XORs in the Air: Practical Wireless Network Coding

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Talk Outline

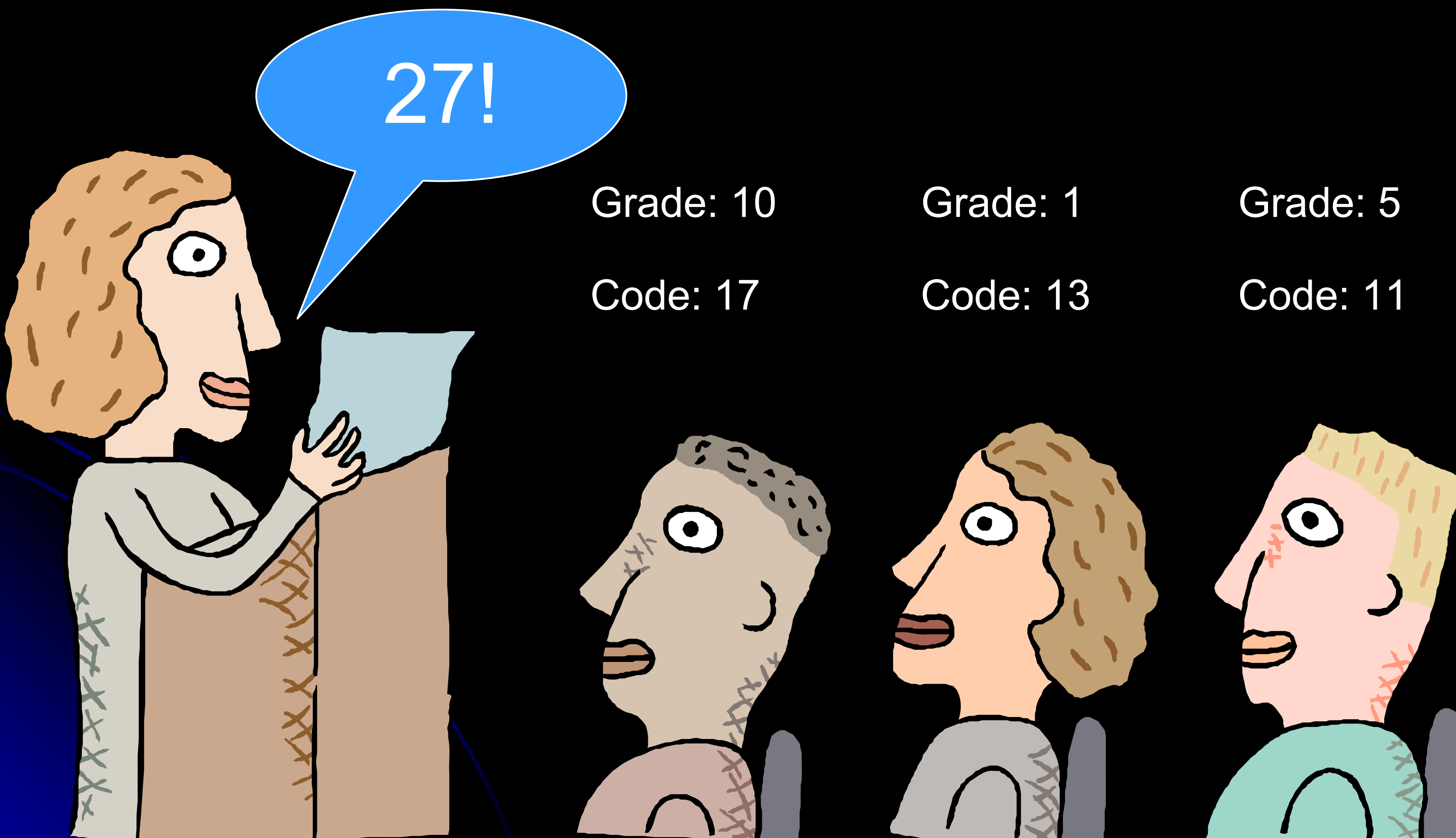
- Theory
  - Network Coding Intro
  - Theoretical model & bounds
  - Emergent properties
- Practice – COPE architecture
  - COPE specification
  - Results \ Simulation analysis
  - Applications
- What's next?

