The Importance of Being Opportunistic

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Bandwidth is scarce in wireless

Can we send more while consuming less bandwidth?

Current Approach

- Requires 4 transmissions
- Can we do it in 3 transmissions?

A Network Coding Approach

3 transmissions instead of 4 → Save bandwidth

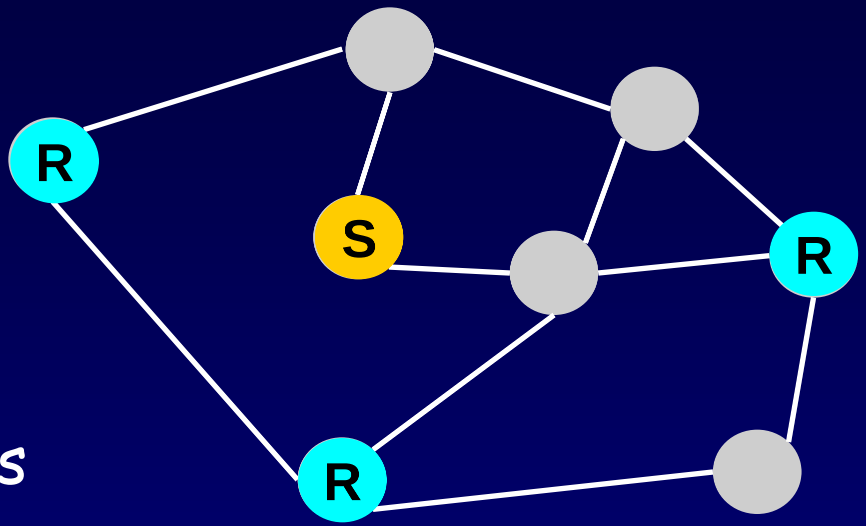
Network Coding

- Routers mix bits in packets, potentially from different flows
- Theoretically shown to achieve capacity for ***multicast***
- No concrete results for unicast case

How to apply network coding?

State-of-the Art

- Multicast
- Given Sender & Receivers
- Given Flow Rate & Capacities



Min-Cost Flow Optimization

Find the routing, which dictates the encoding

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- Multicast
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Min-Cost Flow Optimization

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In Practice

- Unicast
- Many Unknown Changing Sender & Receivers
- Unknown and bursty flow rate

?

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Min-Cost Flow Optimization

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Opportunism

Opportunism (1)

Opportunistic Listening:

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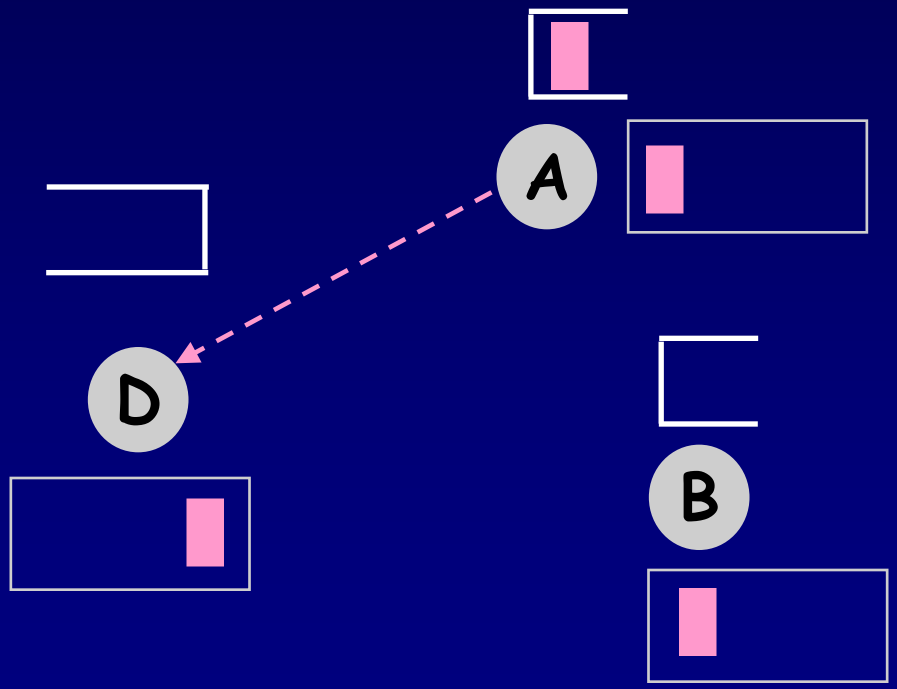


Opportunism (1)

Opportunistic Listening:

- Every node listens to all packets
- It stores all heard packets for a limited time

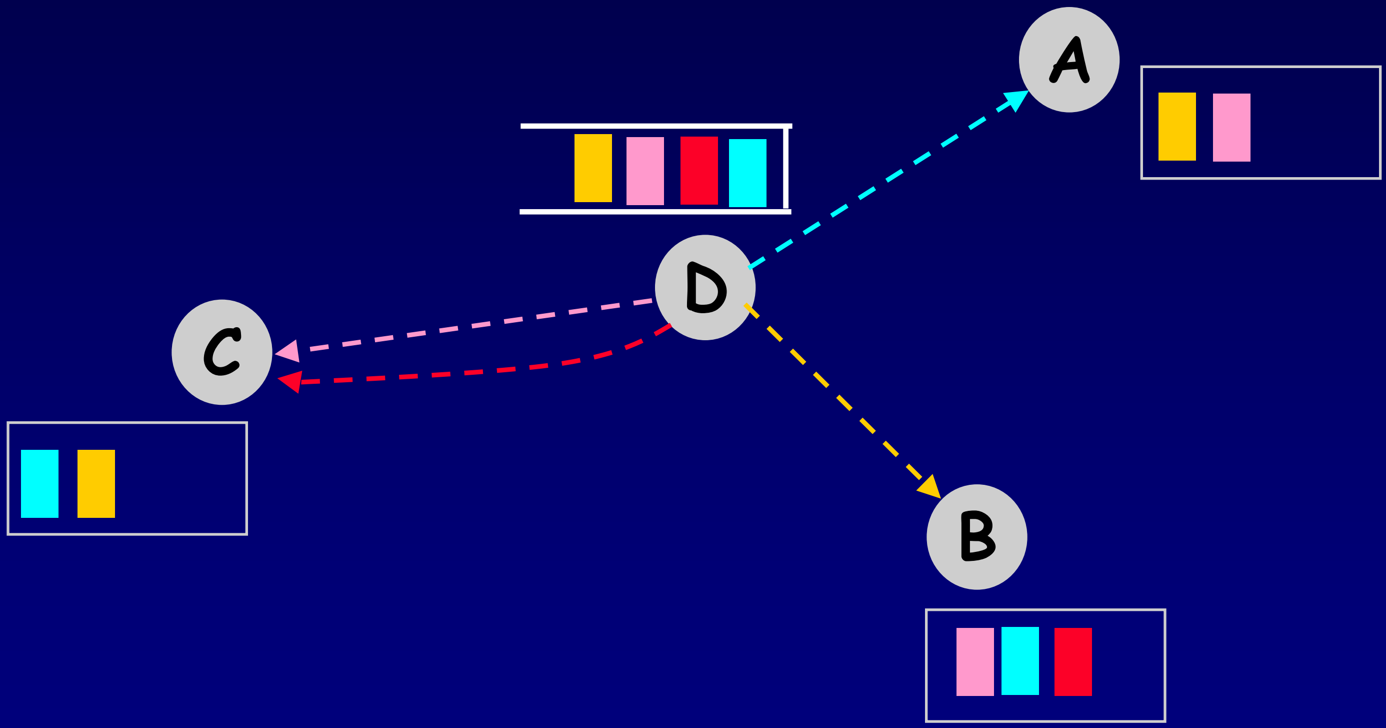
- Node sends Reception Reports to tell its neighbors what packets it heard
  - Reports are annotations to packets
  - If no packets to send, periodically send reports

Opportunism (2)

Opportunistic Coding:

- Each node uses only local information
- Use your favorite routing protocol
- To send packet *p* to neighbor *A*, XOR *p* with packets already known to *A*
  - Thus, *A* can decode
- But how to benefit multiple neighbors from a single transmission?

