

Network Coded Wireless Networks

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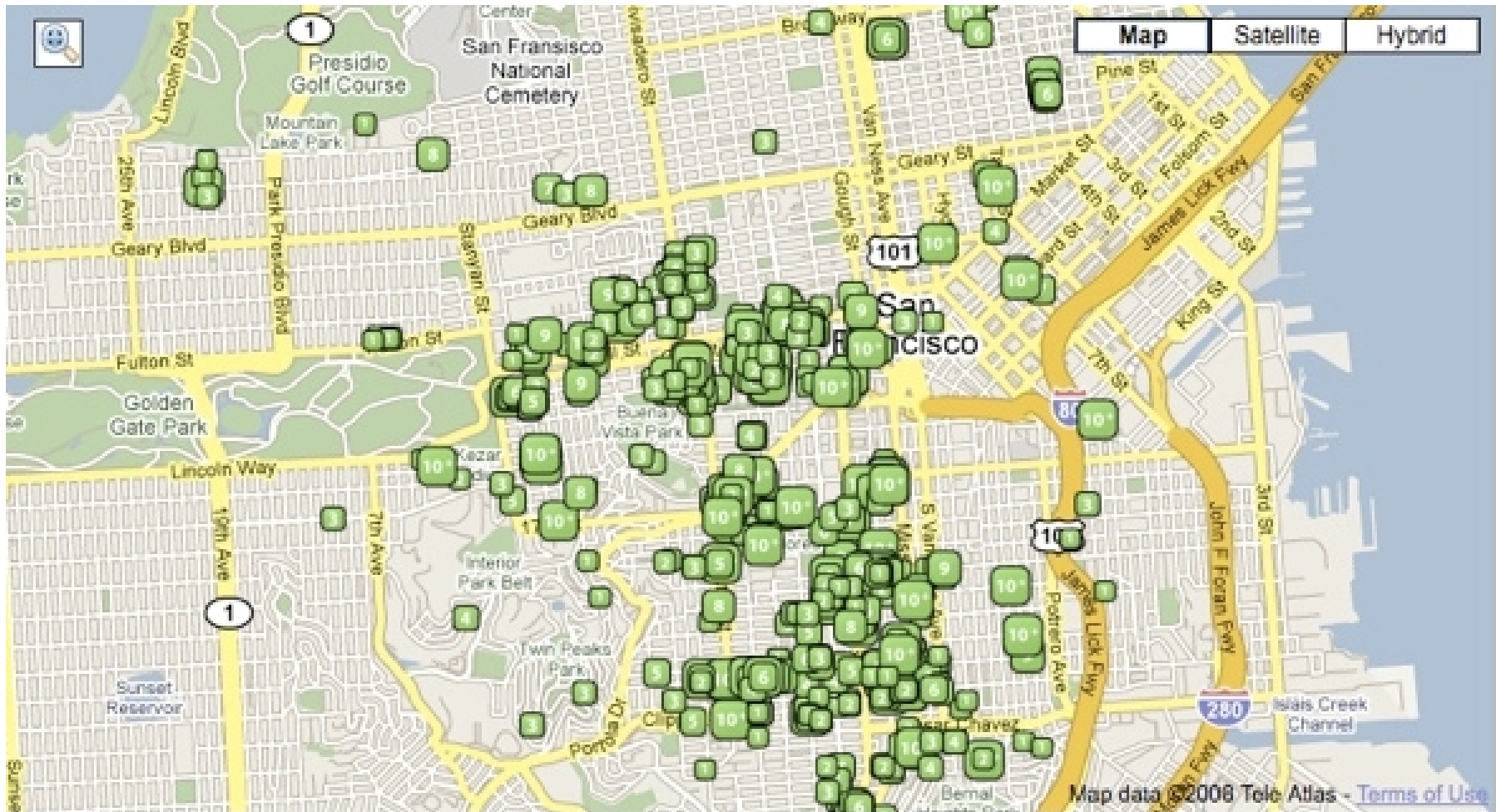
Wireless Mesh Networks



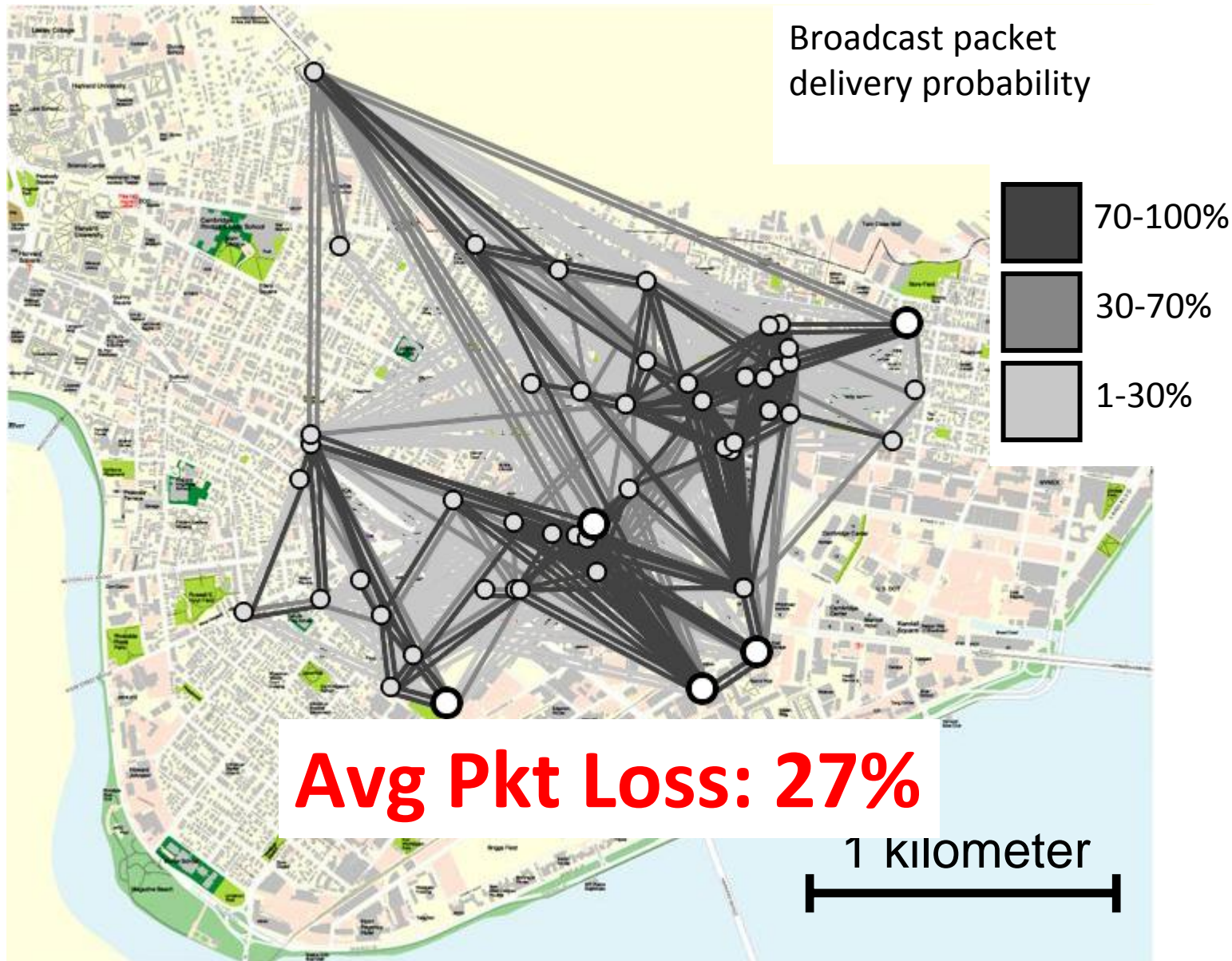
Decentralized, multi-hop wireless networks

- Chaotic: Easy to deploy
- Cheap: Dense and hence better coverage
- Decentralized: Self organizing and managing

Commercial Deployments: Free the Net (SF)



Wireless Mesh Networks – In Practice



Challenges: Wireless Properties

- Shared broadcast medium
 - Low throughput
- Interference
 - Conservative scheduling
- Variable link quality
 - Excessive retransmissions

This talk...

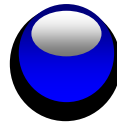
Exploiting the broadcast medium, interference and variability using network coding

Exploiting Broadcast

Current Approach



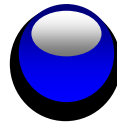
Router



Current Approach



Router

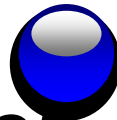


- Requires 4 time slots
- Can we do it in fewer time slots?