Network Coding

- Use **receiver-context** to share single transmission between several receivers
  - Transmission decoded based on context
  - Assumes broadcast\multicast
- Context can be anything
  - Personalized key
  - Previous transmissions
    - Standard network coding

Network Coding - concept

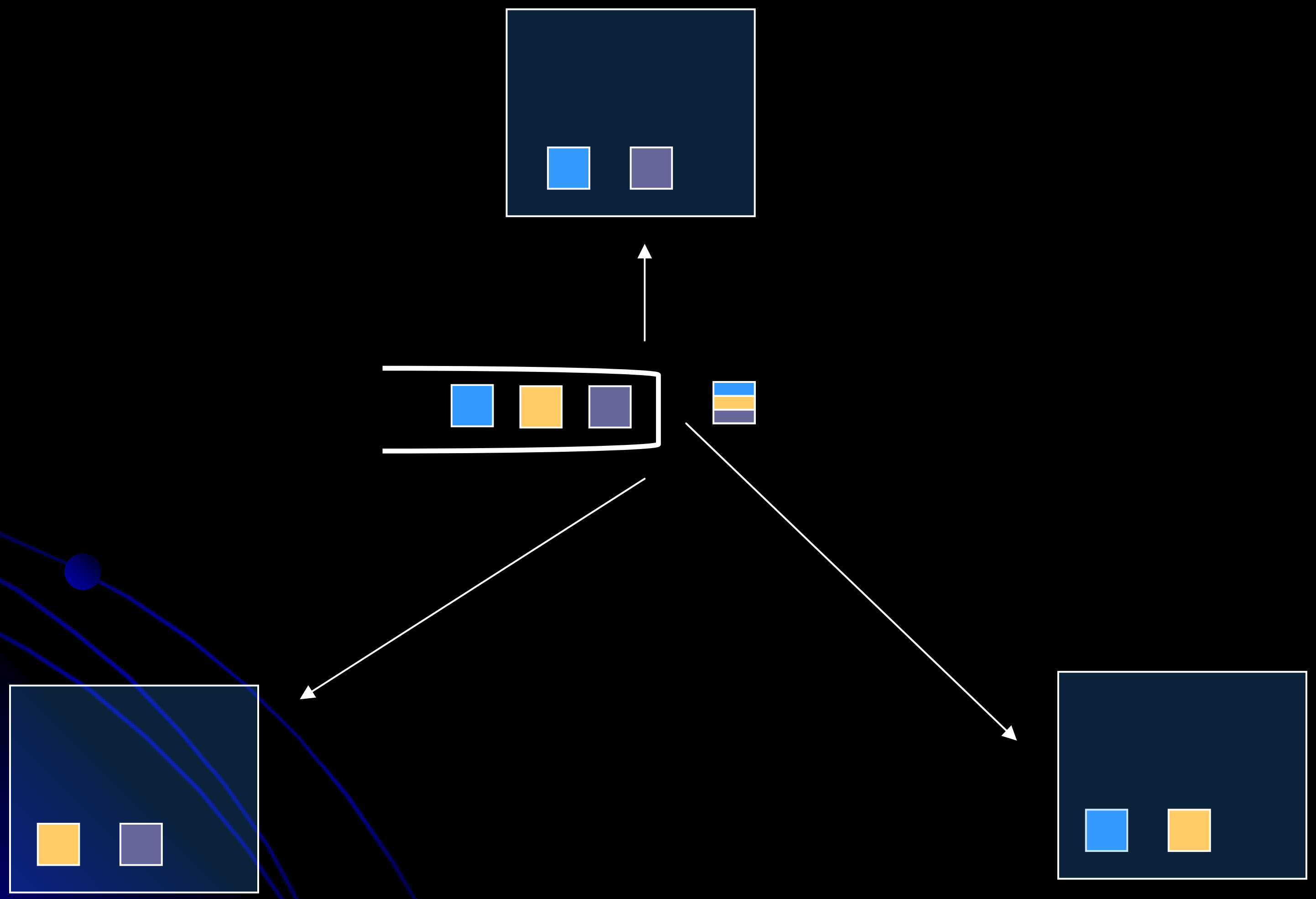
Based on the Chinese
Remainder Theorem



Network Coding

- COPE coding at relay node
  - p_i = next packet to send to R_i (receiver i)
  - Assume: for all i, R_i has all packets p_j, $j \neq i$
  - Transmit $p = p_1 \oplus p_2 \oplus \ldots \oplus p_n$
- Decode
  - XOR received packet with all packets p_j, $j \neq i$
  - Only decode when annotation indicates this is possible

