ExOR: Opportunistic Multi-Hop Routing For Wireless Networks

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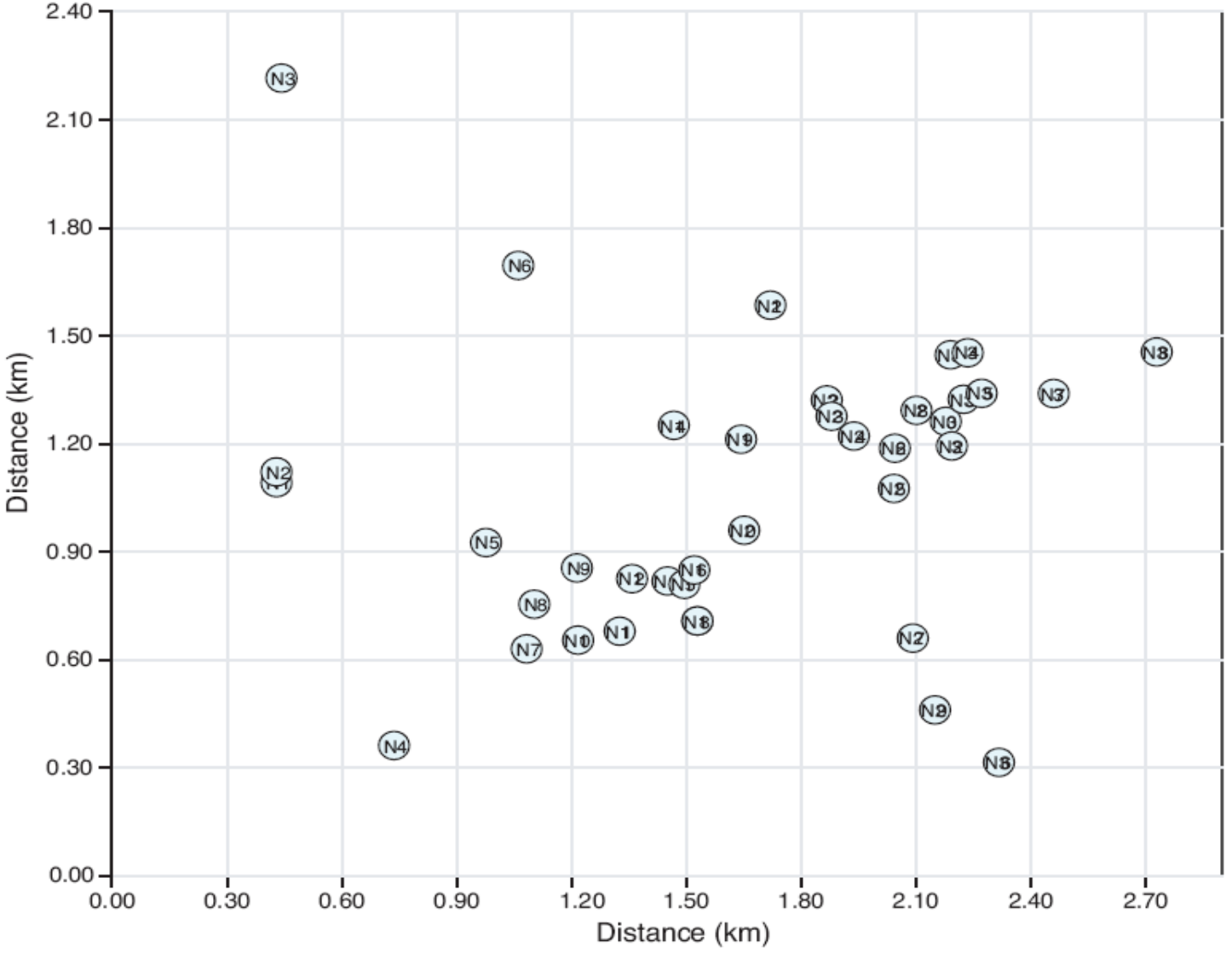
Motivation


Distance (km)
Distance (km)
0.00
0.30
0.60
0.90
1.20
1.50
1.80
2.10
2.40
2.70

Motivation

- If the end-to-end capacity is the most concerned,
  - Is the framework of traditional deterministic hop-by-hop unicast-based routing the best approach?
  - If there is another way around to improve the e2e capacity, what would it be?
  - What about the simple definition?
    - Throughput = number of delivered packets per second

Motivation

- Intuition is that ...
  - The best path for unicast is determined by typically the expectation of overall link quality
  - A physical topology of wireless link may or may not support this assumption
  - What about using multi-path?
    - Whatever path available at whatever link quality
    - Implications?