Efficient Coding

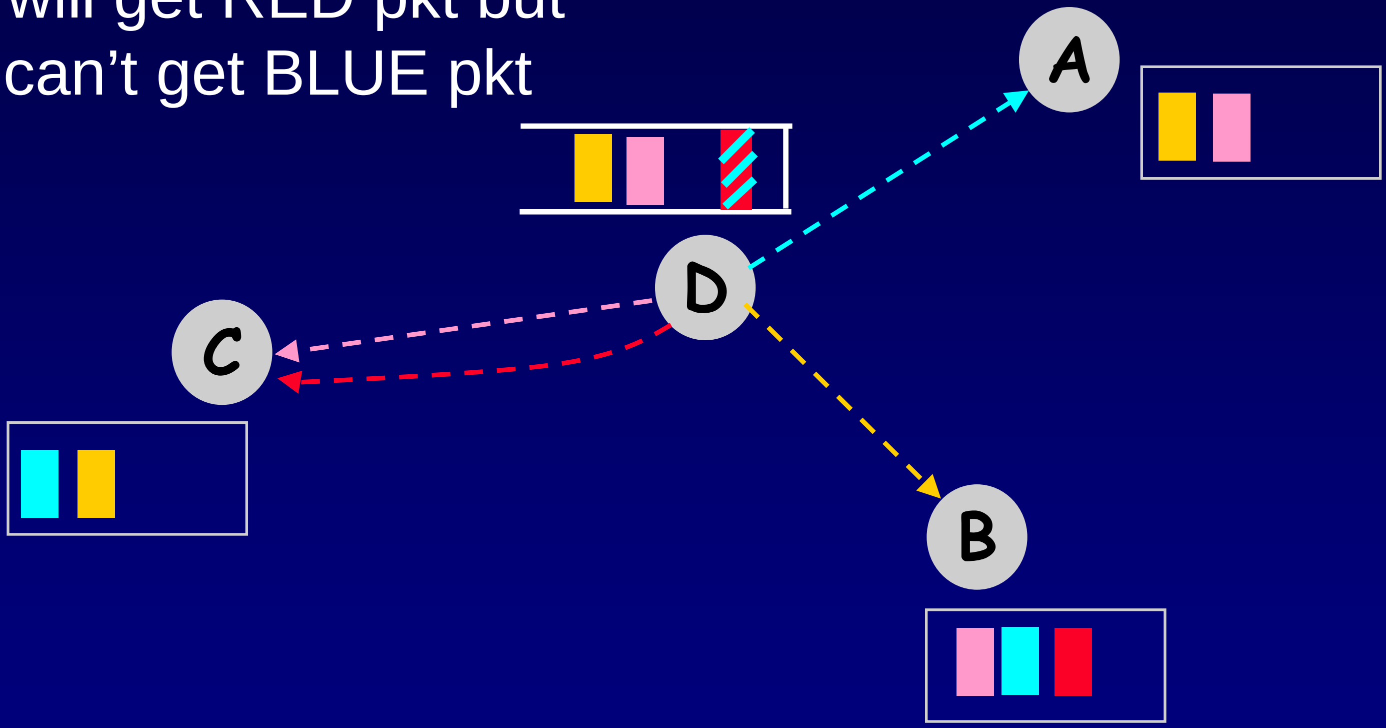


Arrows show next-hop

Efficient Coding

Bad Coding

C will get RED pkt but
A can't get BLUE pkt



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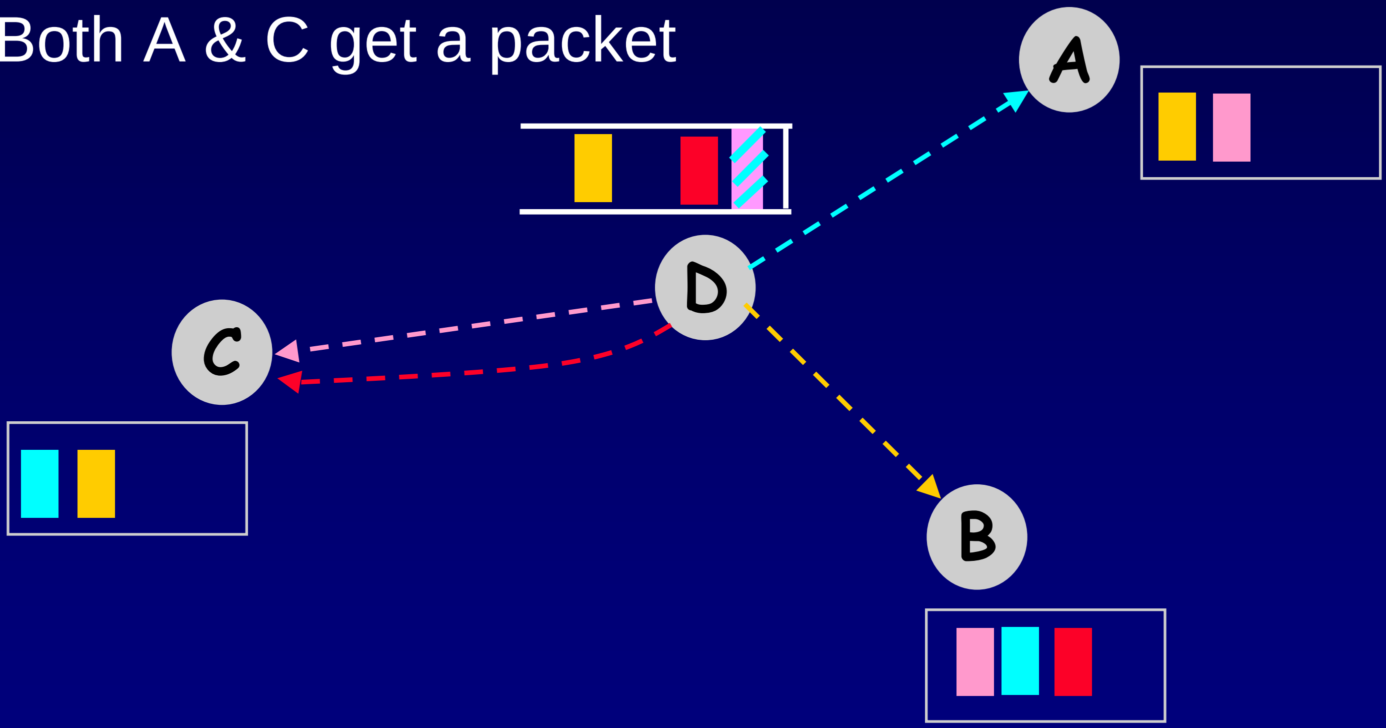
Efficient Coding

