Practical Network Coding for Wireless Mesh Networks

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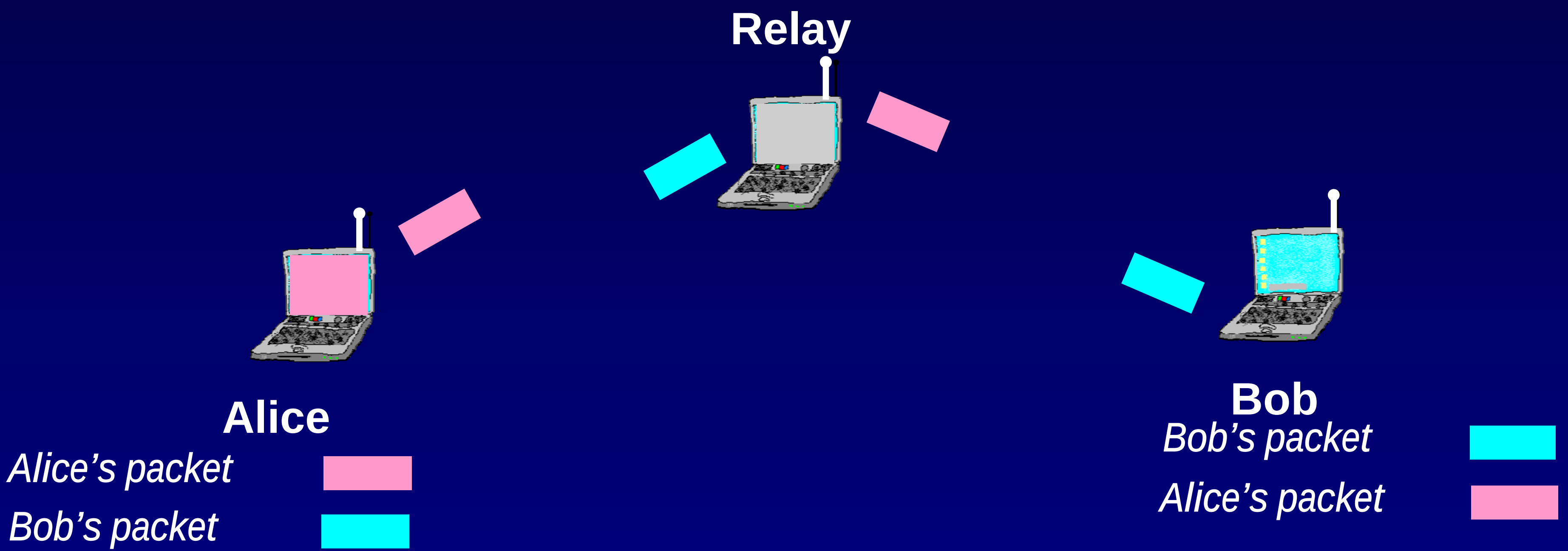
The problem

