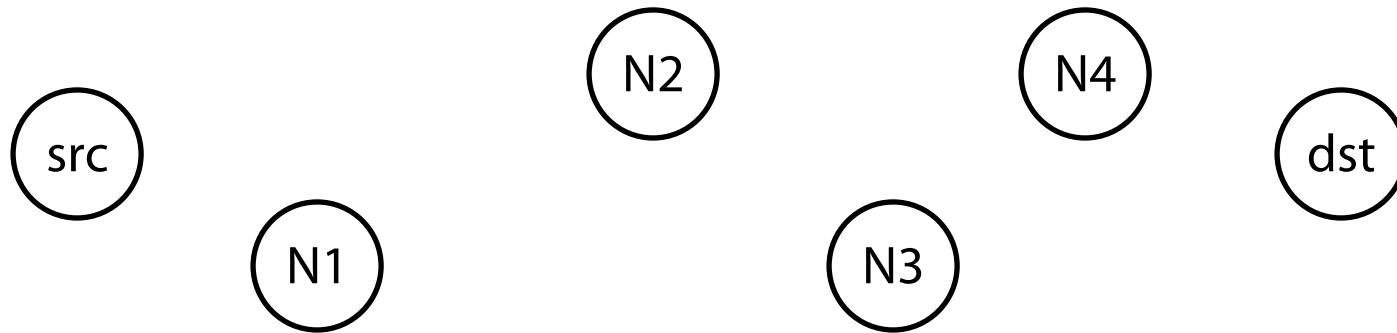


tx: {1, 6, 7 ... 91, 96, 99}

summary: {1, 6, 7 ... 91, 96, 99}

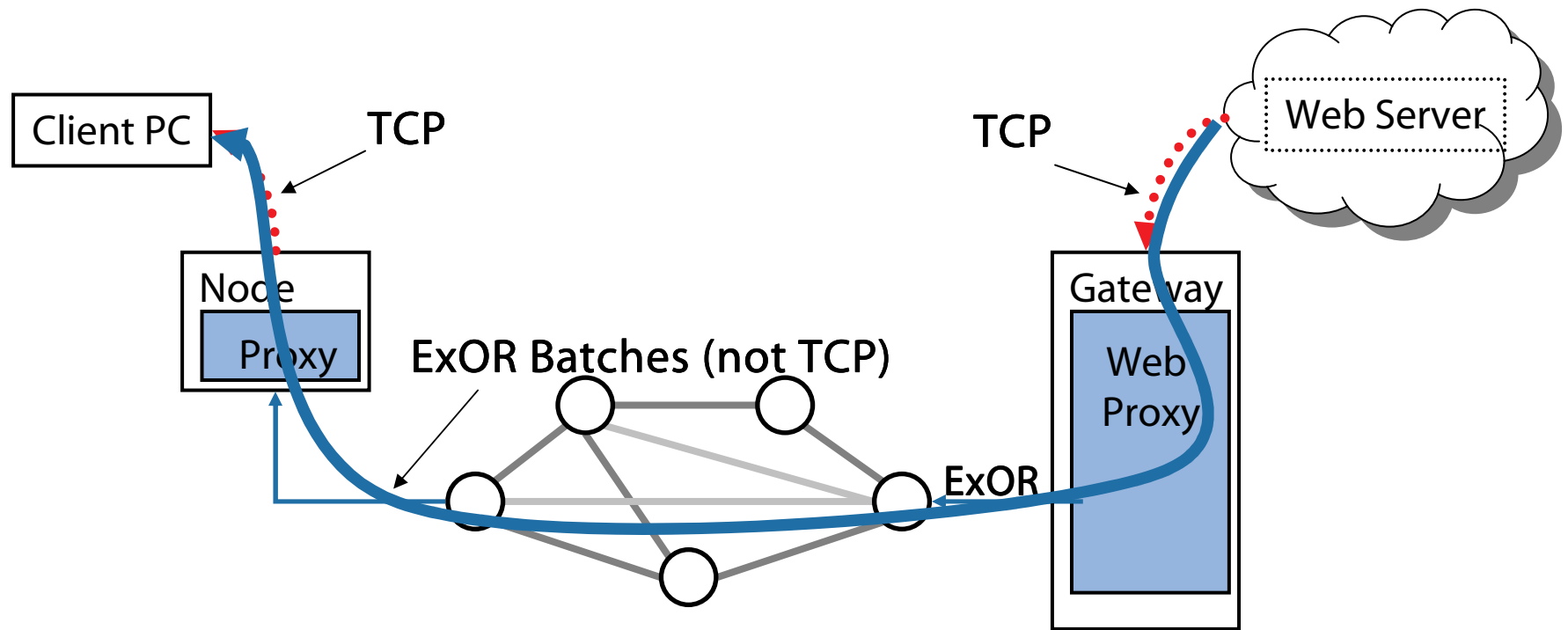
- Repeat summaries in every data packet
- Cumulative: what all previous nodes rx'd
- This is a gossip mechanism for summaries