Better Coding

Both A & C get a packet

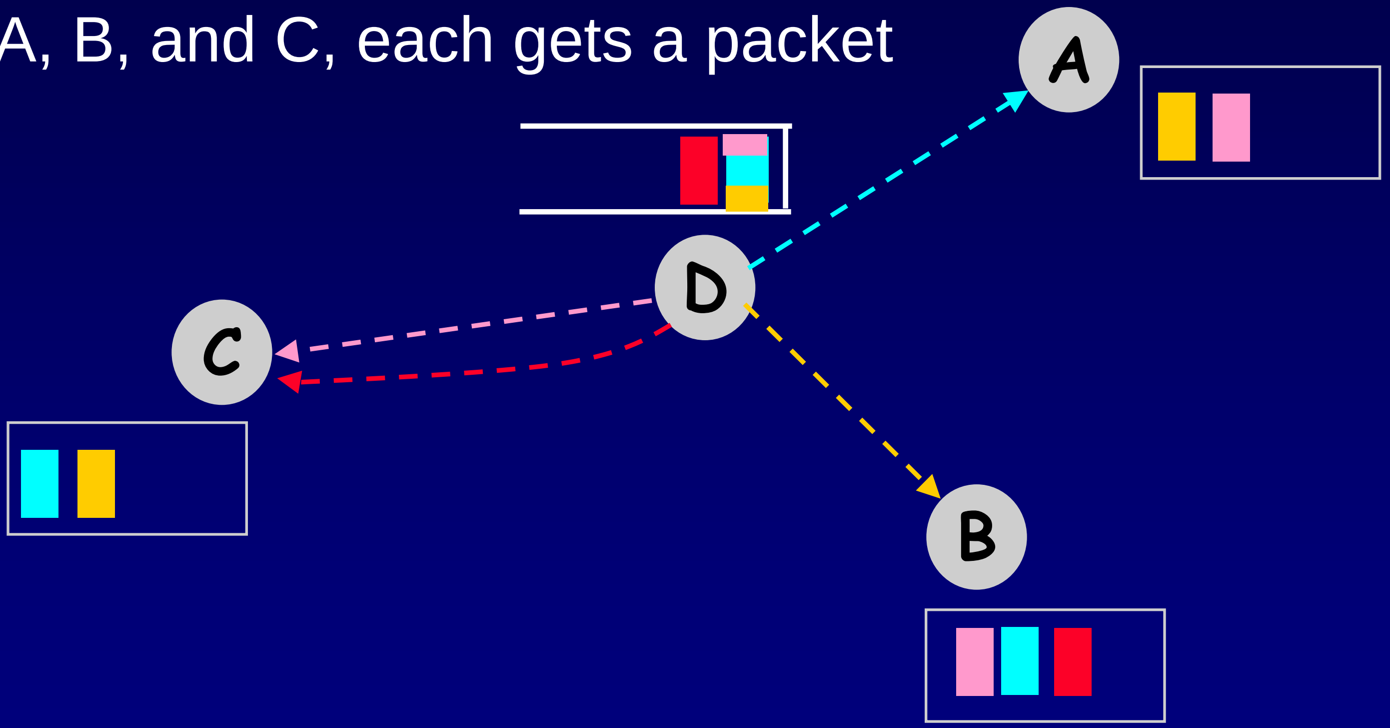


Arrows show next-hop

Efficient Coding

Best Coding

A, B, and C, each gets a packet

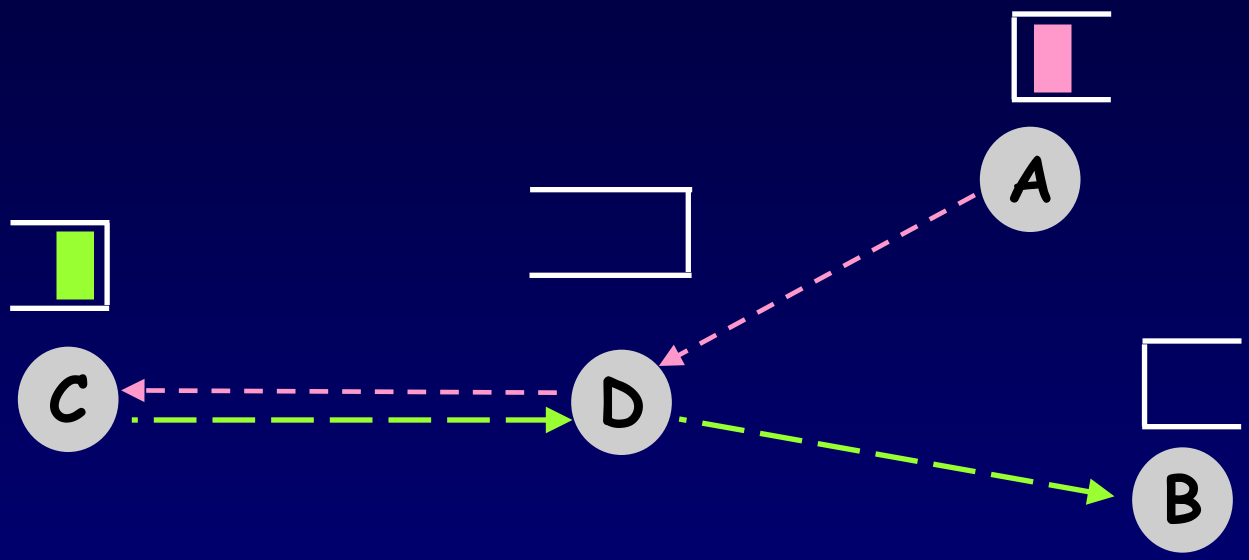


To XOR *n* packets, each next-hop should have the *n-1* packets encoded with the packet it wants

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

- Reception Reports
- But reception reports may get lost or arrive too late
- Use Guessing
  - If I receive a packet I assume all nodes closer to sender have received it

Putting It Together



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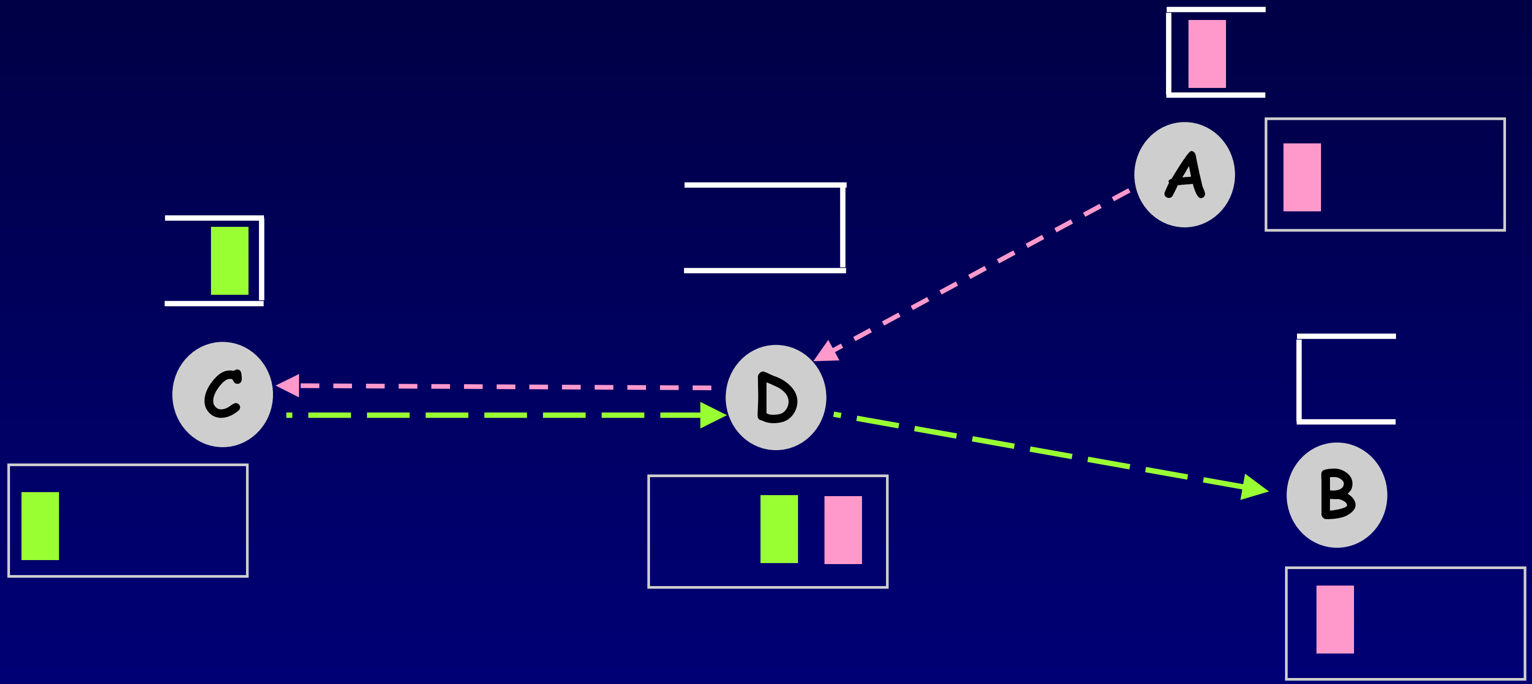