- 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

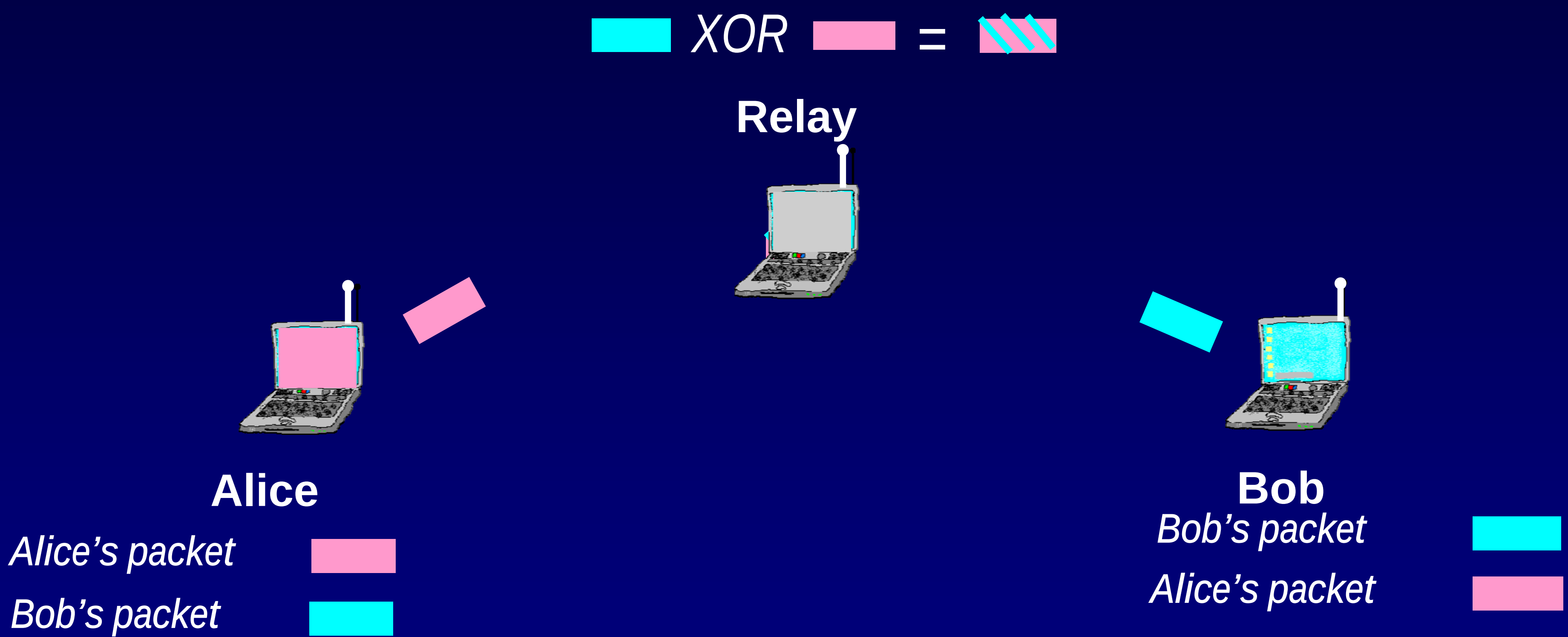
Network coding – practical issues

- 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



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

fg: 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

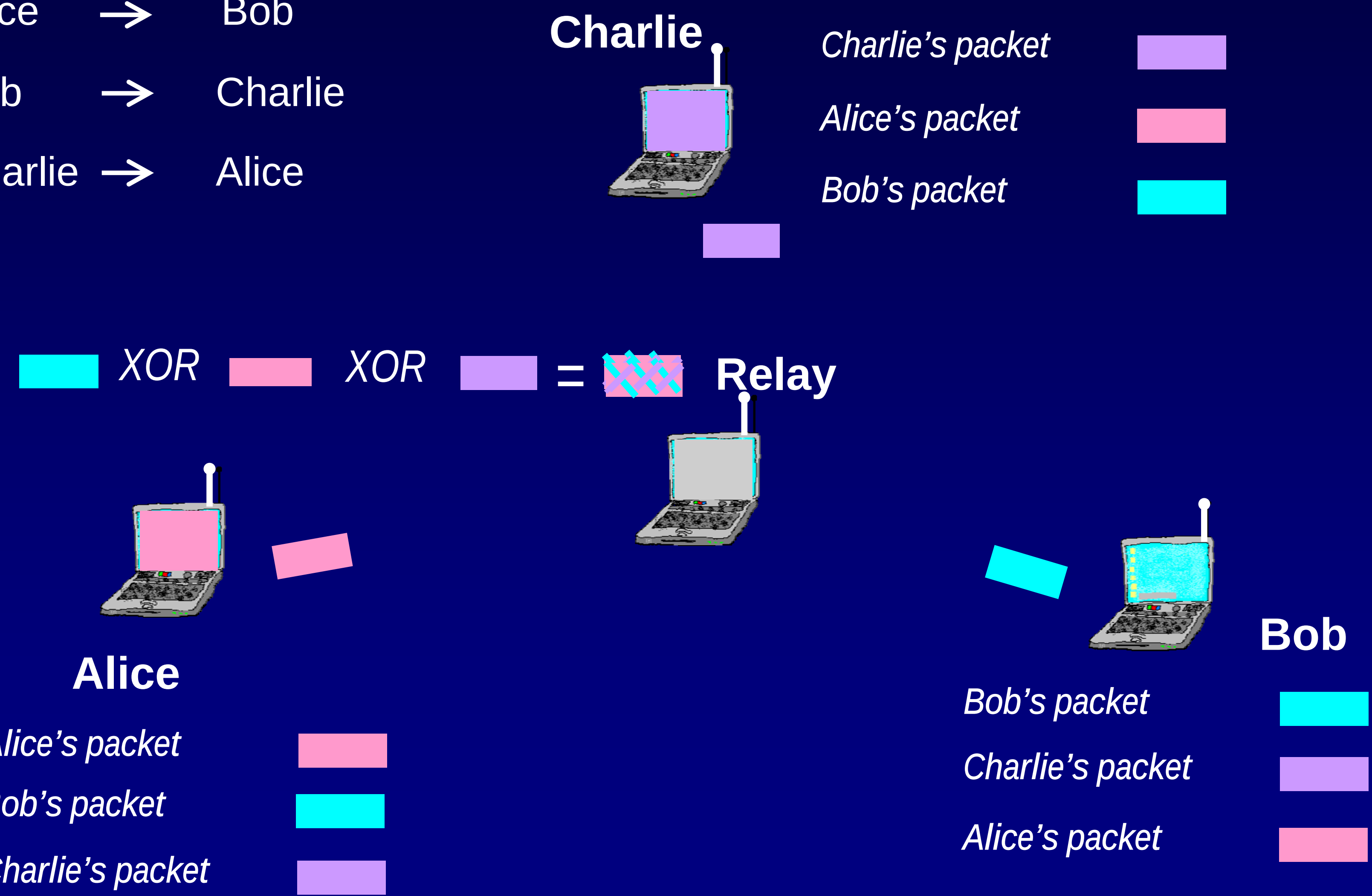
Katti et al. *The importance of being opportunistic: Practical network coding for wireless environments.* Allerton, 2005

