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GZ06 Adaptive and Mobile Systems
Dr. Cecilia Mascolo

XORs in The Air:

Practical Wireless Network Coding

Sachin Katti, Hariharan Rahul, Wenjun Hu, Dina Katabi, Muriel Medard and Jon Crowcroft

[thanks to the authors for making me use their slides]

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A bit about me…

- Senior Lecturer and EPSRC Advanced Research Fellow
- Research Interests
  - Opportunistic networking
  - Mobile systems
  - Mobility models
  - Sensor systems

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Lectures Overview

- Today: XORs
- Friday: ZebraNet
- Monday: Cartel
- Monday: Publish/Subscribe
- Tuesday: Sensor Programming Abstractions
- Wednesday: Mobile Bazaar
- Thursday: Reality Mining

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Problem

Increasing the throughput of dense wireless mesh networks

- Applications
  - City-wide wireless mesh
  - All-wireless office
  - Home multimedia wireless networks

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- Wireless networks are ubiquitous
- But, wireless still struggles with low throughput

Focus on WiFi, but applies to any system with omni-directional antennae

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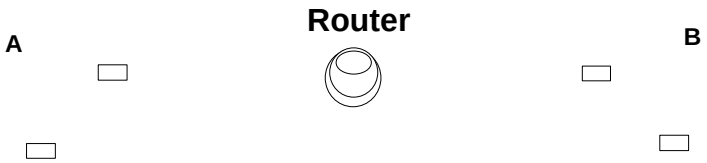
Current Approach

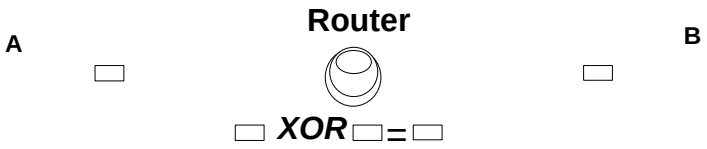
A **Router** **B**

Current Approach

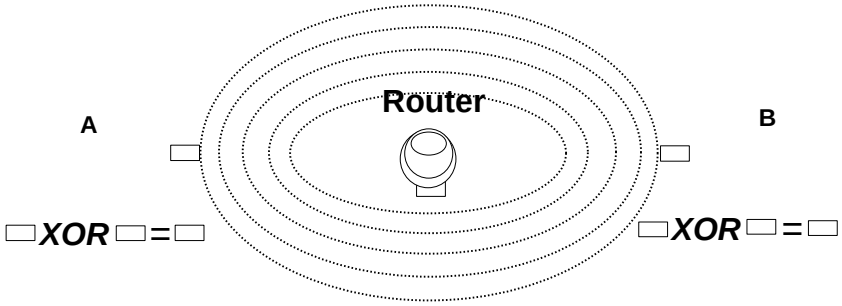


- Requires 4 transmissions
- Can we do it in fewer transmissions?

XOR

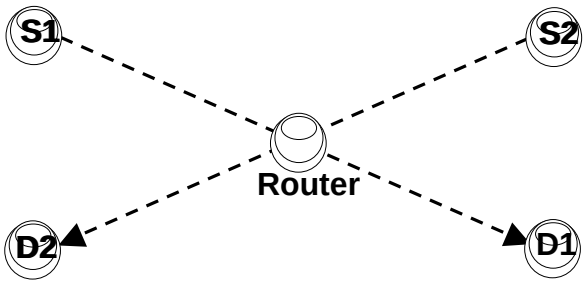


XOR



- Requires 3 transmissions instead of 4
- Increased throughput

Beyond duplex flows



Two flows that intersect at a router

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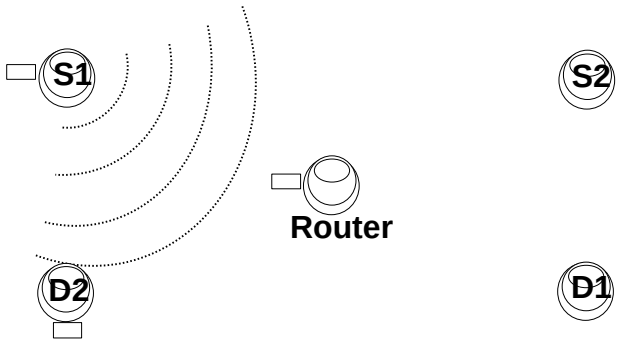
Beyond duplex flows