Motivation

- Using multiple paths require:
  - Need to know what paths are available at what expected throughput (quality)
  - Need to schedule packet transmission on multiple paths
  - Who to reassemble all the sent packets?
  - Reassembly may need per-packet state at intermediate and the destination nodes

New Approach

- Opportunistic packet transmission!
  - Whoever receives this, please forward it toward the destination
- Table driven routing
- Cooperative transfer
- Target traffic
  - Bulk transfer (web traffic?)
  - Interactive traffic is out of the scope (ssh)

Outline

- **Basics of ExOR**
  - Introduction
  - Functioning
  - Comparison
- **Design Challenges**
  - Packet Buffer
  - Forwarder List
  - Batch Maps
  - Transmission Tracker
  - Forwarding Timer
- **Evaluation**
  - Setup
  - Results
- **Advantages/Limitations**
- **Conclusion**

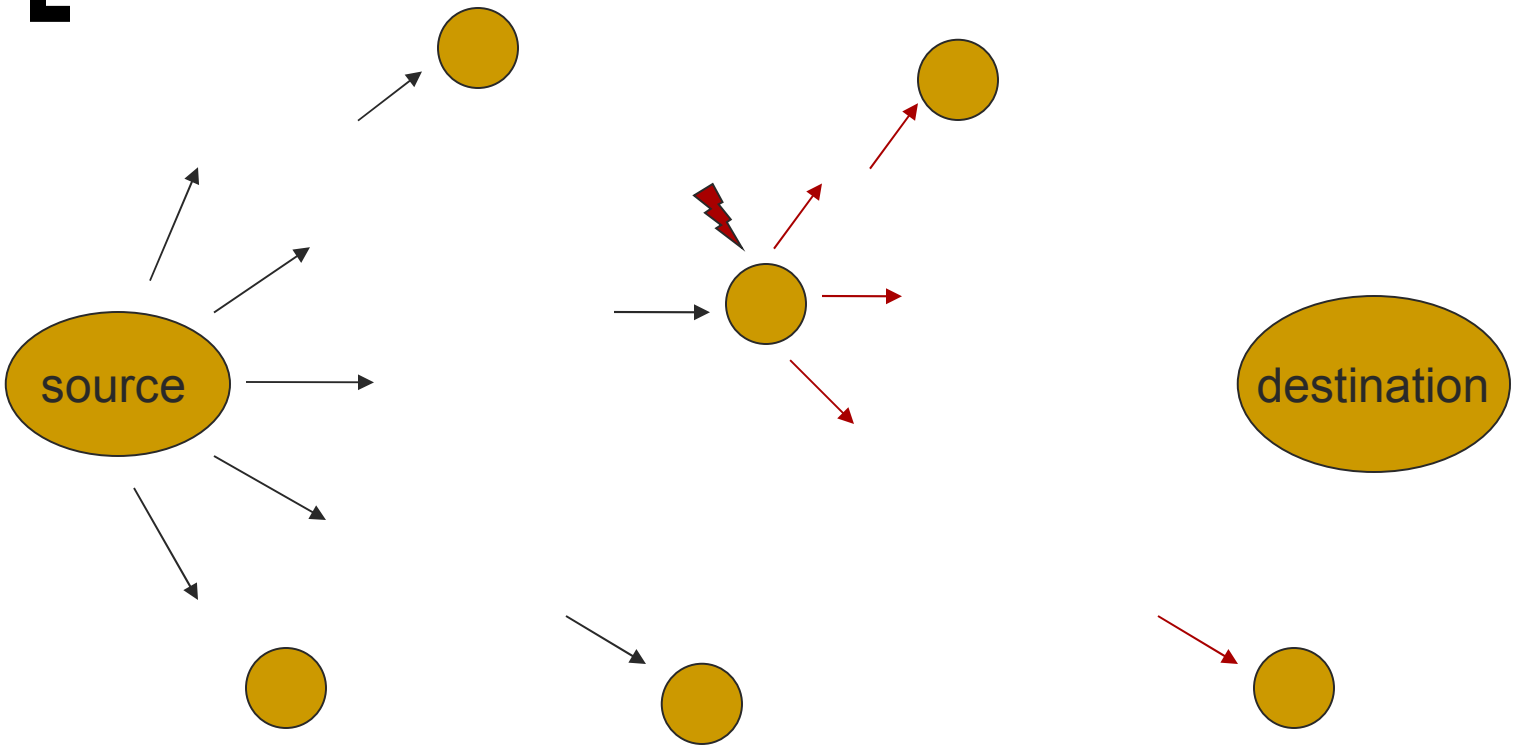
Introduction

- Its an integrated routing and MAC protocol
- Used in multi-hop wireless networks
- Delayed Forwarding
  - Each hop of packet's route is chosen after transmission for that hop
- Operates on batches of packets

Functioning

- Source broadcasts each packet
- A subset of nodes receive the packet
  - Subset runs a protocol to find who all are in the subset
- Node closest to destination broadcasts the packet

Functioning (contd…)



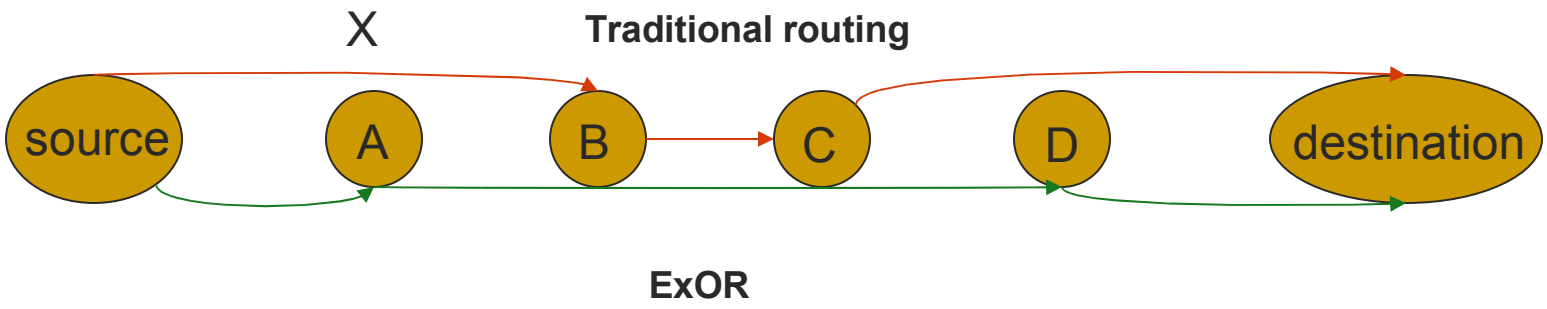
continues……

Comparing ExOR

- Traditional Routing:
  - One path followed from source to destination
  - All packets sent along that path
- Co-operative Diversity:
  - Broadcast of packets ***by*** all nodes
  - Destination chooses the best one
- ExOR:
  - Broadcast packets ***to*** all nodes
  - Only one node forwards the packet
  - Basic idea is delayed forwarding

ExOR Vs. Traditional Routing

- Each transmission may have more ***independent*** chances of being received or forwarded
- Transmissions may reach unexpectedly far or fall unexpectedly short



Design Challenges

- Determine which subset received the broadcast
- Decide on a forwarder among the subset
- In large networks, choosing too many potential forwarders incurs greater cost for agreement
- Avoiding simultaneous transmissions (collisions)

Maintaining State For Each Packet

- Packet Buffer
- Local Forwarder List
- Batch Map
- Transmission Tracker
- Forwarding Timer

Packet Buffer

- Place where each node stores the packets that it receives
- Packets are stored according to their batch numbers
- If the node is the selected forwarder, all packets for that batch are sent out from the buffer

Forwarder List (FL)

- Prioritized List of Nodes
  - Based on expected cost of packet delivery to destination
- Specified by source
  - For a batch, all nodes use the same list

Batch Map (BM)

- Highest priority node known to have received a copy of the packet
- Sent for each packet in the batch
- Guessed by the current forwarder
- Included in the broadcast message

Transmission Tracker (TT)

- Measures sending rate of current forwarder
- Tells the expected number of packets left to be sent by the current forwarder
- Used to adjust the forwarding timer

Forwarding Timer (FT)