Network Coding Approach



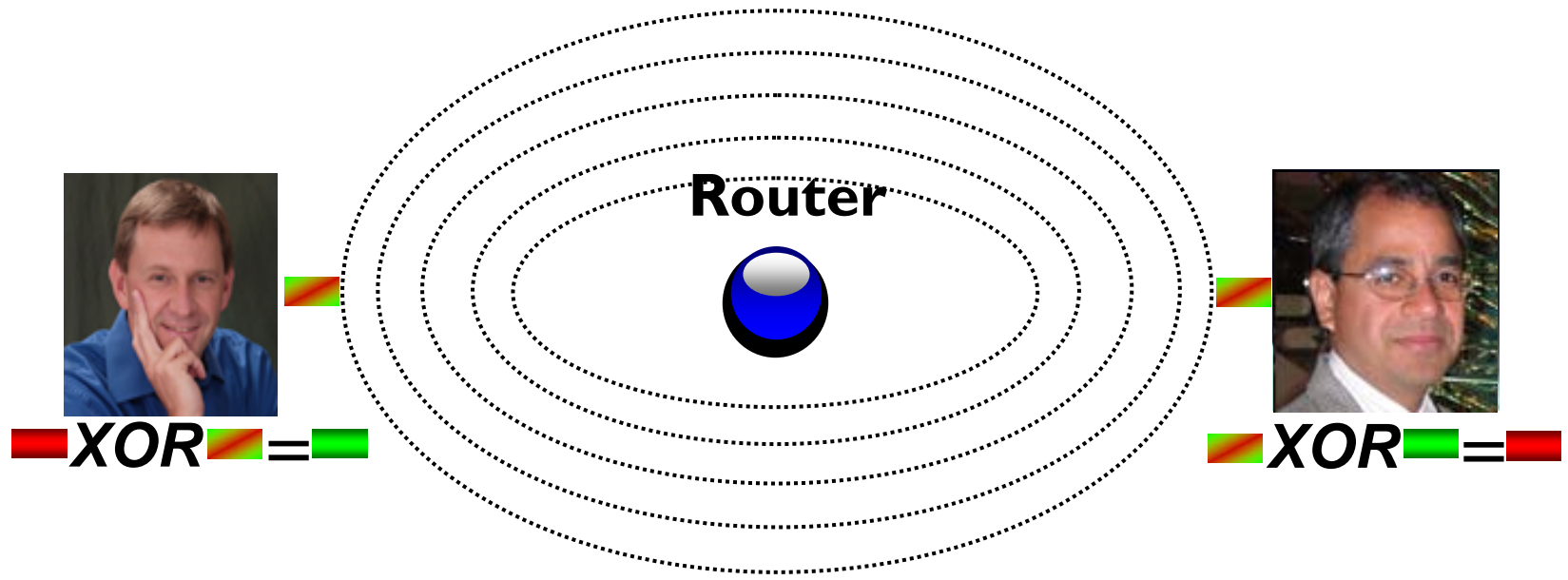
Router



$$\text{Red Square} \oplus \text{Green Square} = \text{Rainbow Square}$$

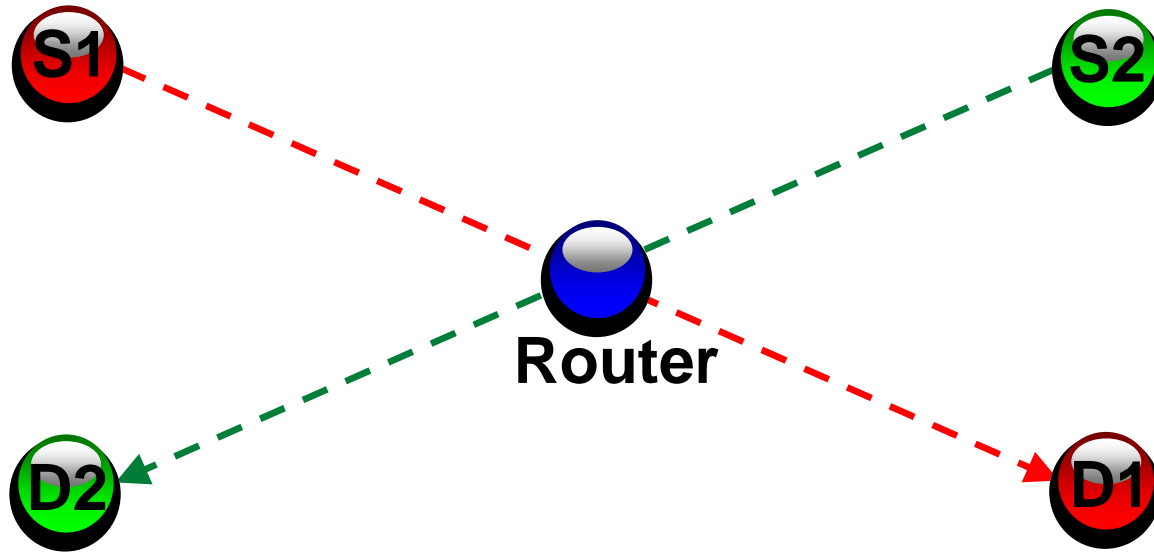


Network Coding Approach



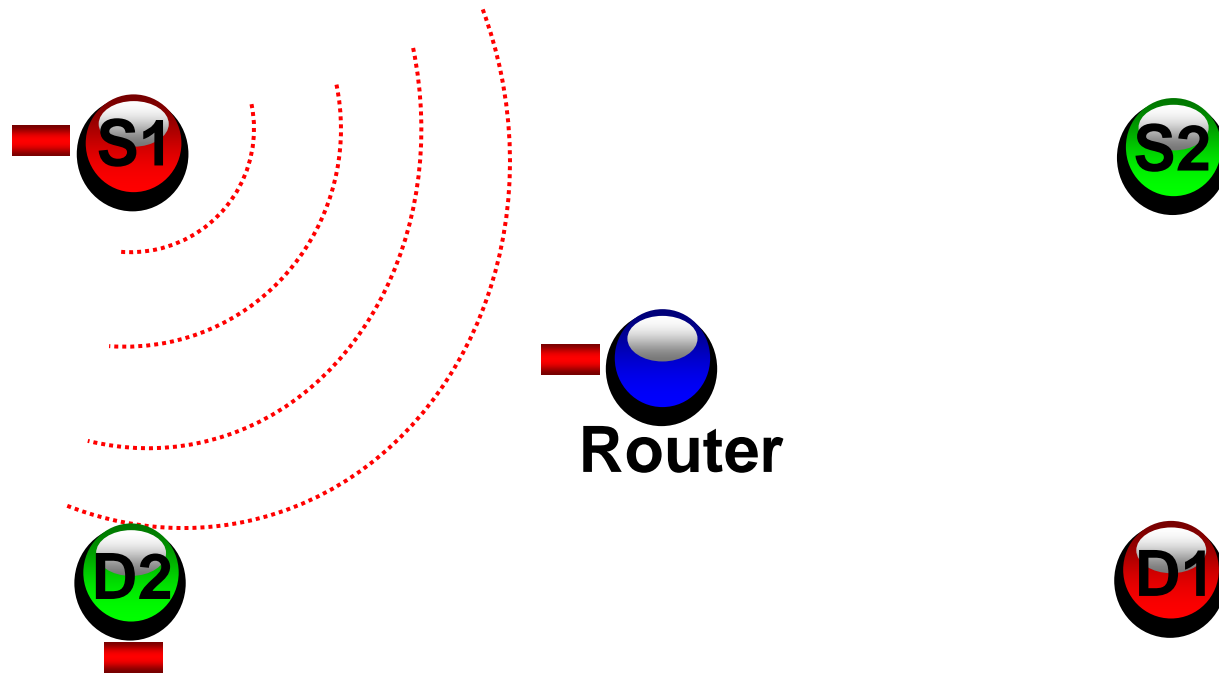
- Requires 3 time slots instead of 4
- Fewer time slots → Higher throughput

