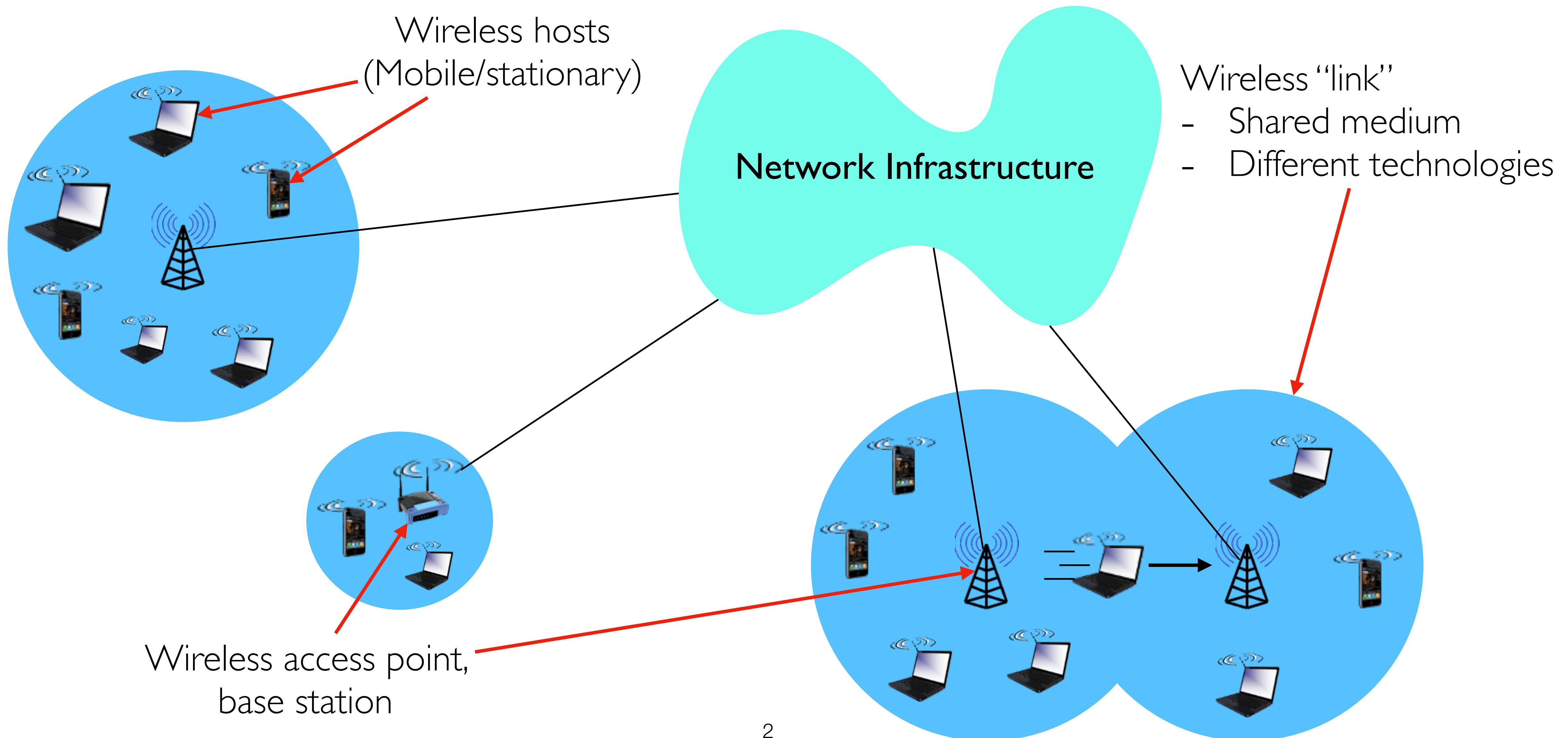


# Wireless Networks

CPSC 433/533, Spring 2021

Anurag Khandelwal

# Elements of a Wireless Network



# Comparing Wireless Technologies

- Bitrate or Bandwidth
- Range - PAN (personal), LAN (local), MAN (metropolitan), WAN (wide)
- Stationary vs. Mobile
- Two-way vs. One-way
- Digital vs. Analog
- Multi-access vs. Point-to-point
- Frequency or Wavelength

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# Common Wireless Standards

- **Cellular (Typically 800/900/1800/1900/3300/4200 Mhz)**
  - **2G**: GSM/GPRS/EDGE/CDMA/CDMA2000
  - **3G**: UMTS/HSDPA/EVDO; **4G**: LTE, WiMax; **5G**: LTE
- **IEEE 802.11 (aka WiFi):**
  - **b**: 2.4Ghz band, 11 Mbps (~4.5 Mbps operating rate)
  - **g**: 2.4Ghz, 54-108Mbps (~19 Mbps operating rate)
  - **a**: 5Ghz band, 54-108Mbps (~19 Mbps operating rate)
  - **n**: 2.4/5Ghz, 150-600Mbps (4x4 MIMO)
  - **ac**: 2.4/5Ghz, >1 Gbps (4x4 MIMO) (wide channels)
- **IEEE 802.15 — lower power wireless:**
  - **802.15.1**: 2.4Ghz, 2.1 Mbps (Bluetooth)
  - **802.15.4**: 2.4Ghz, 250 Kbps (Sensor networks)

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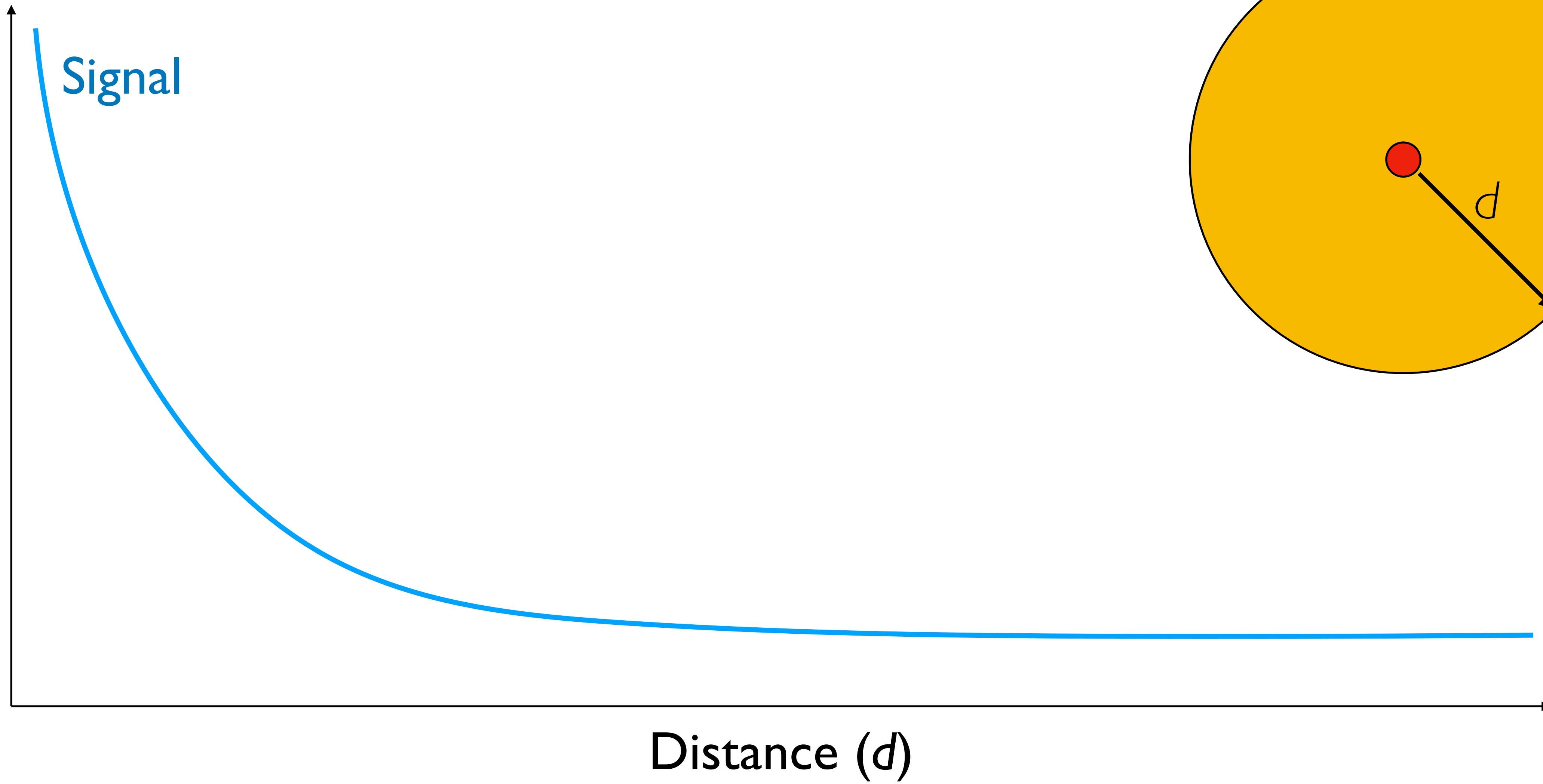
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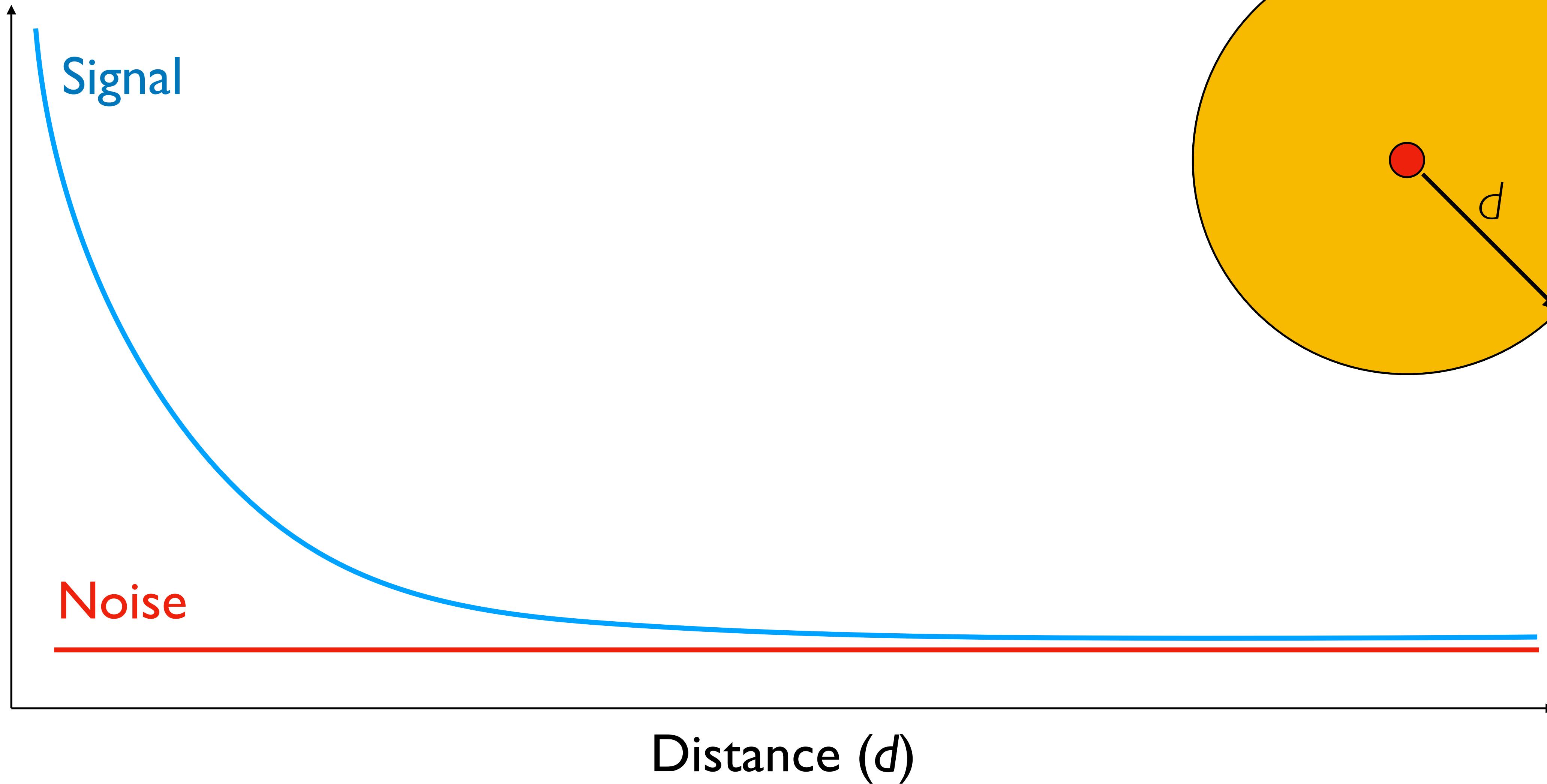
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- A lot really...
- Broadcast medium
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- Cannot receive while transmitting
  - Our own (or nearby) transmitter is deafening our receiver
- Signals from sender not always intact at receiver
  - Complicated physics involved, which won't discuss
  - Path Attenuation, Multipath effects, Interference, Noise

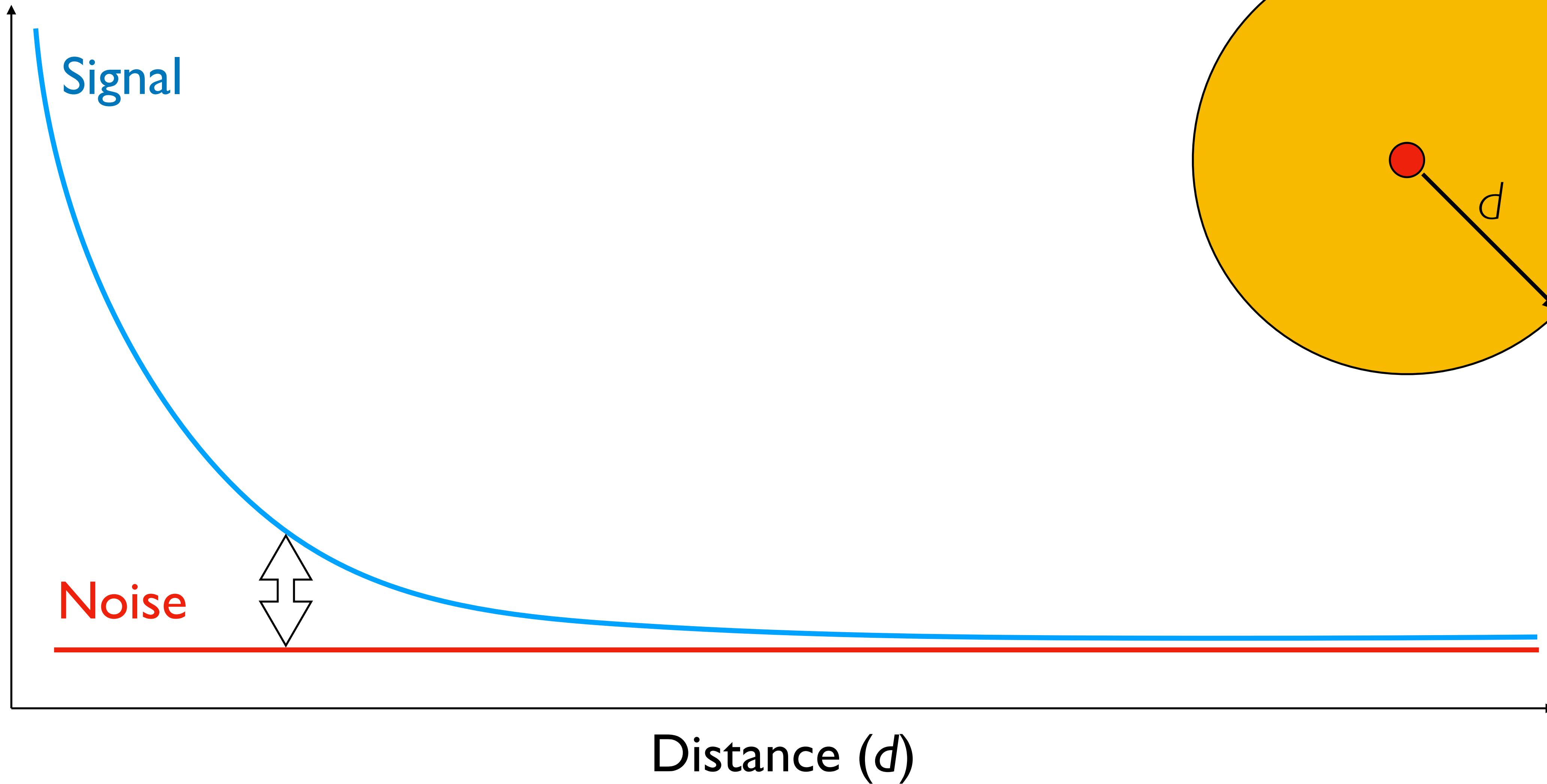
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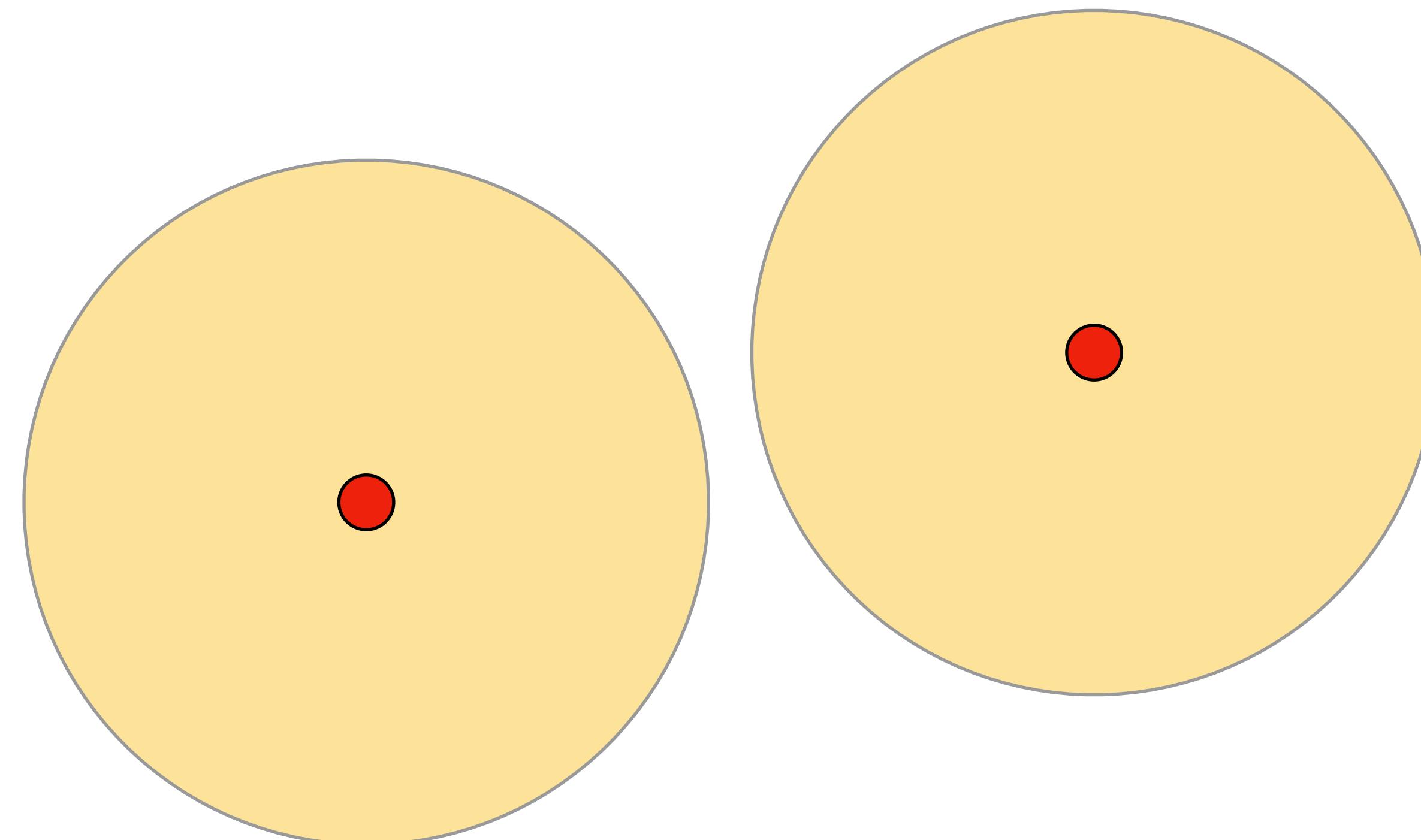
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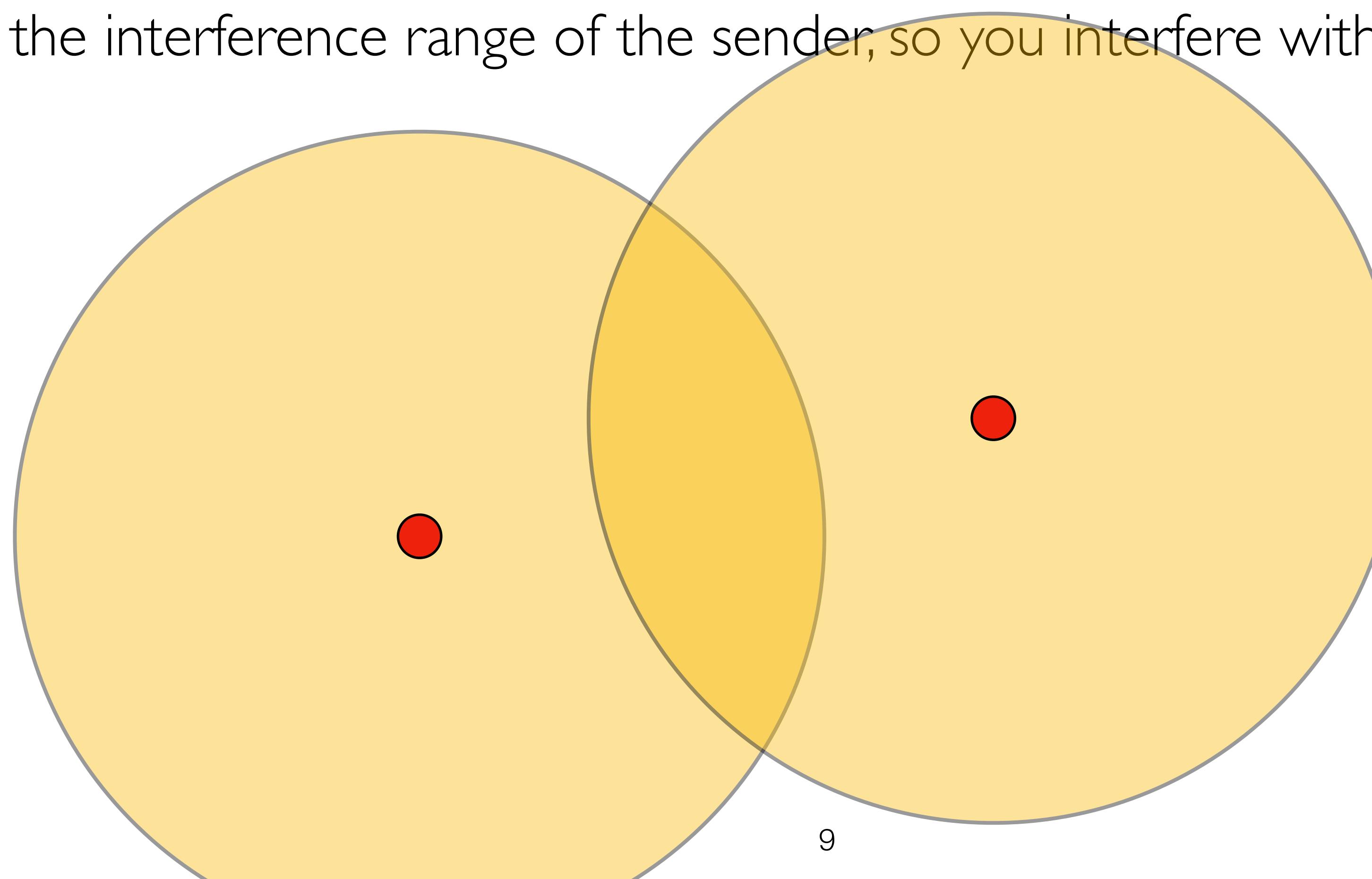
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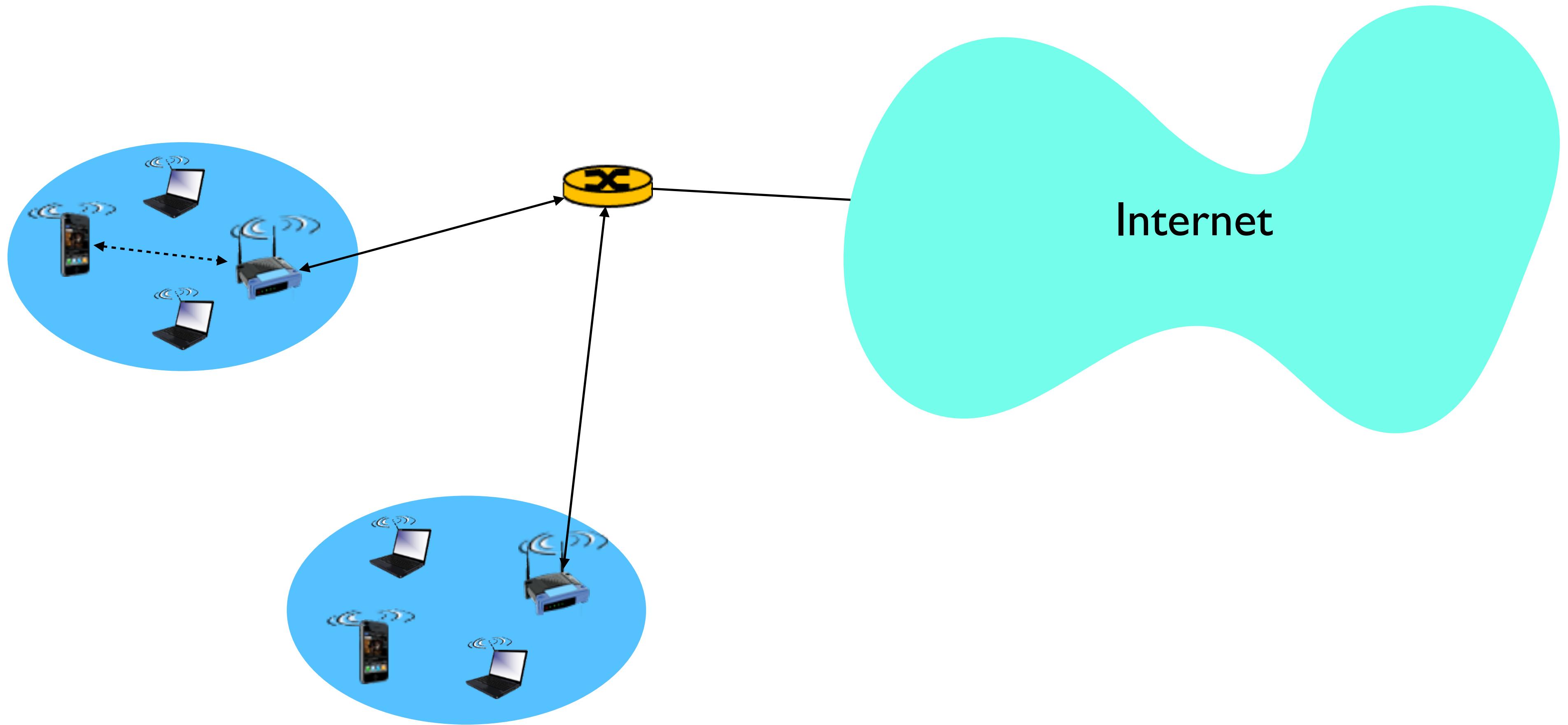
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- How would TCP behave in the face of losses?

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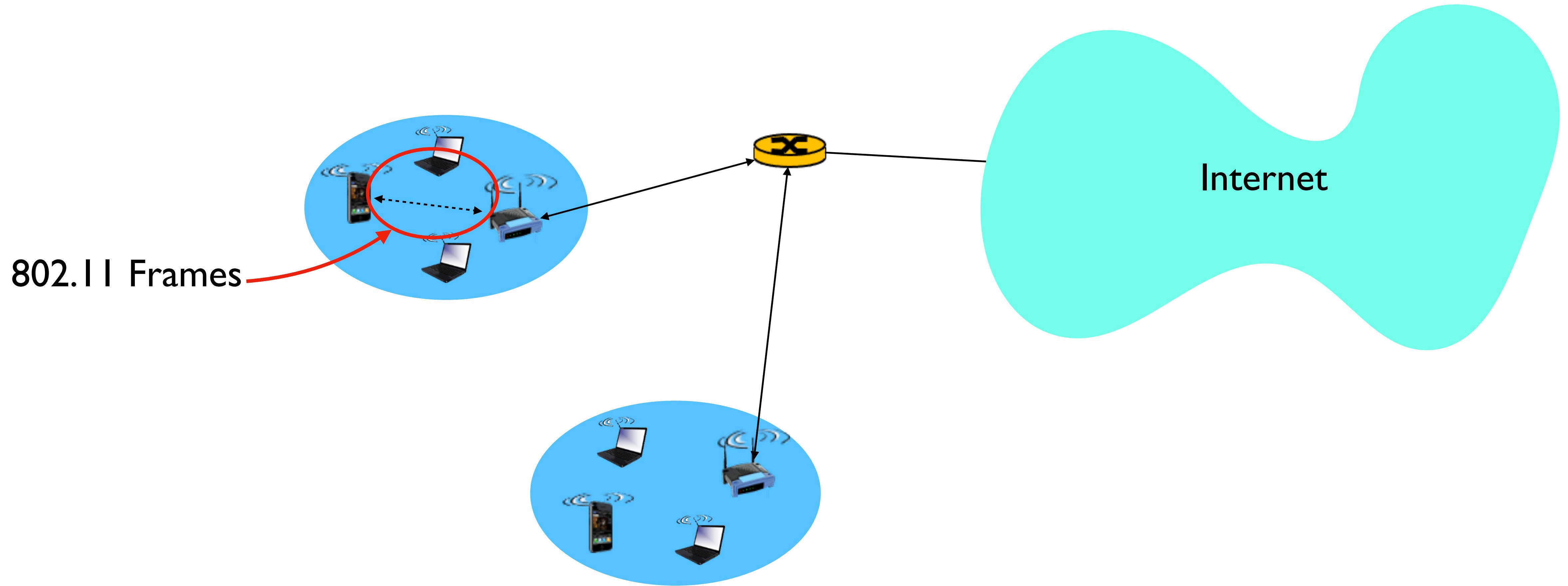
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- How would TCP behave in the face of losses?
- Link-layer Error Correction schemes can correct **some** problems

# **802.11 aka WiFi**

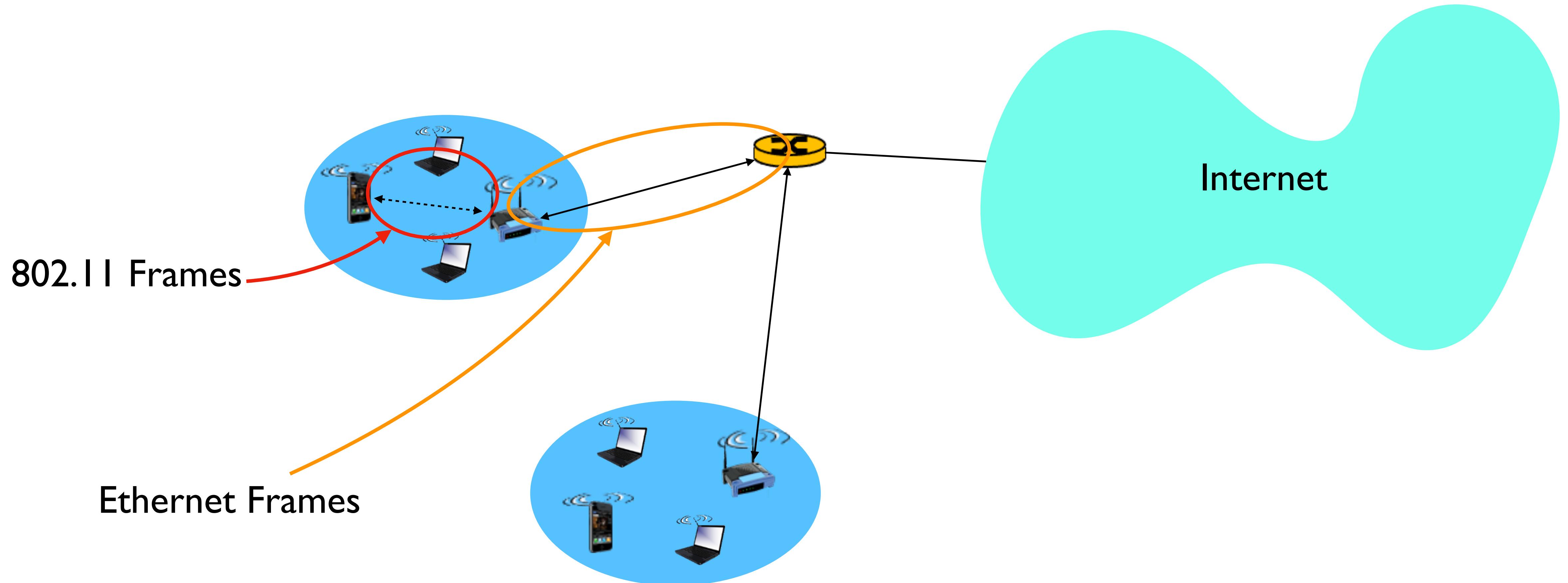
# 802.11 Architecture



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# 802.11: Channels & Association

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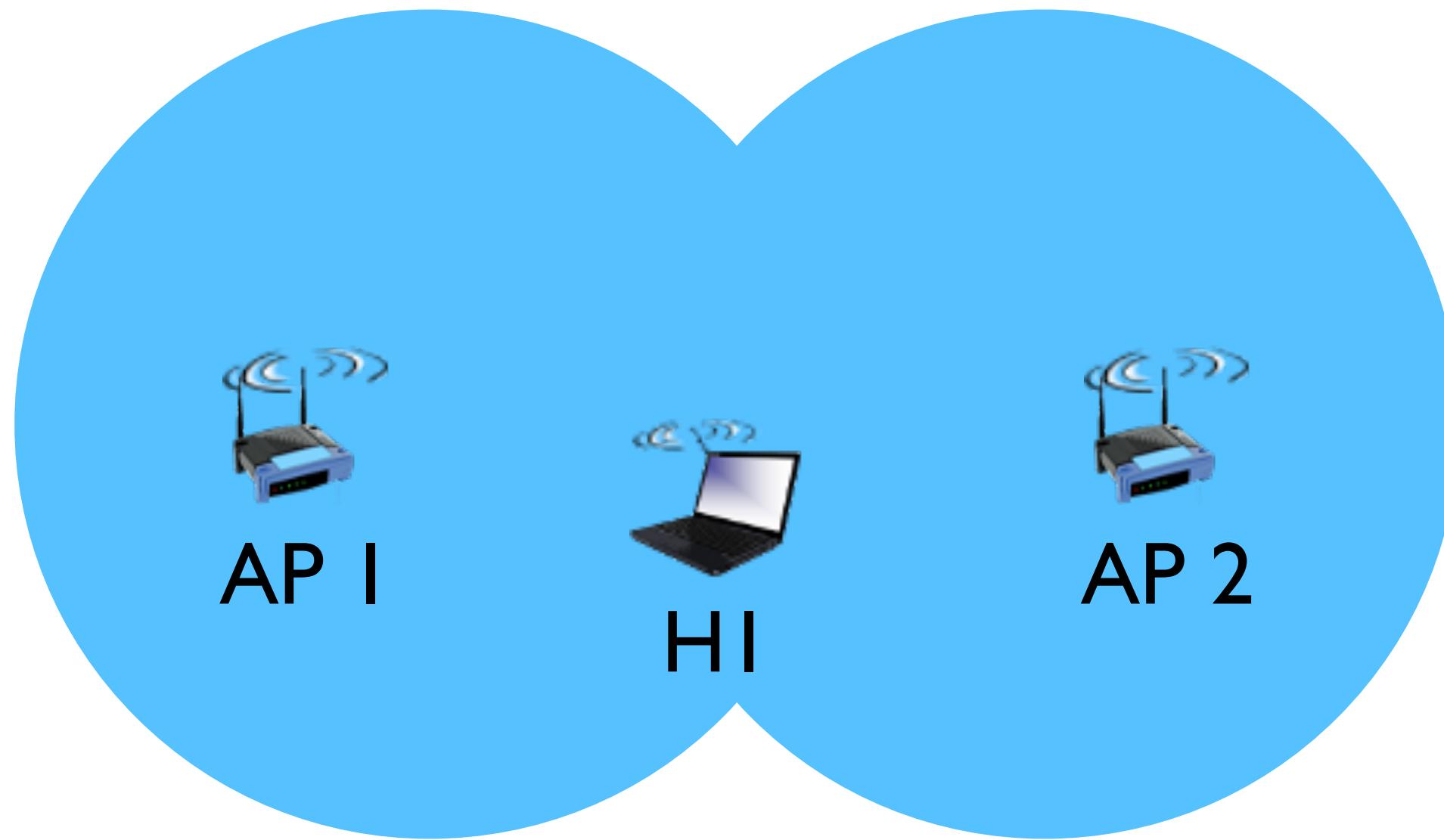
- 802.11b: 2.4GHz - 2.485GHz spectrum divided into 11 channels at different frequencies
  - AP admin chooses frequency for AP
  - Interference possible: channel can be same as that chosen by neighboring AP!

# 802.11: Channels & Association

- 802.11b: 2.4GHz - 2.485GHz spectrum divided into 11 channels at different frequencies
  - AP admin chooses frequency for AP
  - Interference possible: channel can be same as that chosen by neighboring AP!
- Host: must *associate* with an AP
  - Scans channels, listening for *beacon frames* containing AP's name (SSID) and MAC addresses
  - Selects AP to associate with
  - May perform authentication
  - Will typically run DHCP to get IP address in AP's subnet

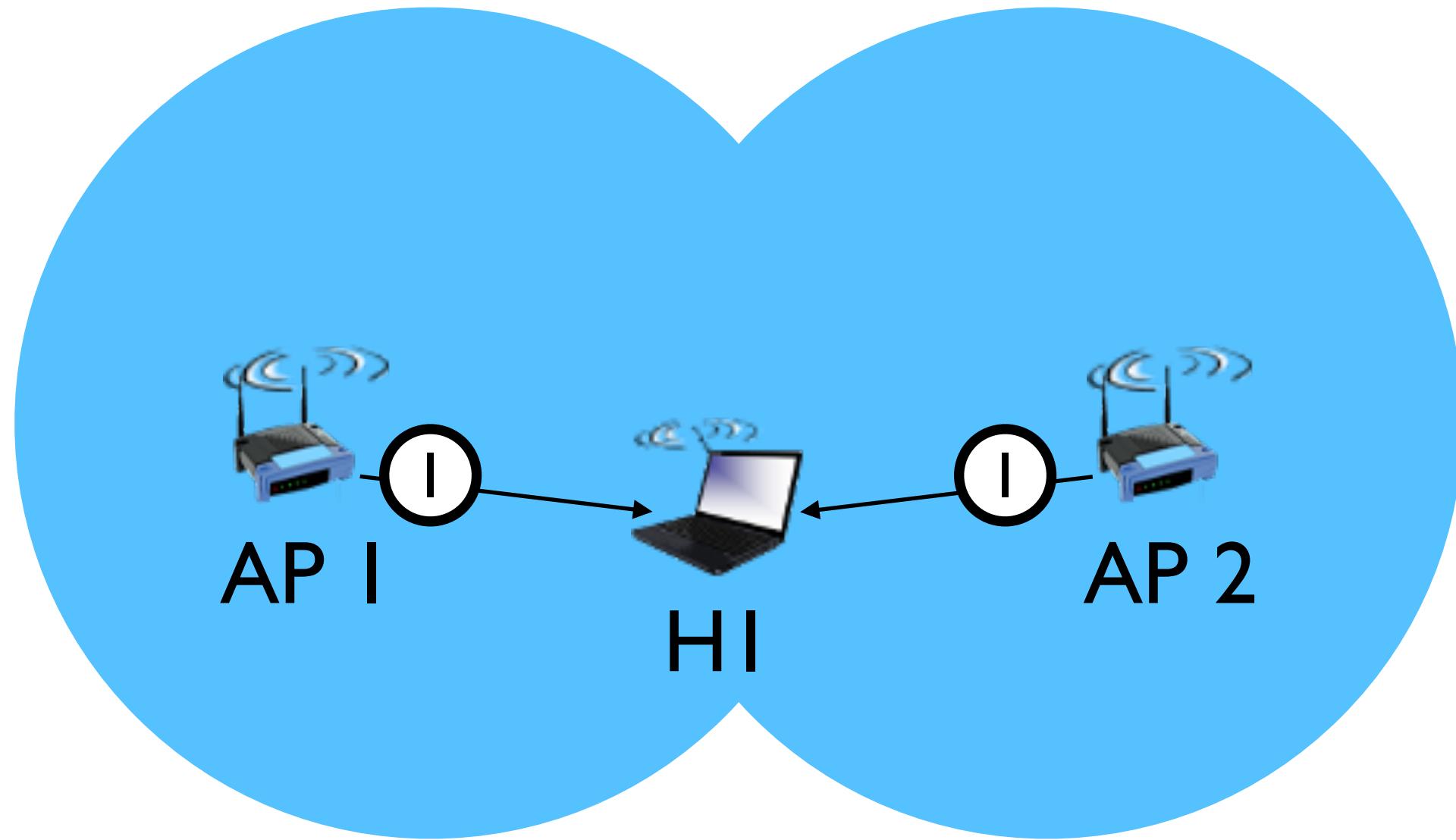
# 802.11: Passive/Active Scanning

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Passive scanning:

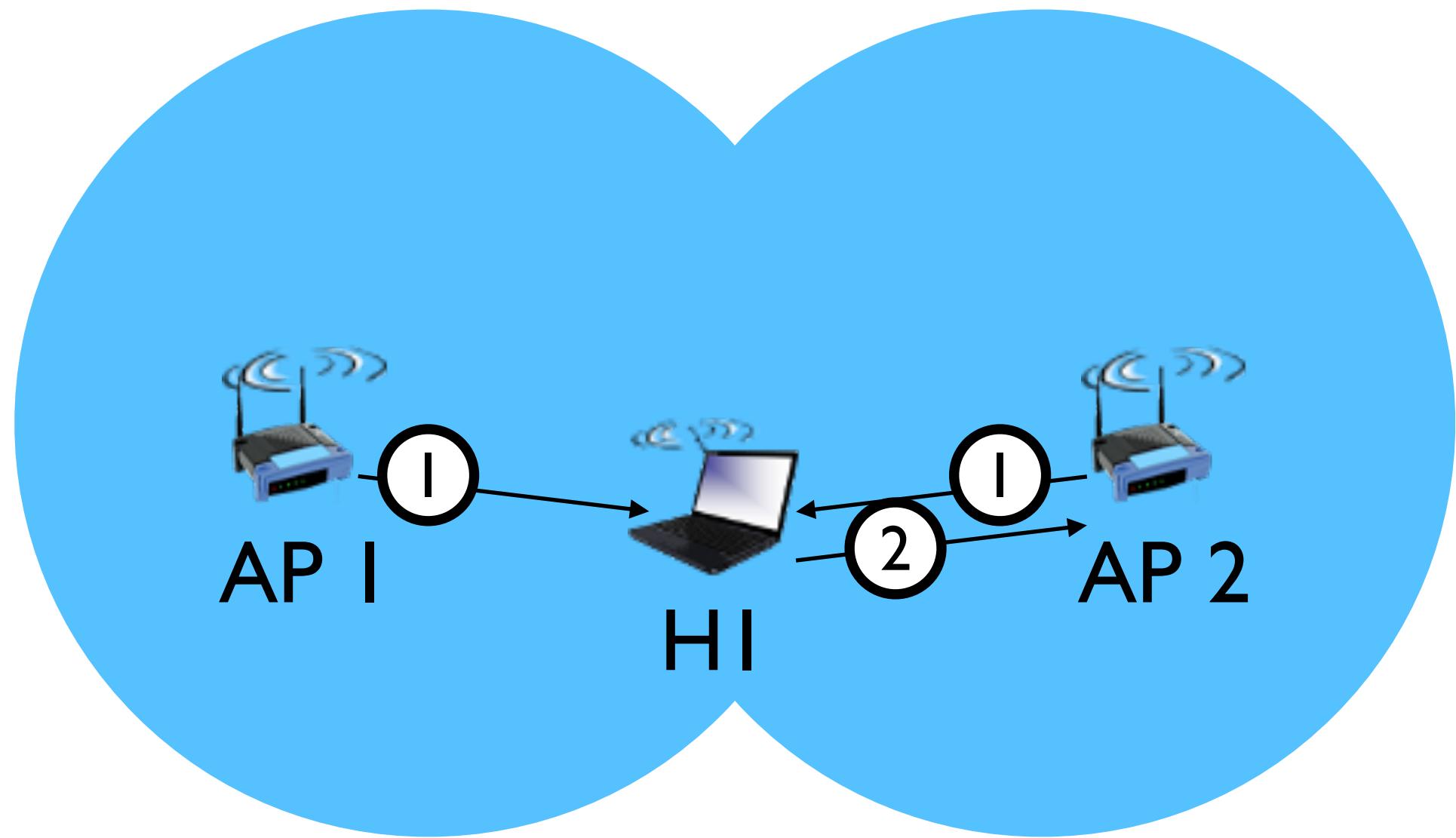
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## Passive scanning:

- (I) Beacon frames sent from APs

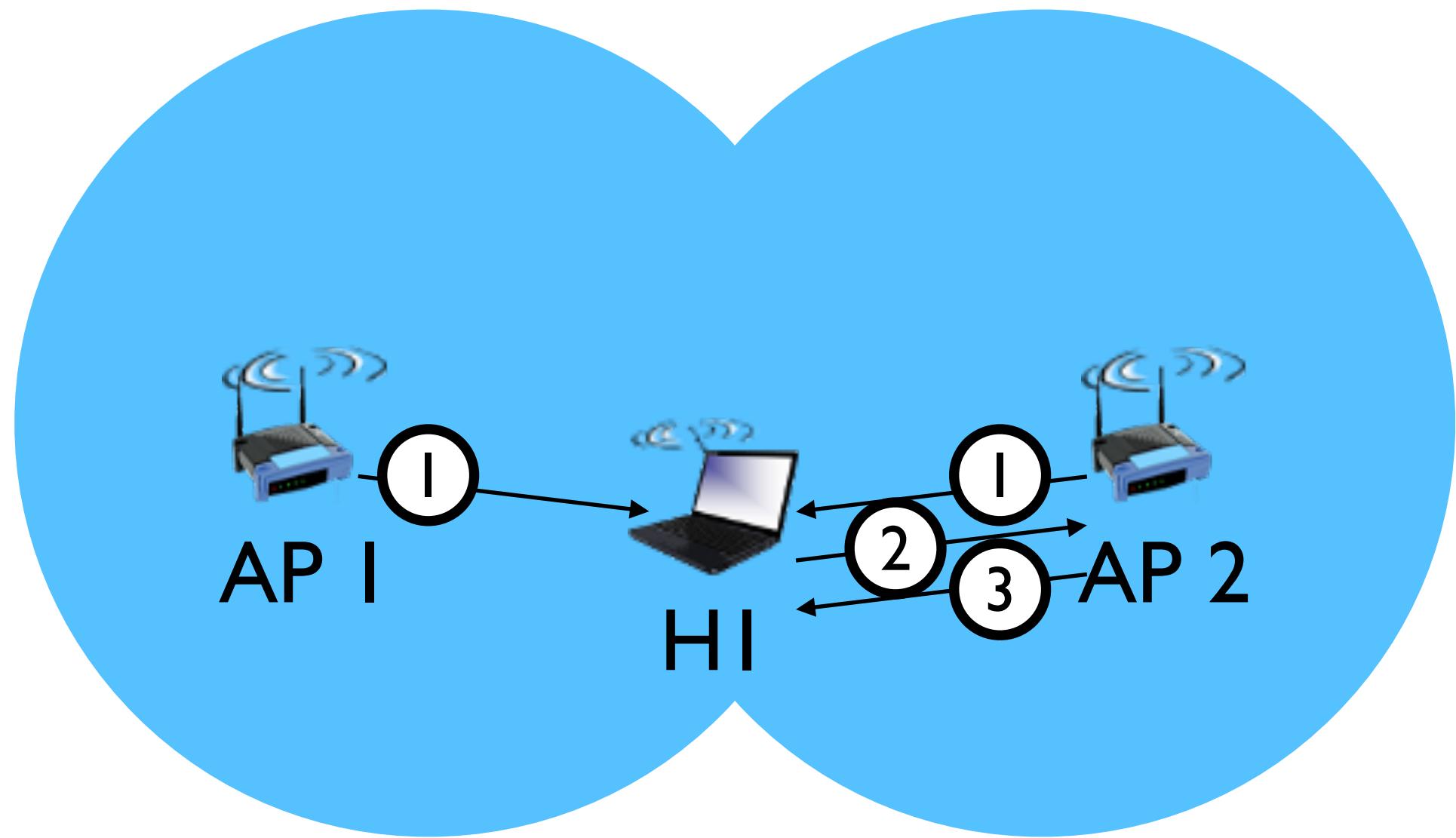
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## Passive scanning:

- (1) Beacon frames sent from APs
- (2) Association request frame sent:  
HI to selected AP

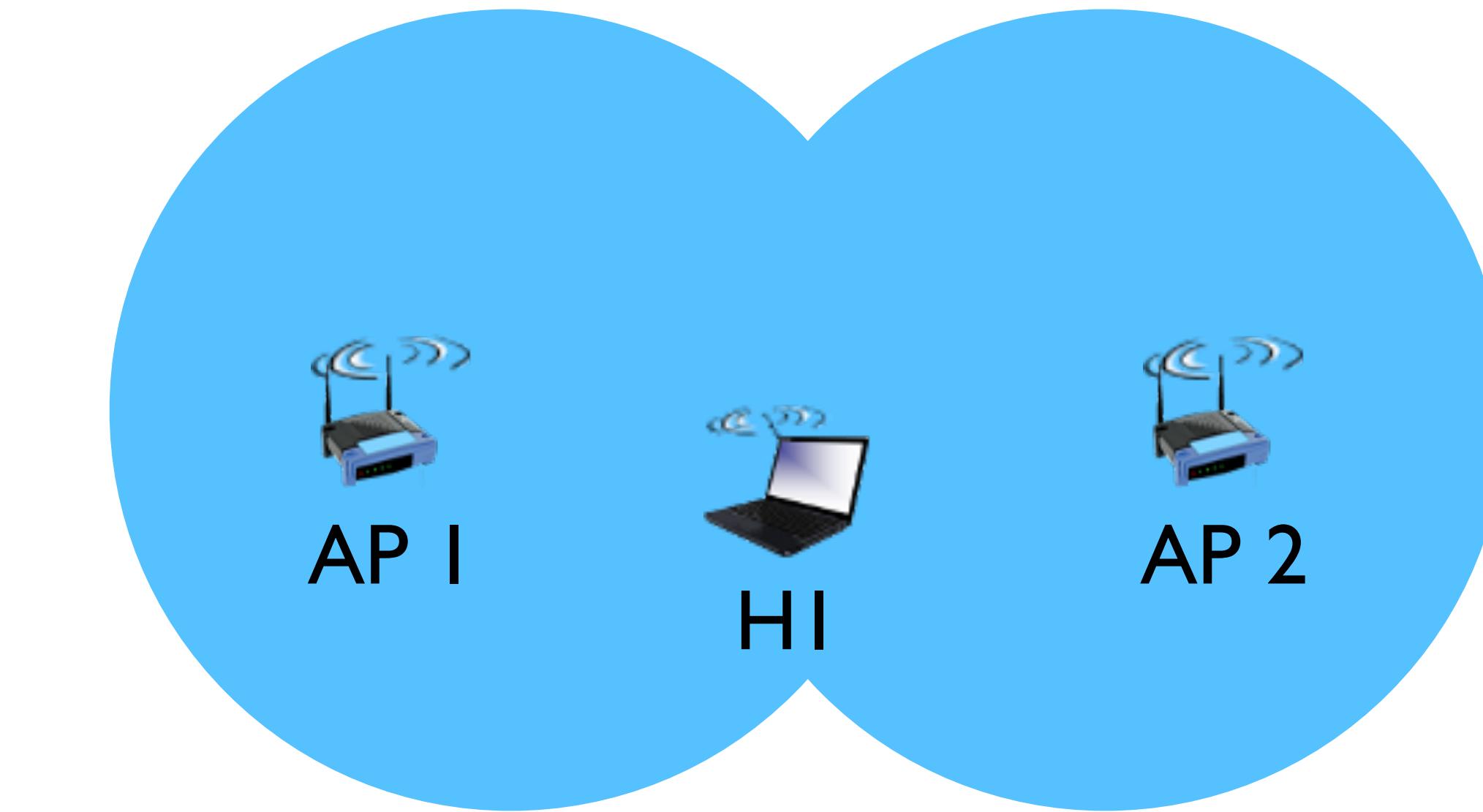
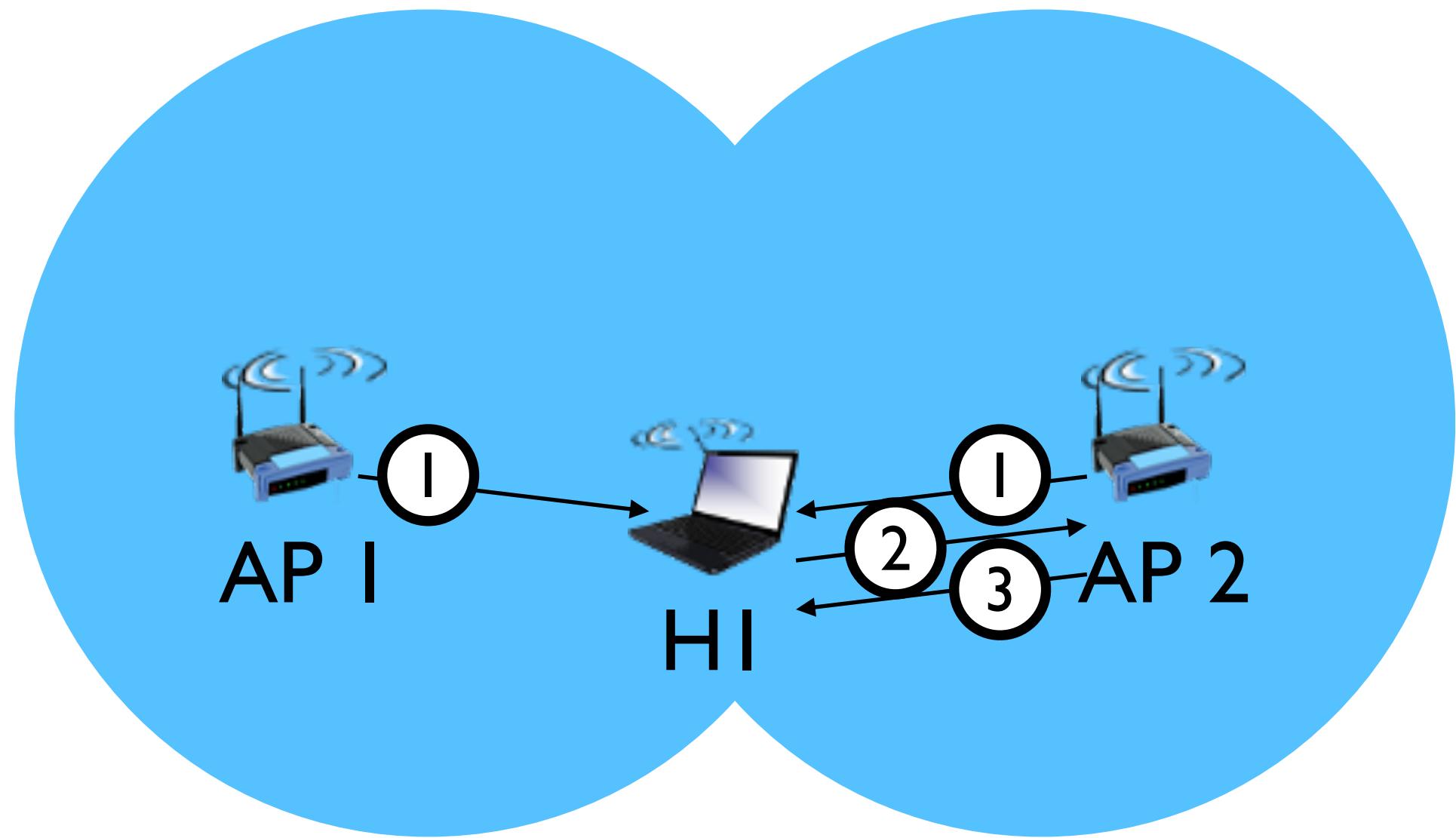
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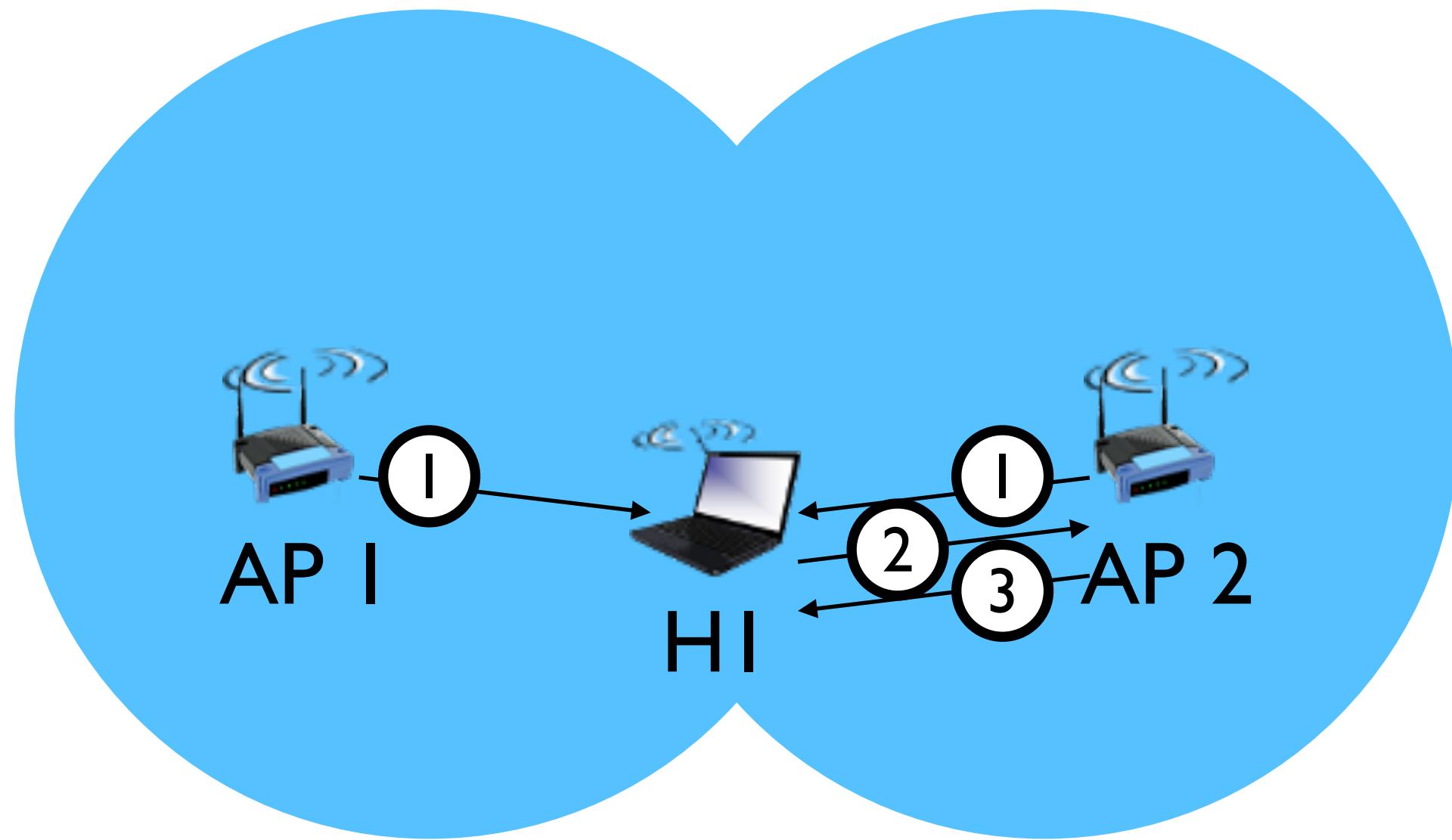


