XORs in the Air
Practical Wireless Network Coding

Sachin Katti

Hariharan Rahul, Wenjun Hu, Dina Katabi,
Muriel Medard, Jon Crowcroft

Problem

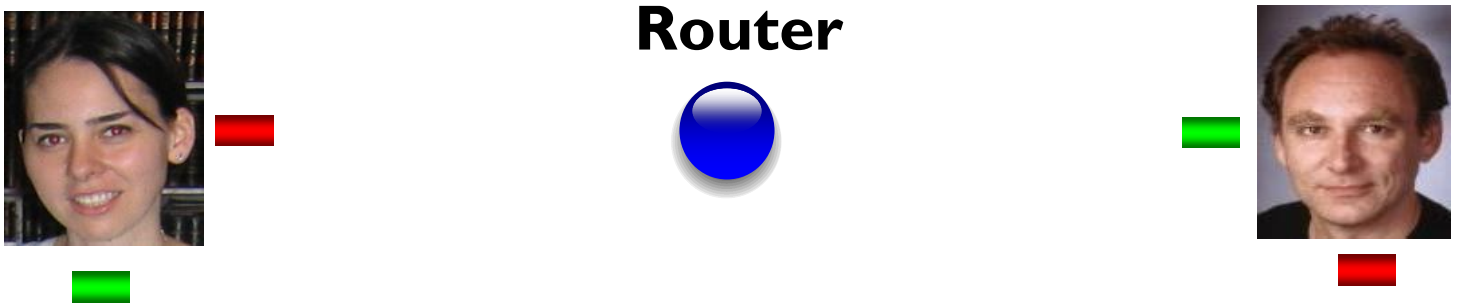
Increasing the throughput of dense wireless mesh networks

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

Current Approach

Router

Current Approach

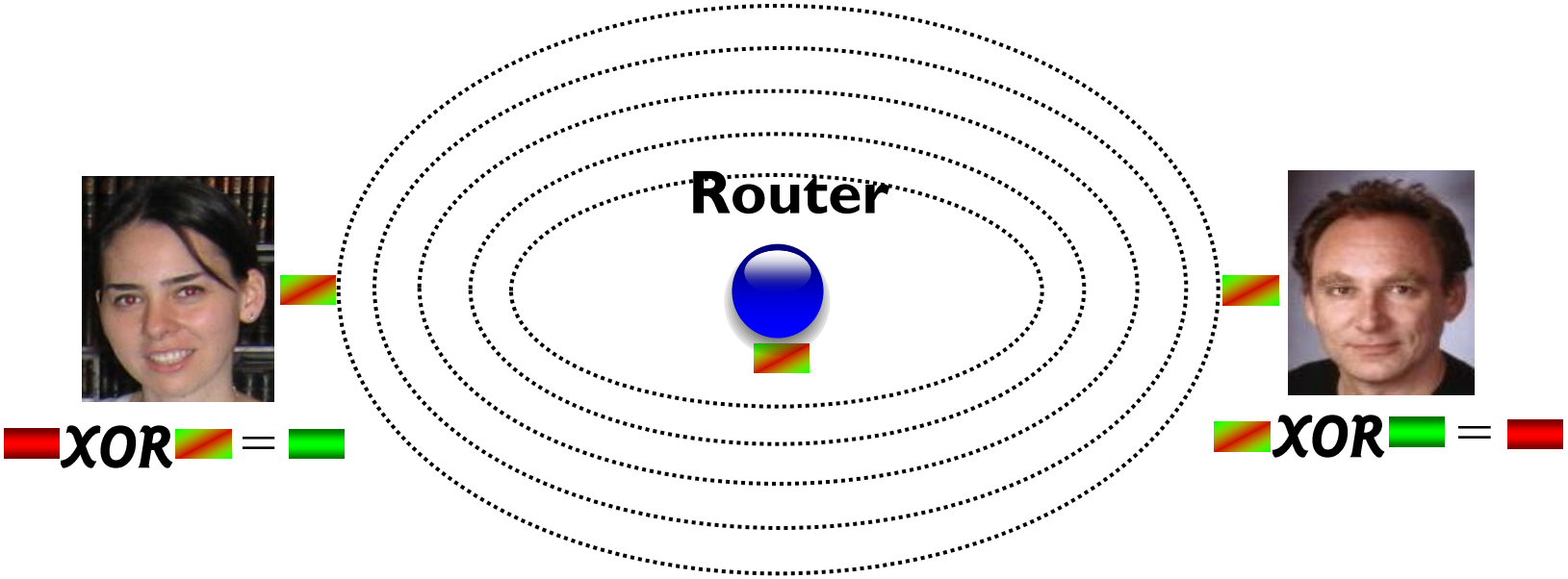


- Requires 4 transmissions
- Can we do it in fewer transmissions?