Beyond duplex flows



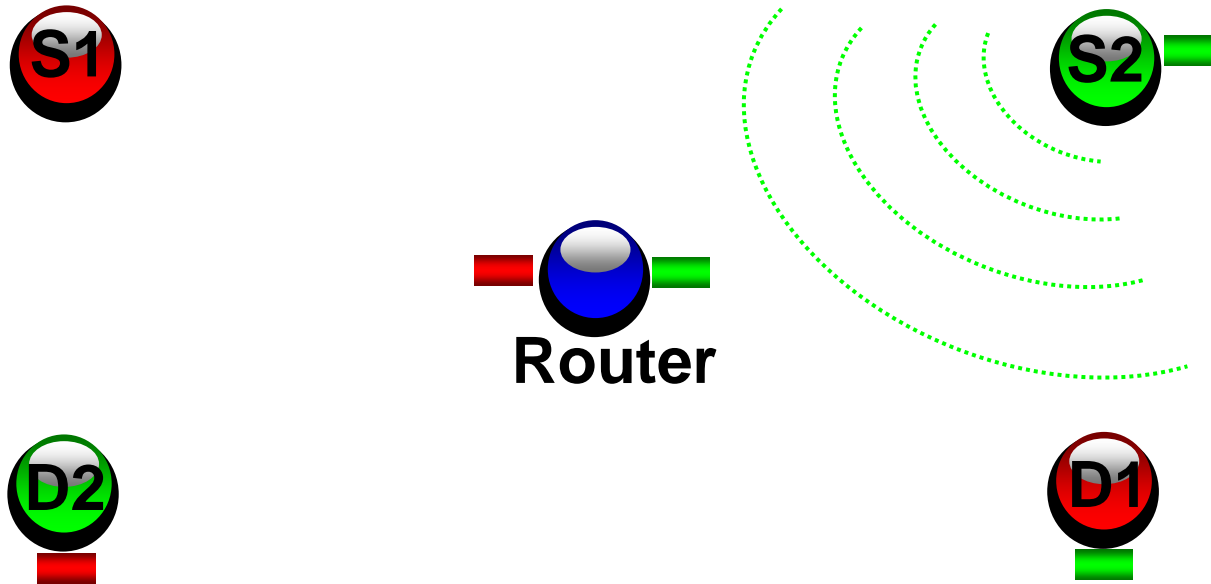
Two flows that intersect at a router

Beyond duplex flows

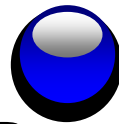


Traditional approach: D2 drops the packet

Beyond duplex flows



Beyond duplex flows

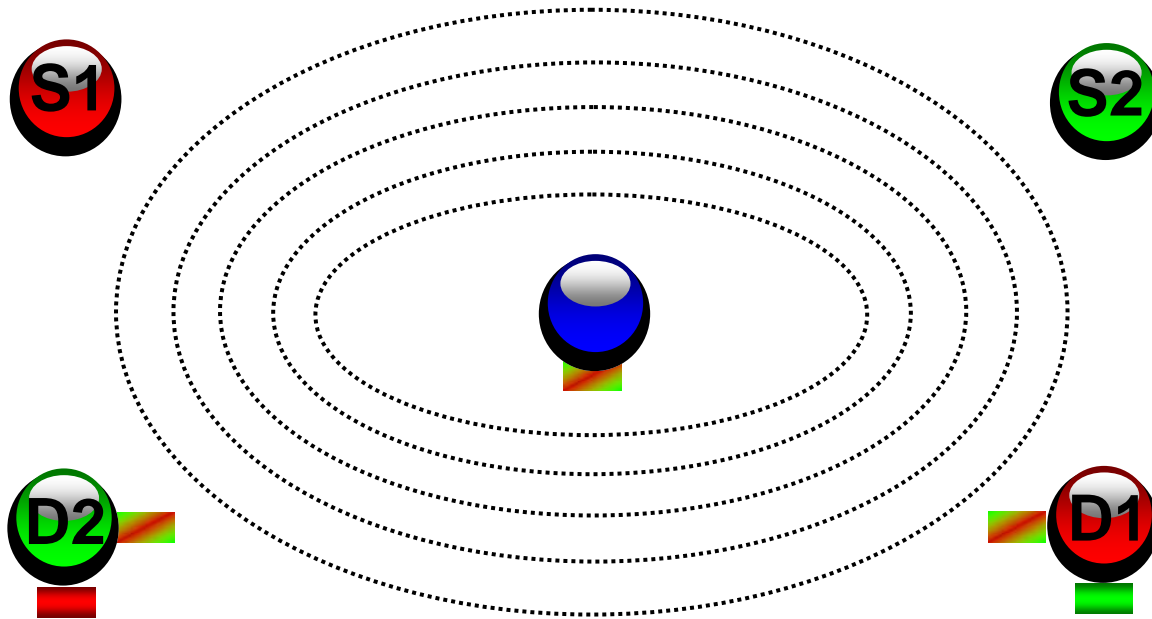


Router

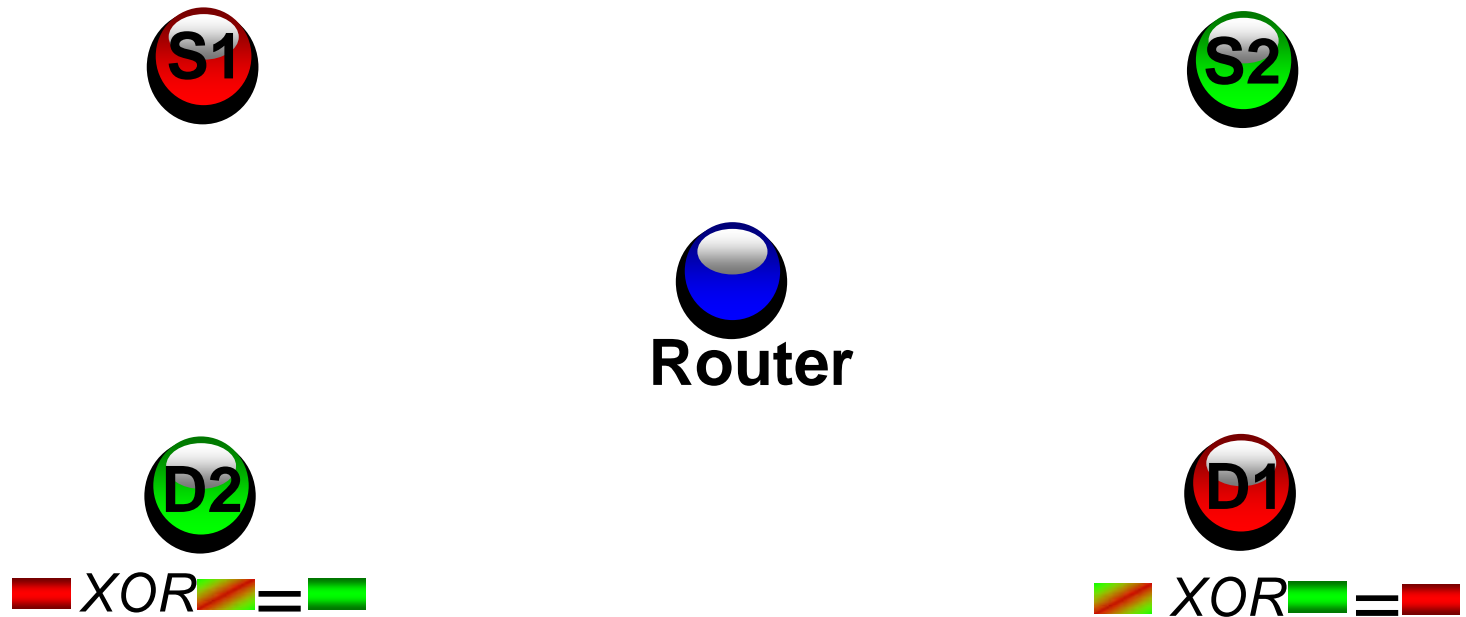
$$\text{red} \oplus \text{green} = \text{orange}$$