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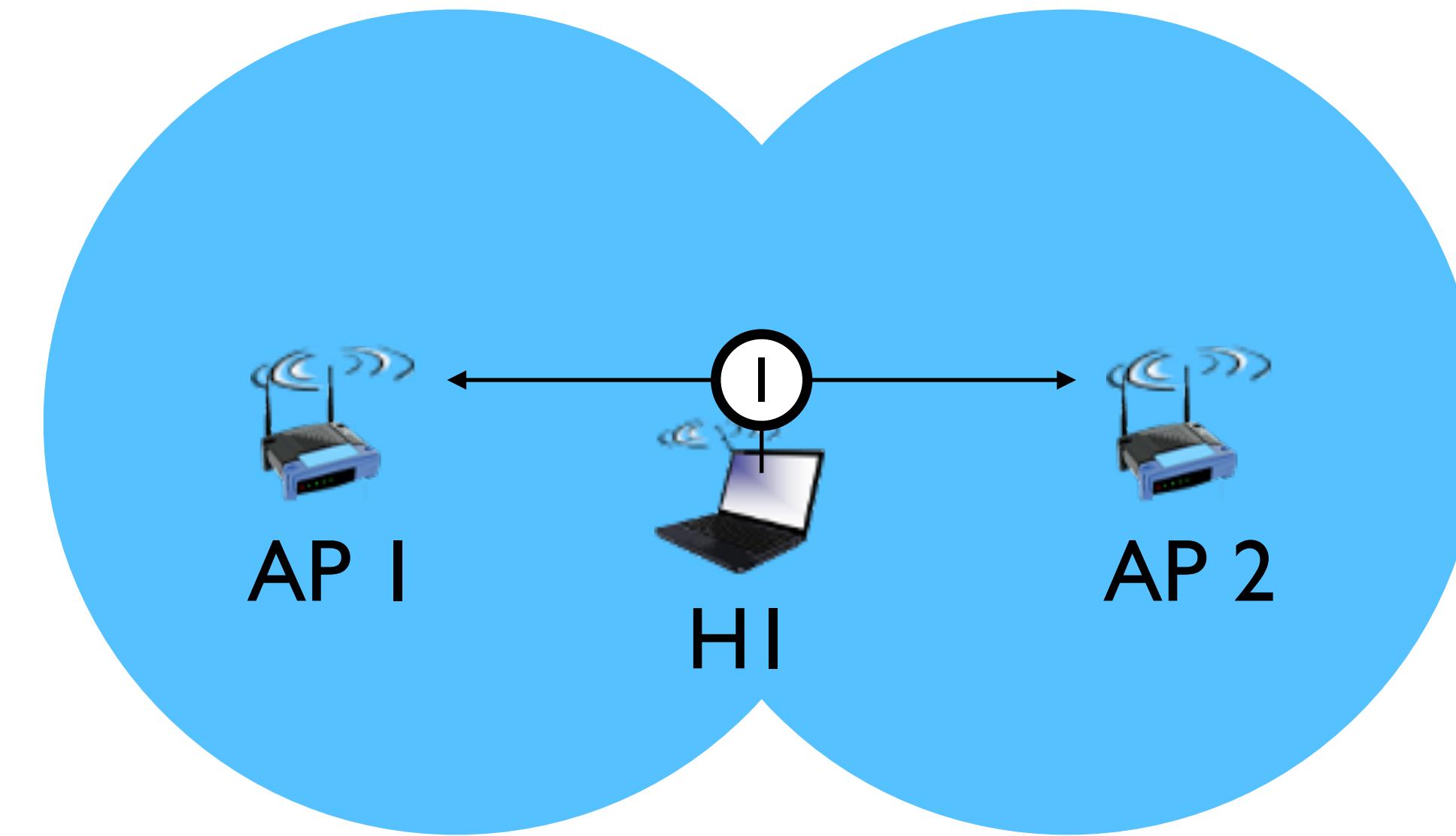
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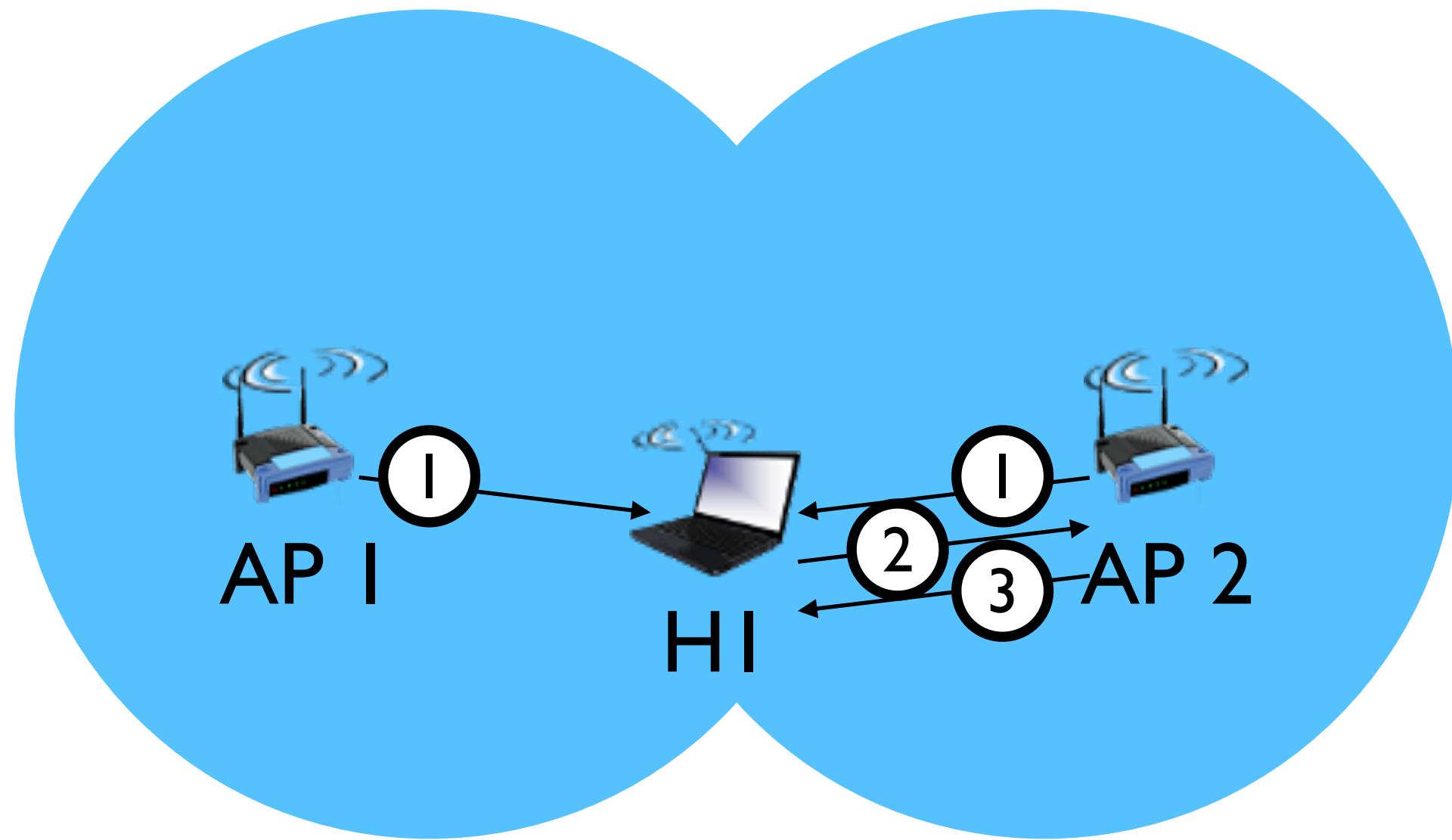
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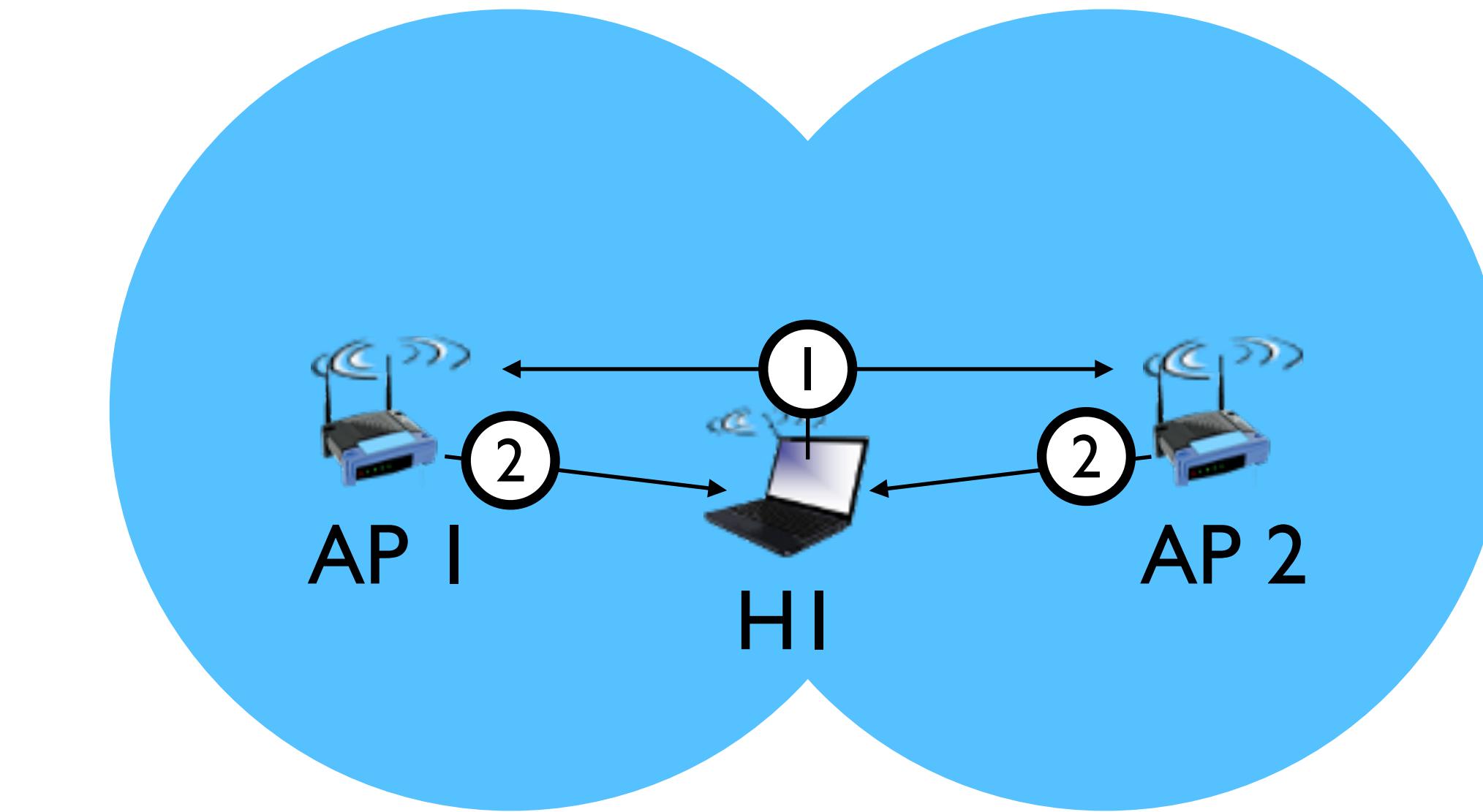
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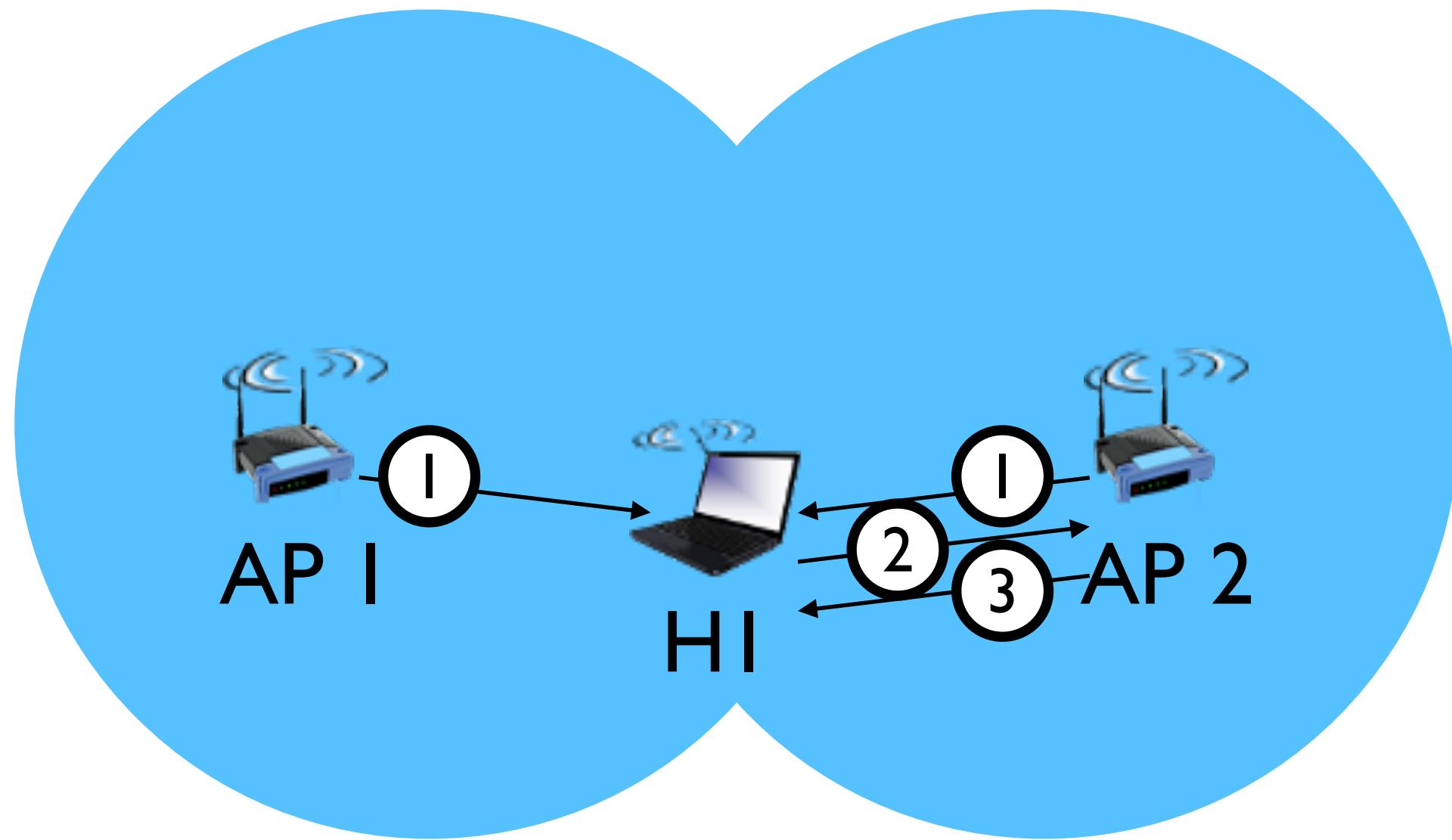
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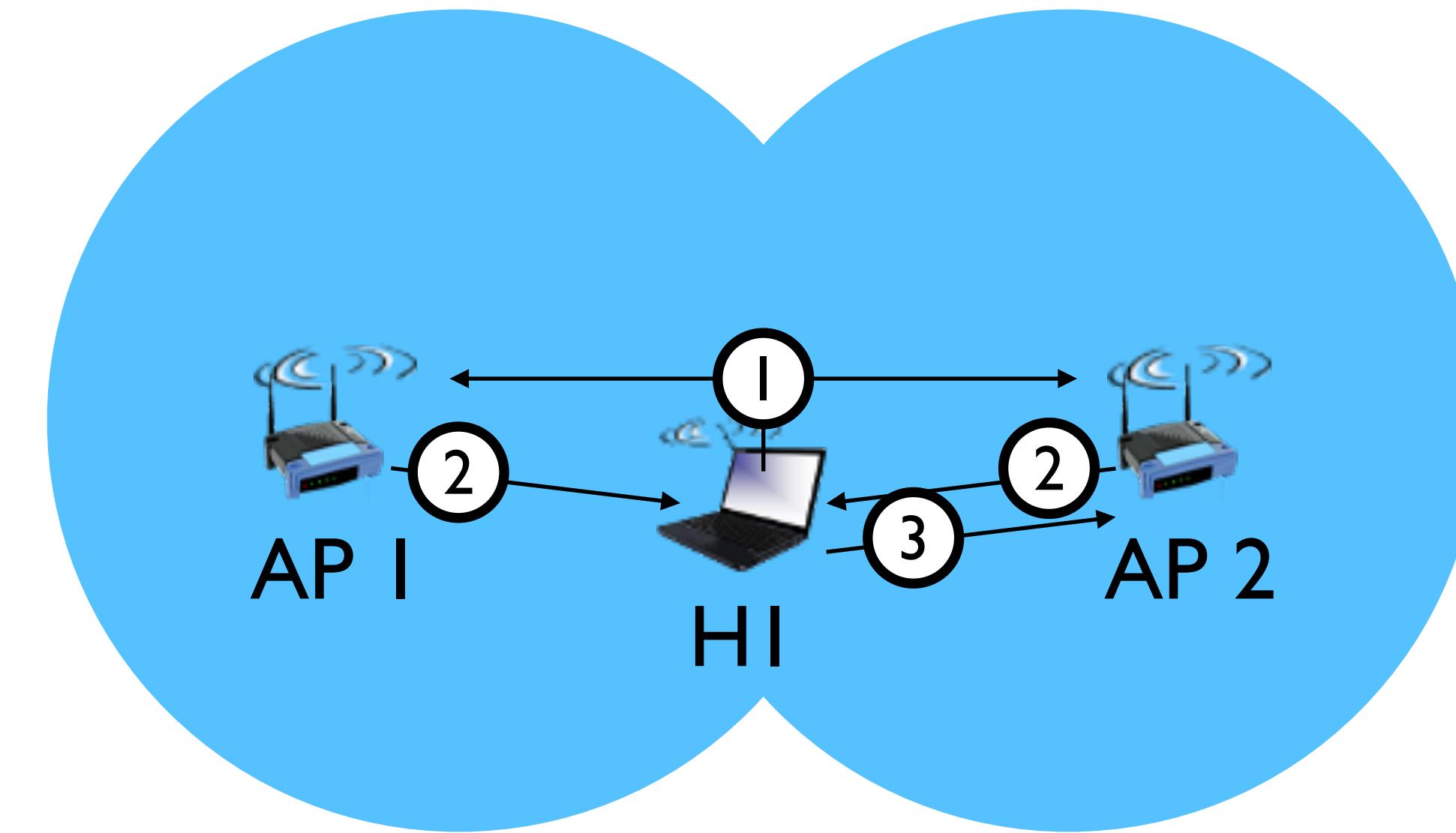
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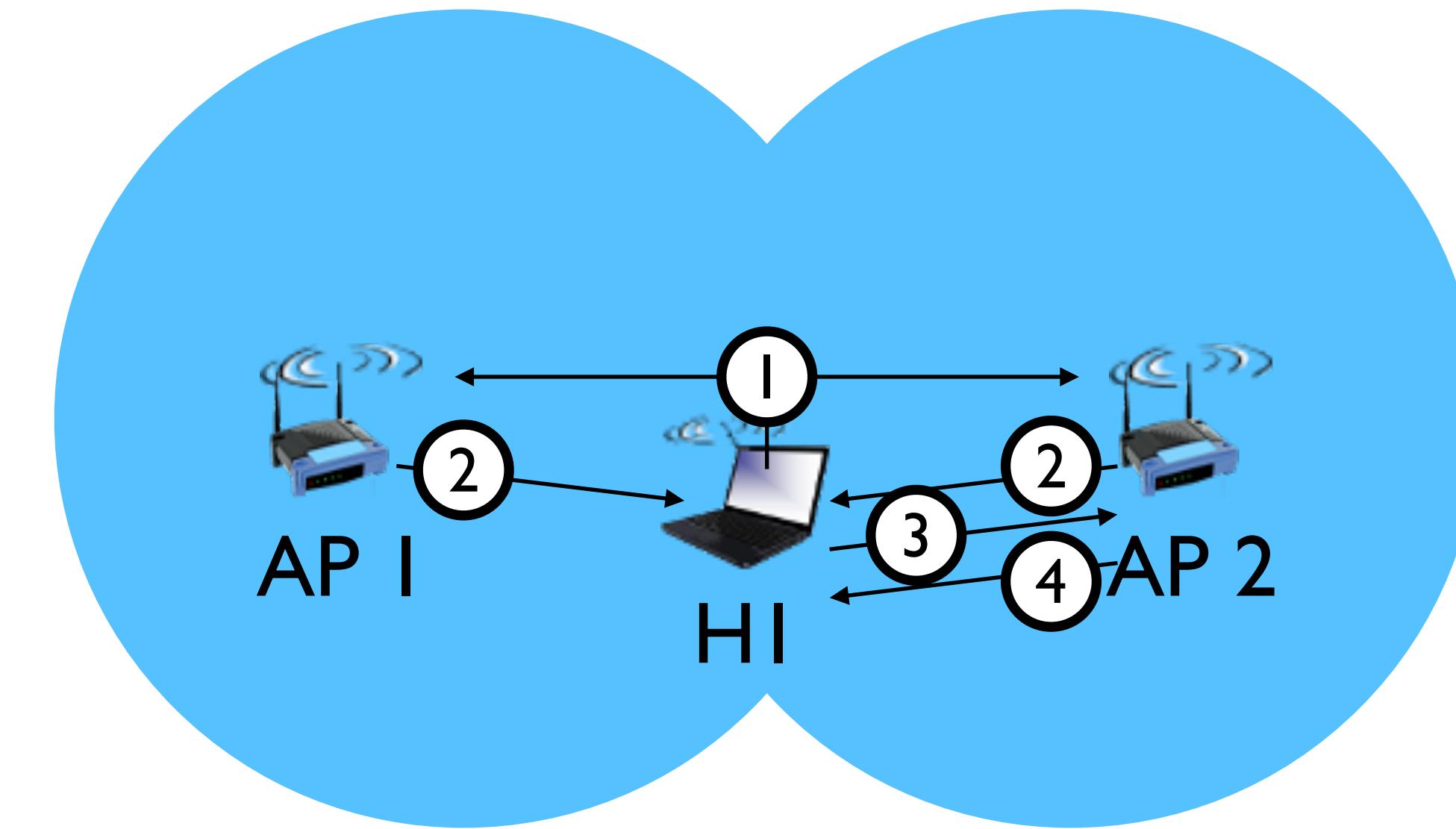
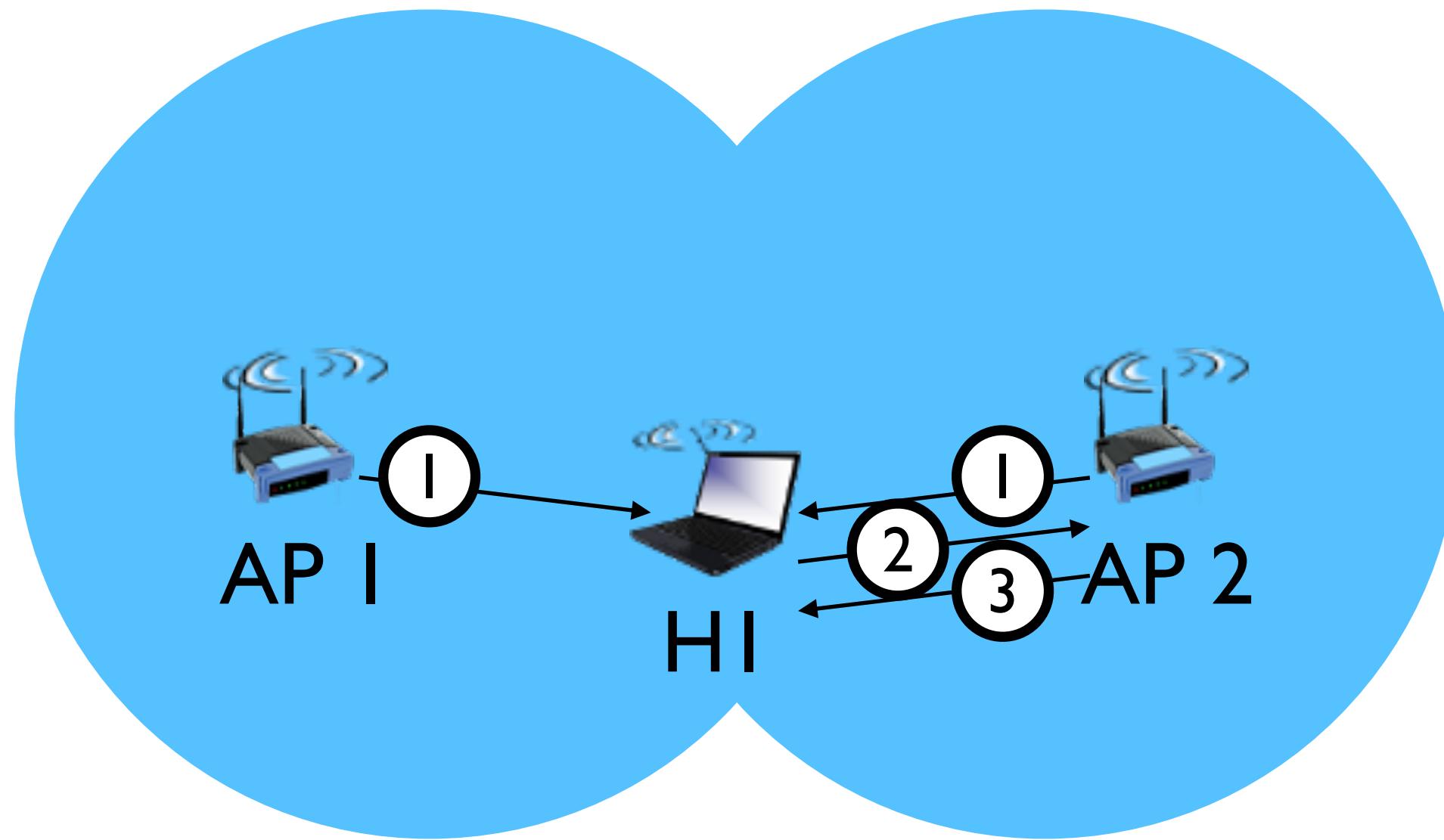
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## Active scanning:

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# Wireless Multiple Access

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- Recap: CSMA/CD in wired Ethernet
  - *Carrier sense*: listen before you speak (wait for link to be idle)
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- **Carrier sense in wireless**
  - Sender can listen before sending
  - Is it always possible?
  - Is it always useful?

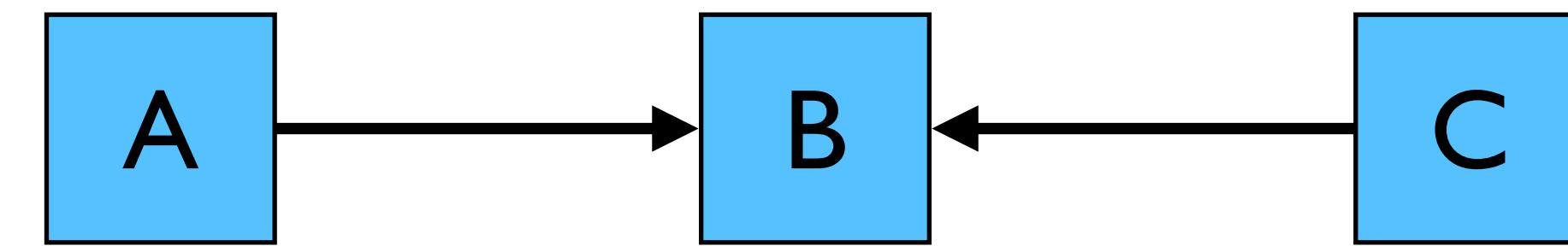
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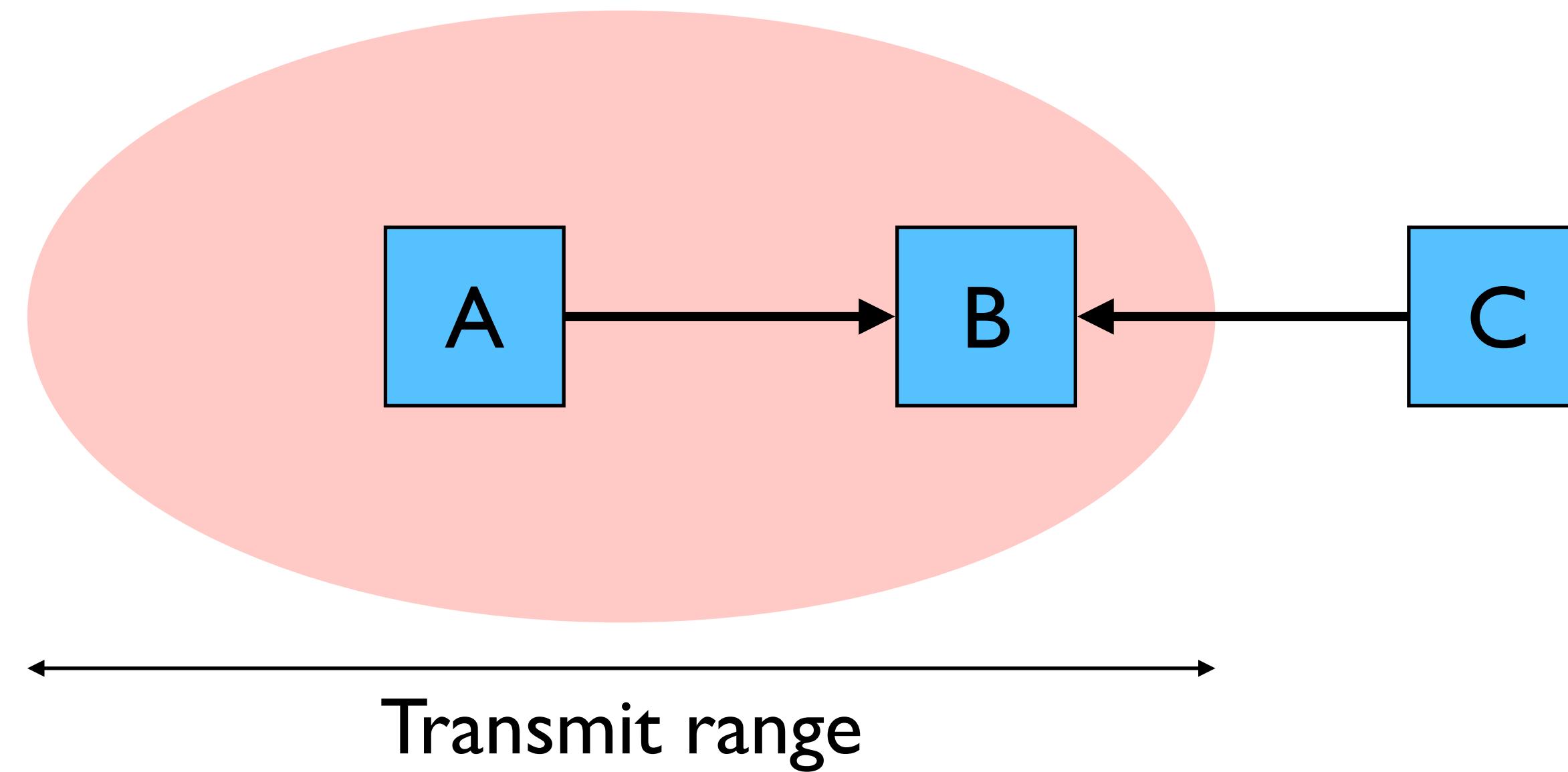
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- Collision detection in wireless
  - Is it possible?

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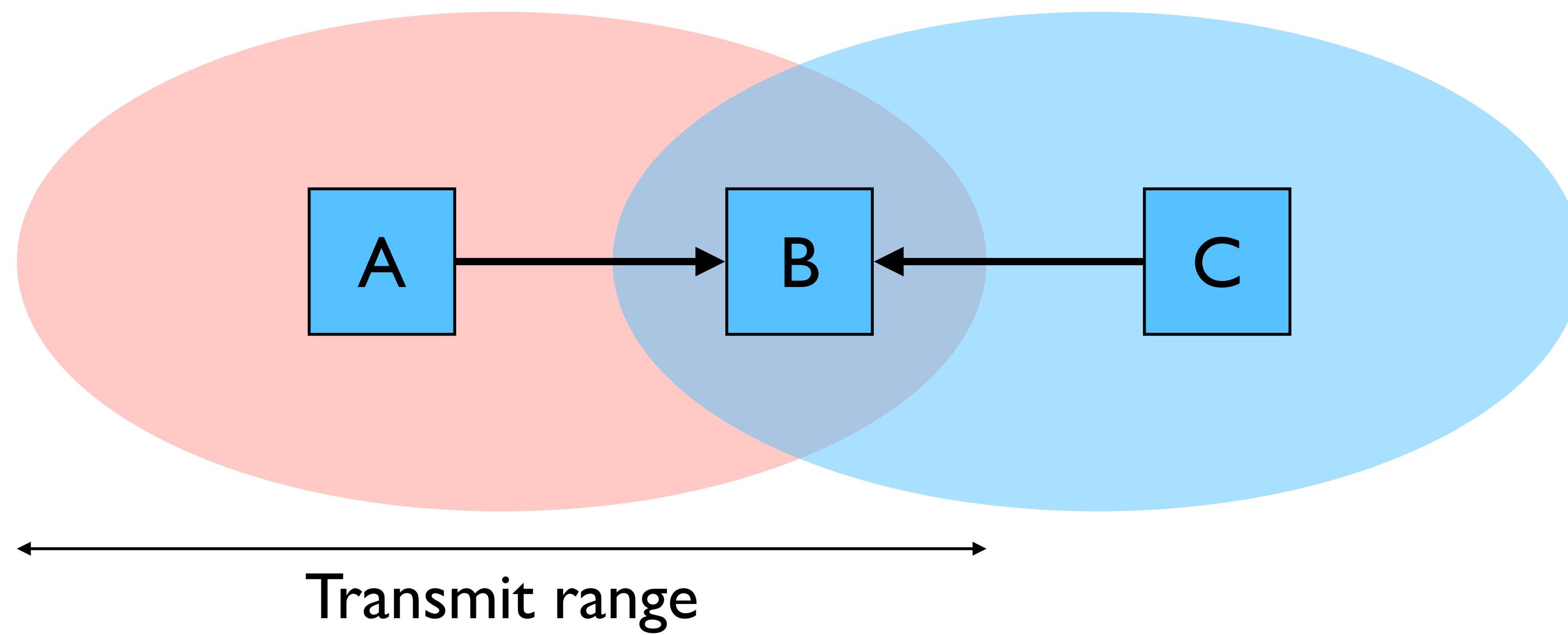


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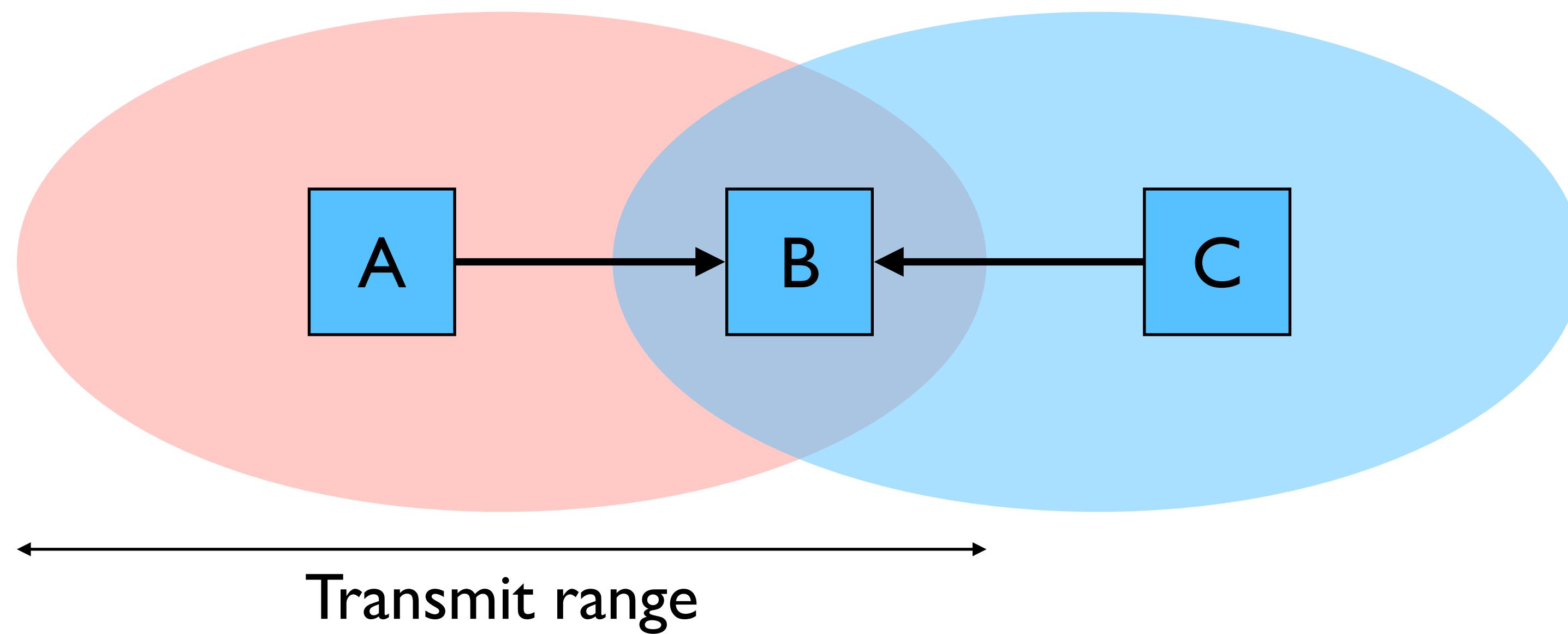
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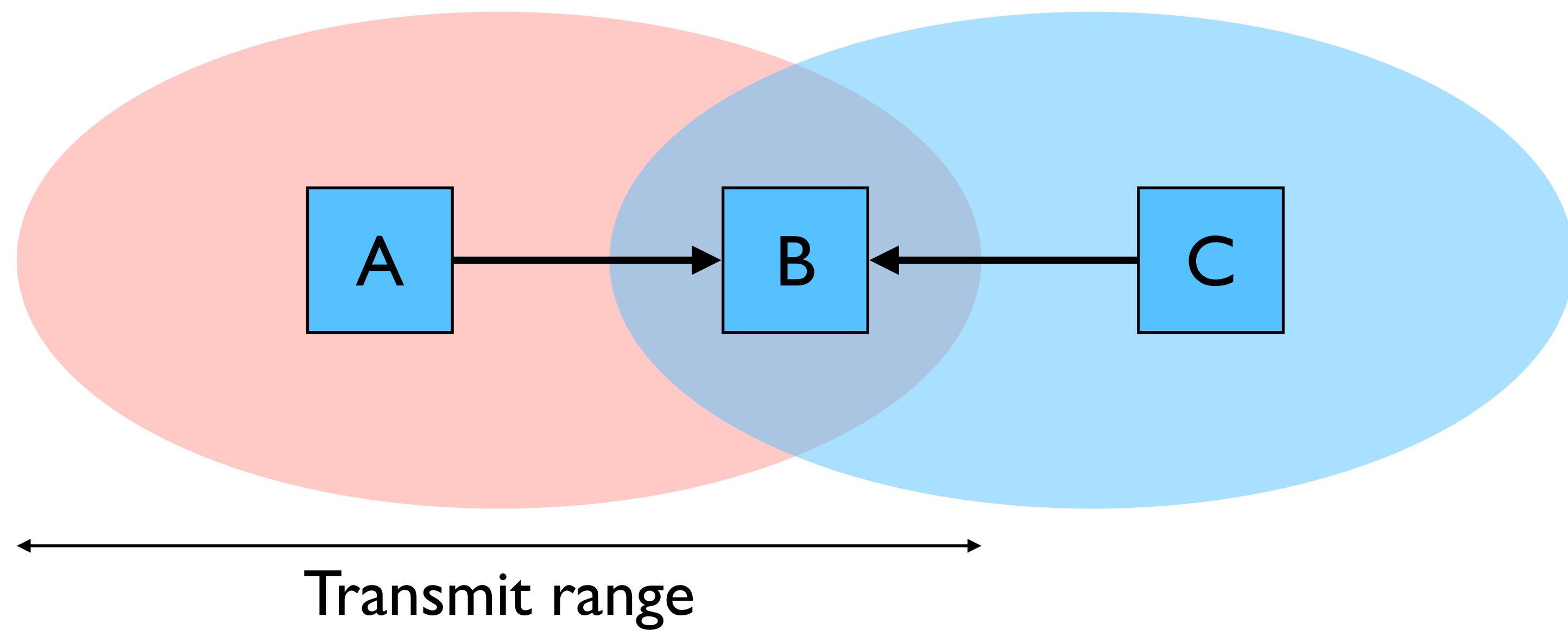
- A and B hear each other
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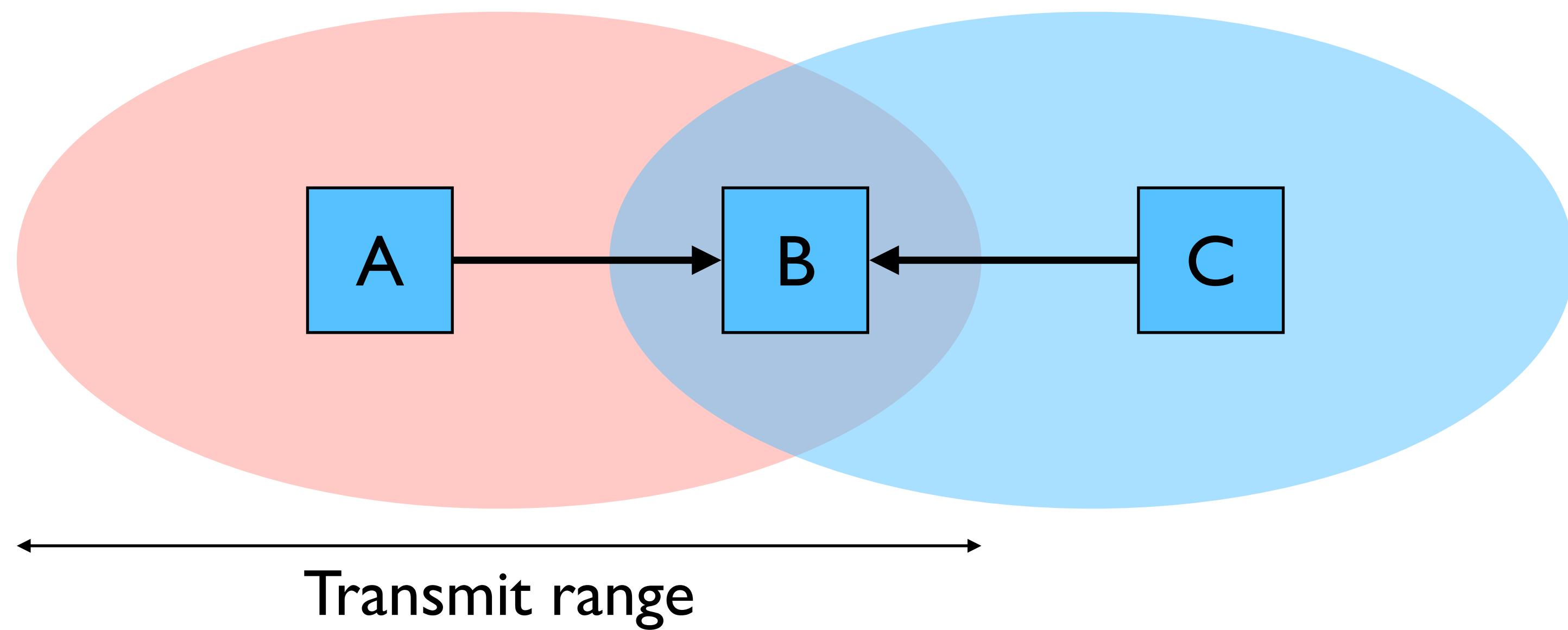
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# Hidden Terminals



- A and B hear each other
- B and C hear each other
- But, A and C do not
  - So A and C are *unaware of their interference at B!*
- Carrier sense at A cannot listen to C (and vice versa)

# Exposed Terminals

A



B



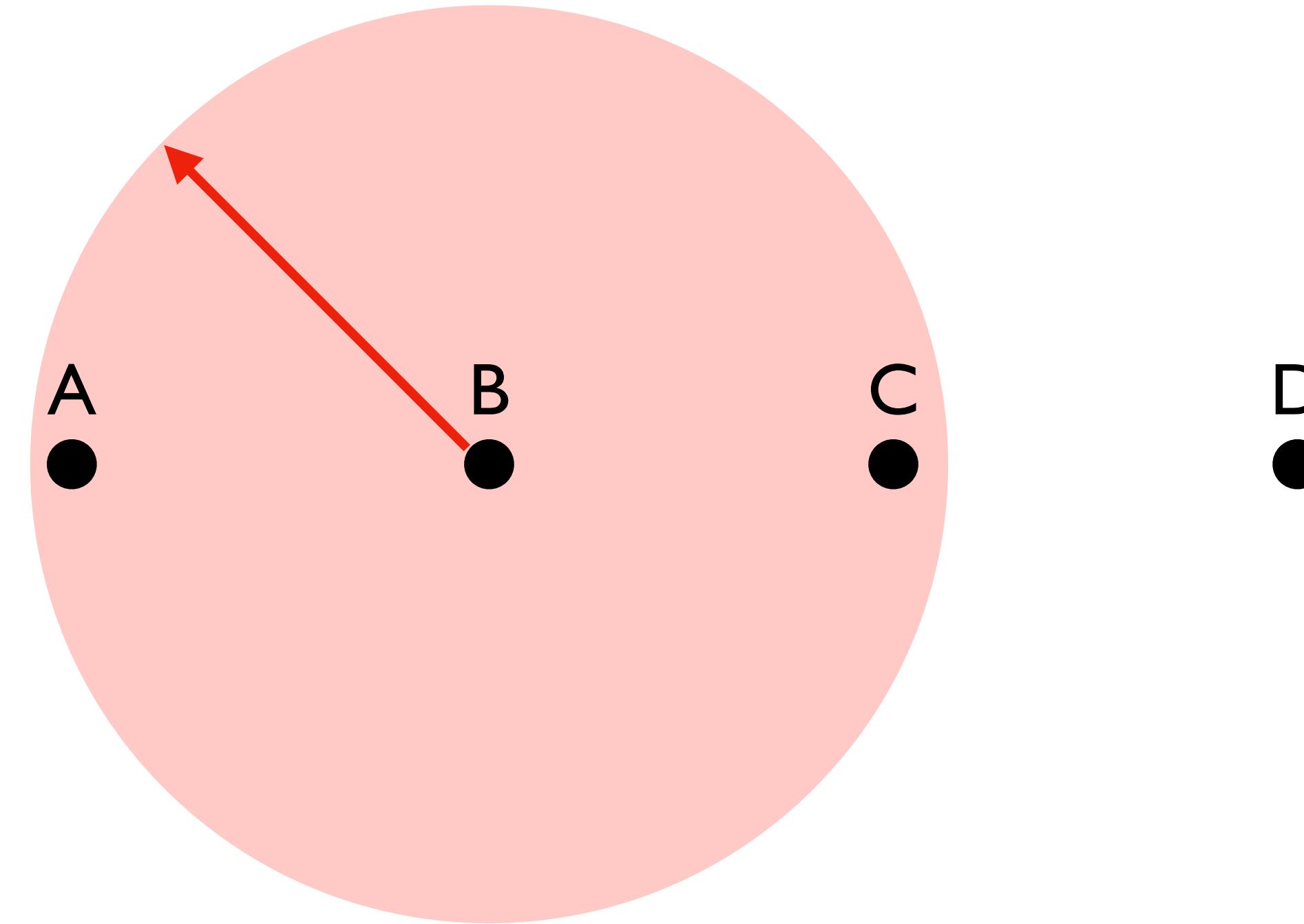
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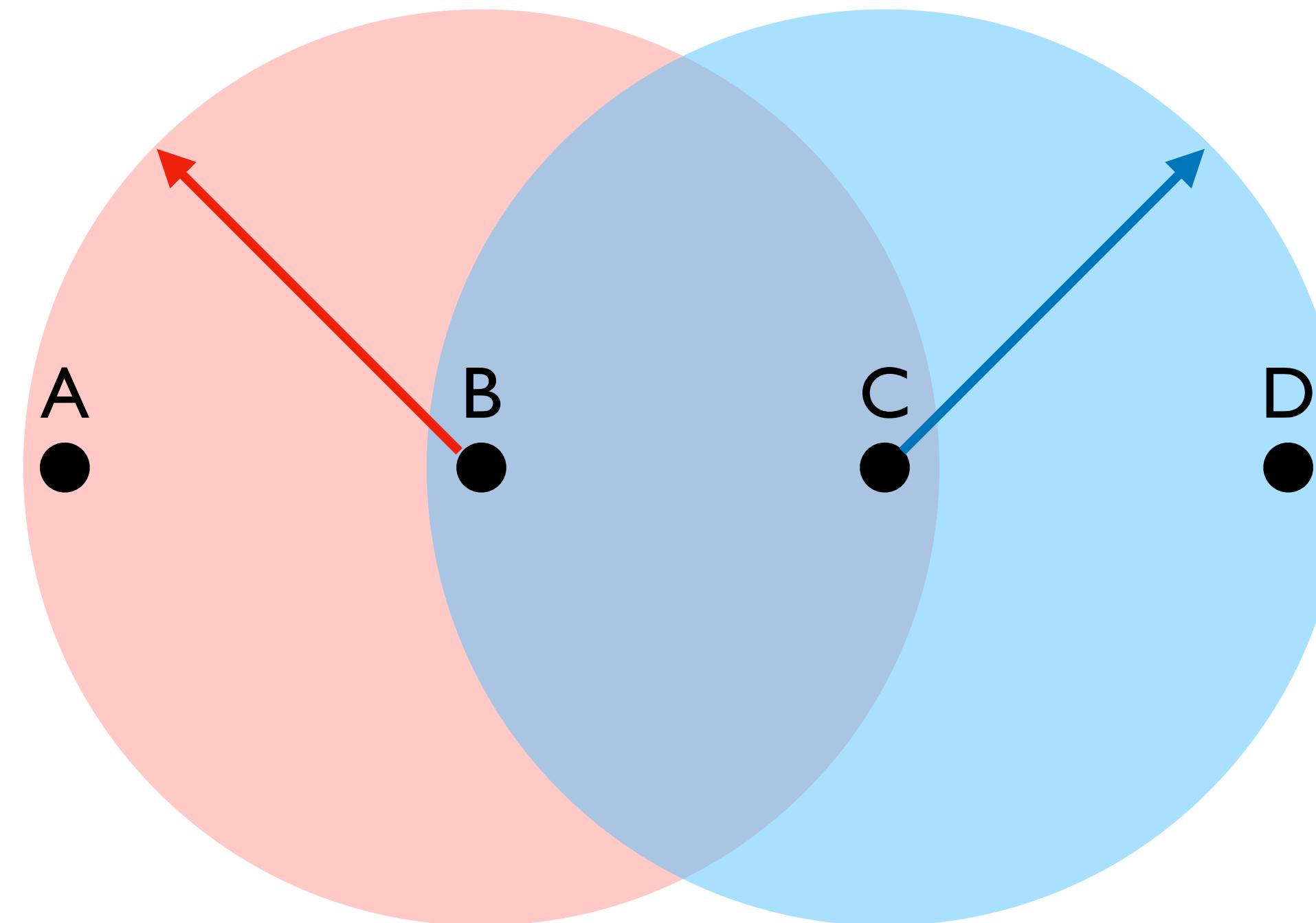
D



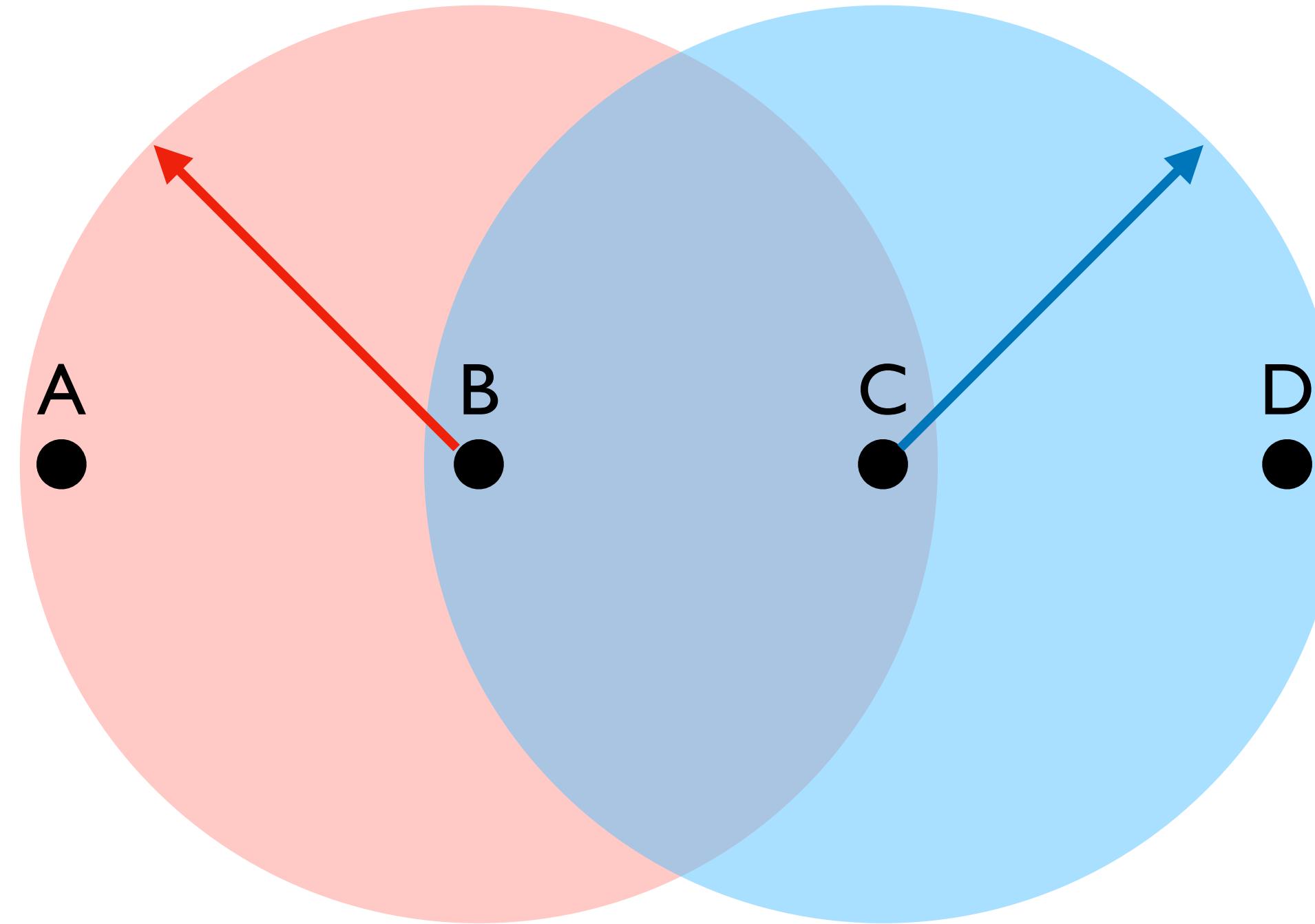
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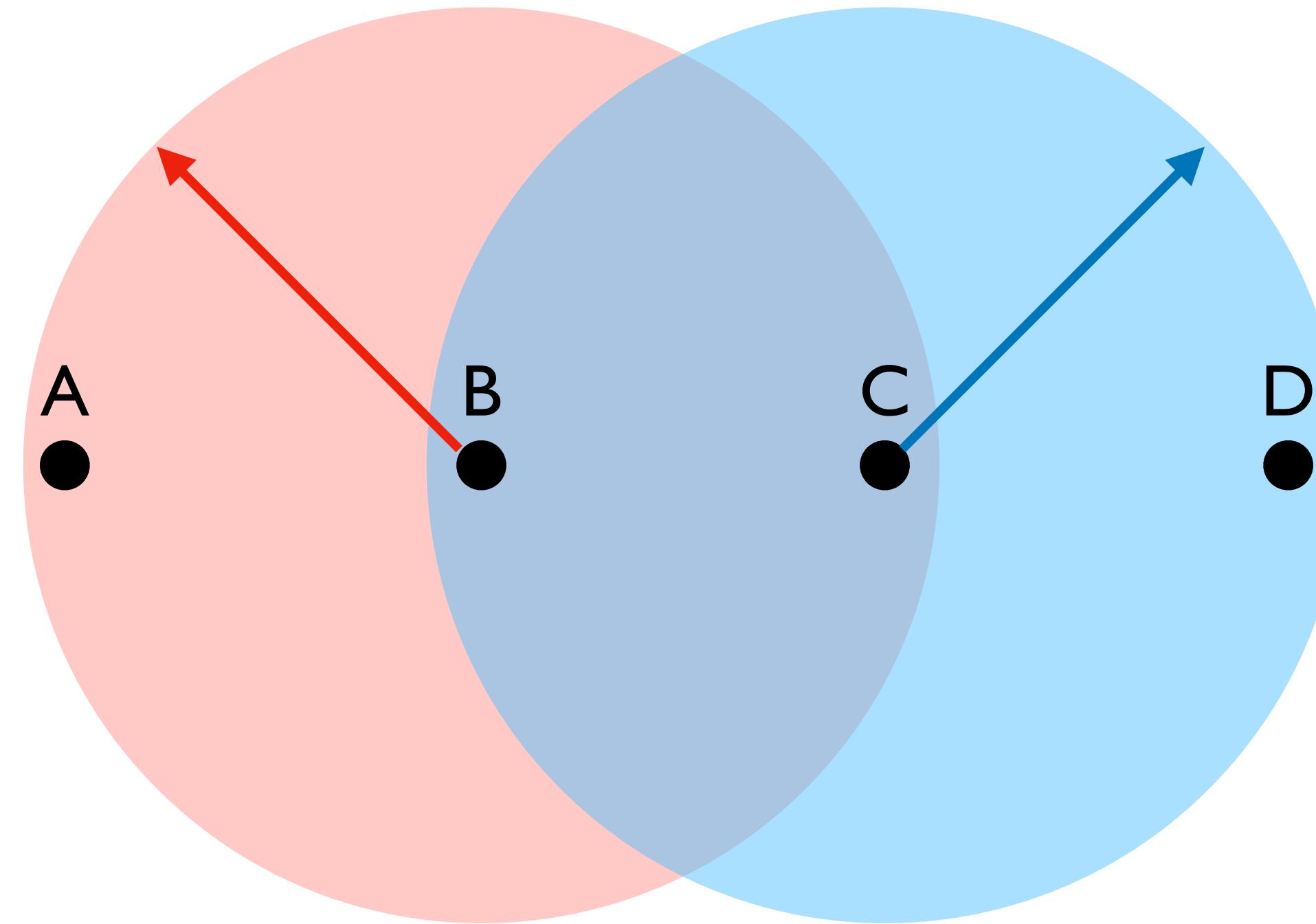


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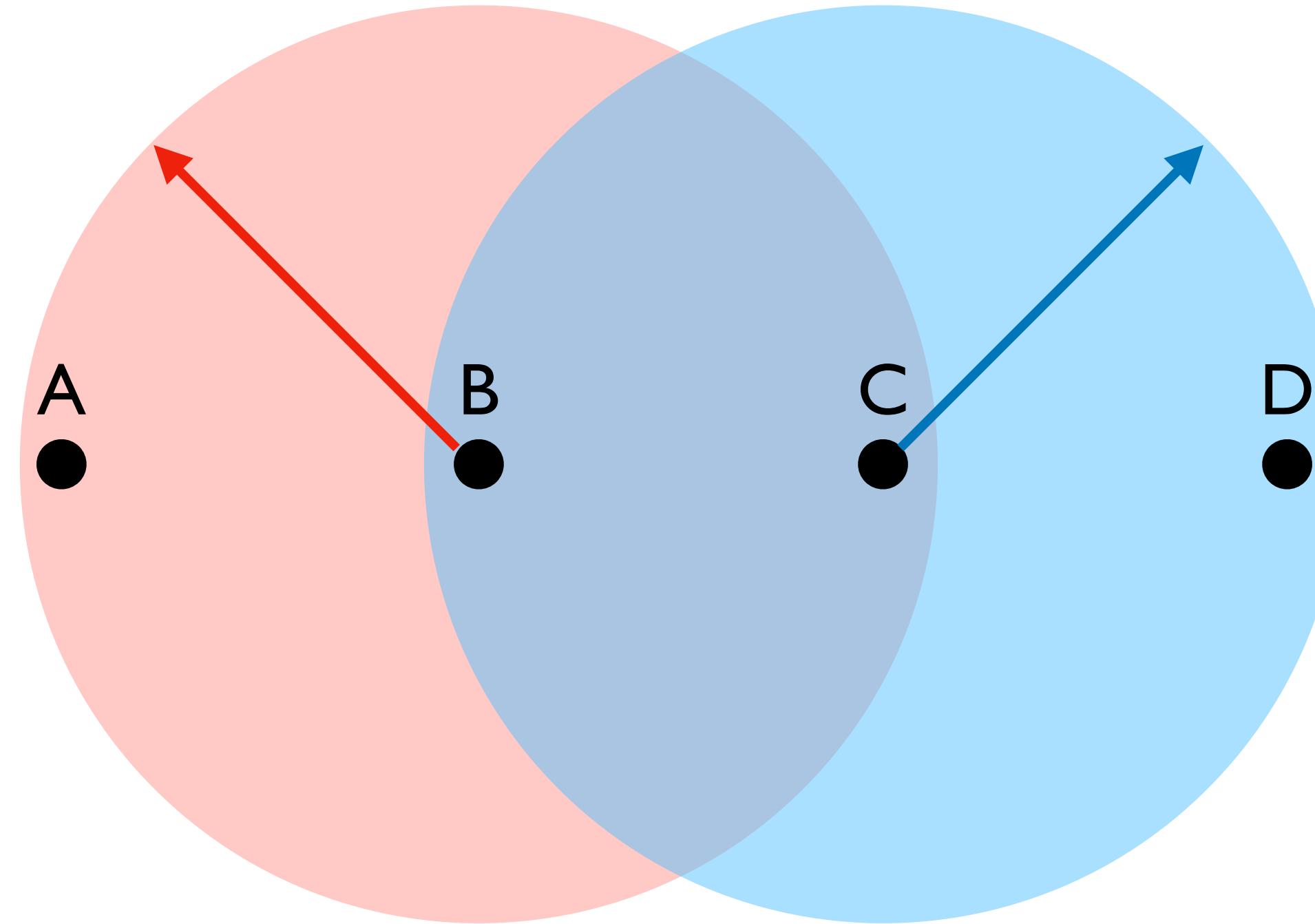
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# Exposed Terminals



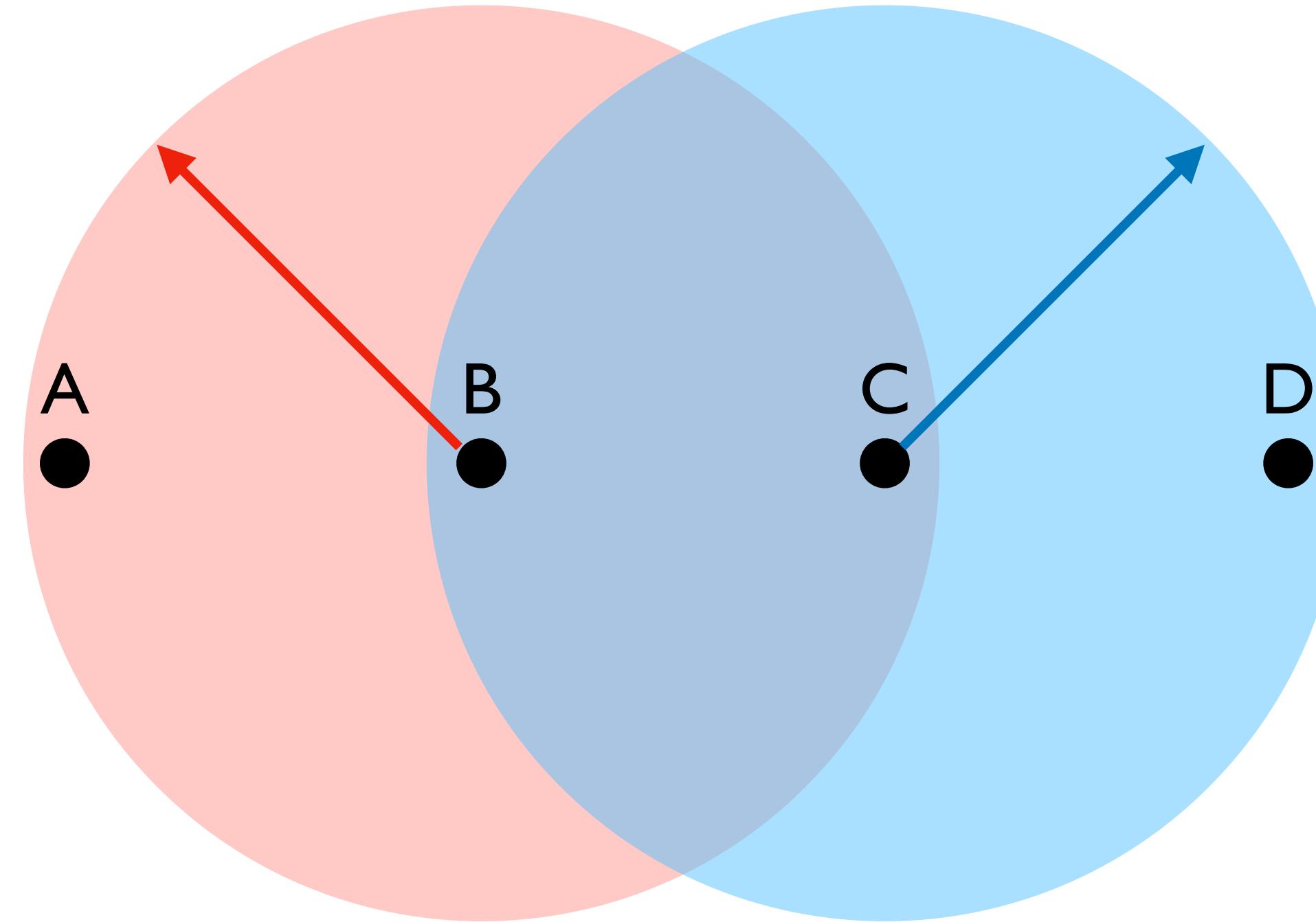
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# Exposed Terminals



- B sends a packet to A
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  - *Even though this will not cause interference*

# Exposed Terminals



- B sends a packet to A
- C hears this and decides not to send a packet to D
  - Even though this will not cause interference
- Carrier sense would prevent a successful transmission

# Questions?

# What have we learned?

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- *No global collisions* due to path attenuation
  - Different receivers hear different signals
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- **No global collisions due to path attenuation**
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  - Doesn't matter if sender can hear someone else (exposed terminal)
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- ***Collisions are at receiver, not sender***
  - Only care if receiver can hear sender clearly
  - Doesn't matter if sender can hear someone else (exposed terminal)
  - As long as signal does not interfere with receiver
- **So better to avoid collisions than detecting them...**
  - Detect if receiver can hear sender
  - Tell sender who *might* interfere with receiver to shut up

# Collision Avoidance

Sender



Receiver



Other node in  
sender's range



# Collision Avoidance

Sender



Receiver

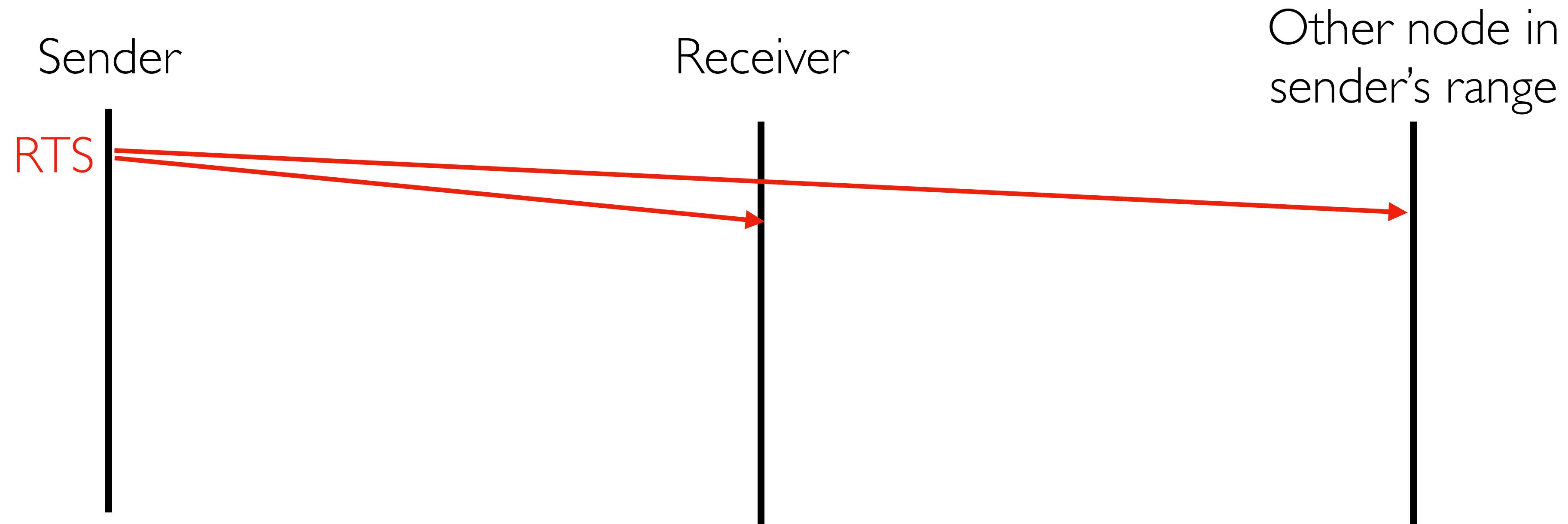


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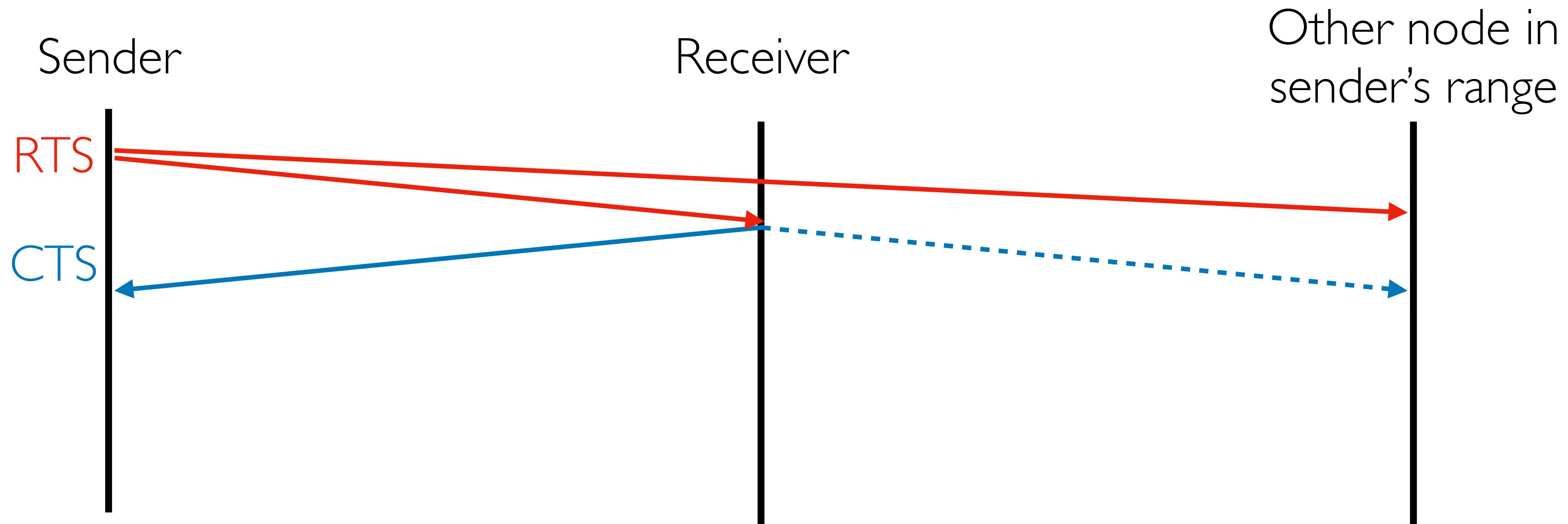
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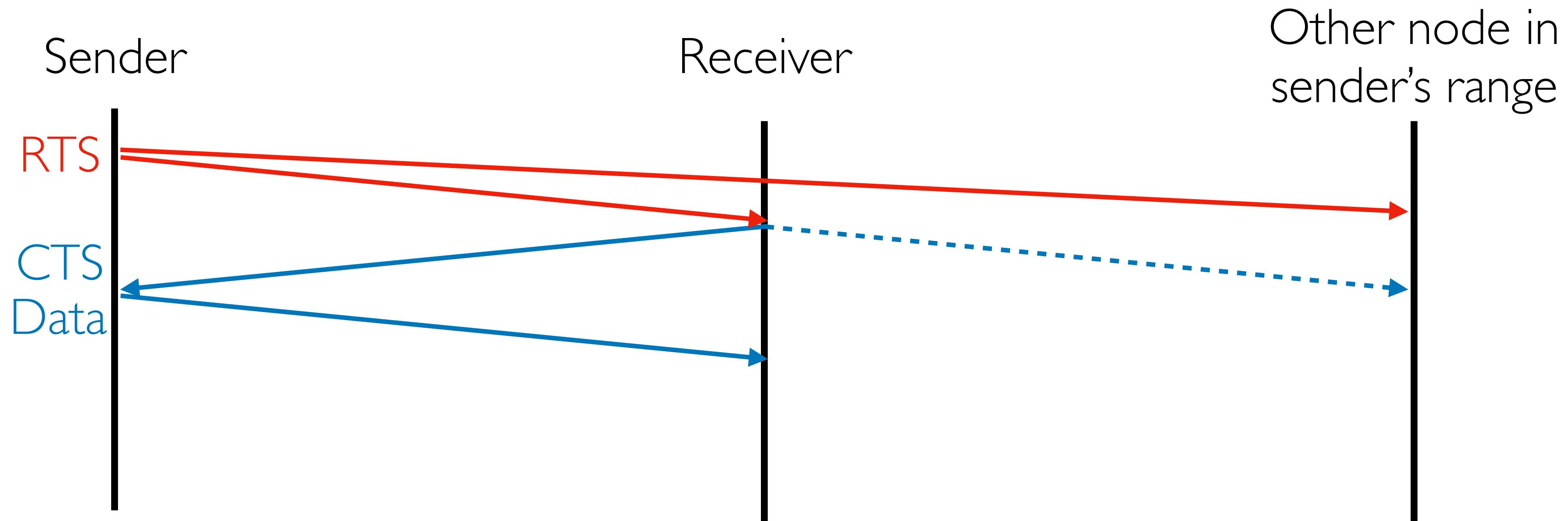
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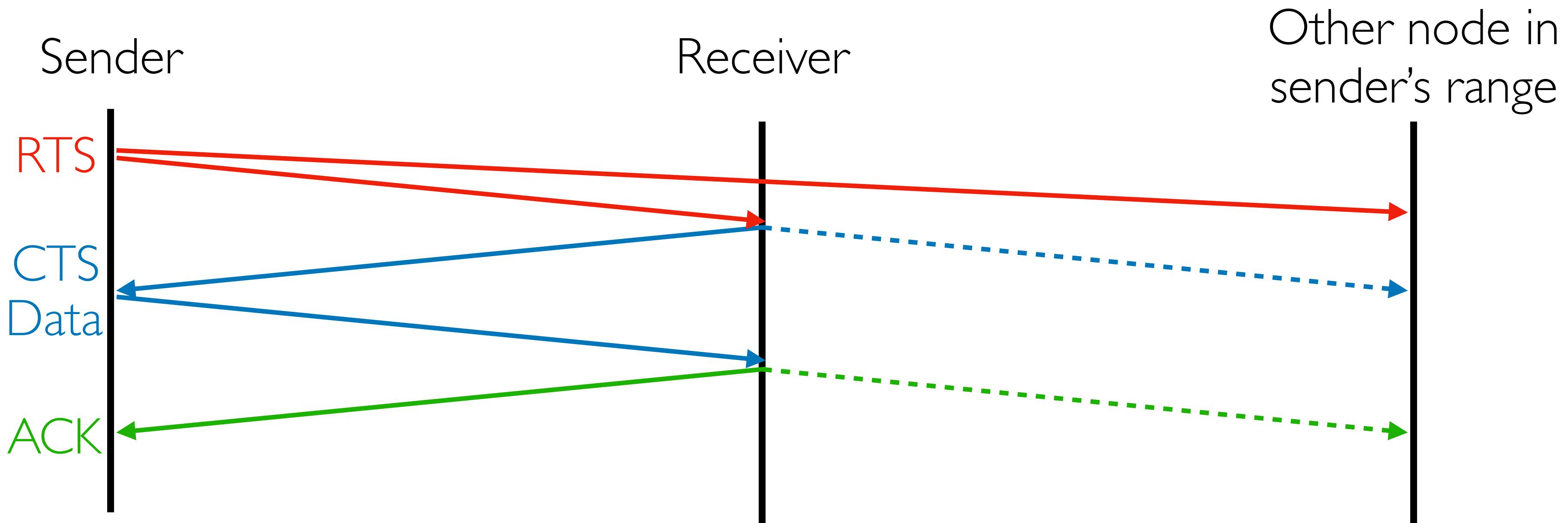
- First exchange control frames before transmitting data
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  - Receiver responds with Clear to Send (CTS)

