Lecture 18:
Mesh Networking

CSE 222A: Computer Communication Networks
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Thanks: Sanjit Biswas, Lili Qiu
Lecture 18 Overview

- Wireless mesh networks
- ExOR
MIT Roofnet

- Dense 802.11-based mesh
- Goal is high-throughput and capacity
Multi-hop 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
Decide who forwards after reception

Goal: only closest receiver should forward

Challenge: agree efficiently and avoid duplicate transmissions
Example scenarios

- Traditional routing: \( \frac{1}{0.25} + 1 = 5 \text{ tx} \)
- ExOR: \( \frac{1}{(1 - (1 - 0.25)^4)} + 1 = 2.5 \) transmissions
- Assumes independent losses
Example scenarios

- Best traditional route over 50% hops: $3^{(1/0.5)} = 6$ tx
- Throughput $\approx \frac{1}{\text{# transmissions}}$
- ExOR exploits lucky long receptions: 4 transmissions
- Assumes probability falls off gradually with distance
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 the forwarding?
  - Too many participants cause large overhead
- When should each participant forward?
  - Avoid simultaneous transmissions
- What should each participant forward?
  - Avoid duplicate transmissions
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 to 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
ExOR batching

- Source estimates ETX between each node and the destination
- Source decides on a list of forwarders and prioritizes the list. Let the list be (dst, N4, N3, N2, N1)
- Node closest to the dst sends the overheard packet first
  - Other nodes listen, send remaining packets in turn
Which packets: Batch maps

- 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: 1, 2, 7, 8  Tx: batch map only
Batch map: 03030000
End Game

- 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.
Forwarder list: N24\textbf{(dst)}, N20, N18, N11, N8, N17, N13, N5\textbf{(src)}
Using ExOR with TCP

- Batching requires more packets than typical TCP window
Evaluation on Roofnet
Evaluation setup

- 65 Node pairs
- 1.0-MB file transfer
- 1 Mbit/s 802.11 bit rate
- 1-KB packets

<table>
<thead>
<tr>
<th>Traditional Routing</th>
<th>ExOR</th>
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<tbody>
<tr>
<td>802.11 unicast with link-level retransmissions</td>
<td>802.11 broadcasts</td>
</tr>
<tr>
<td>Hop-by-hop batching</td>
<td>100 packet batch size</td>
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<tr>
<td>UDP, sending as MAC allows</td>
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Throughput improves

- Median throughputs: 240 Kbits/sec for ExOR, 121 Kbits/sec for Traditional
25 Highest throughput pairs

<table>
<thead>
<tr>
<th>Node Pair</th>
<th>Throughput (Kbits/sec)</th>
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<tbody>
<tr>
<td>0</td>
<td>200</td>
</tr>
<tr>
<td>20</td>
<td>400</td>
</tr>
<tr>
<td>1000</td>
<td>600</td>
</tr>
<tr>
<td>2000</td>
<td>800</td>
</tr>
<tr>
<td>3000</td>
<td>1000</td>
</tr>
</tbody>
</table>

ExOR Traditional Routing

1 Traditional Hop

1.14x

1 Traditional Hop

1.7x

2 Traditional Hops

2.3x

3 Traditional Hops

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25 Lowest throughput pairs

Longer Routes

4 Traditional Hops

3.3x

Throughput (Kbits/sec)

Node Pair

ExOR

Traditional Routing

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ExOR uses links in parallel

Traditional Routing
3 forwarders
4 links

ExOR
7 forwarders
18 links
For Next Class...

- Review for quiz Thursday