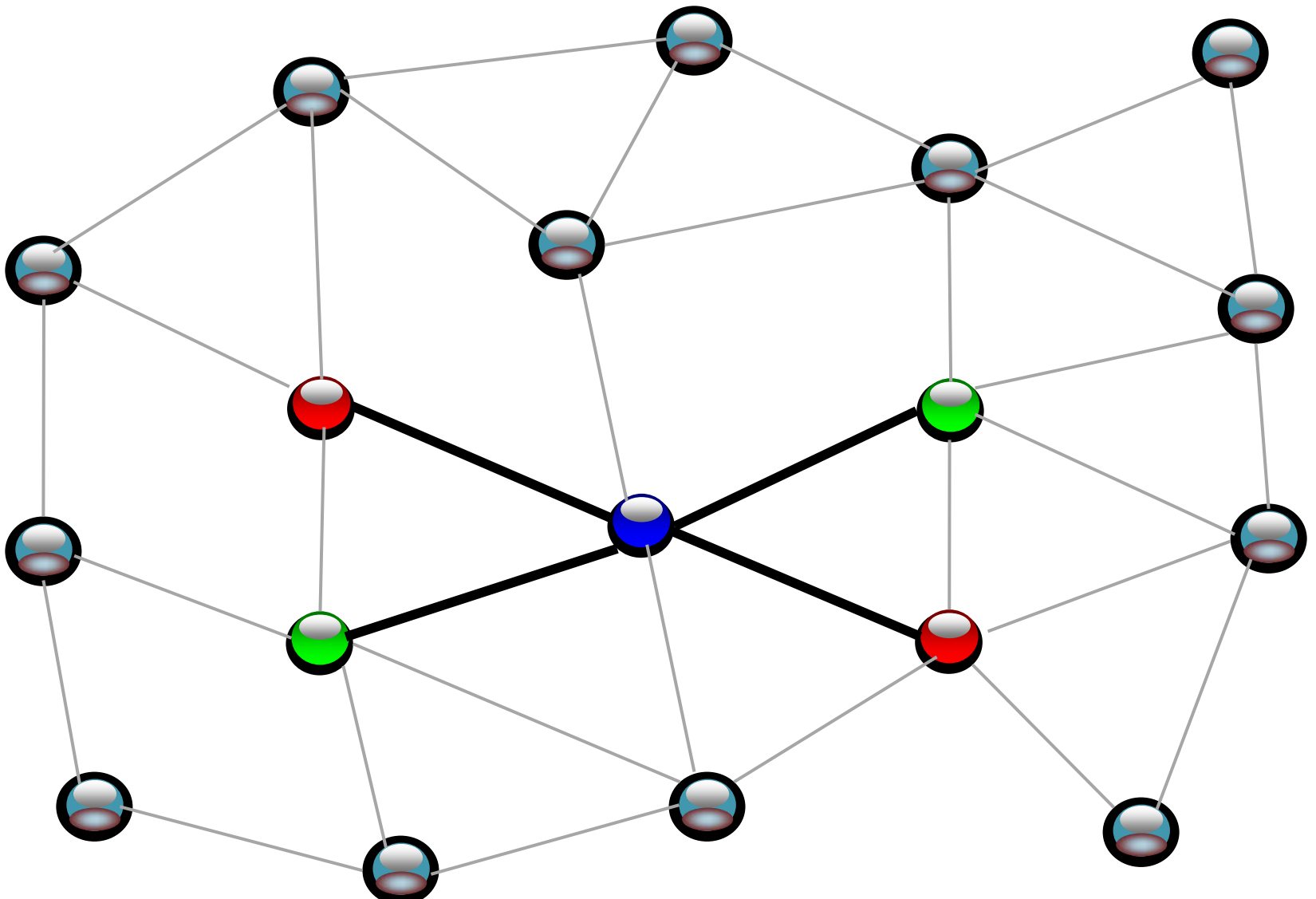
Beyond duplex flows



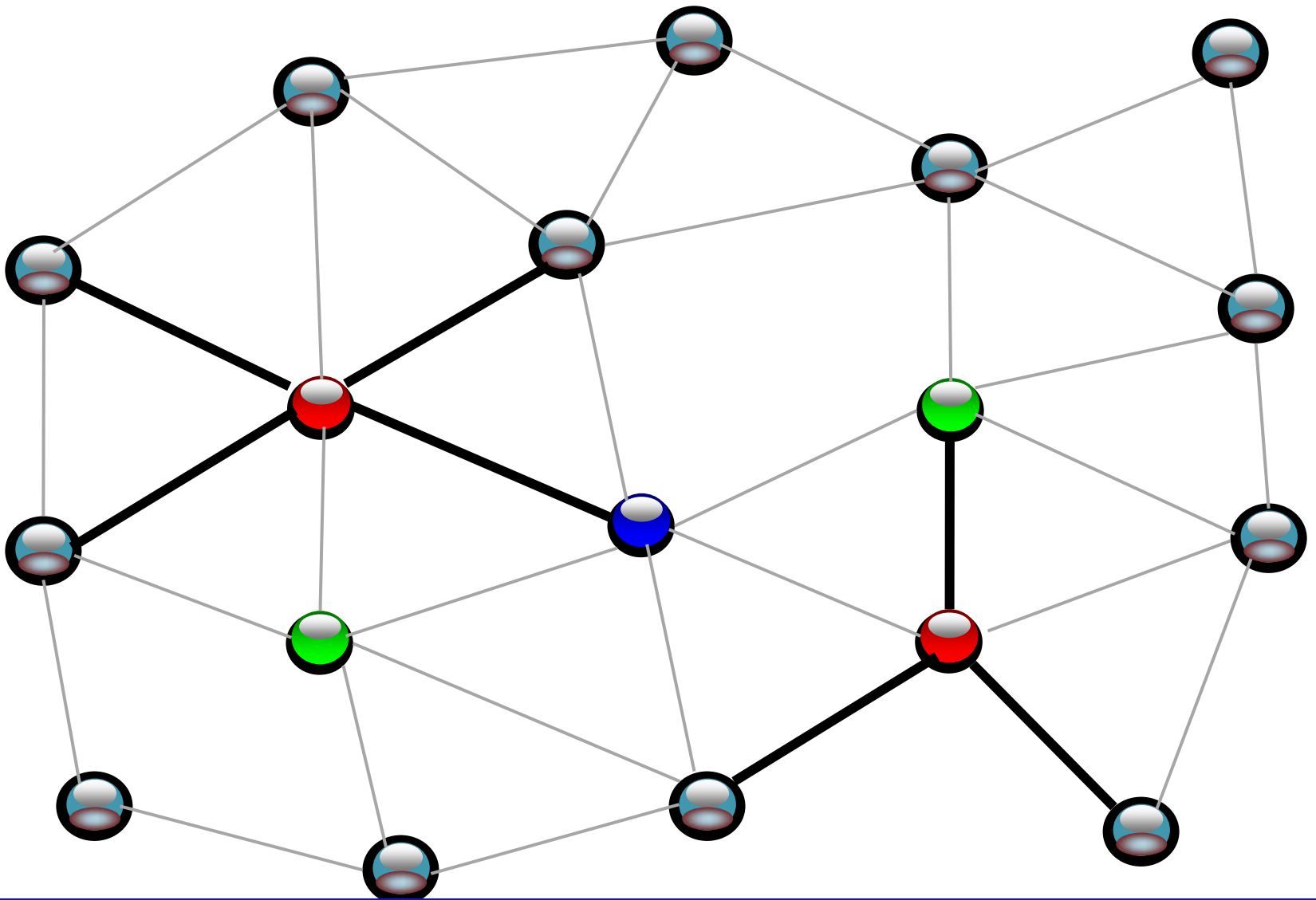
Beyond duplex flows



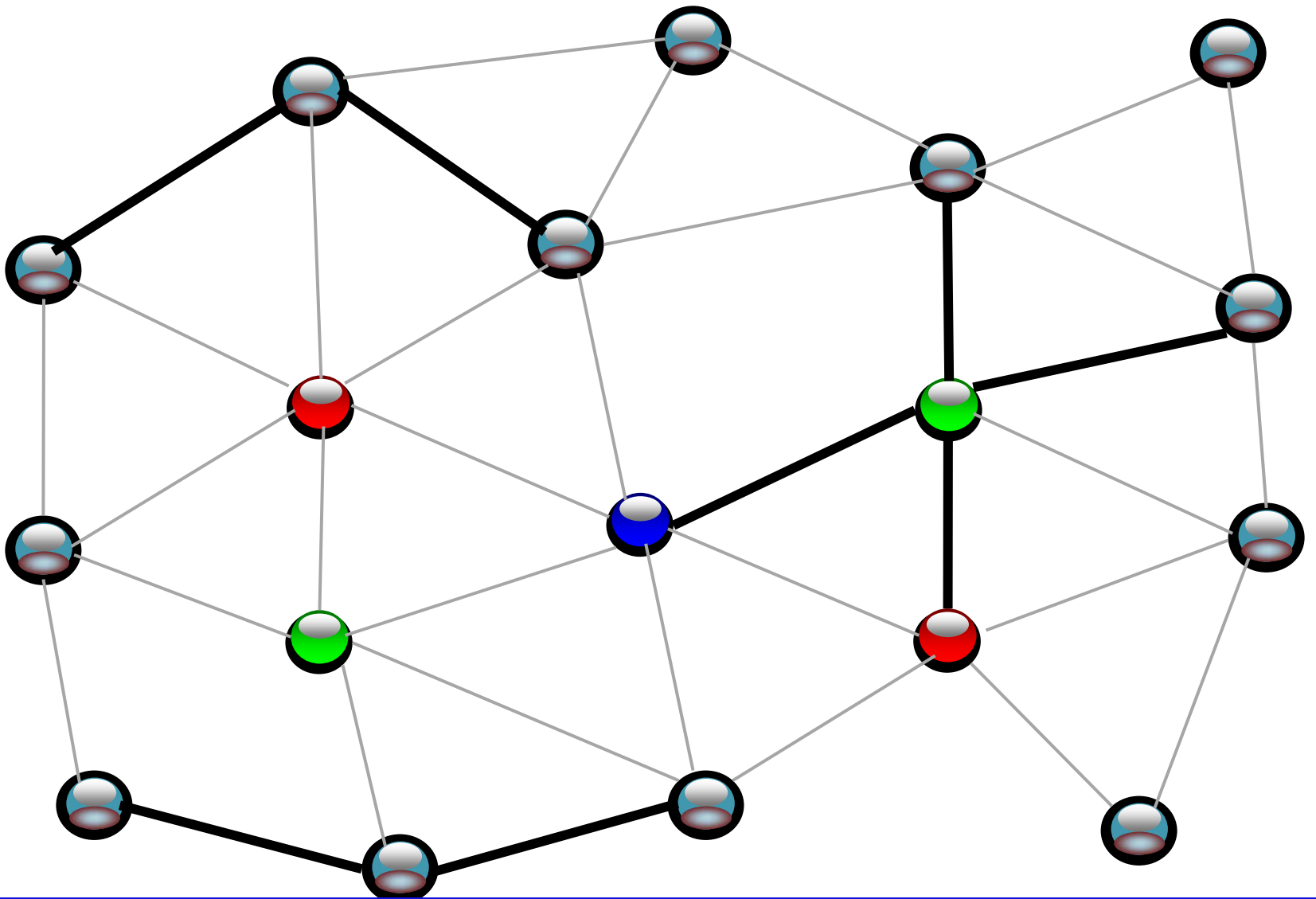
- Requires 3 time slots instead of 4
- Shared broadcast medium creates opportunities



Generalizes to arbitrary flows and topologies



Generalizes to arbitrary flows and topologies



Generalizes to arbitrary flows and topologies

Departures

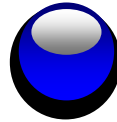
- Dispose of point to point abstraction
 - Exploit shared broadcast medium
- Routers mix packet content before forwarding → **Network coding**
 - Works for both unicast multicast flows
 - Works in dynamic & unknown environment

Exploiting Interference

Beyond COPE



Router

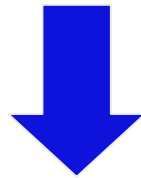


Traditional Forwarding requires 4 time slots

Can we do it in 2 time slots?

