# Lecture 07-03: Network Layer Routing in Mesh Network

CS 356R

Intro to Wireless Networks

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Internet Reference Model

| Example Protocols | | Responsible for |
|---|---|---|
| FTP, HTTP, SMTP | Application | application specific needs |
| TCP, UDP | Transport | process to process data transfer |
| IP | Network | host to host data transfer across different network |
| Ethernet, WiFi | Link | data transfer between physically adjacent nodes |
| 802.3 PHY | Physical | bit-by-bit or symbol-by-symbol delivery |



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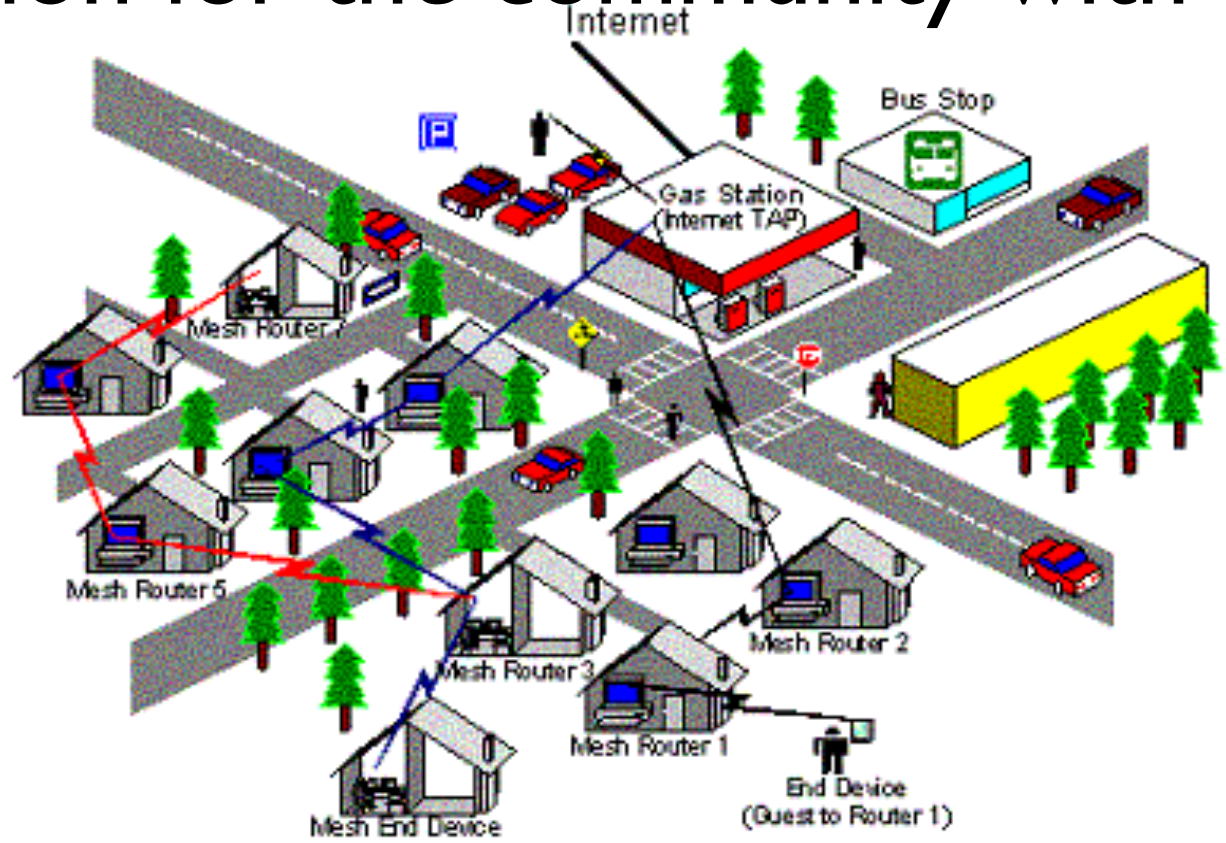
# Outline

1. What is Wireless Mesh Network?

# Multi-hop Wireless Networks

| | Stationary Nodes | Mobile Nodes |
|---|---|---|
| Motivating scenario | Community wireless networks (Mesh Networks) | Battlefield networks |
| Key challenge | Improving Network Capacity | Handling mobility, limited power. |

# Wireless mesh networks provides Internet connection for the community with lower cost




Mesh routers should be deployed throughout the community

Typically assumes using 802.11 WiFi

# Routing challenges in mesh network

How to determine "best routes" over wireless links

- Links are lossy
- Transmissions among nodes create interference
- Routing metric

What should be the "cost" of the links?