Network Coding



Coding Opportunities

- Nodes can share a “sender transmission slot” only when they know of eachothers packets

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Opportunistic listening (promiscuous mode) improves performance

Emergent Properties

- Coding + MAC gain

Coding Opportunities

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Queue at relay-node drains faster

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Less packet drops

Lower network congestion

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Increased Throughput

Emergent Properties

- Throughput vs. Fairness
  - In standard systems, increased throughput can come at the expense of fairness
    - E.g. transmit always to user with strongest signal
  - With COPE, throughput & fairness go hand-in-hand

Fair division of resource (time)

More coding opportunities

Higher throughput

Competitive ratio bounds

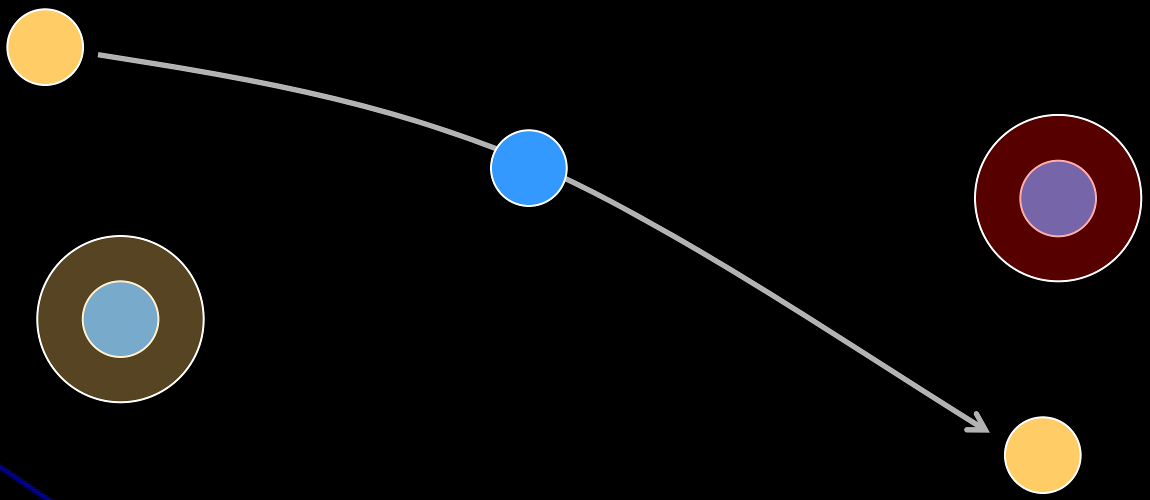
	Coding	Coding + MAC
Infinite Chain	2	2
Infinite Star	2	∞

COPE Specification

- Packets are never delayed
  - Coding is done only when possible
- Packet-length sensitive
  - XOR first with similar-length packets
- Maintain list of received packets for each neighboring node
  - Reception reports
  - Topology-based guesses

} **List population tools**

Topology-based guessing



Topology-based guessing

- For each packet, P_i^j is the chance that node i has heard packet j
  - $P_i^i = 0$
- Chance that XORed packet can be decoded by user i is $Q_i = \Pi_{j \neq i} P_i^j$
- Packet p_i will be XORed iff the resulting packet p will maintain