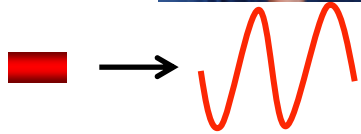
Instead of router mixing packets...

Exploit that the wireless *channel naturally mixes signals when packets interfere!*

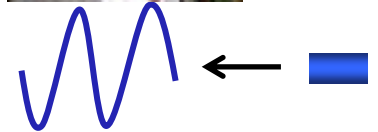
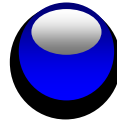


Analog Network Coding (ANC)

Analog Network Coding



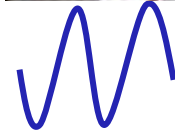
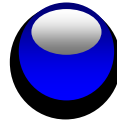
Router



Analog Network Coding



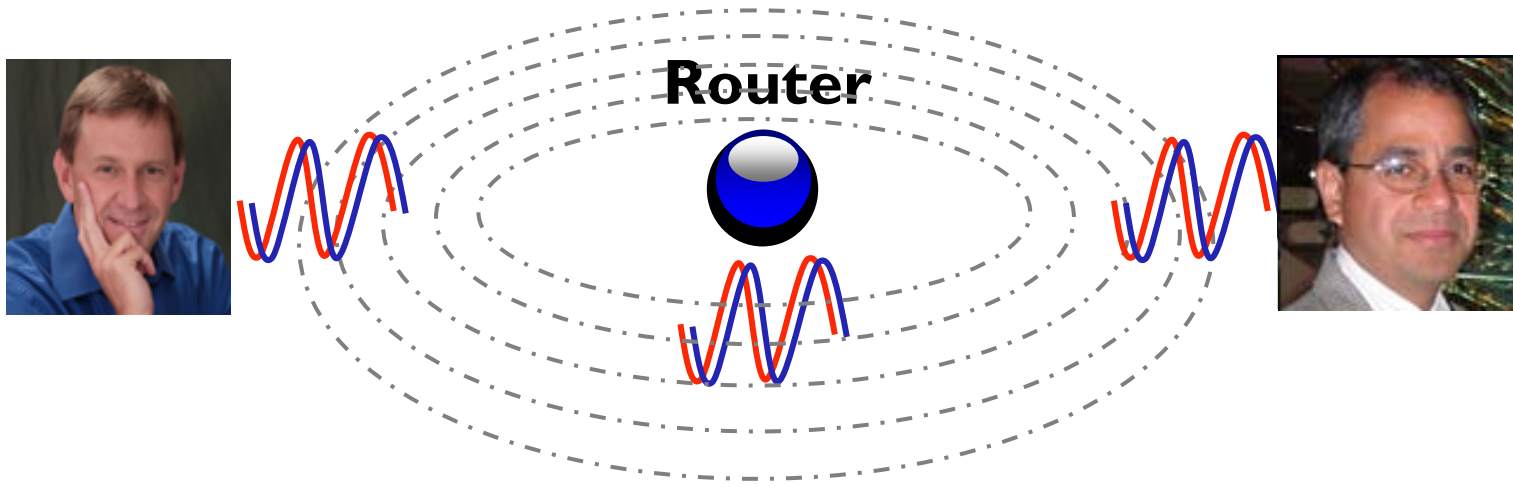
Router



Interference

- 1) Nick and Guru transmit simultaneously

Analog Network Coding

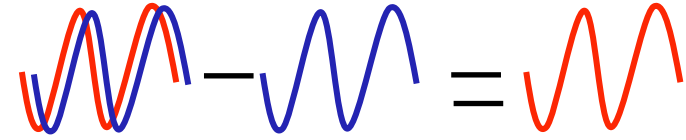
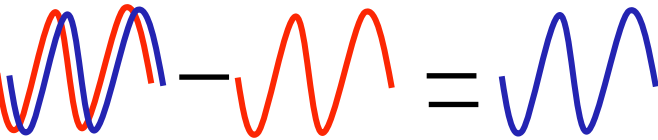
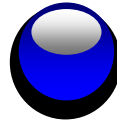


- 1) Nick and Guru transmit simultaneously
- 2) Router amplifies and broadcasts interfered signal

Analog Network Coding



Router

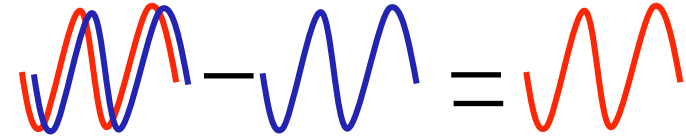
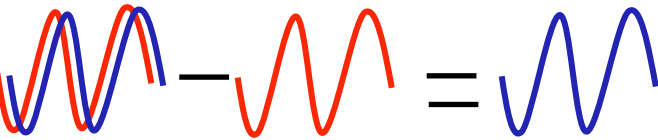
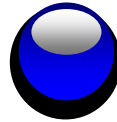


- 1) Nick and Guru transmit simultaneously
- 2) Router amplifies and broadcasts interfered signal
- 3) Nick subtracts known signal from interfered signal

Analog Network Coding



Router



**Analog Network Coding requires 2 time slots
→ Higher throughput**

Departures

- Philosophical shift in **dealing with interference**
 - Strategically exploit interference instead of avoiding it
 - New ways of **dealing with hidden terminals**
- New notion of network coding → Channel mixes signals, router simply amplifies and forwards

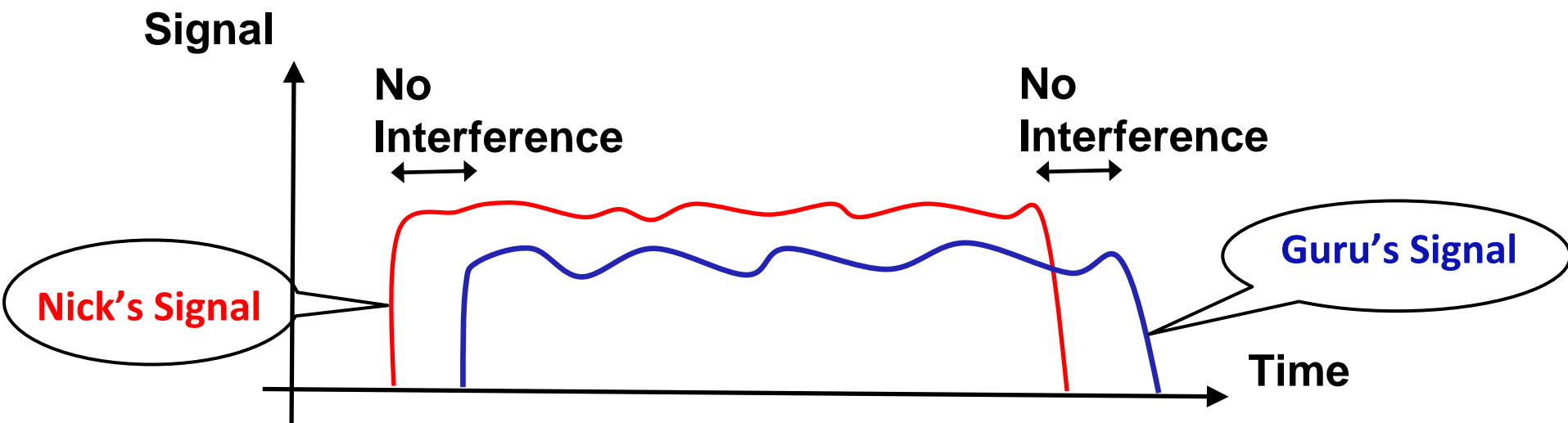
How do we make it work?

Challenges

- Interfered signal is not exactly the sum
 - Channel distorts signals
 - Two signals are never synchronized
 - It is not $s_N(t) + s_G(t)$ but $f1(s_N(t)) + f2(s_G(t-T))$

Key Idea: Exploit Asynchrony!