# Outline

1. What is Wireless Mesh Network?
2. Routing metrics in mesh networks

# Potential metrics in wireless mesh routing

- End-to-end delay
- Per-link delivery ratio
- Throughput of a path's bottleneck link

# End-to-end delay

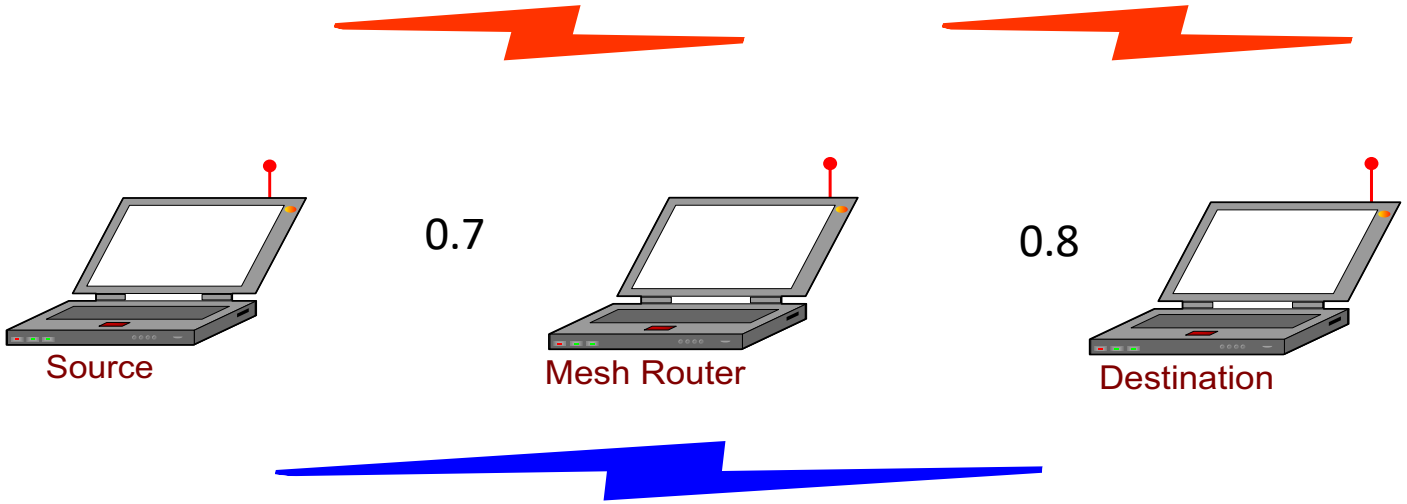
- Pick a route that has lowest end-to-end delay
- Would it work?