Our Approach

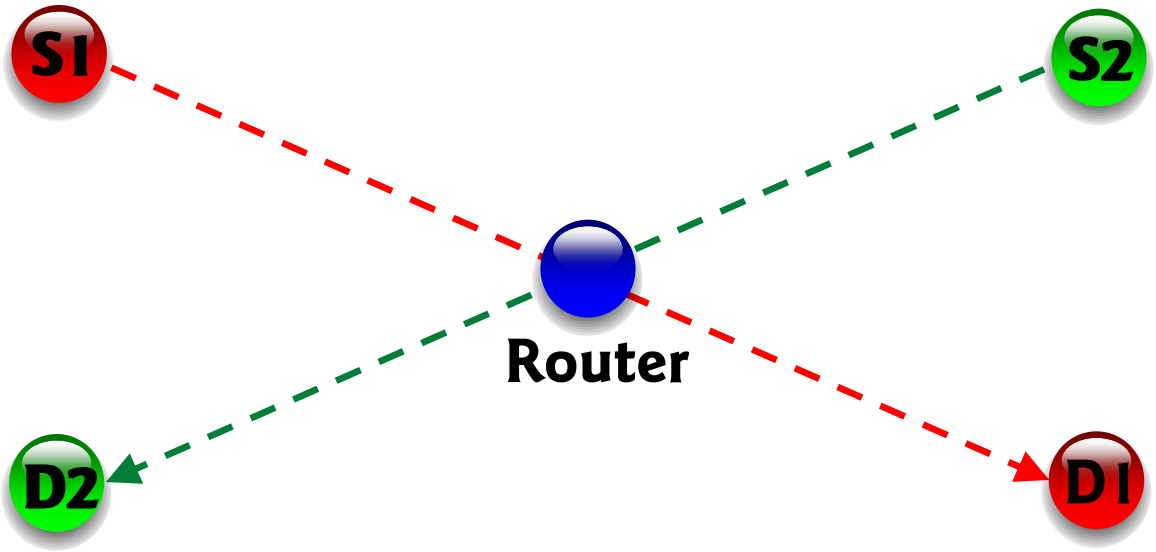
Router

Our Approach



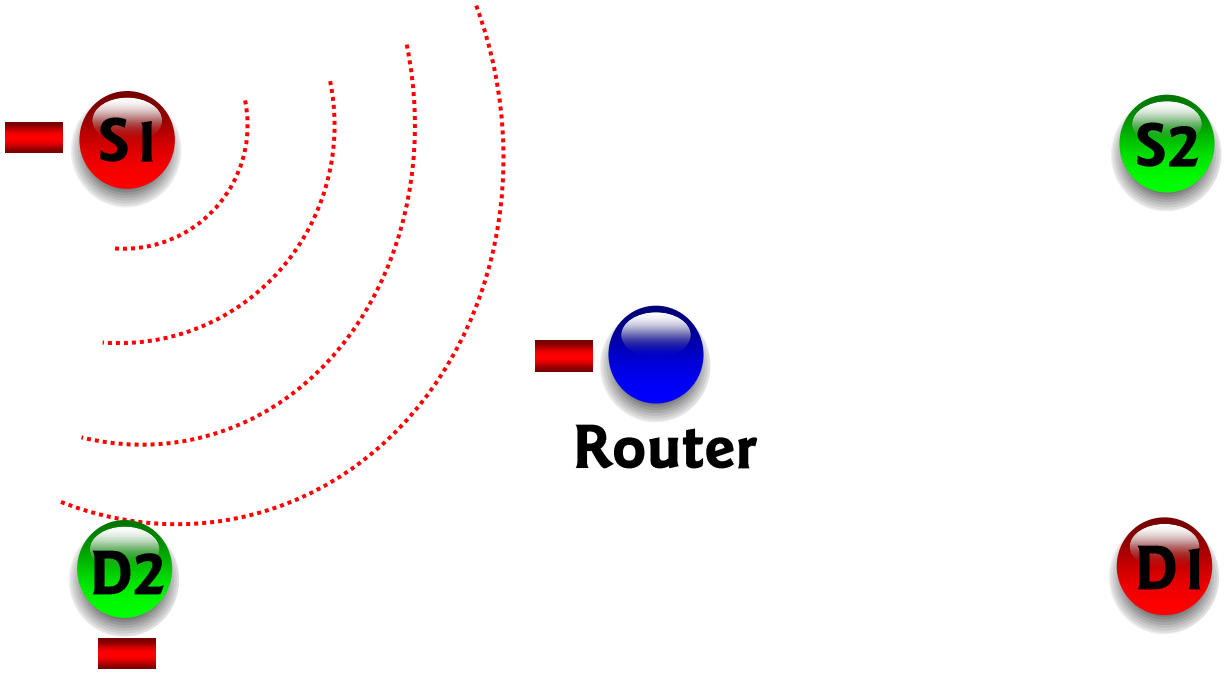
- Requires 3 transmissions instead of 4
- Increased throughput