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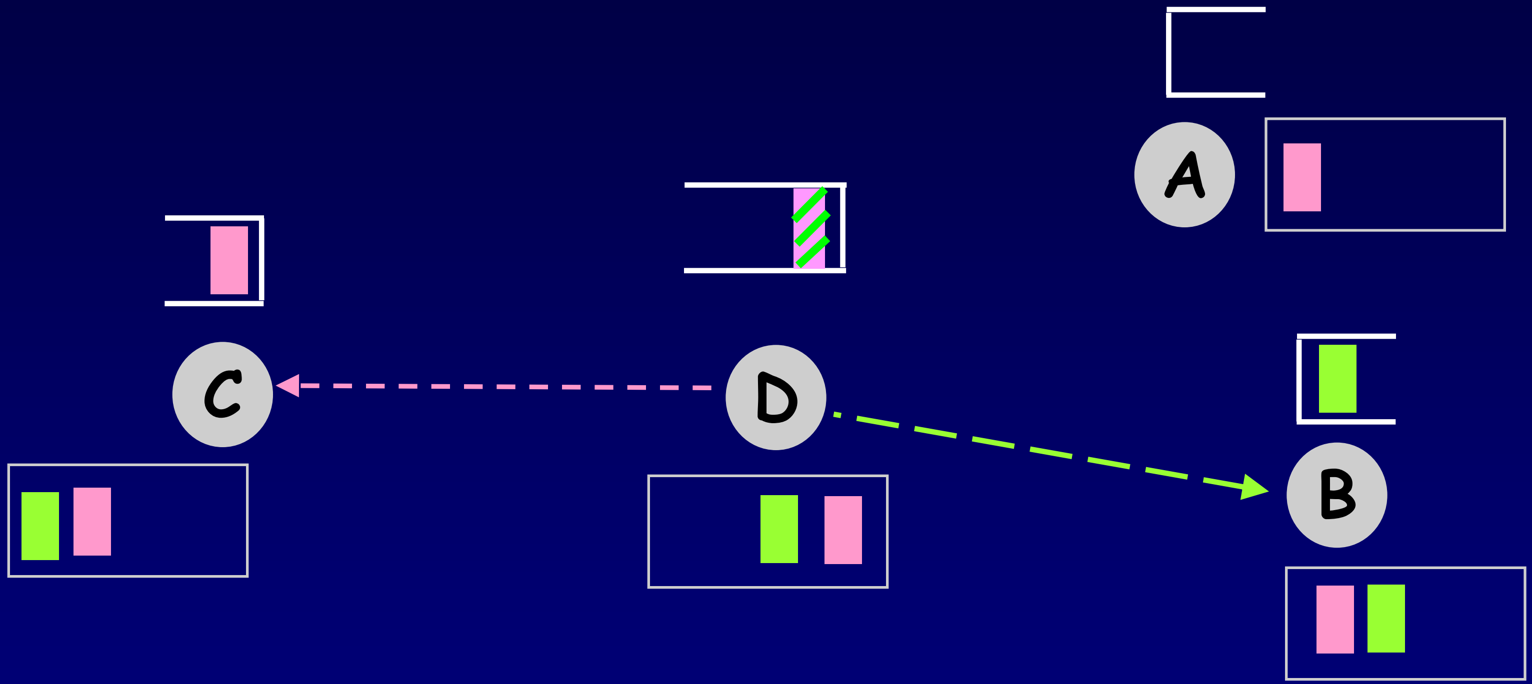
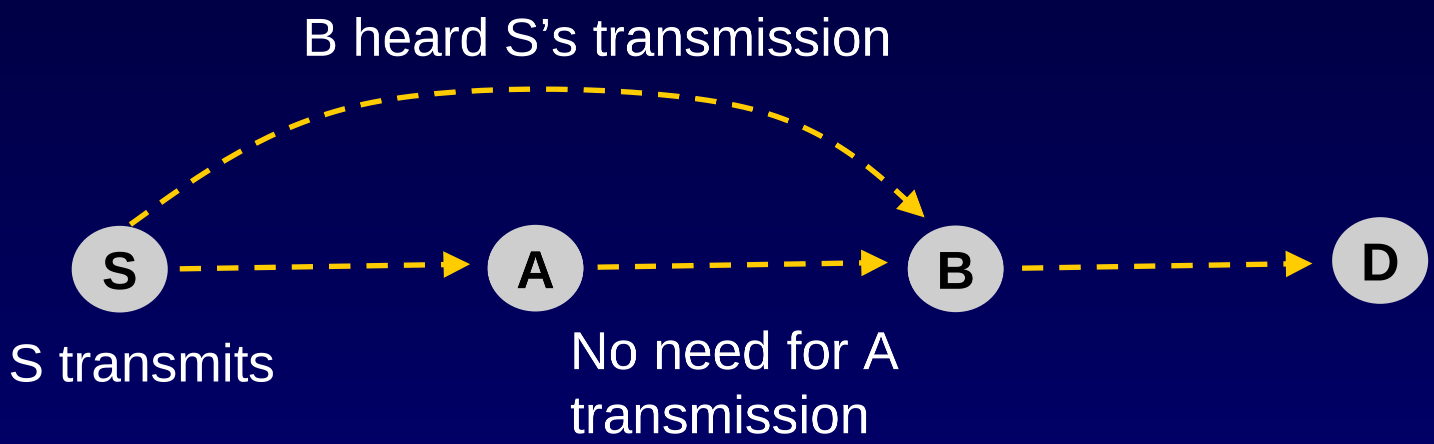


- Don't reorder packets in a flow → Keeps TCP happy
- No scheduling → No packet is delayed