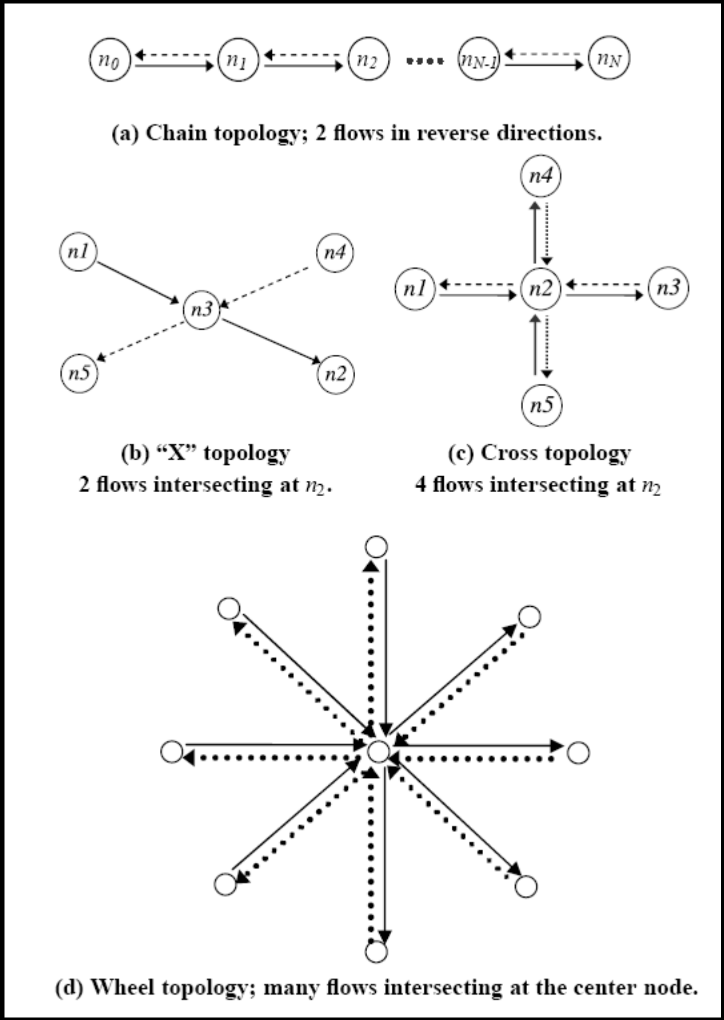
  For all encoded p_j, Q_j > thresh
- Random ordering of packet XOR attempts

COPE Specification

- Coded packets transmitted using *Pseudo-Broadcast*
  - Use 802.11 Unicast protocol
    - Supports reliability and backoff
    - Sent to one of the receivers
  - Multicast information placed after link header
    - Additional next-hops
    - Asynchronous ACK from these nodes
- TCP reordering agent

Simulations

- Simple Topologies
  - Test theoretical bounds
- Ad Hoc networks
- Mesh access networks
- Testbed specs
  - 20-node wireless network
  - 1-6 hops-per-path
  - 802.11a, 6Mbps



Results Analysis: Simple Top.

- Conform to theoretical bounds
  - 5-8% load overhead by XOR headers
  - For TCP flows, mainly coding gain
    - TCP has its own congestion control mechanism