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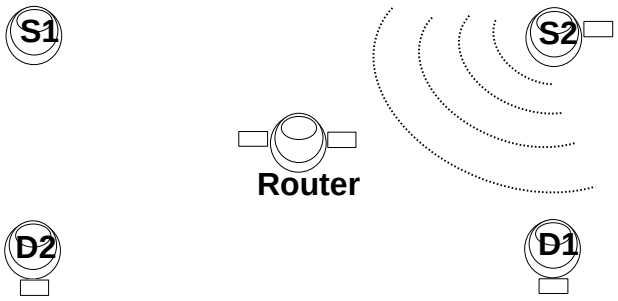
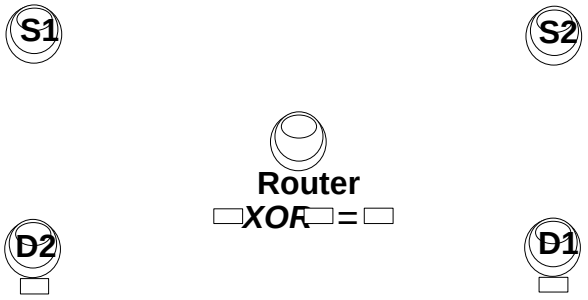
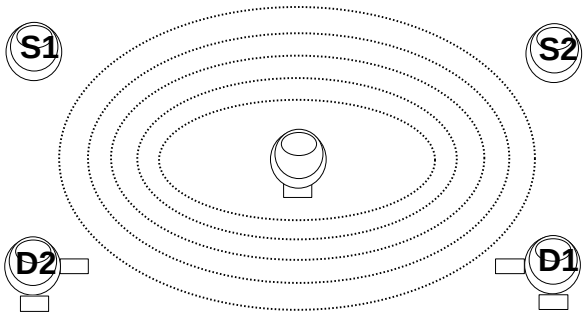
Beyond duplex flows



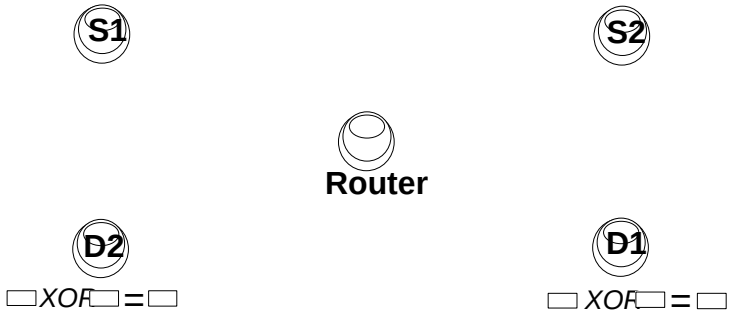
Beyond duplex flows



Beyond duplex flows



Beyond duplex flows



- Again 3 transmissions instead of 4

COPE Bridges Theory With Practice

- 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

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Design

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COPE - Snooping

- Exploit wireless broadcast
- Every node snoops on all packets
- A node stores all heard packets for a limited time

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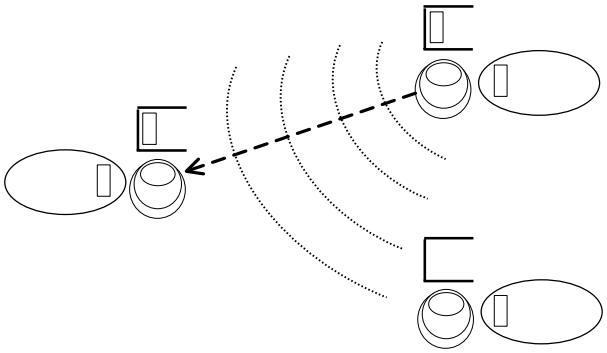

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COPE - Snooping

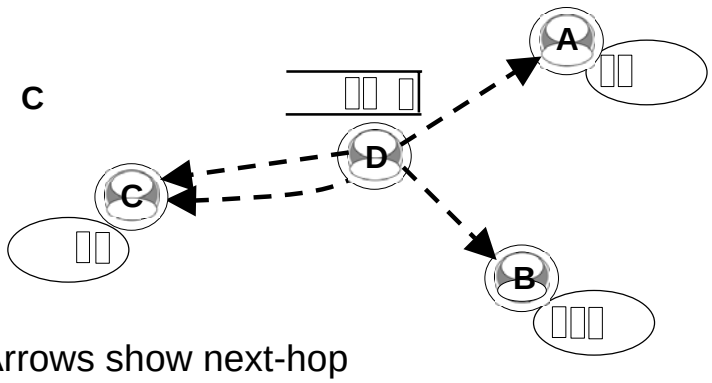
- Exploit wireless broadcast
- Every node snoops on all packets
- A node stores all heard packets for a limited time

