XORs in the Air: Practical Wireless Network Coding

S. Katti, H. Rahul, W. Hu, D. Katabi, M. Medard, J. Crowcroft

MIT & University of Cambridge
Can we use 3 transmissions to send traffic?
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Network Coding

• Three types
  - Store and forward
  - Source coding (FEC, compression)
  - Network coding

• Goal: increase the amount of information that is transported
Networking coding is beneficial for multicast in wireline networks. Networking coding has little benefit for unicast in wireline networks.
Coding Gain

- Coding gain = $\frac{4}{3}$
Coding Gain: more examples

Without opportunistic listening, no coding gain.
Coding Gain: more examples

With opportunistic listening, coding gain = 4/3.
Throughput Improvement

• UDP throughput improvement ~ a factor 2
  > 4/3 coding gain
Coding Gain: more examples

With opportunistic listening, coding gain = \( \frac{2N}{1+N} \) \(\rightarrow\) 2.

With opportunistic listening, coding gain + MAC gain \(\rightarrow\) \(\infty\)
COPE Overview

• Layer between IP and MAC

• Techniques
  - Opportunistic listening (promiscuous mode)
  - Opportunistic coding
  - Learning neighbor state
Opportunistic Coding

**B's queue**

<table>
<thead>
<tr>
<th>Coding</th>
<th>Is it good?</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1+P2</td>
<td>Bad (only C can decode)</td>
</tr>
<tr>
<td>P1+P3</td>
<td>Better coding (Both A and C can decode)</td>
</tr>
<tr>
<td>P1+P3+P4</td>
<td>Best coding (A, C, D can decode)</td>
</tr>
</tbody>
</table>

**Next hop**

<table>
<thead>
<tr>
<th>B's queue</th>
<th>Next hop</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>A</td>
</tr>
<tr>
<td>P2</td>
<td>C</td>
</tr>
<tr>
<td>P3</td>
<td>C</td>
</tr>
<tr>
<td>P4</td>
<td>D</td>
</tr>
</tbody>
</table>
Packet Coding Algorithm

- **When to send?**
  - Option 1: delay packets till enough packets to code with
  - Option 2: never delaying packets -- when there's a transmission opportunity, send packet right away

- **Which packets to use for XOR?**
  - Prefer XOR-ing packets of similar lengths
  - Never code together packets headed to the same next hop
  - Limit packet re-ordering
  - XORing a packet as long as all its nexthops can decode it with a high enough probability
Packet Decoding

• **Where to decode?**
  - Decode at each intermediate hop

• **How to decode?**
  - Upon receiving a packet encoded with $n$ native packets
    • find $n-1$ native packets from its queue
    • XOR these $n-1$ native packets with the received packet to extract the new packet
Prevent Packet Reordering

- Packet reordering due to async acks degrade TCP performance

- Ordering agent
  - Deliver in-sequence packets immediately
  - Order the packets until the gap in seq. no is filled or timer expires
Summary of Results

• Improve UDP throughput by a factor of 3-4

• Improve TCP by
  - w/o hidden terminal: up to 38% improvement
  - w/ hidden terminal and high loss: little improvement

• Improvement is largest when uplink to downlink has similar traffic
Lessons

• **Wireless link ≠ lossy wireline lines**
  - Both COPE and opportunistic routing discard the point-to-point wireless link abstraction
  - Leverage broadcast nature of wireless medium to its advantage

• **Network coding has a great potential in wireless network**