COPE: Opportunistic Coding Protocol

Alice → Bob

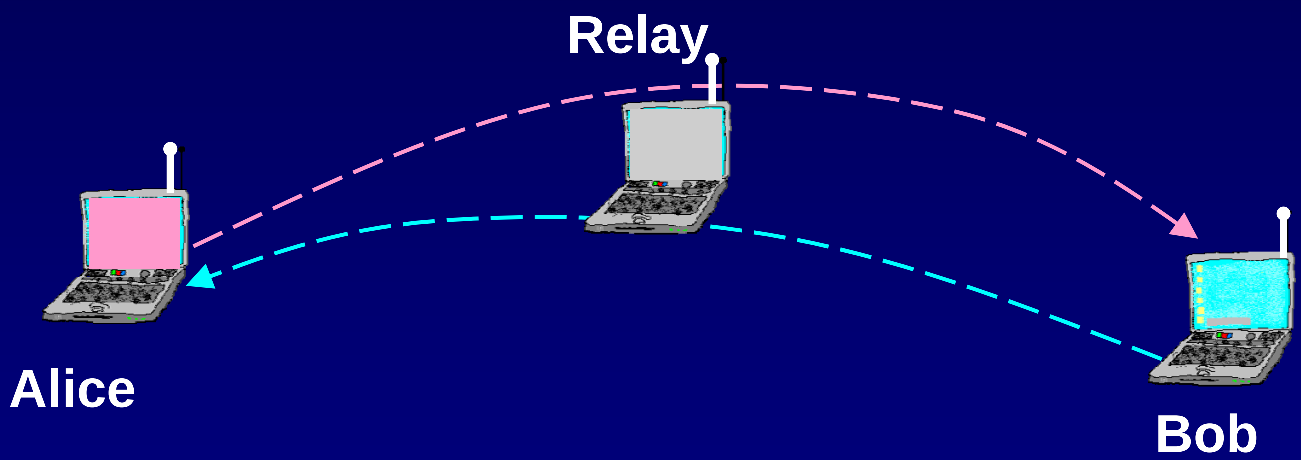
Bob → Charlie

Charlie → Alice



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

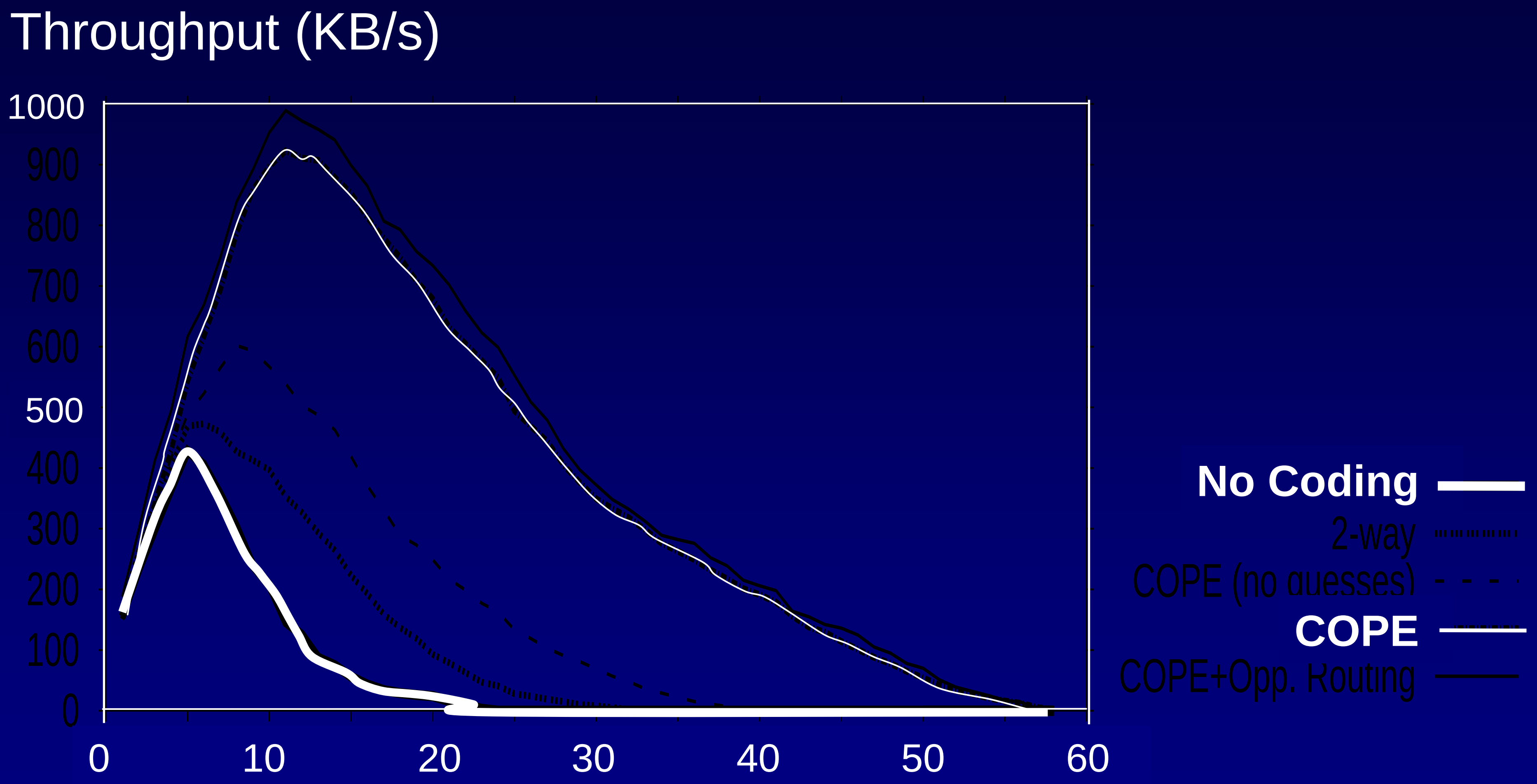
Implementation

- 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