Beyond Fixed Routes



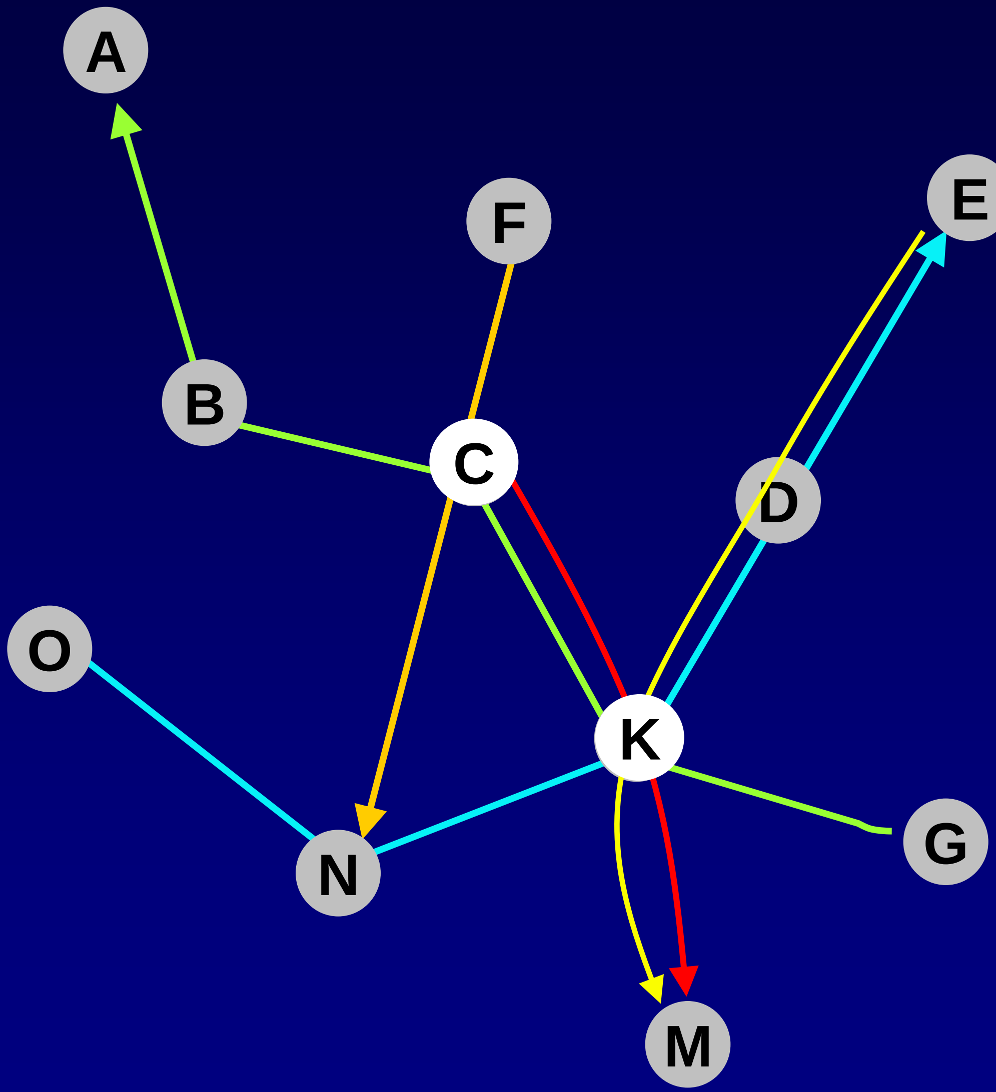
Route Chosen by Routing Protocol

Opportunistic Routing *[BM05]*

- Piggyback on reception report to learn whether next-hop has the packet
- cancel unnecessary transmissions

Opportunism

- Unicast
- Flows arrive and leave at any time
- No knowledge of rate
- No assumption of smooth traffic

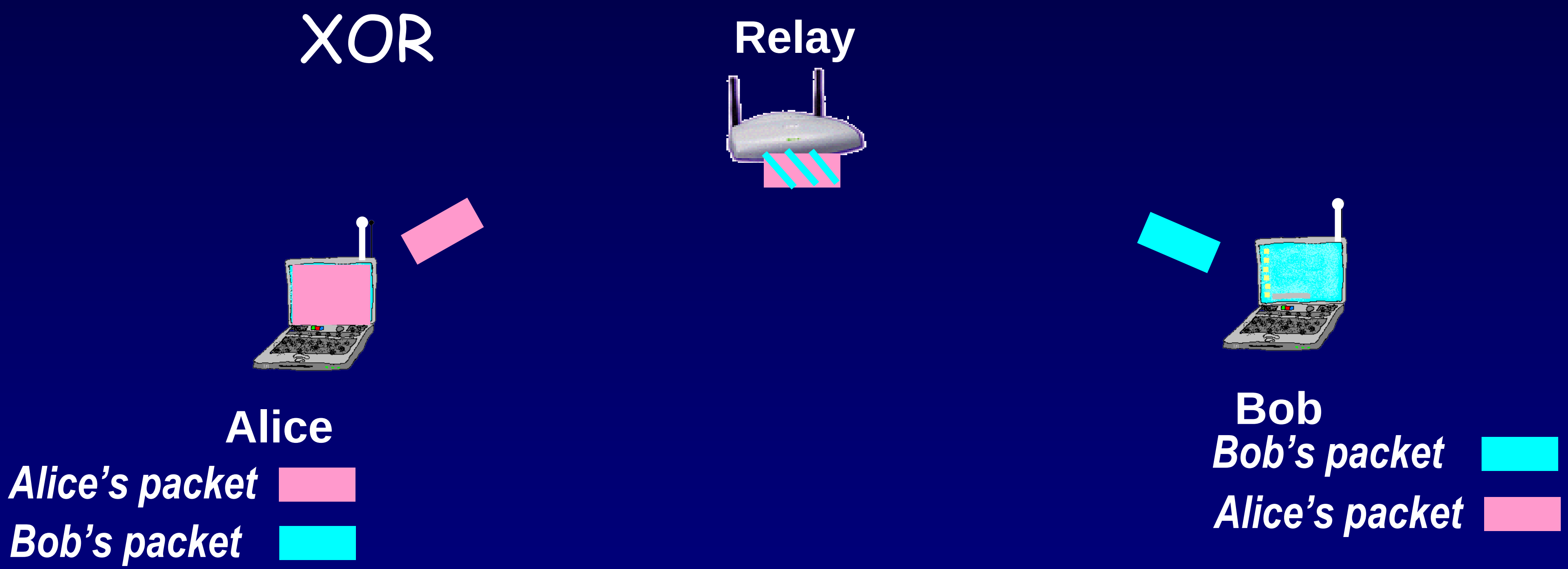


Performance

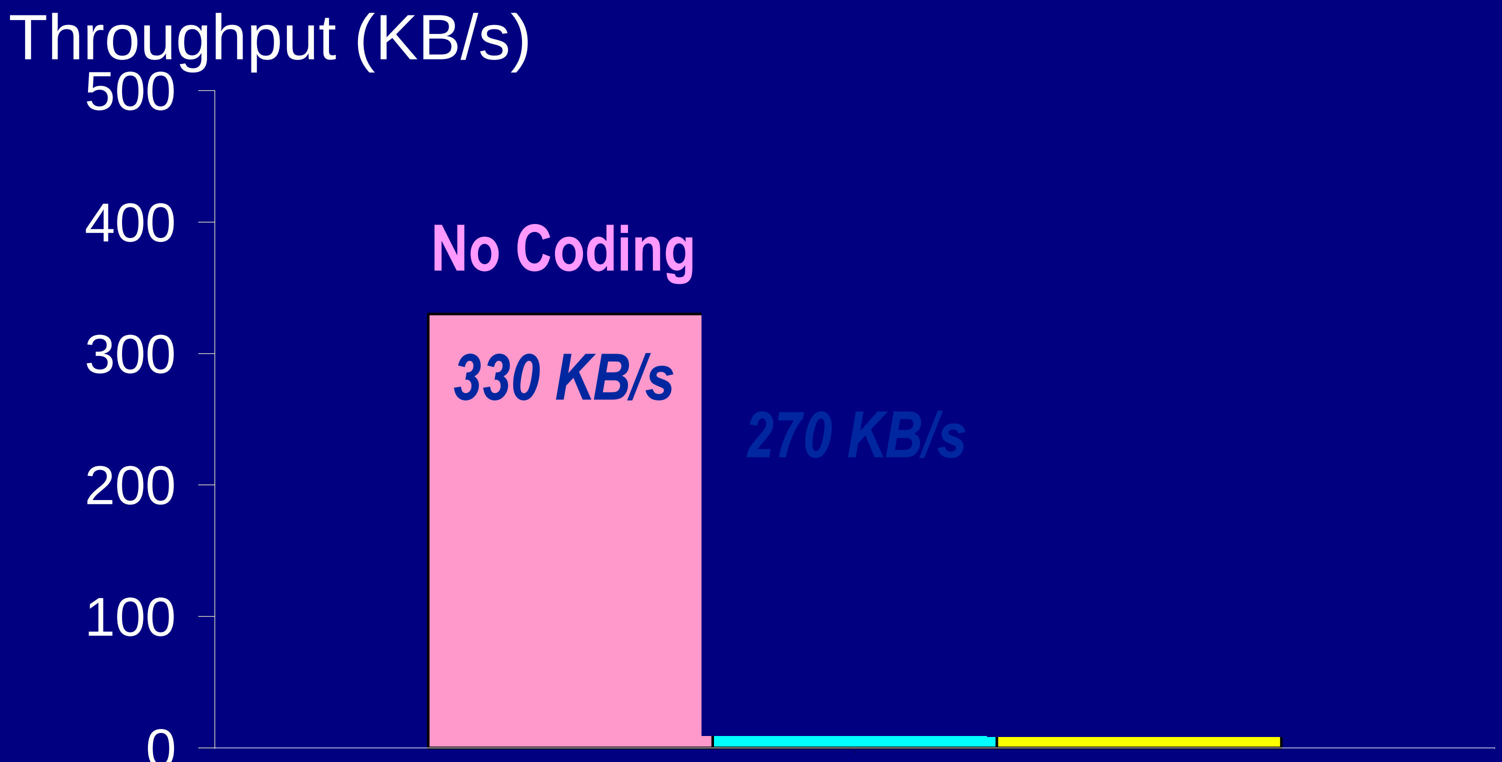
Emulation Environment

- We use Emstar
  - "Real code" simulator
  - 802.11 radios
  - Power Level: 200mW
  - 11Mbps bit rate
  - *Simulated radio channel*