Beyond duplex flows

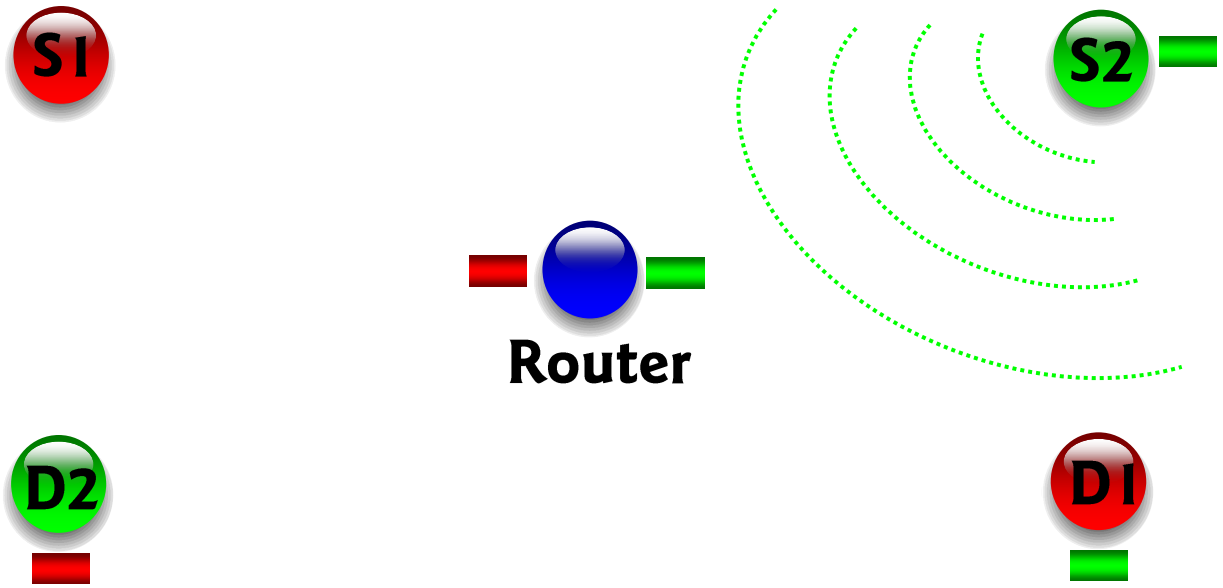


Two flows that intersect at a router

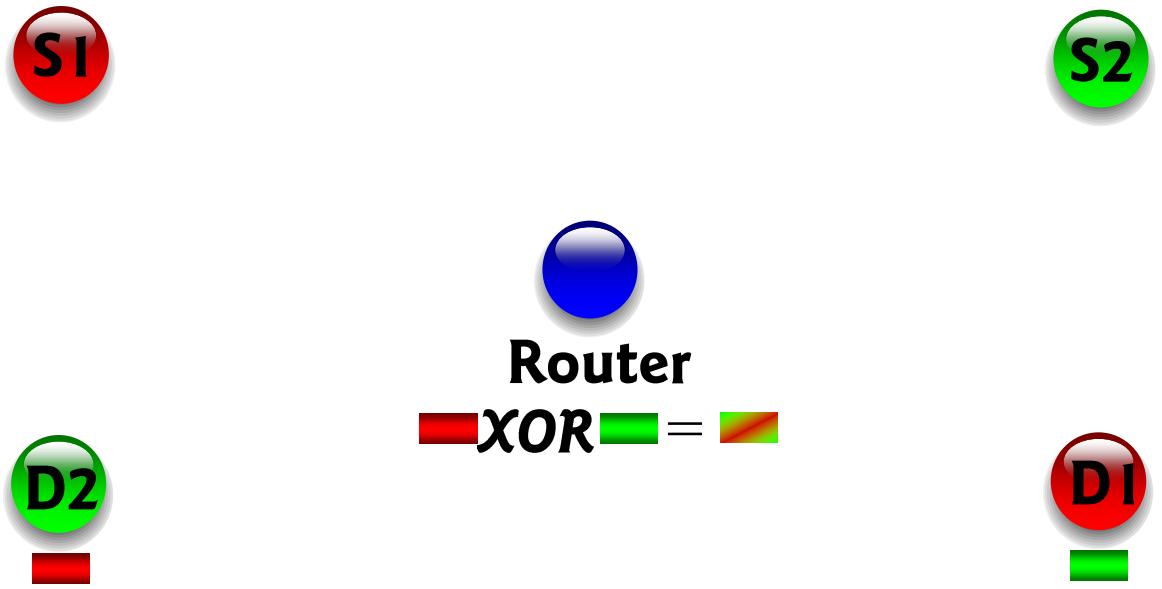
Beyond duplex flows



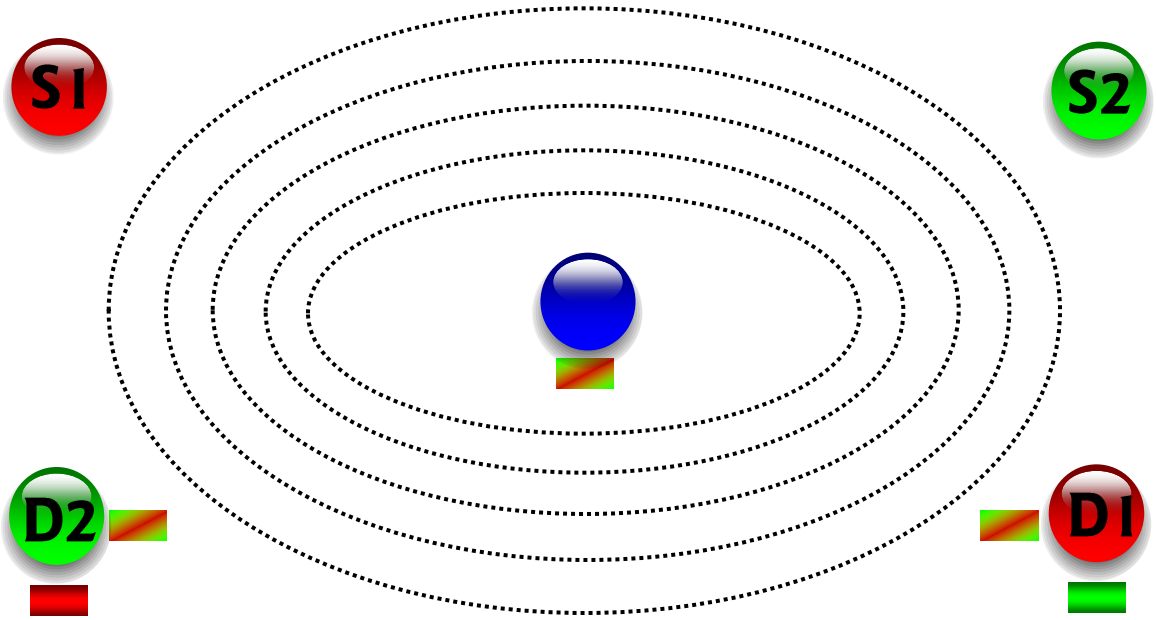
Beyond duplex flows



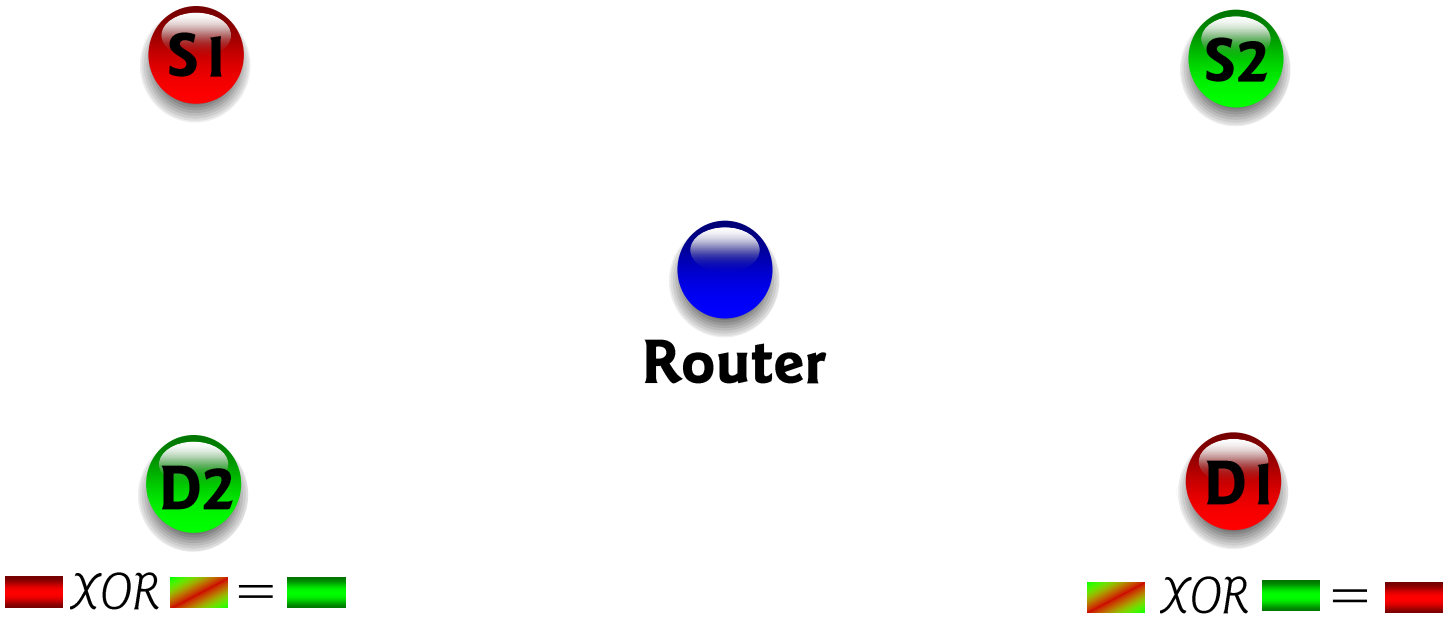
Beyond duplex flows



Beyond duplex flows



Beyond duplex flows



- Again 3 transmissions instead of 4

XOR

Two Departures

- Accept wireless as a broadcast medium
  - Dispose of the point to point abstraction
- Routers mix bits in packets, then forward them → Network Coding!

COPE
(Coding Opportunistically)

- Large throughput increase
- First integration of network coding into the network stack
- New network coding algorithm that deals with general unicast flows

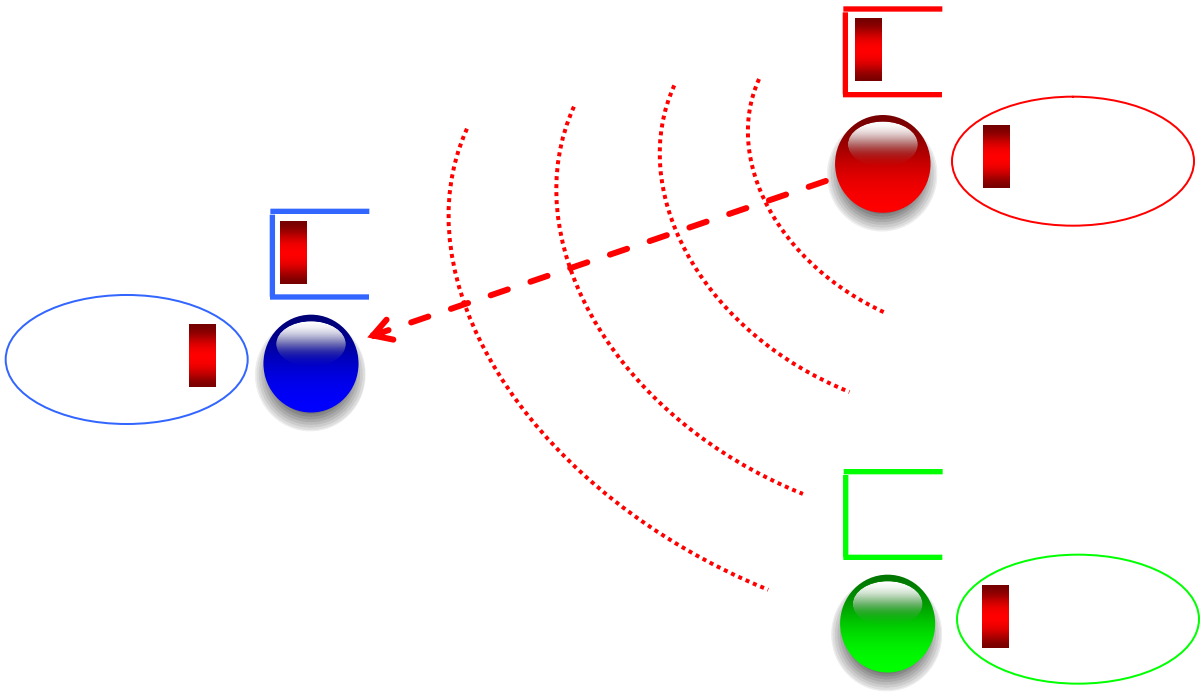
Design

COPE - Snooping

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

COPE - Snooping

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



COPE - Snooping

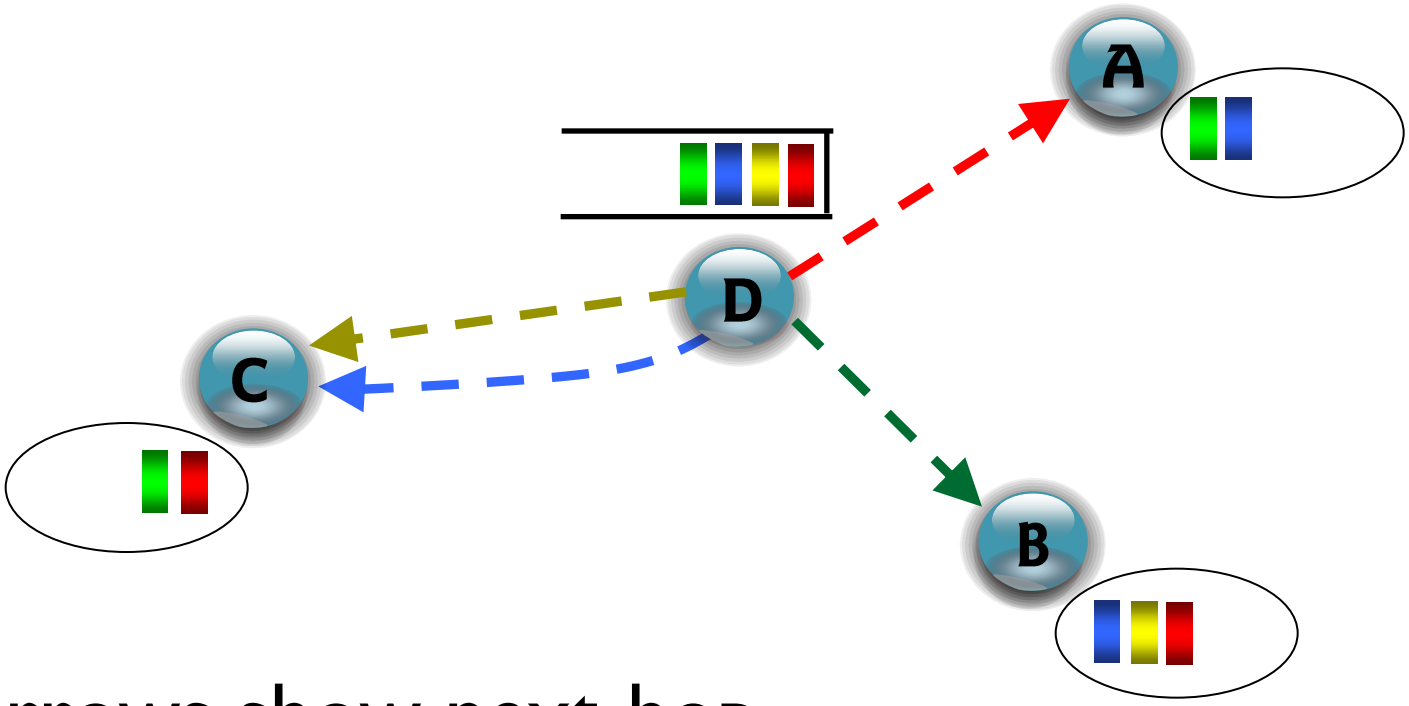
- Exploit wireless broadcast
- Every node snoops on all packets
- A node stores all heard packets for a limited time