End-to-End delay depends on the traffic + interference

# How about measuring something per-link?

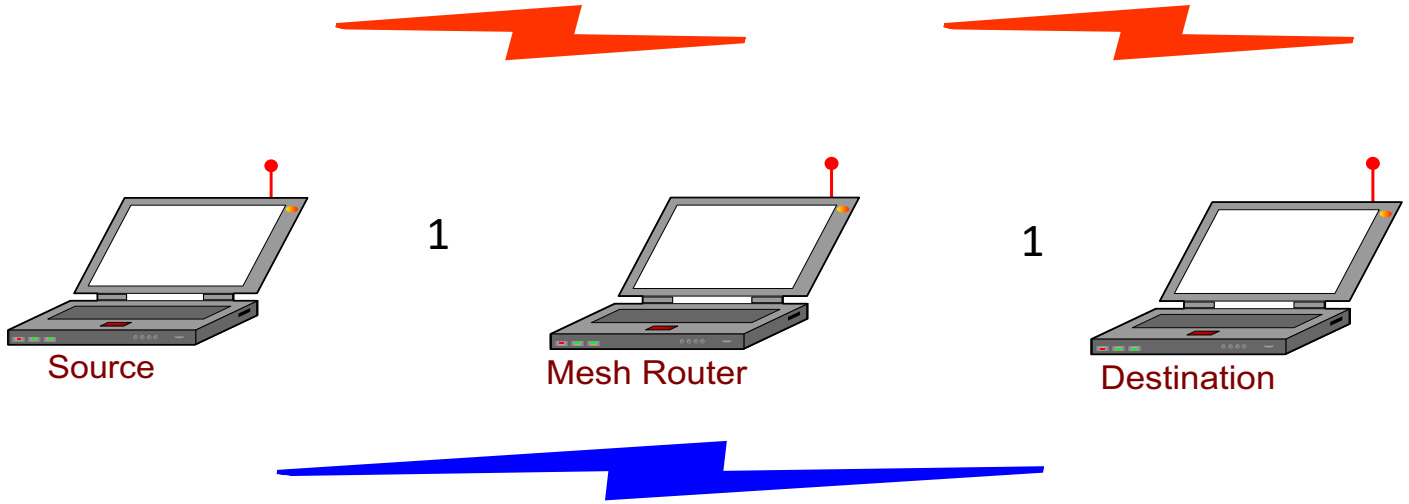
# Per-link delivery ratio

- Ex) Consider 2 hop path: src – mesh router - dst
  - 0.7 x 0.8 = 0.56



# Per-link delivery ratio can be misleading

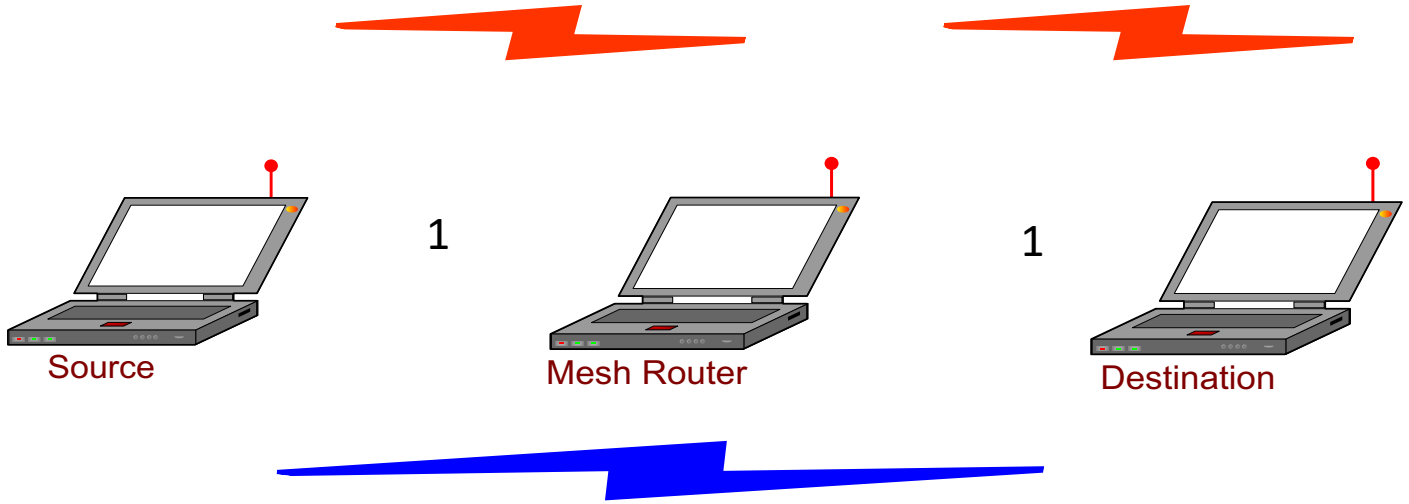
- A perfect 2 hop route vs 1-hop route with 10% loss
  - Ex1) 2 hop path: src – mesh router - dst
    - 1 x 1 = 1
  - Ex2) 1 hop direct path
    - 0.9




Perfect 2 hop is NOT better than 1 hop with 10%. Why?