- Node sends Reception Reports to tell its neighbors what packets it heard
  - Reports are piggybacked on packets
  - If no packets to send, periodically send reports

COPE - Coding

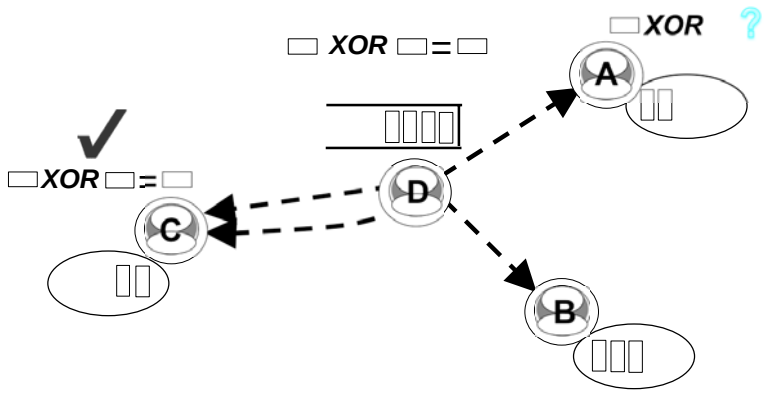
- To send packet *p* to neighbor A, XOR *p* with packets already known to A
  - Thus, A can decode
- But how can multiple neighbors benefit from a single transmission?

Efficient Coding



Arrows show next-hop

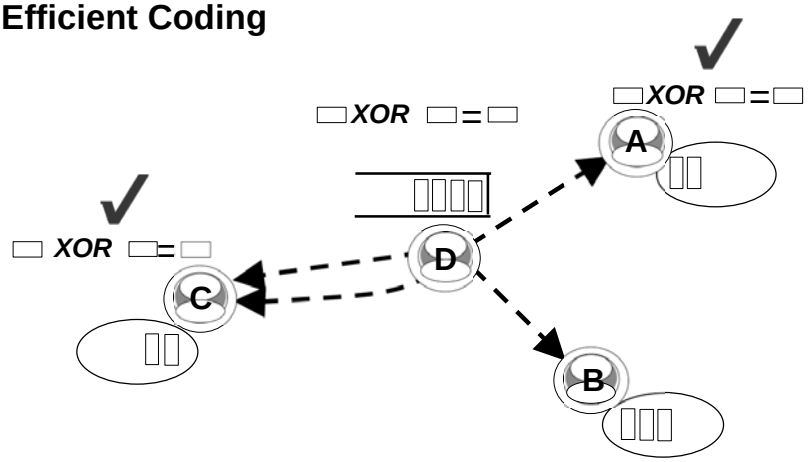
Efficient Coding



Bad Coding

Only one neighbor benefits from one transmission

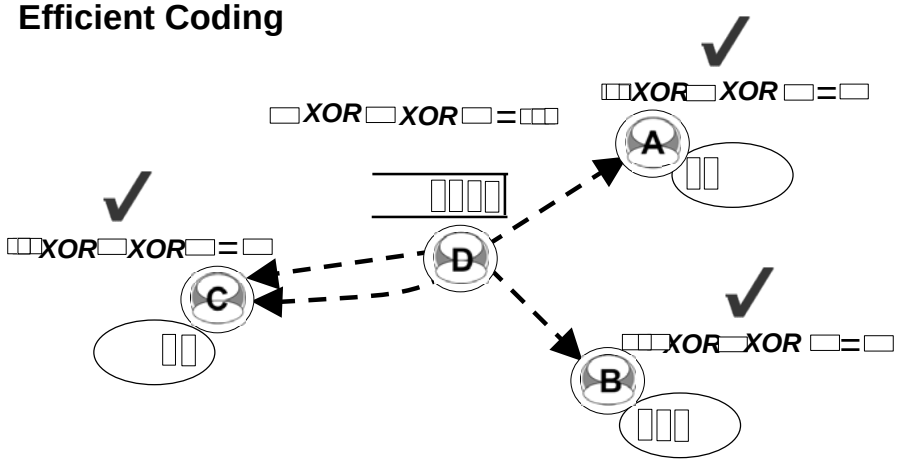
Efficient Coding



Good Coding

Two neighbors benefit from one transmission!