# Collision Avoidance



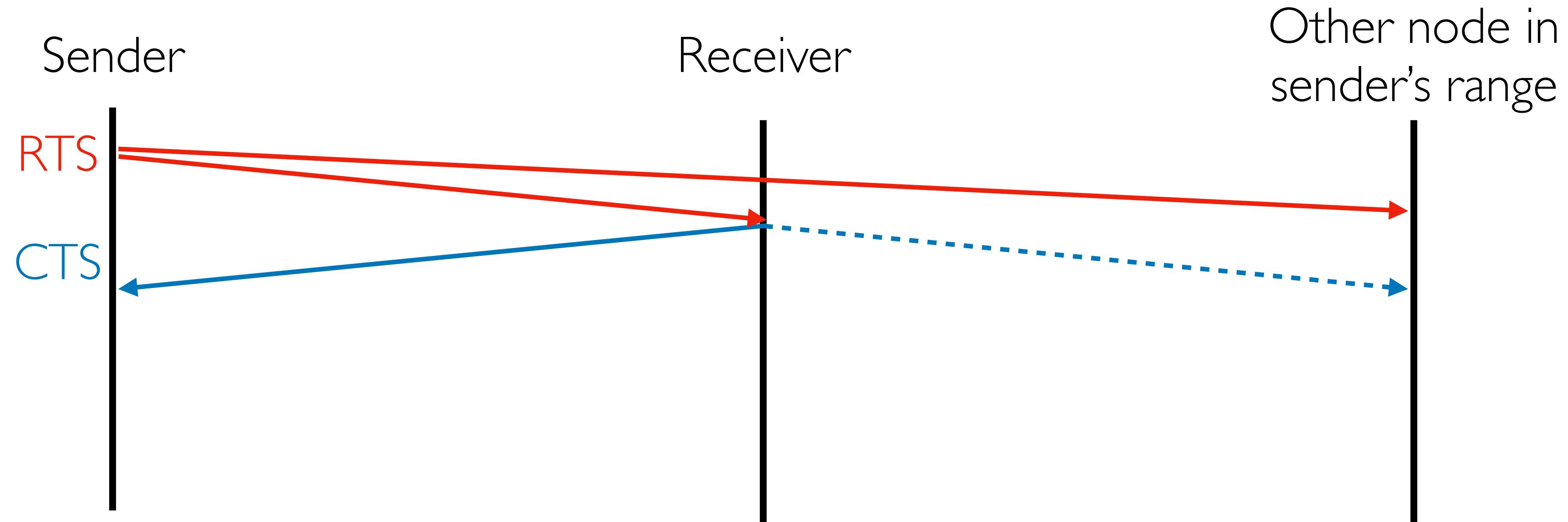
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  - If sender sees CTS for its own RTS, transmits data

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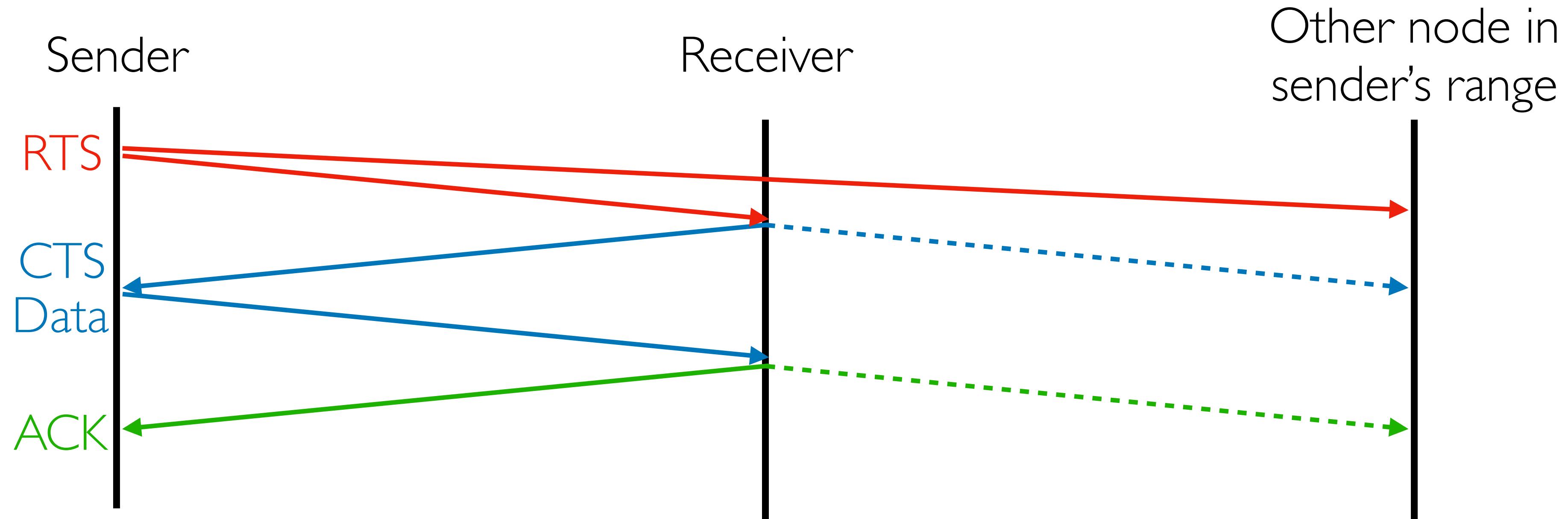


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  - Sender issues Request to Send (RTS), including length of data and destination
  - Receiver responds with Clear to Send (CTS)
  - If sender sees CTS for its own RTS, transmits data
  - Receiver sends an ACK; now other sender can send

# Collision Avoidance: Note# I

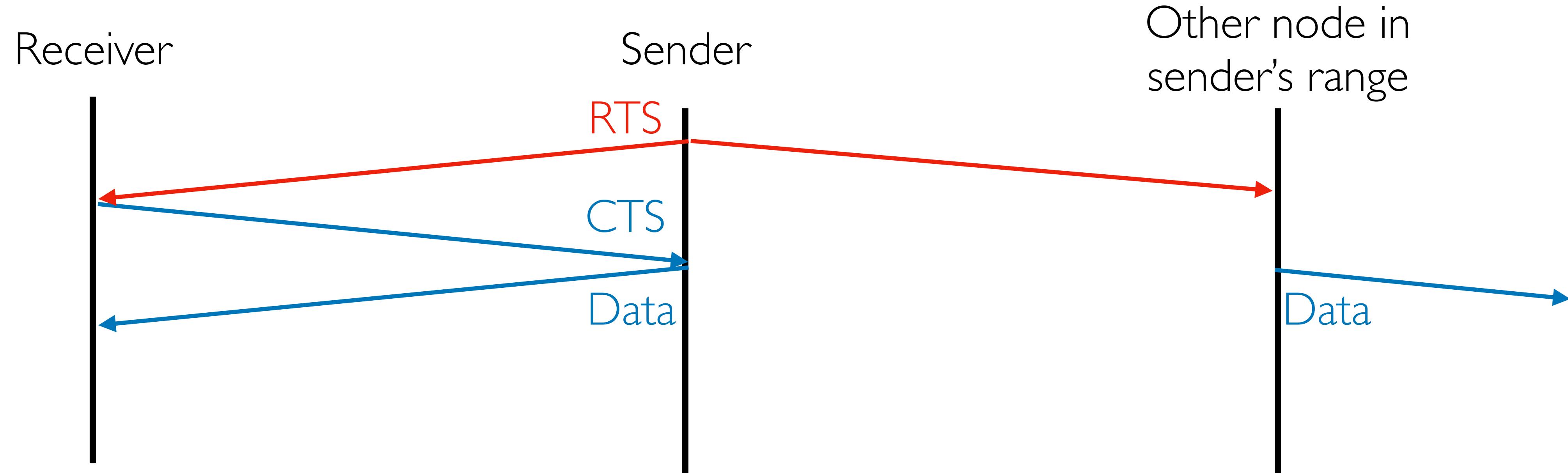


# Collision Avoidance: Note# I

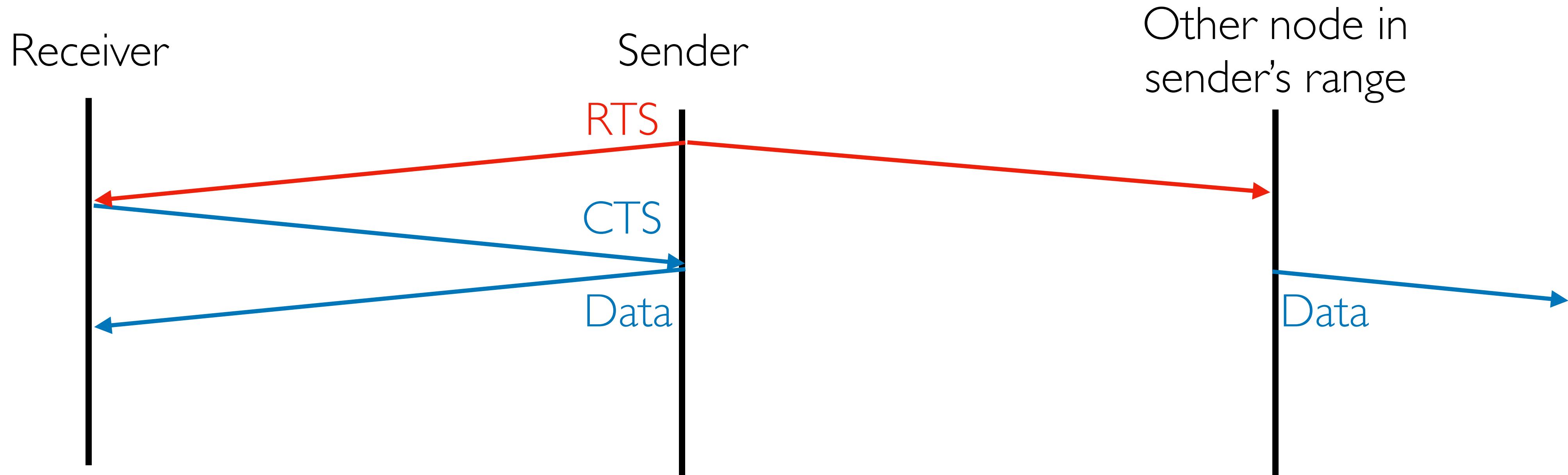


- When you hear a CTS, you keep quiet until scheduled transmission is over (hear ACK)

# Collision Avoidance: Note#2

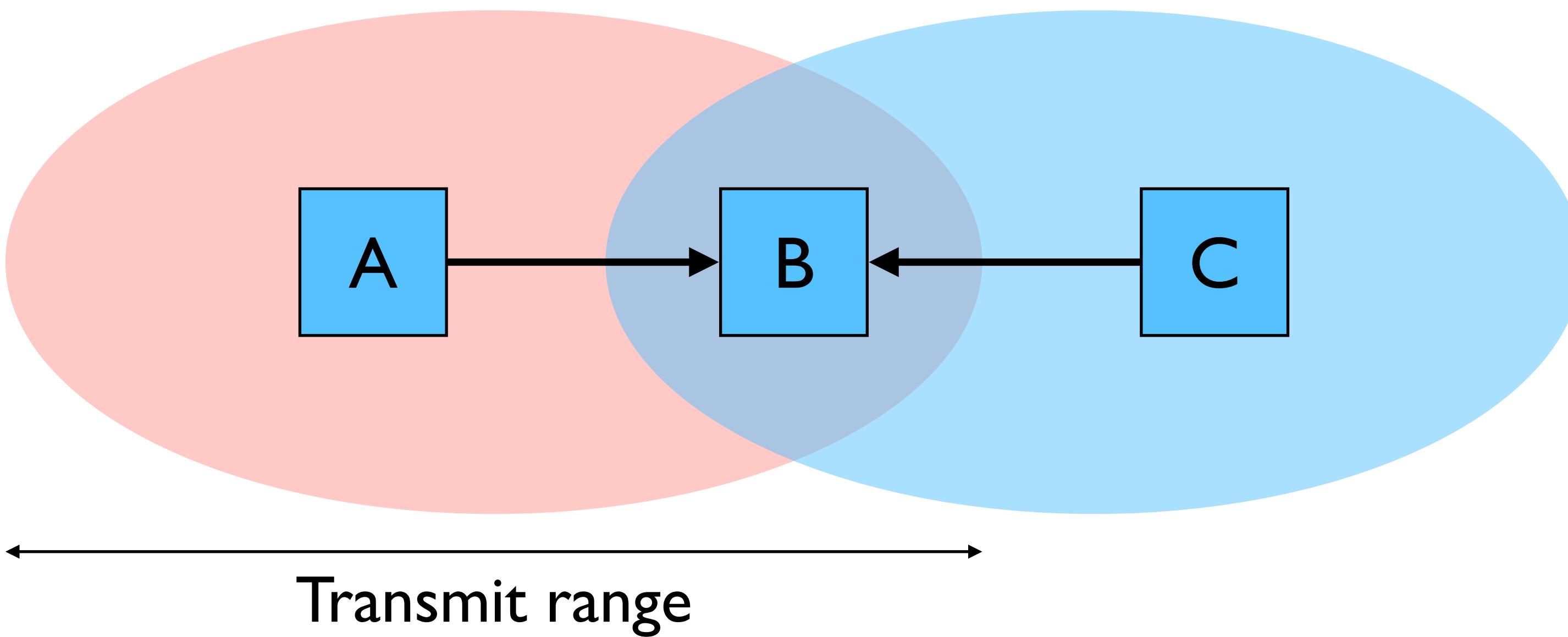


# Collision Avoidance: Note#2



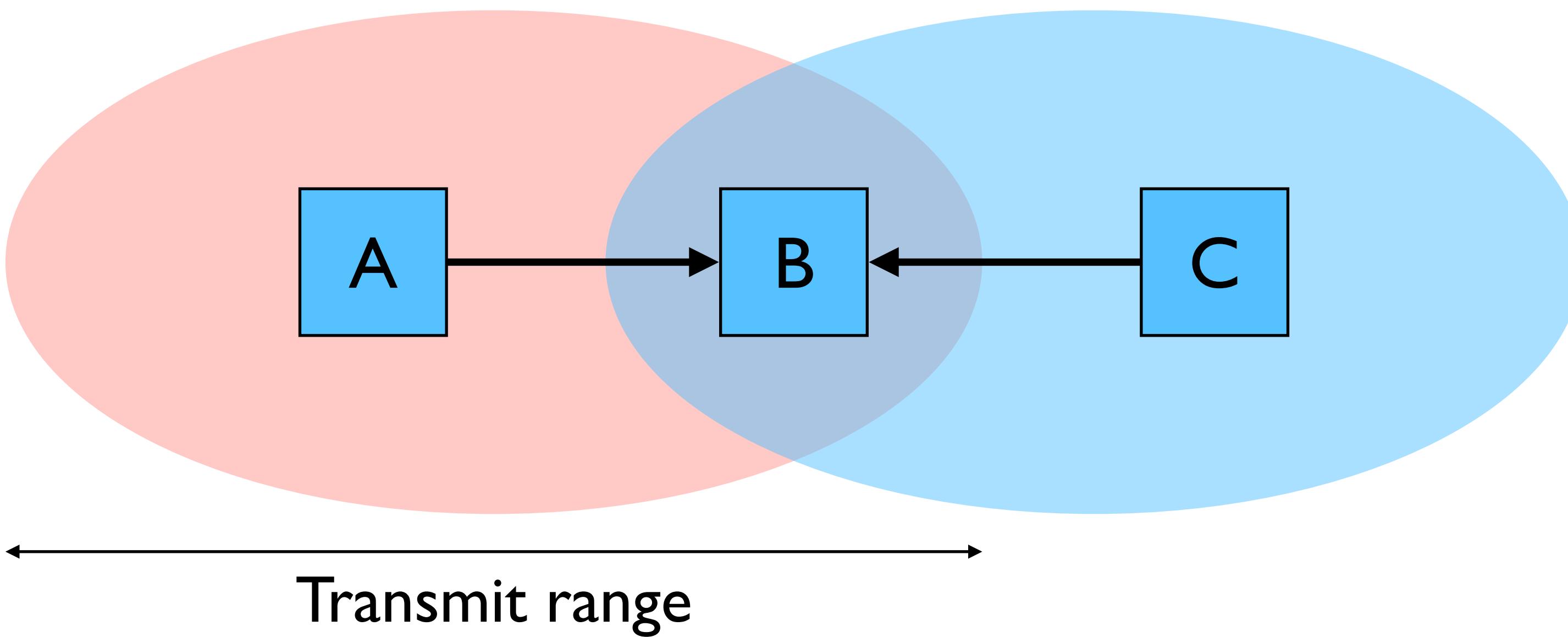
- If other nodes hear RTS, but not CTS: send
  - Presumably, destination for first sender is out of node's range...

# Hidden Terminals



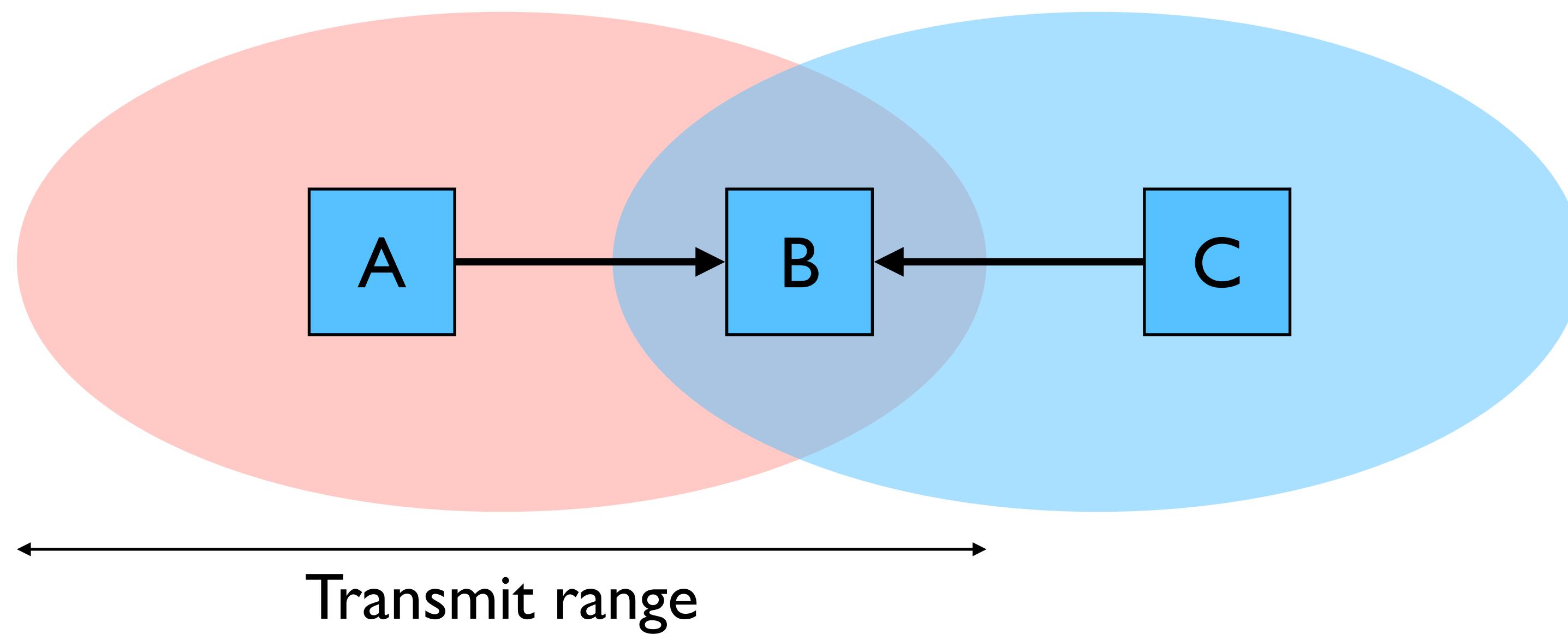
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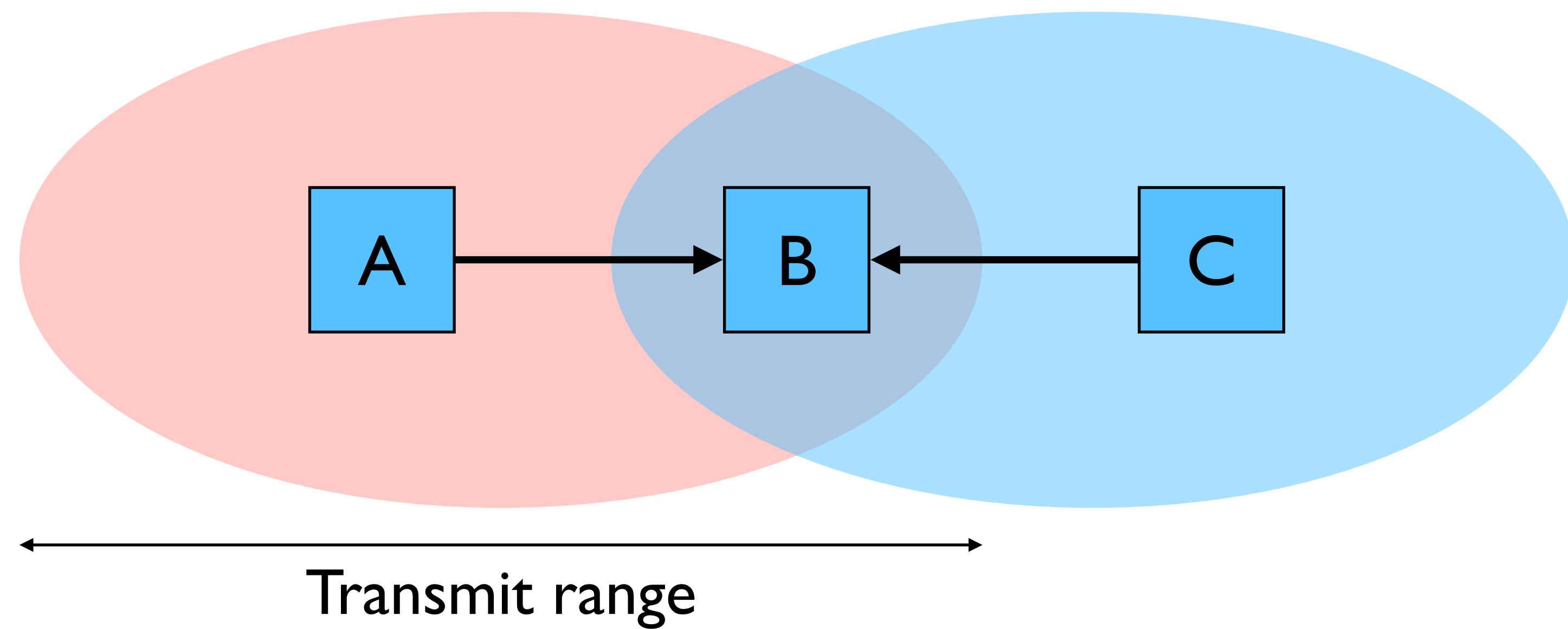
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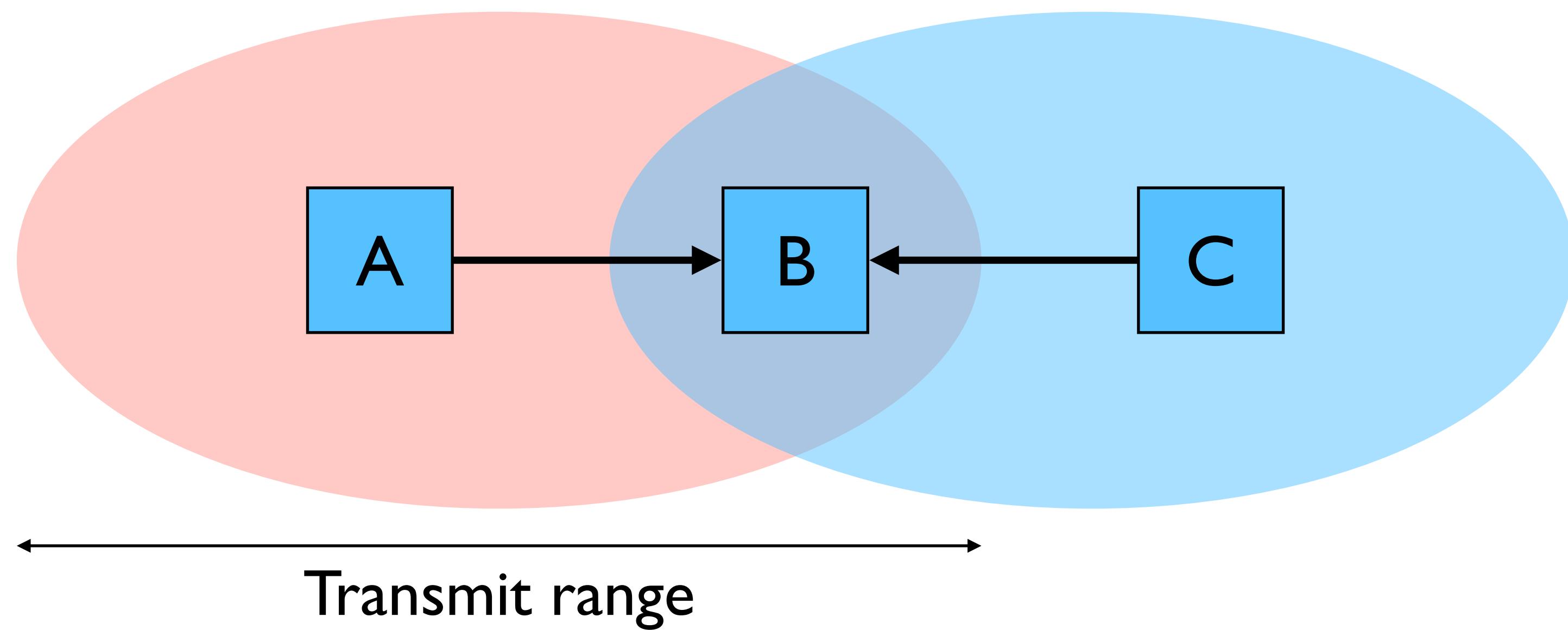
- A and C cannot see each other, both send to B
- RTS/CTS can help
  - Both A and C would send RTS that B would see first

# Hidden Terminals



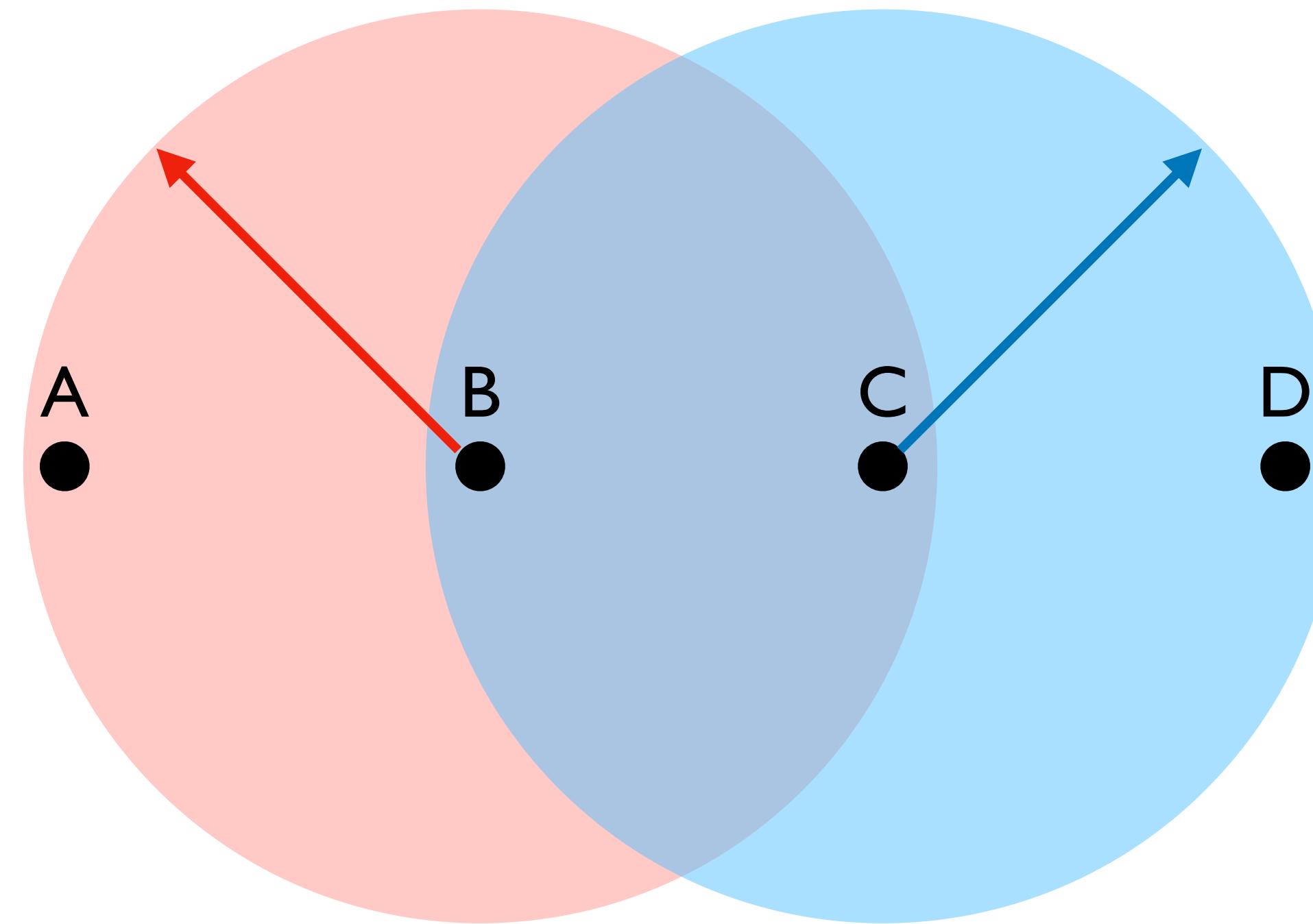
- A and C cannot see each other, both send to B
- RTS/CTS can help
  - Both A and C would send RTS that B would see first
  - B only responds with one **CTS** (say, echoing A's RTS)

# Hidden Terminals

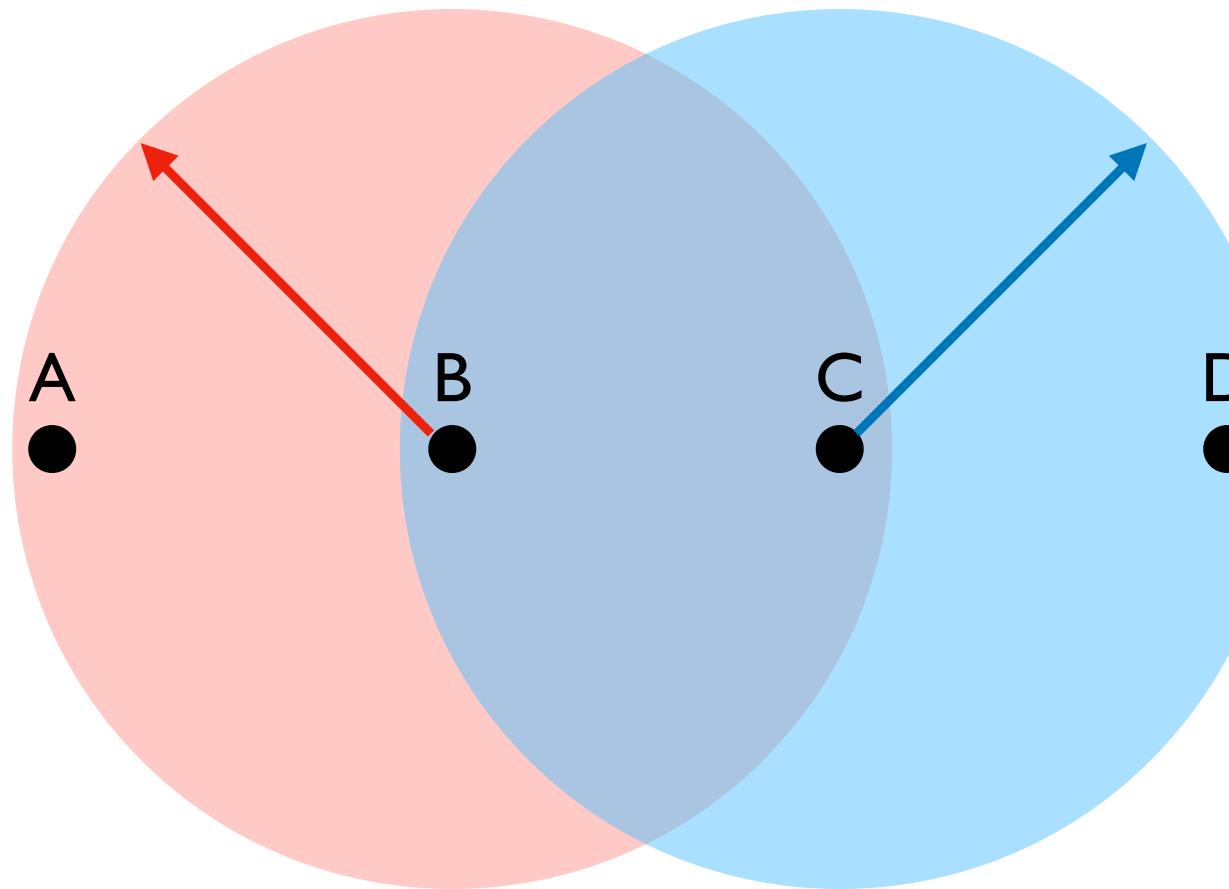


- A and C cannot see each other, both send to B
- RTS/CTS can help
  - Both A and C would send RTS that B would see first
  - B only responds with one **CTS** (say, echoing A's RTS)
  - C detects that CTS does not match and will not send

# Exposed Terminals

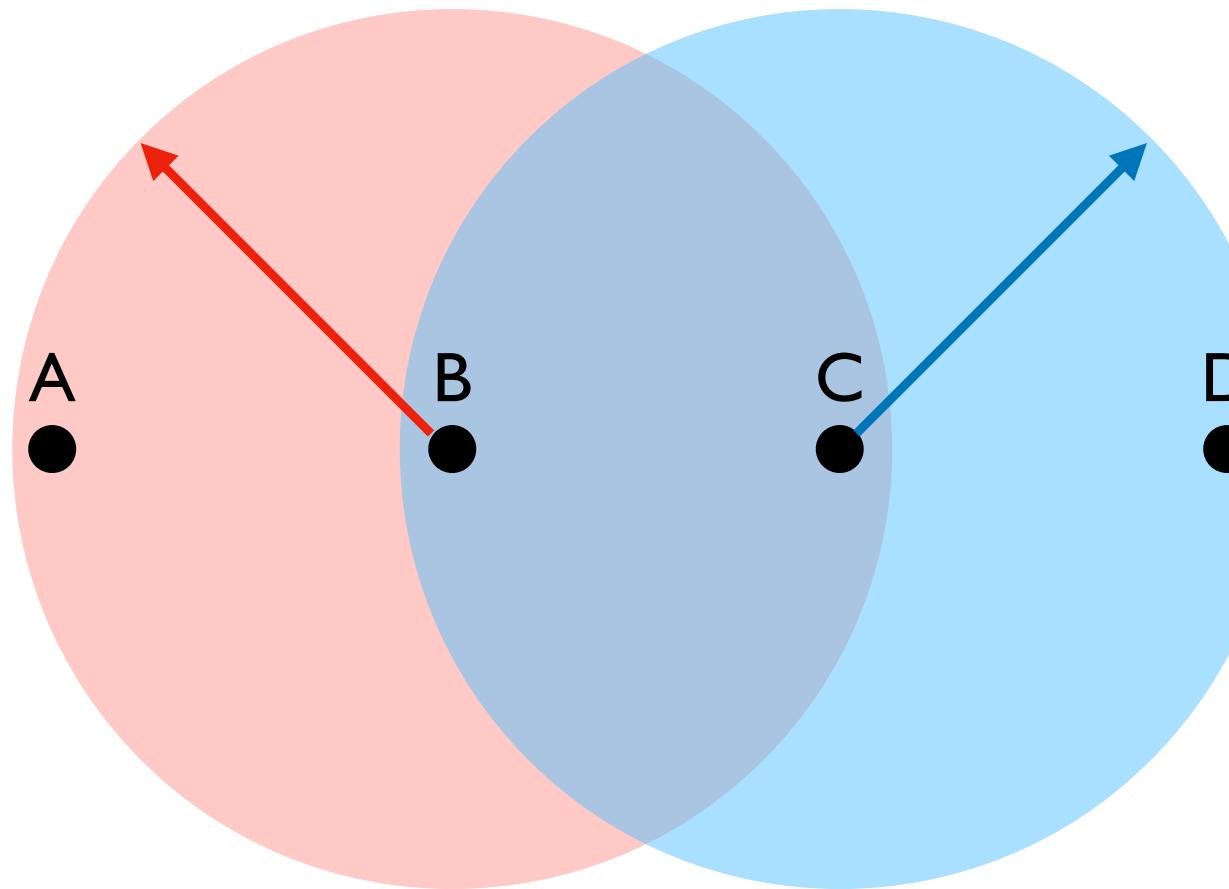


# Exposed Terminals



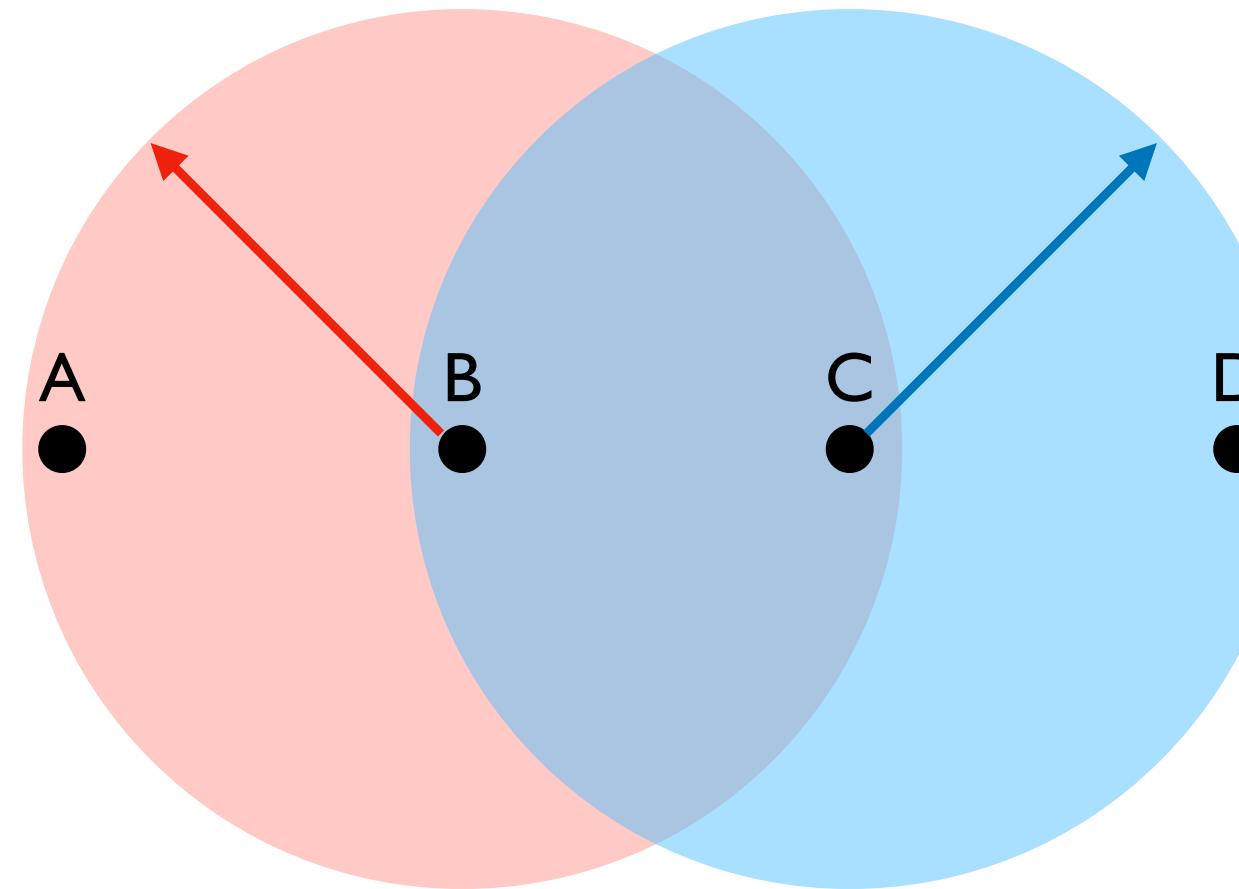
- B sending to A, C wants to send to D
- As C receives B's packets, carrier sense prevents it from sending to D, even though it wouldn't have interfered

# Exposed Terminals



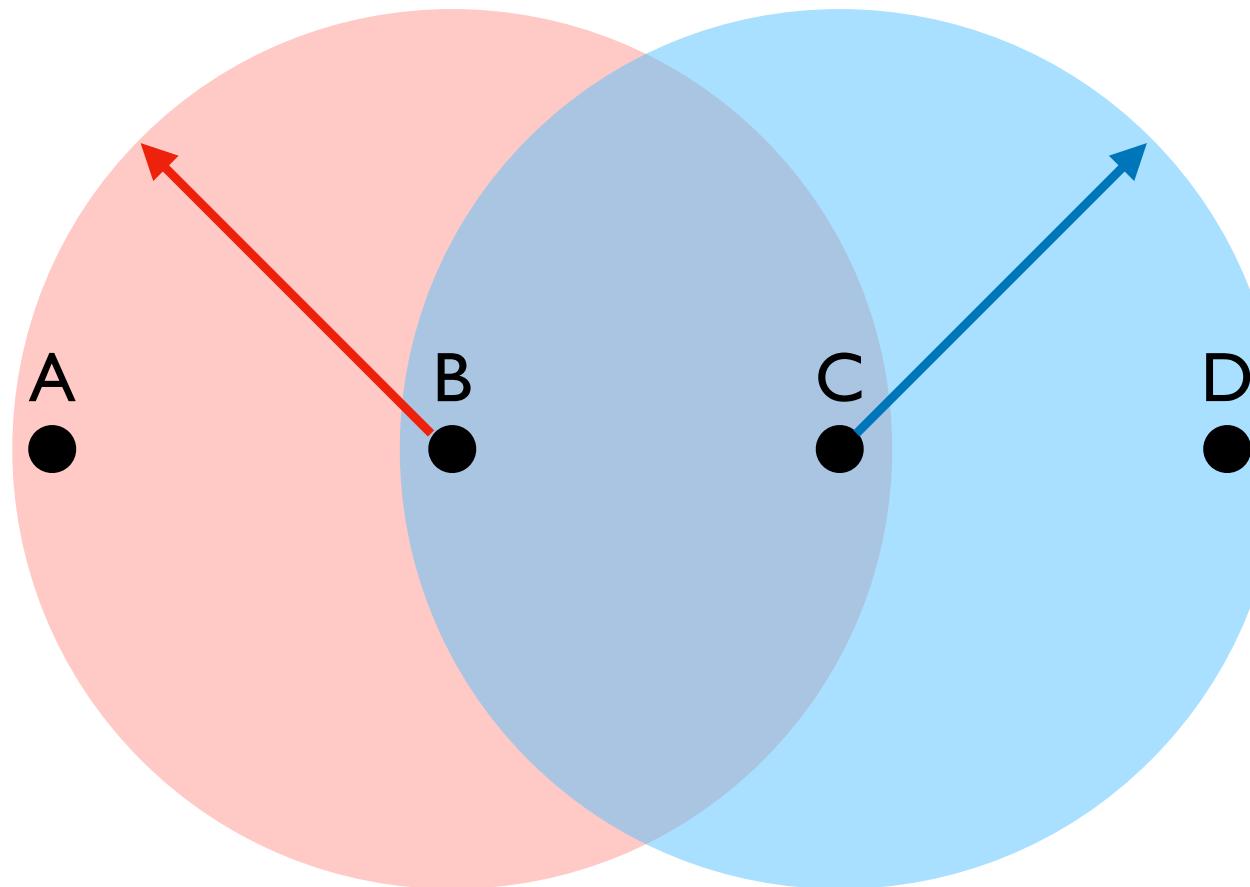
- B sending to A, C wants to send to D
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- RTS/CTS can help

# Exposed Terminals



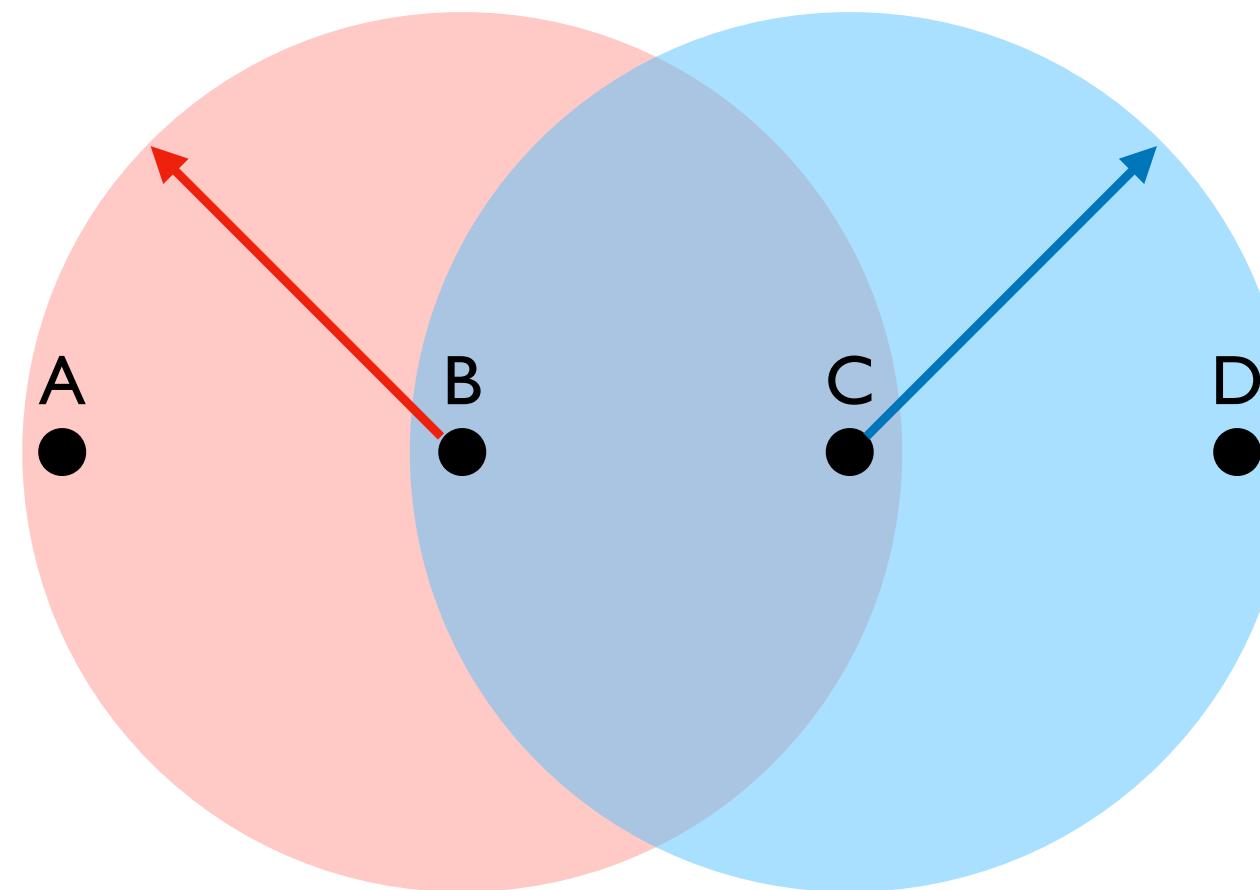
- B sending to A, C wants to send to D
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- RTS/CTS can help
  - C hears RTS from B, but not CTS from A

# Exposed Terminals



- B sending to A, C wants to send to D
- As C receives B's packets, carrier sense prevents it from sending to D, even though it wouldn't have interfered
- RTS/CTS can help
  - C hears RTS from B, but not CTS from A
  - C knows its transmission will not interfere with A

# Exposed Terminals



- B sending to A, C wants to send to D
- As C receives B's packets, carrier sense prevents it from sending to D, even though it wouldn't have interfered
- RTS/CTS can help
  - C hears RTS from B, but not CTS from A
  - C knows its transmission will not interfere with A
  - C is safe to transmit to D

# Questions?

# Multi-Hop Wireless Ad-hoc Networks



# Multi-Hop Wireless Ad-hoc Networks



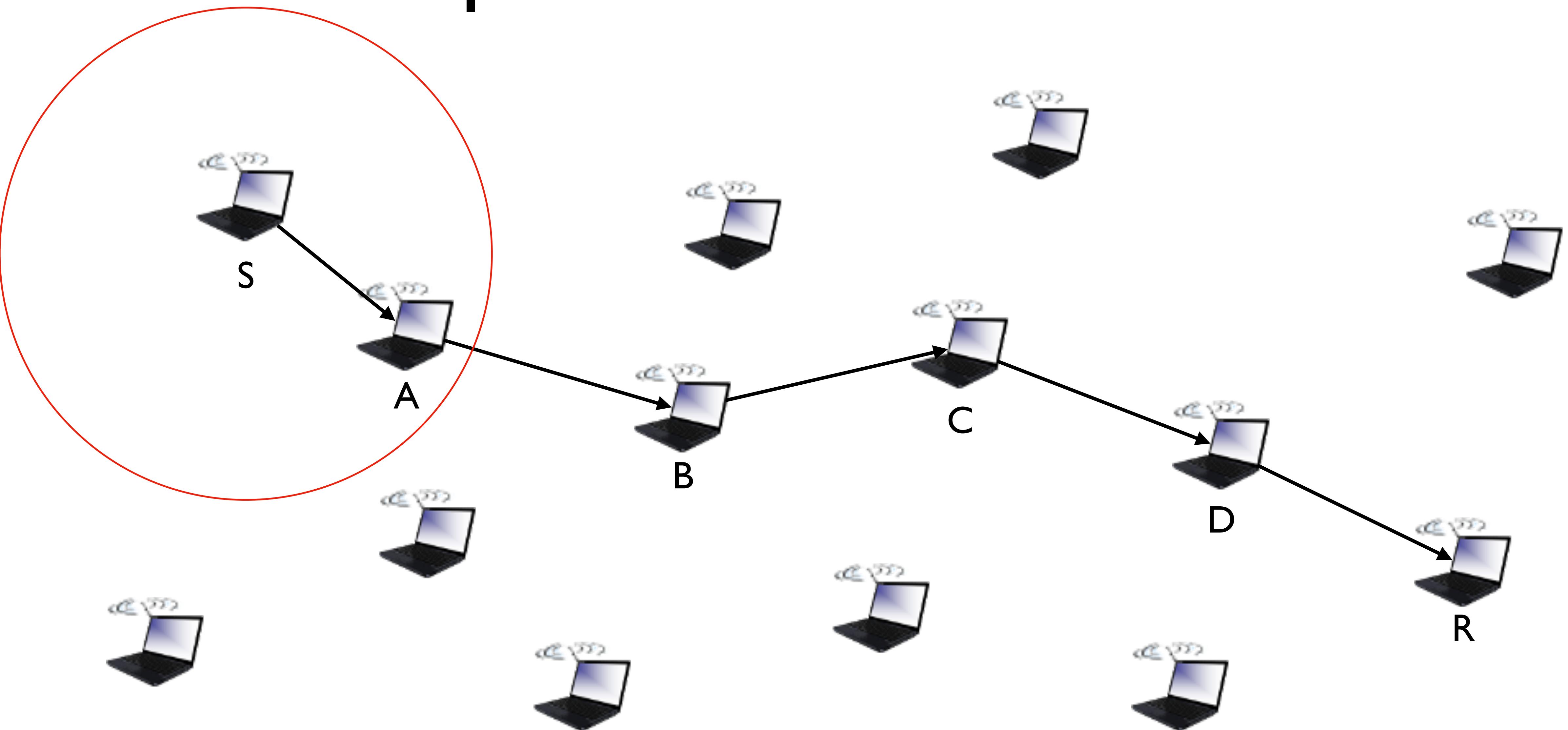
# Multi-Hop Wireless Ad-hoc Networks



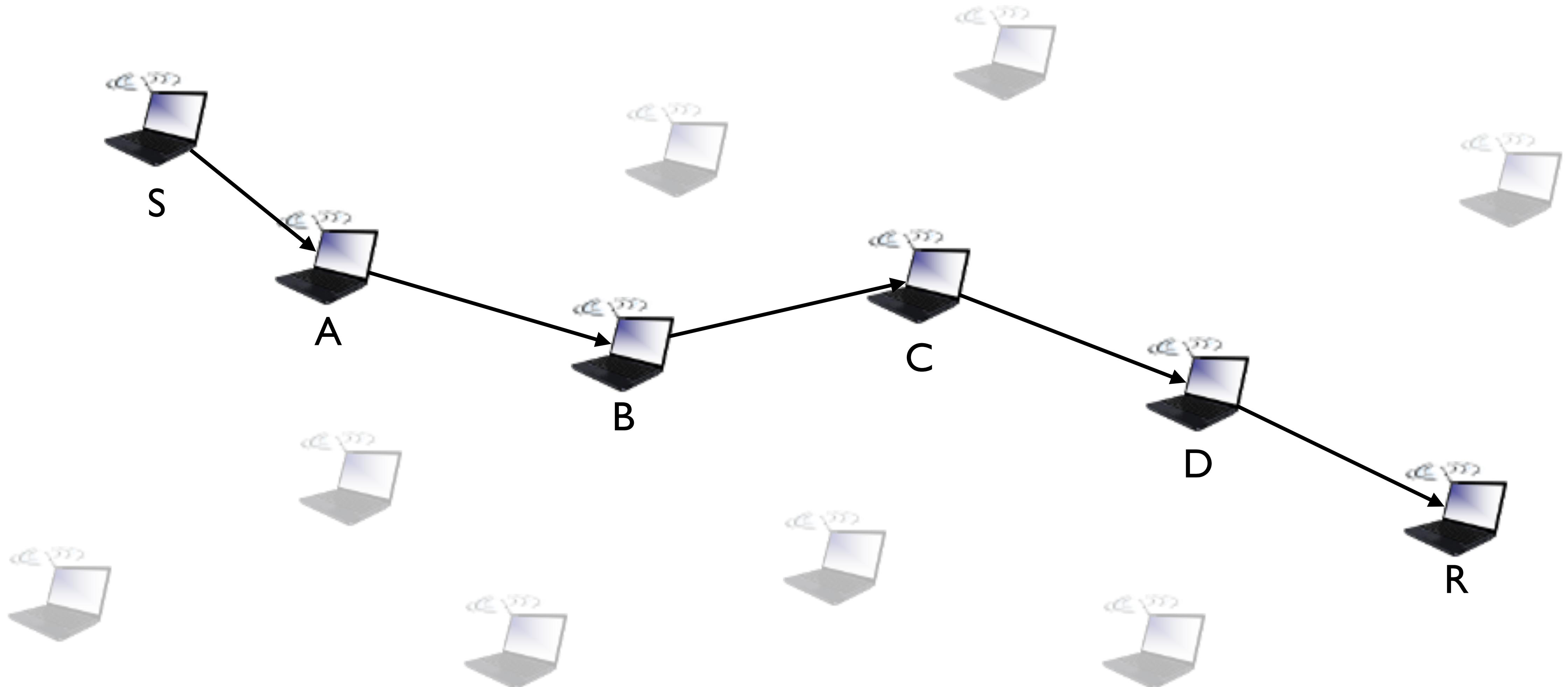
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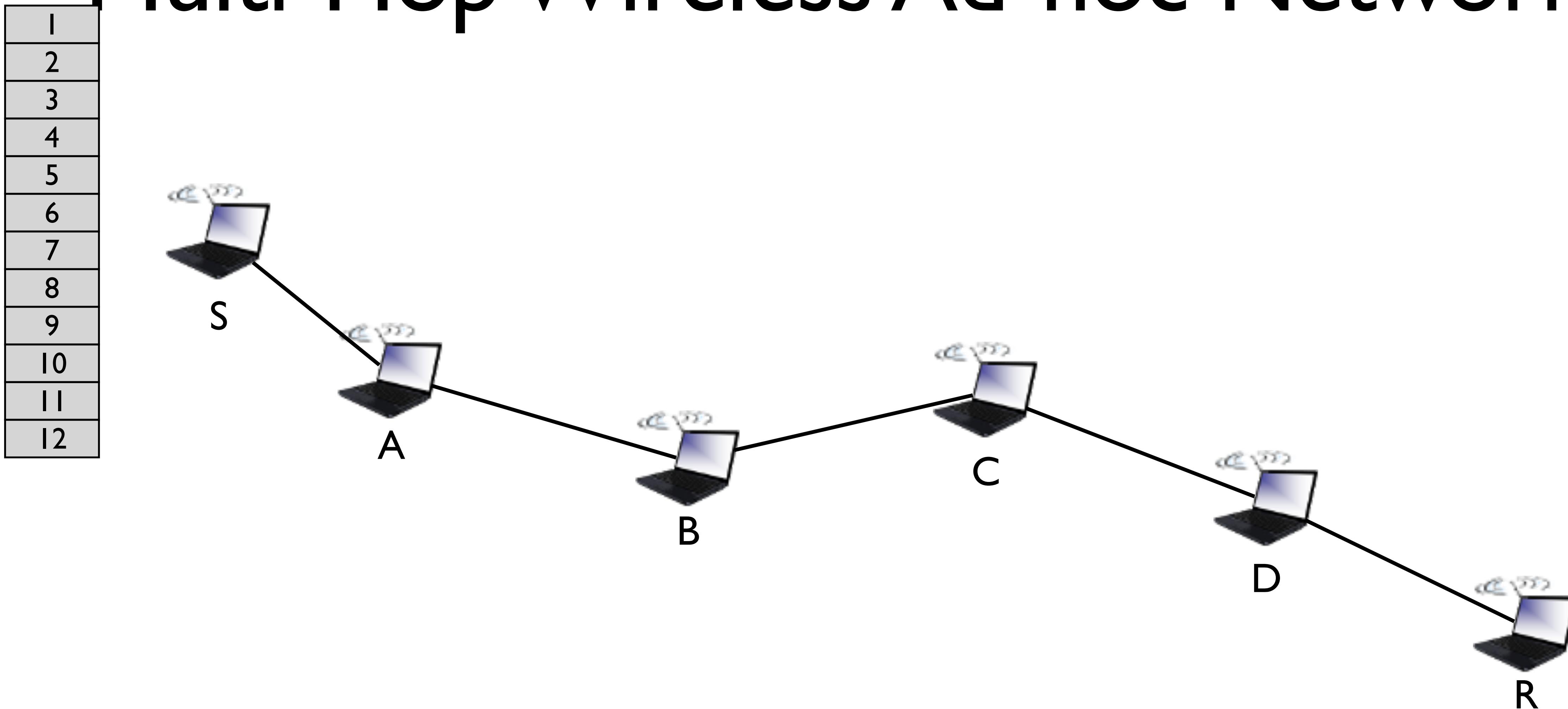
# Multi-Hop Wireless Ad-hoc Networks



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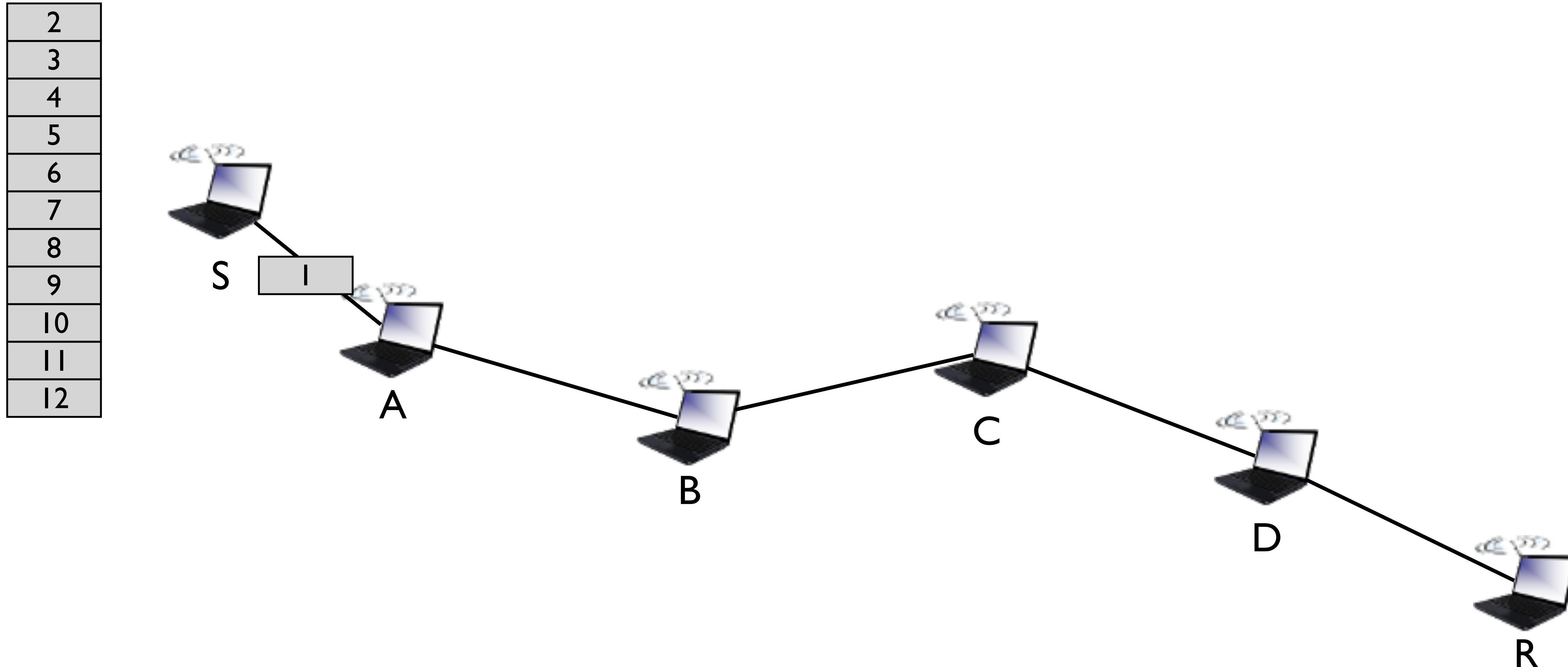