- Indicates the time at which the node should start sending
- Set far enough to account for higher priority nodes
- Adjusted when packets from other nodes are heard
- Predicted value

Design Challenges (Revisited)

- Determine which subset received the broadcast
- Decide on a forwarder among the subset
- In large networks, choosing too many potential forwarders incurs greater cost for agreement
- Avoiding simultaneous transmissions (collisions)

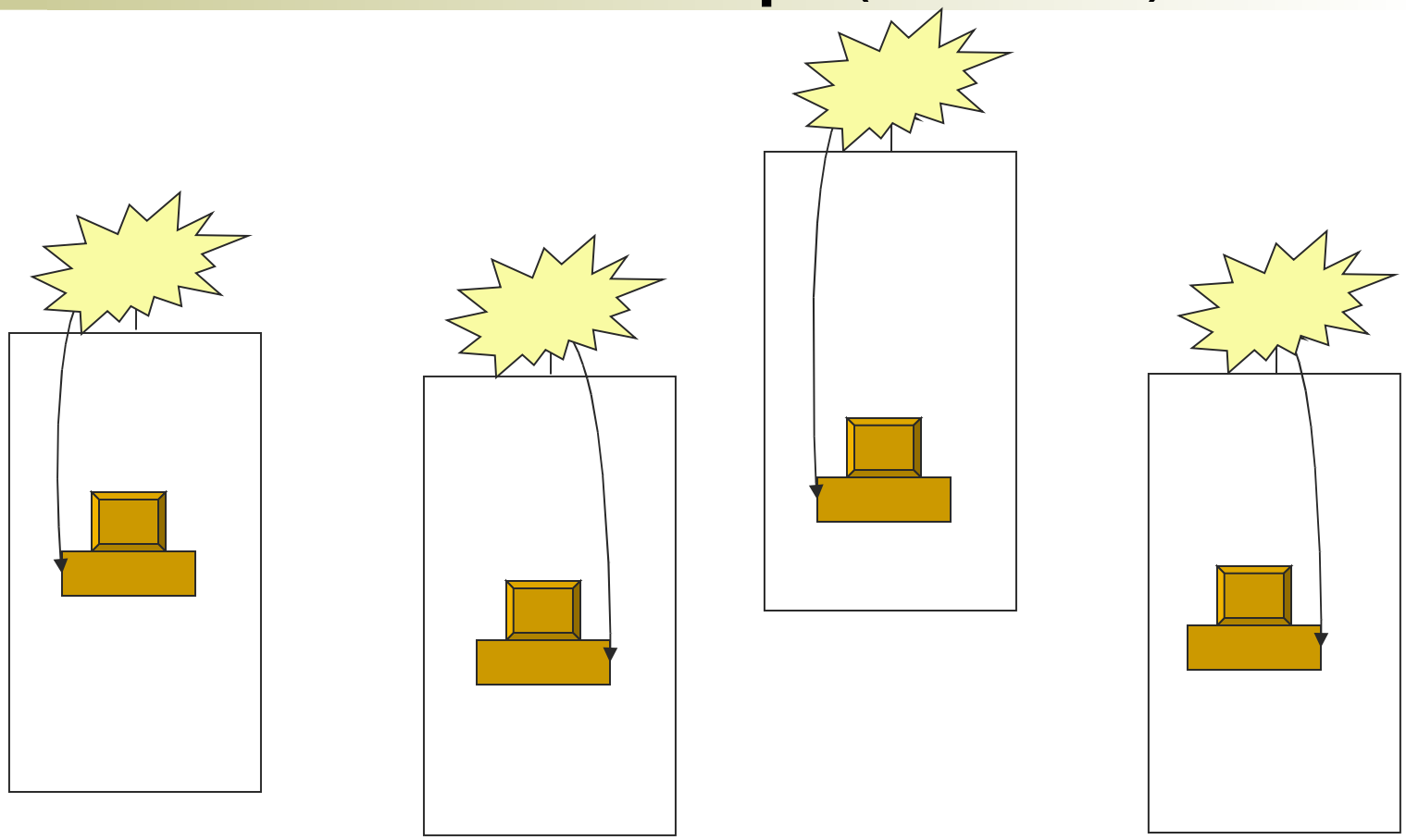
Solution

- FL is included in each packet
- Receiver examines packets that it receives:
  - If FL includes the recipient, the packet is buffered for the corresponding batch
  - For each entry in BM of packet, if packet's entry > corresponding entry in local BM => replace local BM
- Highest priority forwarder forwards the packets in its buffer
- Forwarder also forwards its own BM for each packet
- Remaining forwarders transmit packets not acknowledged in BMs of higher priority nodes, in order