Efficient Coding



Best Coding

Three neighbors benefit from one transmission!

Coding Rule

XOR n packets together iff the next hop of each packet already has the other ***n-1*** packets apart from the one he wants

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But how does a node know what packets a neighbor has?

- Reception reports
- But reception reports may be late or get lost
- Make informed guesses based on delivery rate between the two nodes
- If error occurs, recover by retransmission

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Design Choices

- Sit transparently between IP and MAC
- Opportunistic → Code packets if possible, if not forward without coding
- Do not delay packets

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Performance

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COPE Implementation

- Linux
- Click + Roofnet
- Userspace module

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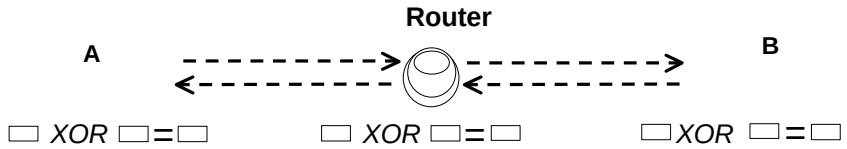
Performance



- Requires 3 transmissions instead of 4
  - Expected throughput gain of 4/3 = 1.33

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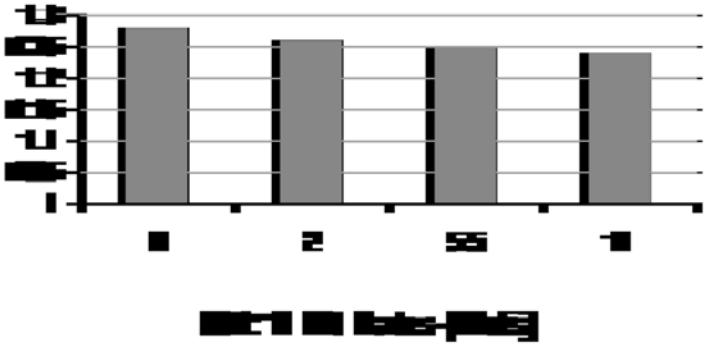
Performance: TCP



Throughput increase in line with analysis

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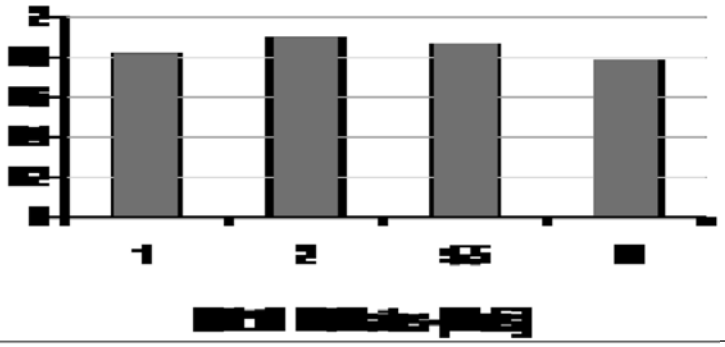
Performance: UDP



COPE almost doubles the throughput

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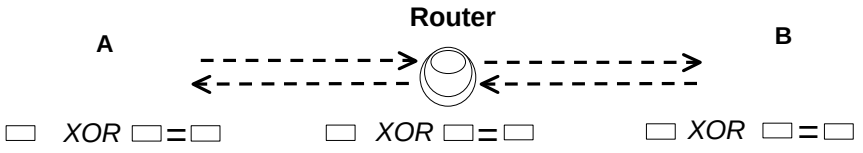
Why More Than 1.33?



802.11 is fair → 1/3 capacity for each node

- With COPE, all nodes need equal rate

COPE alleviates the mismatch between MAC's capacity allocation and the congestion at a node

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Large-Scale Experiments

- Wireless testbed
  - 20 nodes
  - 2 floors
- Experiments
  - Pick sender and receiver randomly
  - Transfer size based on actual measurements
  - Flow arrivals are Poisson