# Multi-Hop Wireless Ad-hoc Networks

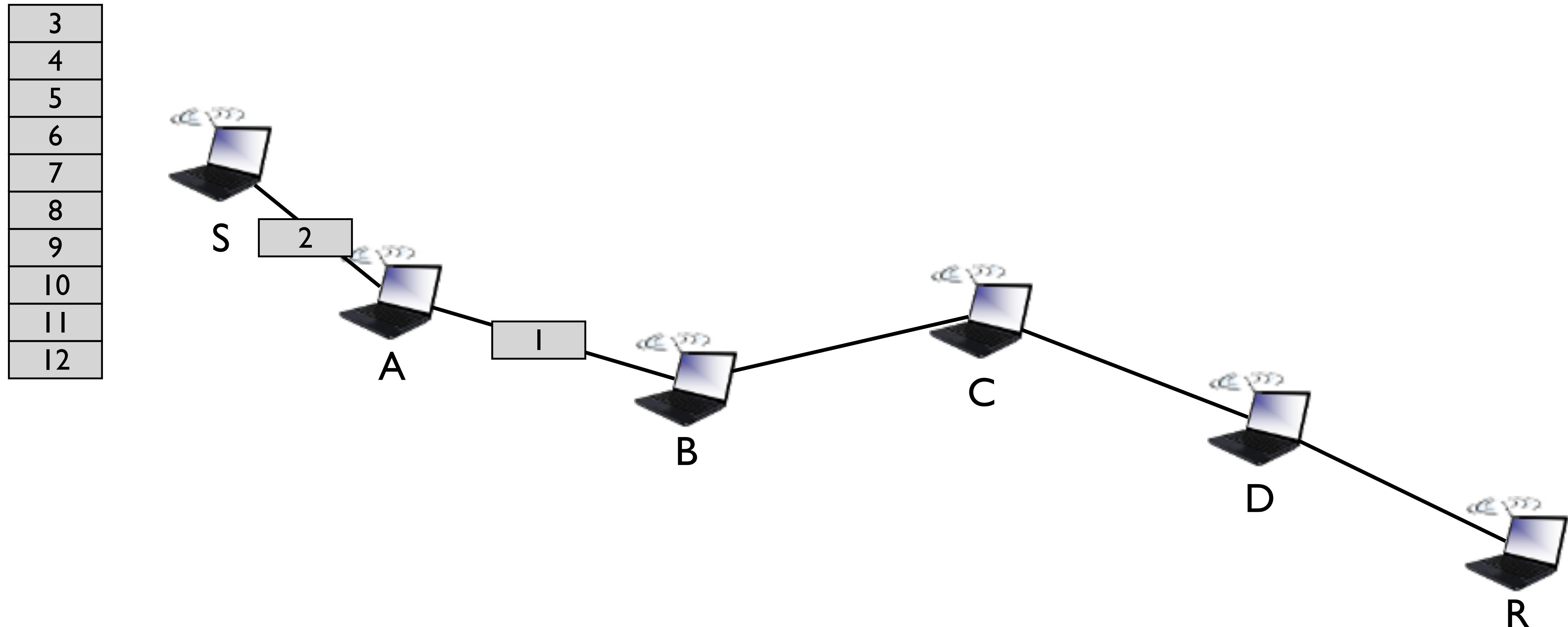


**(Assume ideal world...)**

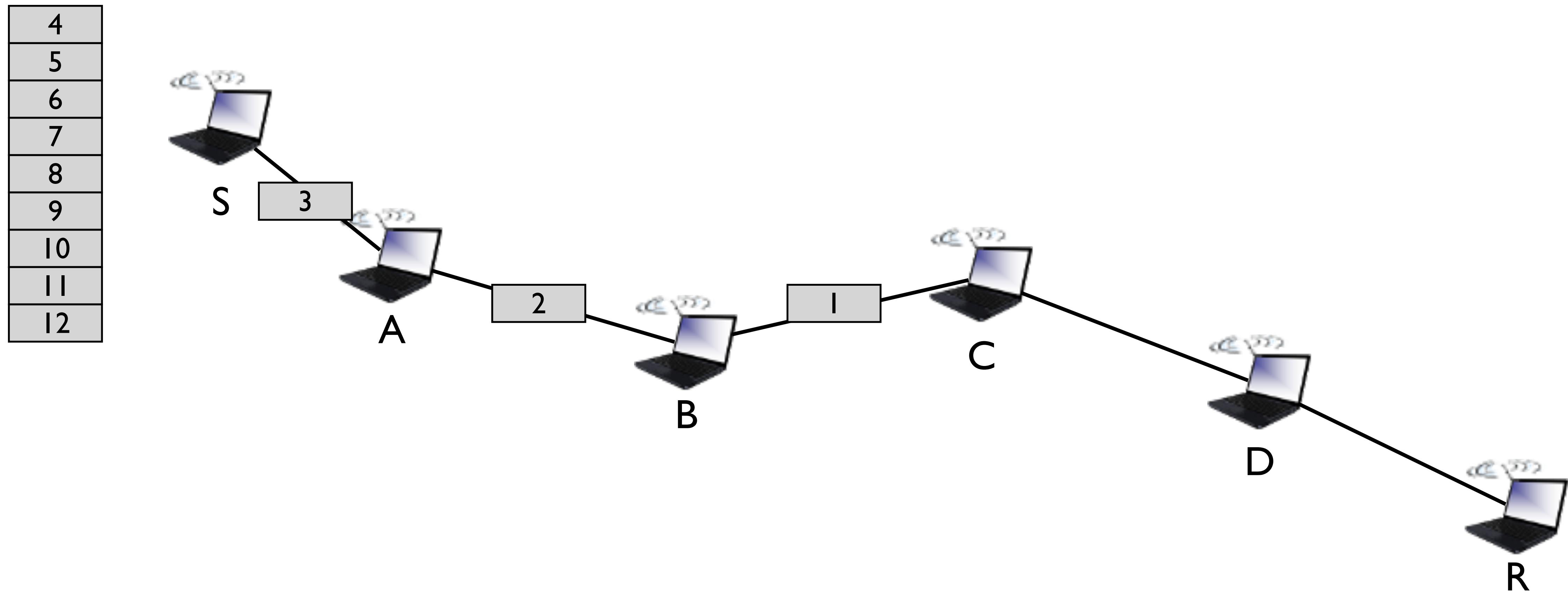
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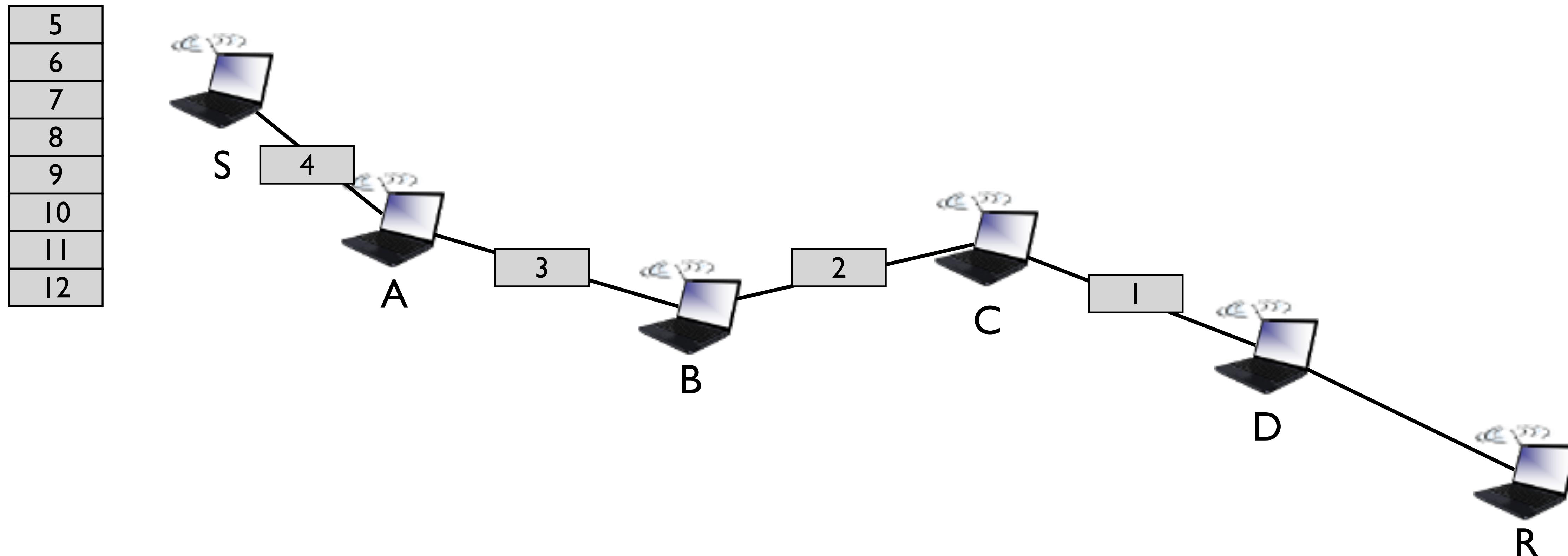
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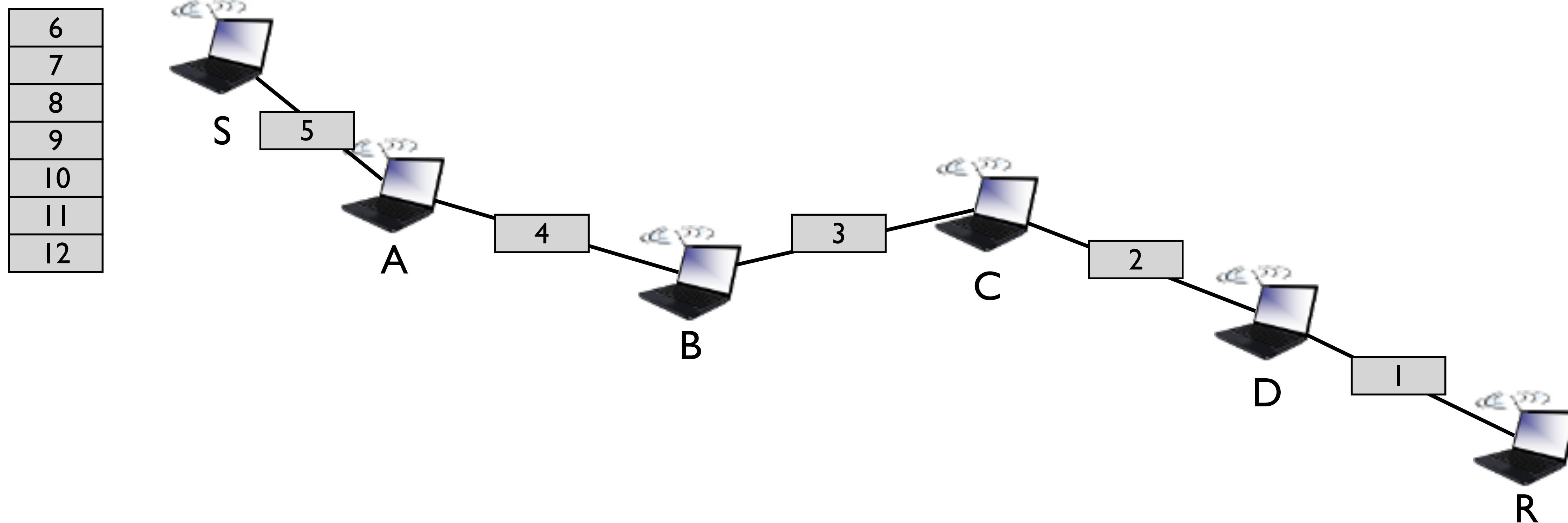
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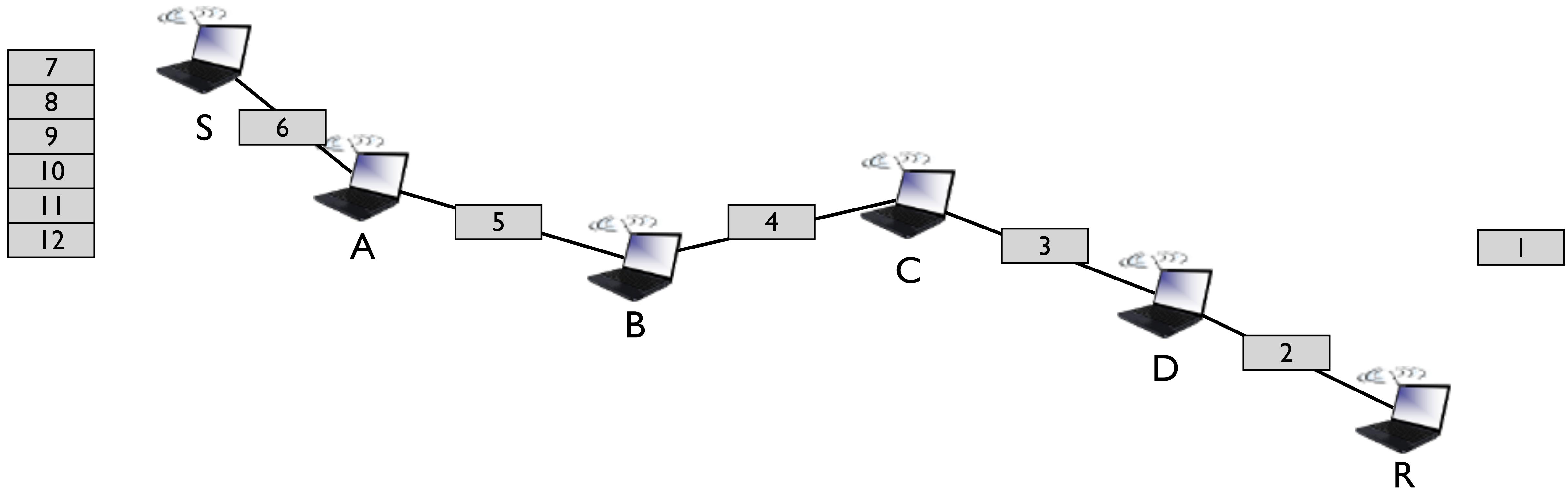
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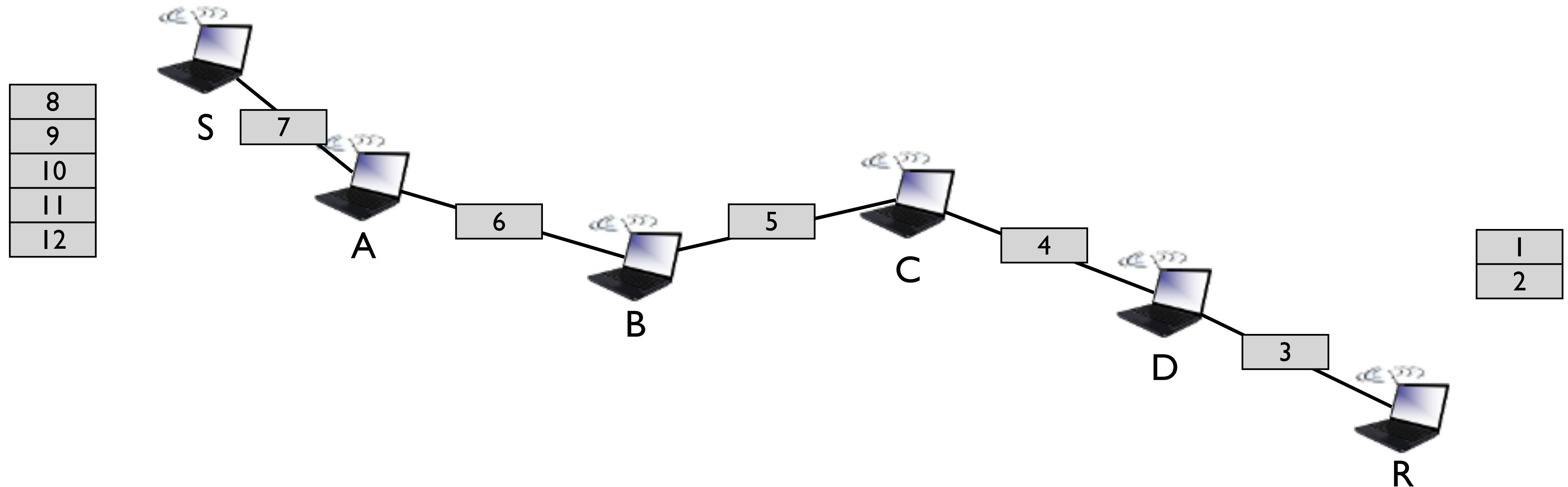
# Multi-Hop Wireless Ad-hoc Networks



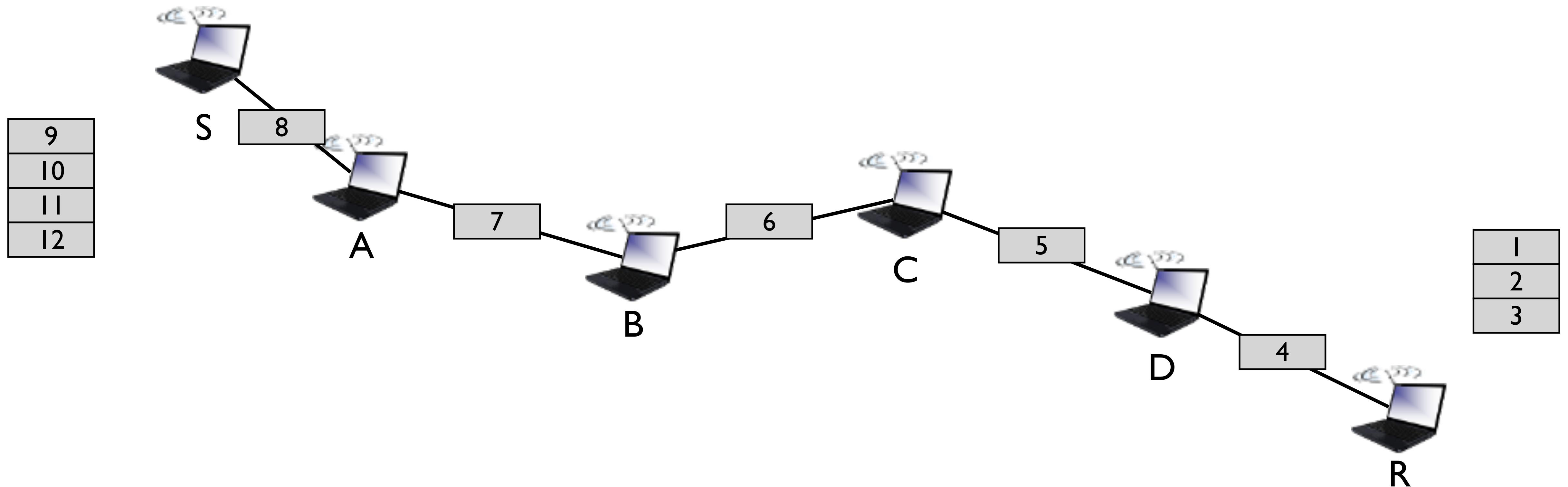
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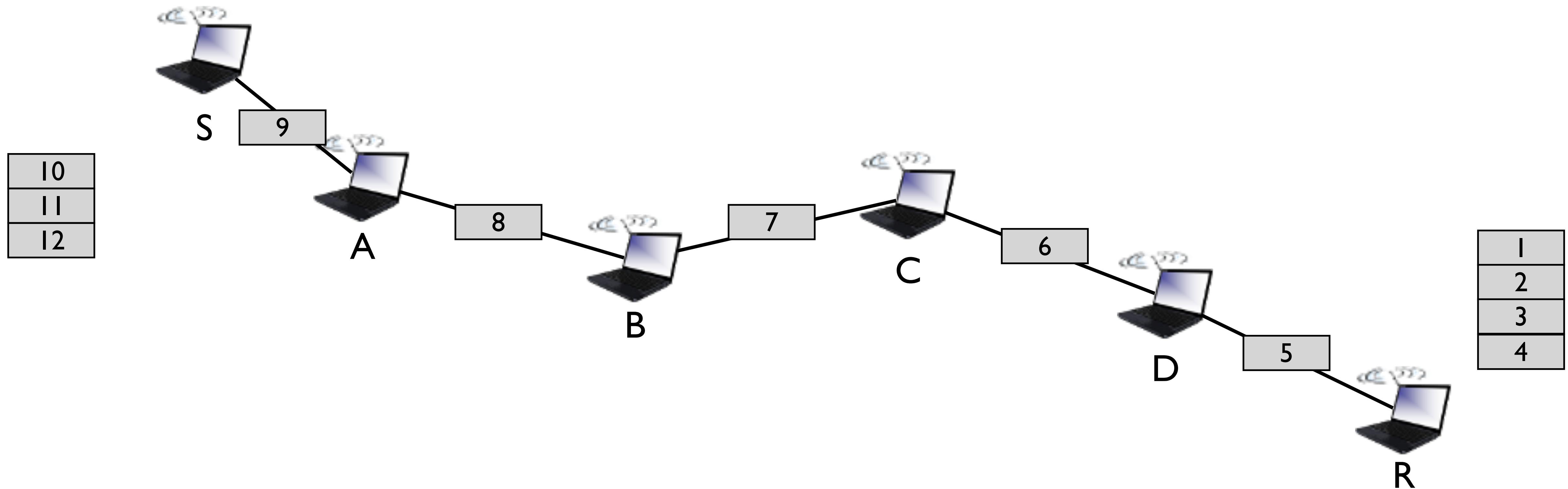
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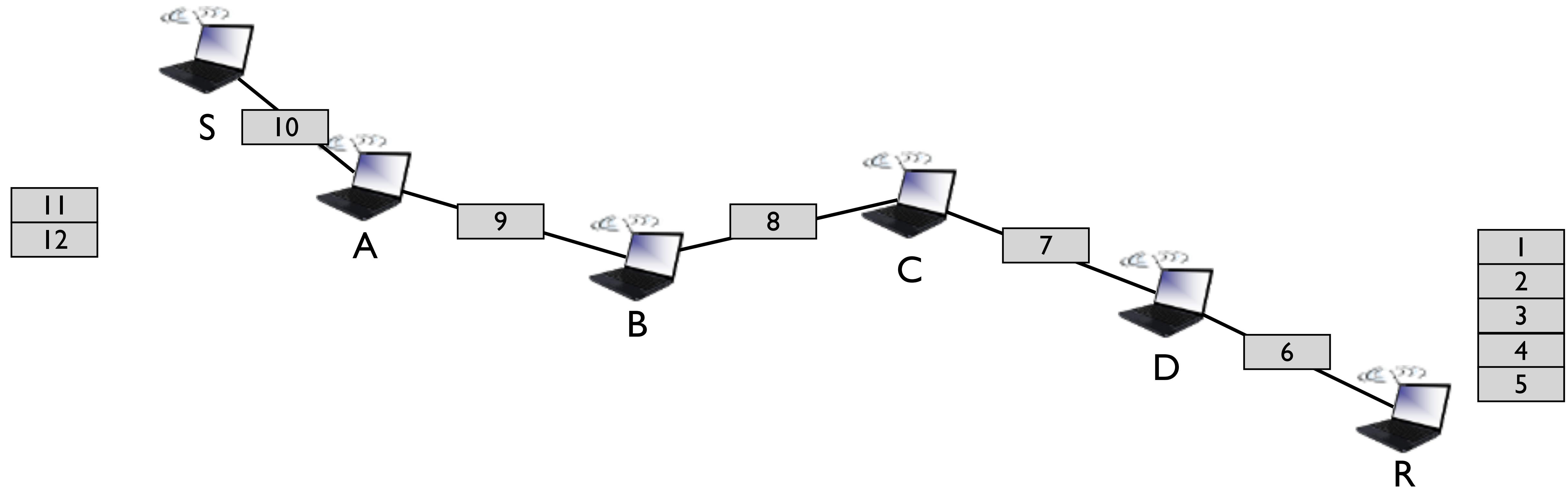
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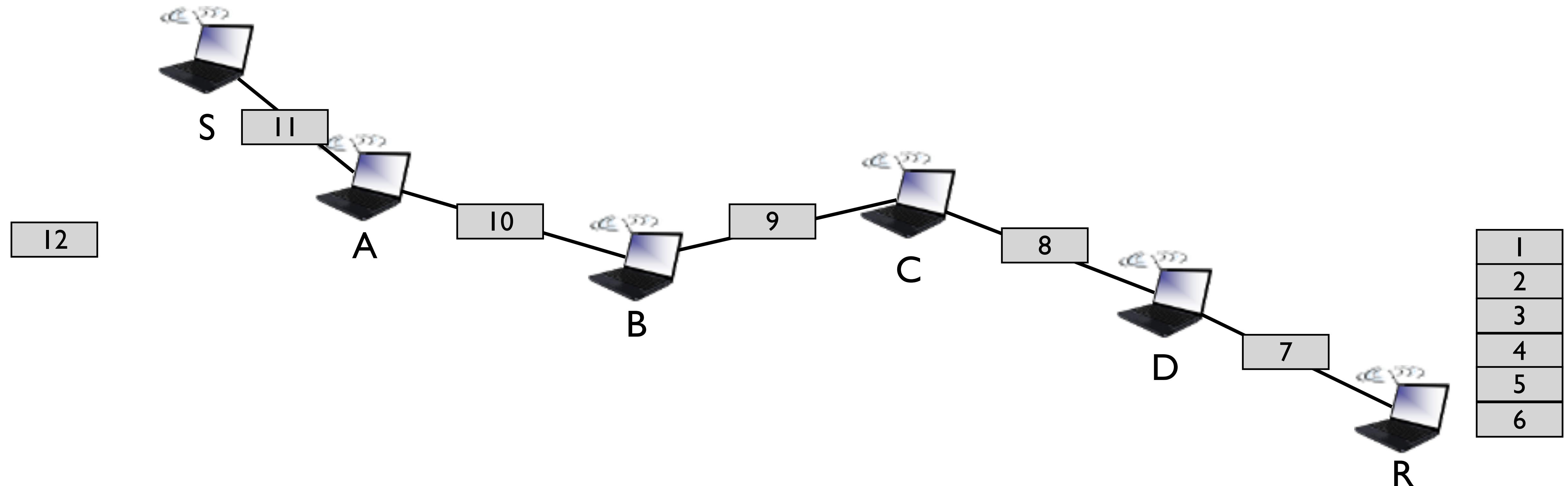
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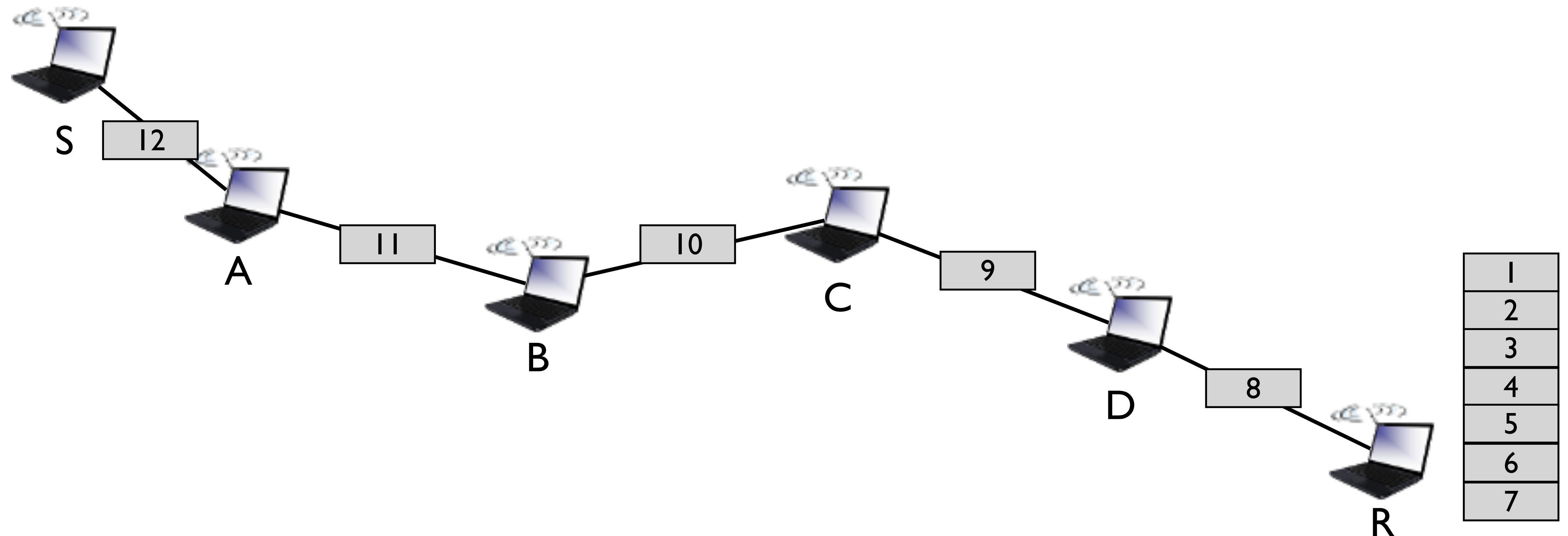
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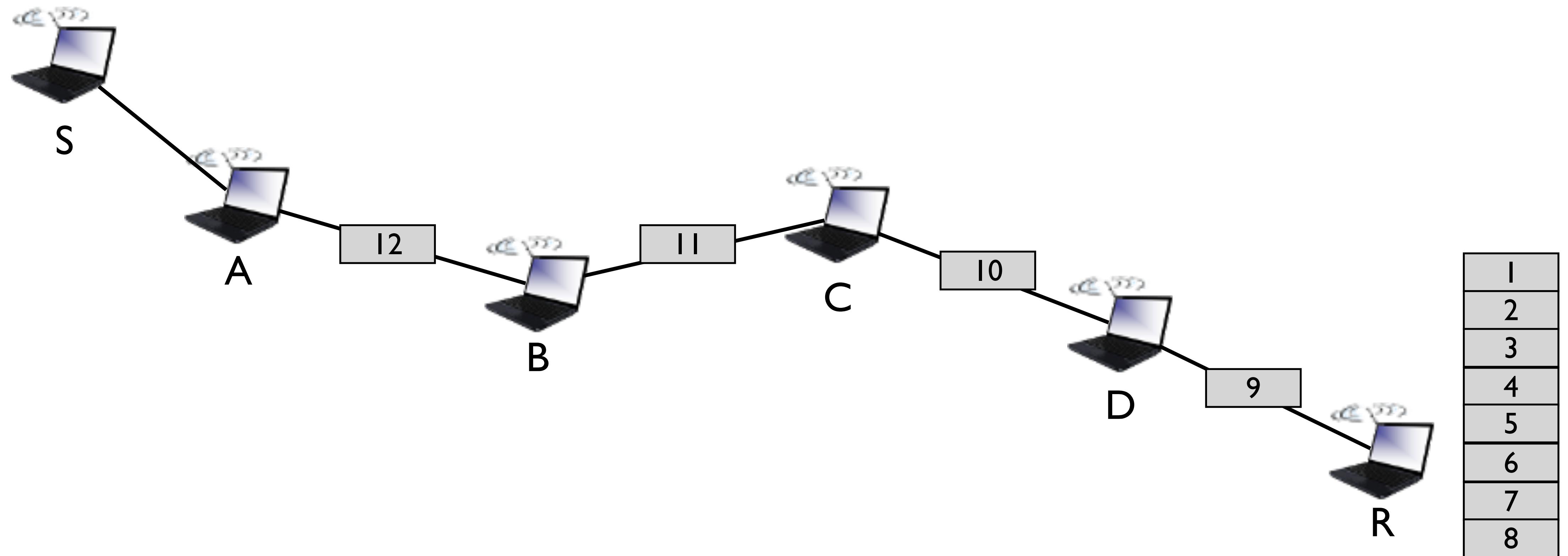
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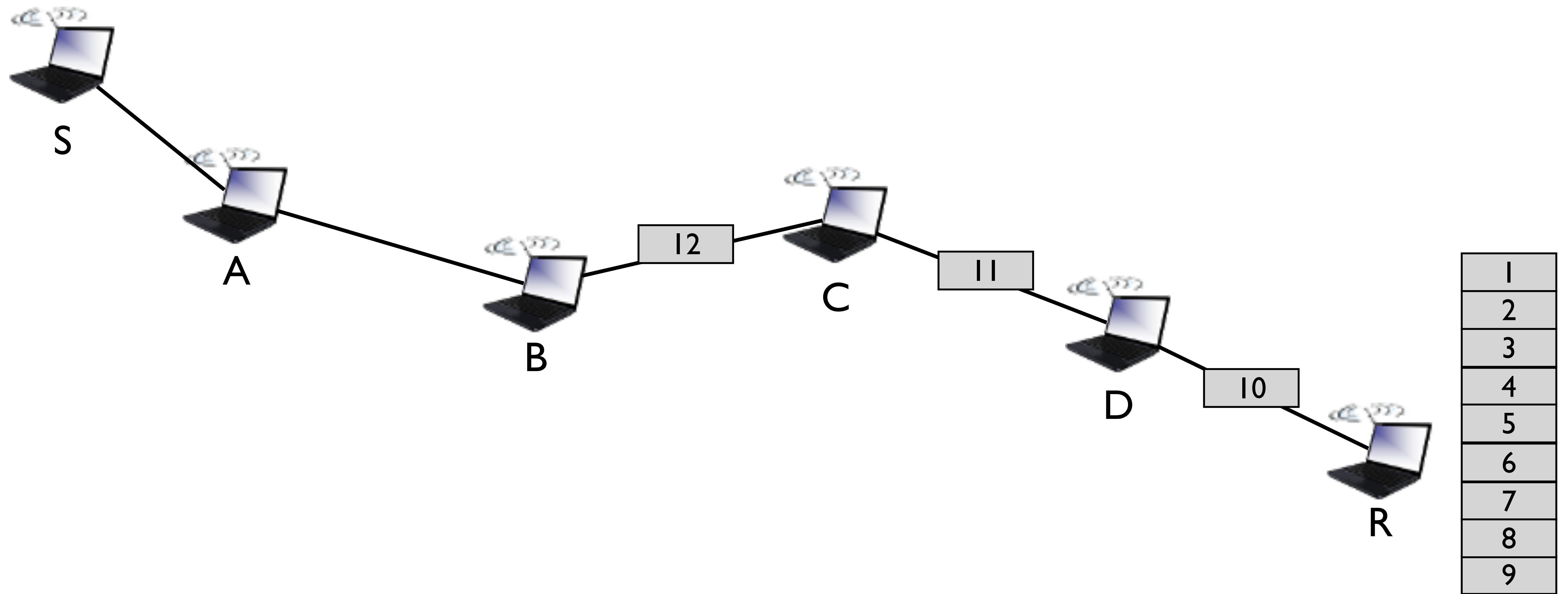
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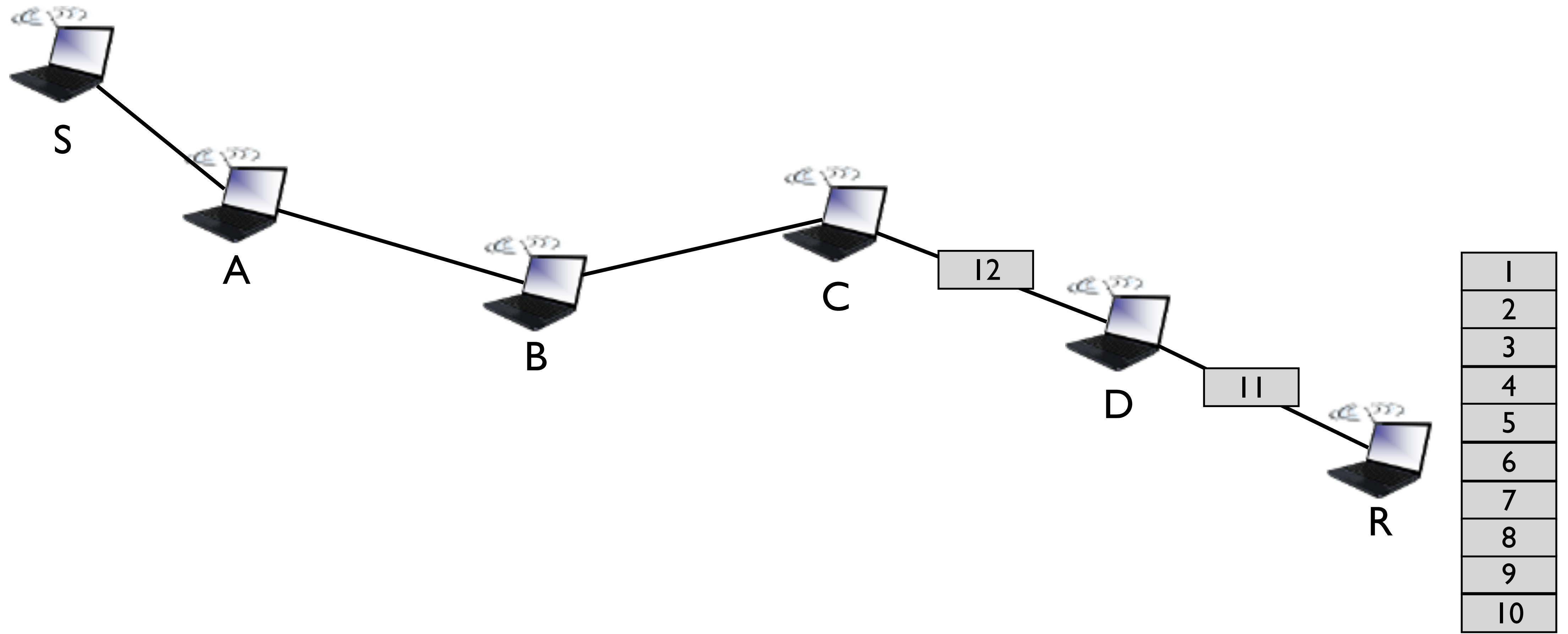
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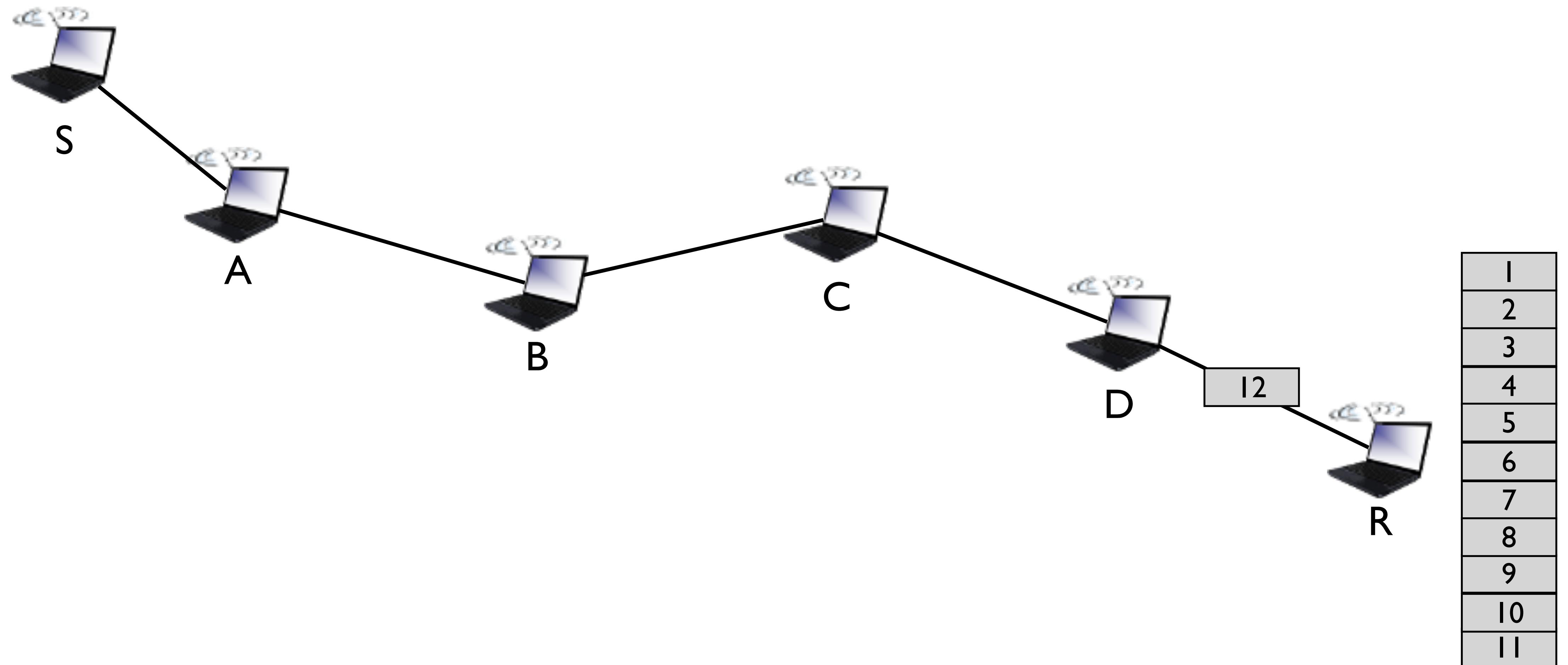
# Multi-Hop Wireless Ad-hoc Networks



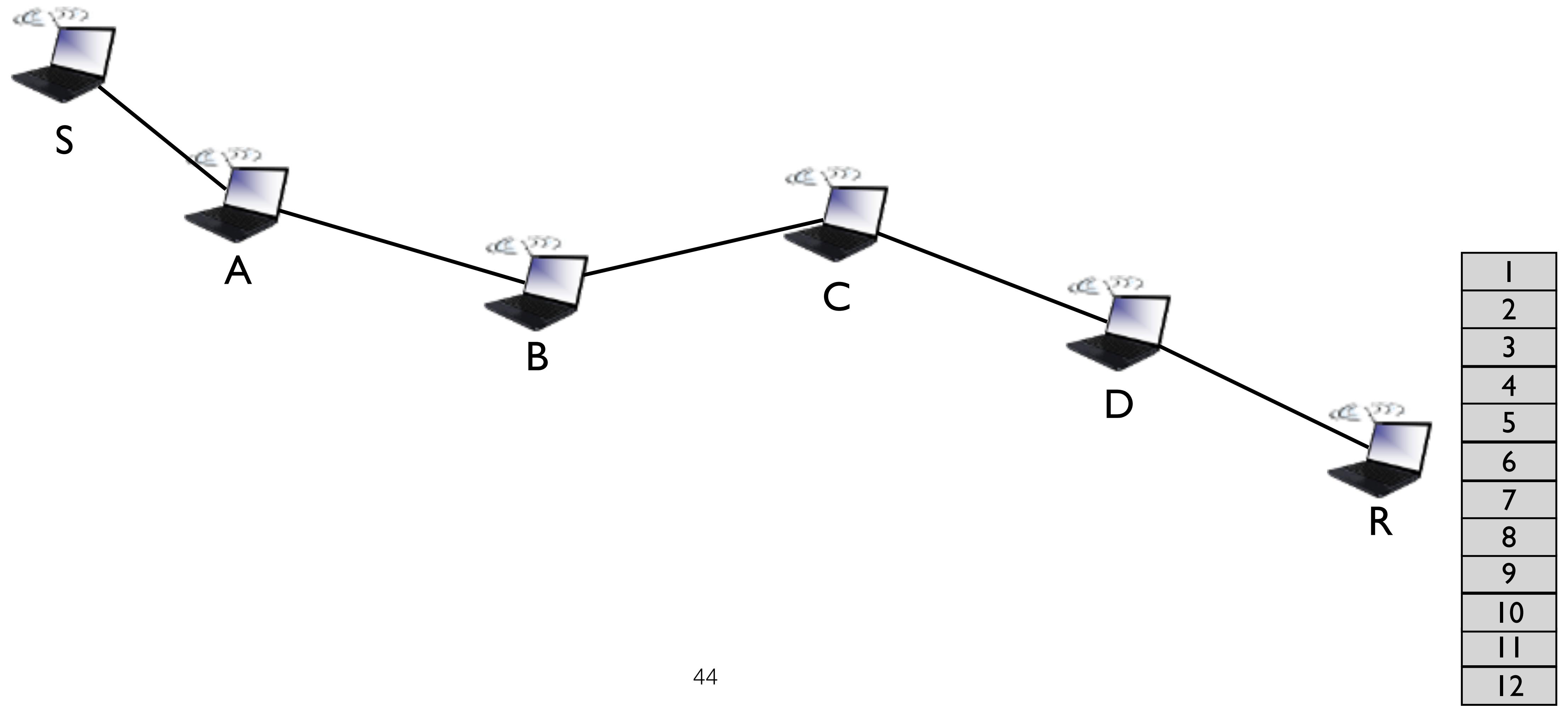
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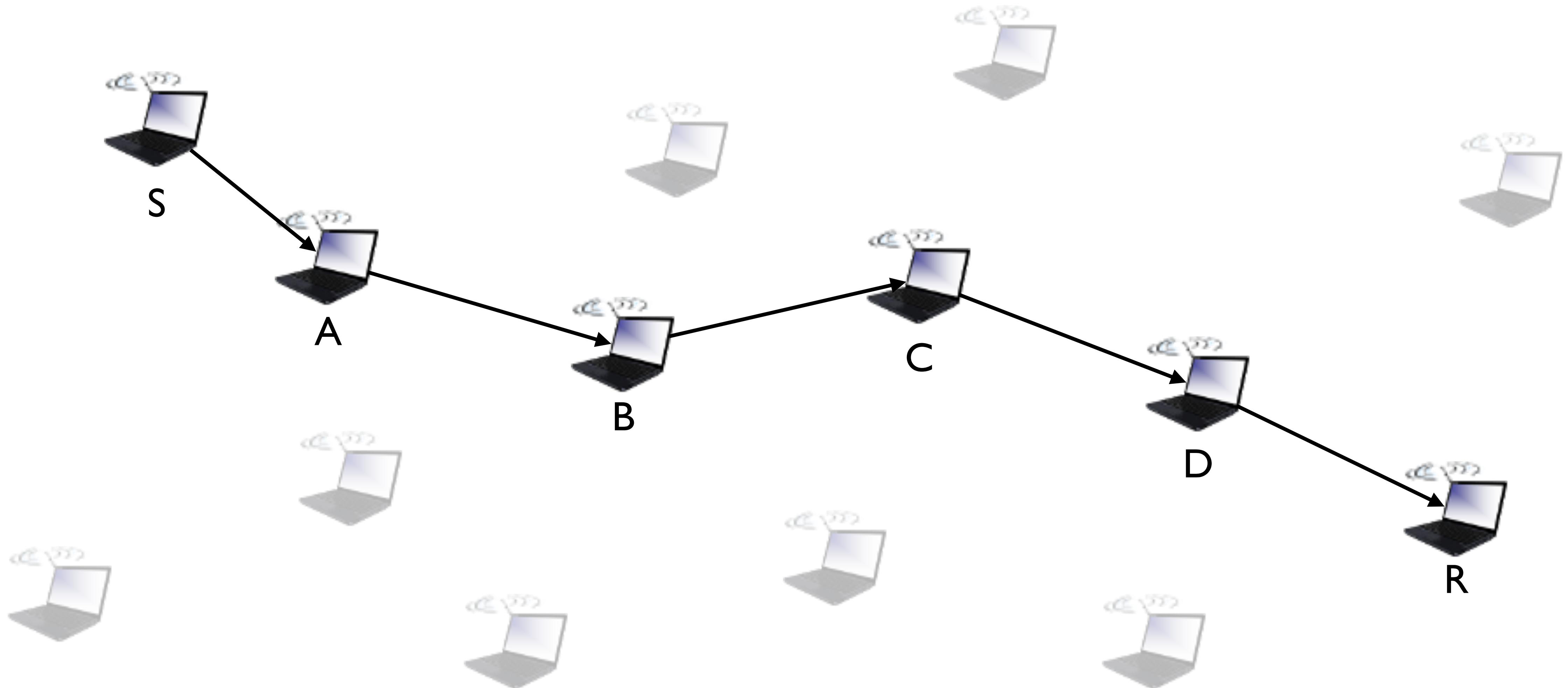
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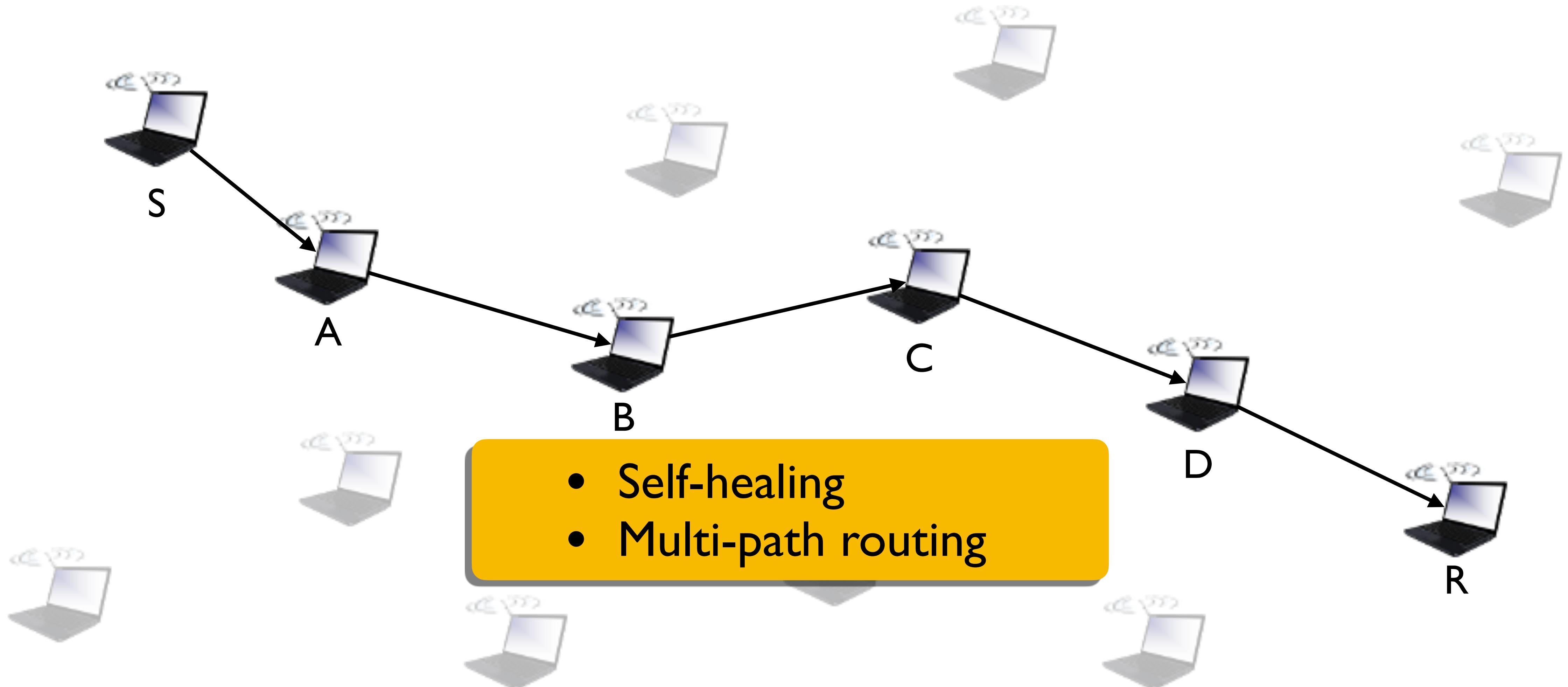
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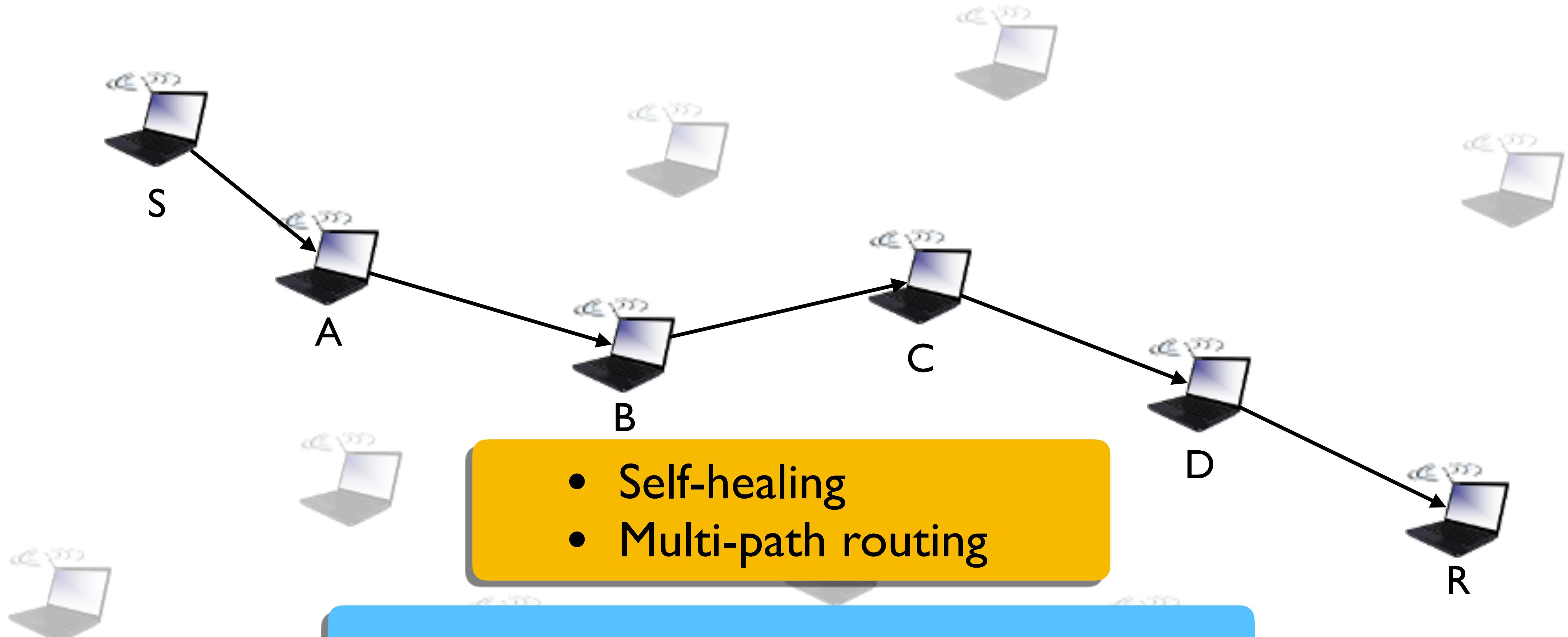
# Multi-Hop Wireless Ad-hoc Networks



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# Multi-Hop Wireless Ad-hoc Networks

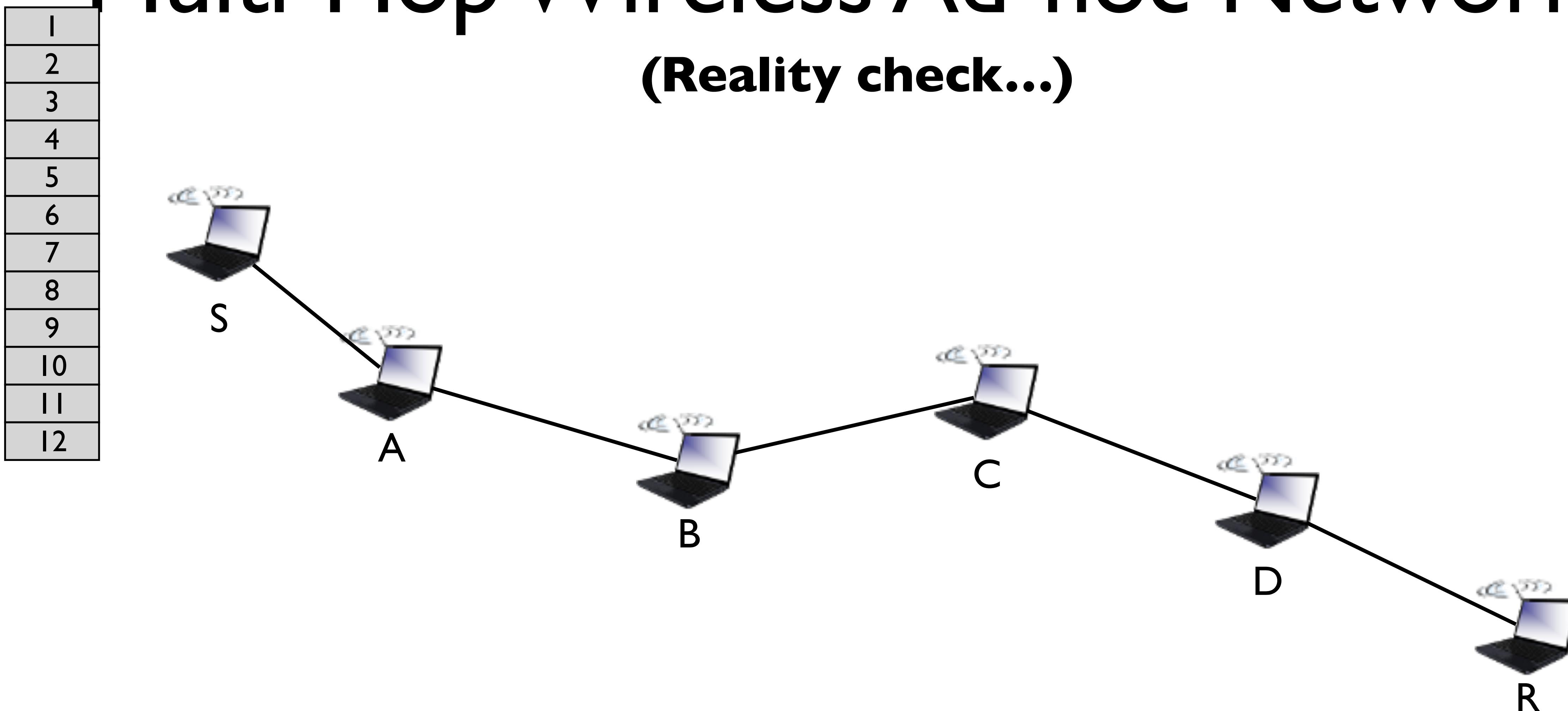


# What do you think really happens?



# Multi-Hop Wireless Ad-hoc Networks

(Reality check...)



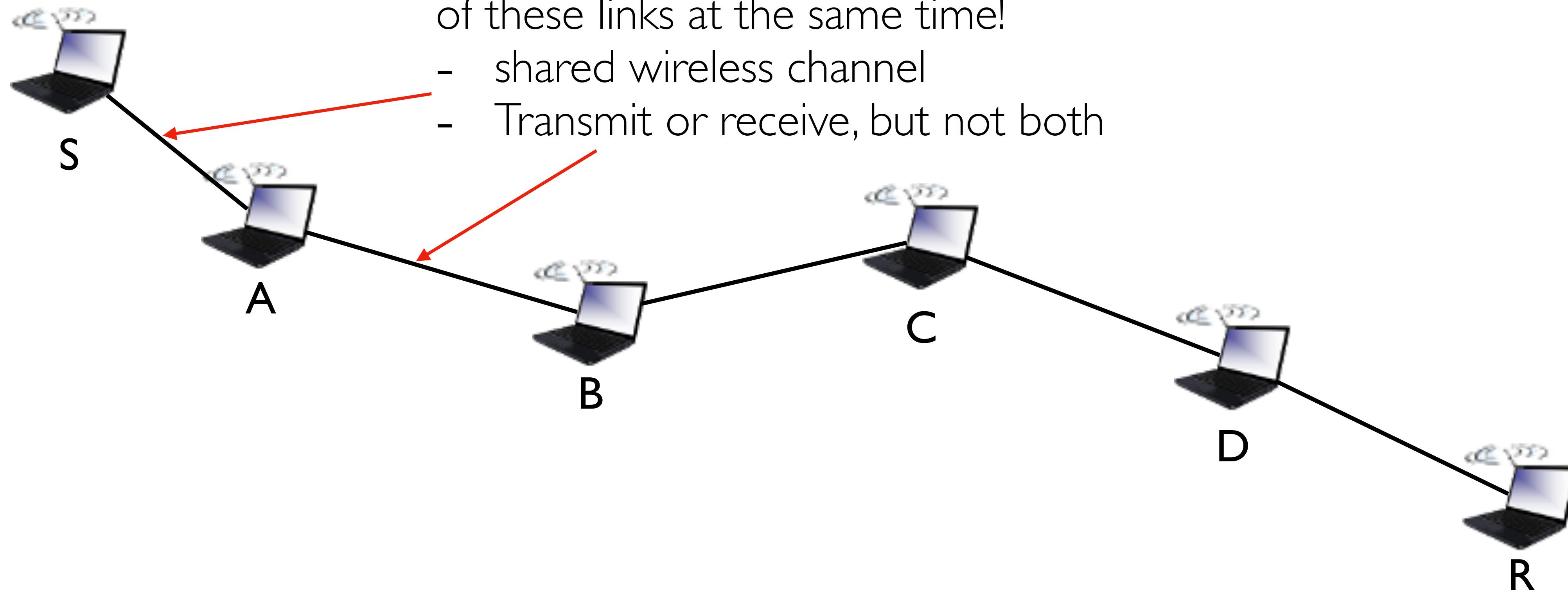
# Multi-Hop Wireless Ad-hoc Networks

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## (Reality check...)

**Problem I:** node A cannot use both of these links at the same time!

- shared wireless channel
- Transmit or receive, but not both



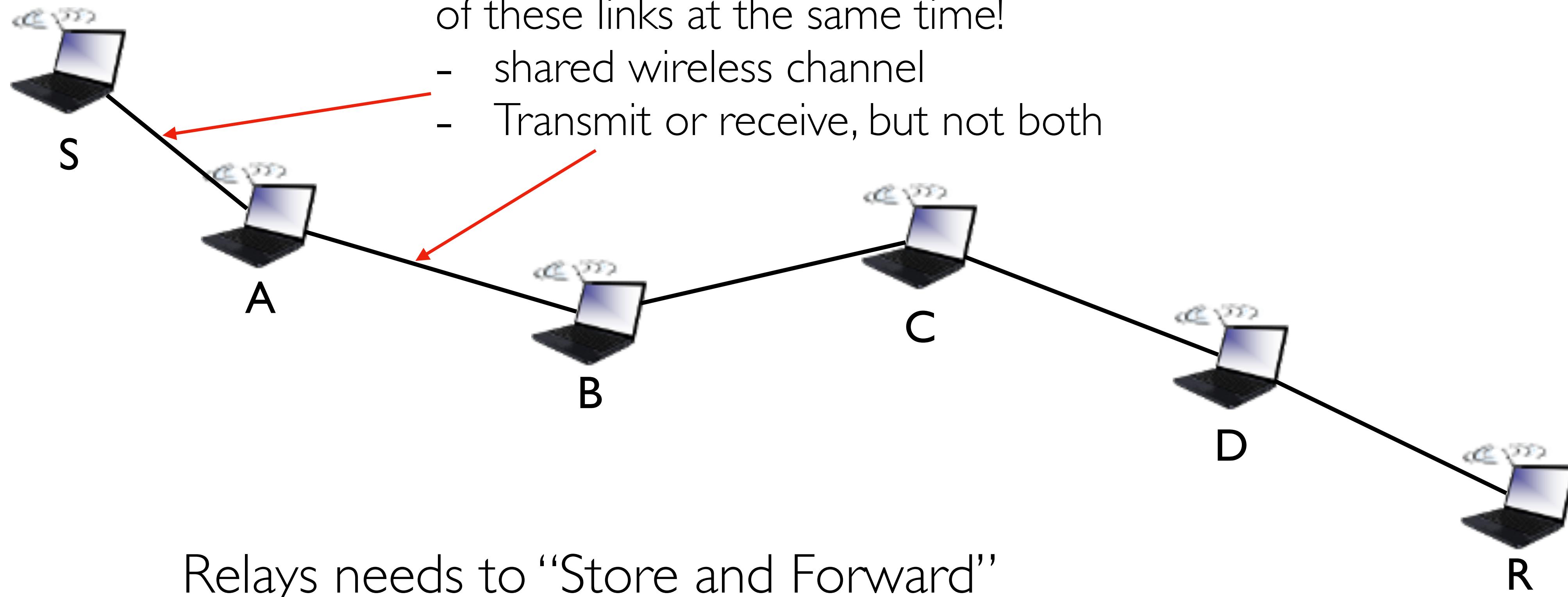
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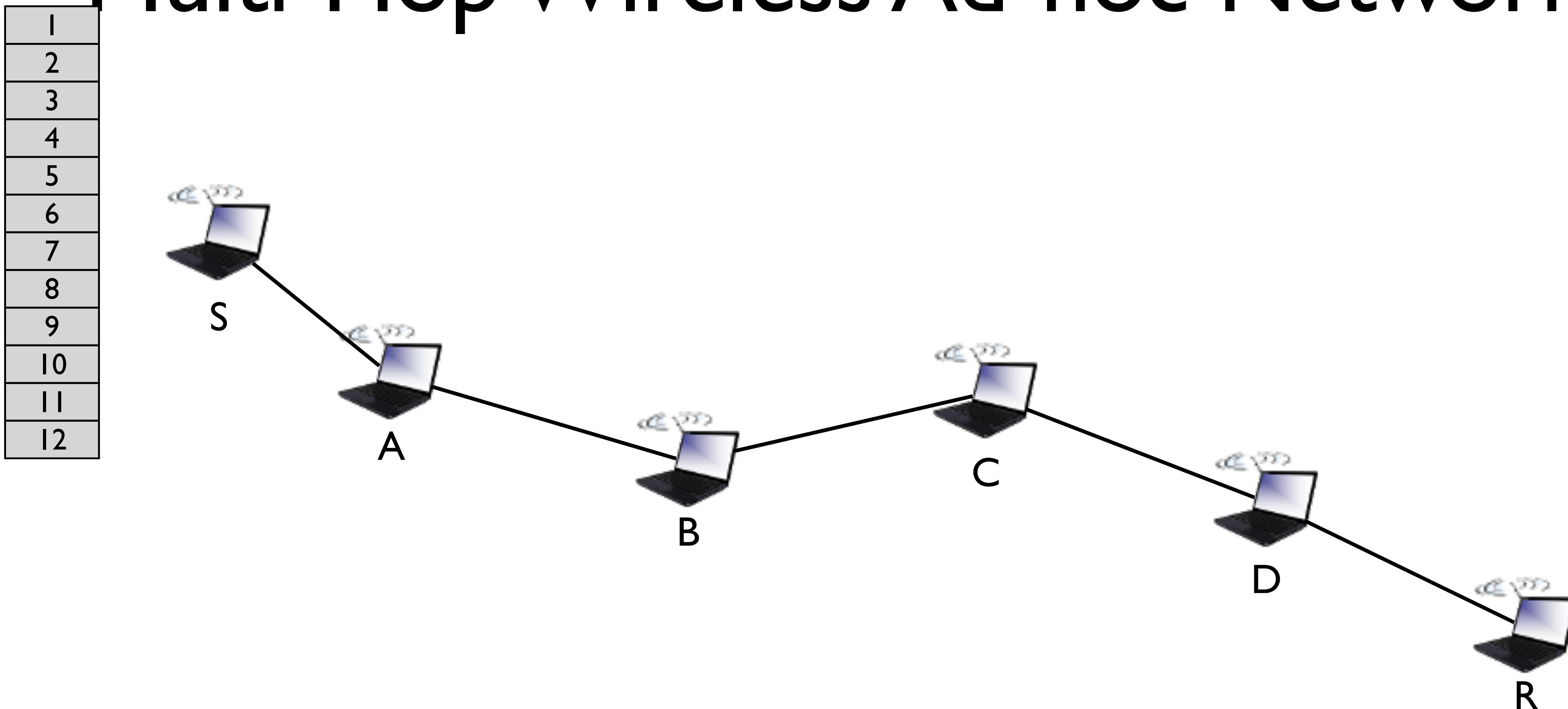
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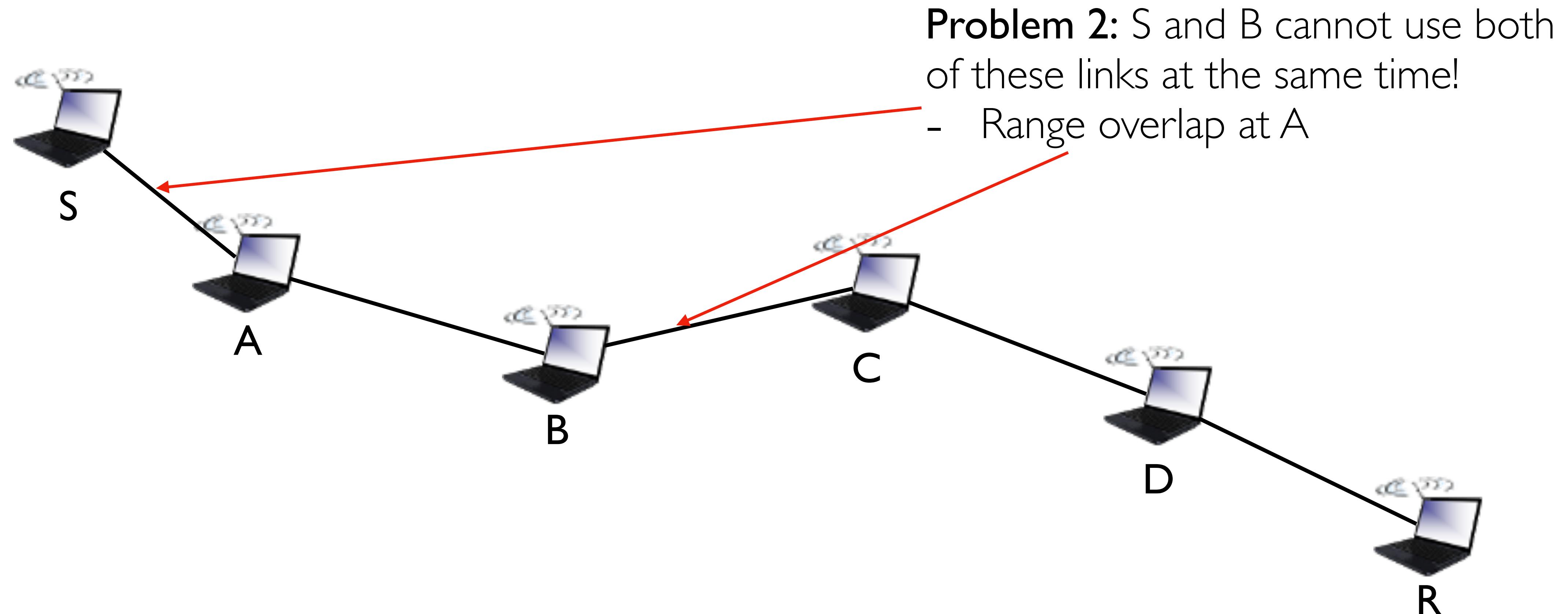