Evaluation: Setup

- Roofnet
  - Outdoor rooftop 802.11b network
  - 38 nodes distributed over 6 sq. kilometers of Cambridge
  - Each node a PC
    - With 802.11b card connected to a roof mounted omni-directional antenna

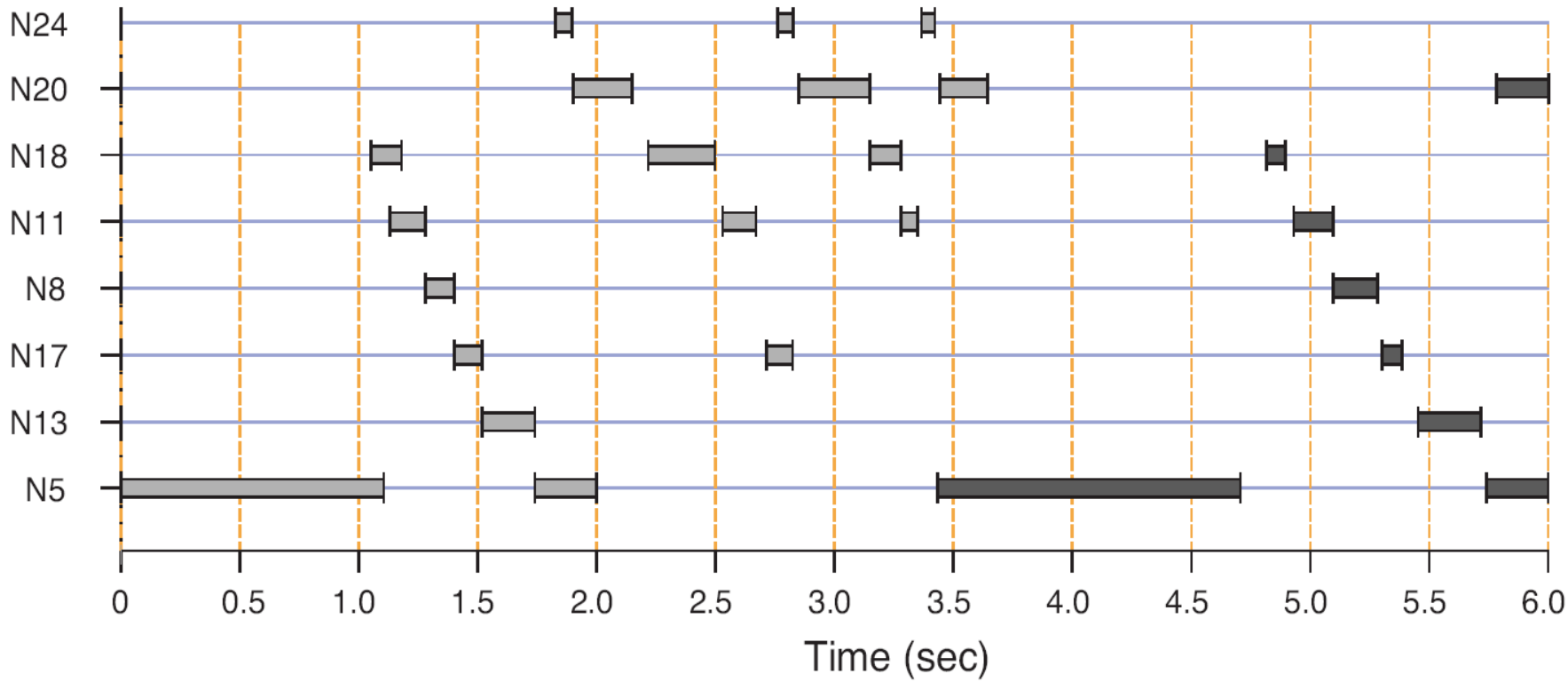
Evaluation: Setup (contd…)