- 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

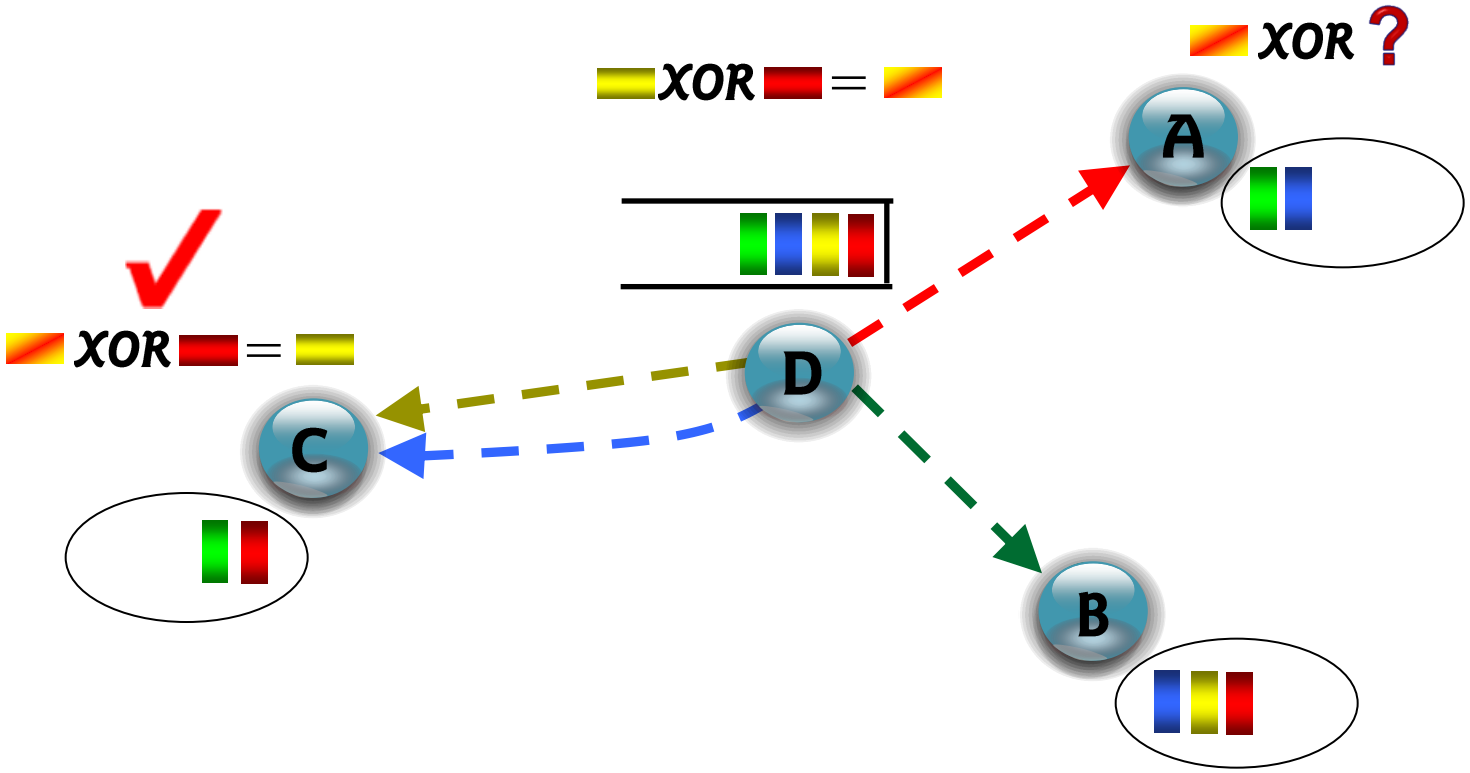
- To send packet *p* to neighbor A, XOR *p* with packets already known to A
  - Thus, A can decode
- But how can multiple neighbors benefit from a single transmission?