# Multi-Hop Wireless Ad-hoc Networks

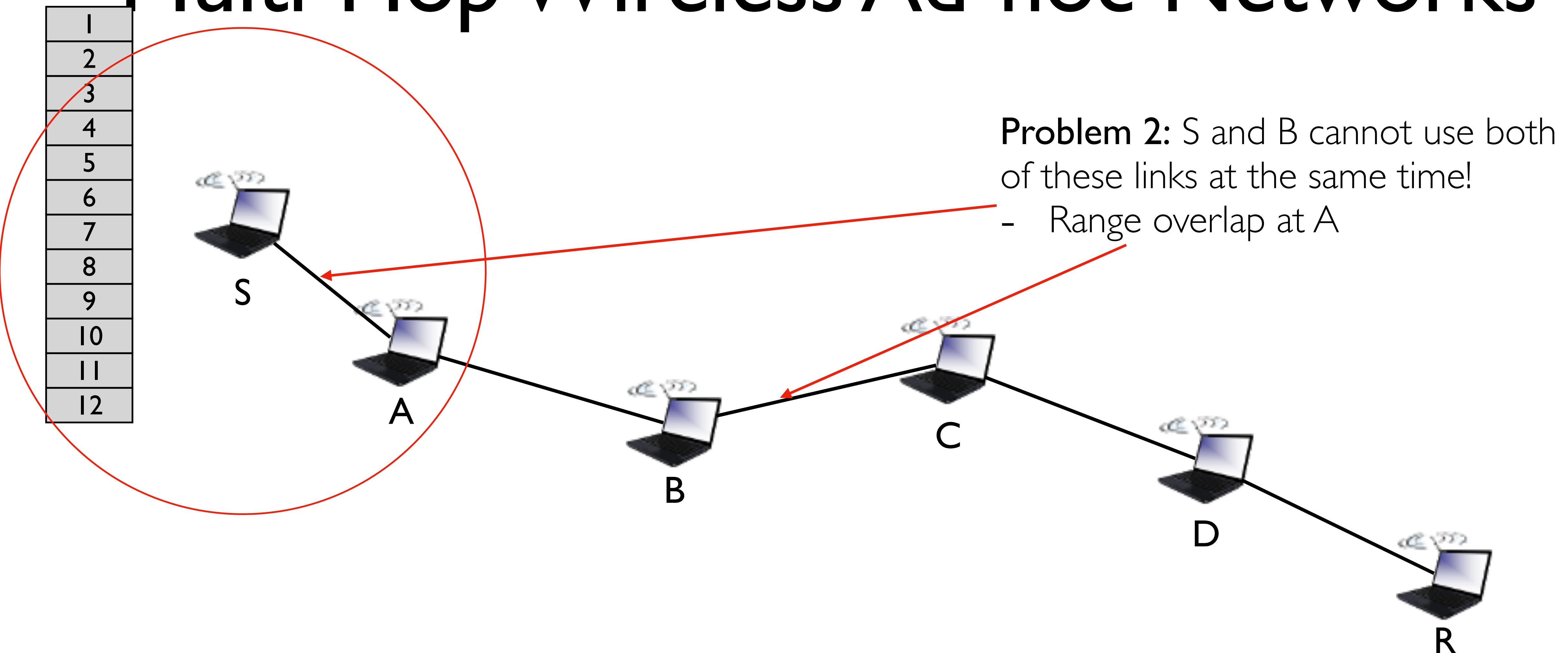


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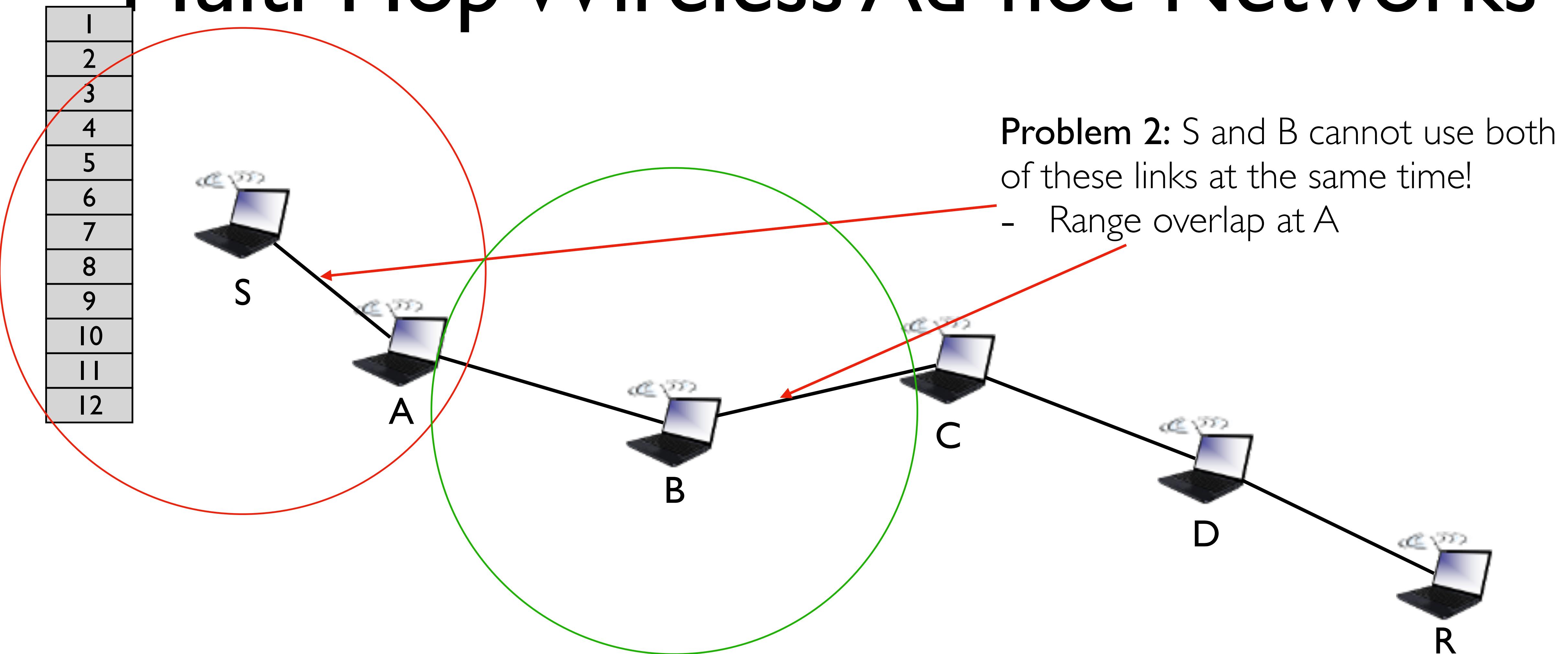
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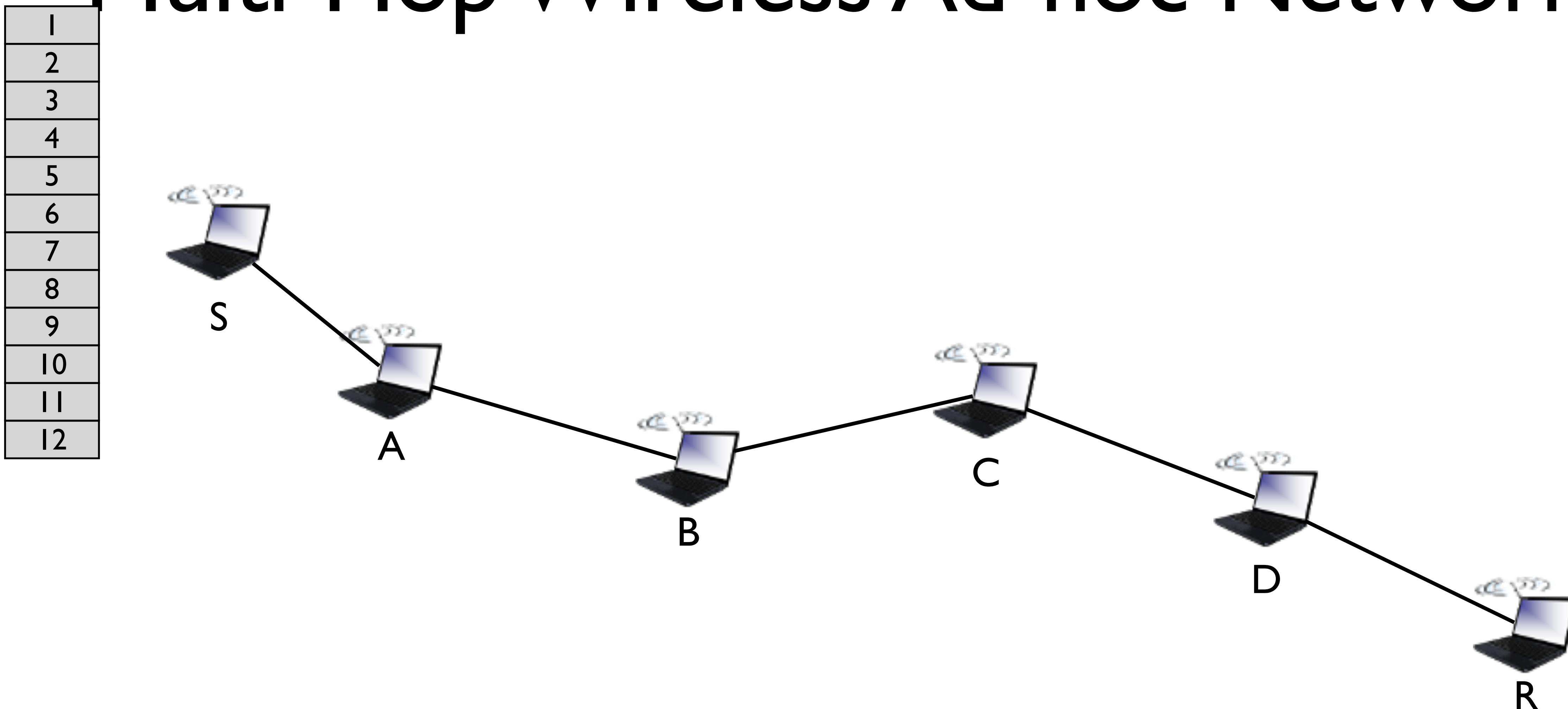
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# Multi-Hop Wireless Ad-hoc Networks

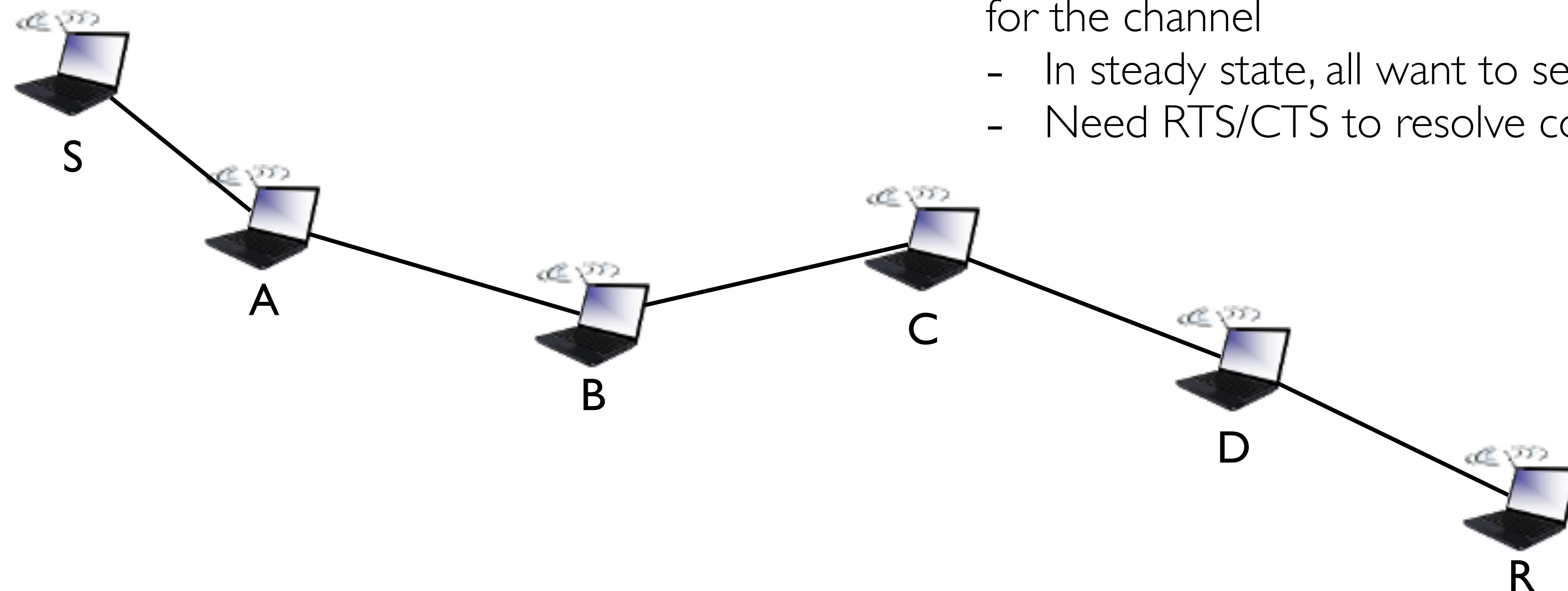


# Multi-Hop Wireless Ad-hoc Networks



# Multi-Hop Wireless Ad-hoc Networks

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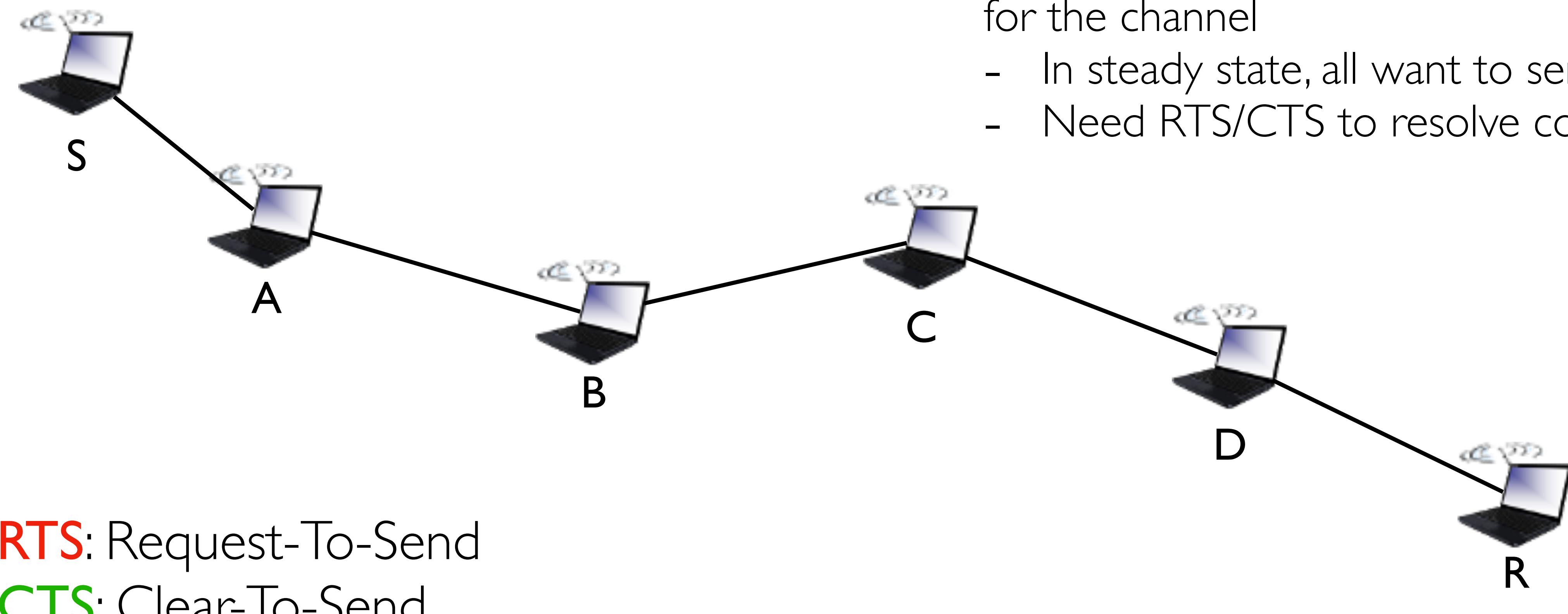


**Problem 3:** LOTS of contention  
for the channel

- In steady state, all want to send
- Need RTS/CTS to resolve contention

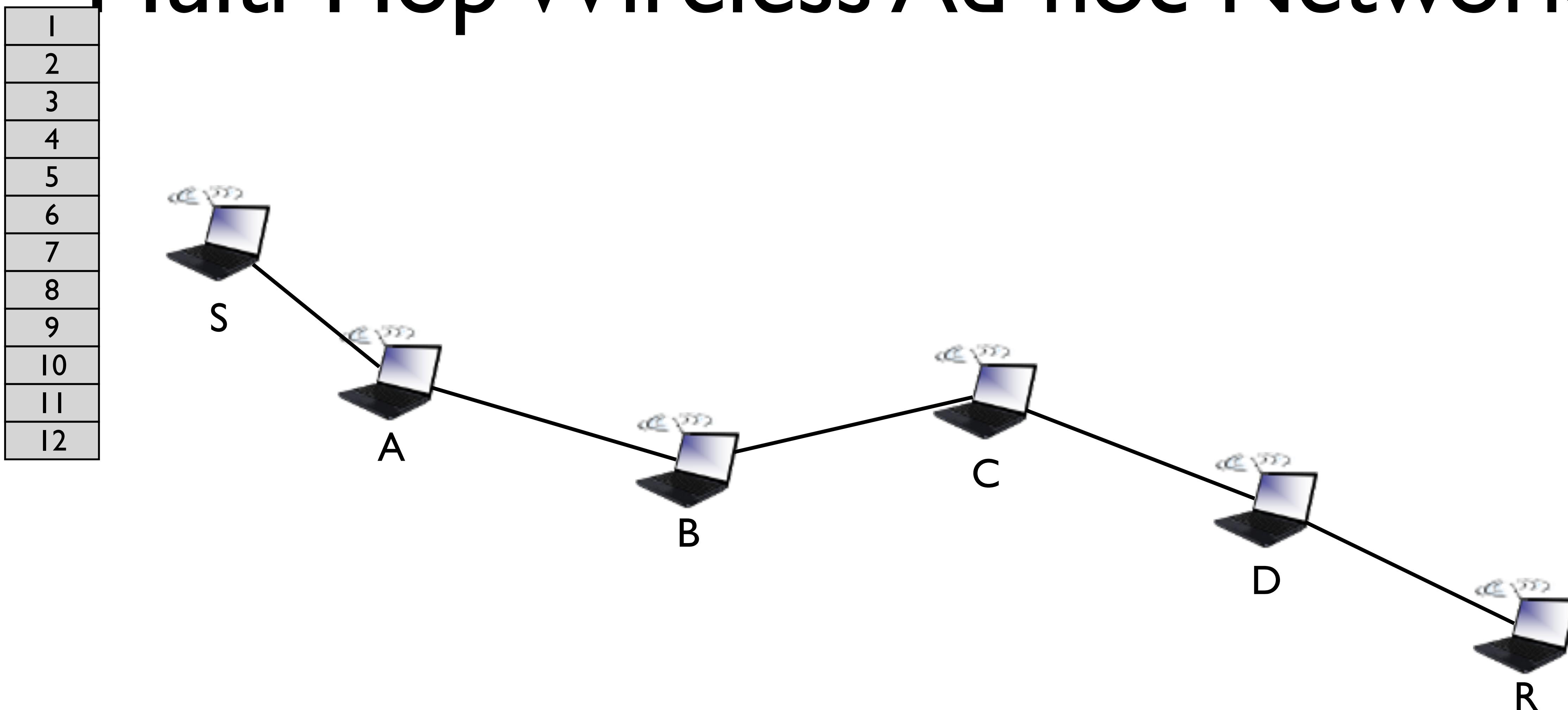
# Multi-Hop Wireless Ad-hoc Networks

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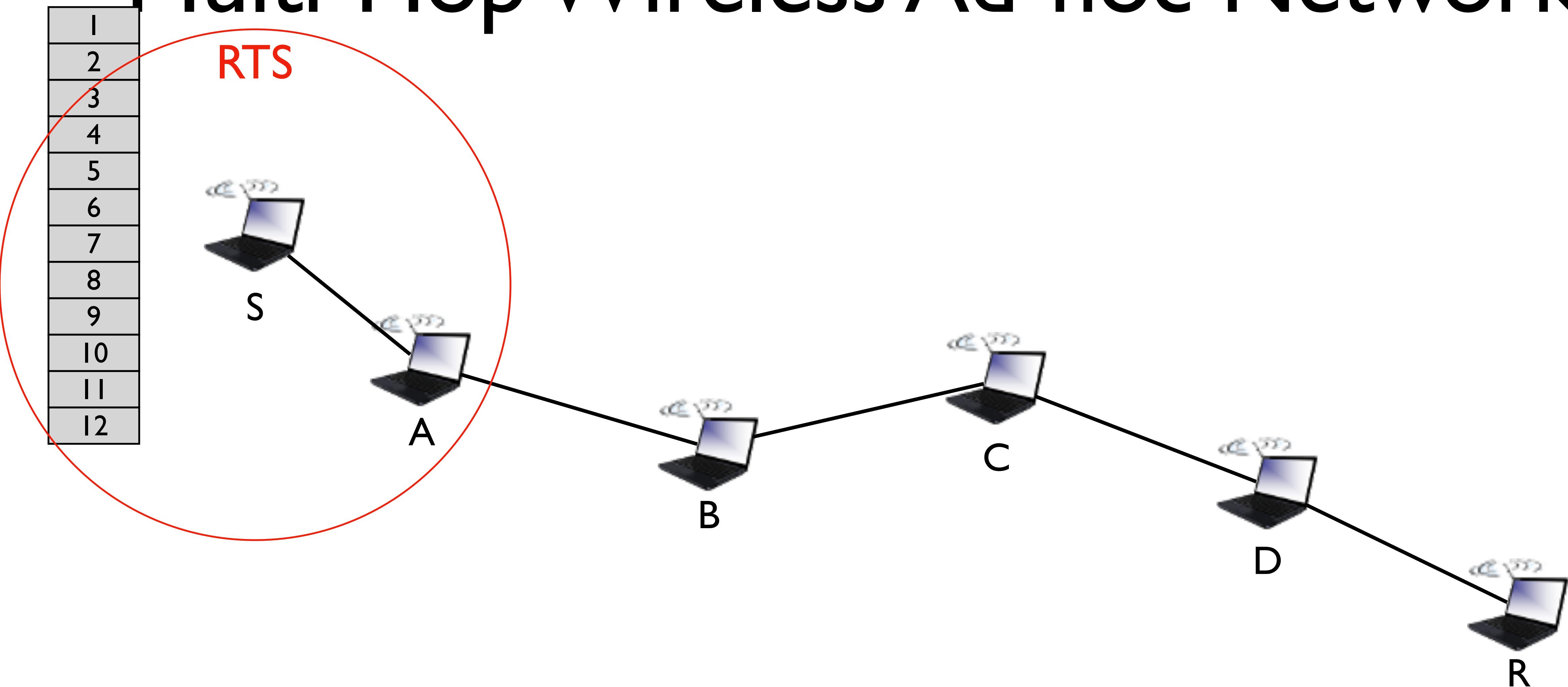


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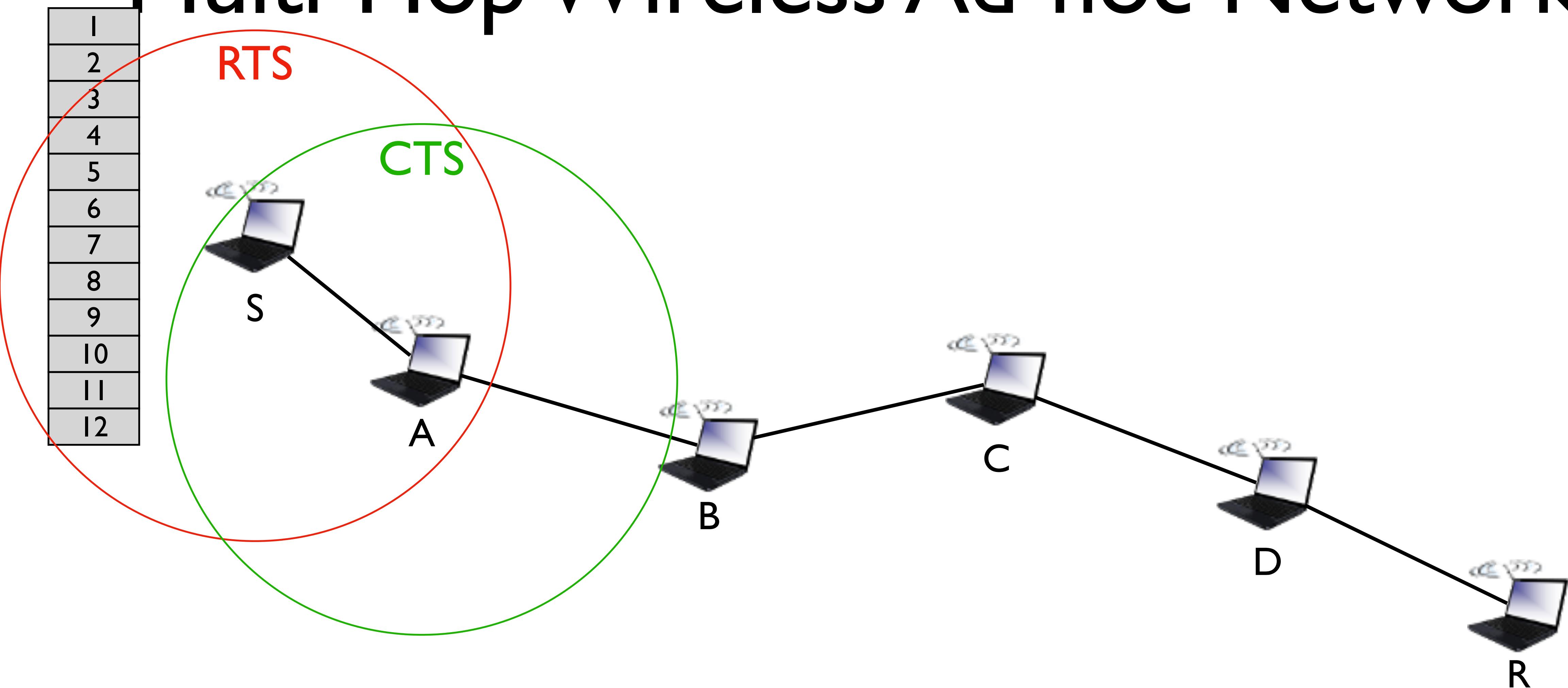
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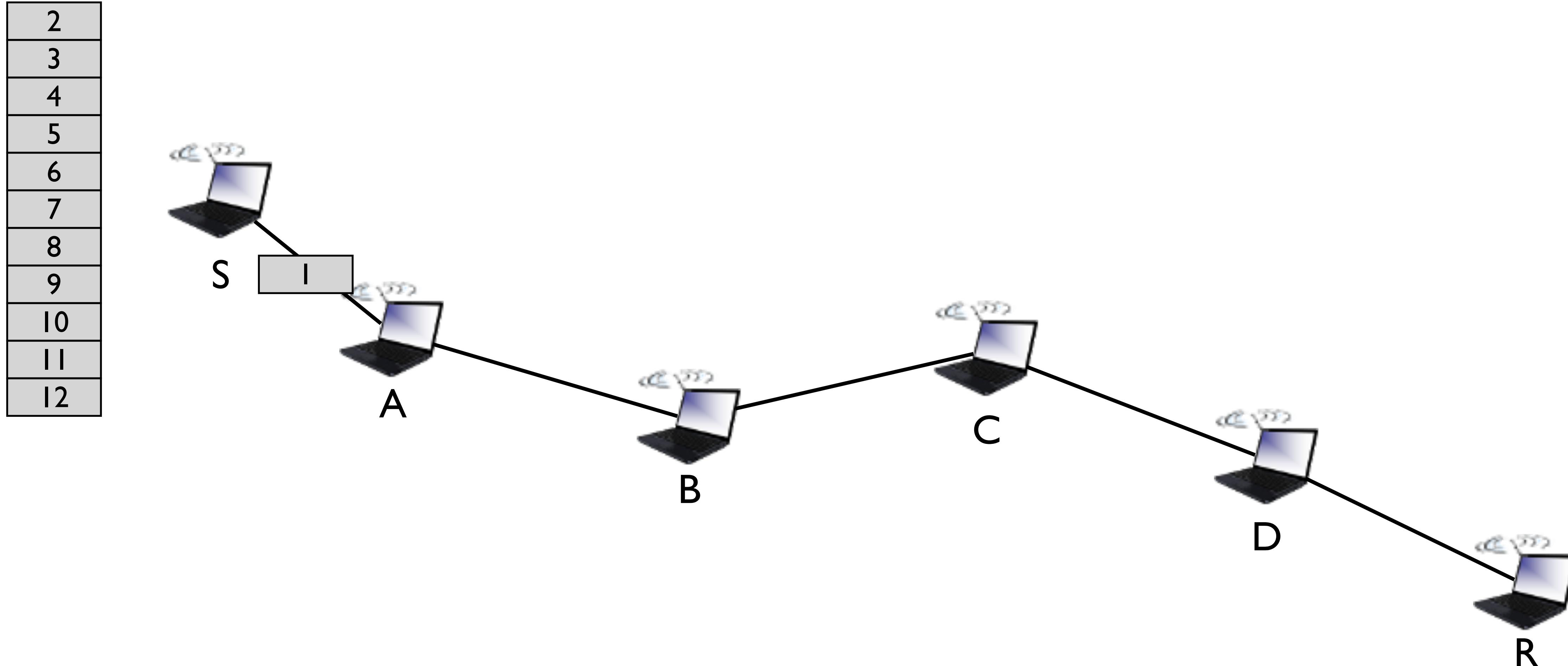
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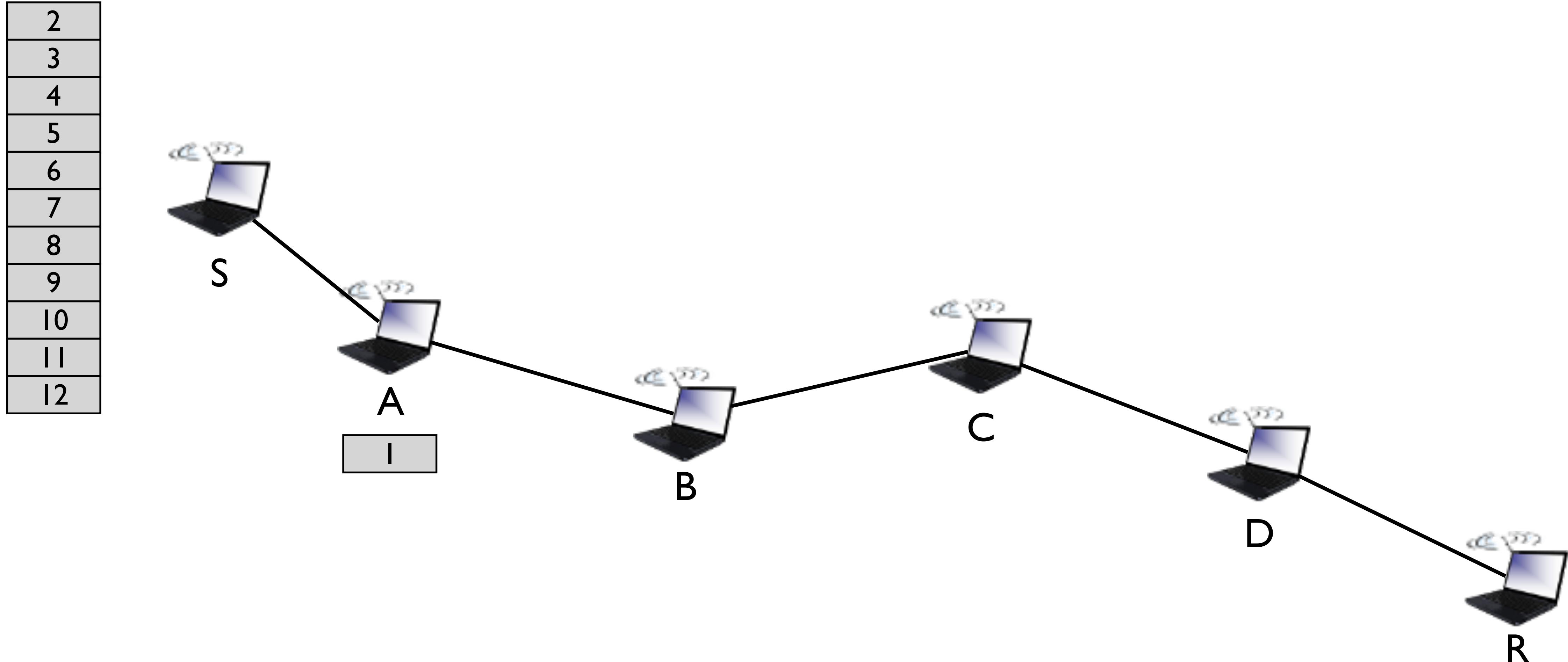
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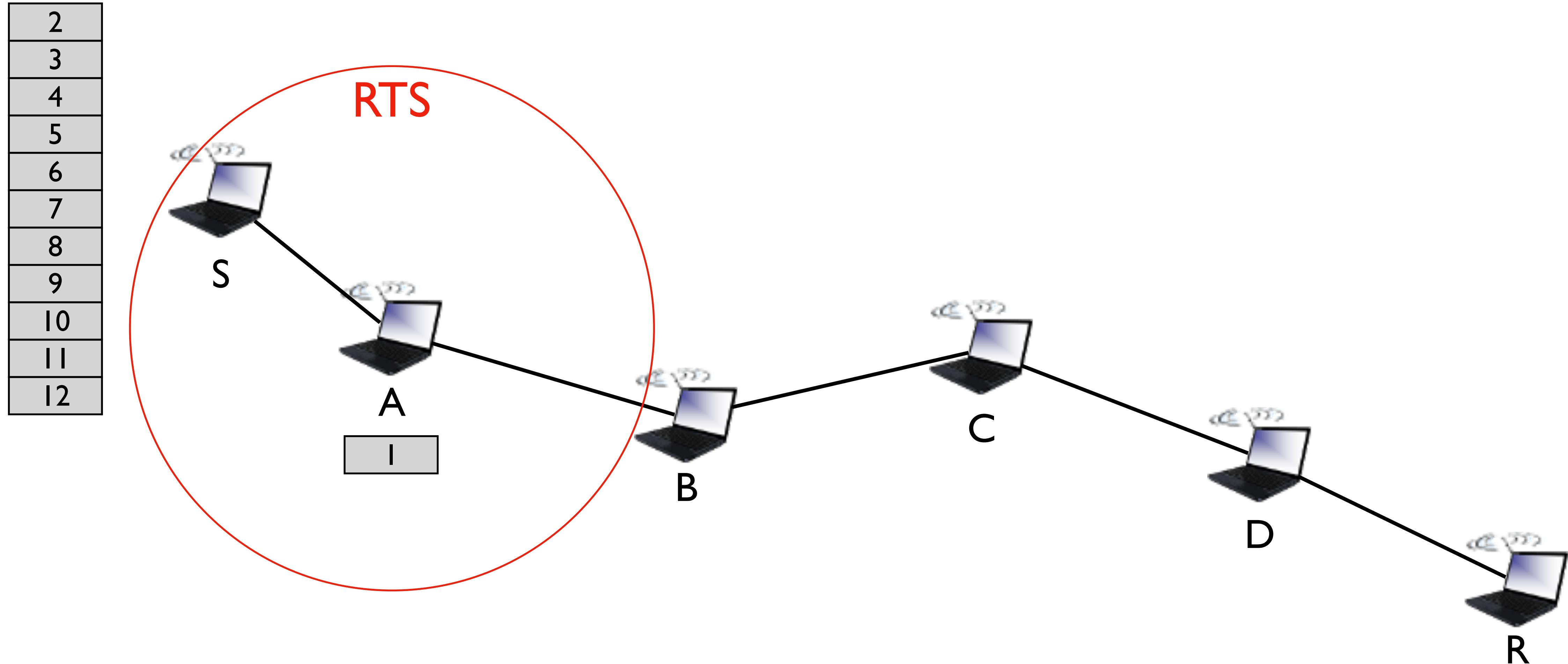
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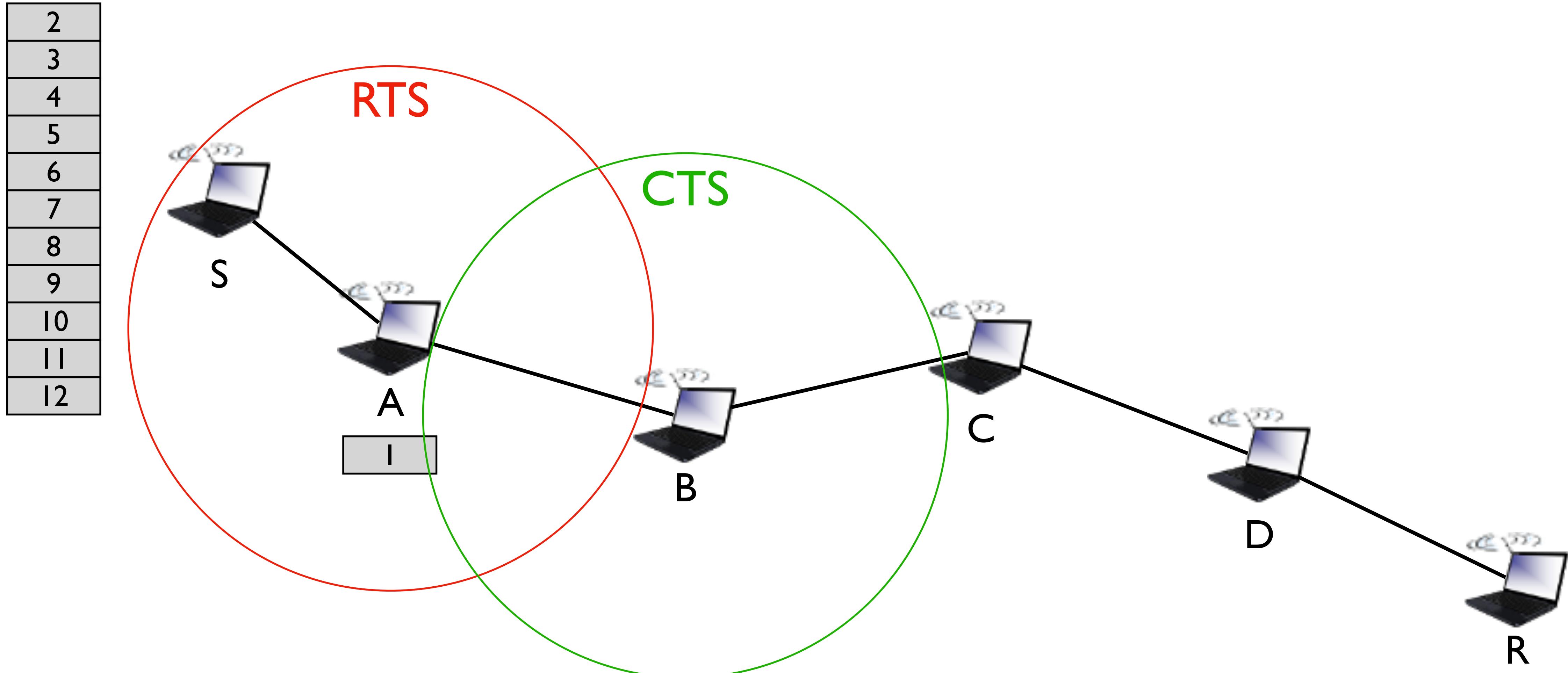
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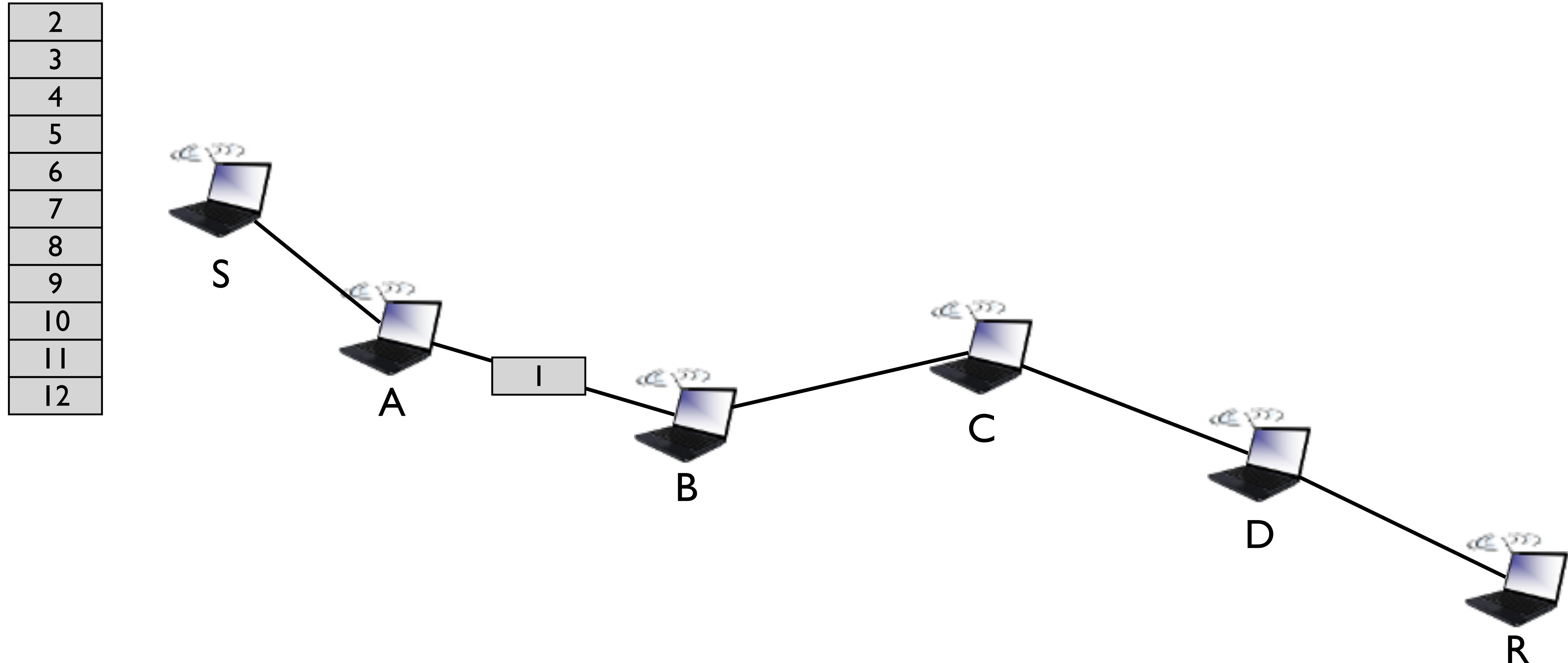
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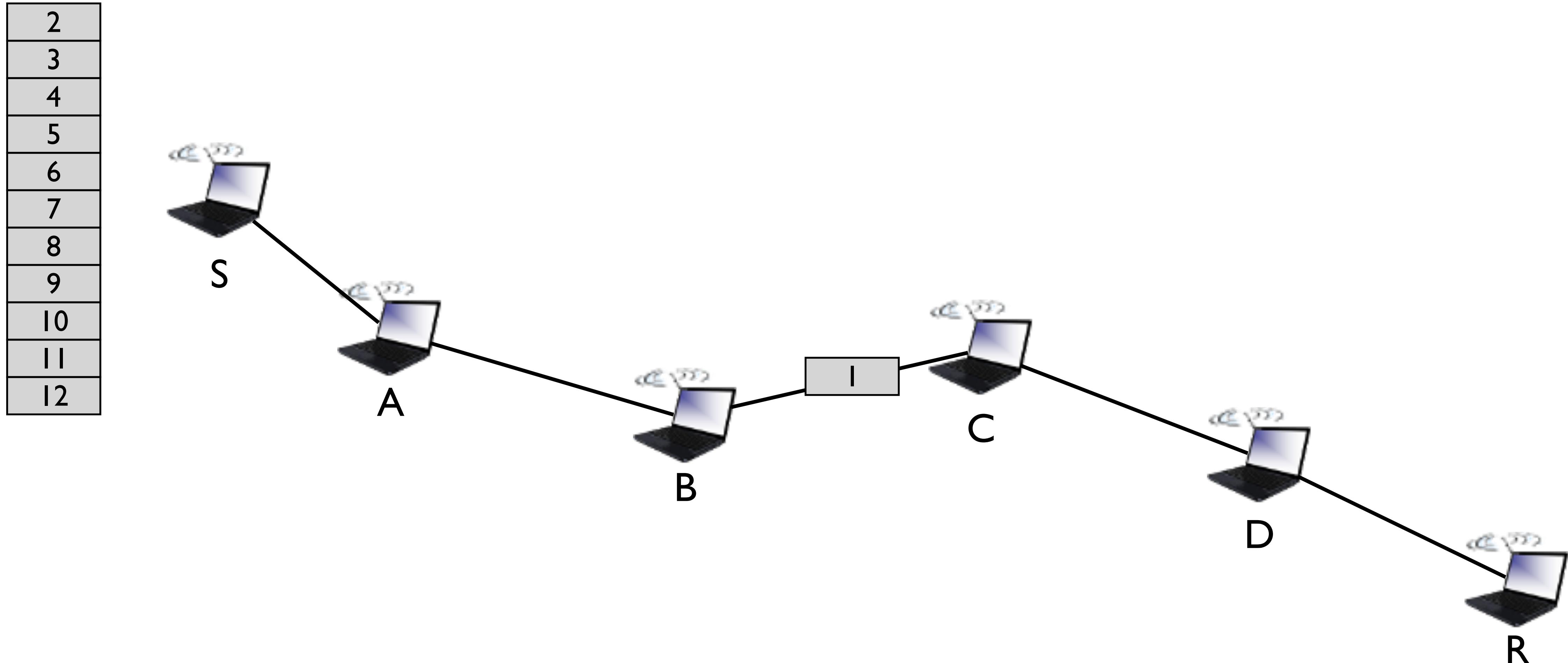
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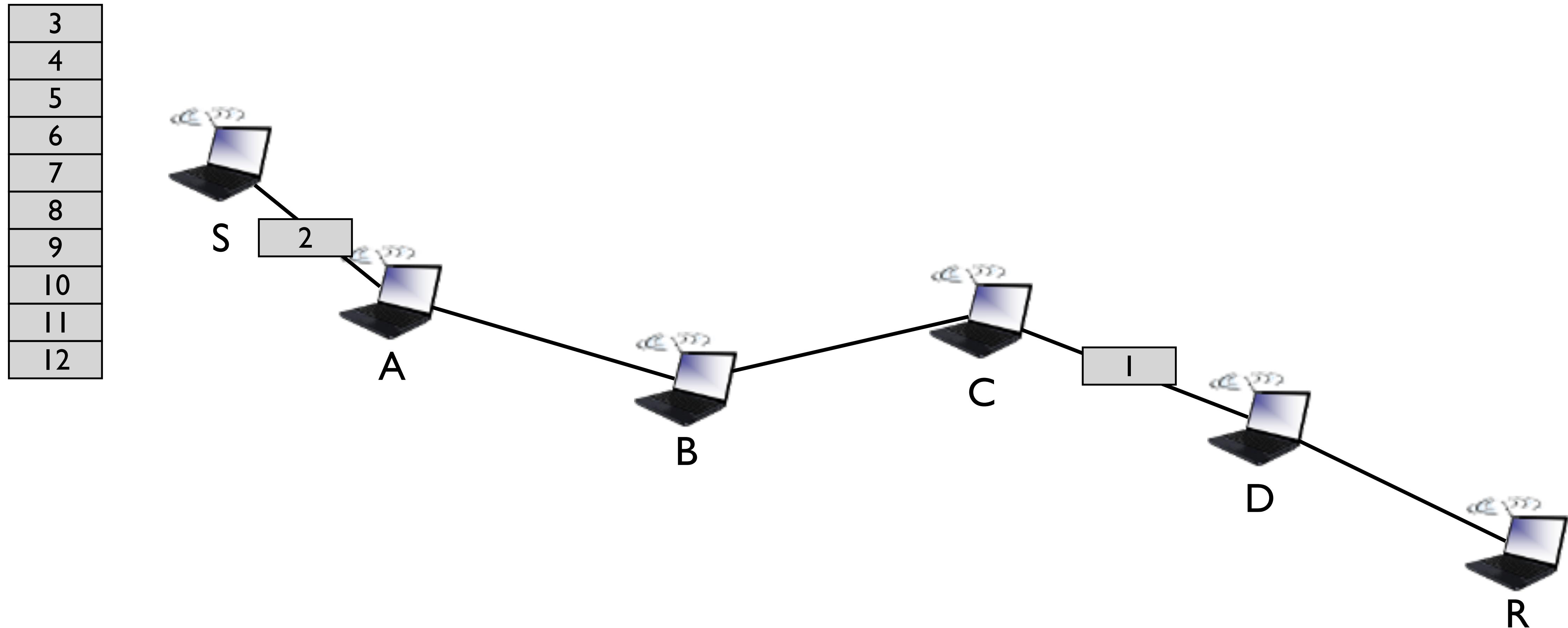
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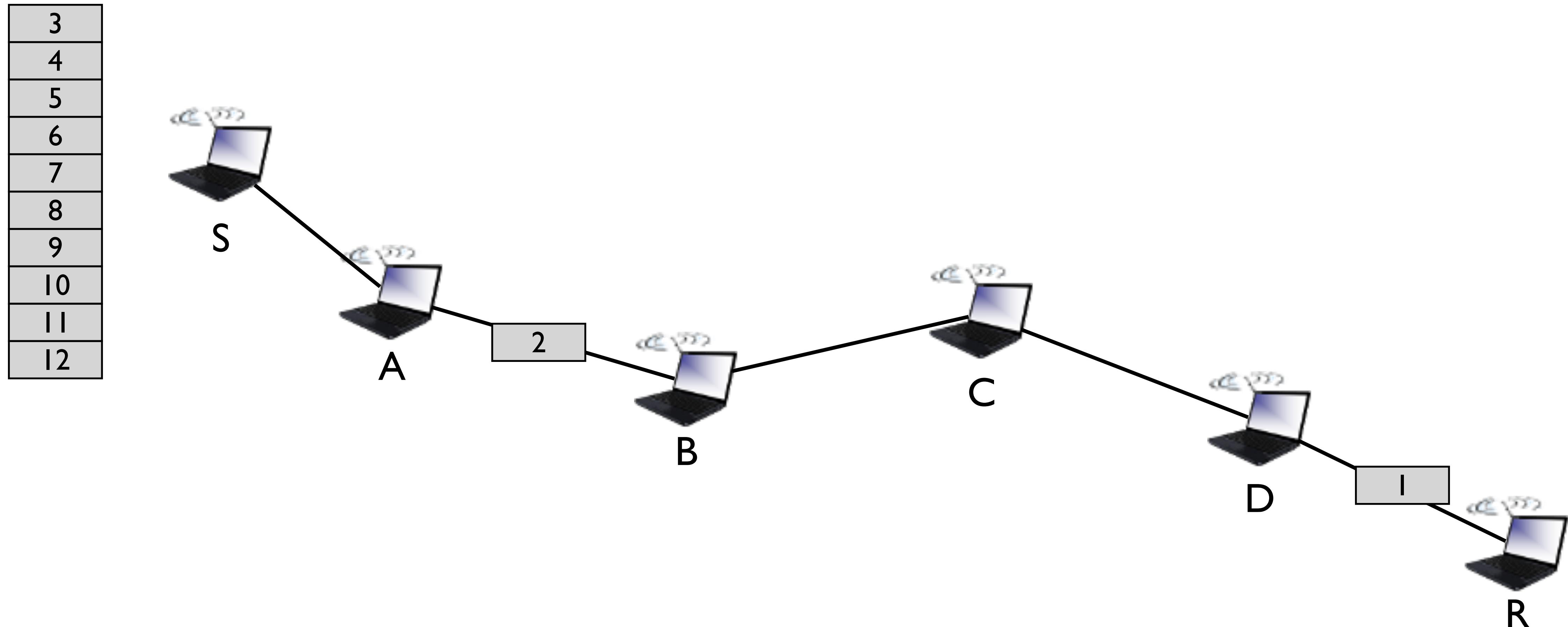
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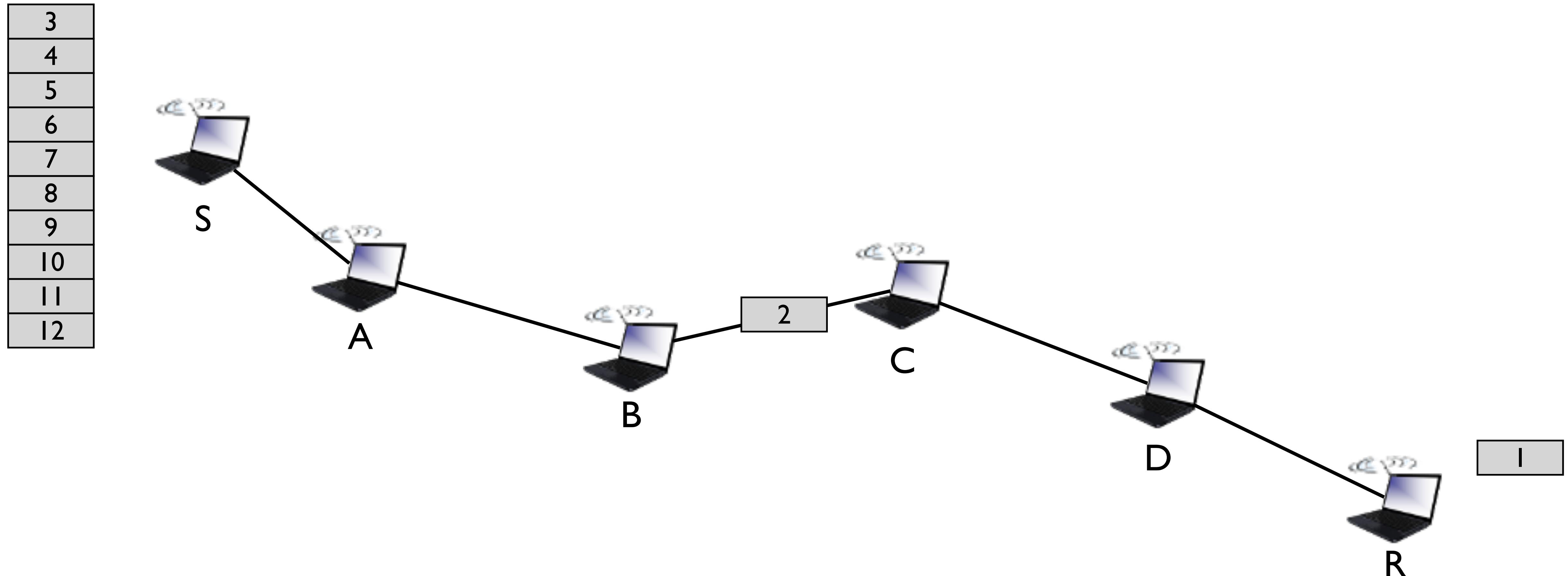
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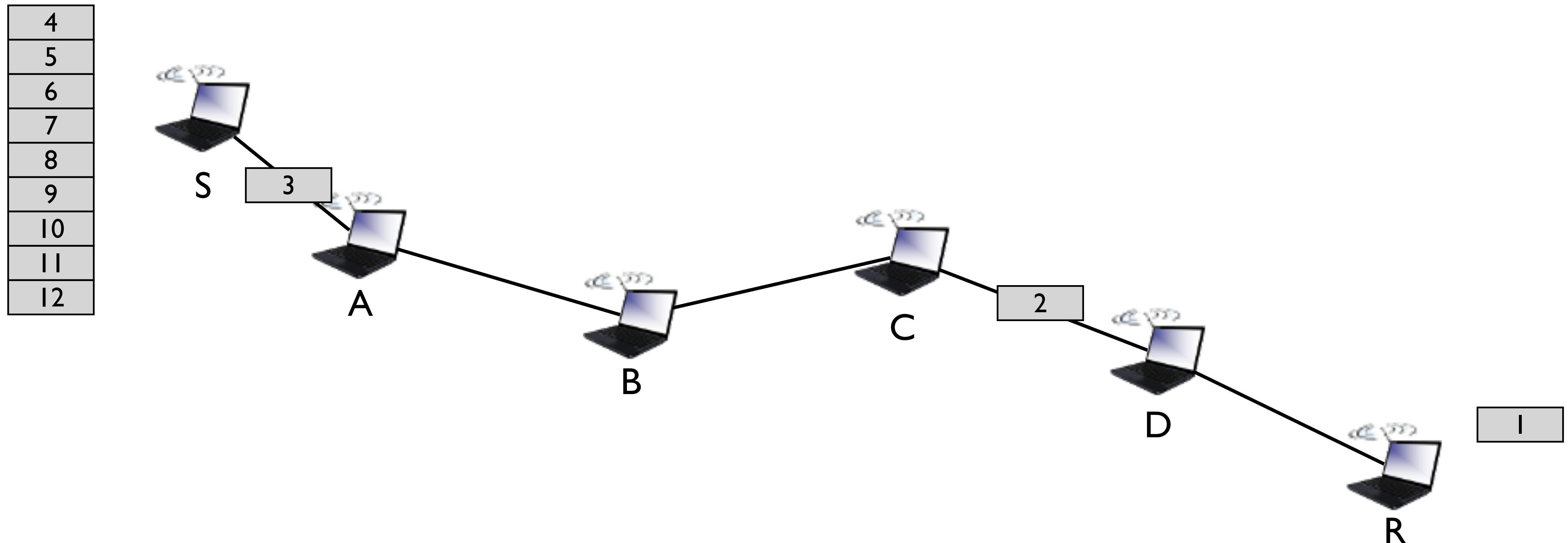
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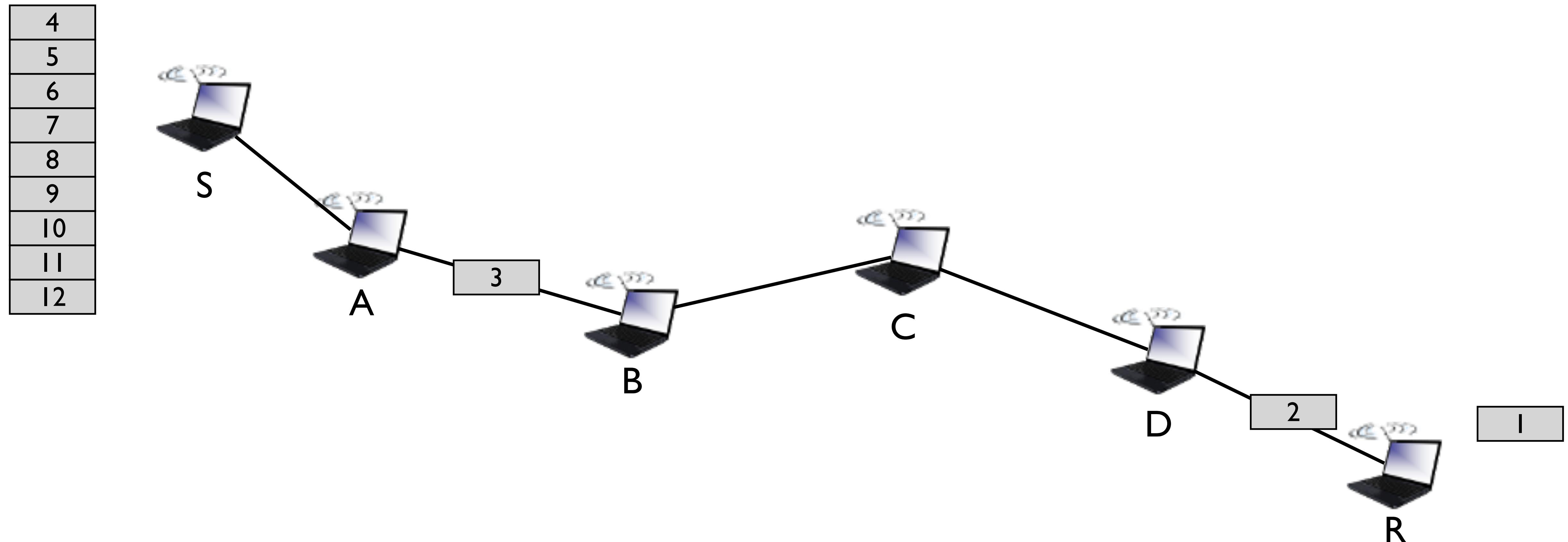
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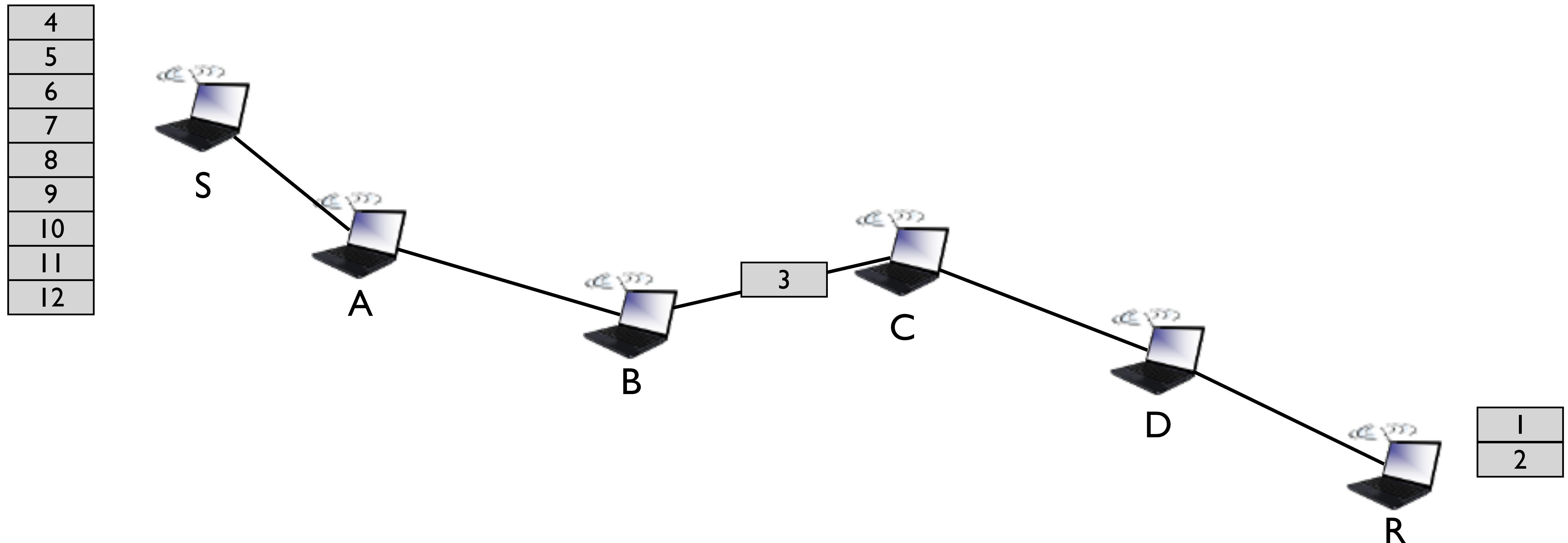
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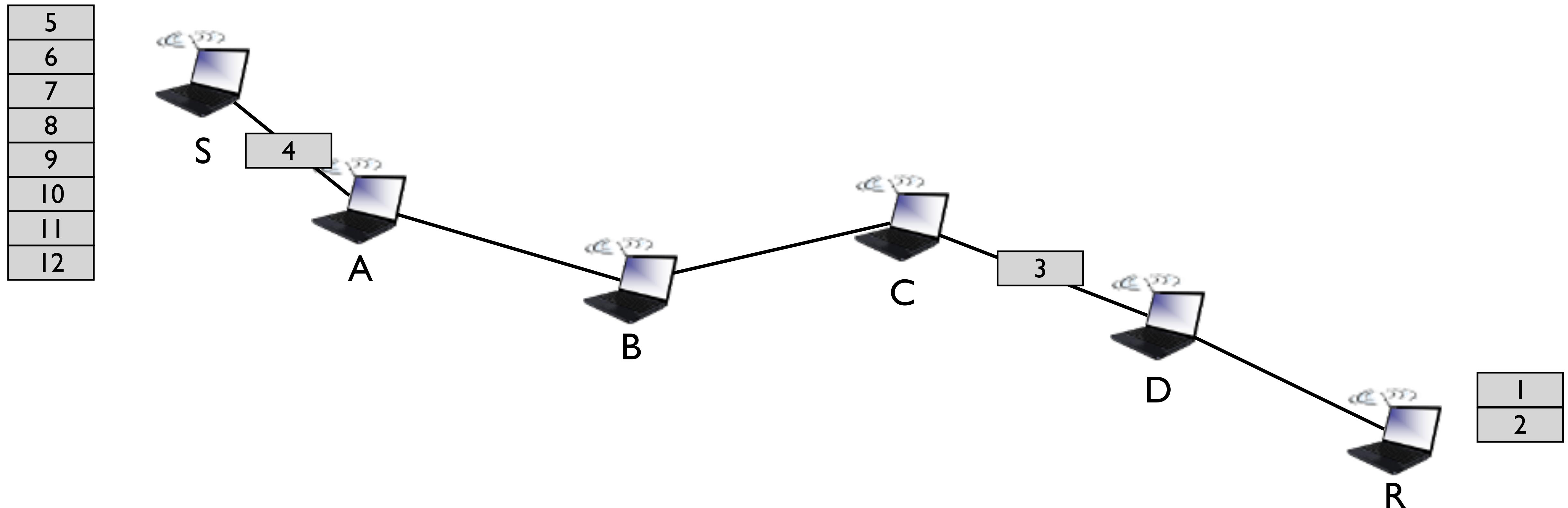
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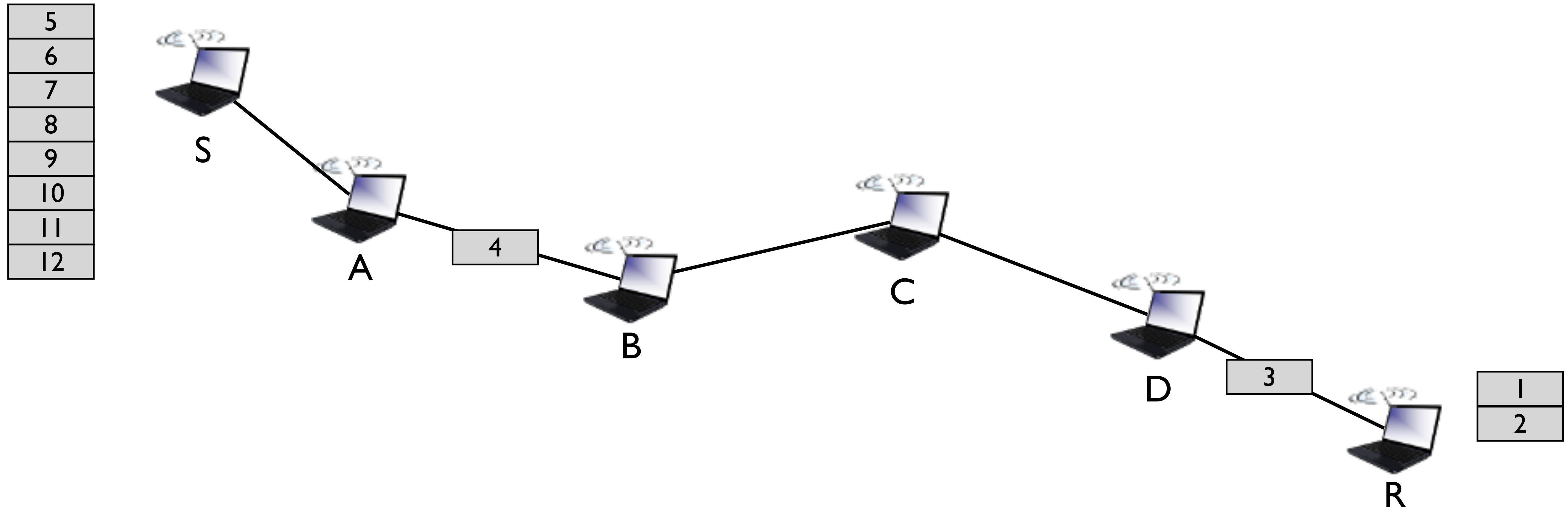
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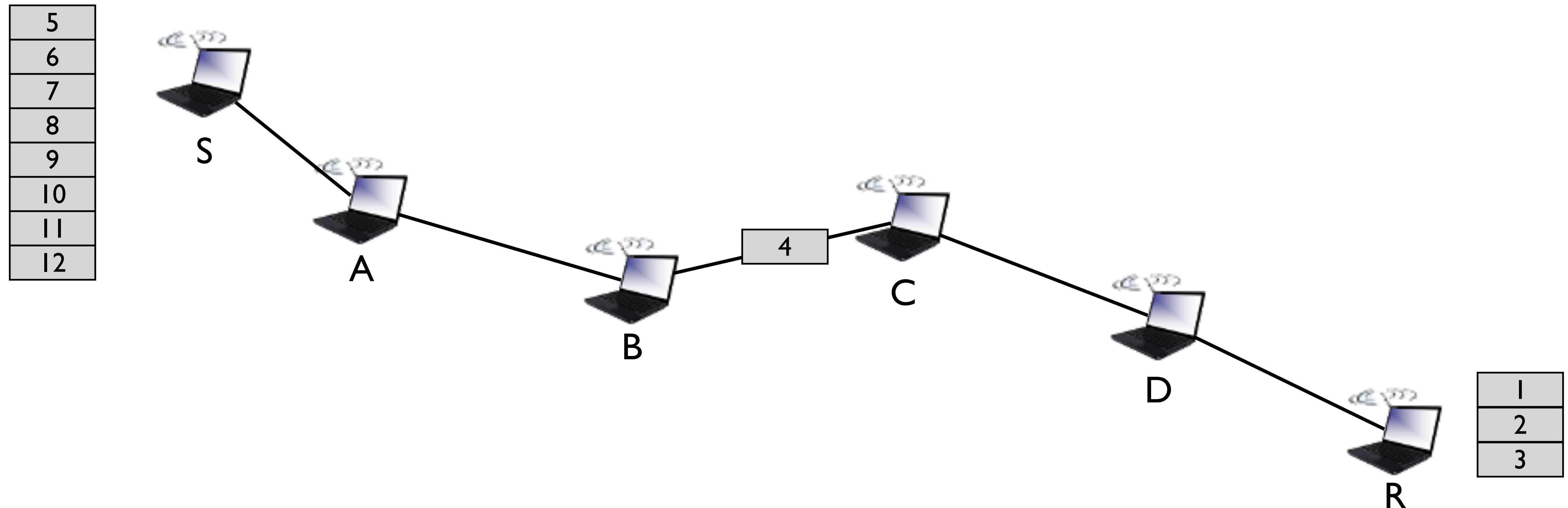
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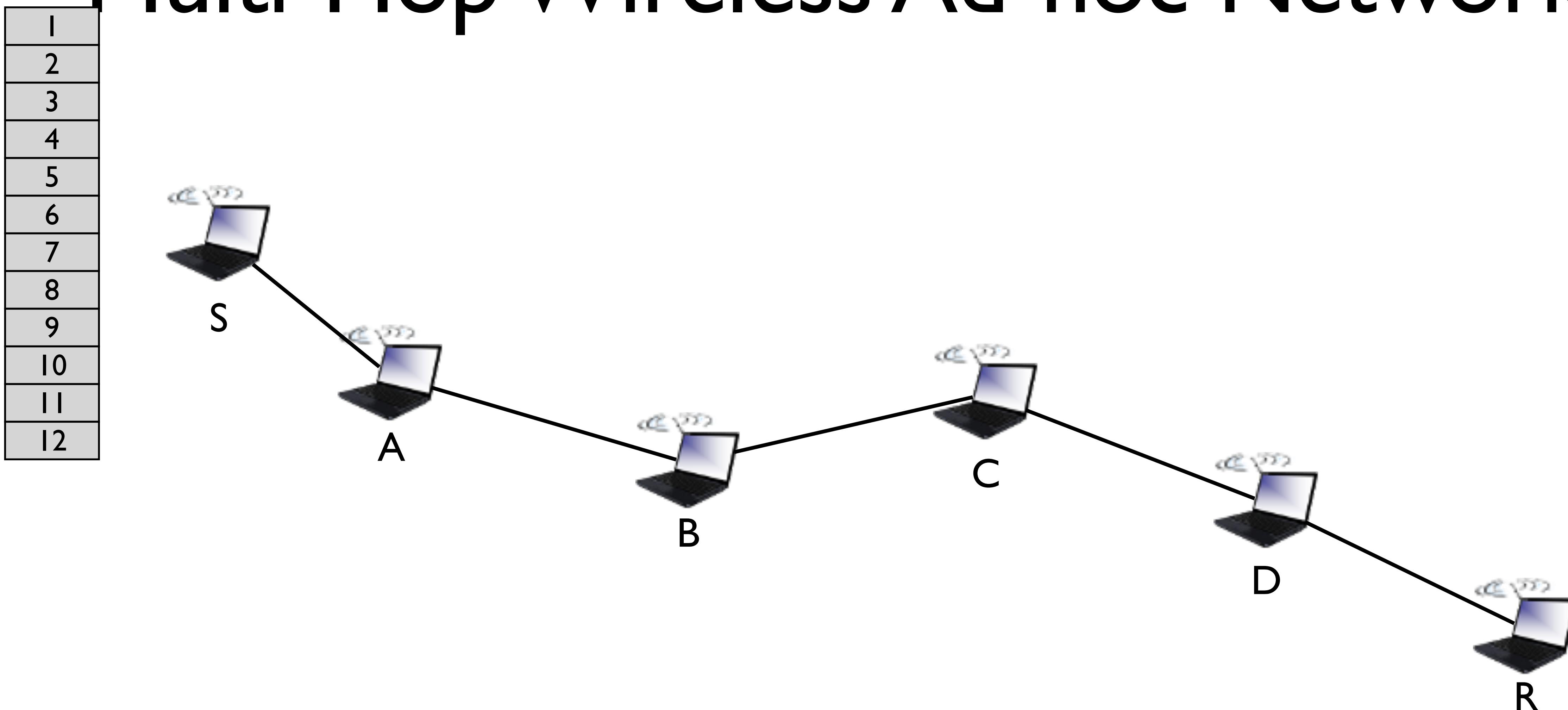
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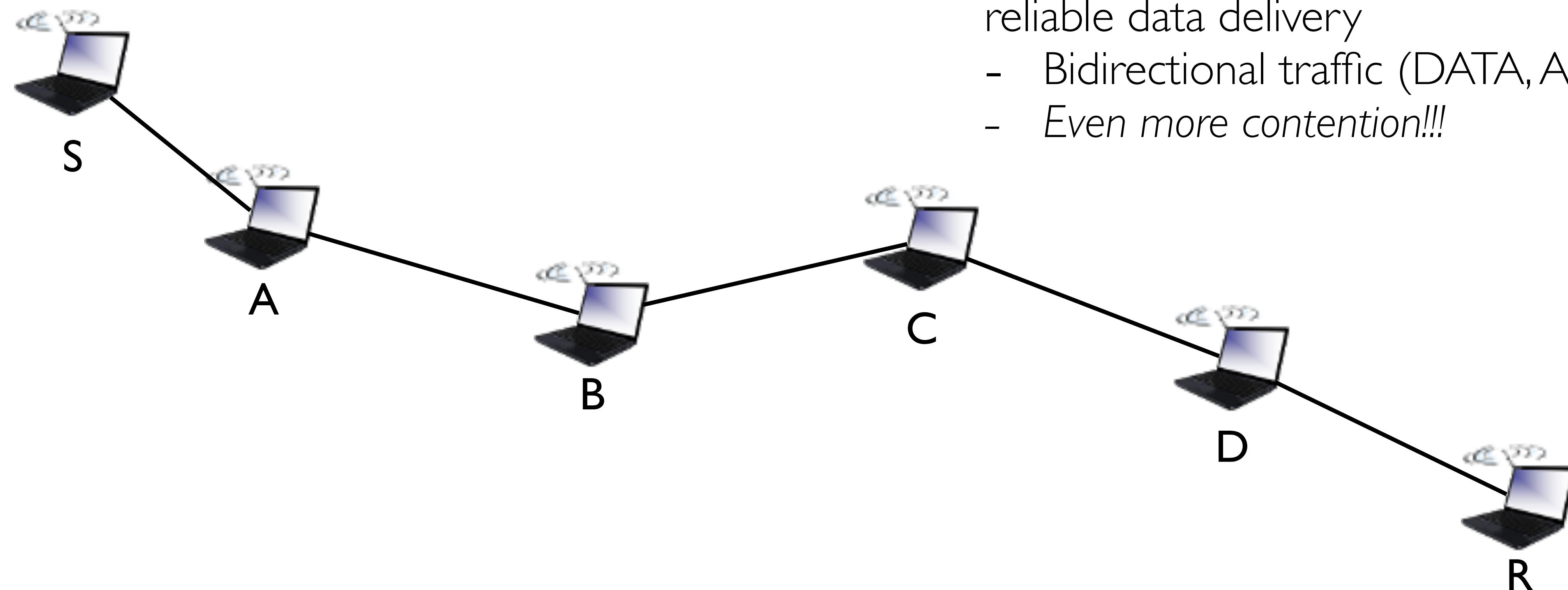