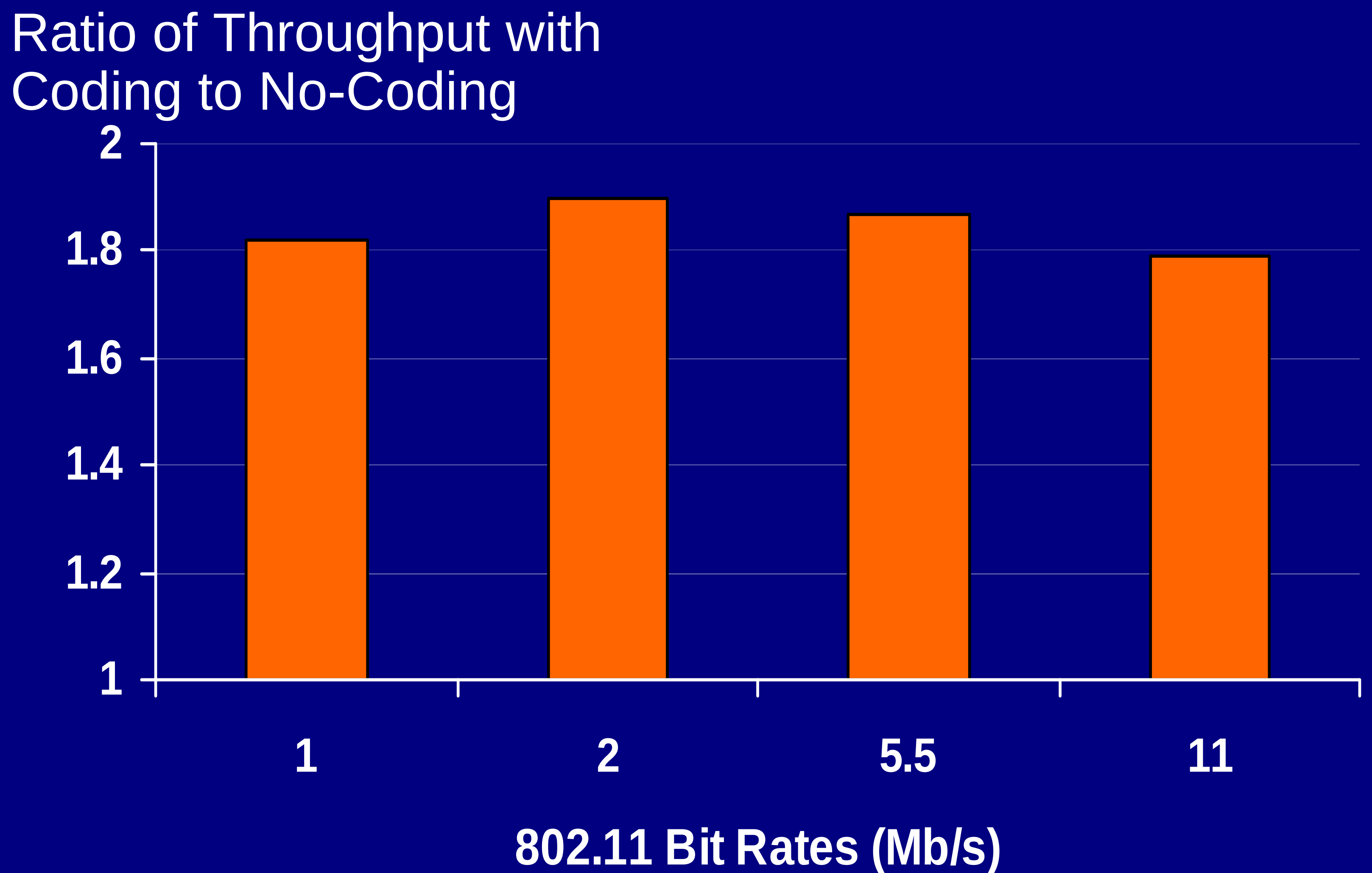


Coding always outperforms no-coding

Testbed setup

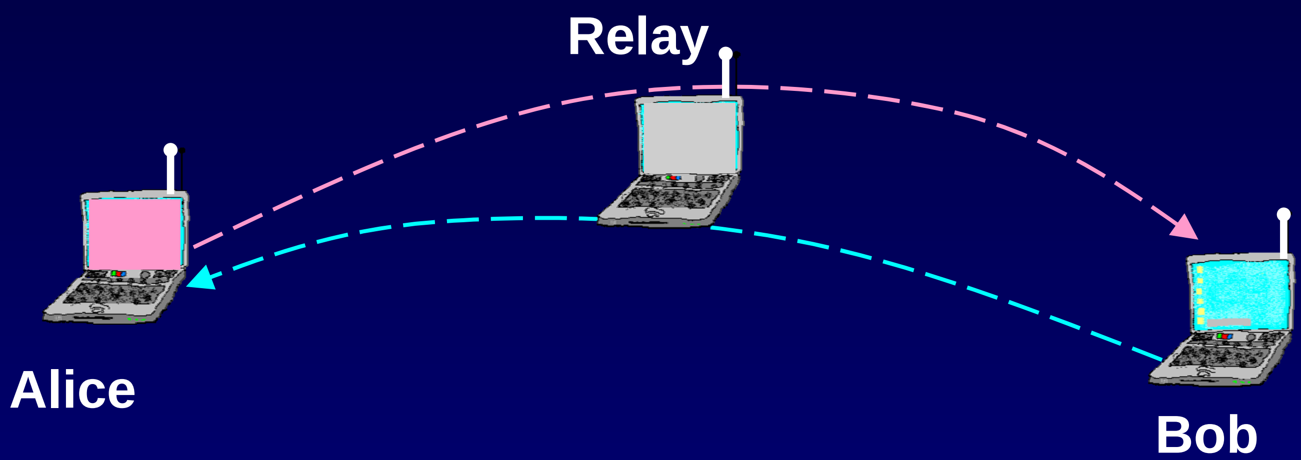
- Indoor PCs with 802.11b cards
  - Intersil Prism 2.5 802.11b chipset
  - Connected to omni-directional antenna
  - RTS/CTS disabled
  - 802.11 ad hoc mode
- Randomly chosen 3 nodes from testbed
  - Static routes
  - End nodes send UDP traffic to each other

Testbed results



Encoding almost doubles the throughput

Why more than 33%?



MAC is fair → 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?