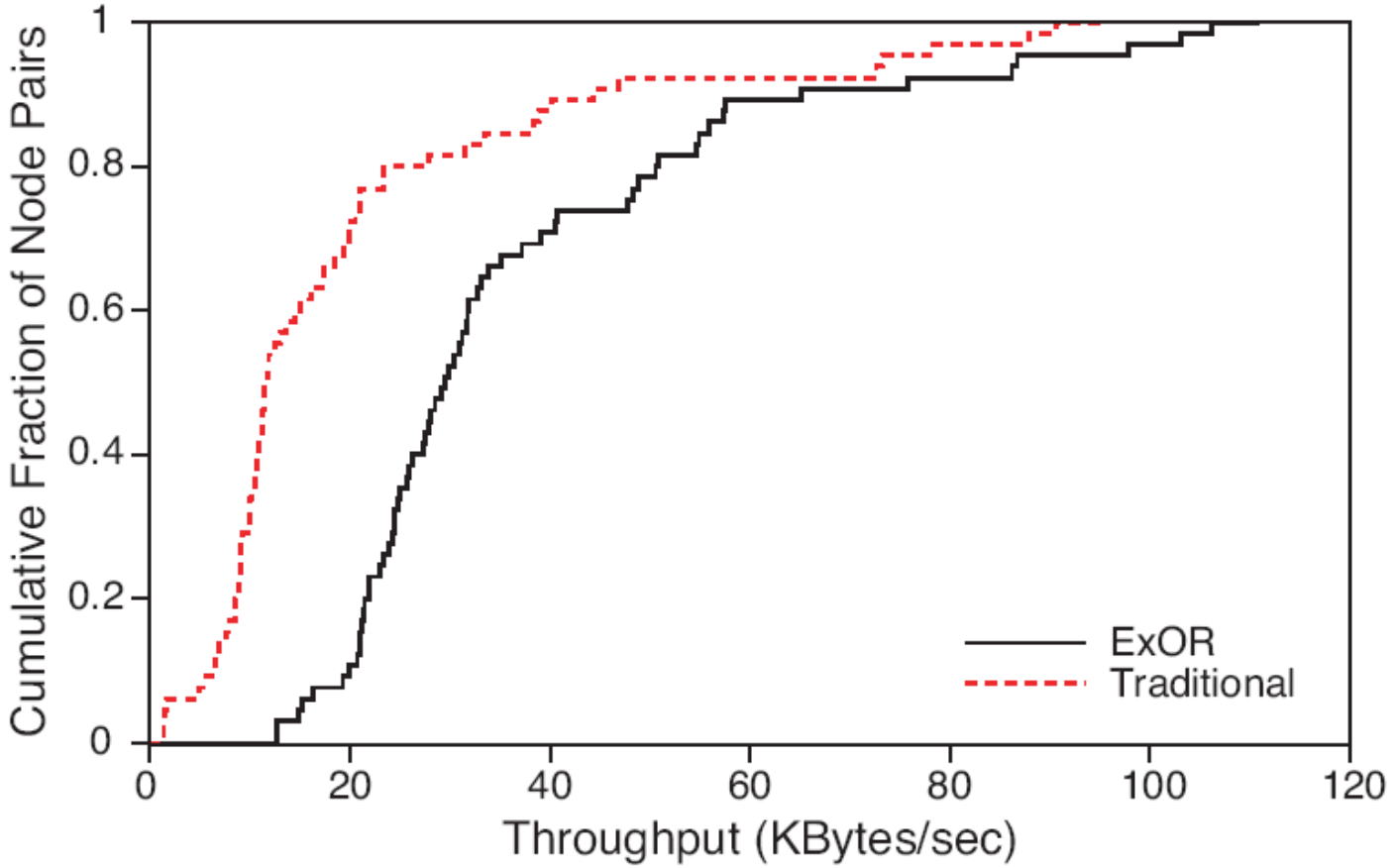
Evaluation: Configuration

- Batch size – 100 packets
- Each packet – 1024 byte payload
- ExOR header – 44 - 114 bytes
- Network bit rate – 1Mb/sec.
- Experiment is performed between 65 randomly selected node pairs