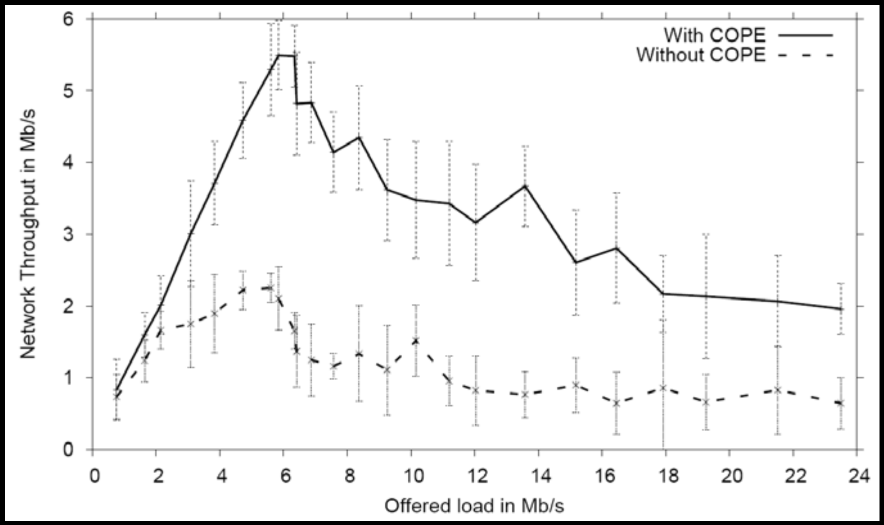
Results Analysis: Ad-Hoc

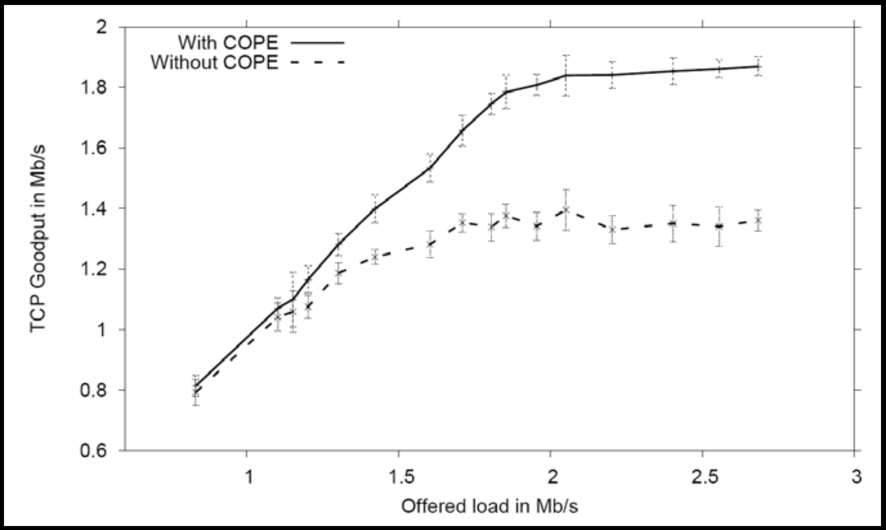
- TCP
  - A relay node suffers by definition from the hidden terminals problem
  - This eliminate practically all possible coding gains (2-3%), due to repetitive TCP backoff
- TCP + no hidden terminals
  - Simulated using a virtual connectivity graph
  - 38% peak gain over uncoded traffic