Priority ordering



- Goal: nodes “closest” to the destination send first
- Sort by ETX metric to dst
 - Nodes periodically flood ETX “link state” measurements
 - Path ETX is weighted shortest path (Dijkstra’s algorithm)
- Source sorts, includes list in ExOR header
- Details in the paper

Using ExOR with TCP



- Batching requires more packets than typical TCP window

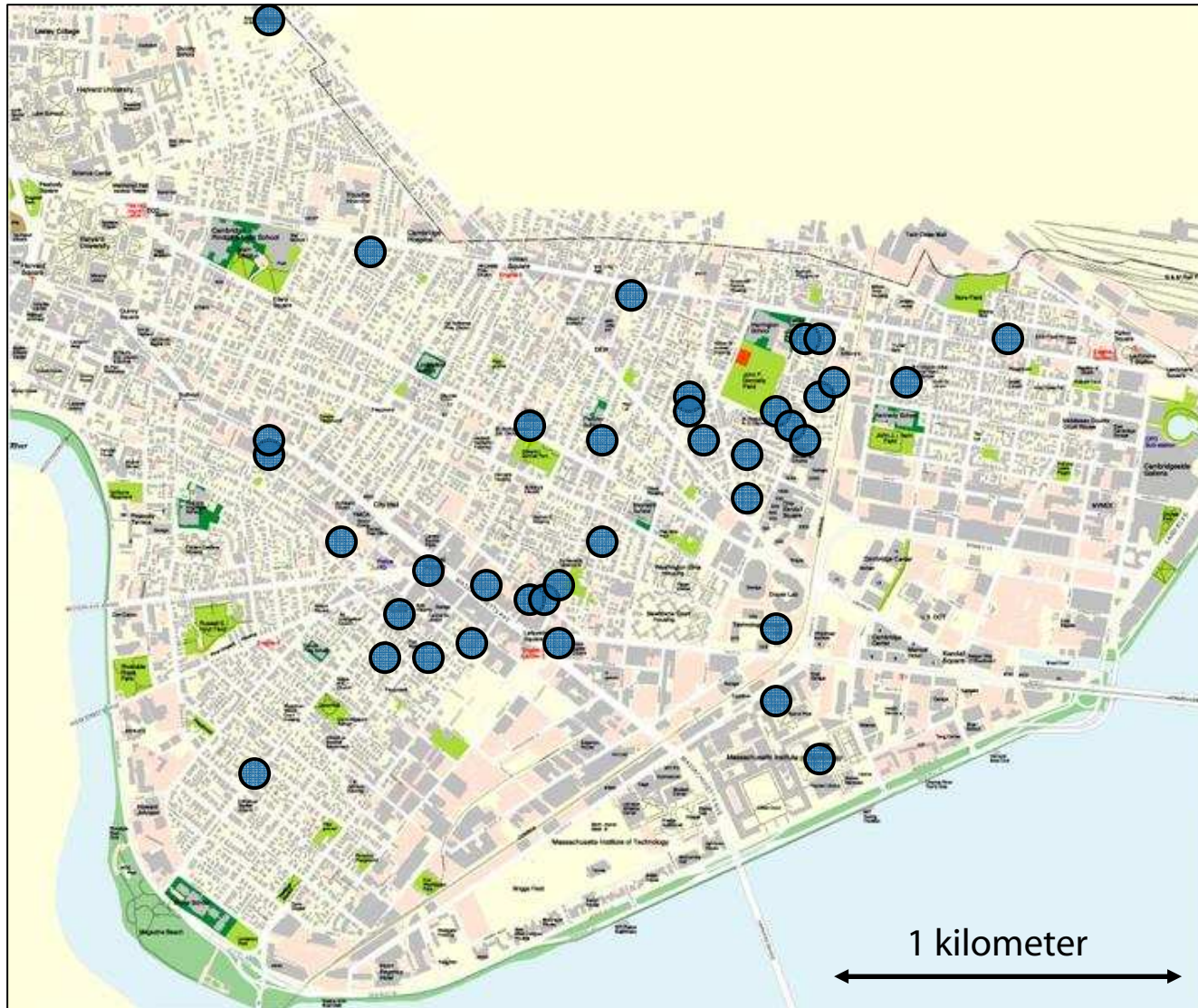
Outline

- Introduction
- Why ExOR might increase throughput
- ExOR protocol
- **Measurements**
- **Related Work**

ExOR Evaluation

- Does ExOR increase throughput?
- When/why does it work well?