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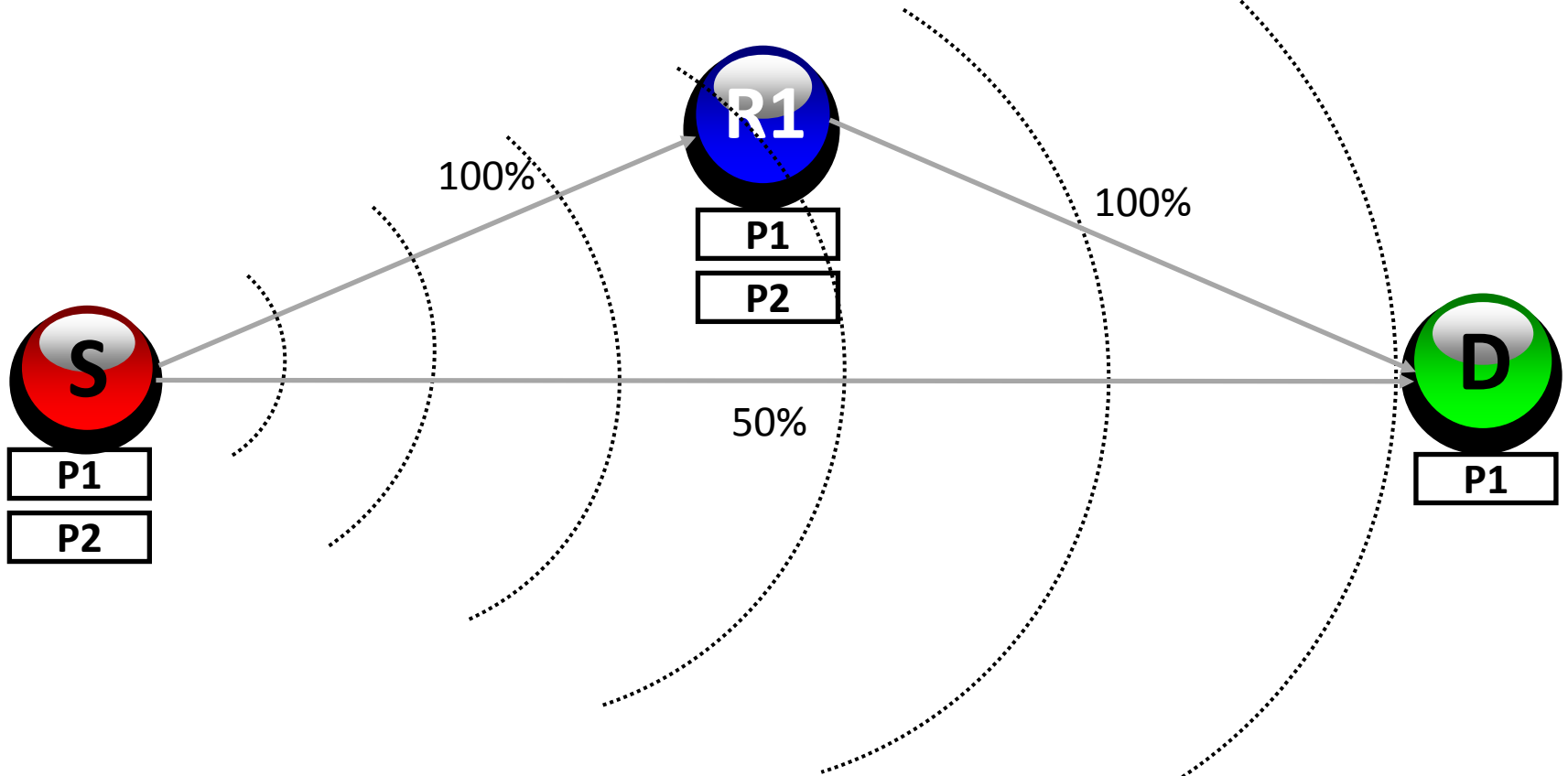


- Nick uses interference-free parts to estimate channel distortion and timing
- Nick compensates for his interfering signal

Exploit asynchrony to make it practical

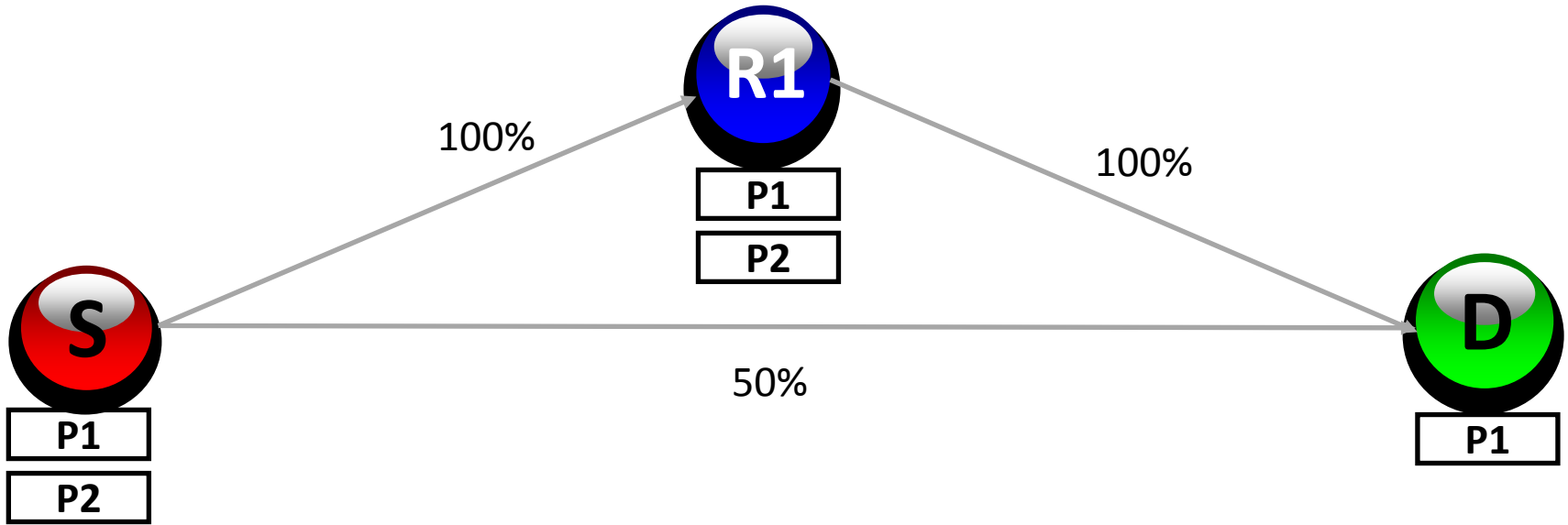
Exploiting Variable Links

Variable Link Quality



Variable link quality → Opportunistic Packet Receptions

How to Exploit Opportunistic Receptions?