# Multi-Hop Wireless Ad-hoc Networks



# Multi-Hop Wireless Ad-hoc Networks

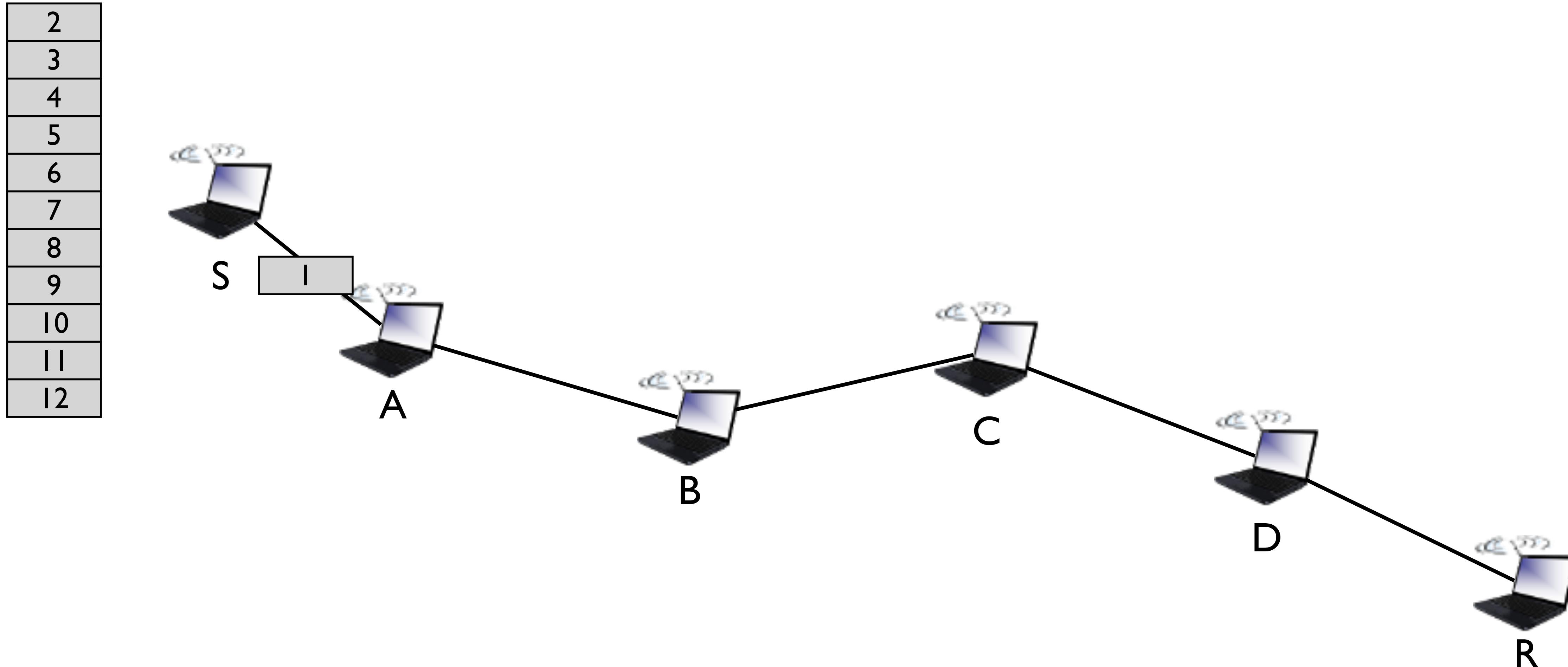
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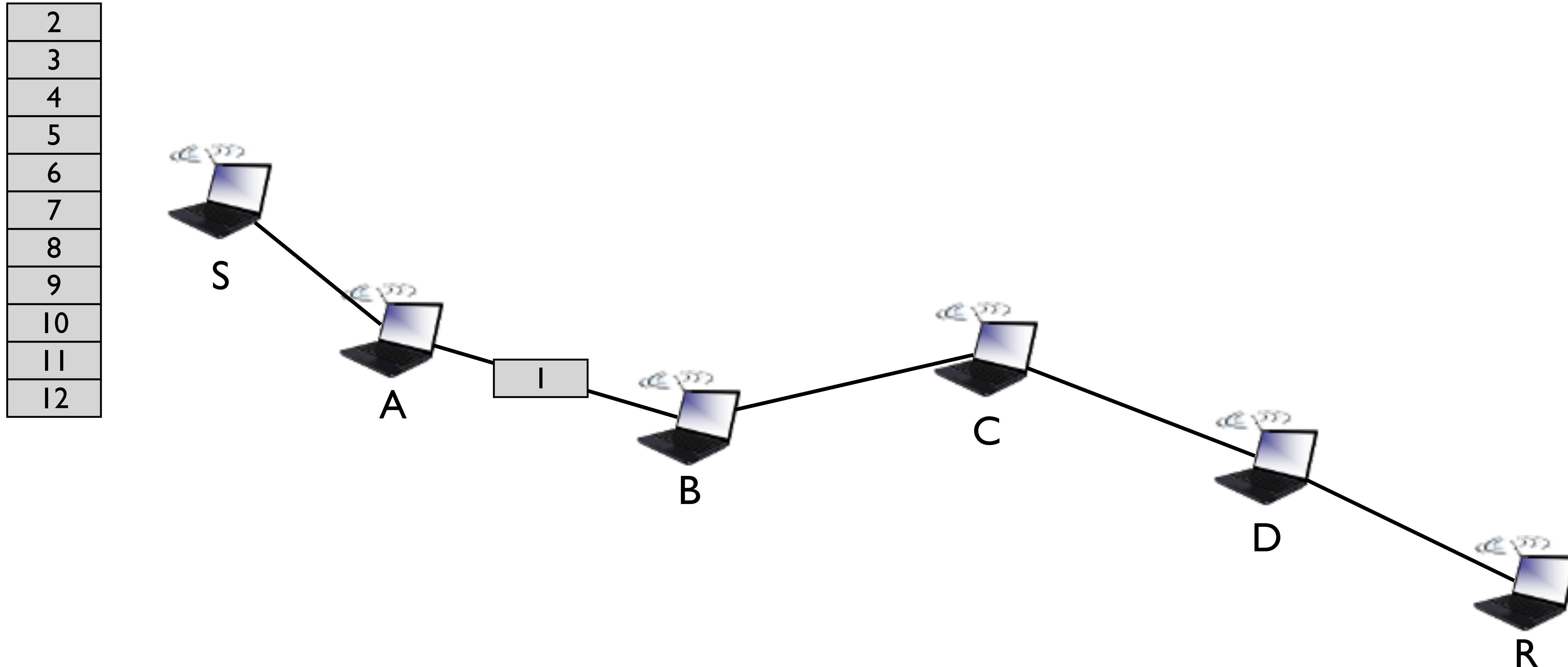
**Problem 4:** TCP uses ACKs to indicate reliable data delivery

- Bidirectional traffic (DATA, ACKs)
- Even more contention!!!

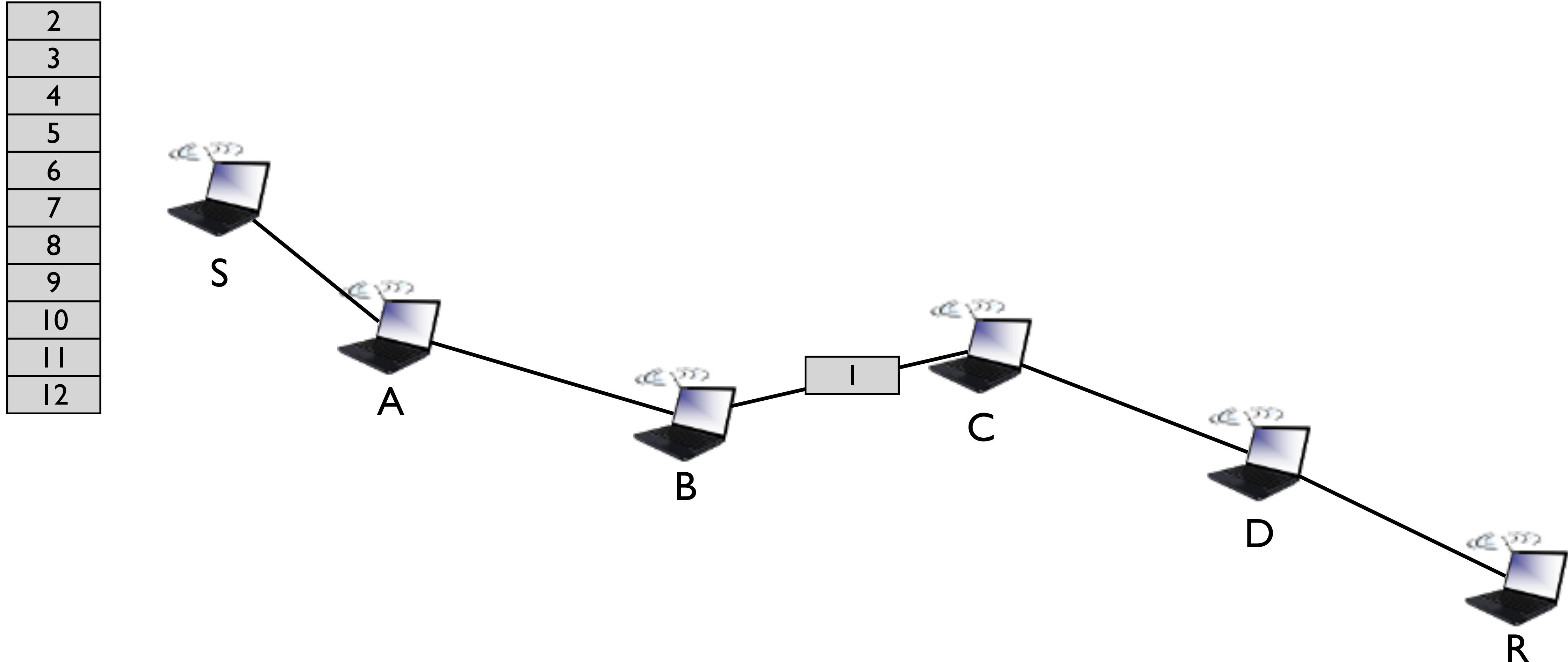
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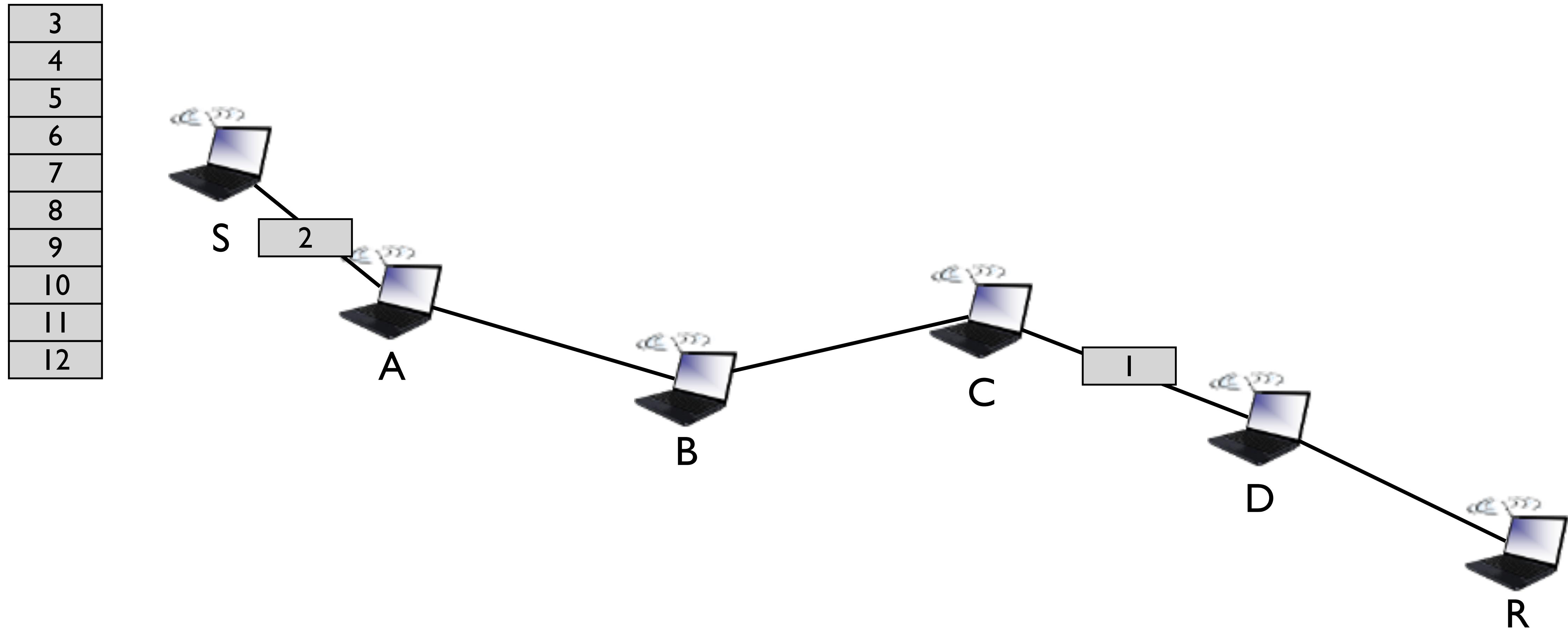
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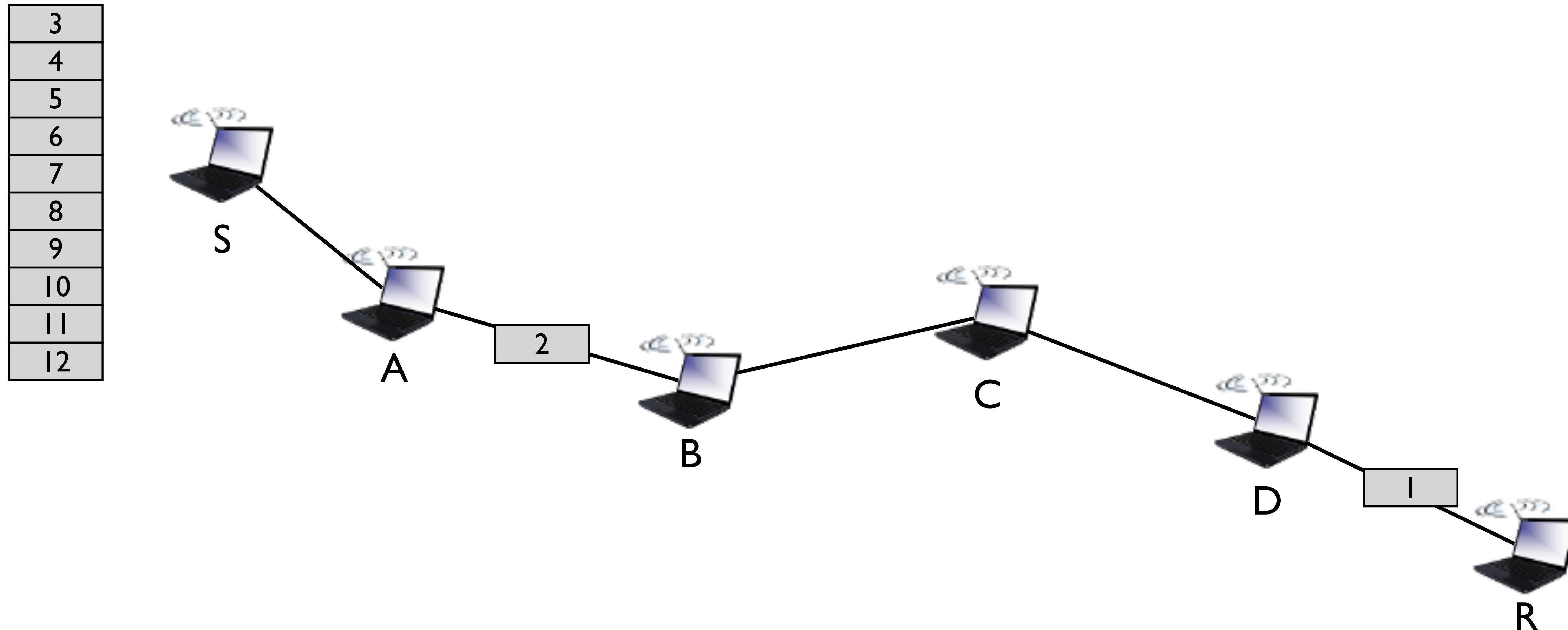
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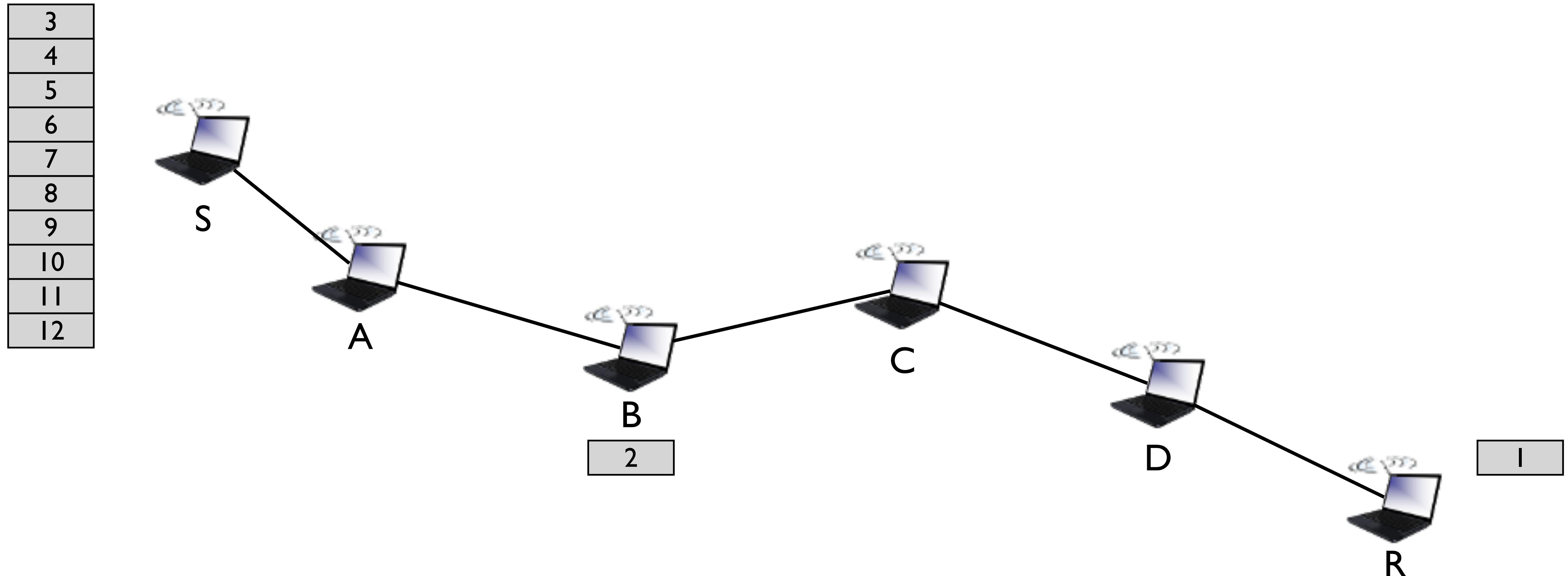
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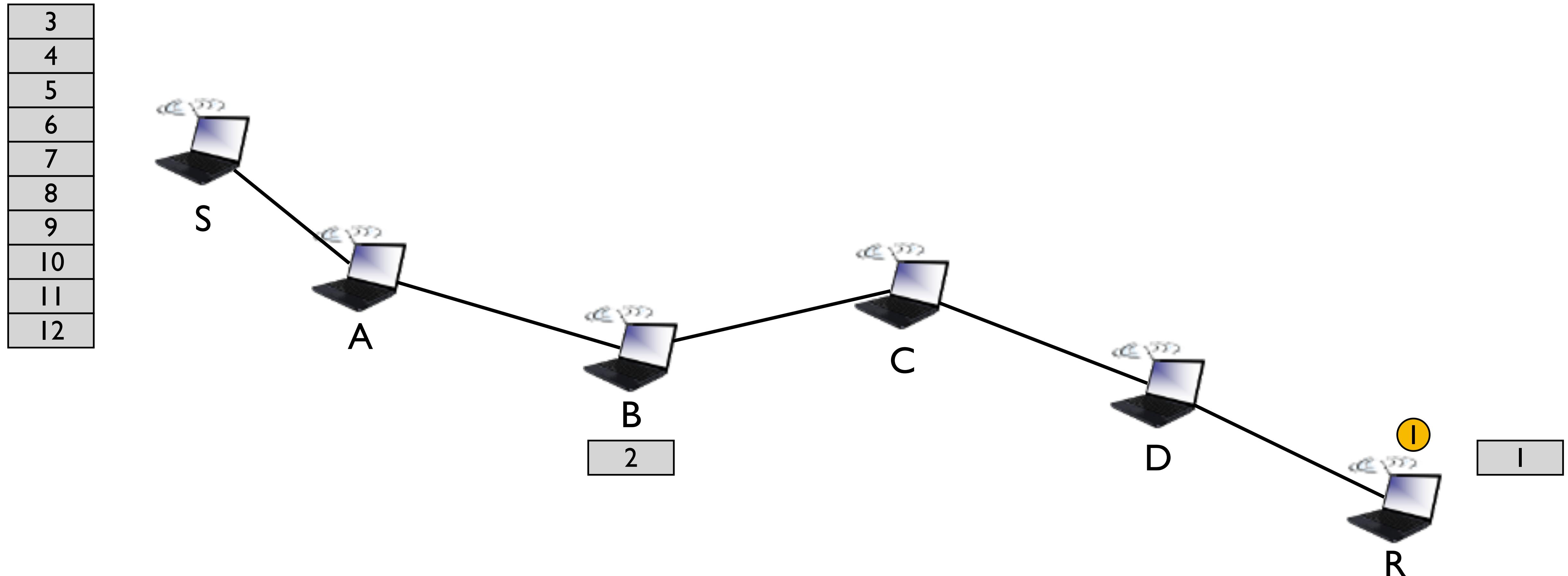
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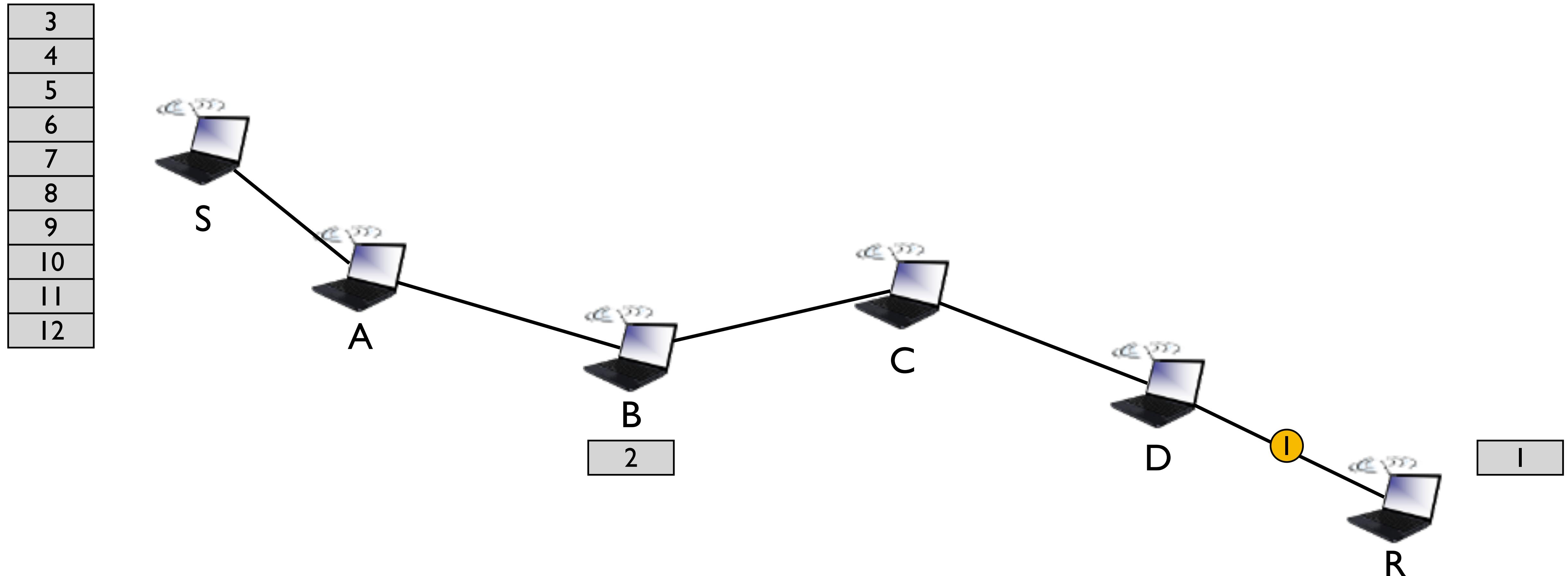
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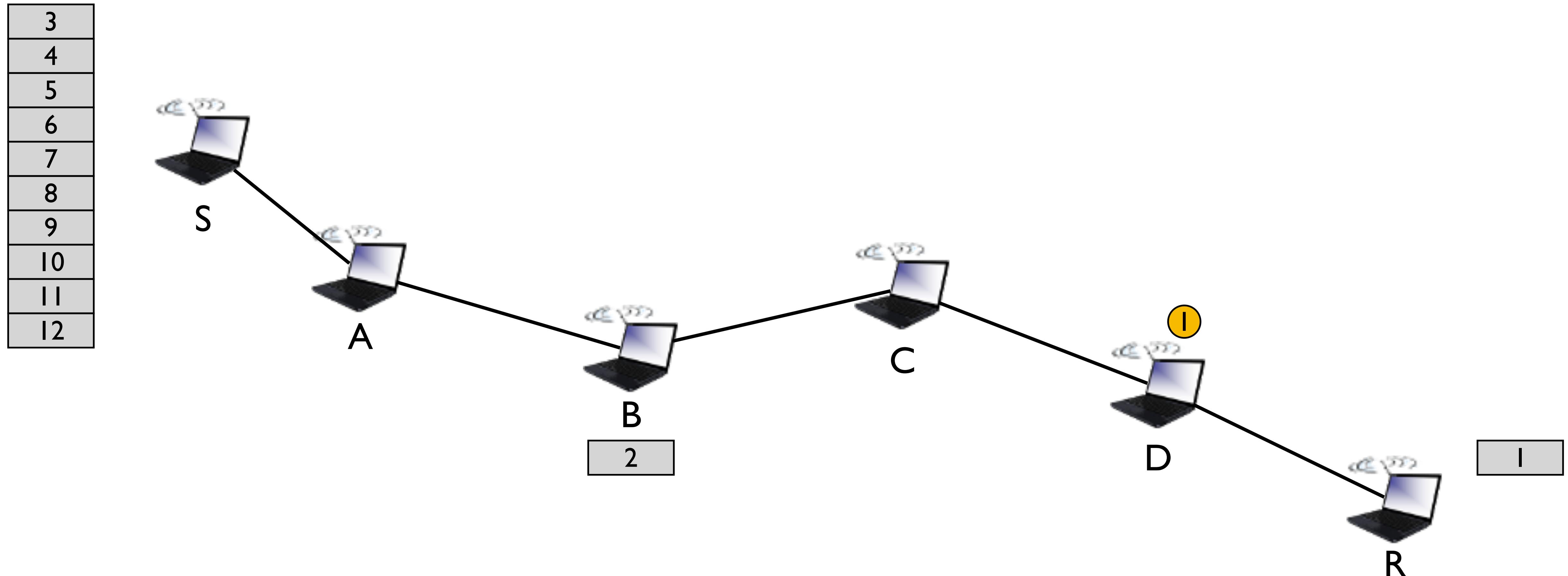
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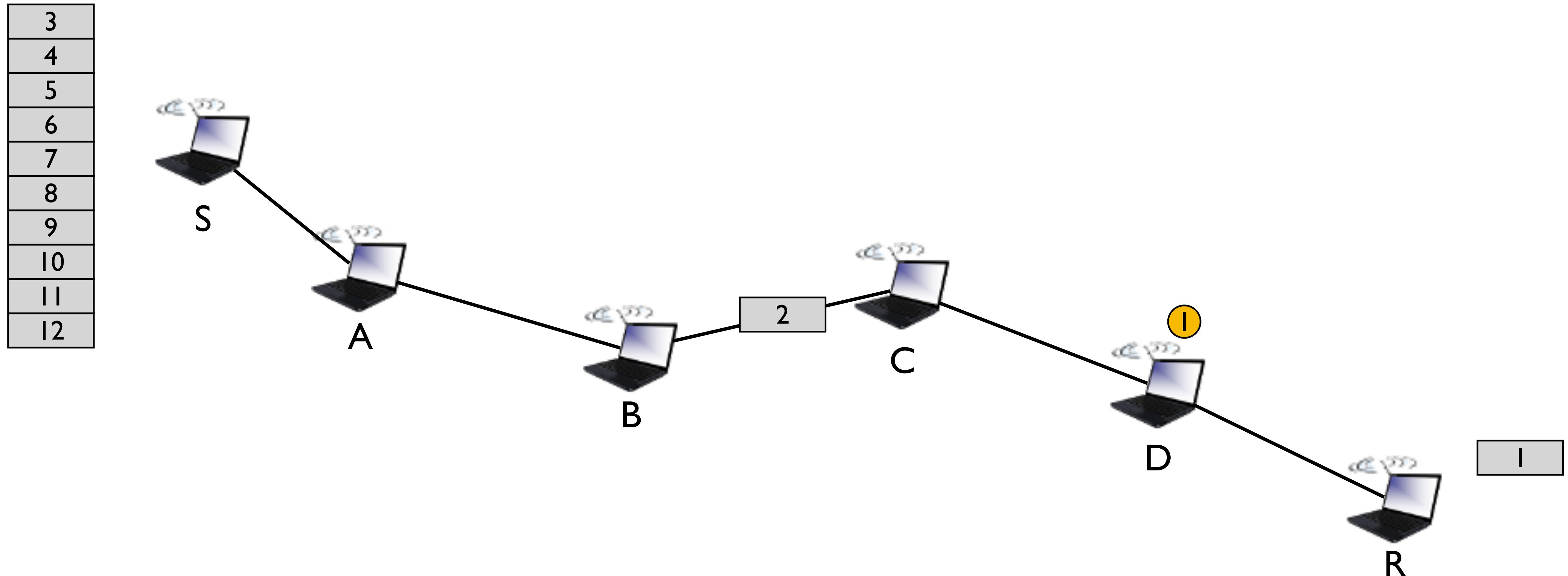
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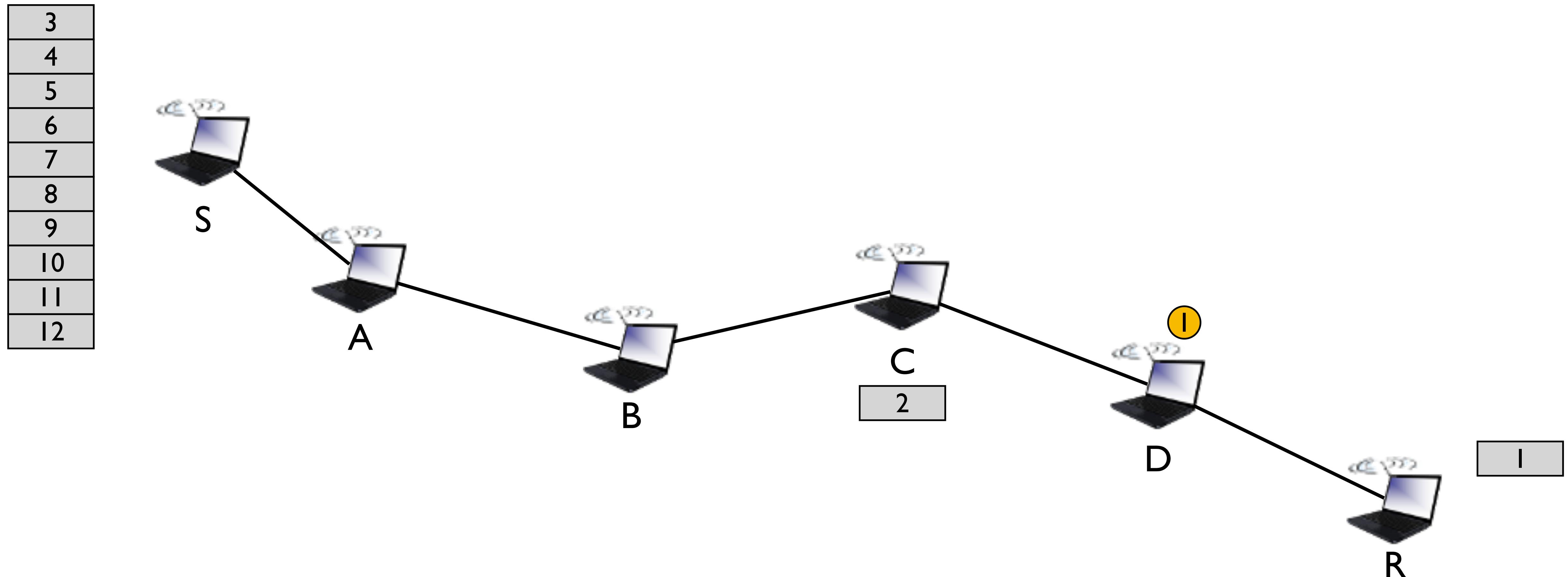
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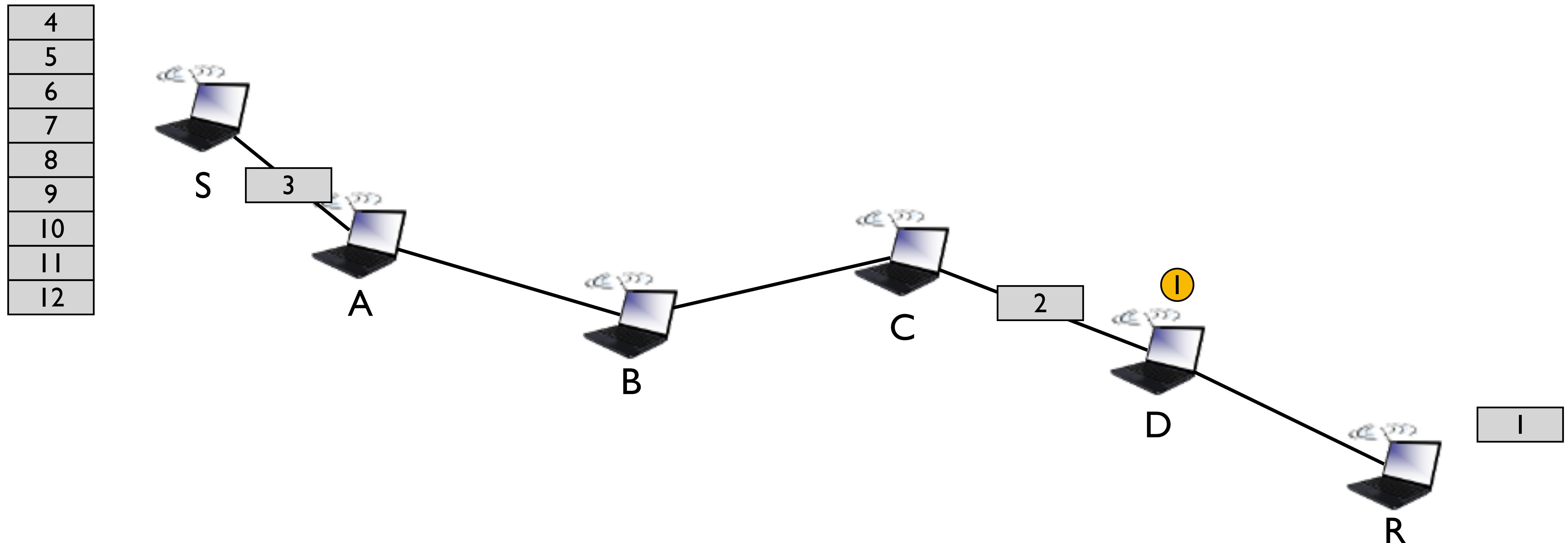
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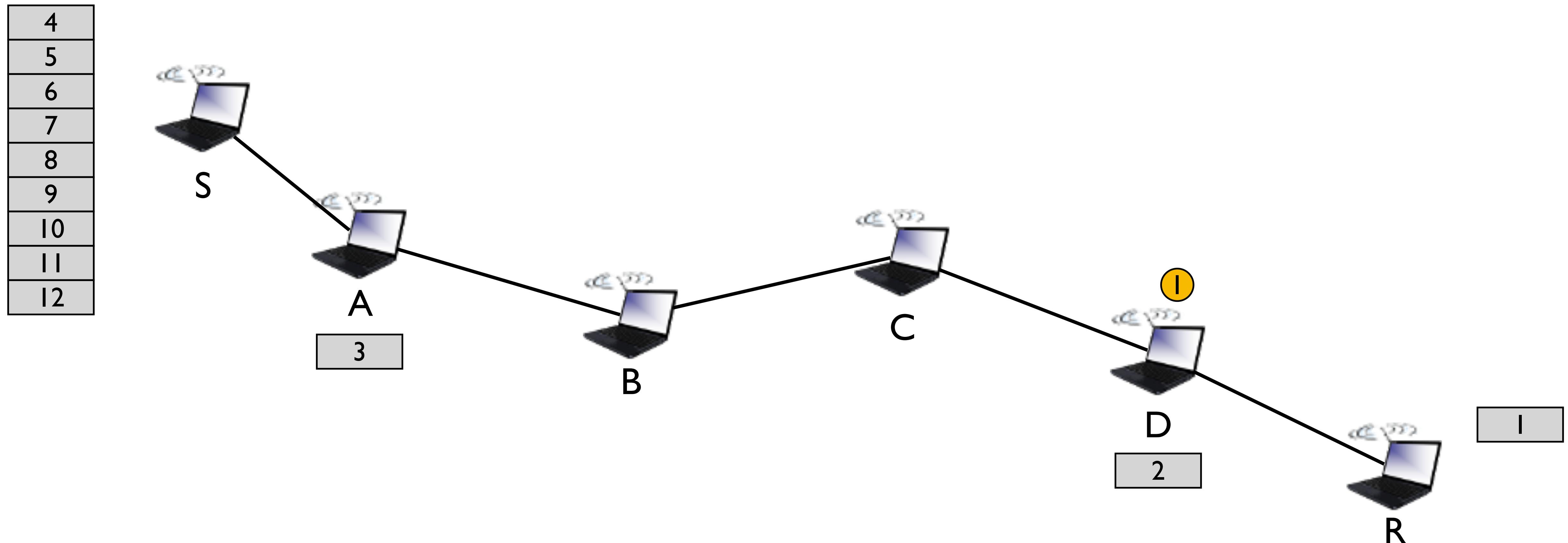
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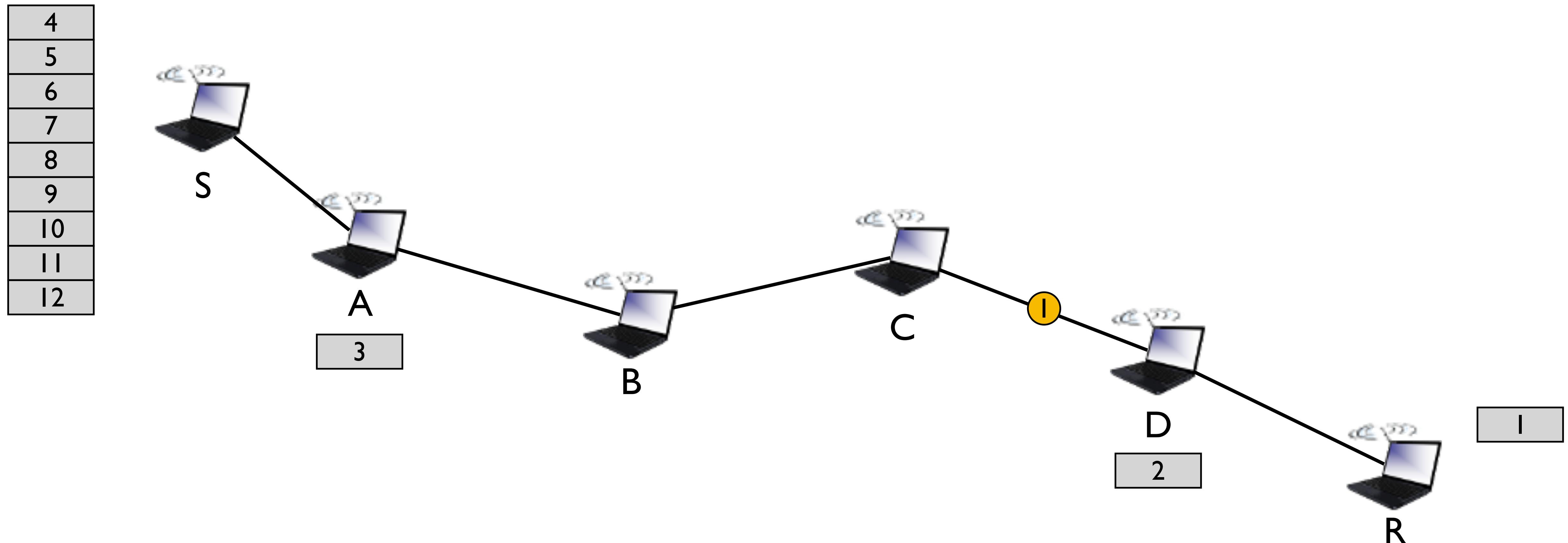
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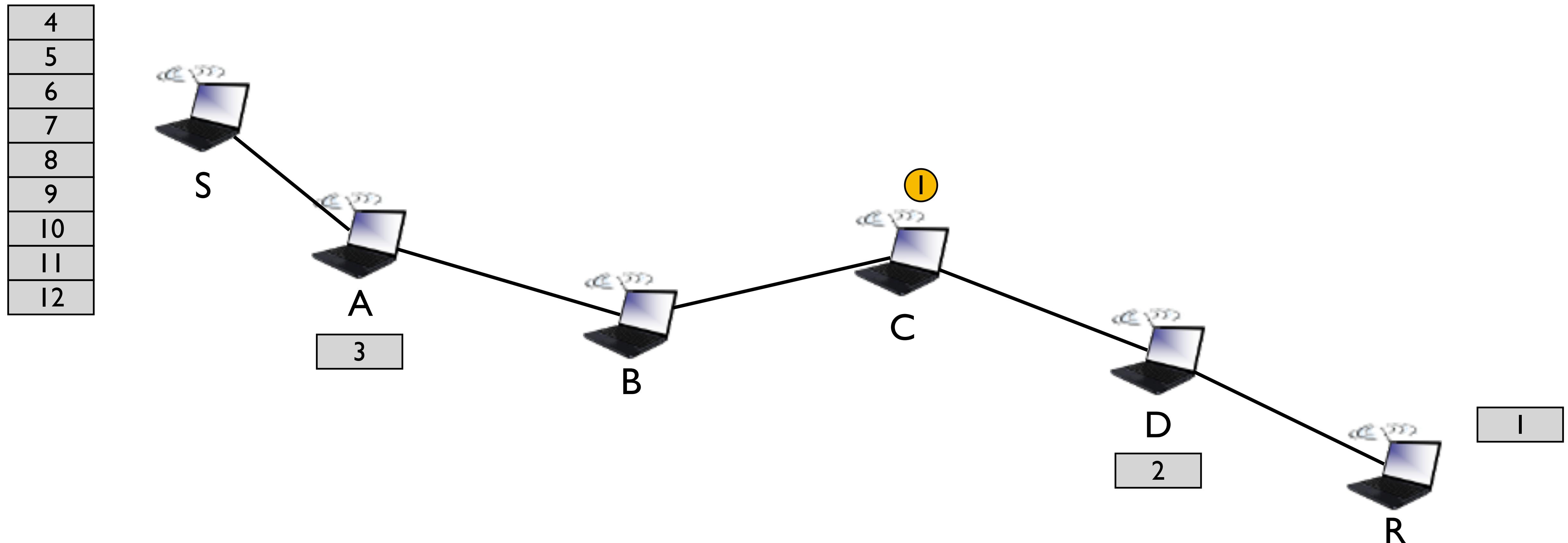
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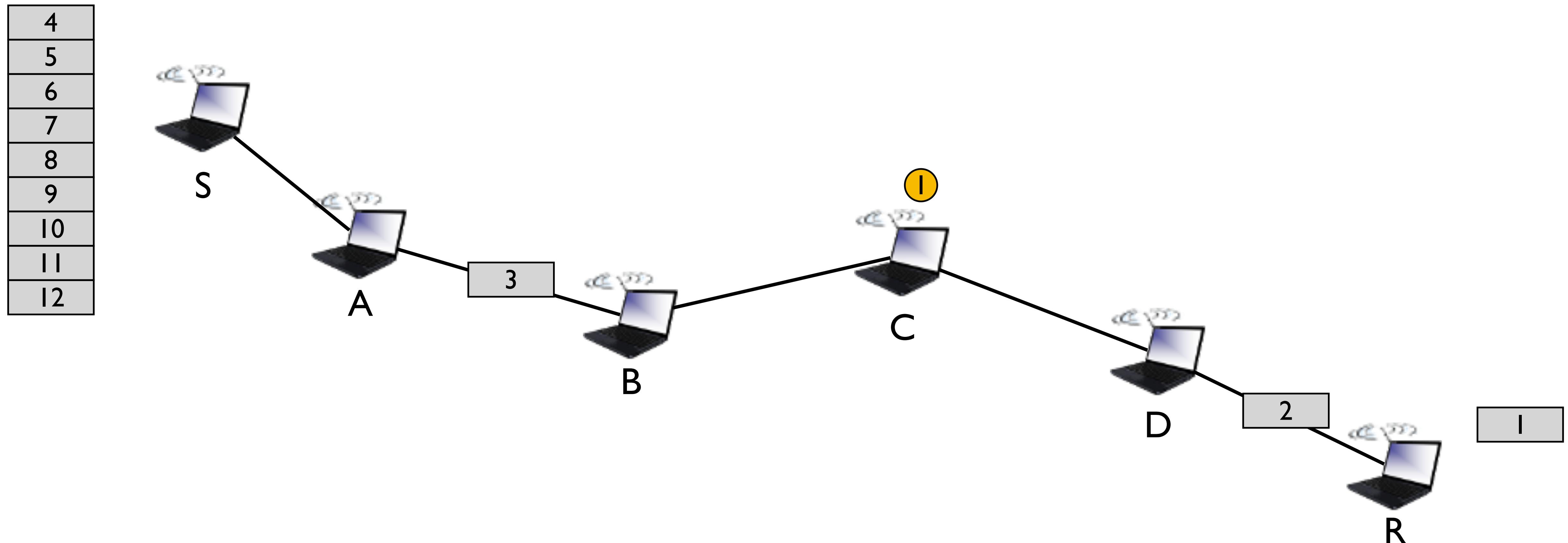
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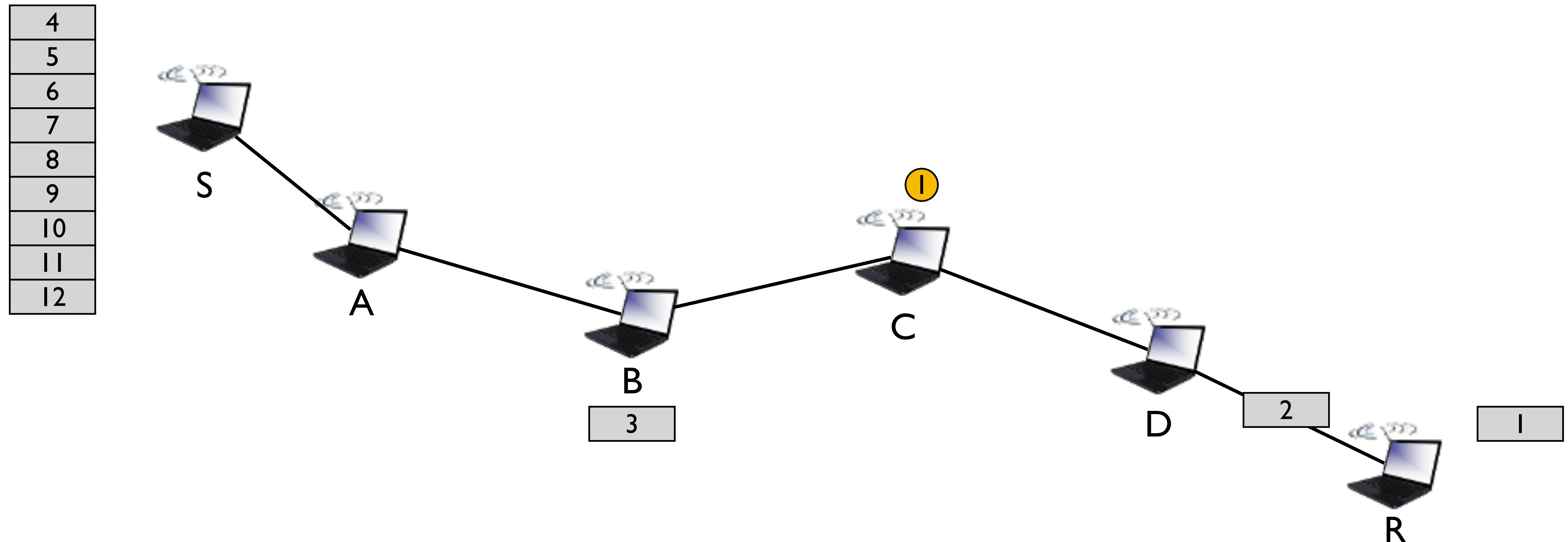
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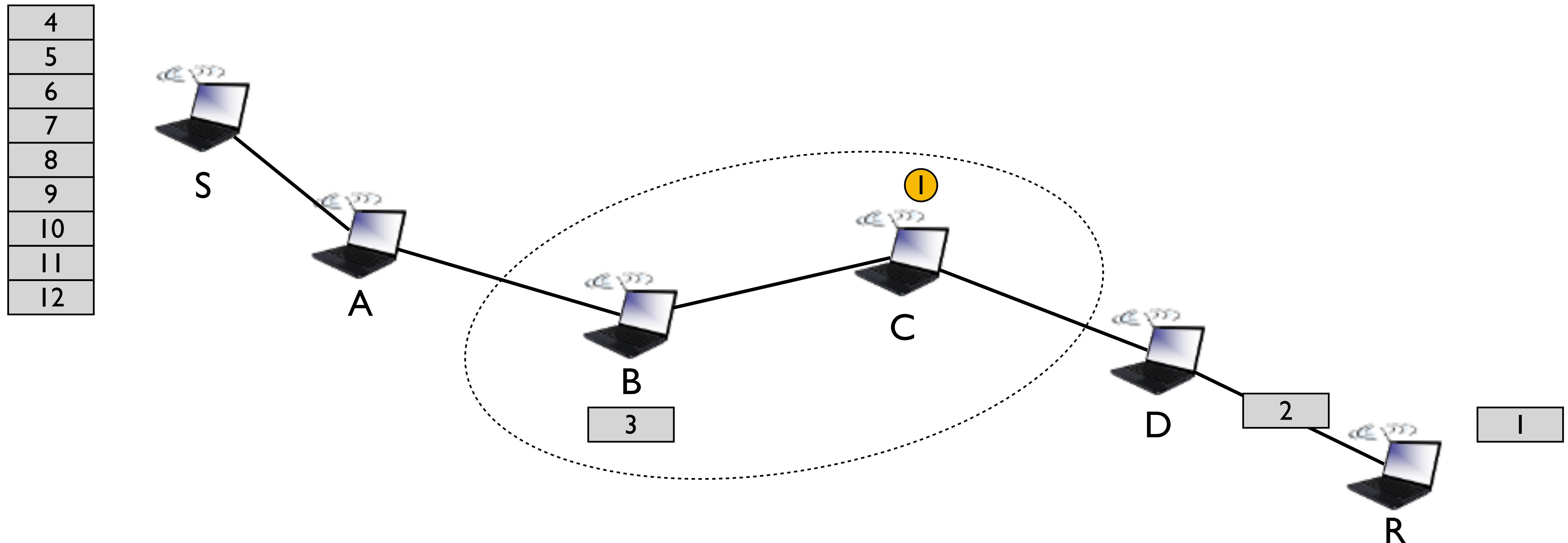
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  - Exposed terminals
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- **Multi-hop even more complicated**