65 Roofnet node pairs

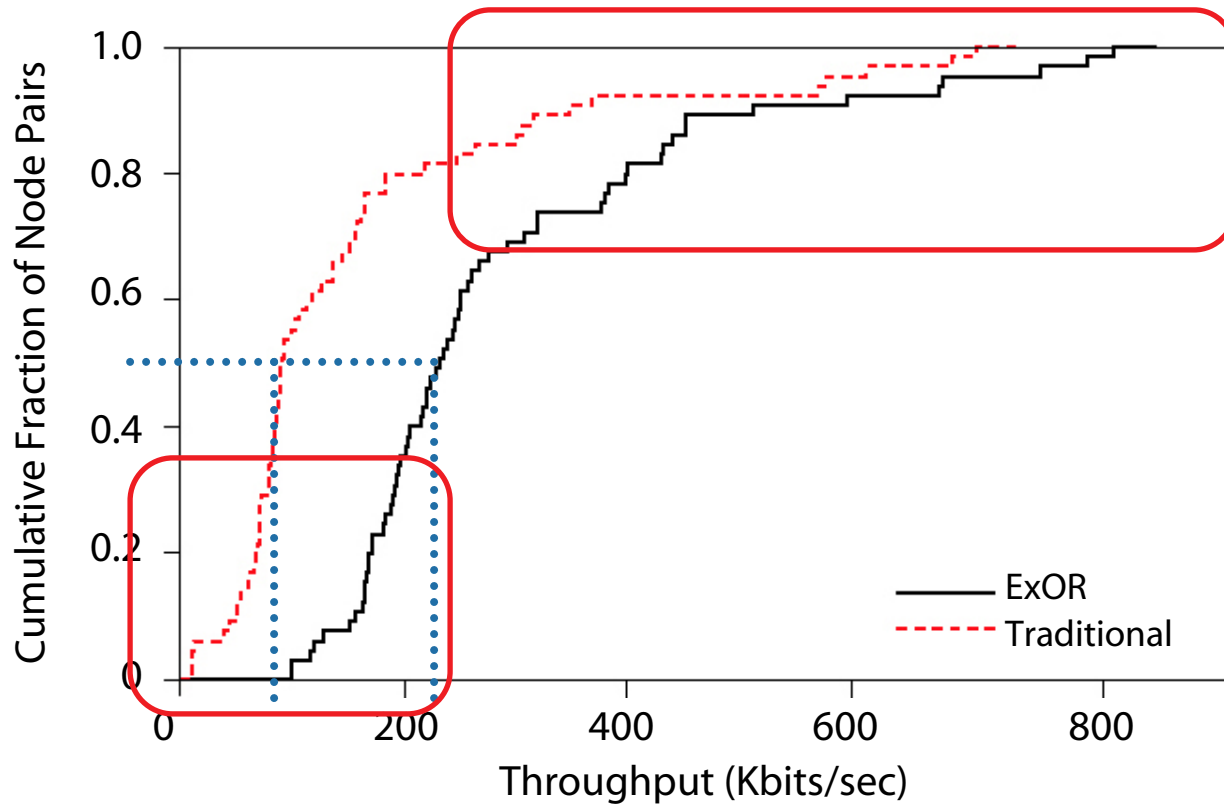


Evaluation Details

- 65 Node pairs
- 1.0MByte file transfer
- 1 Mbit/s 802.11 bit rate
- 1 KByte packets