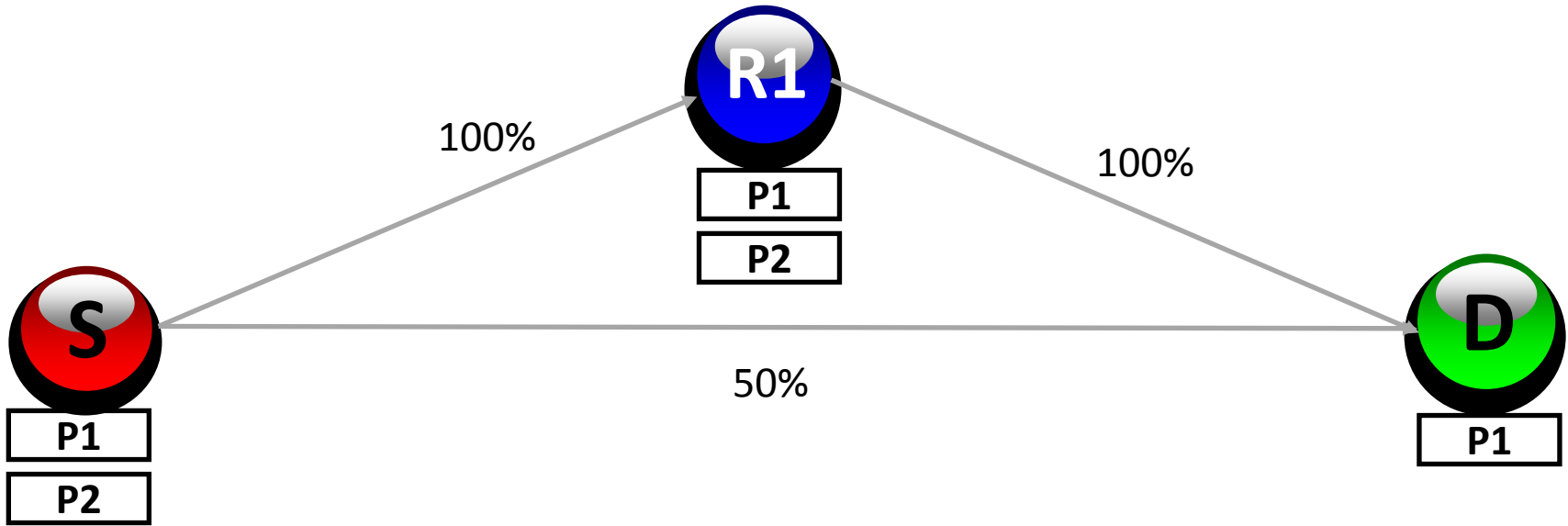
Overlap in received packets

Potential solutions

1) Forward everything → **Inefficient**

2) Coordinate → **Unscalable**

Network Coding to Exploit Variable Links



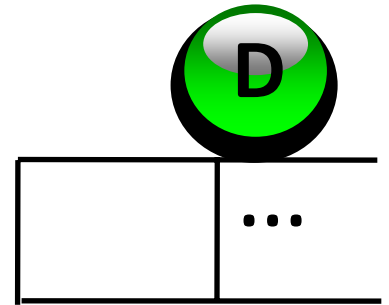
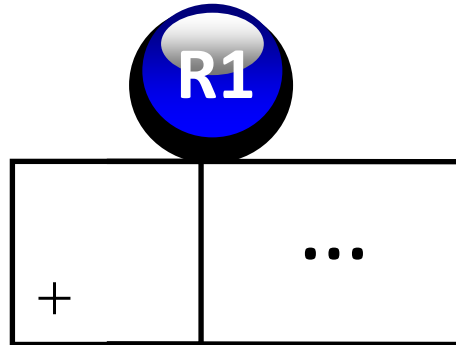
Forward random combinations of packets

Network Coding to Exploit Variable Links



Routers create random combinations of packets

Network Coding to Exploit Variable Links



Solve 2
equations



Network Coding

- No duplicates → Efficient
- No coordination → Scalable

R

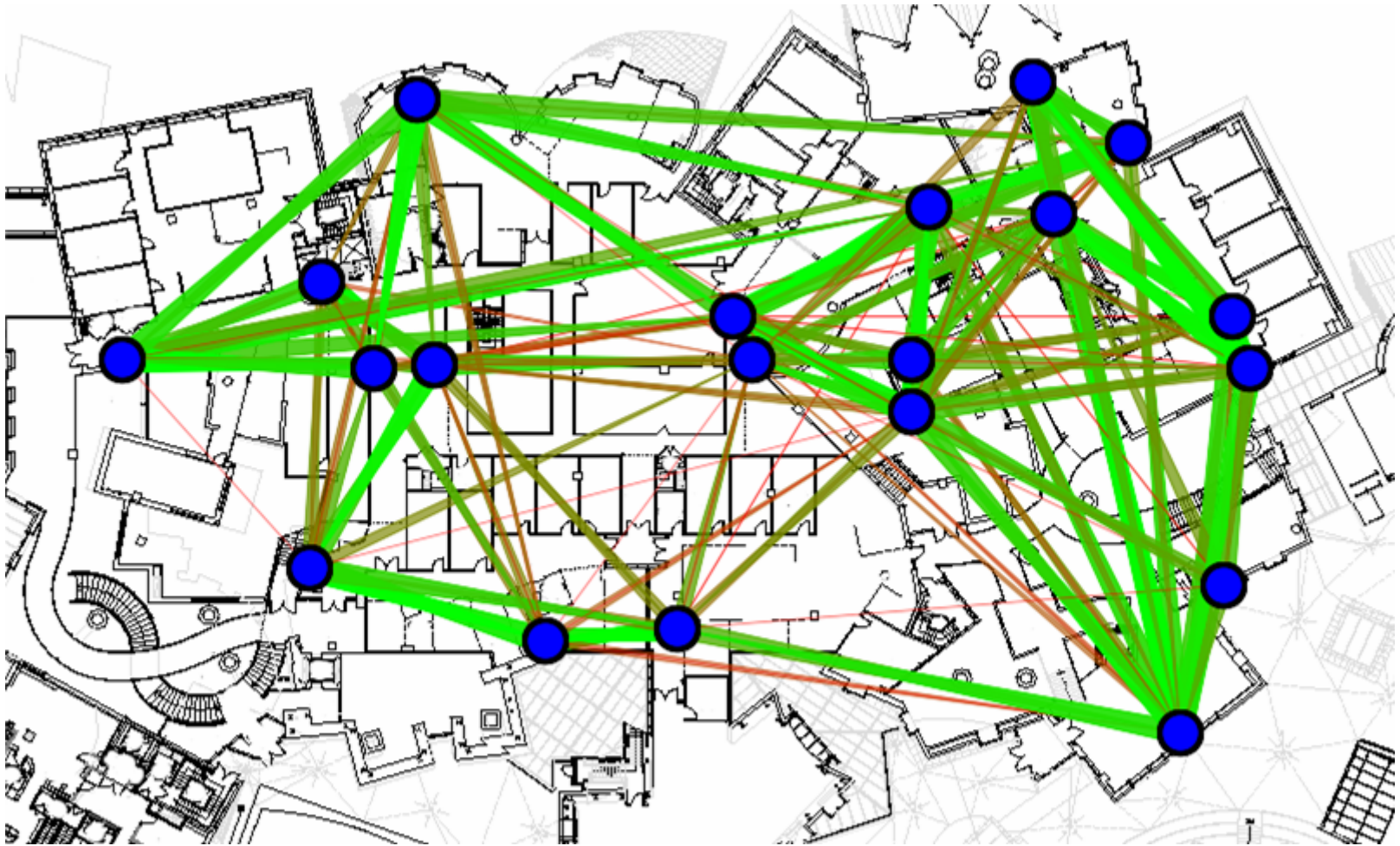
Departures

- Current Architecture:
 - Deliver packets link by link to destination
 - Limits throughput
- Network Coded Architecture:
 - Exploits opportunistic receptions to increase throughput