# Throughput of a path's bottleneck link

- A perfect 2 hop route vs 1-hop route with 10% loss
  - Ex1) 2 hop path: src – mesh router - dst
    - Say both throughput is 1Mbps, so bottleneck throughput is 1 Mbps
  - Ex2) 1 hop direct path with 10% loss
    - 0.9 Mbps



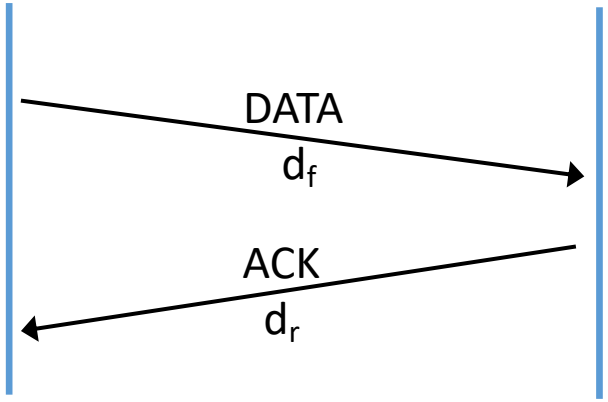

**Higher per-link throughput does not translate to overall throughput**

# ETX: a better metric in wireless mesh network

- $d_f$ = forward delivery rate
- $d_r$ = reverse delivery rate
- ETX of a link = $\frac{1}{d_f * dr}$
- ETX of a path: sum of the ETX values of the links over that path

# ETX: a better metric in wireless mesh network

- Let's consider expected number of data transmissions required
  - Link with 50% loss: 2
  - Link with 75% loss: 4
- In 802.11 WiFi, ACK is followed by DATA
  - delivery rate = 1 – loss rate
  - DATA travels forward direction: $d_f$ = forward delivery rate
  - ACK travels reverse direction: $d_r$ = reverse delivery rate



# ETX pros and cons

- Pros
  - Better than vanilla hop count as it accounts for bi-directional loss rate
  - Easily be incorporated into routing protocols

- Cons
  - Only considers loss rate
  - Does not account for other factors (mobility, power, interference)
  - Prone to oscillation and may select sub-optimal paths

# Outline

1. What is Wireless Mesh Network?
2. Routing metrics in mesh networks
3. Opportunistic routing

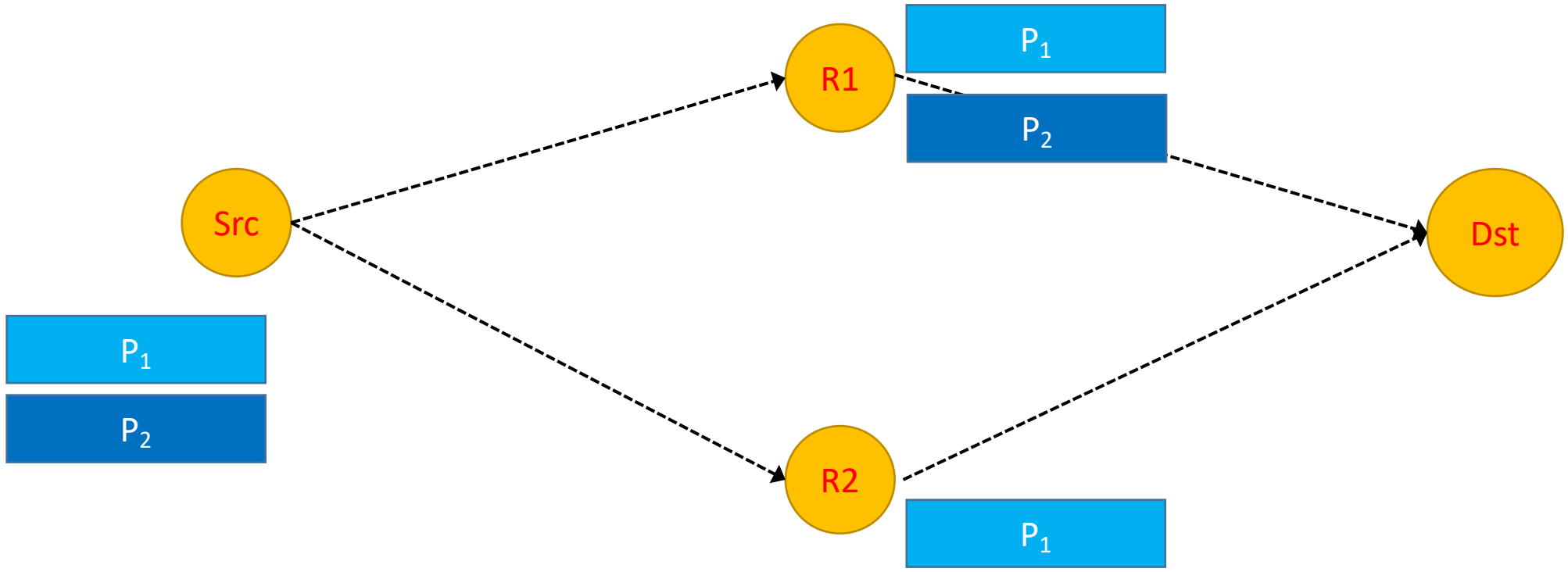
# What is opportunistic routing?