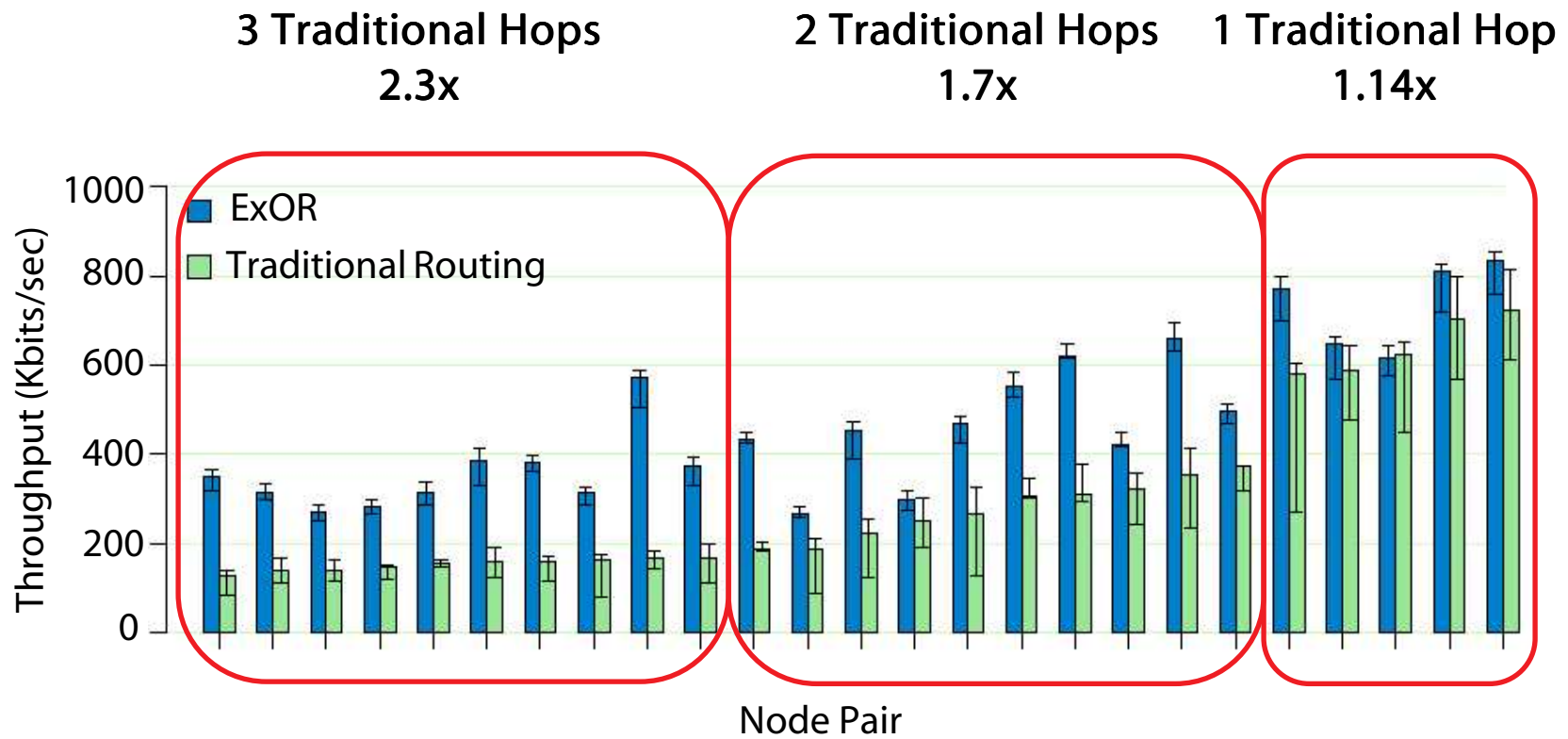
Traditional Routing	ExOR
802.11 unicast with link-level retransmissions Hop-by-hop batching UDP, sending as MAC allows	802.11 broadcasts 100 packet batch size