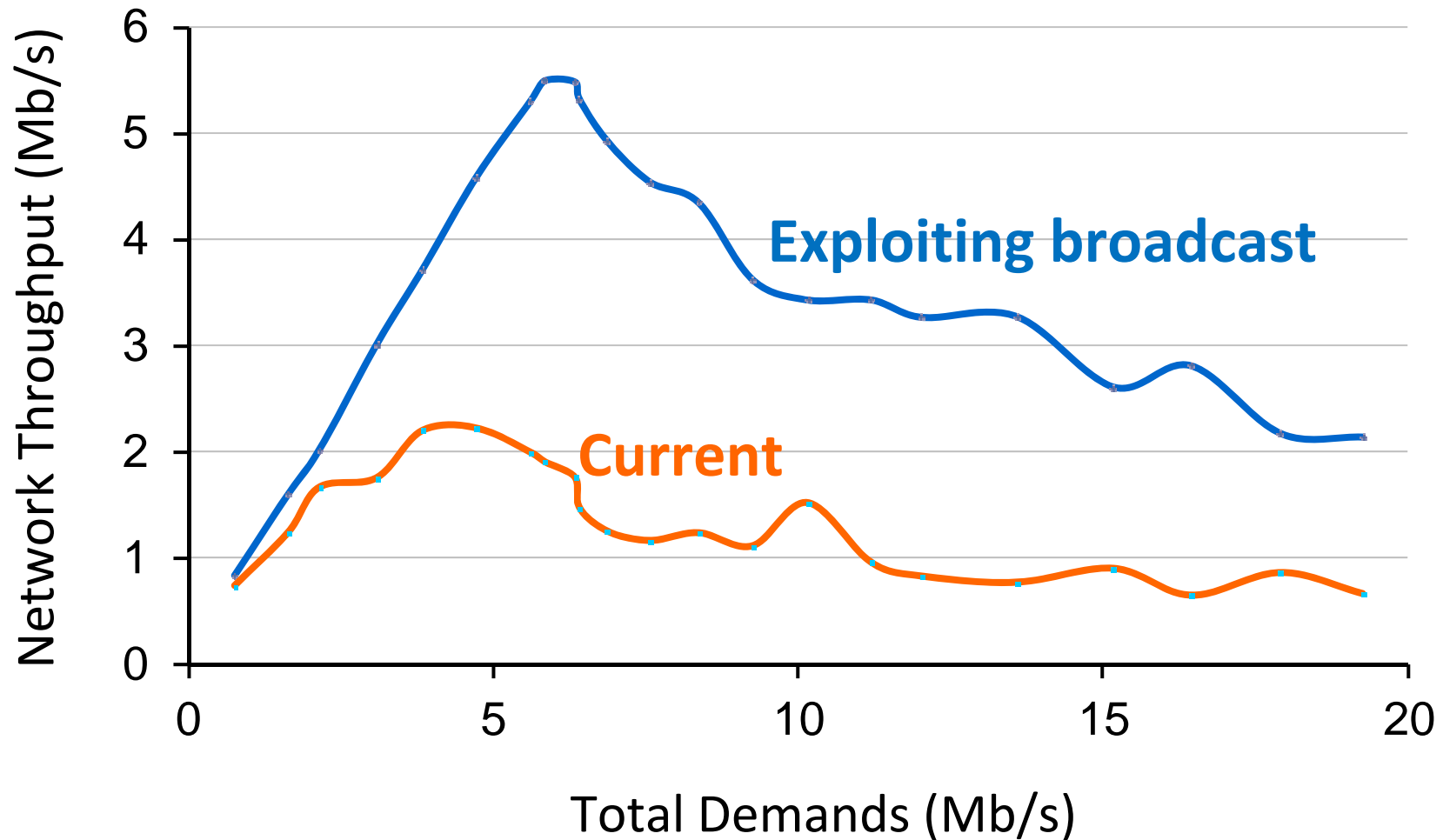
Performance in Practice

Testbed

- 20-node testbed over three floors

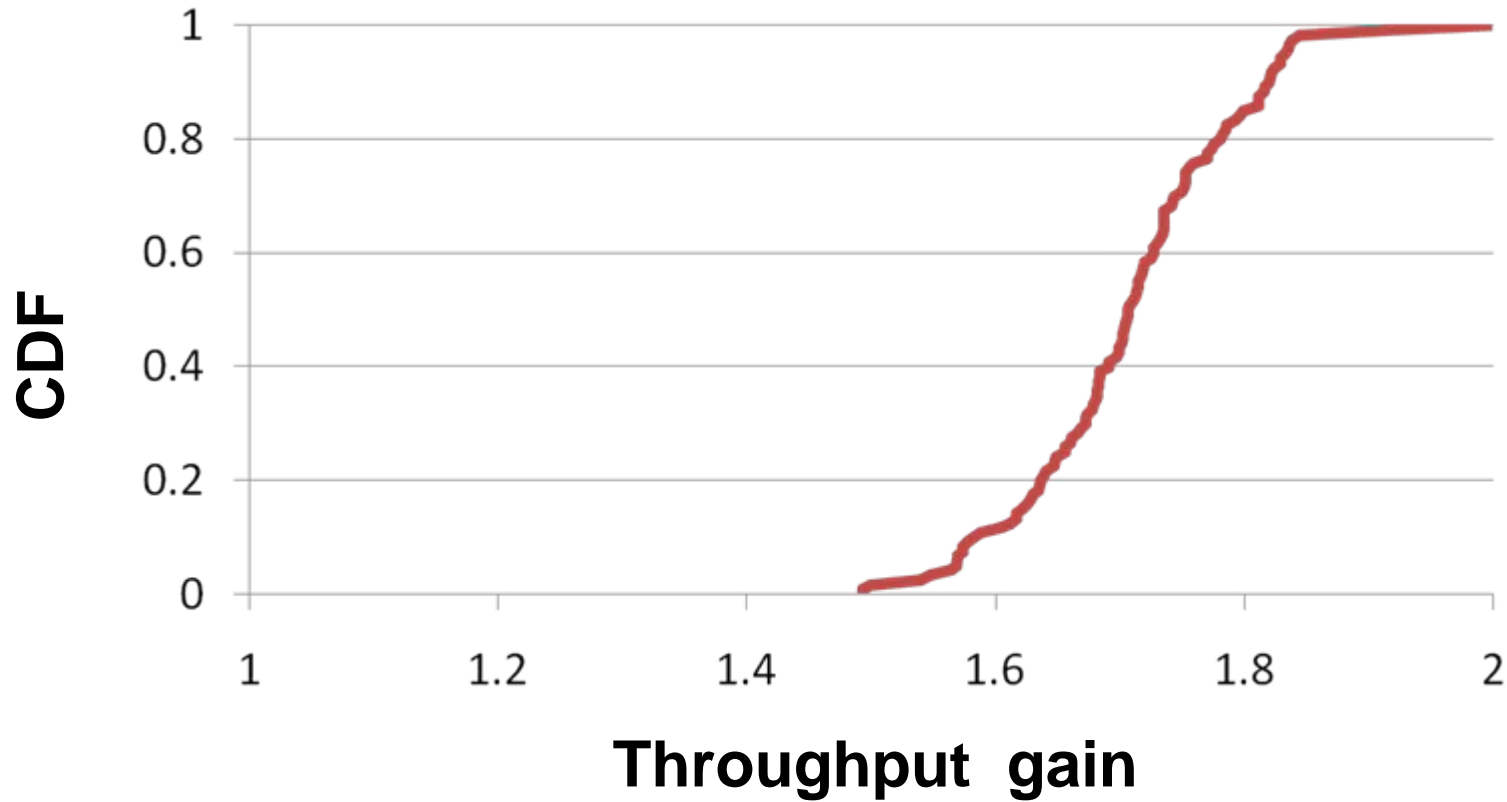


Throughput Gains: Exploiting Broadcast



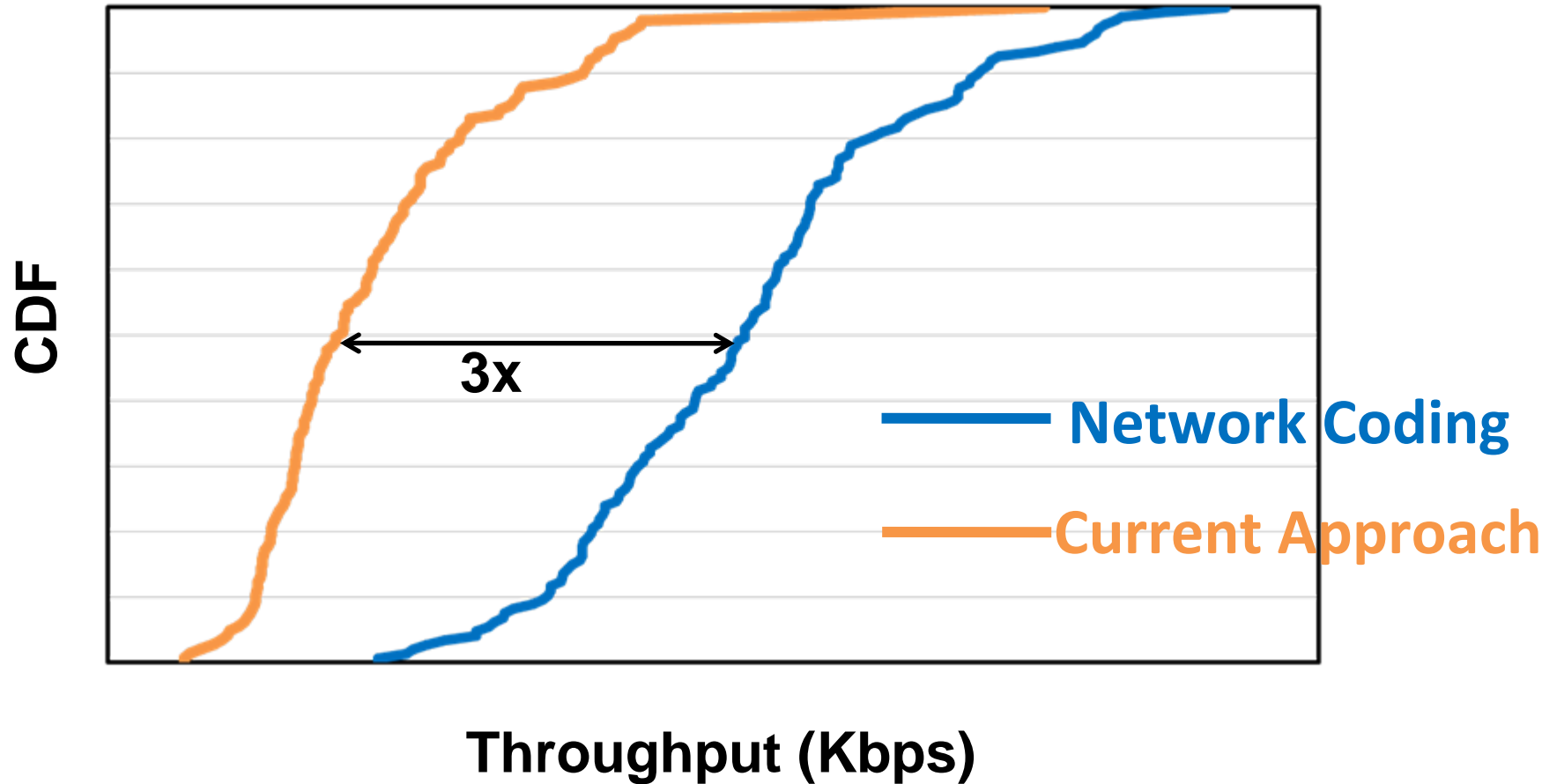
3-fold throughput increase in congested networks

Throughput Gains: Exploiting Interference



Median Gain over Current: 70%

Throughput Gains: Exploiting Variable Links



Throughput increase: 3x over current approach

Conclusion

Network coding is a general technique for wireless mesh network design

- Simple & scalable algorithmic framework for using network coding in wireless networks
- Systematically exploits broadcast, strategic interference & variable links
- Prototype implementations and experimental evaluations showing large throughput gains