Recall Our Simple Experiment



3 transmissions instead of 4 → 25% throughput increase



Practical artifacts make network coding perform poorly

- Network coding requires broadcast
- But 802.11 broadcast has no backoff → more collisions

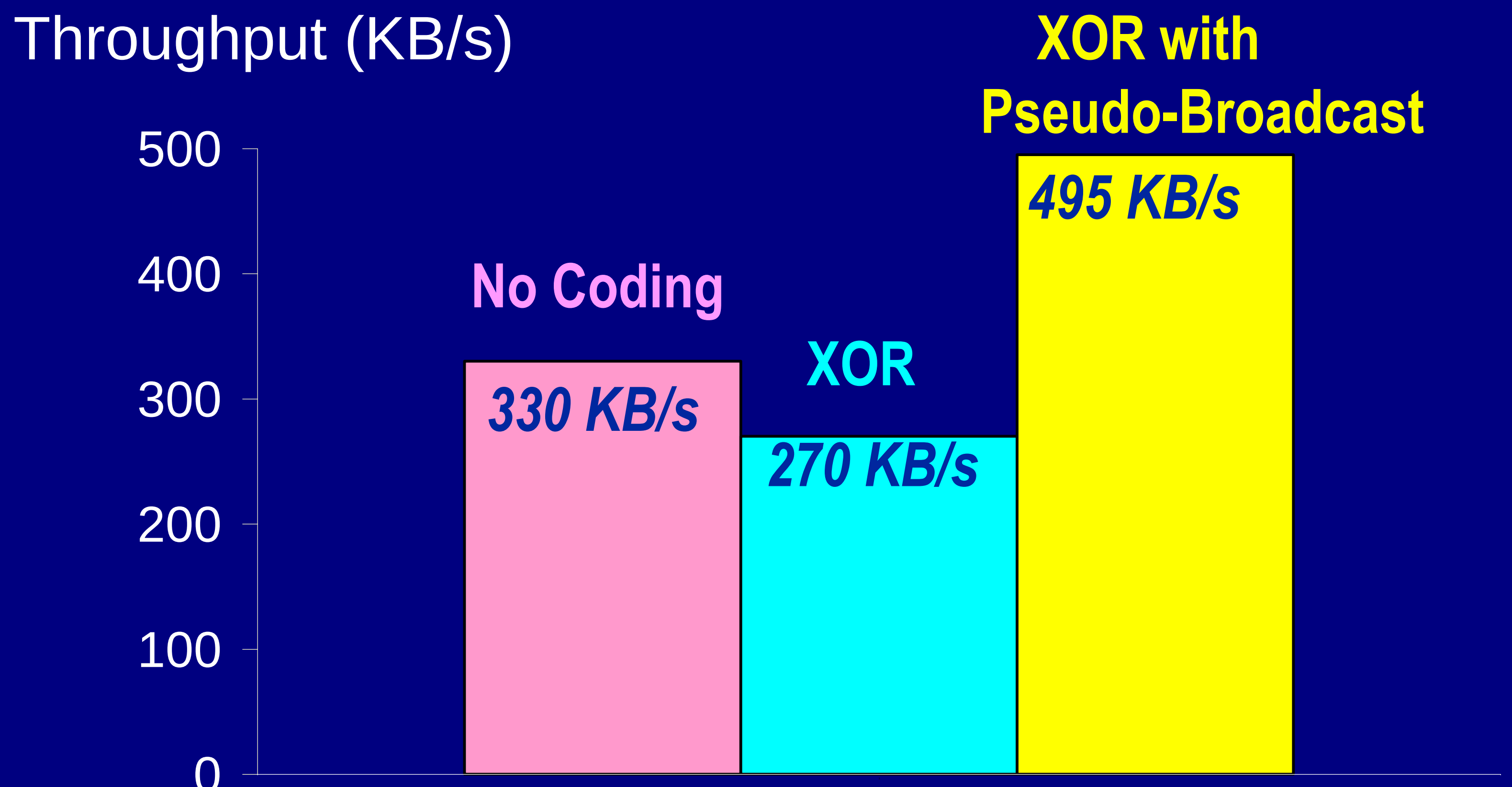
- Ideally, design a back-off scheme for broadcast channels
- In practice, we want a solution that works with off-the-shelf 802.11 drivers/cards

<u>Our Solution:</u> Pseudo Broadcast

Piggyback on 802.11 unicast which has synchronous Acks and backoff

- Each XOR-ed packet is sent to the MAC address of one of the intended receivers

XOR with Pseudo-Broadcast Improves Throughput



Improvement is more than 25% because 802.11 MAC gives nodes equal bandwidth shares

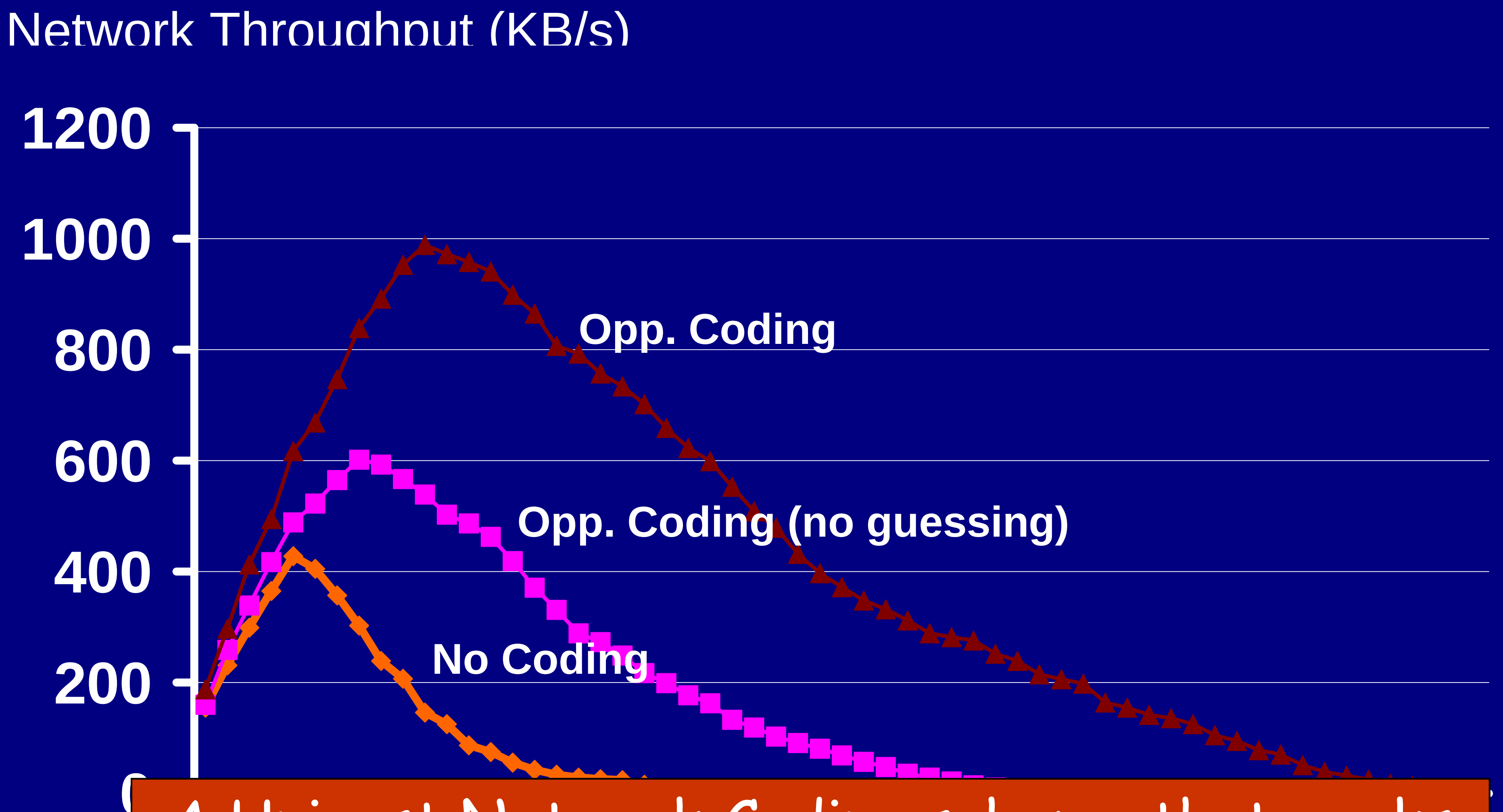
- Without coding, relay needs twice as much bandwidth
- With coding, all nodes need equal bandwidth