- In traditional routing, we commit to a single path for given src – dst
  - Src -> A -> B -> C -> Dst
- In opportunistic routing,  we leverage broadcast nature of wireless link
  - Whoever happens to hear the packet let it forward!

# Outline

1. What is Wireless Mesh Network?
2. Routing metrics in mesh networks
3. Opportunistic routing
4. Network coding

# When R1 and R2 receives the same pkt they need to figure out who sends what



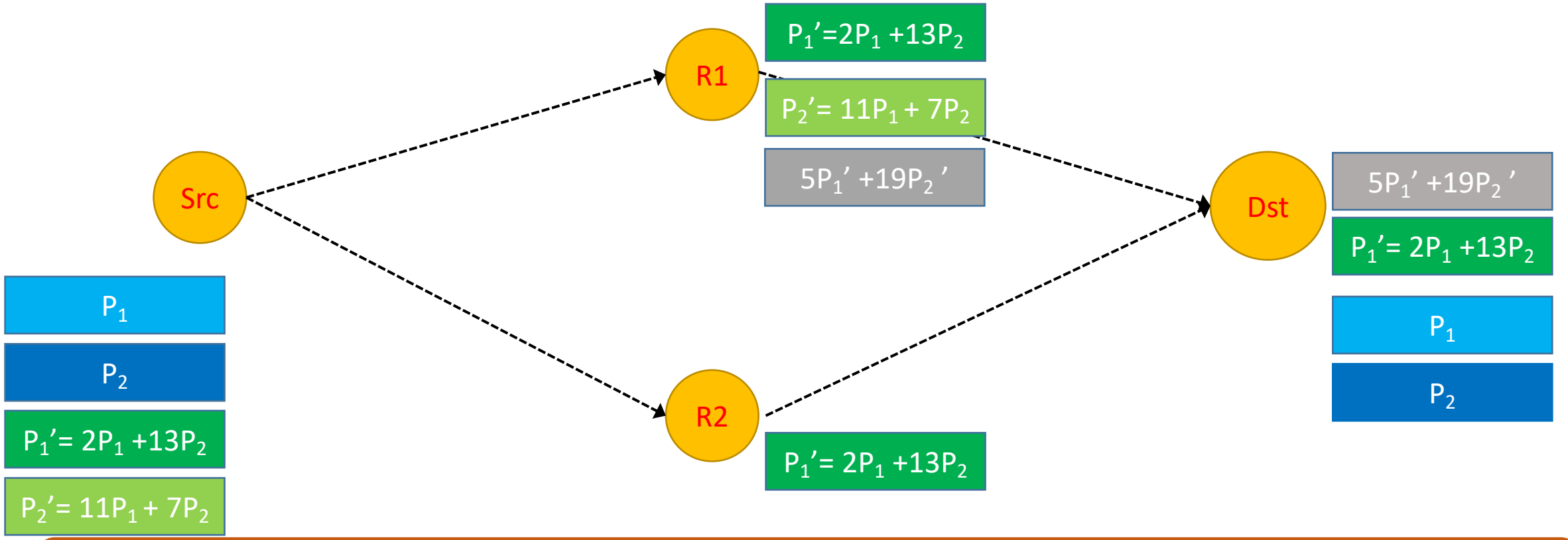

Keeping track of who got what and deciding of who sends what is challenging

# Can we somehow by-pass that?

- Yes! We can use network coding!