ExOR: 2x overall improvement

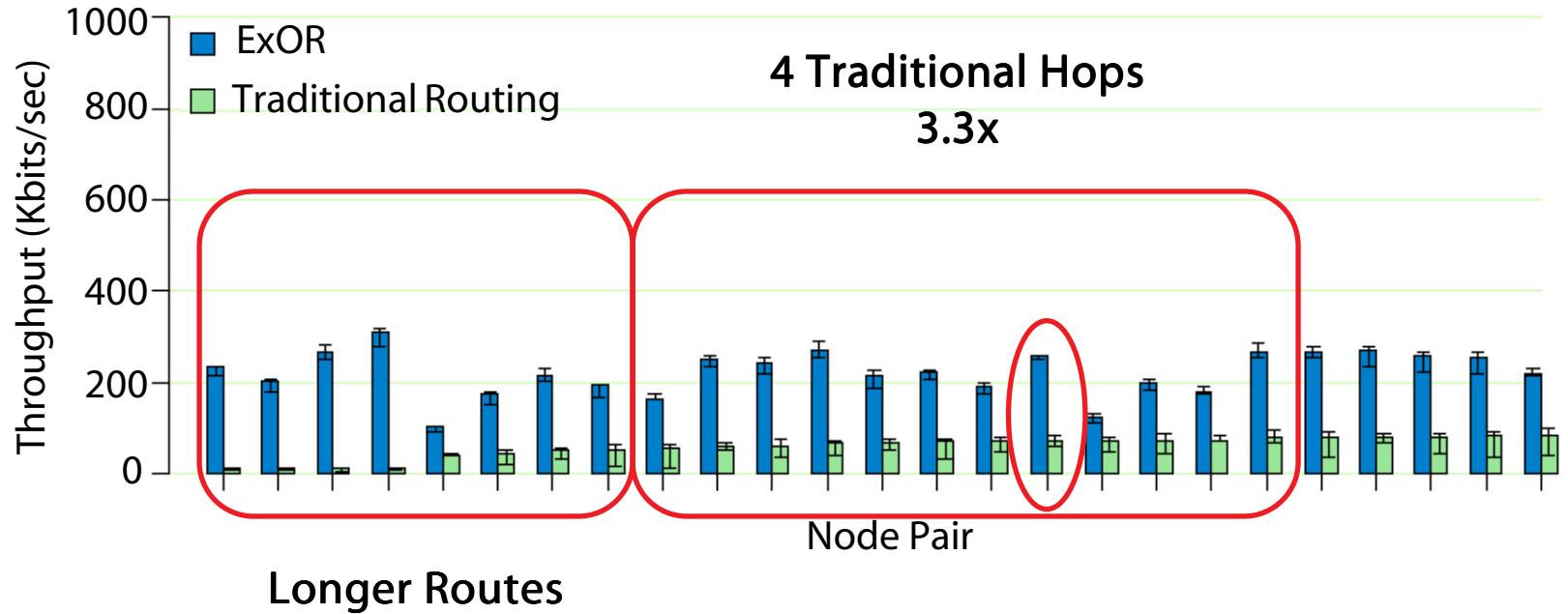


- Median throughputs: 240 Kbits/sec for ExOR,
121 Kbits/sec for Traditional

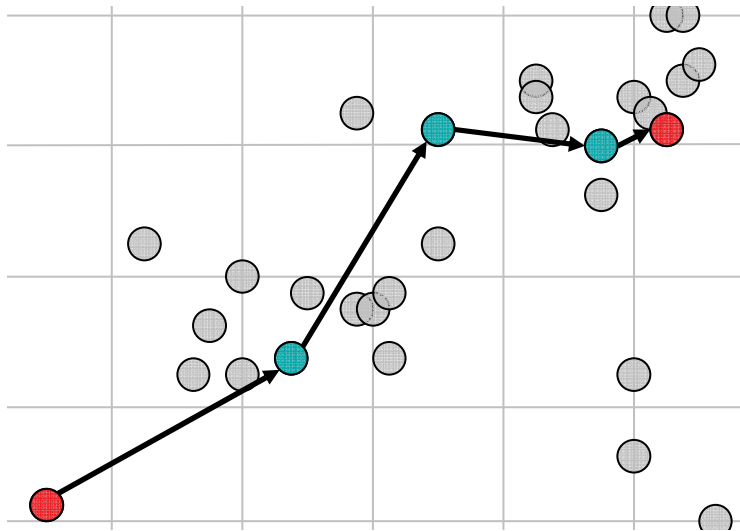
25 Highest throughput pairs



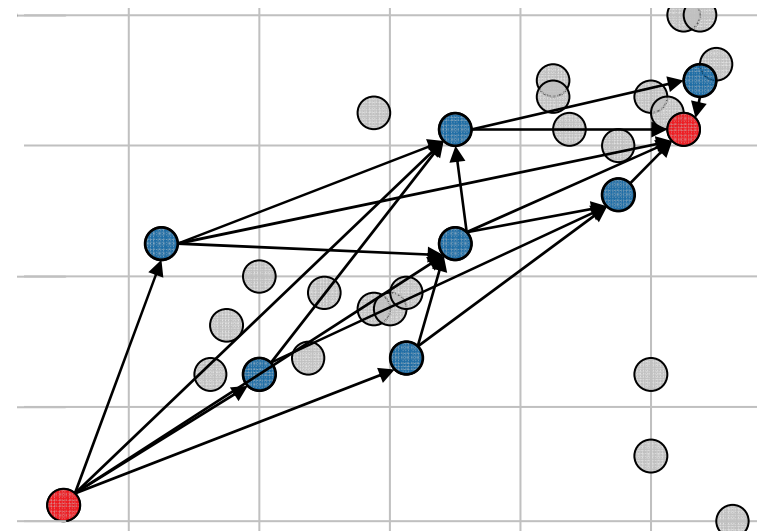
25 Lowest throughput pairs



ExOR uses links in parallel

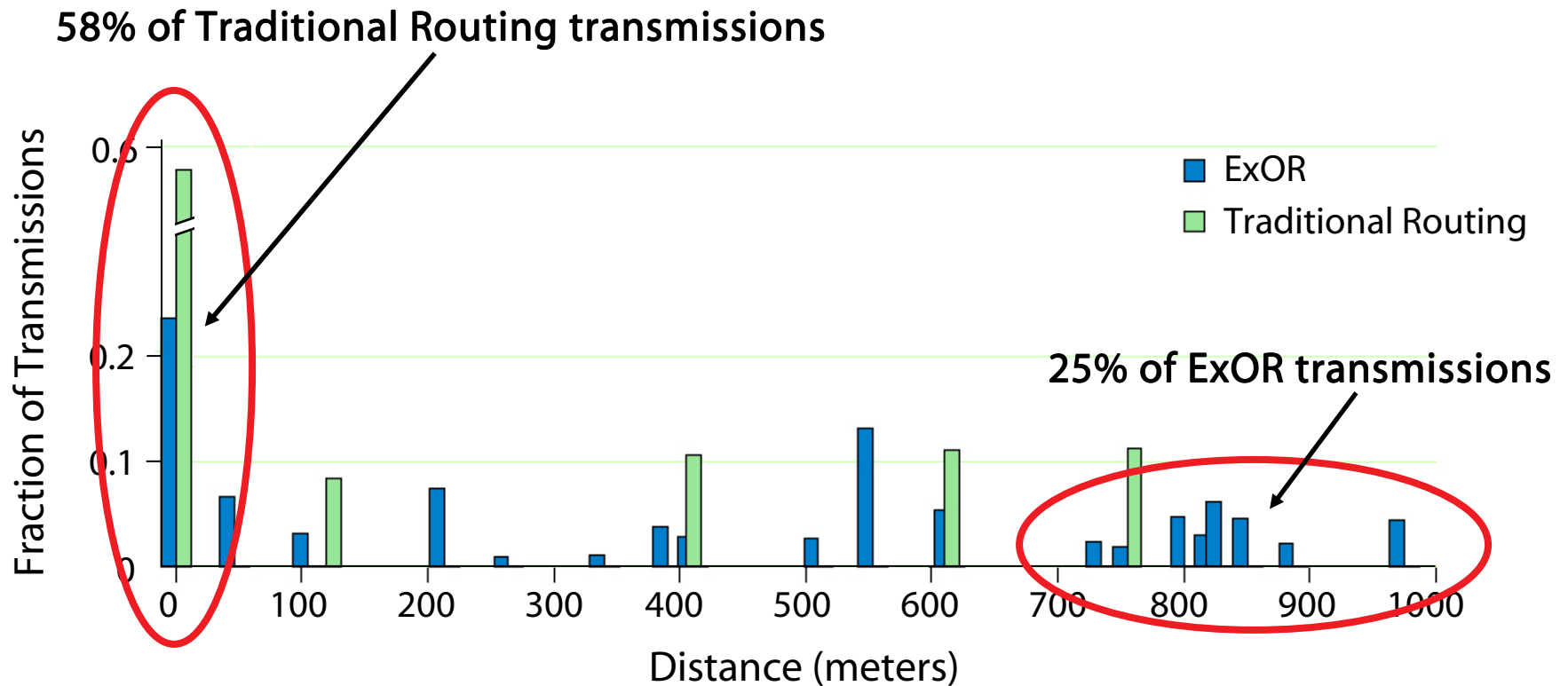


Traditional Routing
3 forwarders
4 links



ExOR
7 forwarders
18 links

ExOR moves packets farther



- ExOR average: 422 meters/transmission
- Traditional Routing average: 205 meters/tx

Future Work

- Choosing the best 802.11 bit-rate
- Cooperation between simultaneous flows
- Coding/combining

Related work

- Relay channels
[Van der Meulen][Laneman+Wornell]
- Flooding in meshes / sensor nets
[Peng][Levis]
- Multi-path routing
[Ganesan][Haas]
- Selection Diversity
[Miu][Roy Chowdhury][Knightly][Zorzi]

Summary

- ExOR achieves 2x throughput improvement
- ExOR implemented on Roofnet
- Exploits radio properties, instead of hiding them

Thanks!

For more information and source code:

<http://pdos.csail.mit.edu/roofnet/>