Larger experiment

- 100 nodes
- 800mx800m
- Senders and receivers are chosen randomly
- Metric:

  Total Throughput of the Network

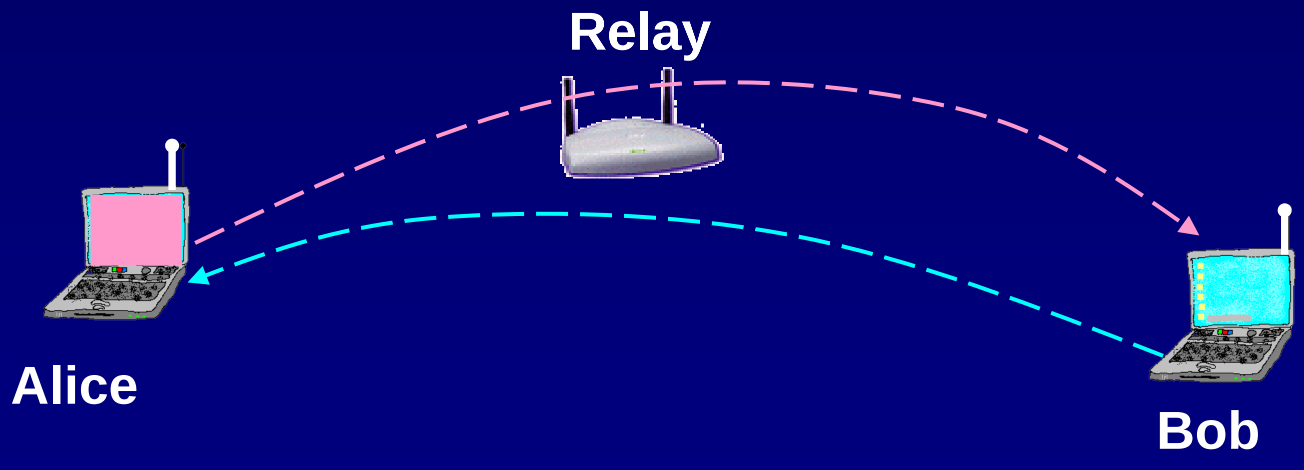
Opportunistic Coding vs. Current



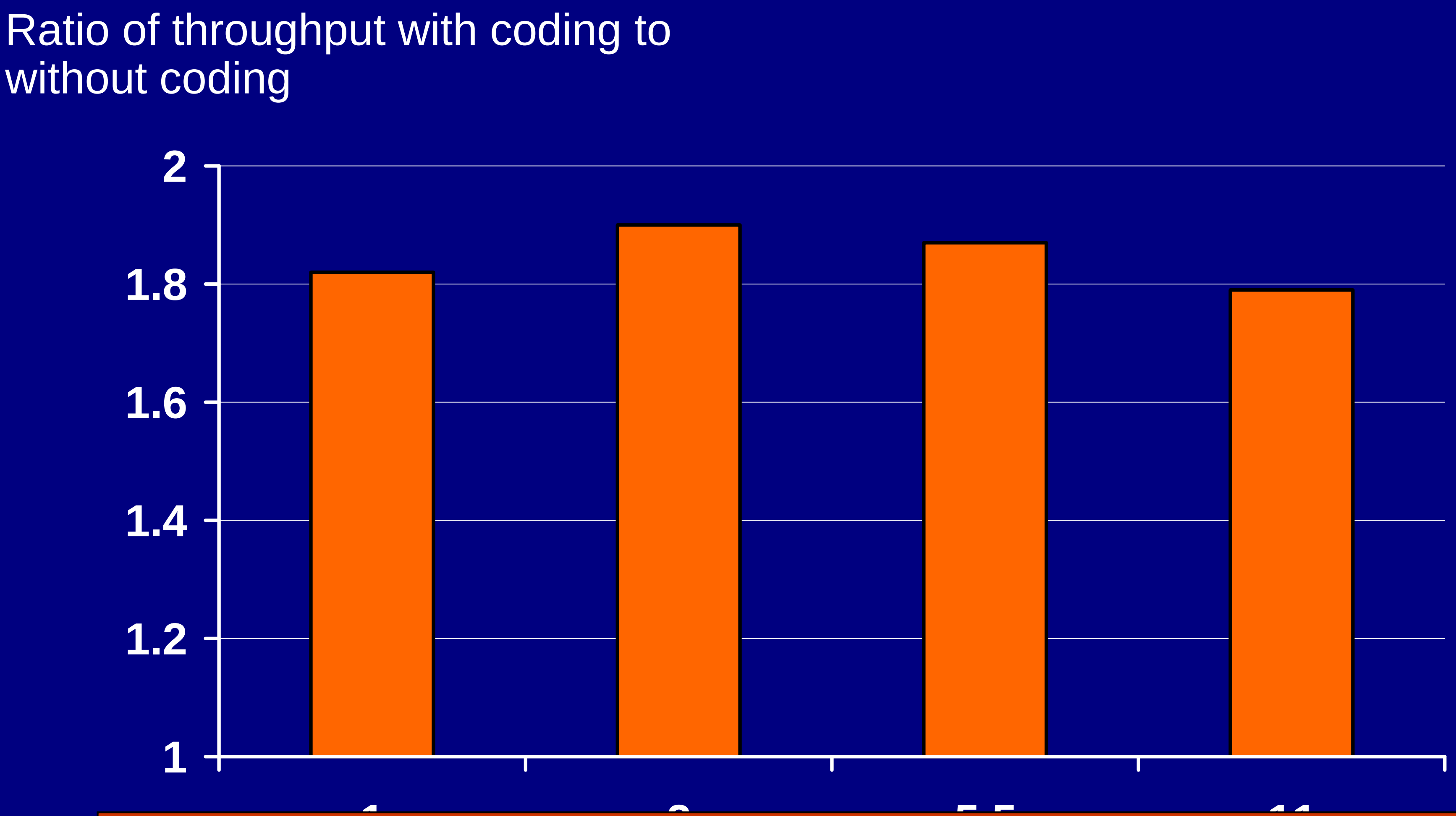
A Unicast Network Coding scheme that works well in realistic situations

Preliminary Implementation Results

- Linux Kernel
- 802.11 MAC
- Click Elements (part of Roofnet)
- Only Opportunistic Coding & Pseudo Broadcast (No opportunistic Listening)



