Practical Network Coding for Wireless Mesh Networks

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The problem

• Wireless networks are highly resource constrained
  - Bandwidth is the most expensive
  - Power is sometimes an issue too

→ Serious problems for mesh networks

• How to optimise throughput?
  - Can we send more information?
  - Can we reduce bandwidth requirement?
  → Do both at the same time?
An information exchange scenario

- Multi-hop unicast requires 4 transmissions
- Can we do better?
Network coding &

- Nodes in network operate on data
  - Output is result of some coding over input
  - C.f. Routing – (replicating and) forwarding

- Network information flow problems
  - Set in multicast in point-to-point networks
  - Originally proposed by Ahlswede et al

- Theorem: Cannot achieve multicast capacity with routing alone
  - Need network coding
Network coding - recent results

• Can extend routing (i.e., forwarding) to optimise throughput
  □ Run min-cost flow optimisations

• Linear codes sufficient

• Decentralised approach to min-cost multicast

• Promising for wireless networks!
  □ Exploit inherent multicast medium
Network coding - beyond theory

- **Application to content distribution**
  - MSR Avalanche

- **Information dissemination in DTN**
  - WDTN’05 paper

- **Unfortunately**
  - Not much otherwise
  - Existing work simulation based
Network coding - practical issues

- Unicast vs Multicast
- Unknown vs known flow characteristics
- Unpredictability in wireless networks

Typical wireless mesh networks do not comply with assumptions in prior work

- Encoding/Decoding complexity
- Delay penalty due to encoding?
Can Network Coding help - An idea

\[ \text{XOR} + \text{Alice’s packet} = \text{Bob’s packet} \]

3 transmissions instead of 4
⇒ Saves bandwidth & power
⇒ 33% throughput increase
Idea cont.

• Applies to duplex flows
• Encodes two packets at a time
• Can extend to longer chains

• Idea outlined in MSR-TR-2004-78
  □ No detailed design or implementation
Our approach - COPE

- Considers multiple unicast flows
  - Generalises the duplex flow scenario
- Opportunistic coding using local info
  - Overhear packets to increase coding gain
  - Online, distributed and deployable
- Emulation and testbed results
  - First real-world implementation

Katti et al. *The importance of being opportunistic: Practical network coding for wireless environments*. Allerton, 2005
COPE: Opportunistic Coding Protocol

Alice ➔ Bob
Bob ➔ Charlie
Charlie ➔ Alice

Alice's packet
Bob's packet
Charlie's packet

XOR = XOR

Alice ➔ Bob
Bob ➔ Charlie
Charlie ➔ Alice

Alice's packet
Bob's packet
Charlie's packet

Bob

XOR XOR = Relay
How it works....

- Back to Alice/Bob scenario
How it works...(Cont.)

• Relay - Encoding
  □ Checks packets in queue
  □ Combines packets traversing the same three hops in opposite directions
  □ Metadata in a header between MAC and IP
  □ Broadcast encoded packets

• Alice/Bob - Decoding
  □ Keep copies of sent packets
  □ Detect the extra header (decoding info)
  □ Retrieve the right packet to decode

• Distributed and local action only!
Generalise to COPE

• Nodes snoop on the medium
  □ Reception reports to neighbours

• When encoding
  □ Identify what packets neighbours have
    • Reception reports and guesses
  □ Encode as many packets as possible
    • Provided intended recipients can decode them

• Still distributed and local action only!
The importance of being opportunistic

• Opportunistic coding
  - Only encode if packets in queue
  - No delay penalty
  - Insensitive to flow characteristics

• Opportunistic listening
  - Helps create more coding opportunities
'Pseudo-broadcast'

- COPE gain is from broadcast medium
- But 802.11 broadcast doesn’t work!
  - No reliability scheme to mask collision loss
  - Send packets at lowest bit rate
  - May actually reduce throughput!
- Pseudo-broadcast
  - Send encoded packets as if unicast
  - Other neighbours overhear
  - Benefit as a unicast packet
Implementation

• A shim between MAC and IP
  □ Agnostic to protocols above/below

• Emulations
  □ General COPE
  □ Emsim (part of Emstar) environment

• Testbed
  □ Based on the Alice/Bob scenario
  □ Extension to Roofnet code (in Click)
Emulation Scenario

• 100 nodes in 800m x 800m
  □ Consider range ~50m
• Random senders/receivers
  □ Senders always backlogged
  □ Bit rate at 11 Mb/s
• Geographic routing
• Metric: end-to-end data traffic throughput over all flows
Emulation performance

Throughput (KB/s)

Coding always outperforms no-coding
Testbed setup

• Indoor PCs with 802.11b cards
  □ Intersil Prism 2.5 802.11b chipset
  □ Connected to omni-directional antenna
  □ RTS/CTS disabled
  □ 802.11 ad hoc mode

• Randomly chosen 3 nodes from testbed
  □ Static routes
  □ End nodes send UDP traffic to each other
Testbed results

Ratio of Throughput with Coding to No-Coding

Encoding almost doubles the throughput
MAC is fair $\rightarrow$ 1/3 BW for each node

- Without coding, relay needs twice as much bandwidth as Alice or Bob
- With coding, all nodes need equal bandwidth
Summary

• Opportunistic approach allows practical integration of network coding into current stack

• Throughput can double in practice
  - Cross-layer effects
  - Congestion plays in our favour

• First implementation of network coding in a wireless environment
  - Many lessons learnt
Future work

• Interaction with TCP
  □ TCP traffic is naturally two-way
  □ A reliability shim between MAC and COPE
  □ Running actual applications

• Occasional mobility?

• Full implementation of COPE

• Large-scale experiments
Thanks for your attention!

Questions?