Overview

• **Most wireless routing protocols abstract wireless links as unreliable wireline links**

• **Are wireless links the same as wireline links except that they are less reliable?**
Overview (Cont.)

• **Difference between wireless and wireline links**
  - Higher loss rate
  - Broadcast medium
  - Wireless interference
  - Highly dynamic and unpredictable
ExOR: Opportunistic Multi-Hop Routing for Wireless Networks

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Traditional Routing

• Committed to a specific route before forwarding

• Problems: don’t fully exploit path diversity
  - Unpredictable wireless medium
  - Intermittent connectivity
  - High mobility
  - Routing attacks
Motivating Scenario I

- Assume independent loss
- Tradition routing has to follow one pre-committed route
Motivating Scenario II

- Assumes loss rate increases gradually with distance
- Tradition routing has to make comprise between progress and loss rate
Opportunistic Routing (ExOR)

- Don’t commit to a route before data forwarding
- Exploit wireless broadcast
- The source broadcasts the packet and then chooses a receiver to forward only after learning the set of nodes which actually received the packet.
- Goal: Among the nodes who receive the packet, the node closest to the destination should forward.
Motivating Scenario I

- Assumes independent loss
- Tradition routing has to follow one pre-committed route
- ExOR can combine multiple weak links into one strong link
• Assumes loss rate increases gradually with distance
• Tradition routing has to make comprise between progress and loss rate
• ExOR can take advantages of transmissions that reach unexpectedly short or unexpectedly far.
Main Challenge

• How to select the node that is closest to the destination and received the packet to forward it with low overhead?
Issues to Address

• What we want?
• How often should ExOR run?
• Who should participate in the forwarding?
• When should each participant forward?
• What should each participant forward?
Issues to Address

• What we want: an effective protocol with low overhead

• How often should ExOR run?
  - Per packet is expensive
  - Use batches
Who should participate?

• A background process collects ETX information via periodic link-state flooding.

• The source chooses the participants (forwarder list) using ETX-like metric.
  - Only consider forward delivery rate
    • Why?
  - The source runs a simulation and selects only the nodes which transmit at least 10% of the total transmission in a batch.
When should each participant forward?

- Forwarders are prioritized by ETX-like metric to the destination
- The highest priority forwarder transmits when the batch ends
- The remaining forwarders transmit in prioritized order
- Question: How does each forwarder know it is its turn to transmit?
  - Assume other higher priority nodes send for five packet durations if not hearing anything from them
What should each participant forward?

- Packets it receives yet not received by higher priority forwarders

- Question: How does a node know the set of packets received by higher priority nodes?
  - Using batch map
Batch map

- Batch map indicates, for each packet in a batch, the highest-priority node known to have received a copy of that packet.

1st round Tx: 1, 2, 3, 4, 5, 6, 7, 8
Batch map: 13032012
Rx: 1,2,7,8  Tx: 1,7
Batch map: 13032012

2nd round Tx: 3,6
Batch map: 13032012

Forwarder list:
N3(dst), N2, N1, N0 (src)

Rx: 2,5,8  Tx: 5,8
Batch map: 03032002

Rx: 2,4  Tx: batch map only
Batch map: 03030000
Completion

• A node stops sending the remaining packets in the batch if its batch map indicates over 90% of this batch has been received by higher priority nodes.

• The remaining packets transferred with traditional routing.
Example

Forwarder list: N24(dst), N20, N18, N11, N8, N17, N13, N5(src)
ExOR with TCP

- ExOR creates lots of packet reordering
- ExOR increases end-to-end delay
- Solution: Split web proxy
Evaluation - Network Description

- Performed on Roofnet, an outdoor roof-top 802.11 networks
- 38 nodes distributed over six square kilometers
- 65 Node pairs
- 1.0MByte file transfer
- 1 Mbit/s 802.11 bit rate
- 1 KByte packets
Evaluation - Throughput

Median throughputs: 2X overall improvement
Evaluation - 25 Highest Throughput Pairs
Evaluation - 25 Lowest Throughput Pairs

The image shows a bar chart comparing throughput (KB/second) for different pairs of nodes with varying numbers of traditional hops: 5-7, 4, and 3. The x-axis lists node pairs such as N17-N14, N17-N33, etc. The y-axis represents throughput. The chart includes bars for ExOR and Traditional Routing.
Evaluation – Distance per Transmission

![Graph showing packet transmissions vs ETX progress from transmitter to receiver. The graph compares ExOR and Traditional methods.](image)
Evaluation – Batch Size
Comments?
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• Pros
  - Takes advantage of the probabilistic reception to increase the throughput
  - Does not require changes in the MAC layer
  - Can cope well with unreliable wireless medium
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• Pros
  - Takes advantage of the probabilistic reception to increase the throughput
  - Does not require changes in the MAC layer
  - Can cope well with unreliable wireless medium

• Cons
  - Cannot take advantage of multiple data rates
  - Forwarders take turns to transmit and do not leverage spectral reuse
  - Does not explicitly support multiple flows or TCP traffic
  - Batches increase delay
  - Hard to scale to a large network
  - Trade-off between spatial reuse and opportunistic gain
  - ETX based forwarder selection does not yield least cost path