Implementation Results



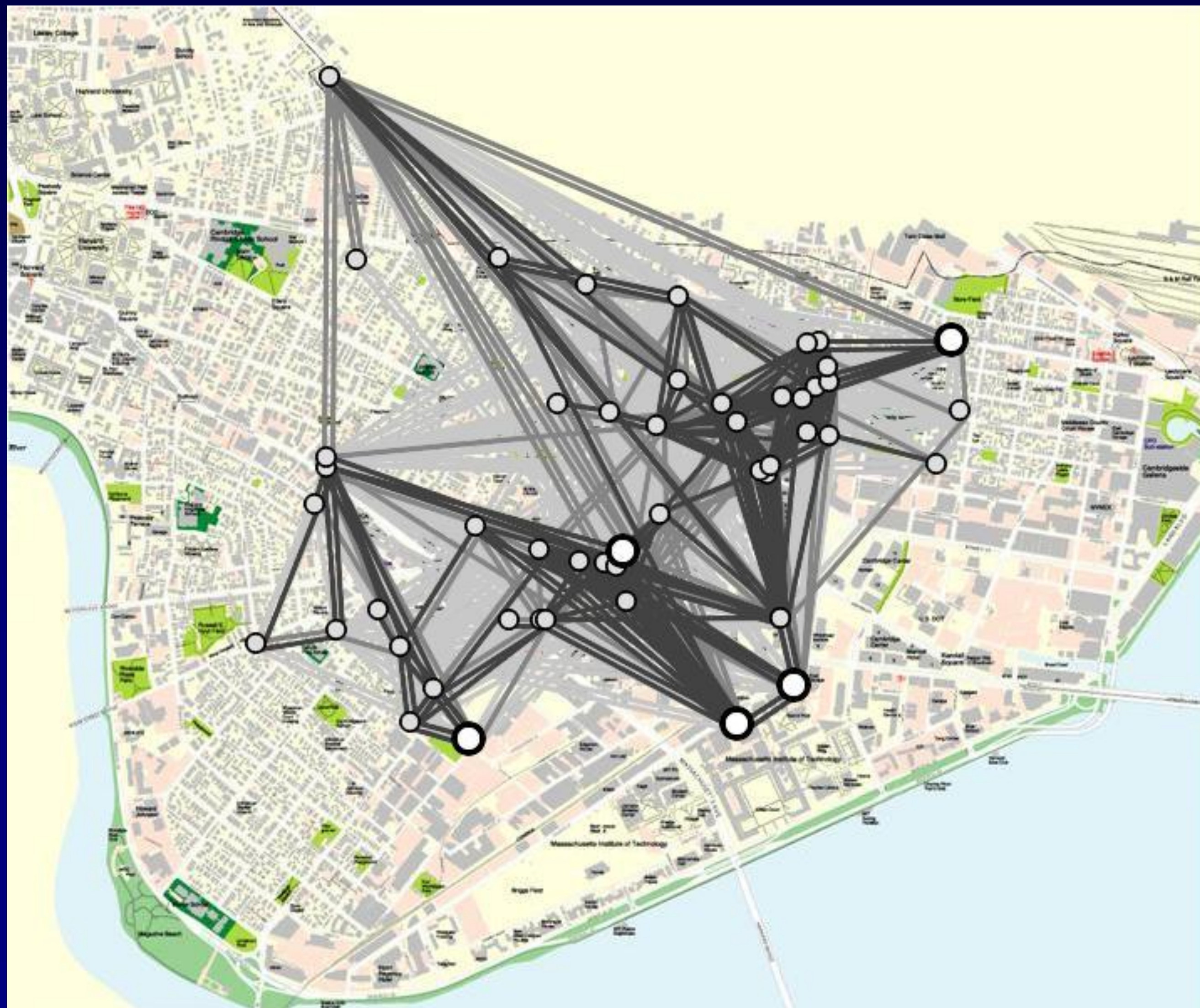
Network Coding Doubles the Throughput

Conclusion

- First implementation of network coding in a wireless network
- Learned Lessons
  - Be opportunistic (greed is good!)
  - Can do a good job with multiple unicast
  - 5x higher throughput in congested networks
  - Preliminary implementation results show throughput doubles

The Wireless Environment

Multi-hop wireless networks (e.g., Roofnet)



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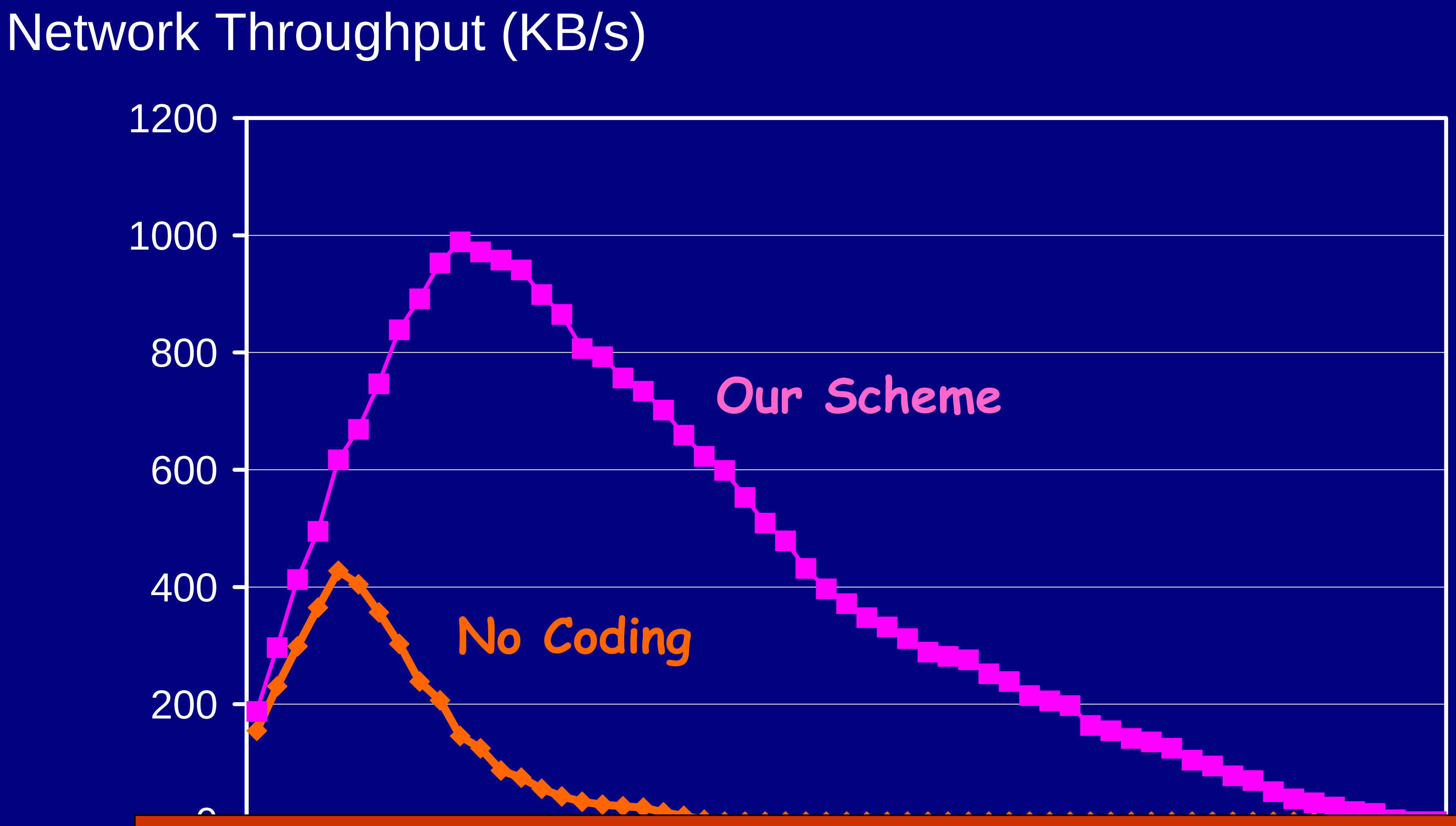

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