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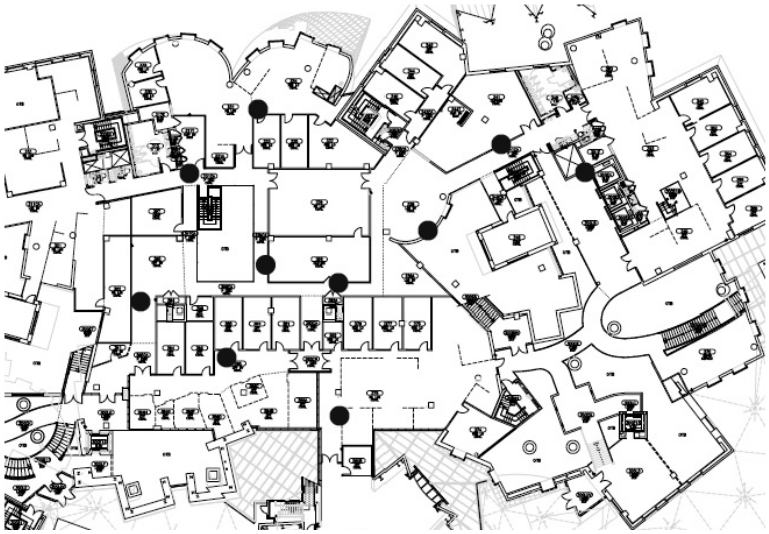
Testbed (one out of 2 floors)



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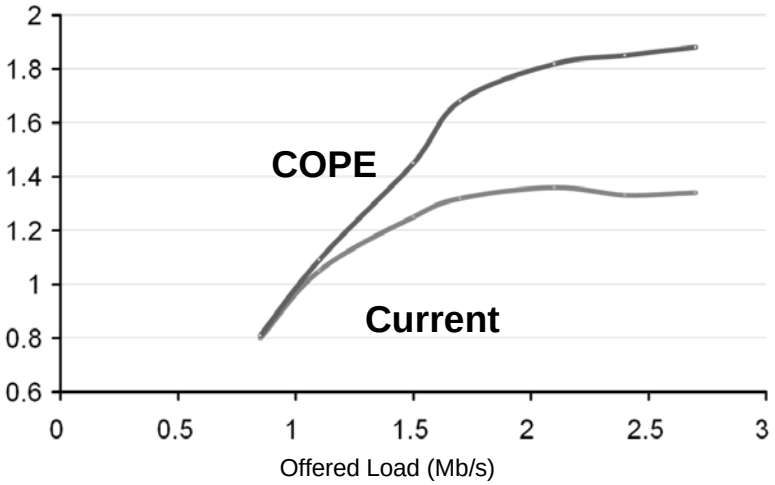
TCP in large network

With Hidden Terminals	No Hidden Terminals
With or without coding	With or without coding
High loss rates (14-40%) due to collisions	Low loss rates (1-2%)
TCP doesn't send much	TCP sends
Medium under-utilized	Coding opportunities
No coding opportunities	

TCP Without Hidden Terminals



With no hidden terminals, COPE substantially increases TCP throughput

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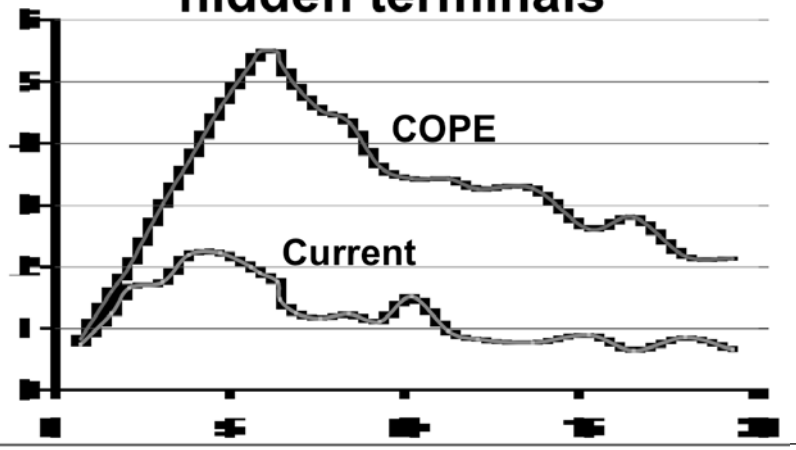
UDP is the same with or without hidden terminals



About 4-fold throughput increase in congested network

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Conclusion

- COPE: a new approach to wireless
- Large throughput increase
- First integration of network coding into the network stack
- New network coding algorithm that deals with general unicast flows

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Discussing

- How practical?
- Evaluation issues?
- Possible evolutions?