# Questions?

# Datacenter Networks

CPSC 433/533, Spring 2021

Anurag Khandelwal

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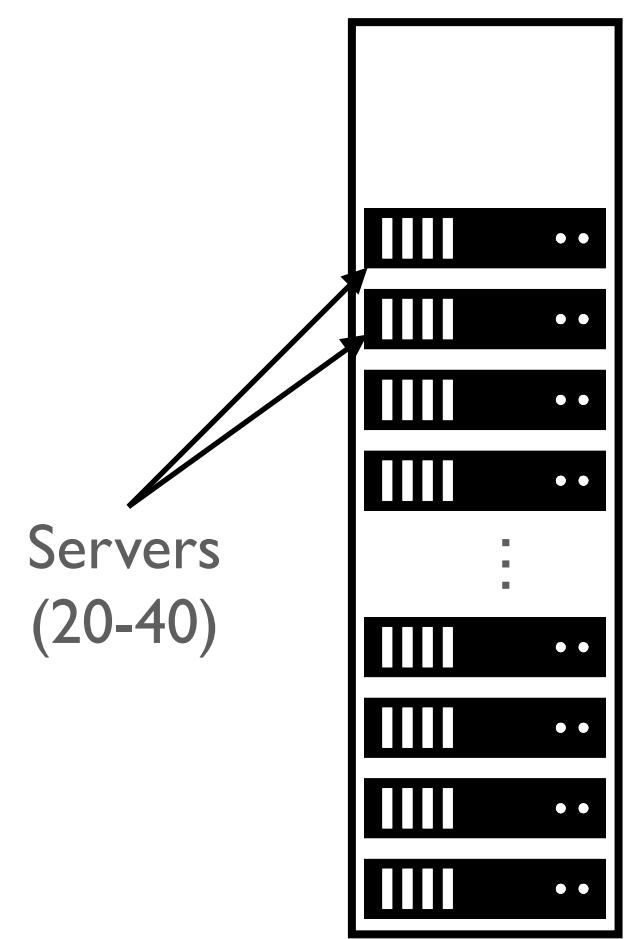
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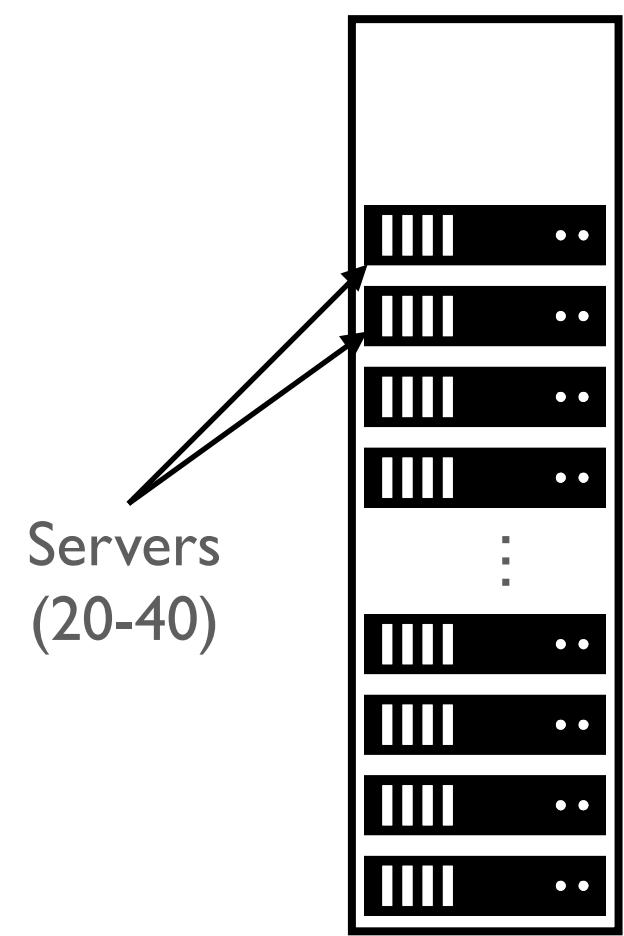
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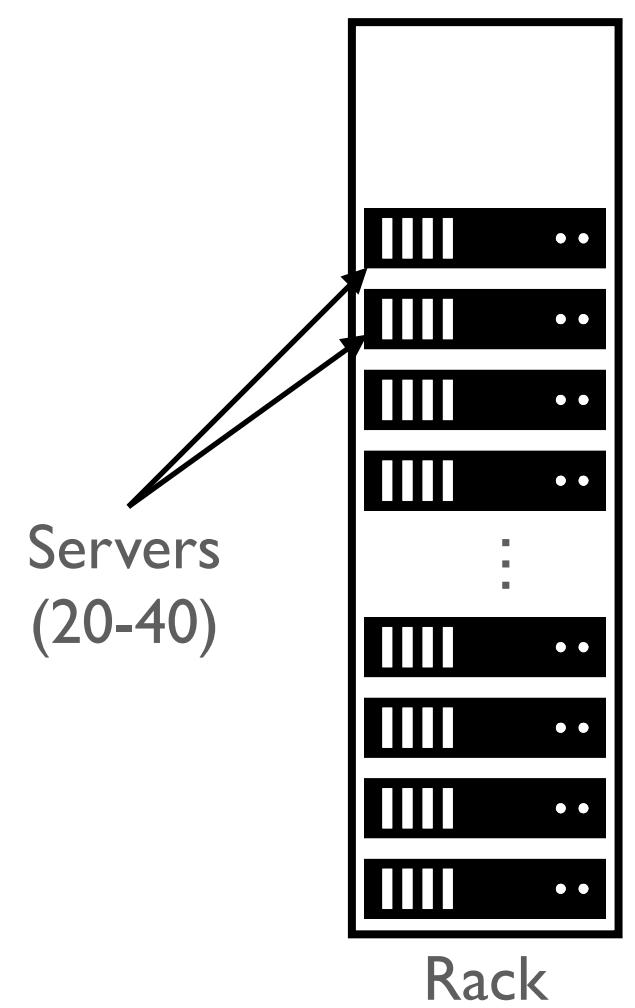
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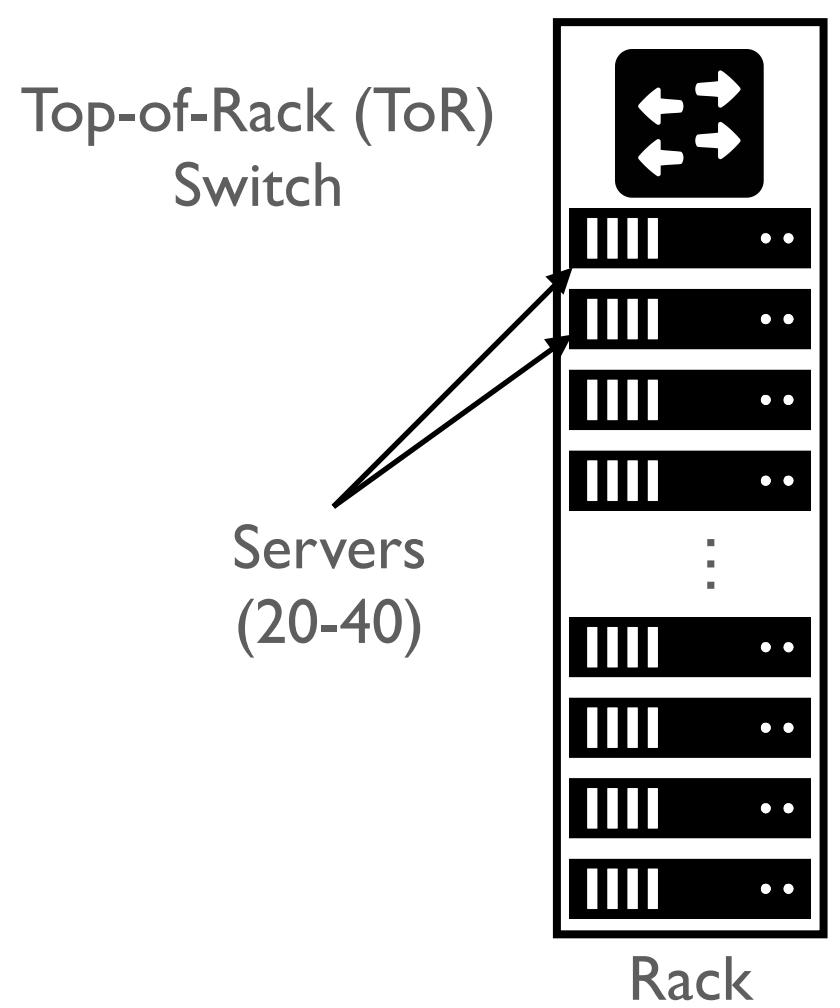
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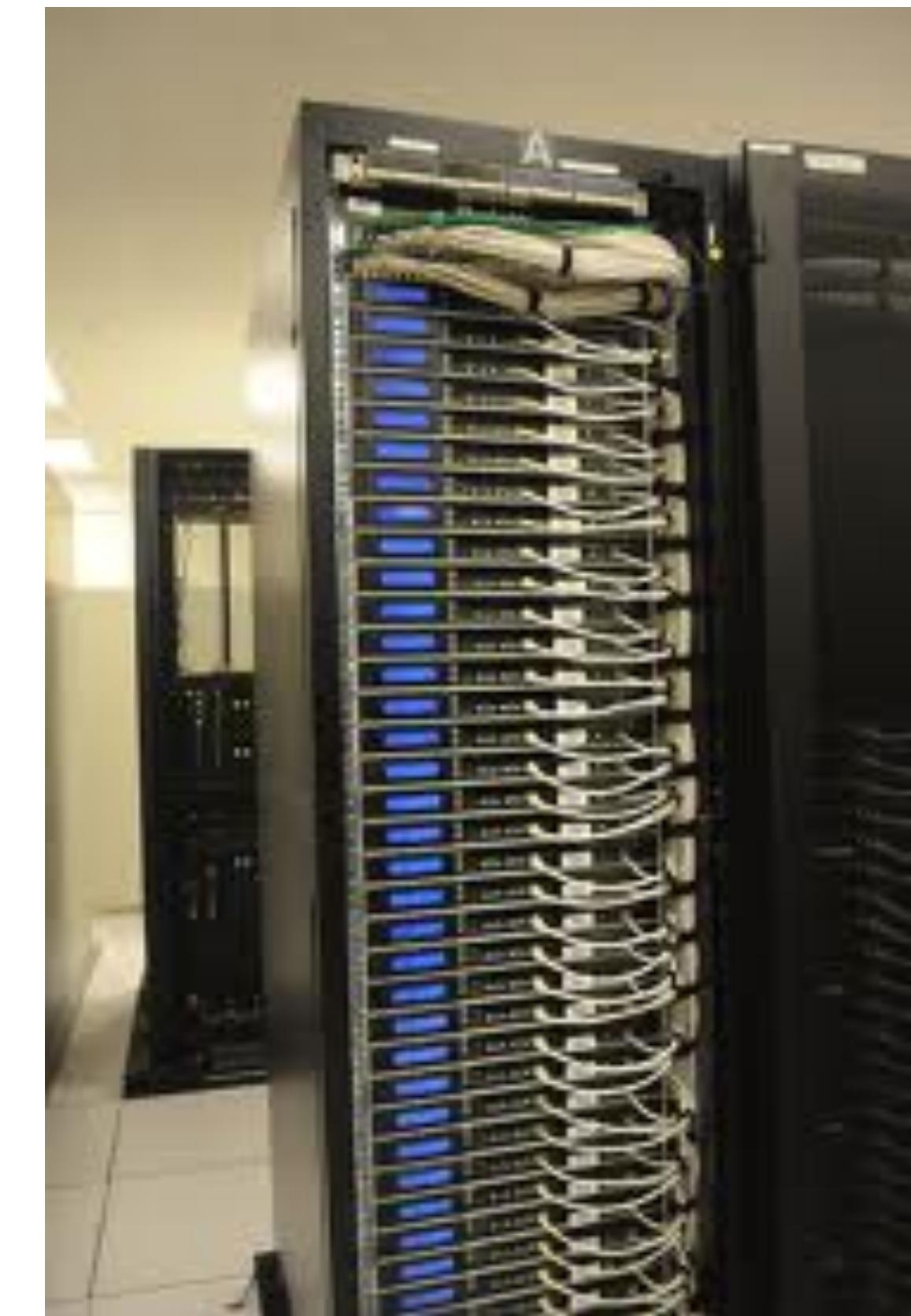
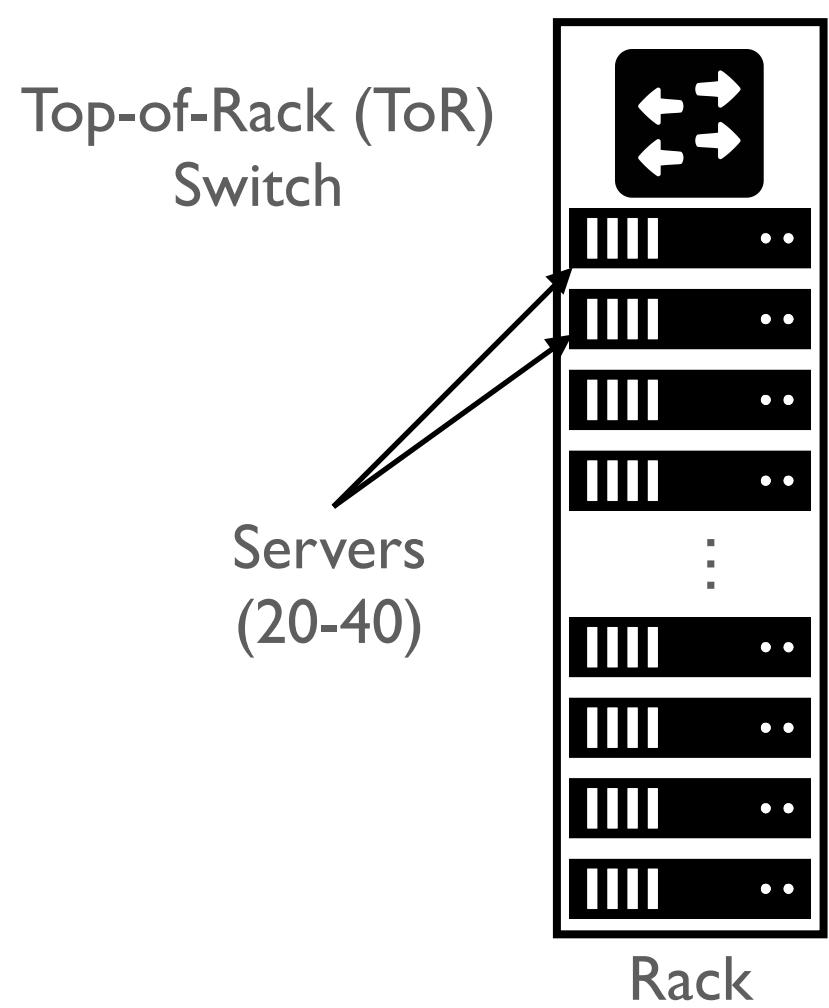
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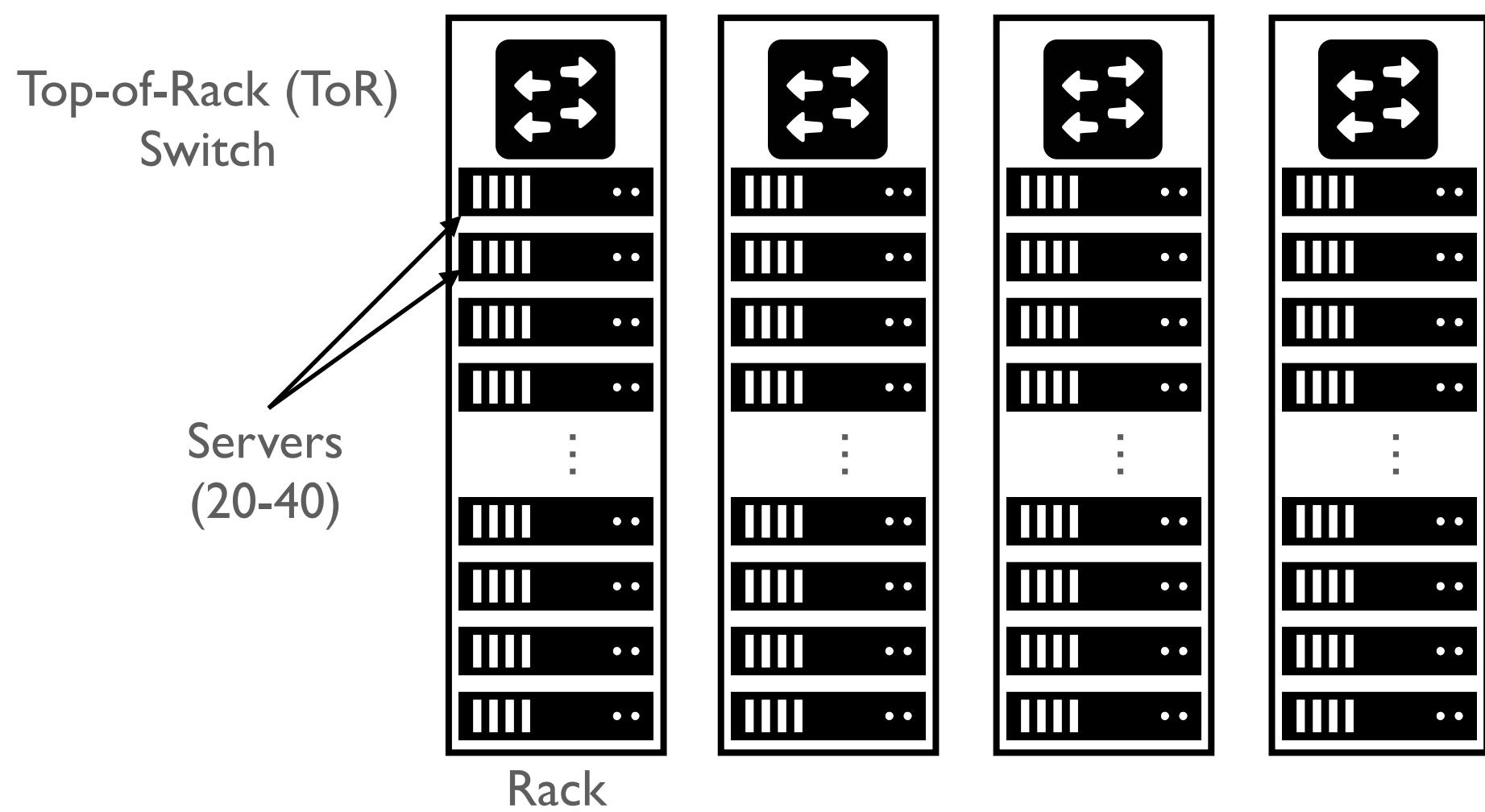
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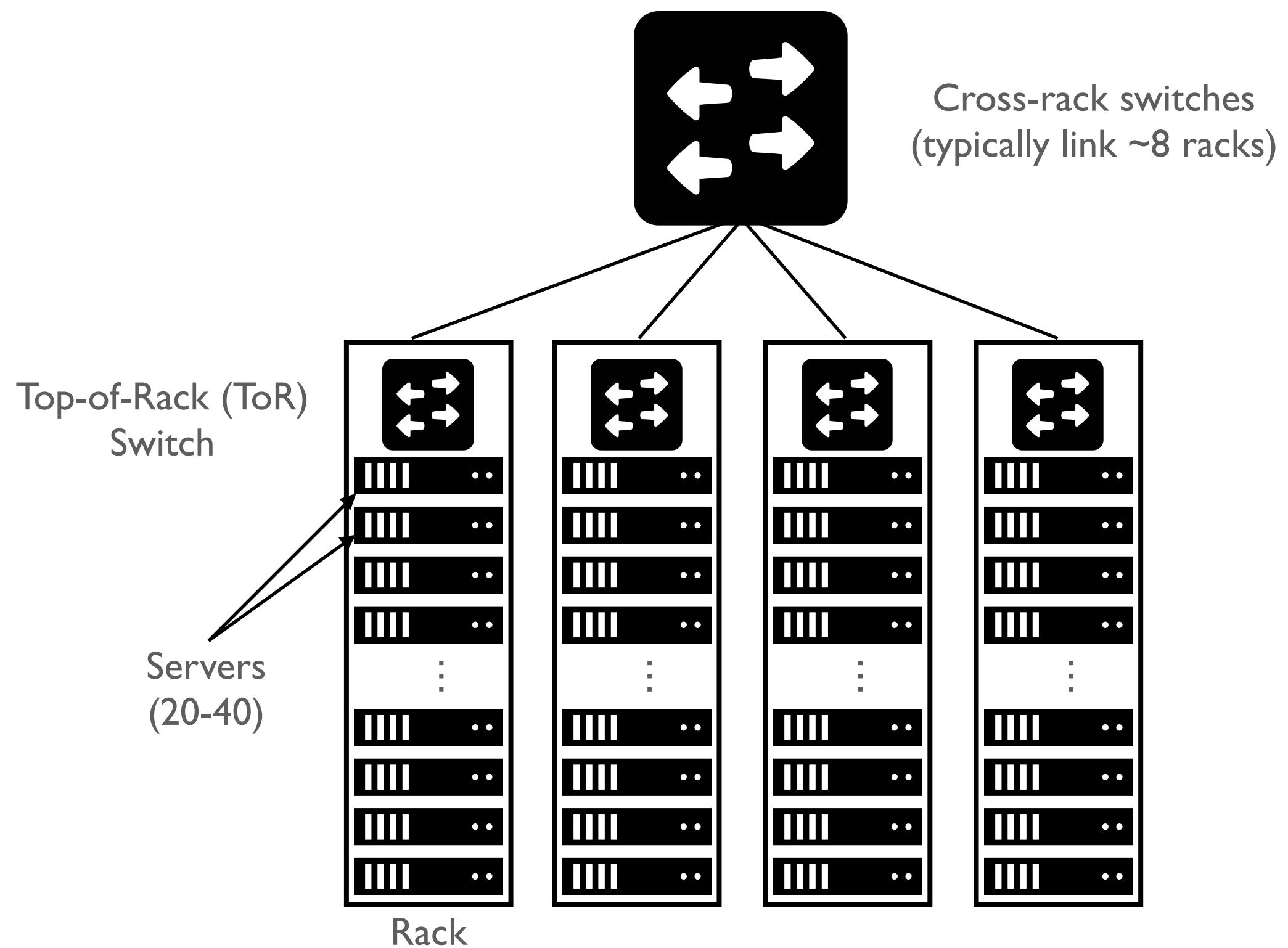
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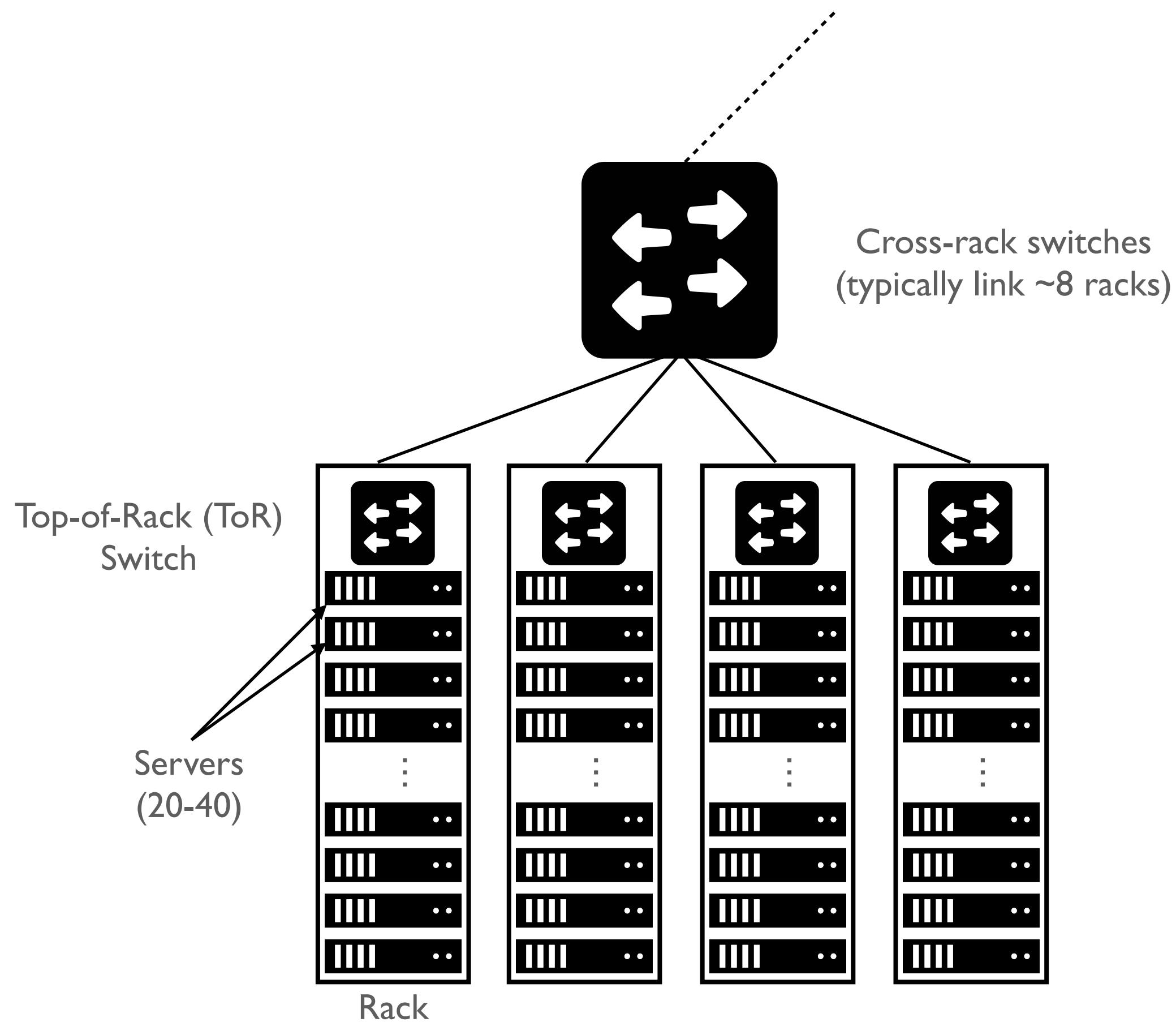
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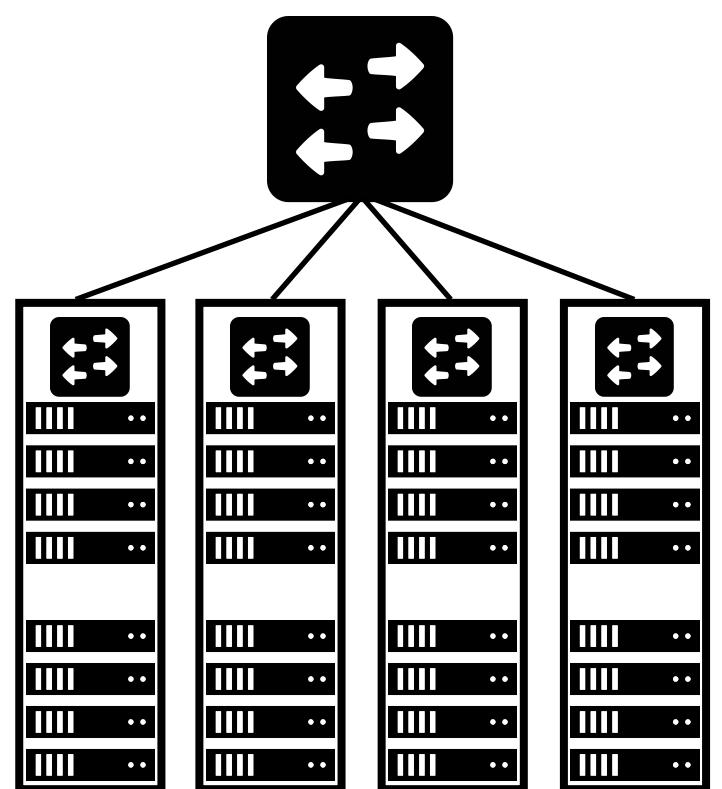
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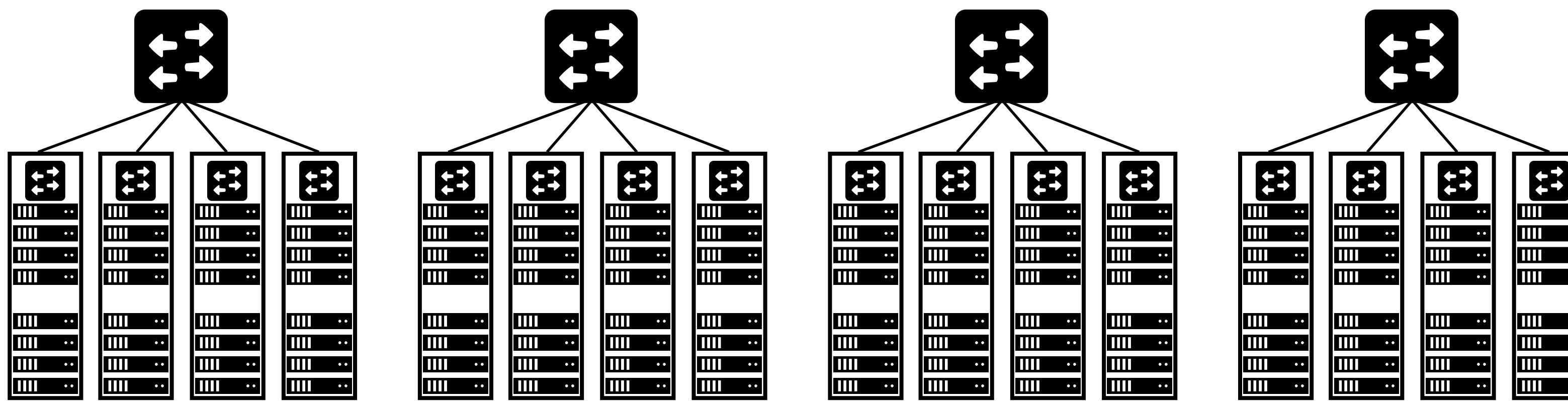
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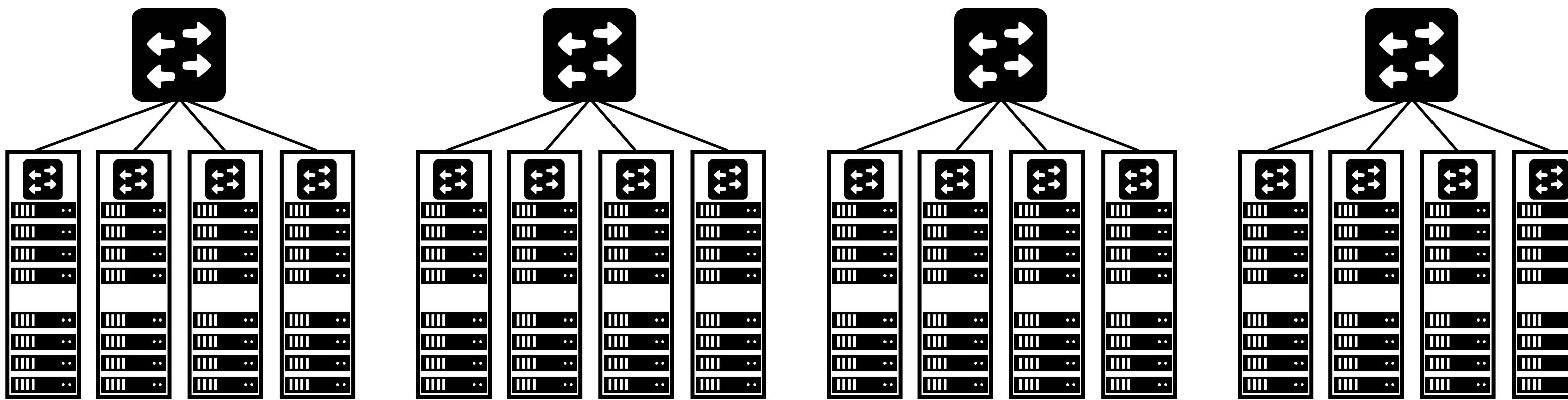
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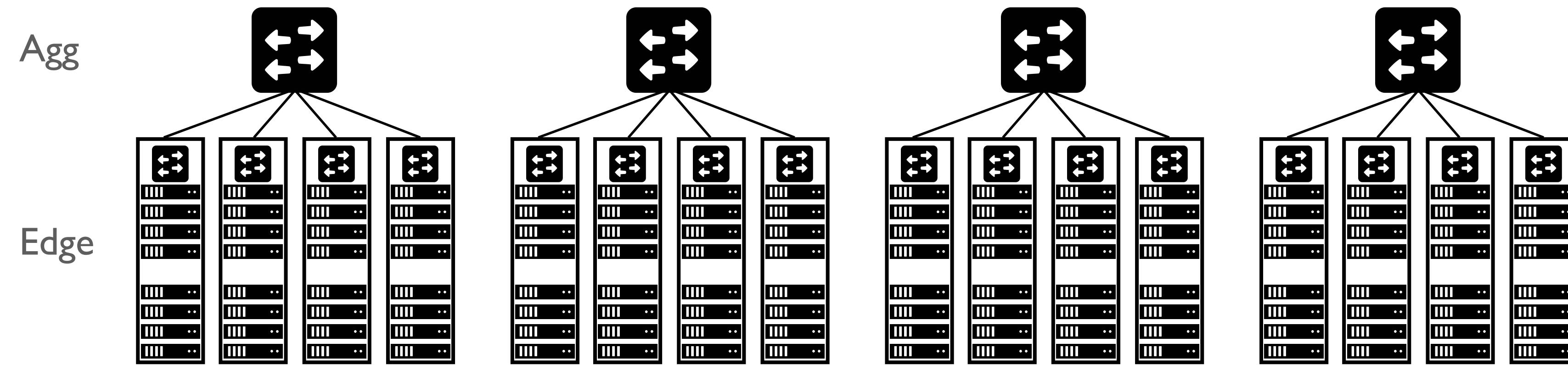


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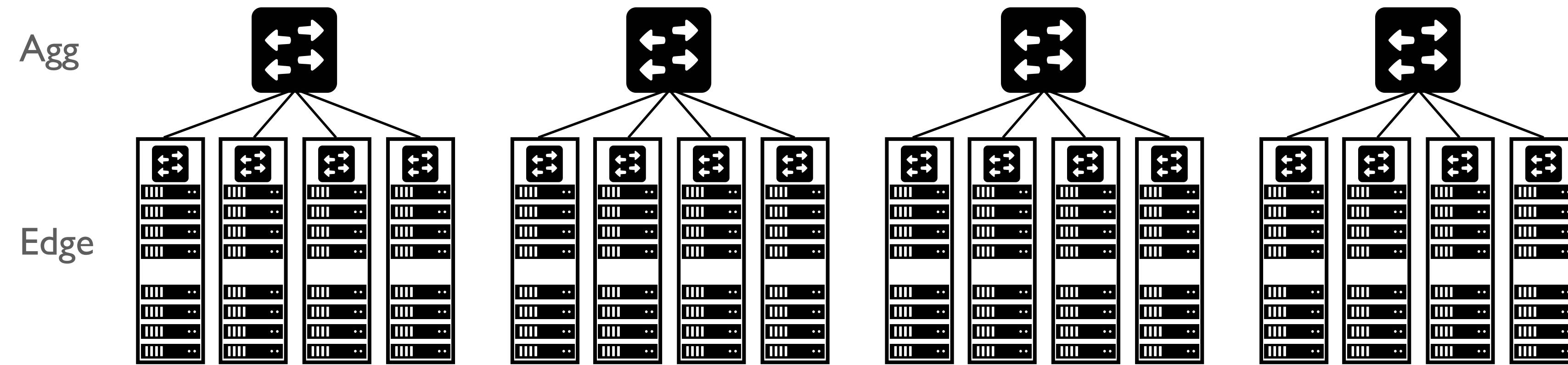
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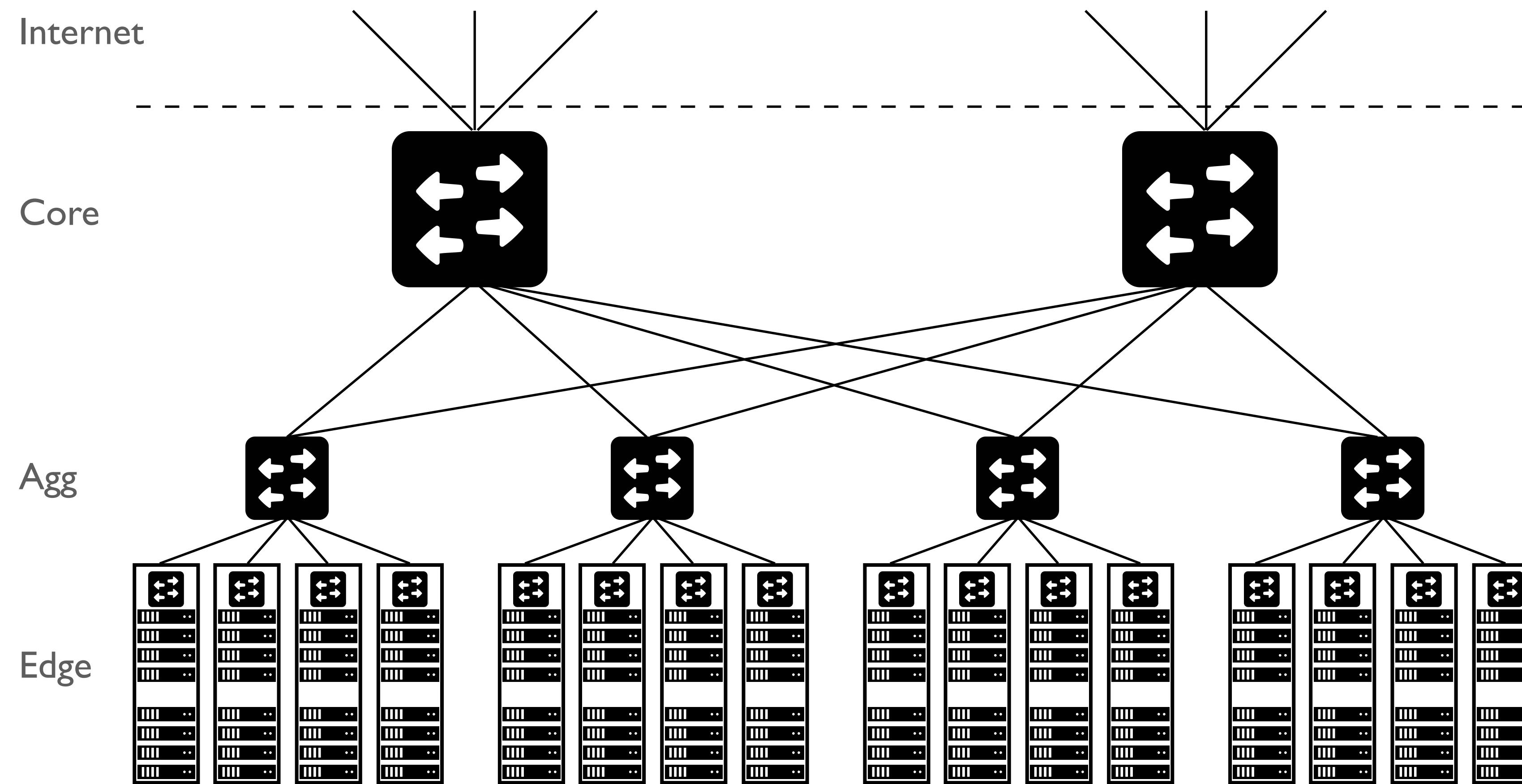


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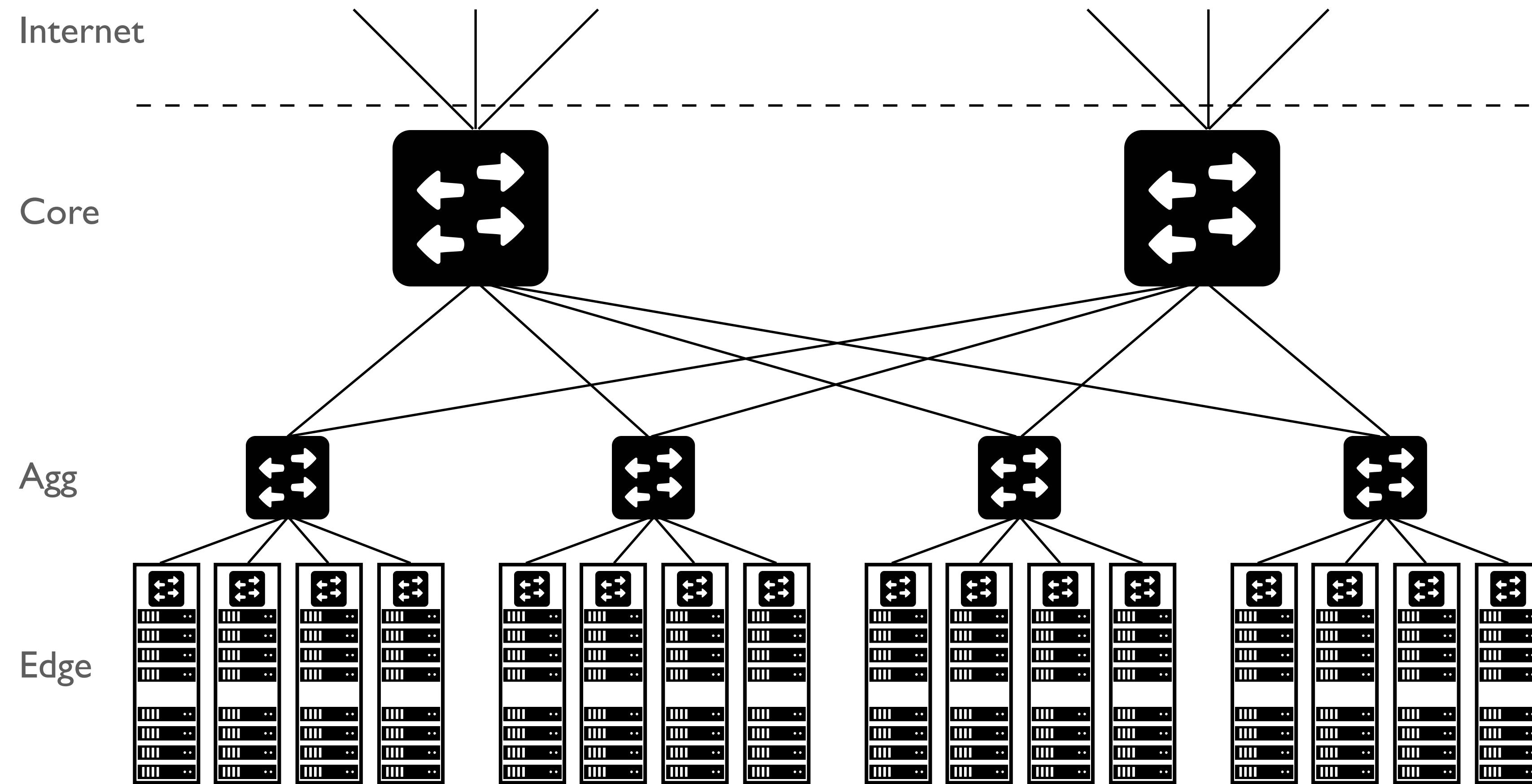


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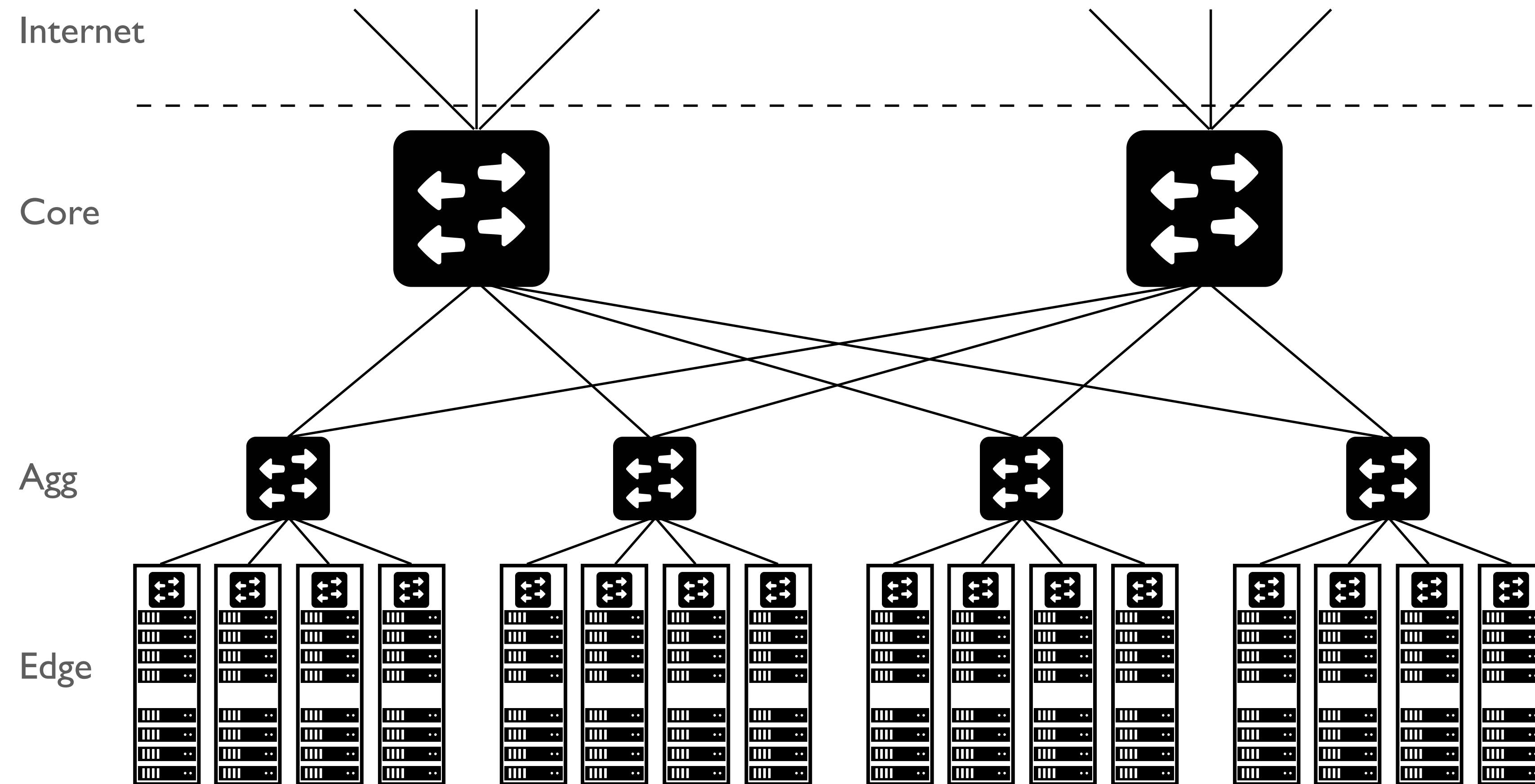
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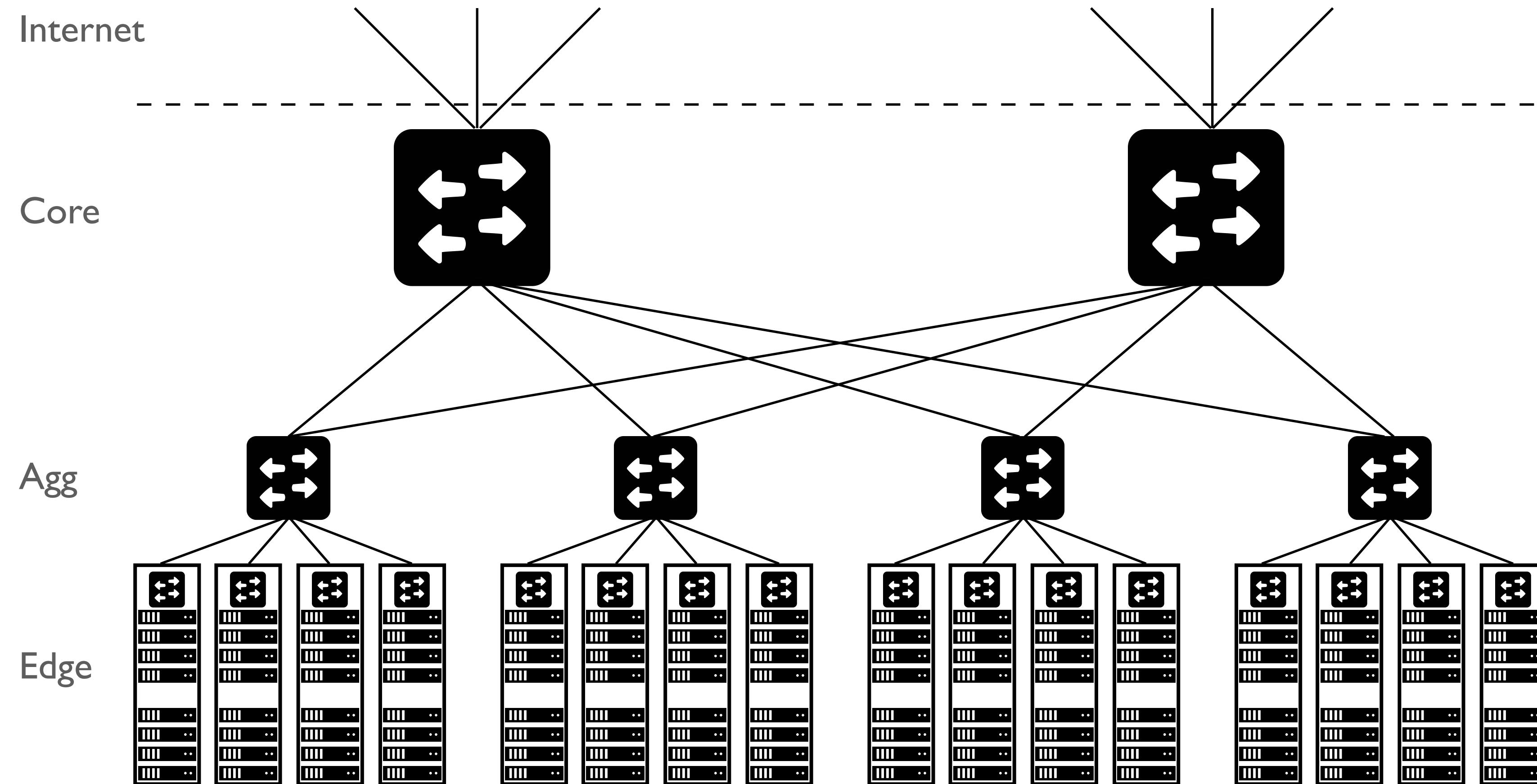
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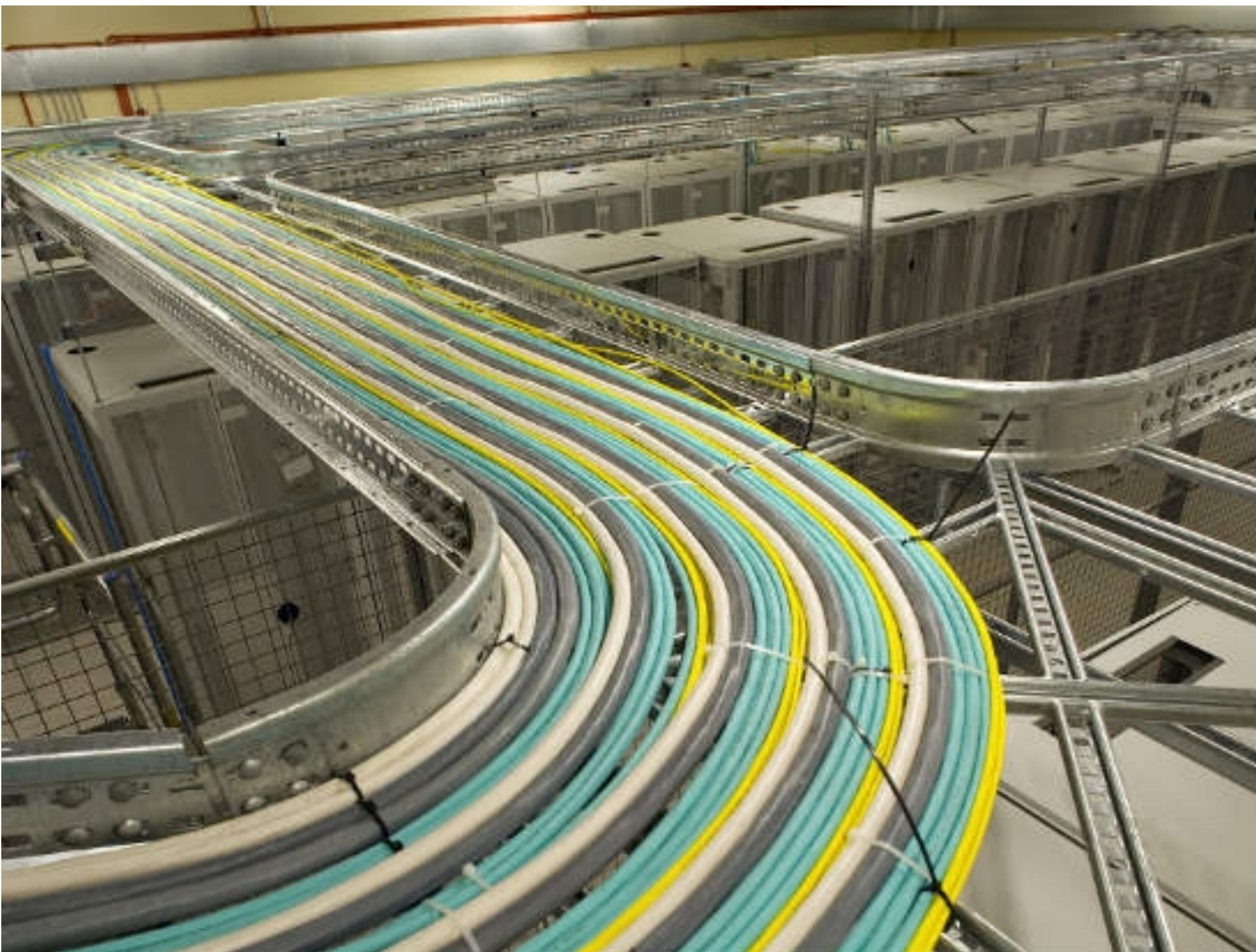
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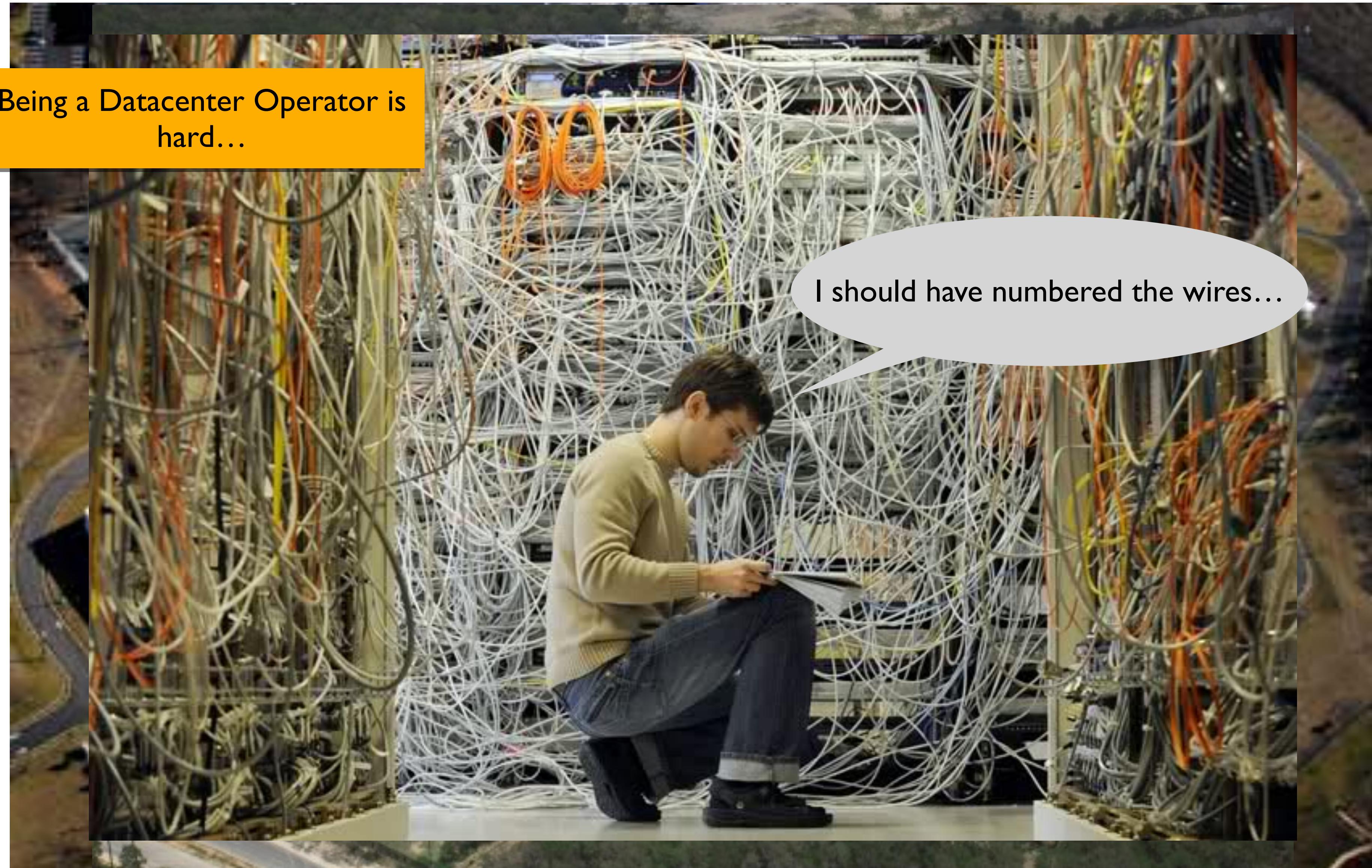
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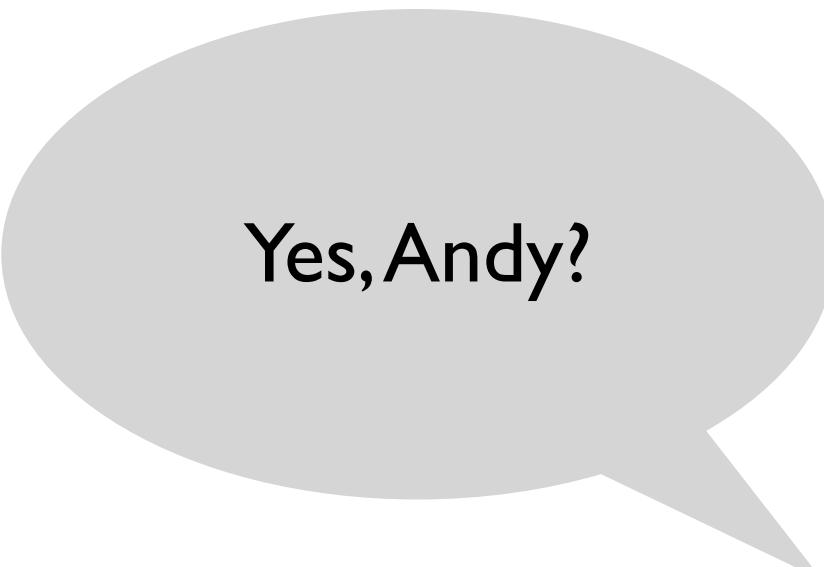
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Hey, Jeff?

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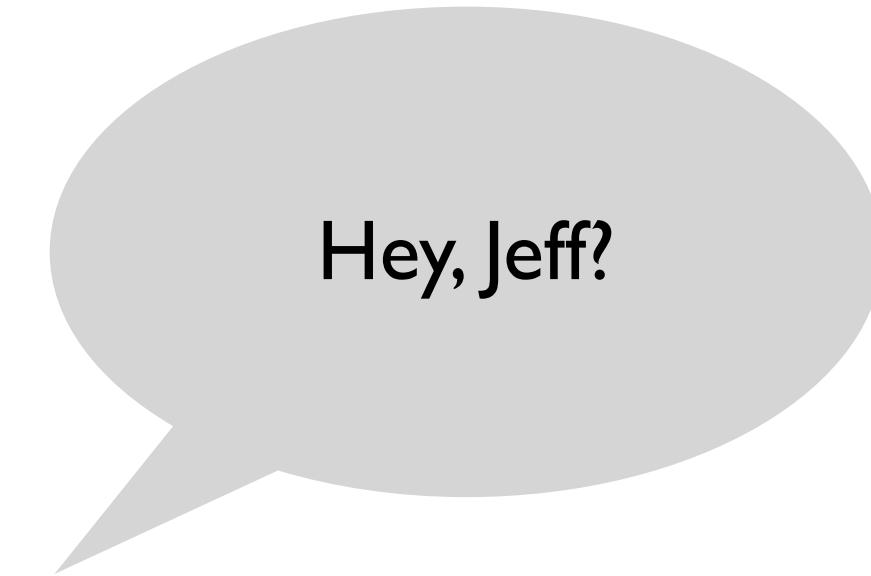
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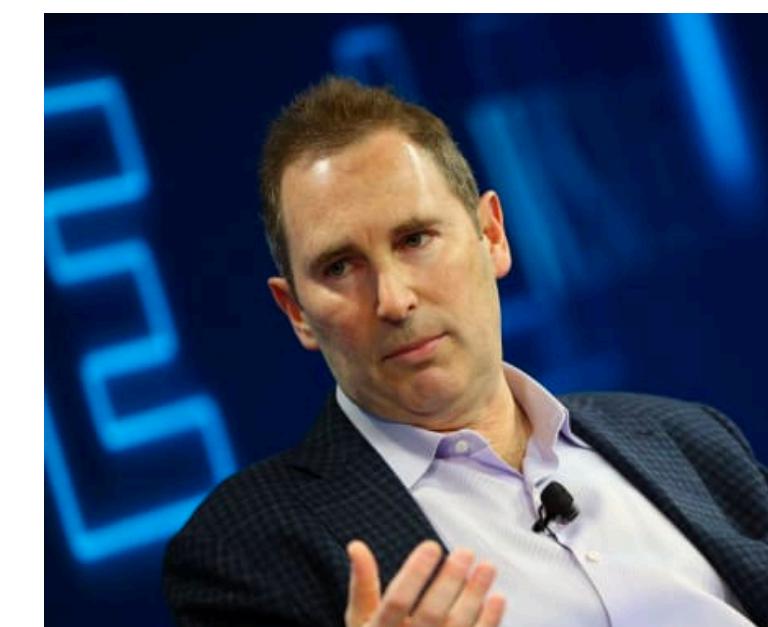
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Today: 12% of total Amazon revenue

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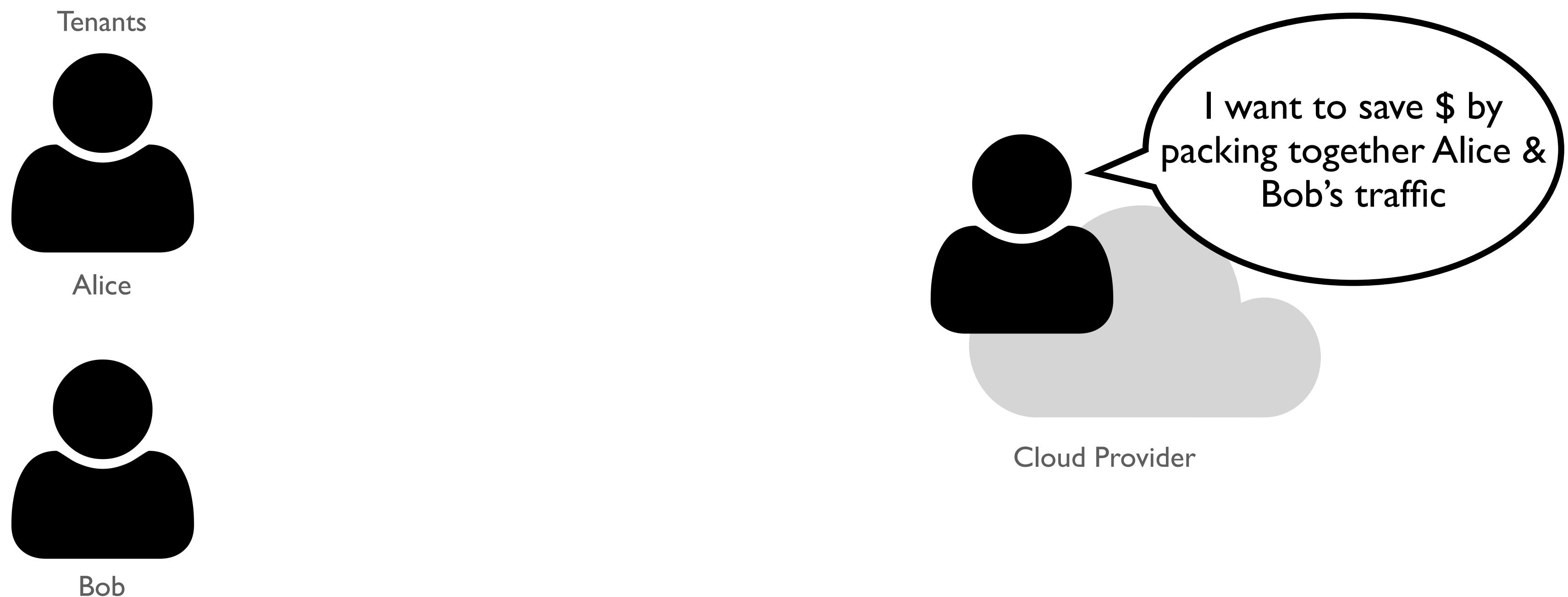
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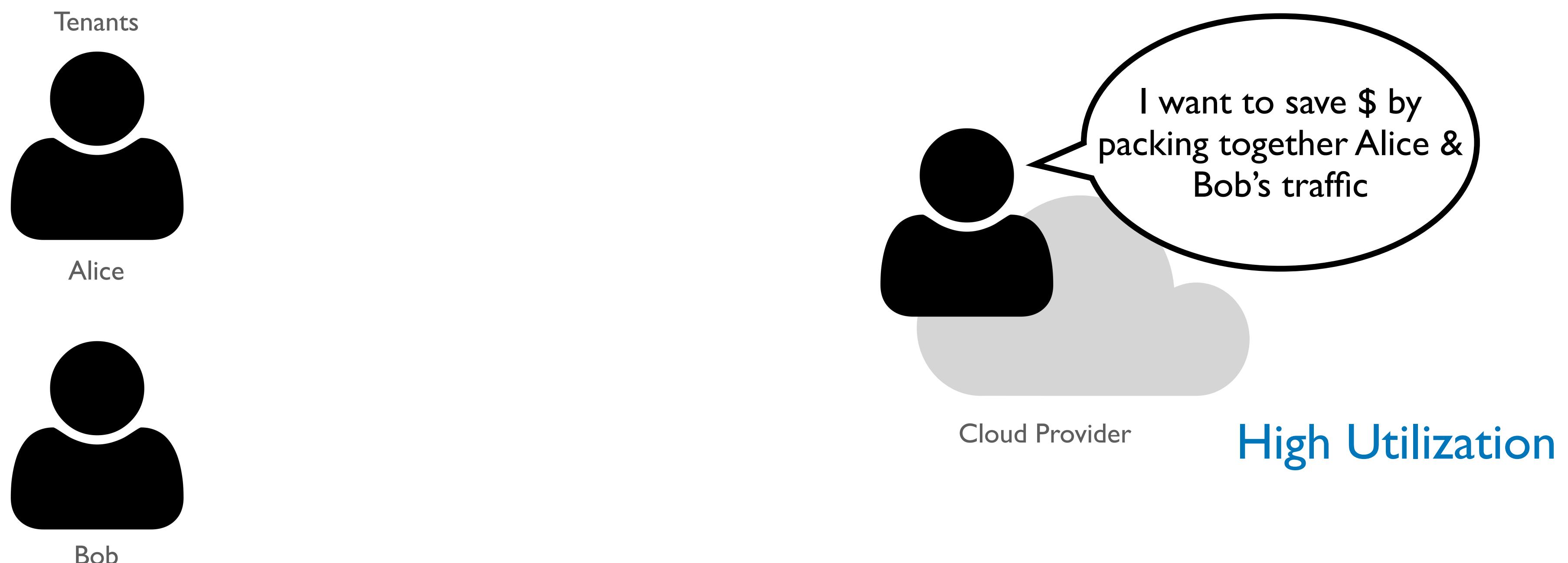
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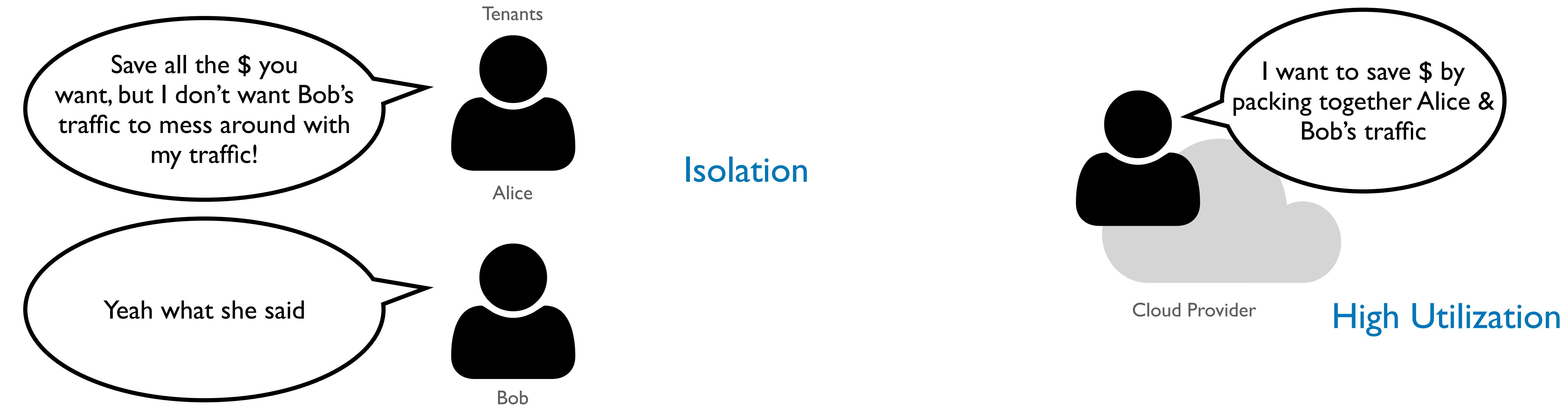
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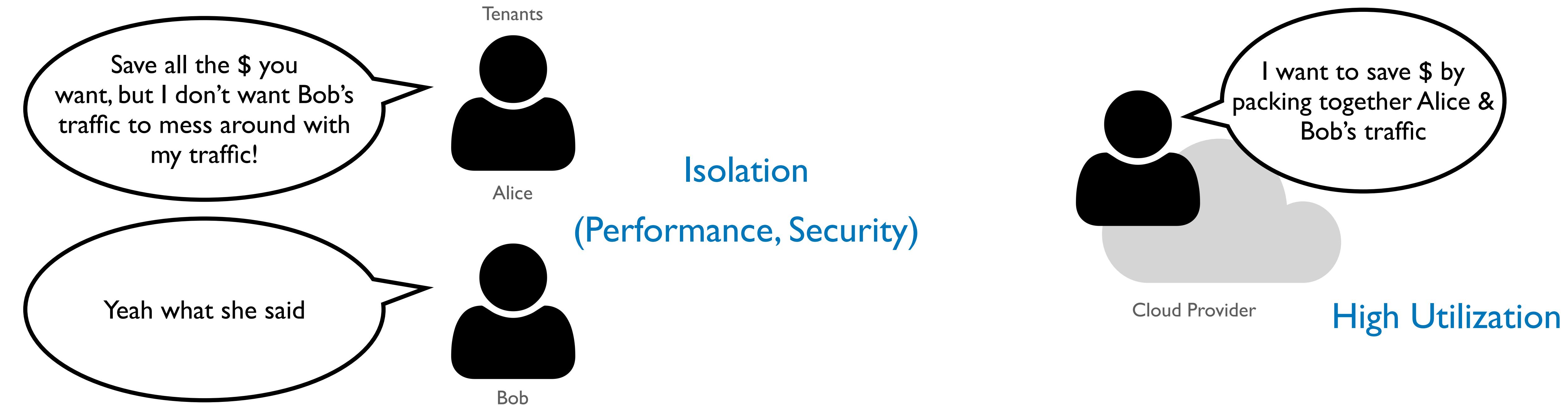
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- **How?**
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User query (from outside datacenter)

Cat pictures

# Workload: Partition Aggregate

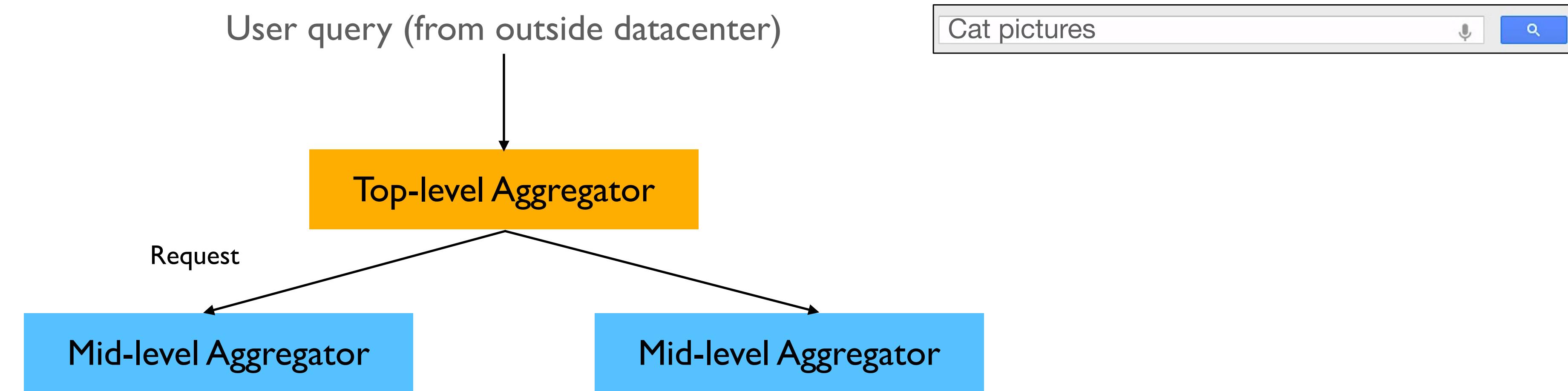
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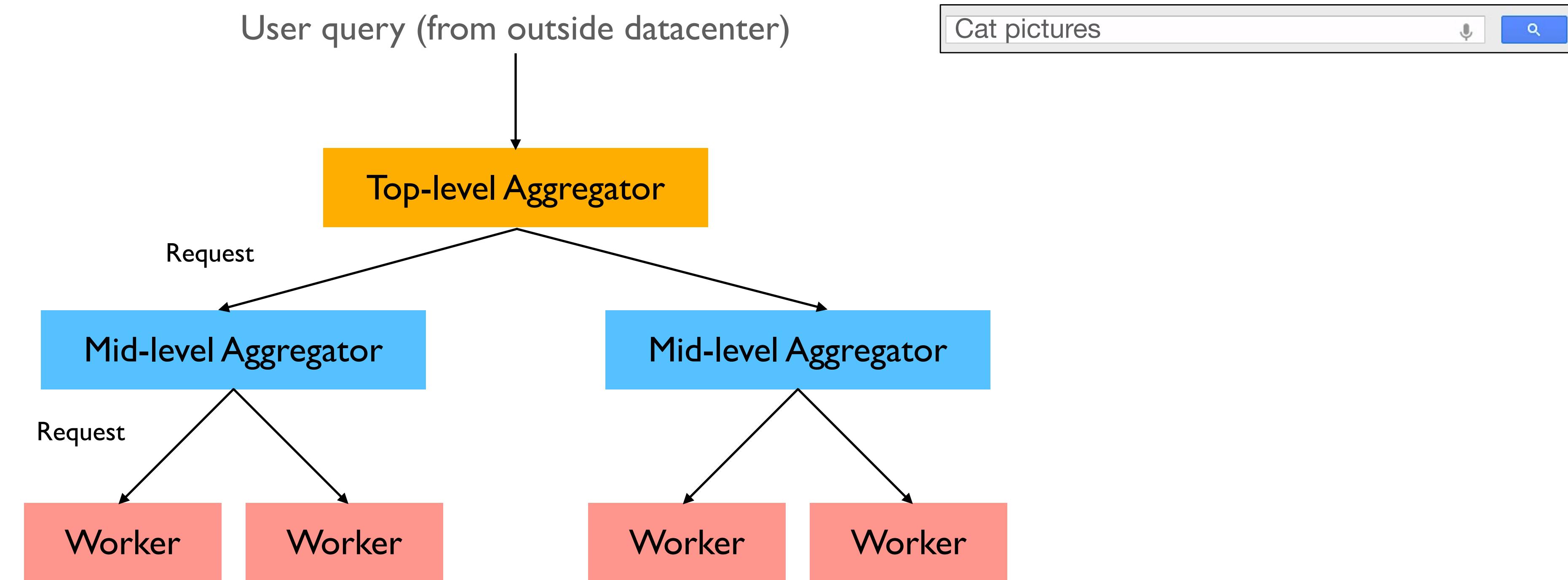
Top-level Aggregator