Efficient Coding



Arrows show next-hop

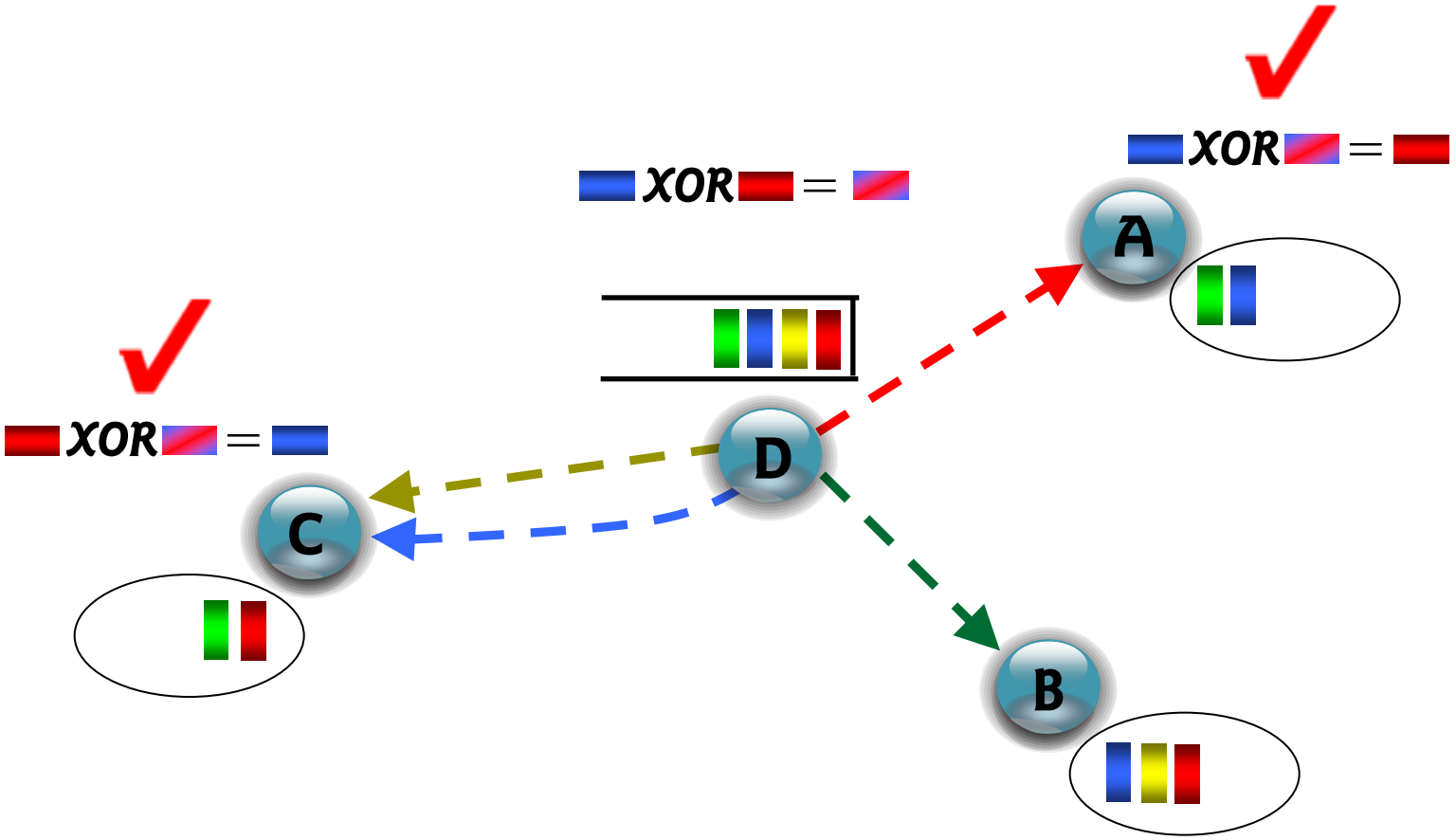
Efficient Coding



Bad Coding

Only one neighbor benefits from one transmission

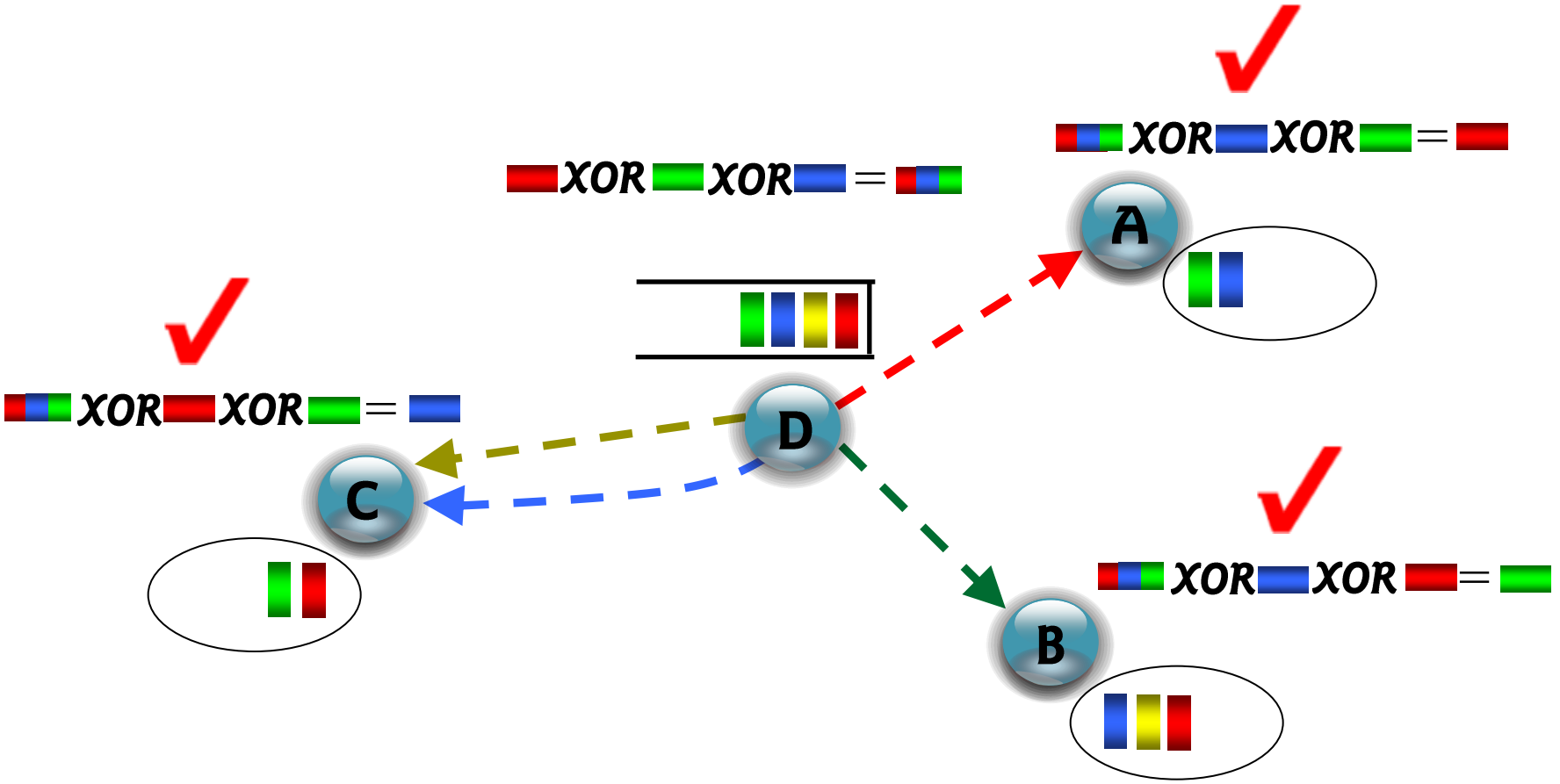
Efficient Coding



Good Coding

Two neighbors benefit from one transmission!

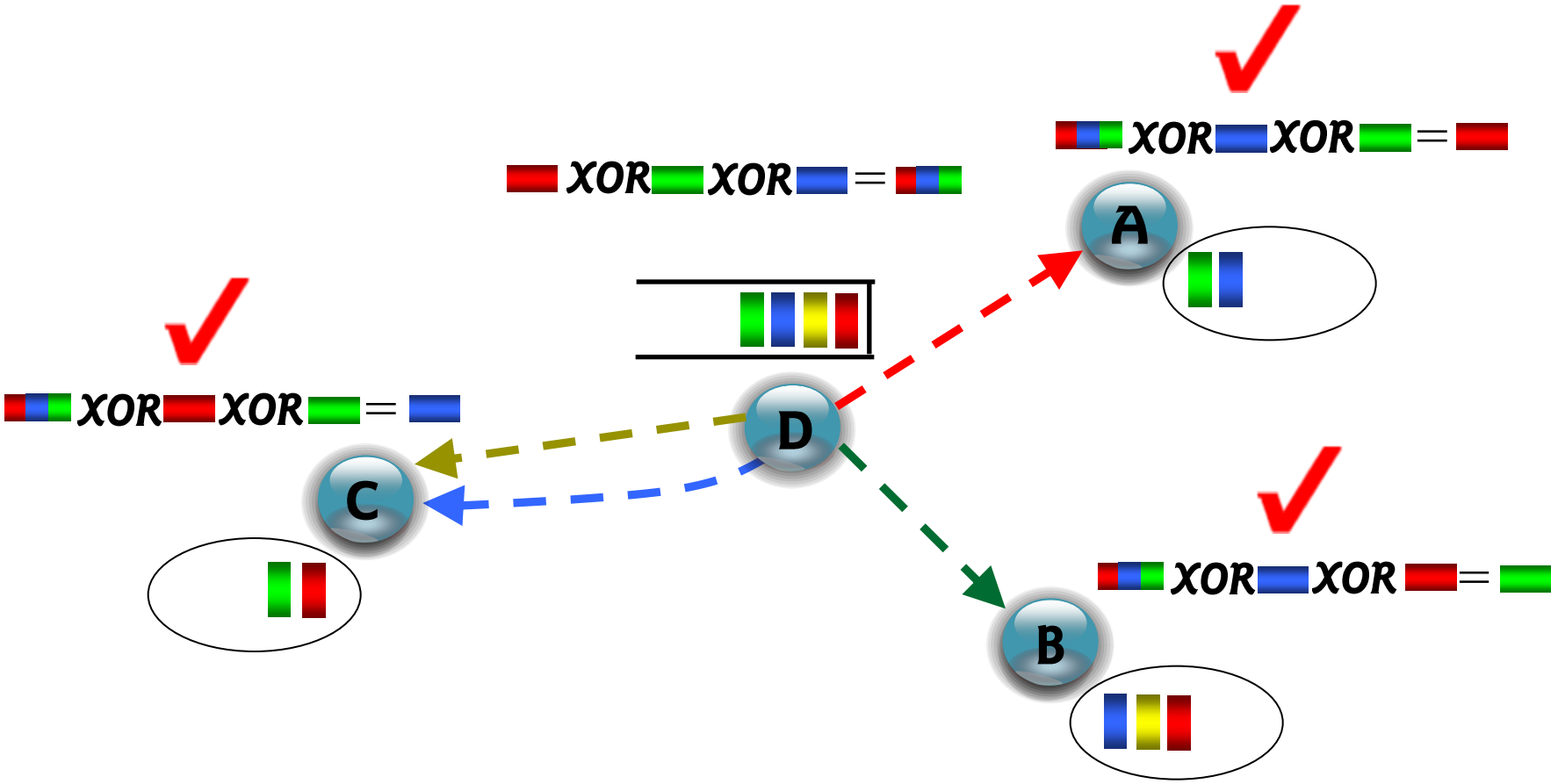
Efficient Coding



Best Coding

Three neighbors benefit from one transmission!