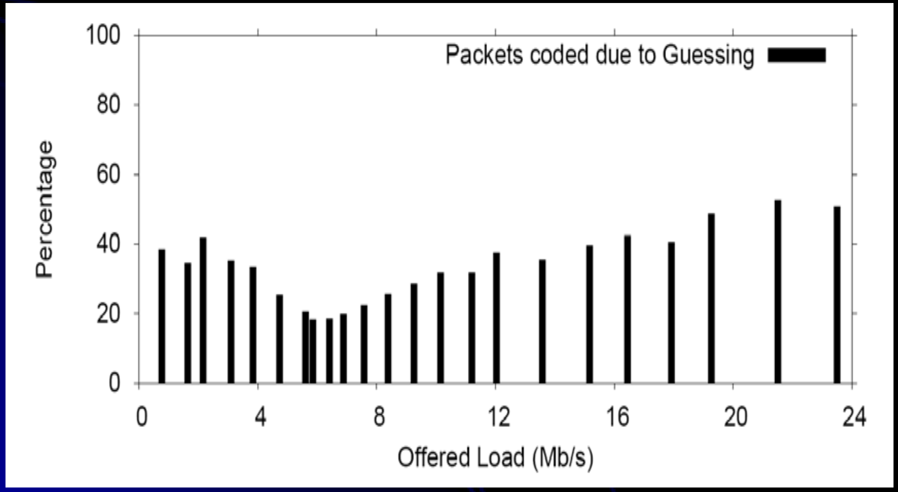
Results Analysis: Ad-Hoc

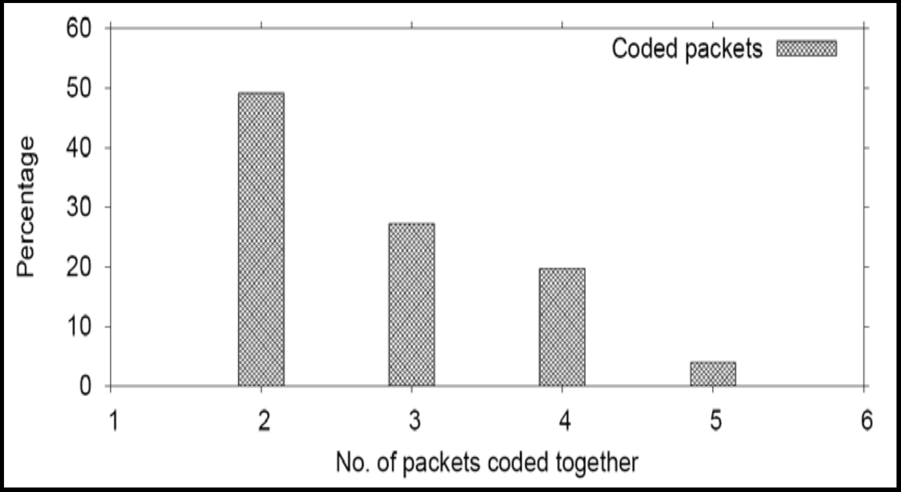
- UDP
  - Considerable throughput increase: 3-4x
  - “Guesses” make up 20-40% of coding decisions
  - At peak, an average of 3 packets are being coded together

Results Analysis: Ad-Hoc



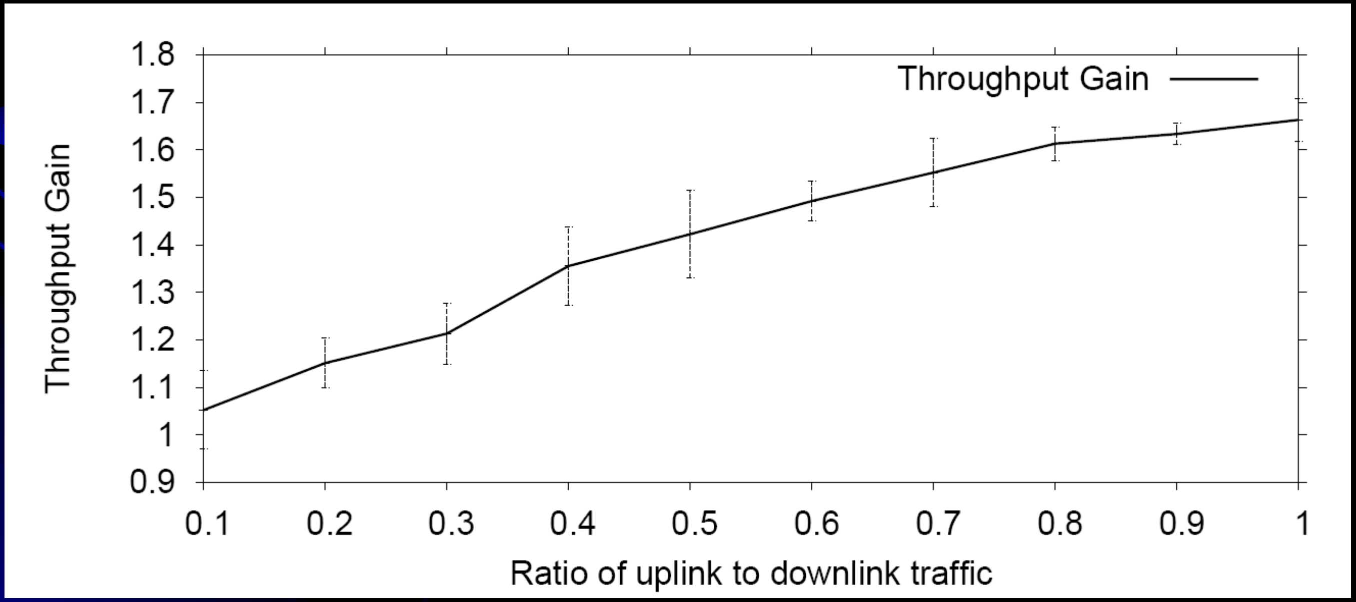






Results Analysis: Mesh Access

- A set of wireless nodes, connecting to the internet via gateway node(s).
- Throughput gain increases as the ratio of upload-to-download traffic gets closer to 1.



What's Next?

- Packet selection: COPE tries to combine flows in random order
  - What is the optimal combination?
  - Better combination schemes?
- Header cost evaluation
  - Header grows with number of combined packets
- Power considerations

Questions?