# Network coding: each node produces linear combination of pkt received and forwards the coded pkt

- P1 and P2 are raw uncoded packets (batch size 2)




With batch size N, dst can decode successfully as long as dst receives N independent coded packets,

# Can we perform network coding with different flows?

- Yes!
- Two flows sharing the same set of intermediate node


(a) Current Approach


(b) COPE

# Can we do network coding in physical layer?

- Yes

- https://www.cs.utexas.edu/~lili/papers/pub/mobicom11-crma.pdf

# Outline

1. What is Wireless Mesh Network?
2. Routing metrics in mesh networks
3. Opportunistic routing
4. Network coding
5. Leveraging multiple radios

# Outline

1. What is Wireless Mesh Network?
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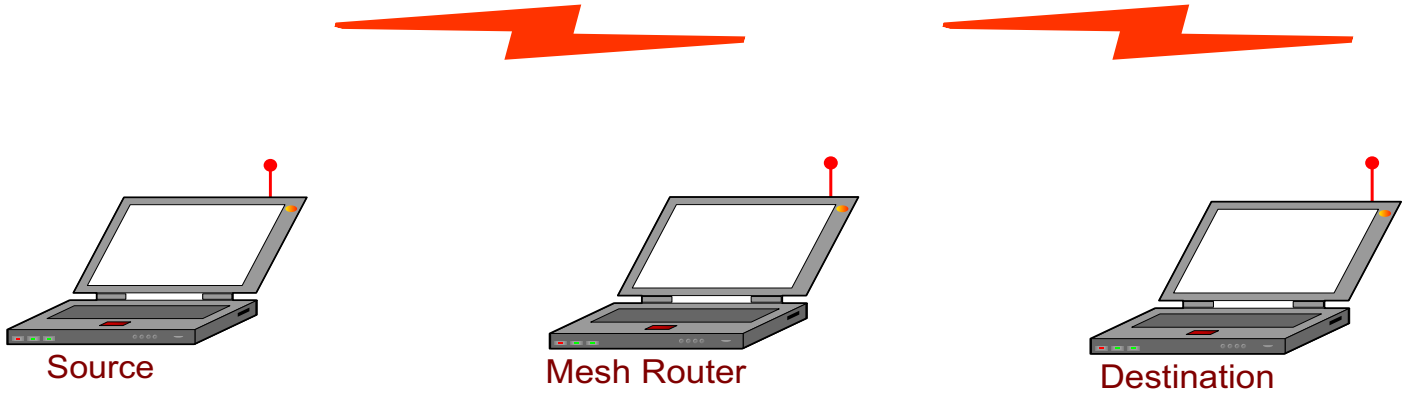
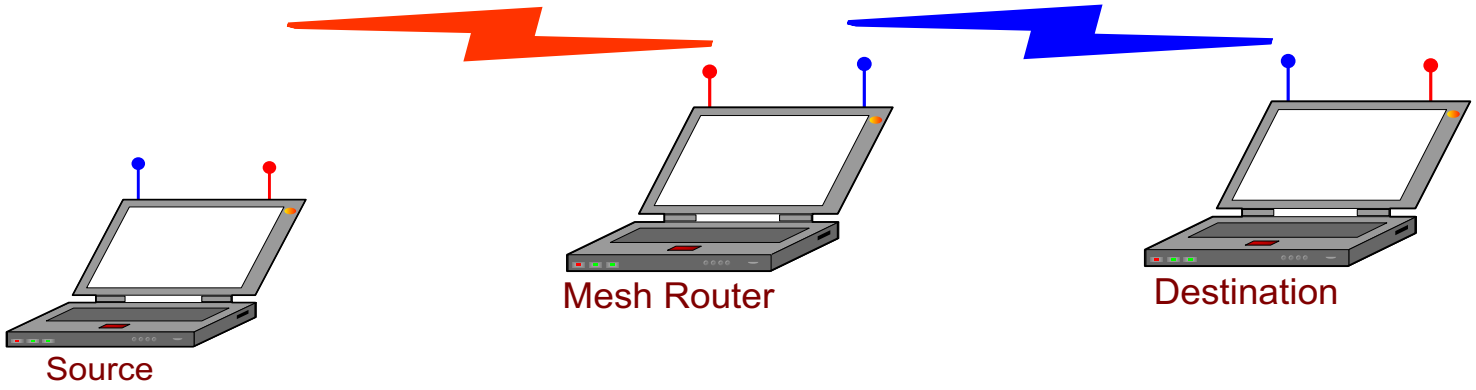
3. Leveraging multiple radios

# What else can we leverage in mesh network to improve performance?

# Nodes with a single radio cannot transmit and receive simultaneously



# With multi-radio, nodes can transmit and receive simultaneously




Two radios should be tuned to non-interfering channels