Efficient Coding



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

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

-
-
-
-

Design Choices

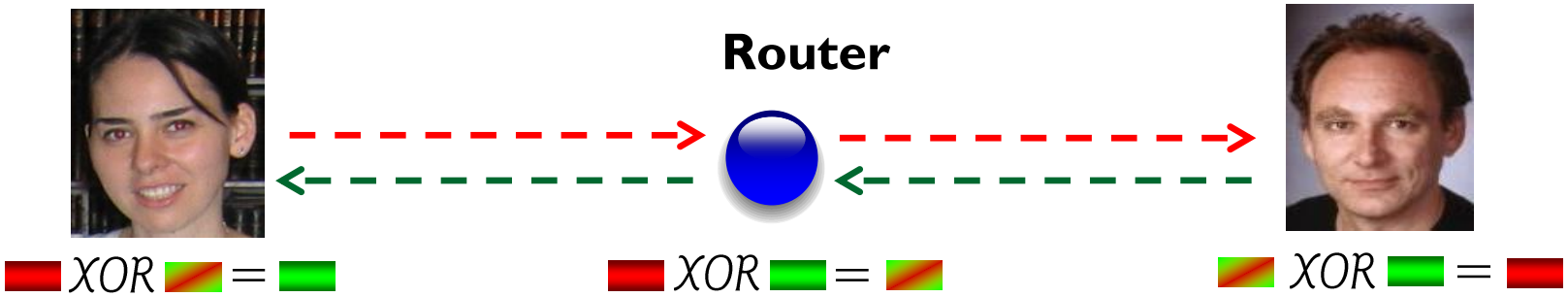
- Sit transparently between IP and MAC
- Opportunistic → Code packets if possible, if not forward without coding
- Do not delay packets

Performance

COPE Implementation

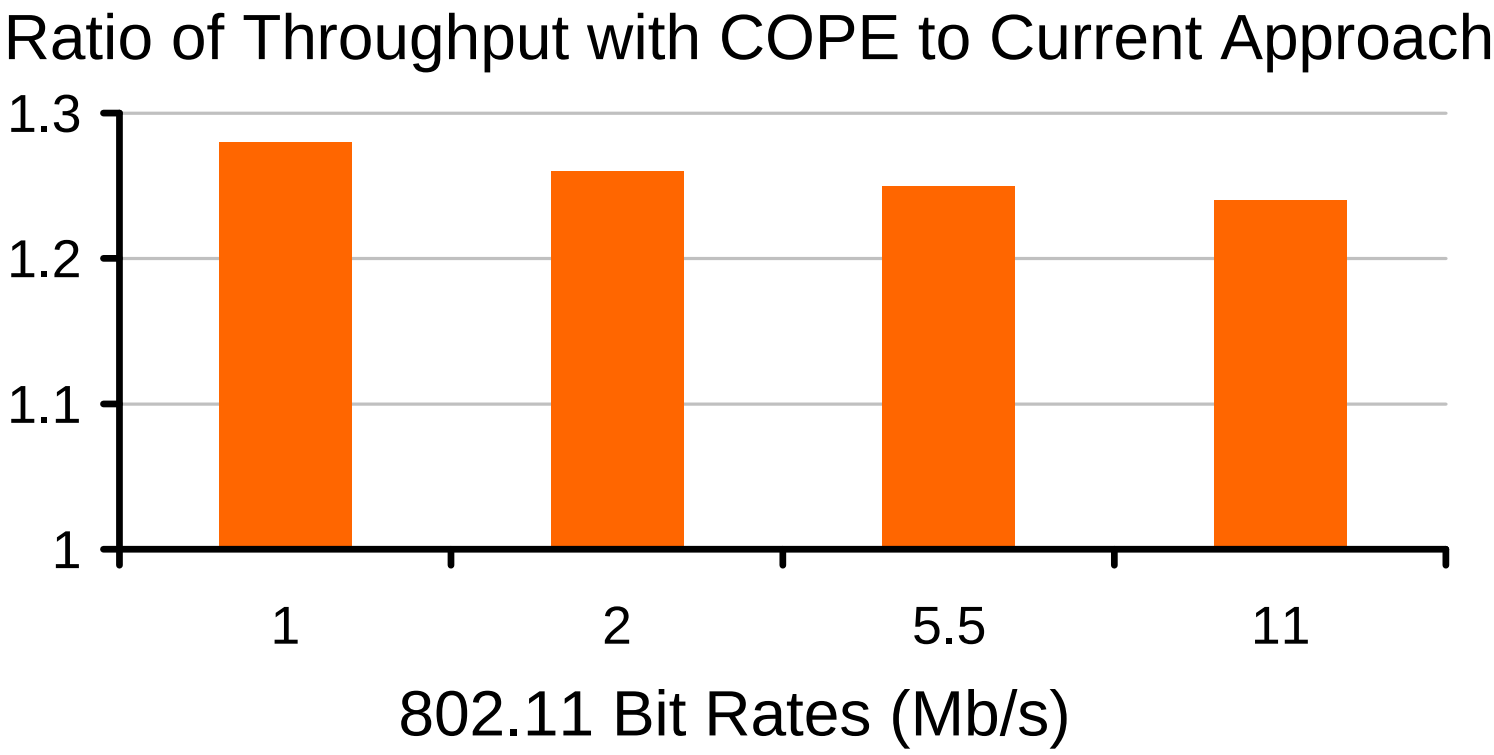
- Linux
- Click + Roofnet
- Userspace module

Dina-and-Jon



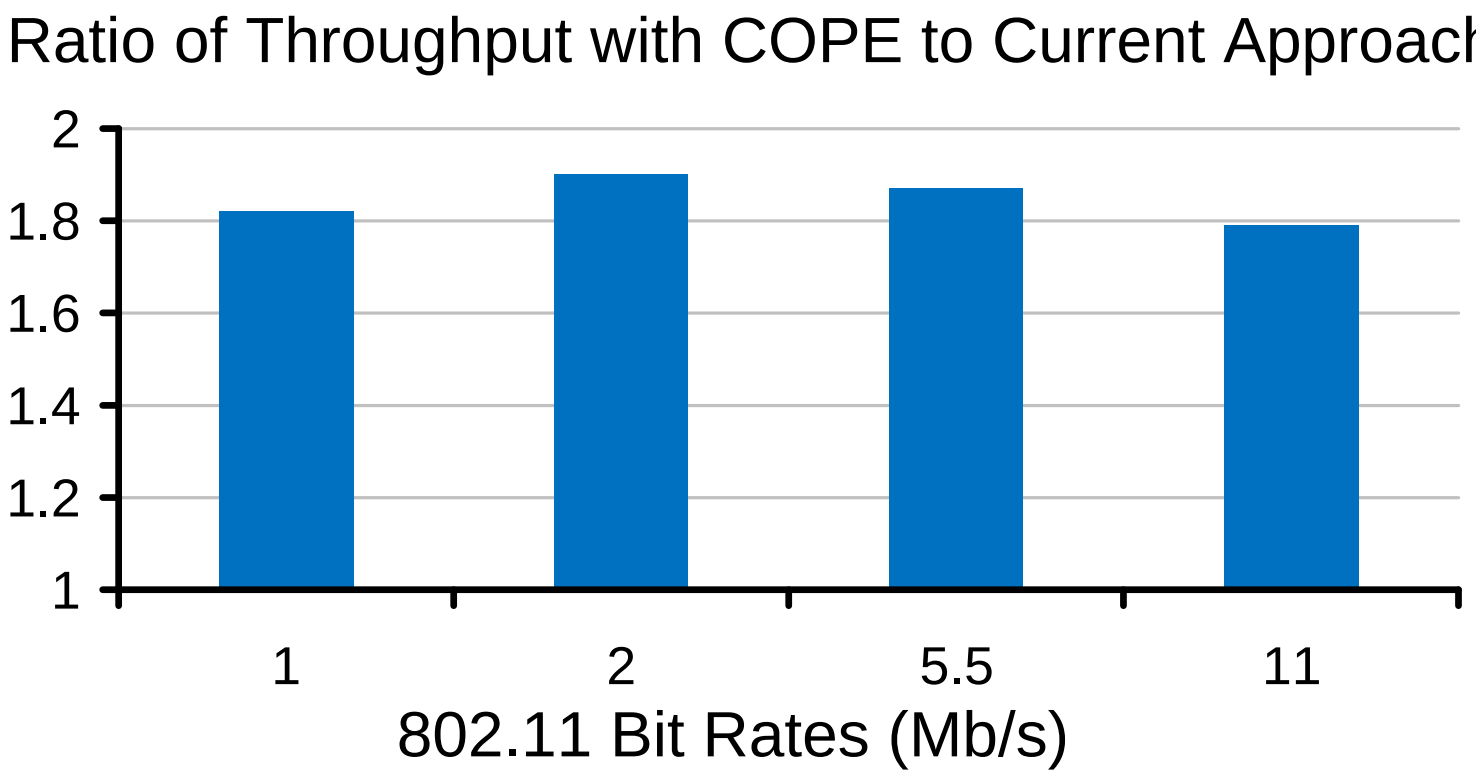
- Requires 3 transmissions instead of 4
  - Expected throughput gain of 4/3 = 1.33