Transmission time-line

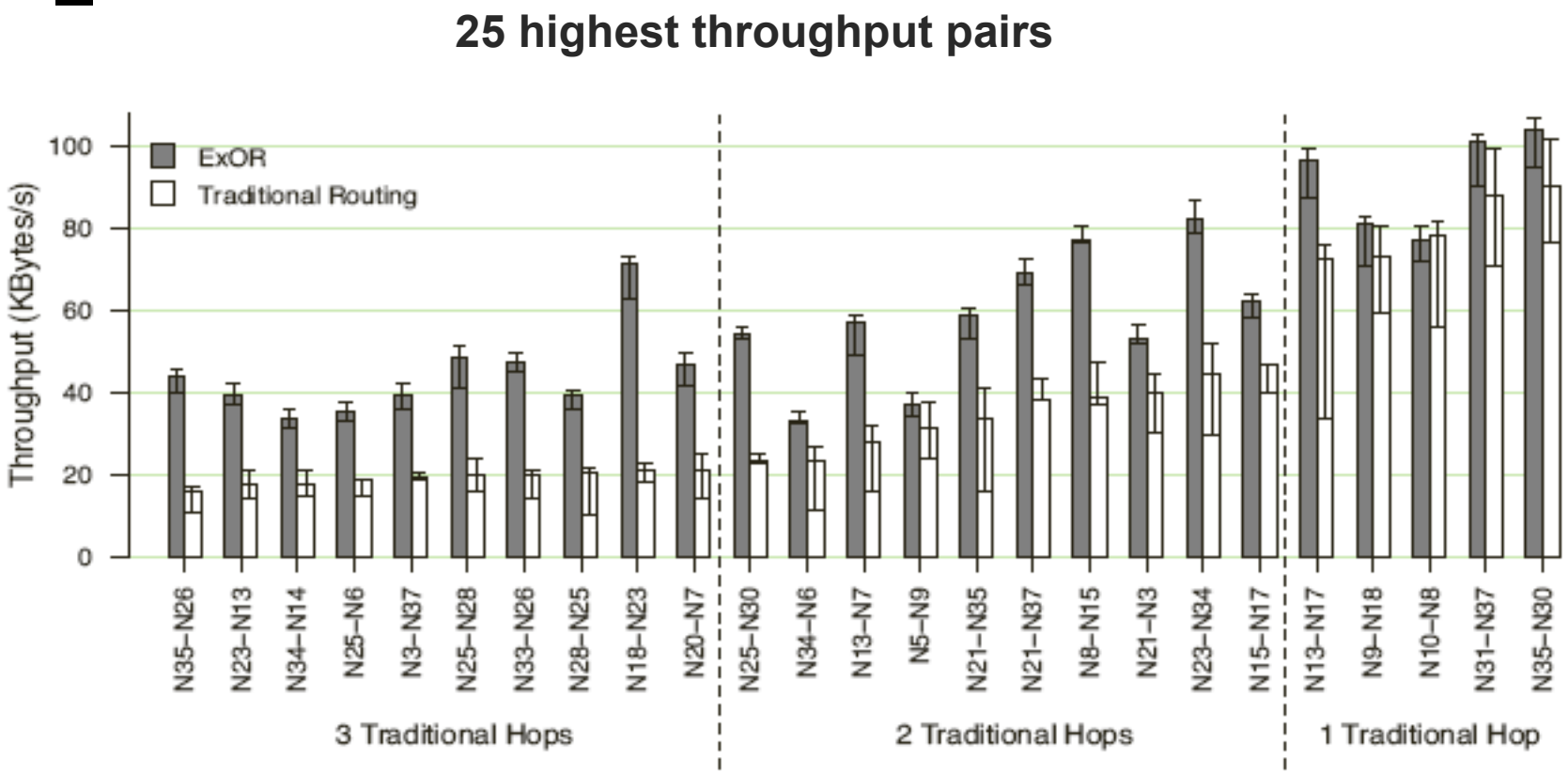


Results: Throughput



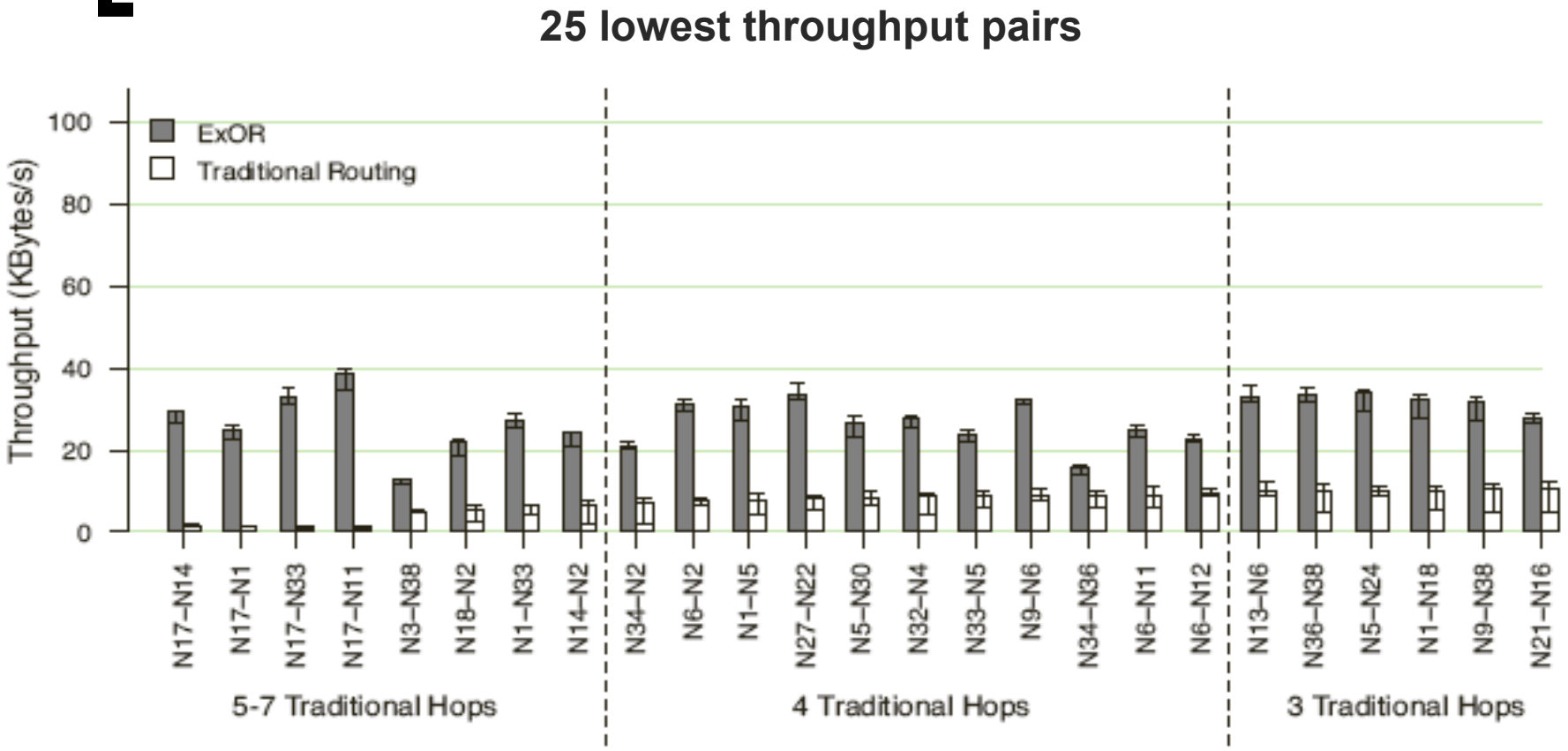
- ExOR – 33 Kbytes/sec.
- Traditional – 11 Kbytes/sec.
- ExOR achieves much higher throughput than traditional routing.

Results: Throughput Vs. Distance



- **ExOR performs much better than traditional routing even for shorter routes.**

Results: Throughput Vs. Distance (contd…)



- **ExOR's throughput increases as the route length increases.**

Results: Summary

- As route length increases, ExOR's performance increases
  - Likelihood of finding additional forwarding nodes increases
- ExOR is able to use long asymmetric links
  - Deliver many packets in forward direction but few packets in reverse direction
  - ExOR batch maps and data packets can follow different paths
  - Traditional Routing needs the same path for both the data packet and the ACK

Advantages

- Transmits each packet fewer times
- Increases total network capacity
- Increases individual connection throughput
  - Each packet is transmitted fewer times, so less interference for other users

Limitations

- Selection of potential forwarders can be tricky
  - As size of FL grows
    - Size of BM also grows
    - Size of ExOR header also grows

Conclusion

- Outperforms traditional routing by increasing network throughput considerably
- Can use long radio links with high loss rates
- Uses no more network capacity than traditional routing

Questions / Comments ?