Dina-and-Jon (TCP)



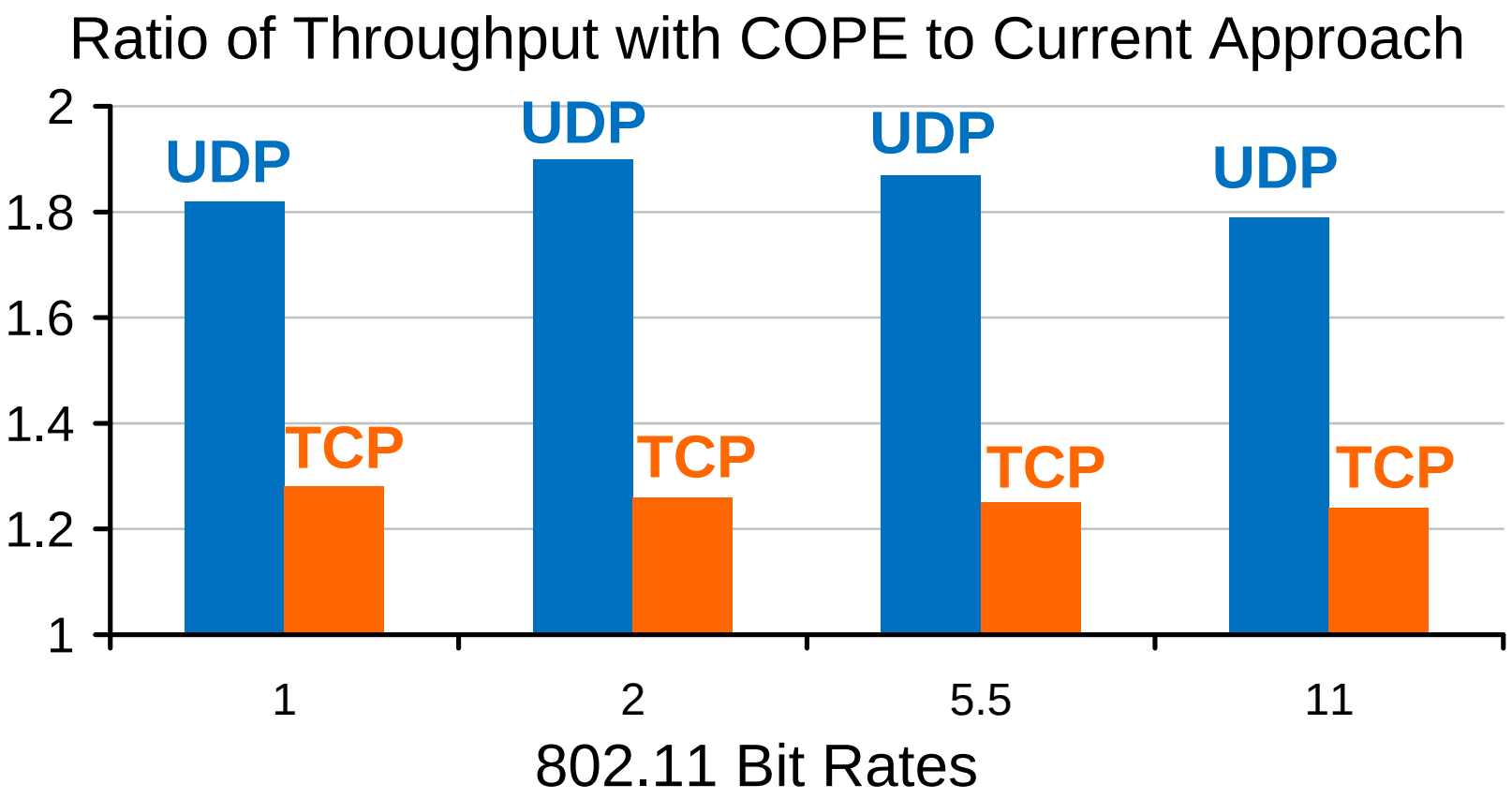
Throughput increase in line with analysis

Dina-and-Jon (UDP)



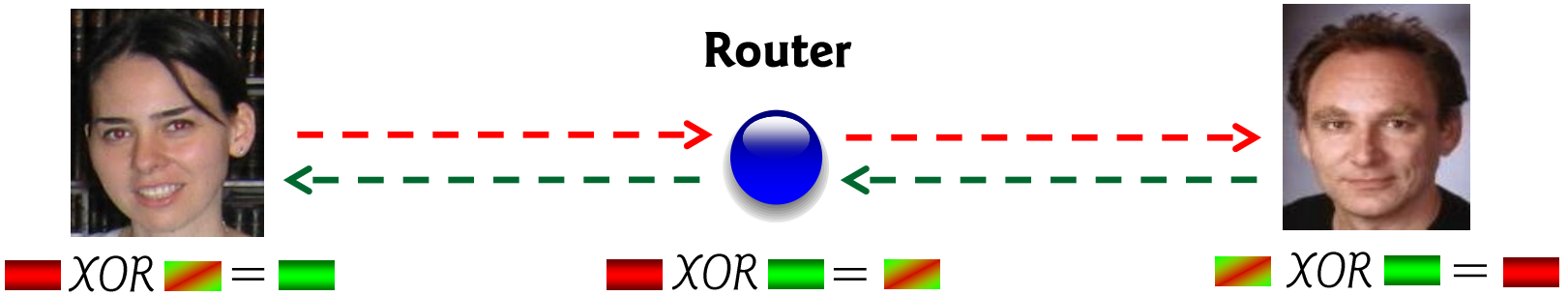
COPE almost doubles the throughput

Dina-and-Jon (UDP)



COPE almost doubles the throughput

Why More Than 1.33?



802.11 is fair → 1/3 capacity for each node

- COPE alleviates the mismatch between MAC's capacity allocation and the congestion at a node
  - With all COPE packets, Dina or Bob drops packets
- With COPE, all nodes need equal rate

Coding Gain

Reduction in #Transmissions

For Dina-and-Jon scenario, Coding Gain is 4/3 = 1.33

Reflects gains when nodes are not backlogged

Coding + MAC Gain

Improvement of draining rate at bottlenecks

For Dina-and-Jon scenario, Coding+MAC Gain is 2

Reflects gains when nodes are backlogged

Theoretically,

Coding gain is bounded by 2

Coding+MAC gain can be infinite

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

TCP in large network

With Hidden Terminals

With or without coding

- High loss rates (14-40%) due to collisions
- TCP doesn't send much
- Medium under-utilized
- No coding opportunities

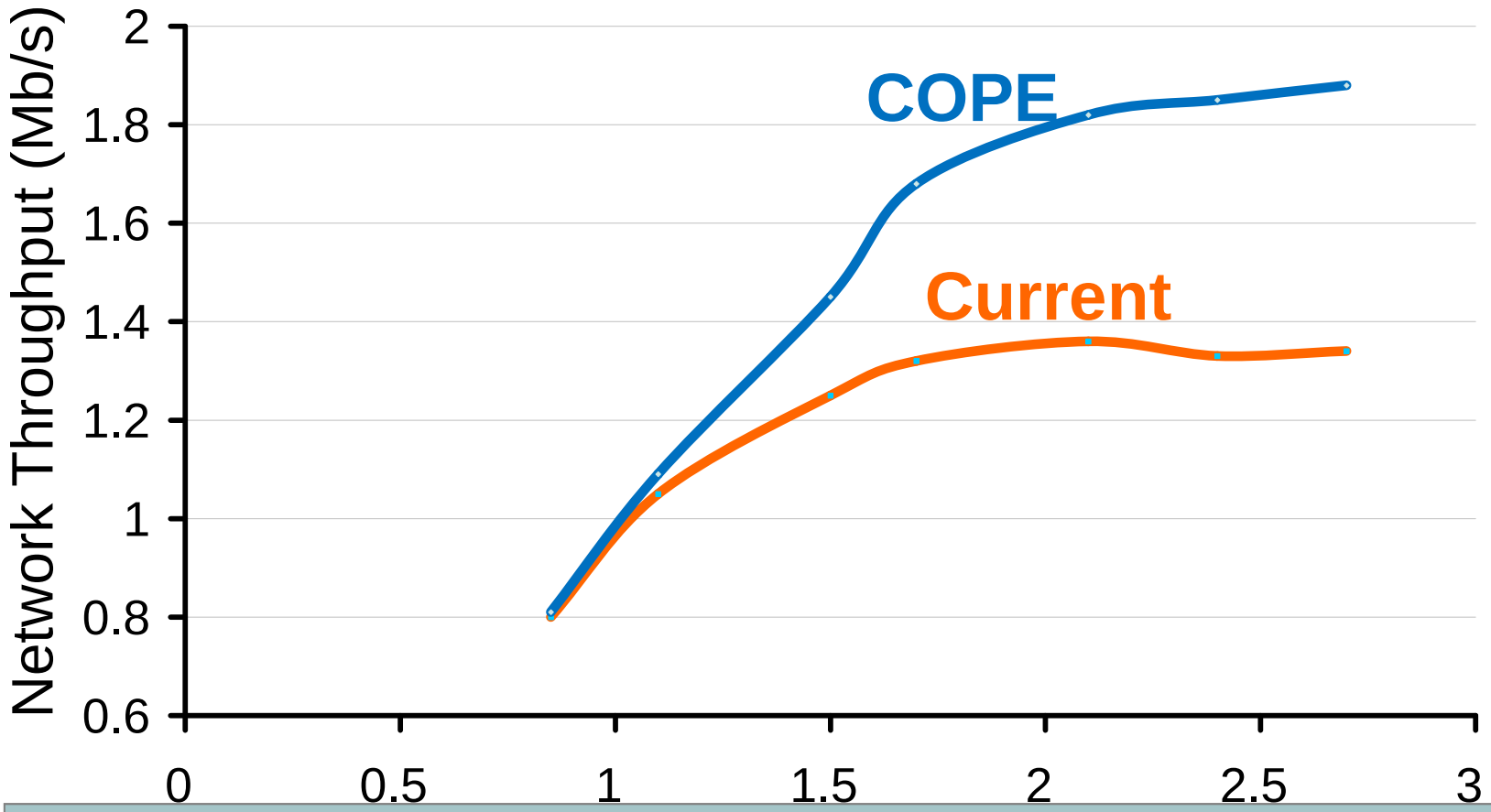
No Hidden Terminals

With or without coding

- Low loss rates (1-2%)
- TCP sends
- Coding opportunities

TCP Without Hidden Terminals

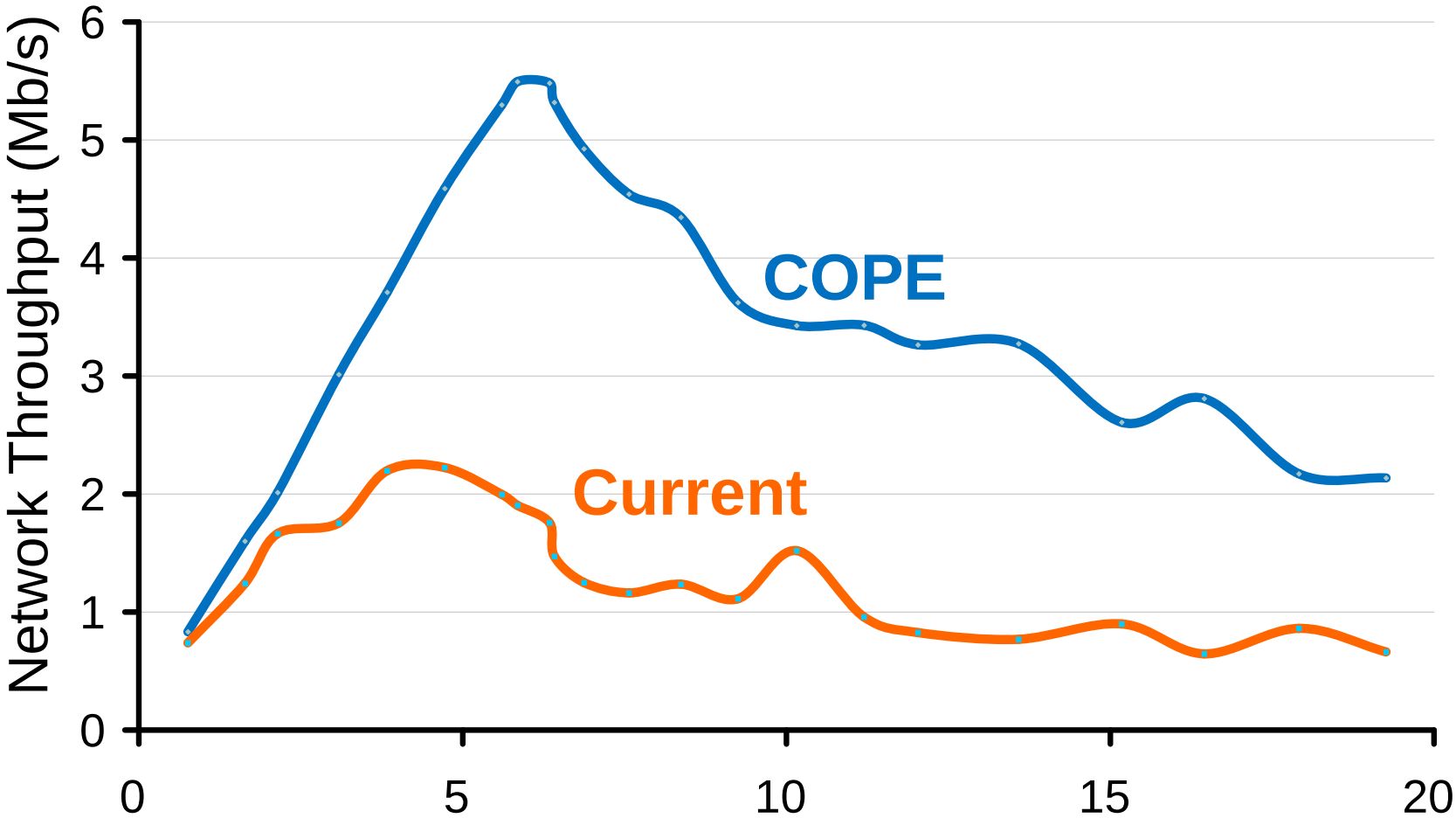
TCP Without Hidden Terminals



With no hidden terminals, COPE substantially increases TCP throughput

UDP is the same with or without hidden terminals

UDP in large network



About 4-fold throughput increase in congested network

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

Simple and practical!