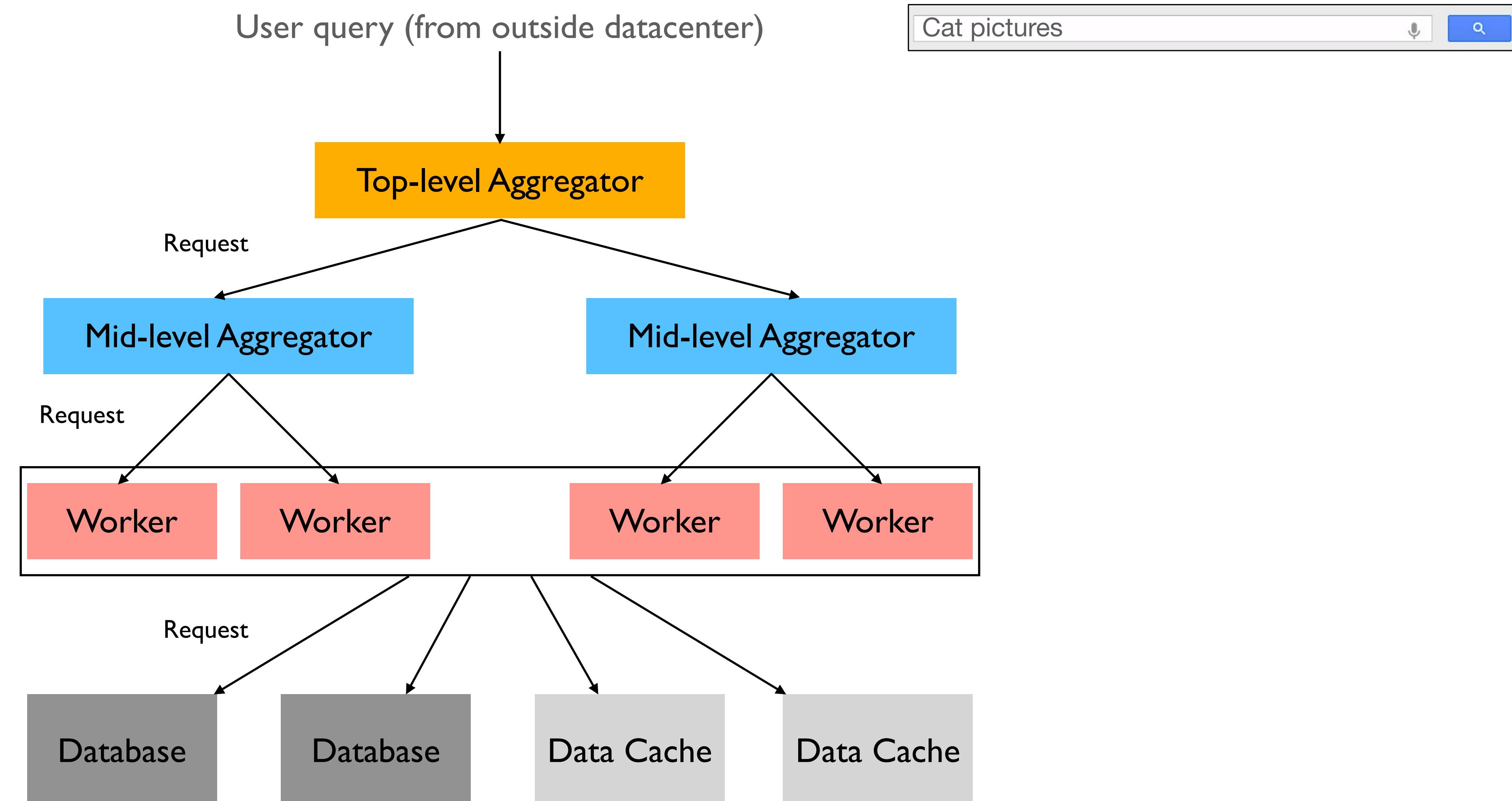
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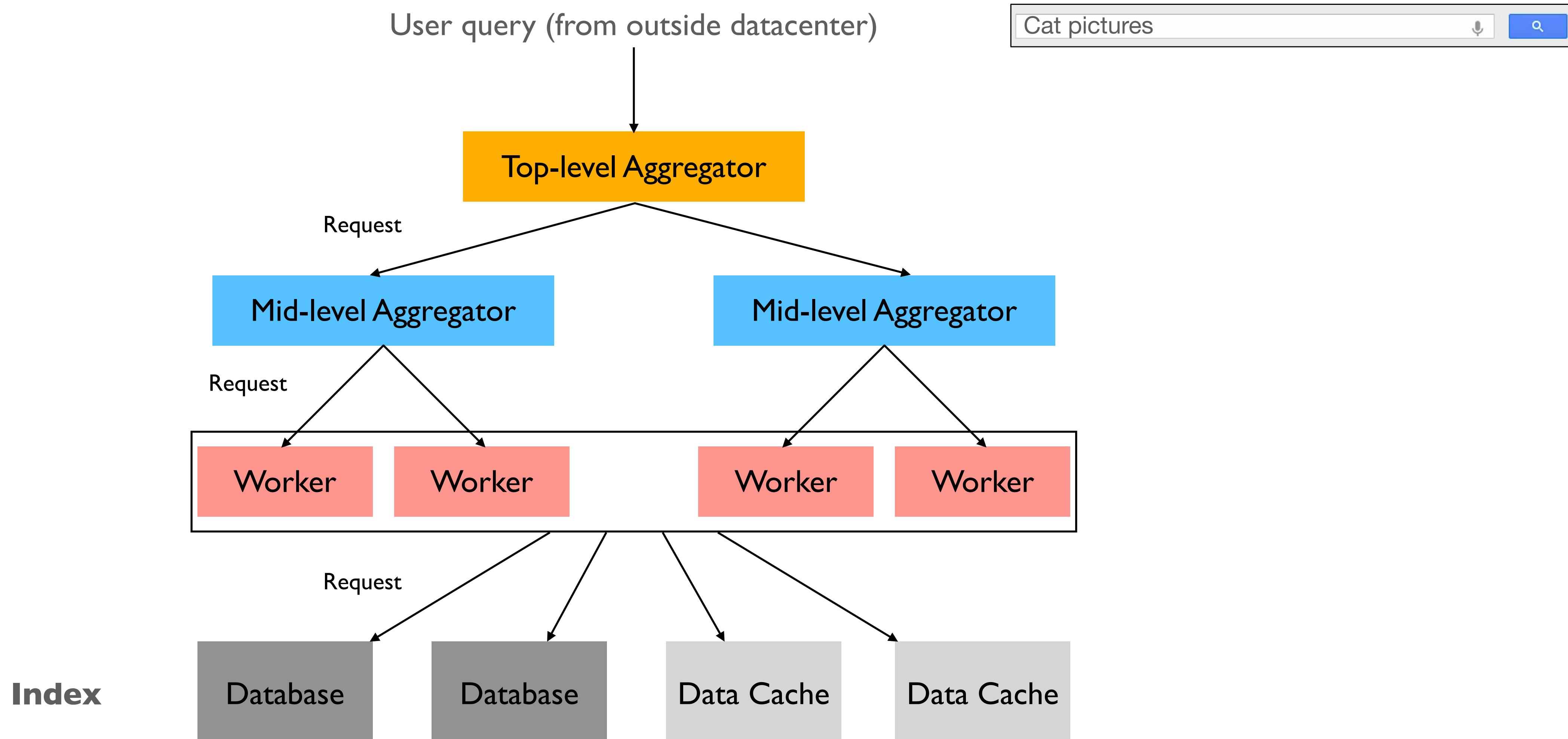
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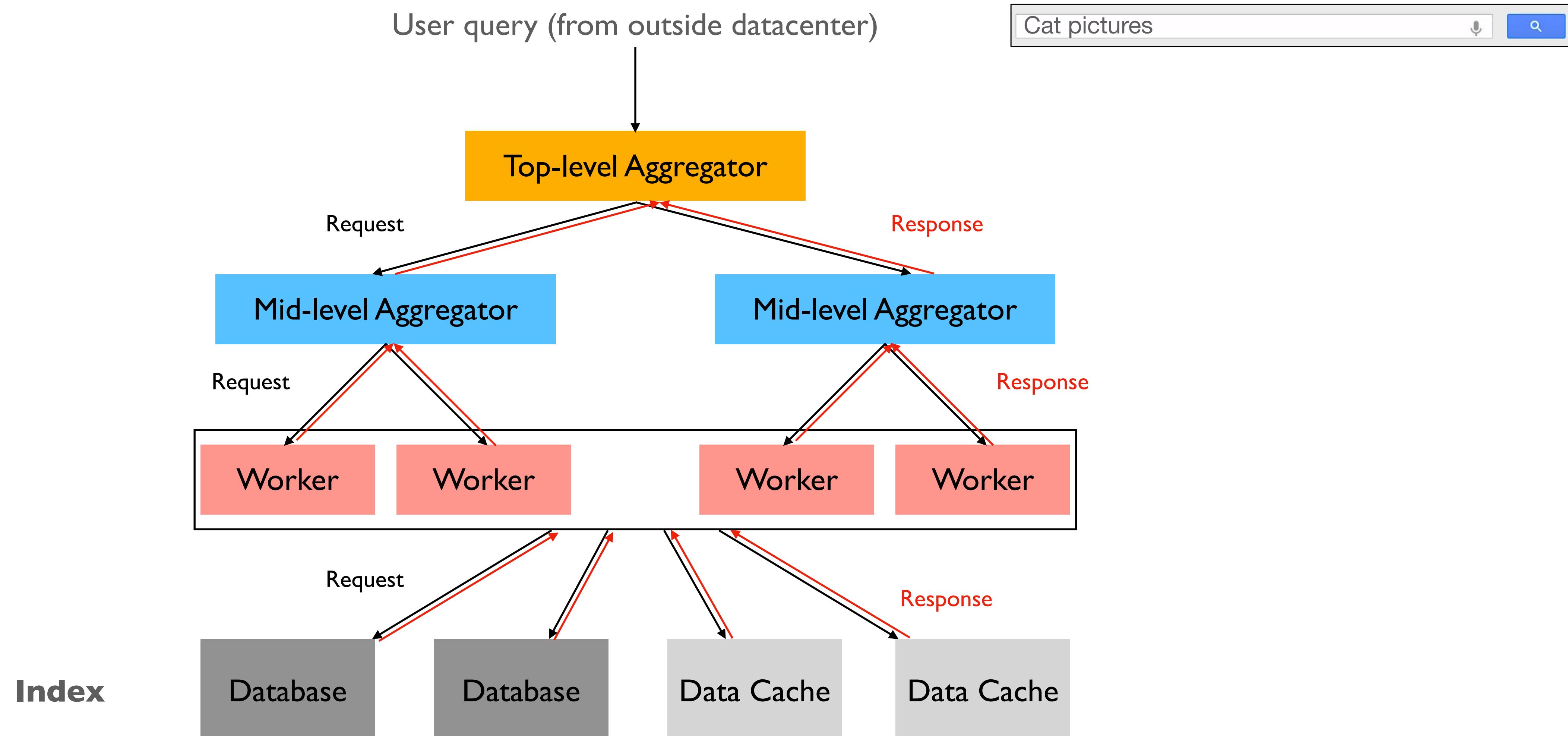
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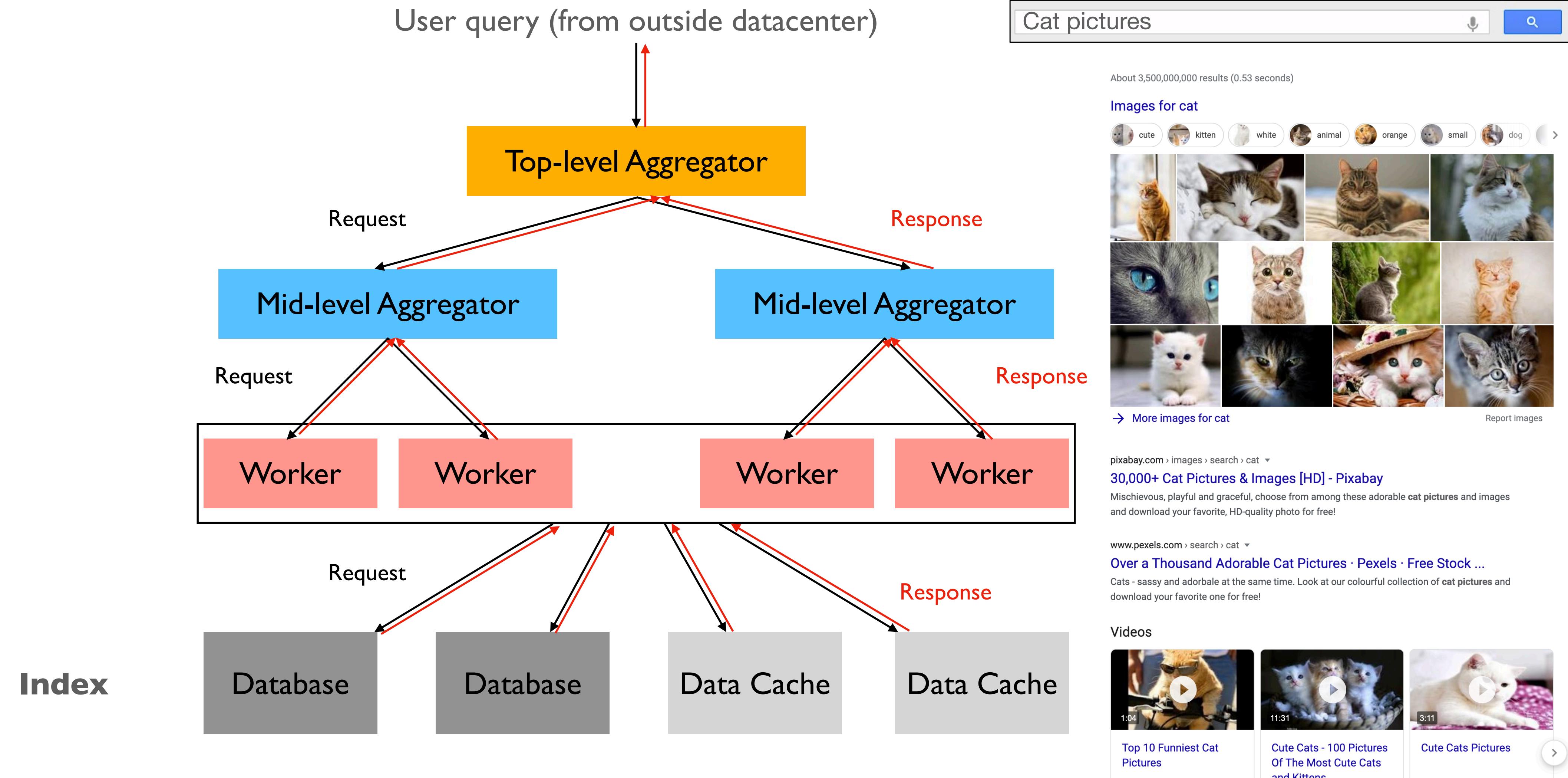
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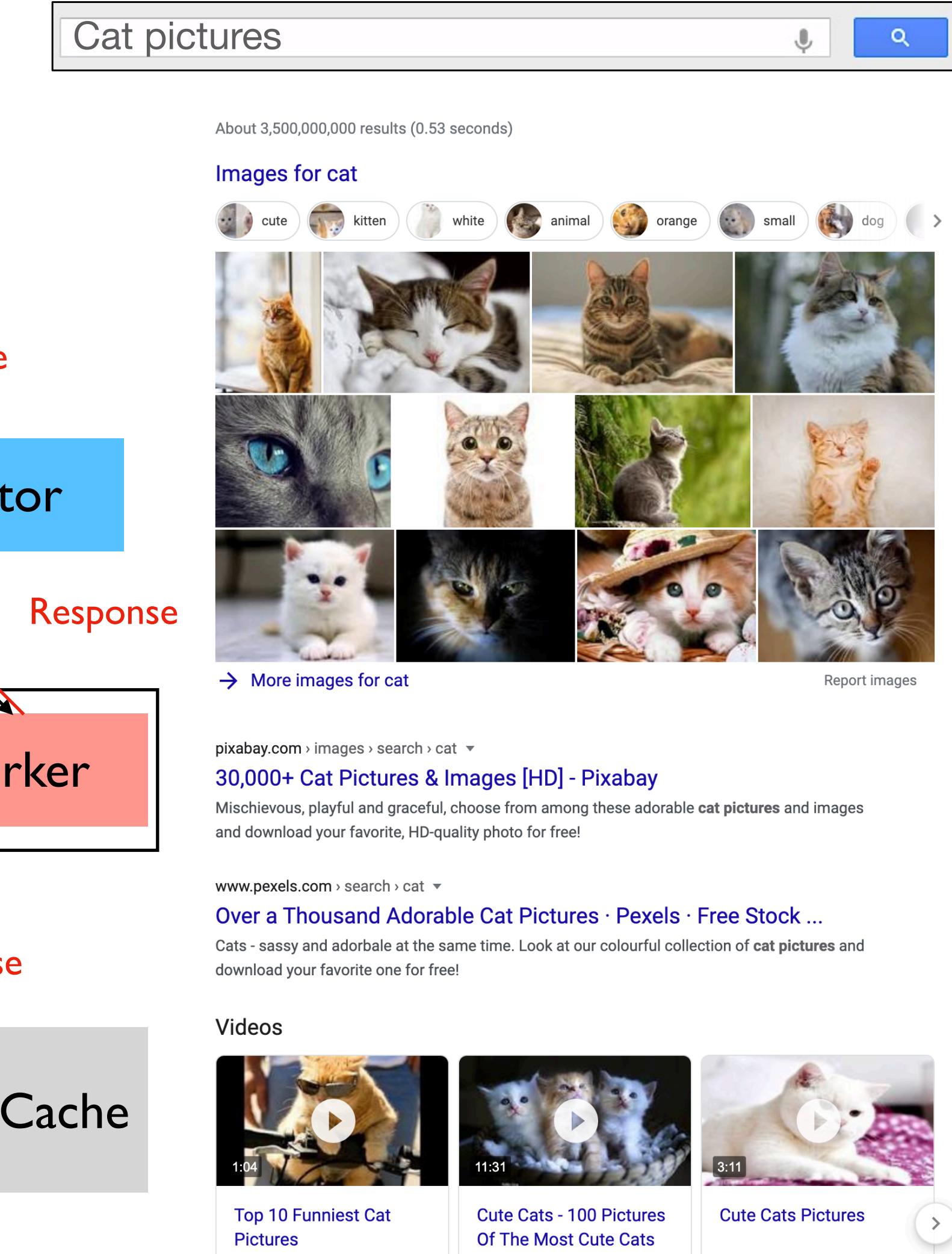
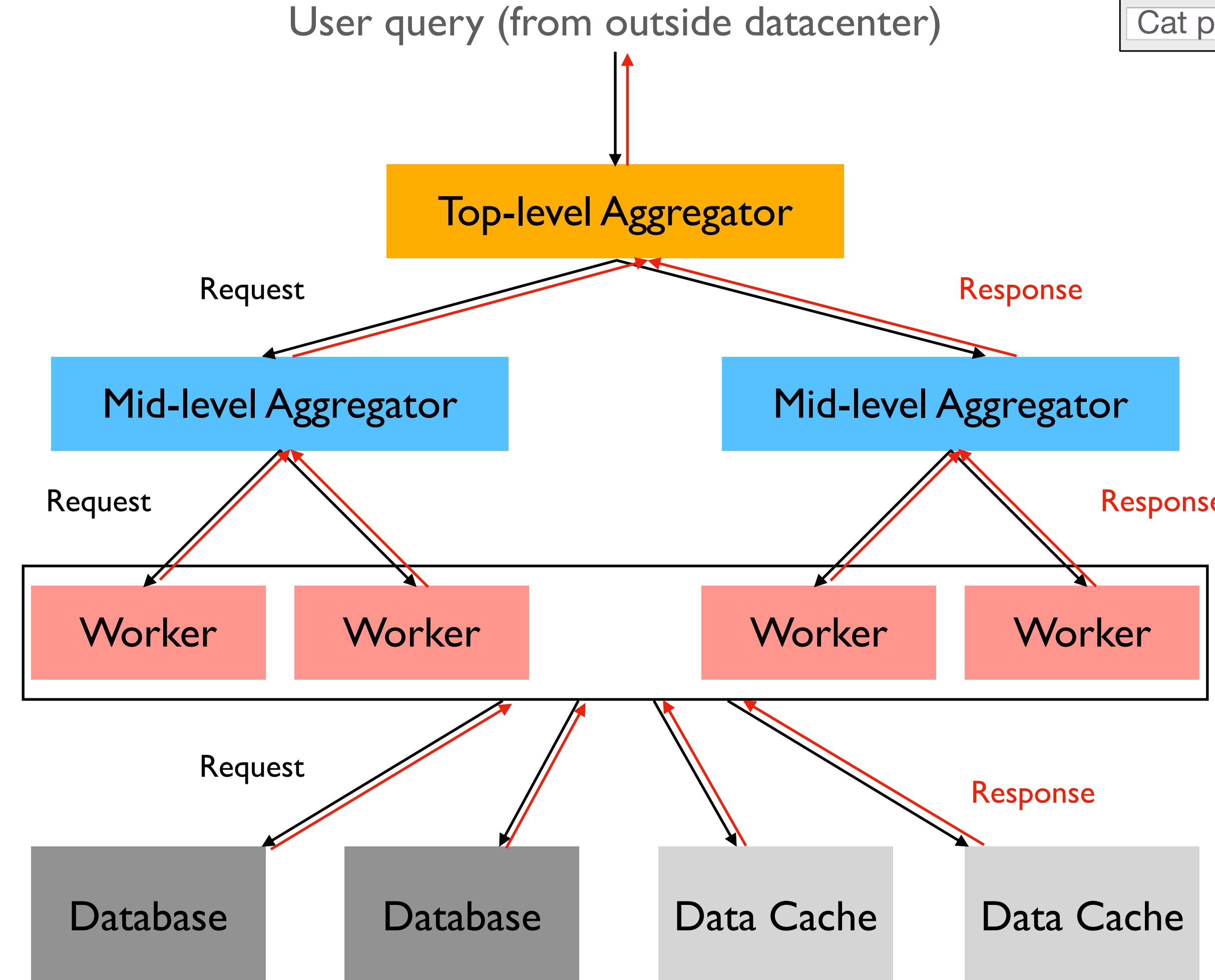
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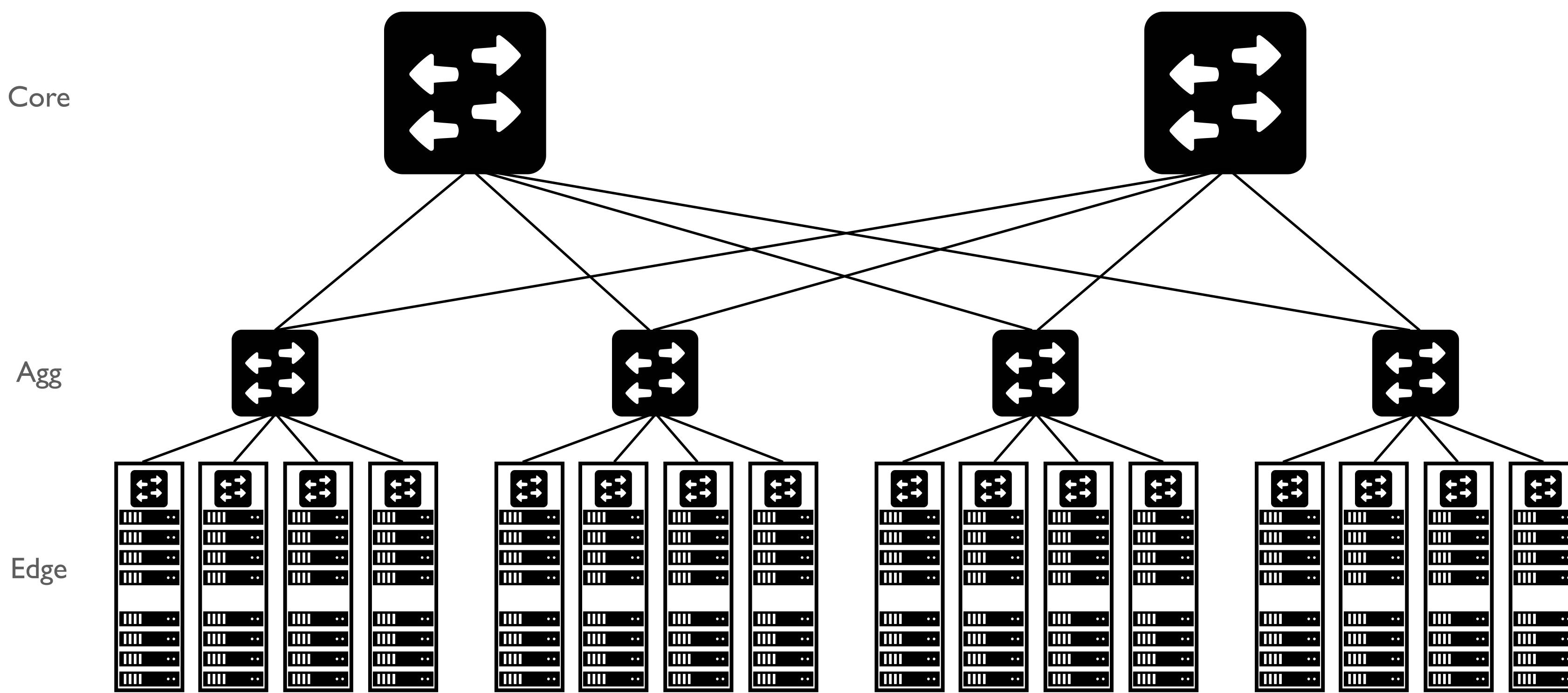
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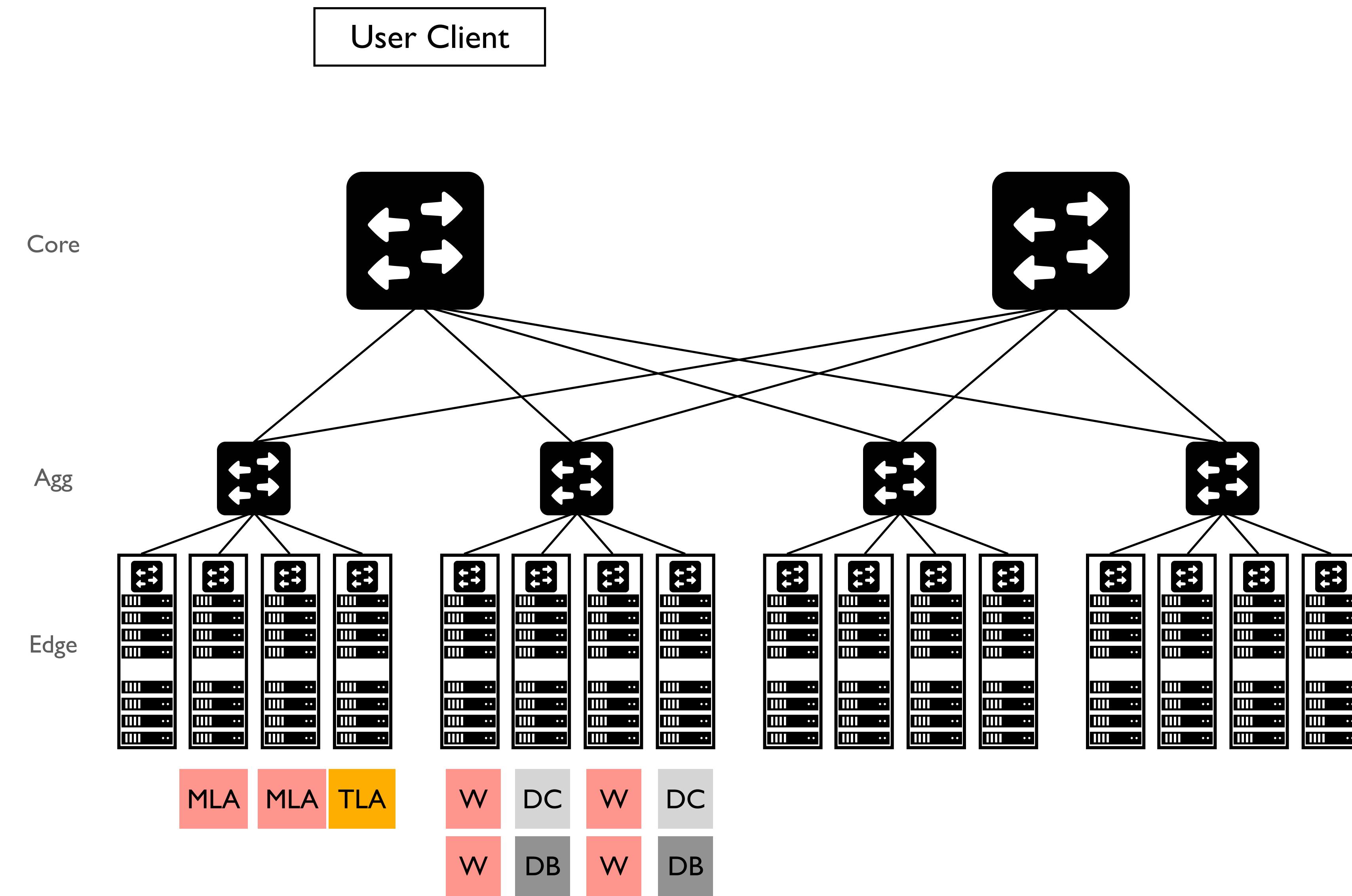
Index



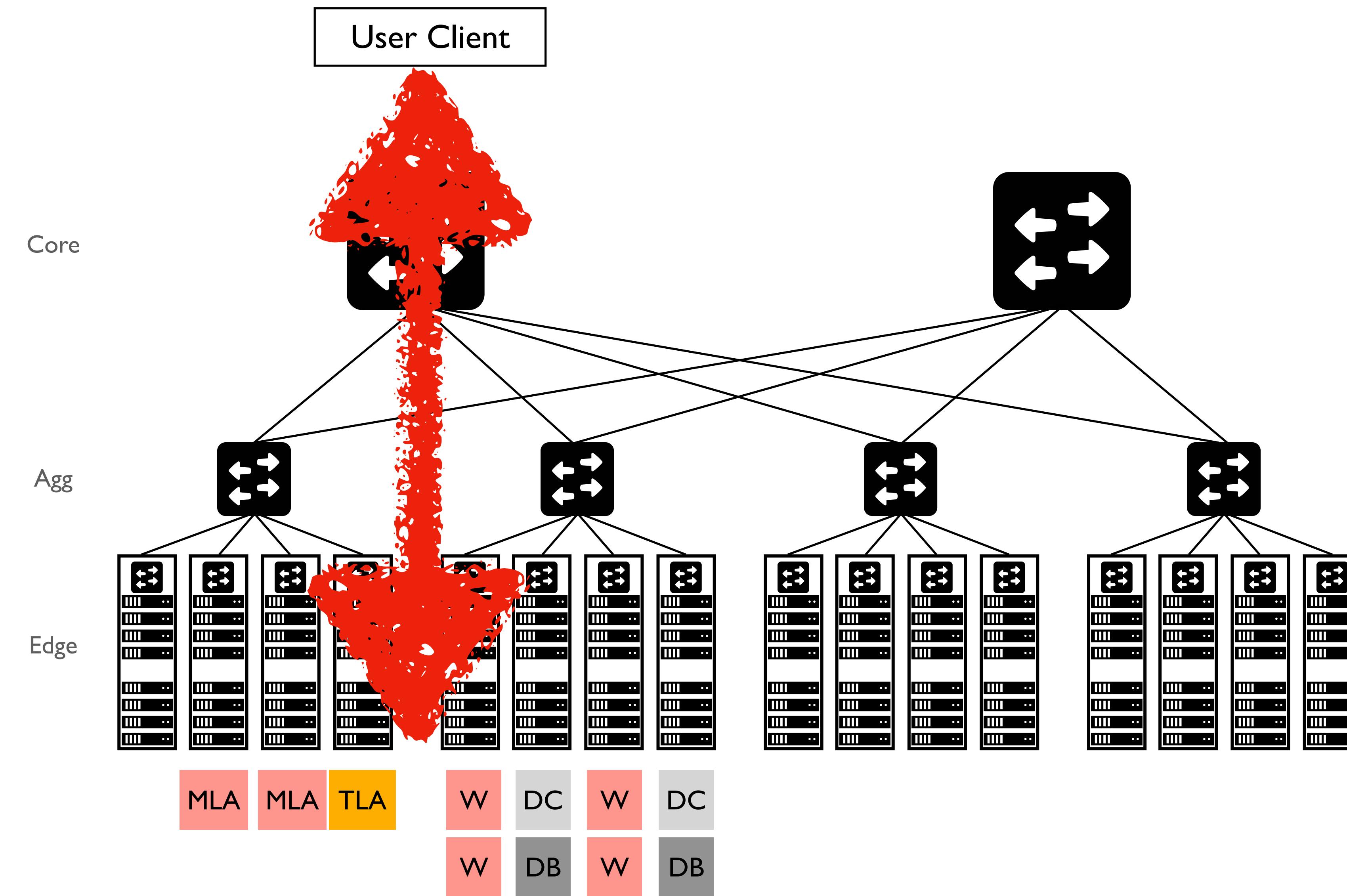
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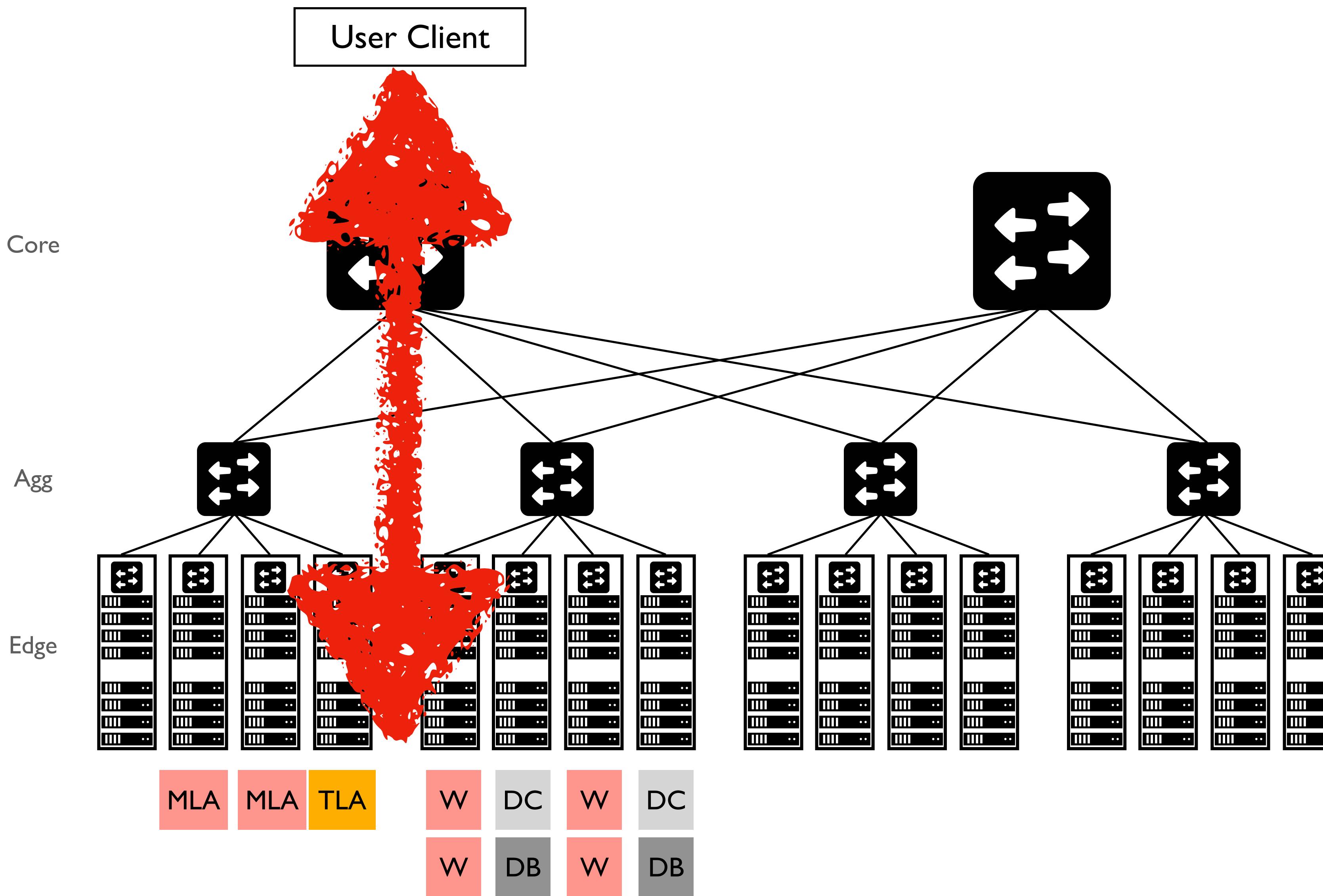
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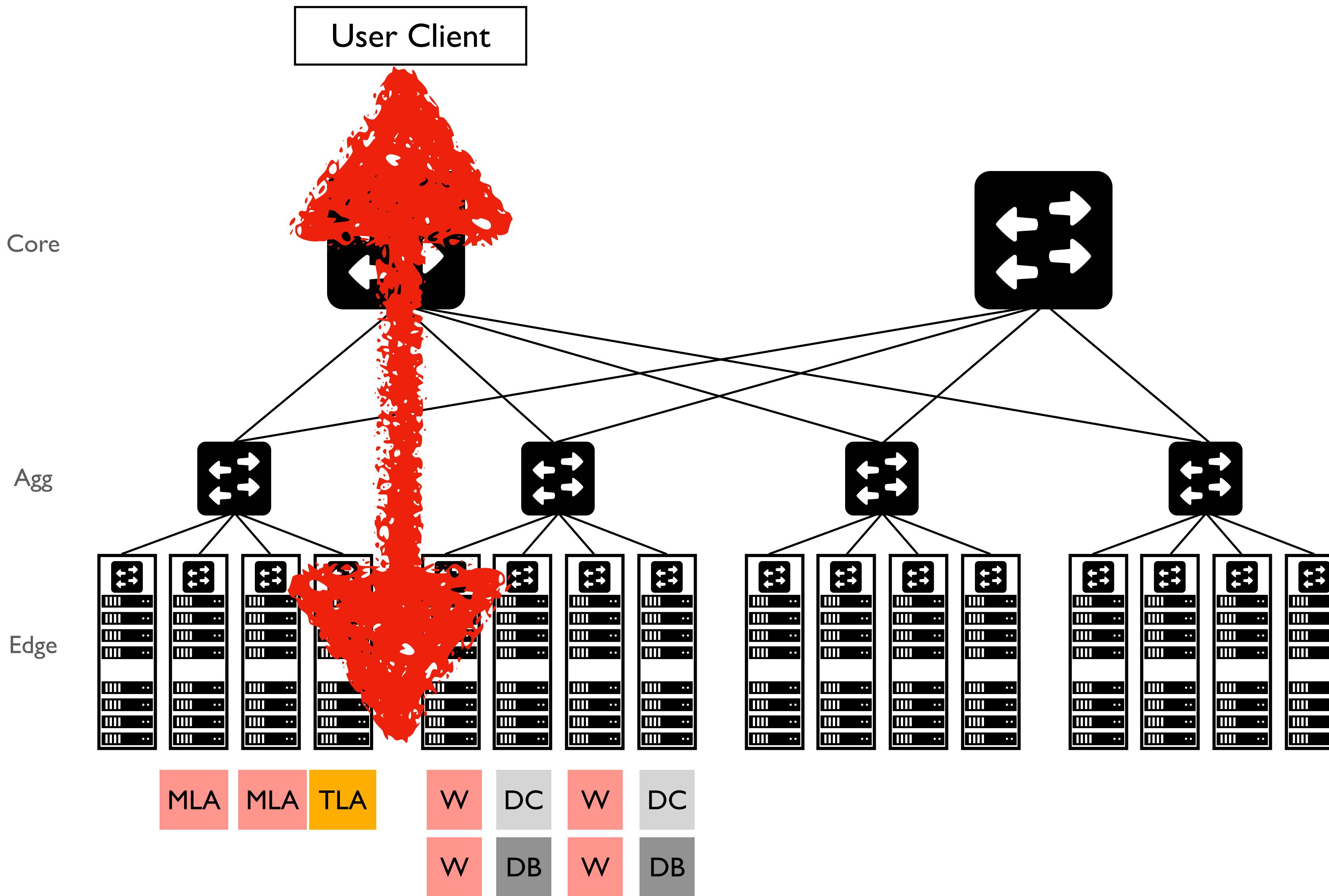


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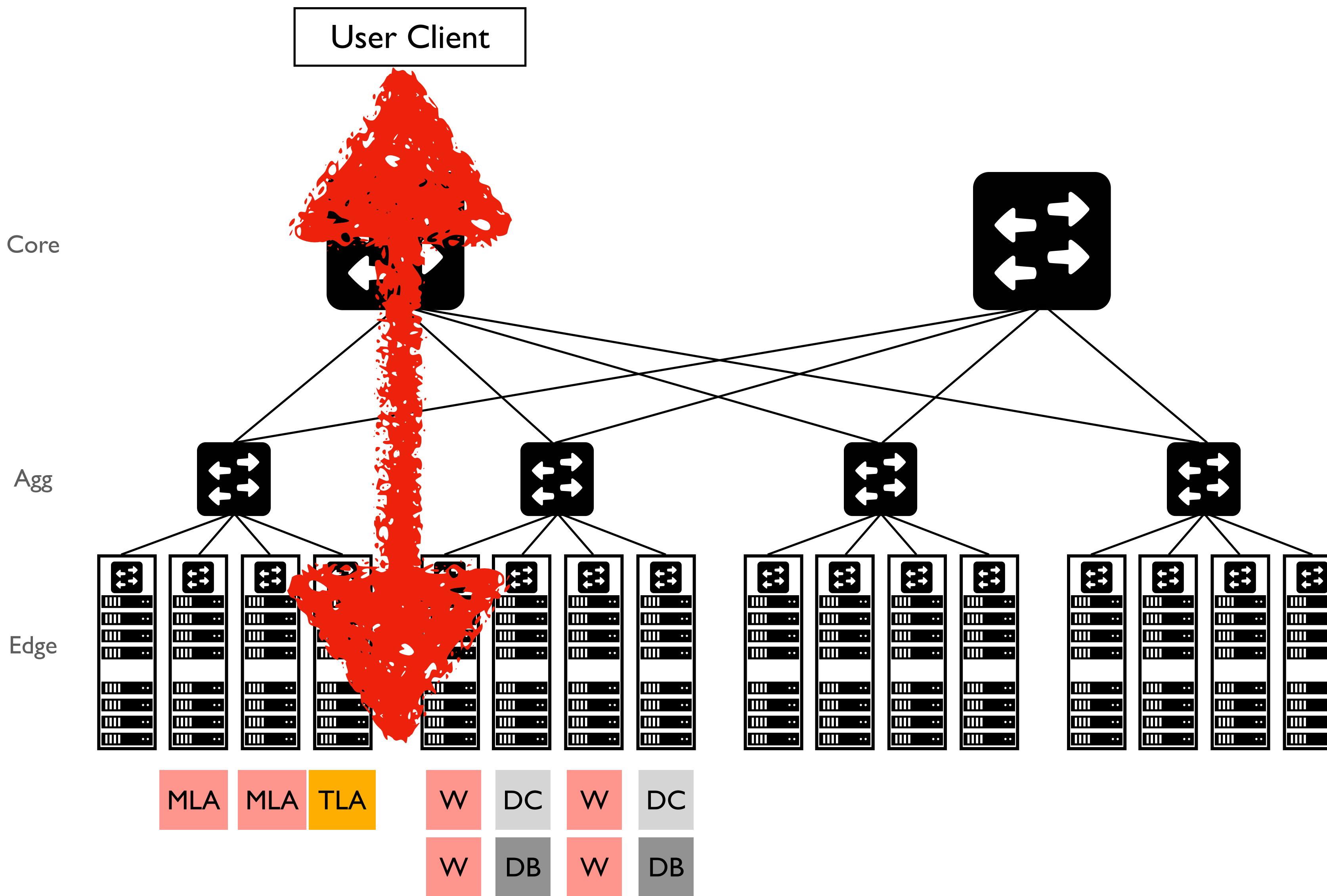
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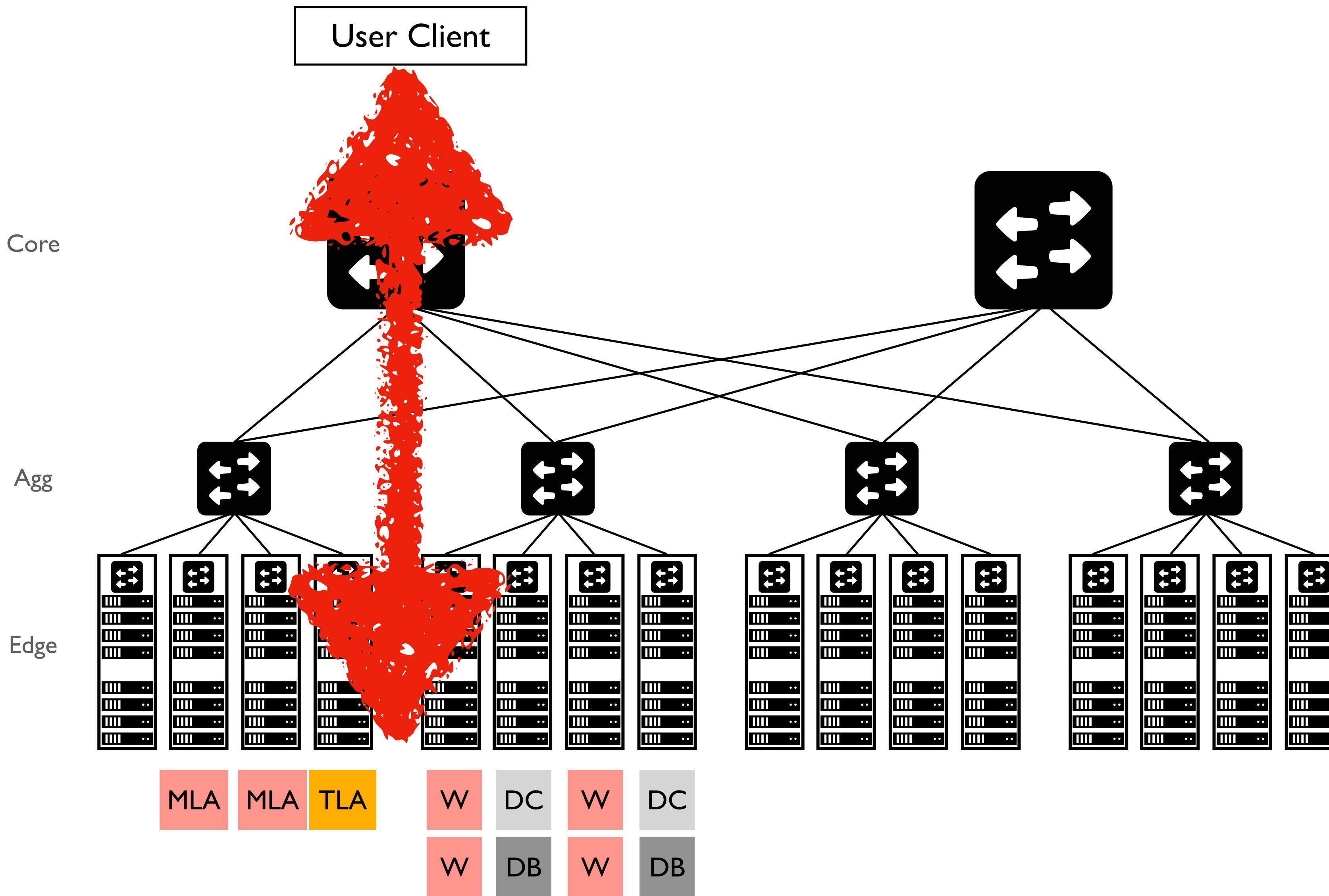
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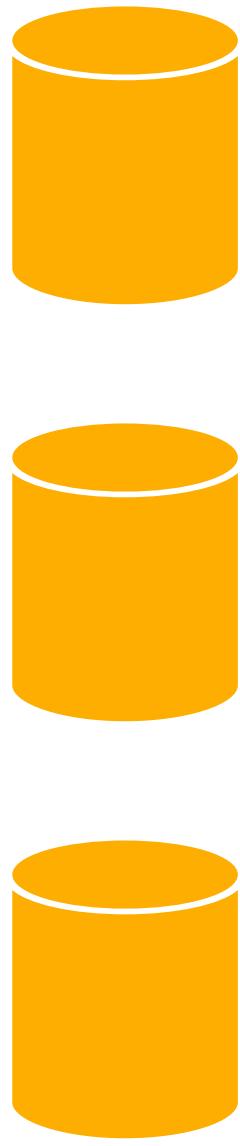
# “North-South” Traffic



- Interactive query-response exchange b/w external clients & datacenter
  - Latency sensitive
  - $O(\text{milliseconds})$
- Handled by worker/aggregator tasks, databases & caches

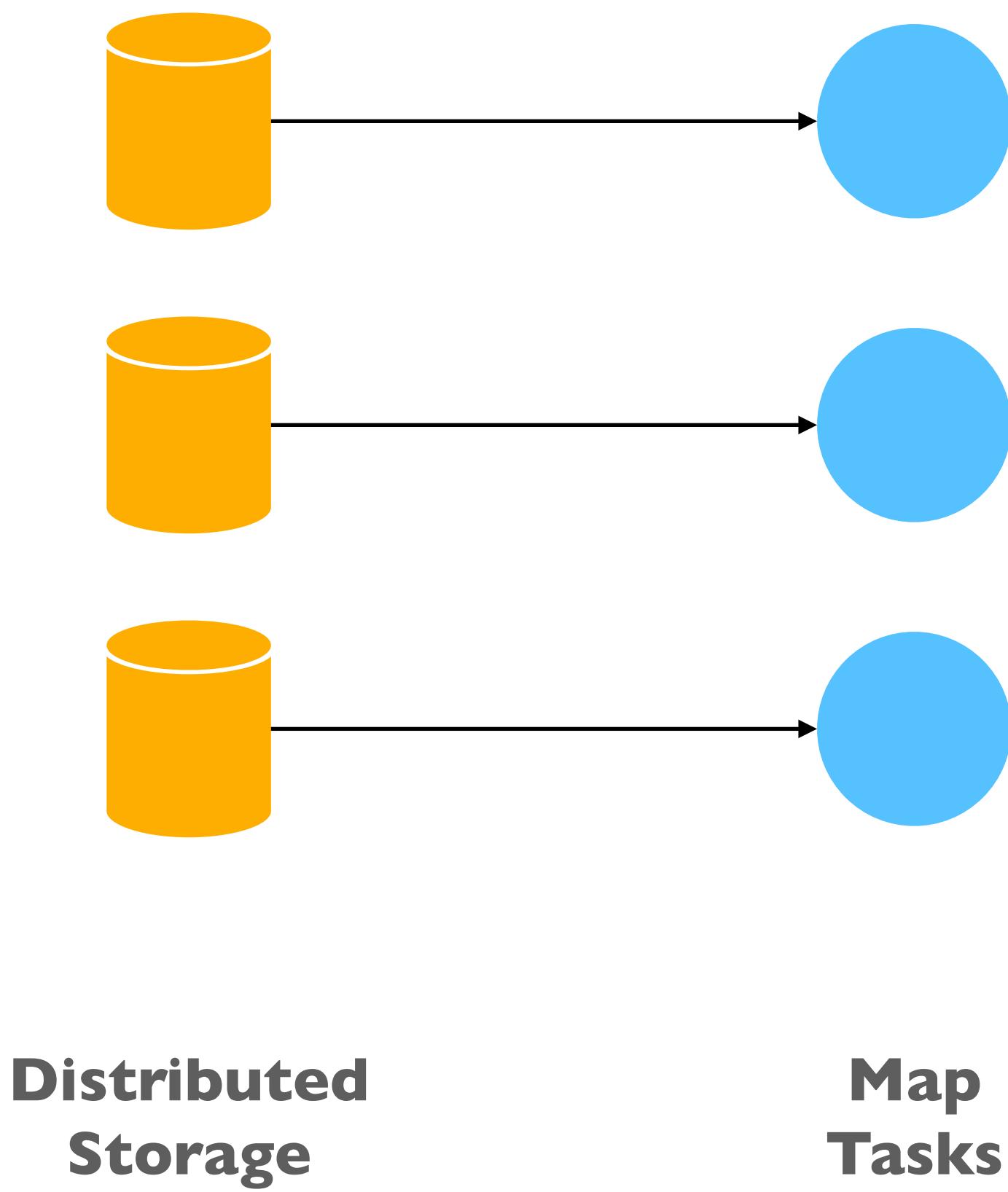
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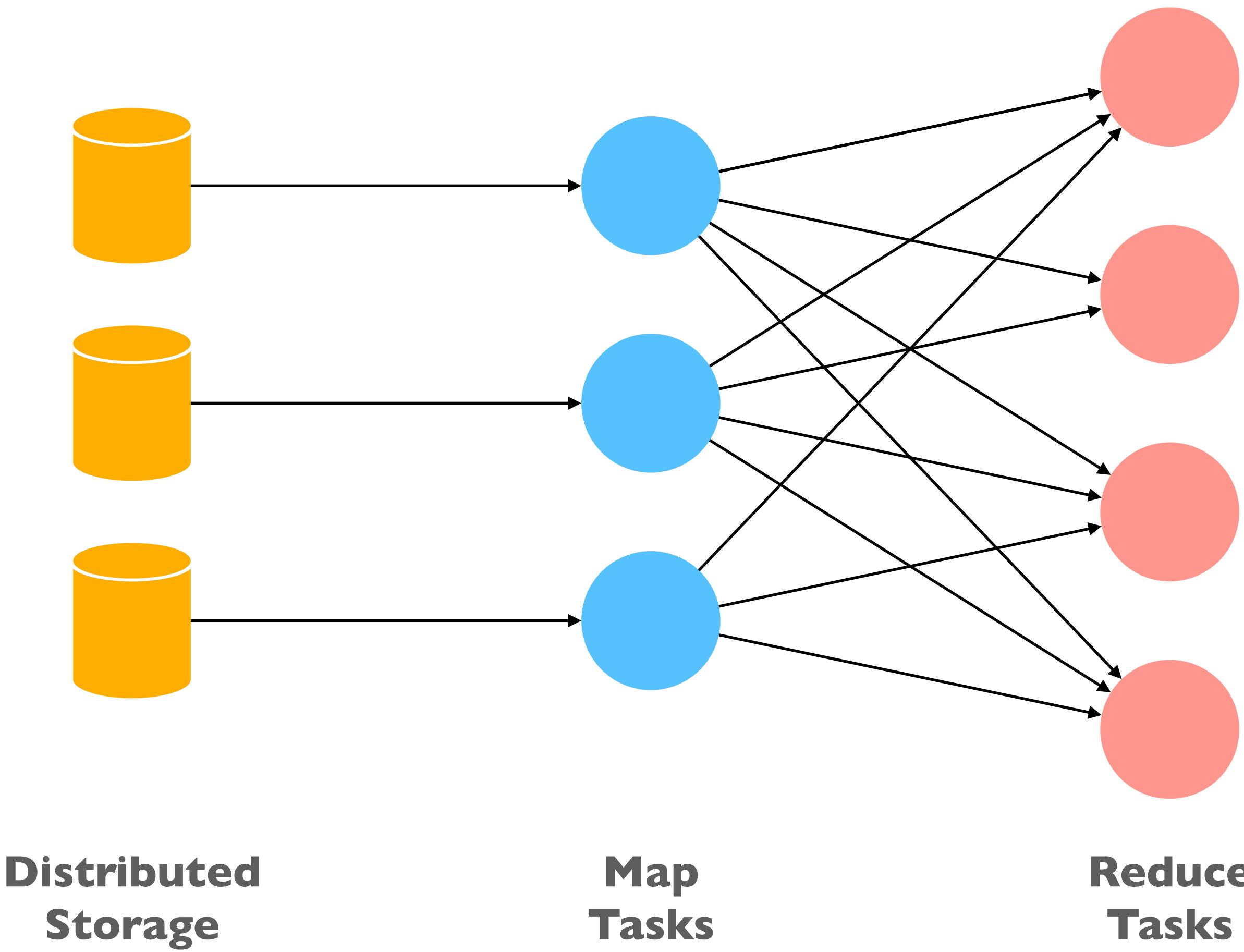


**Distributed  
Storage**

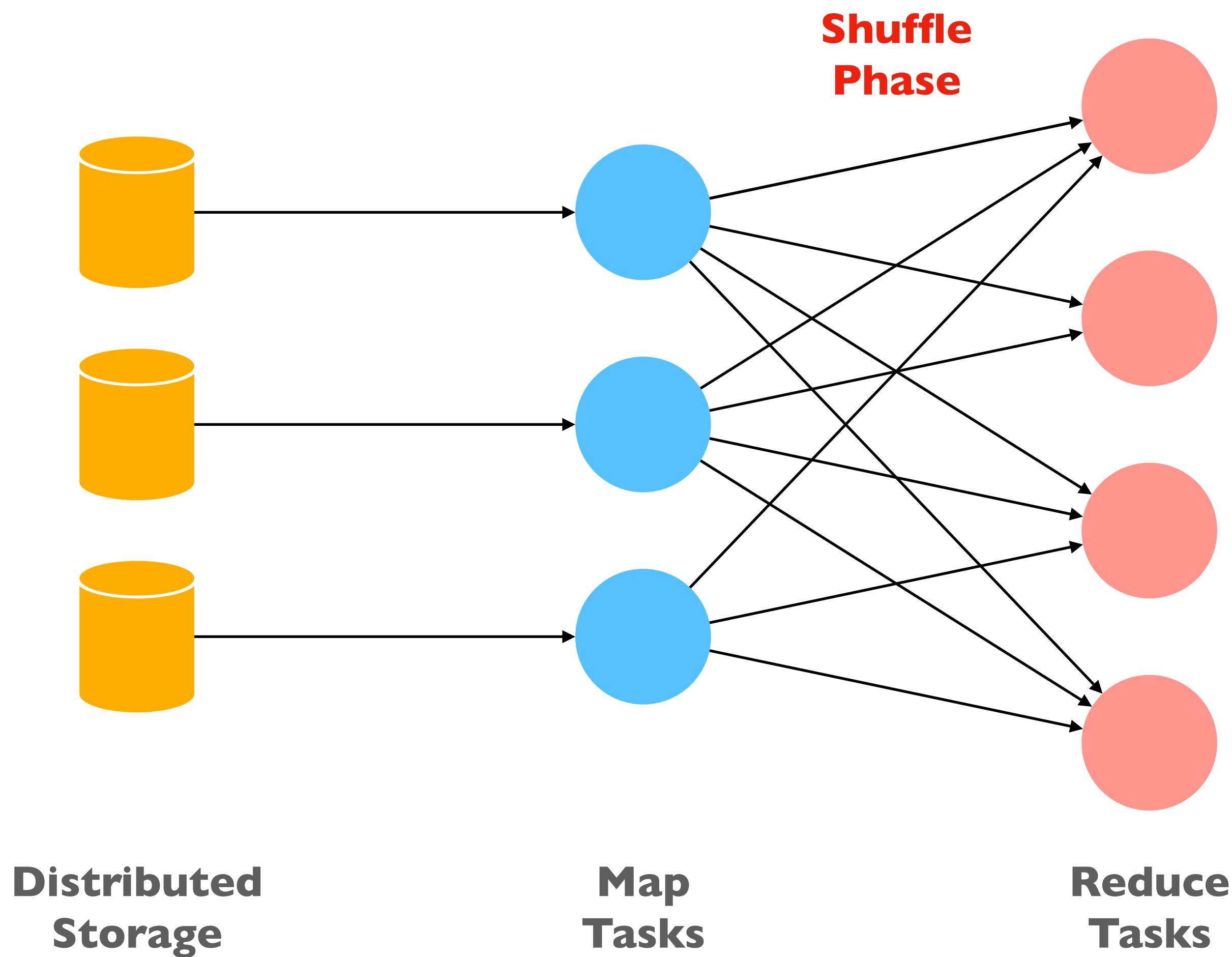
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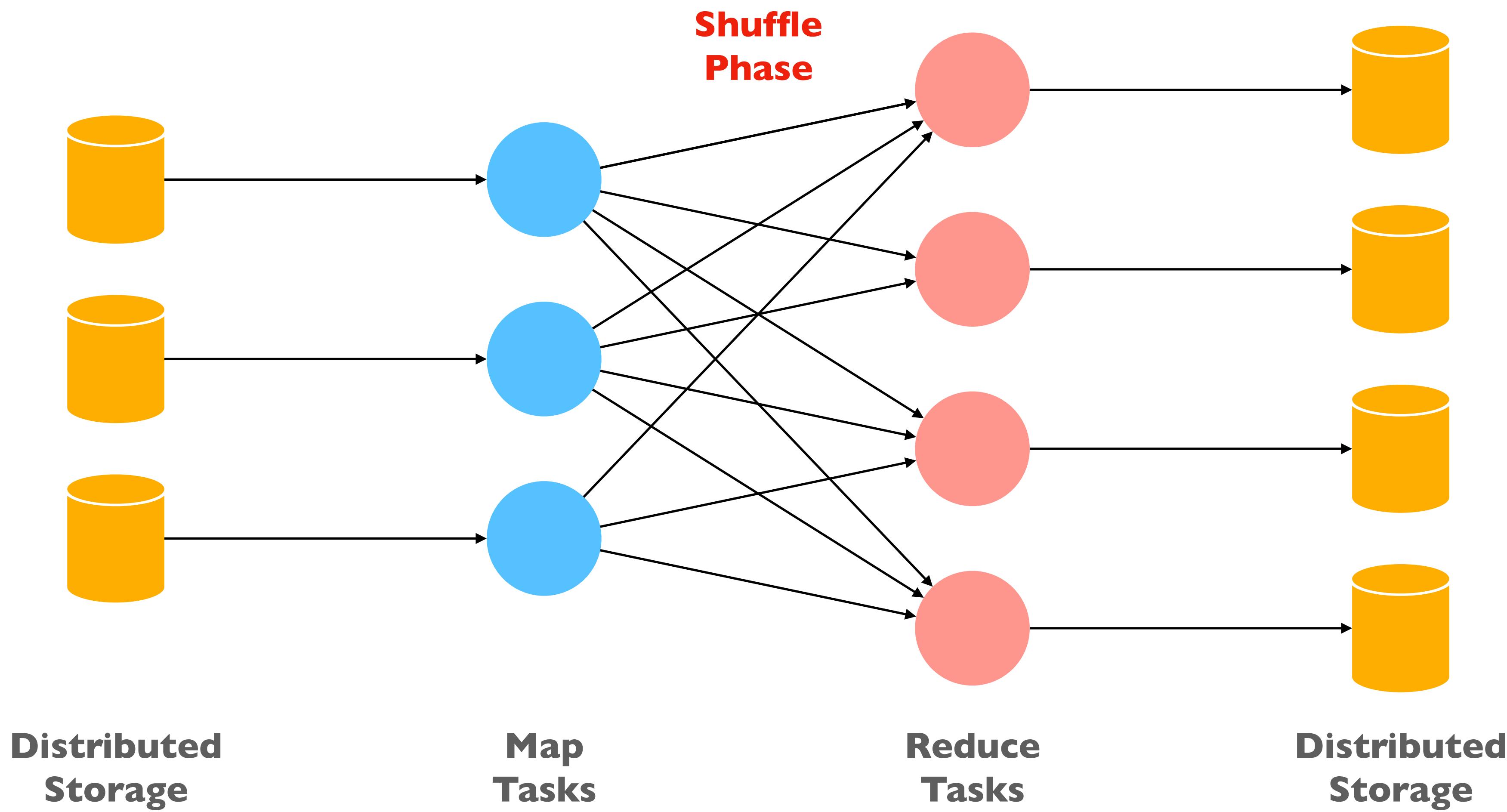
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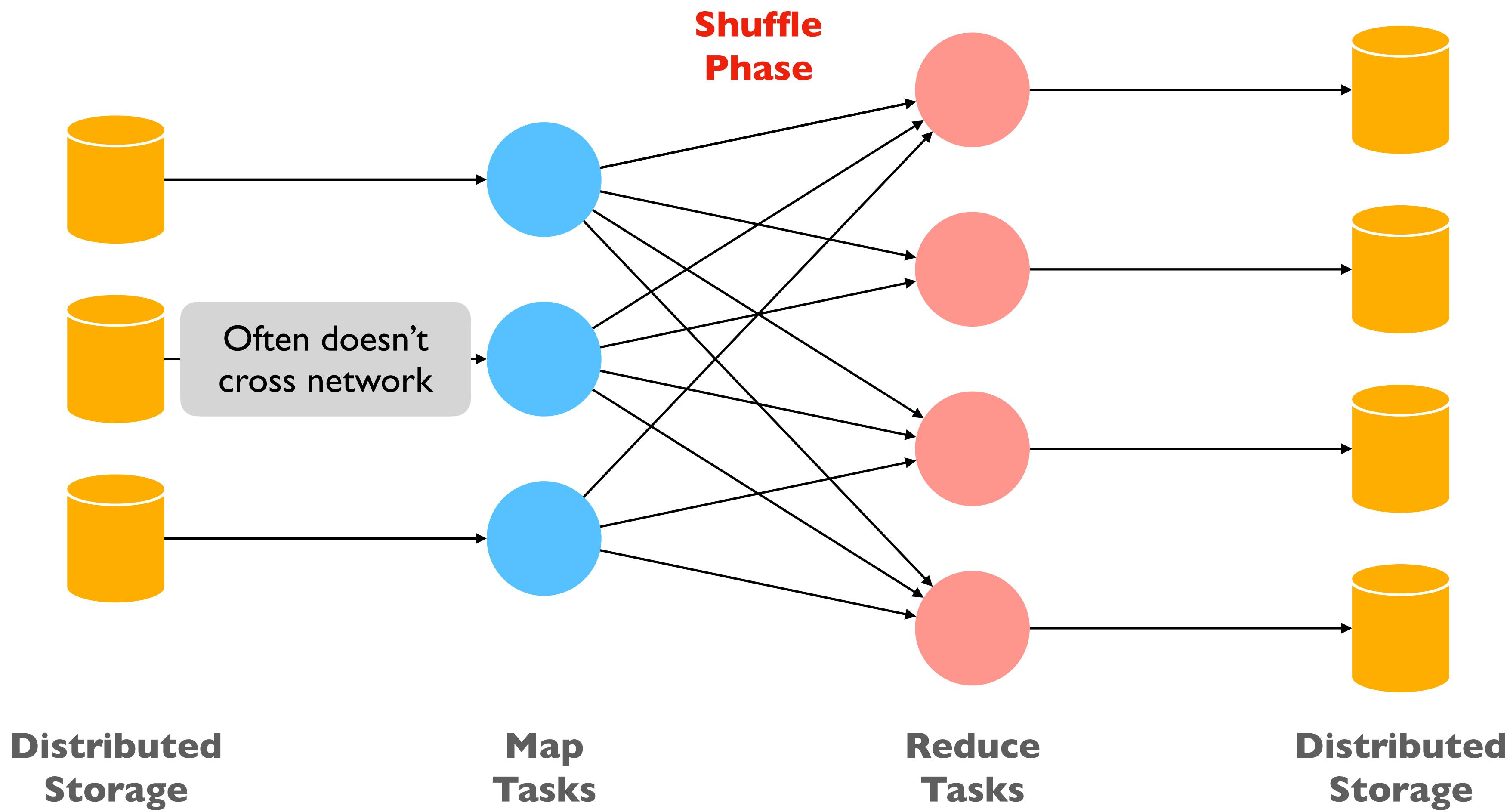
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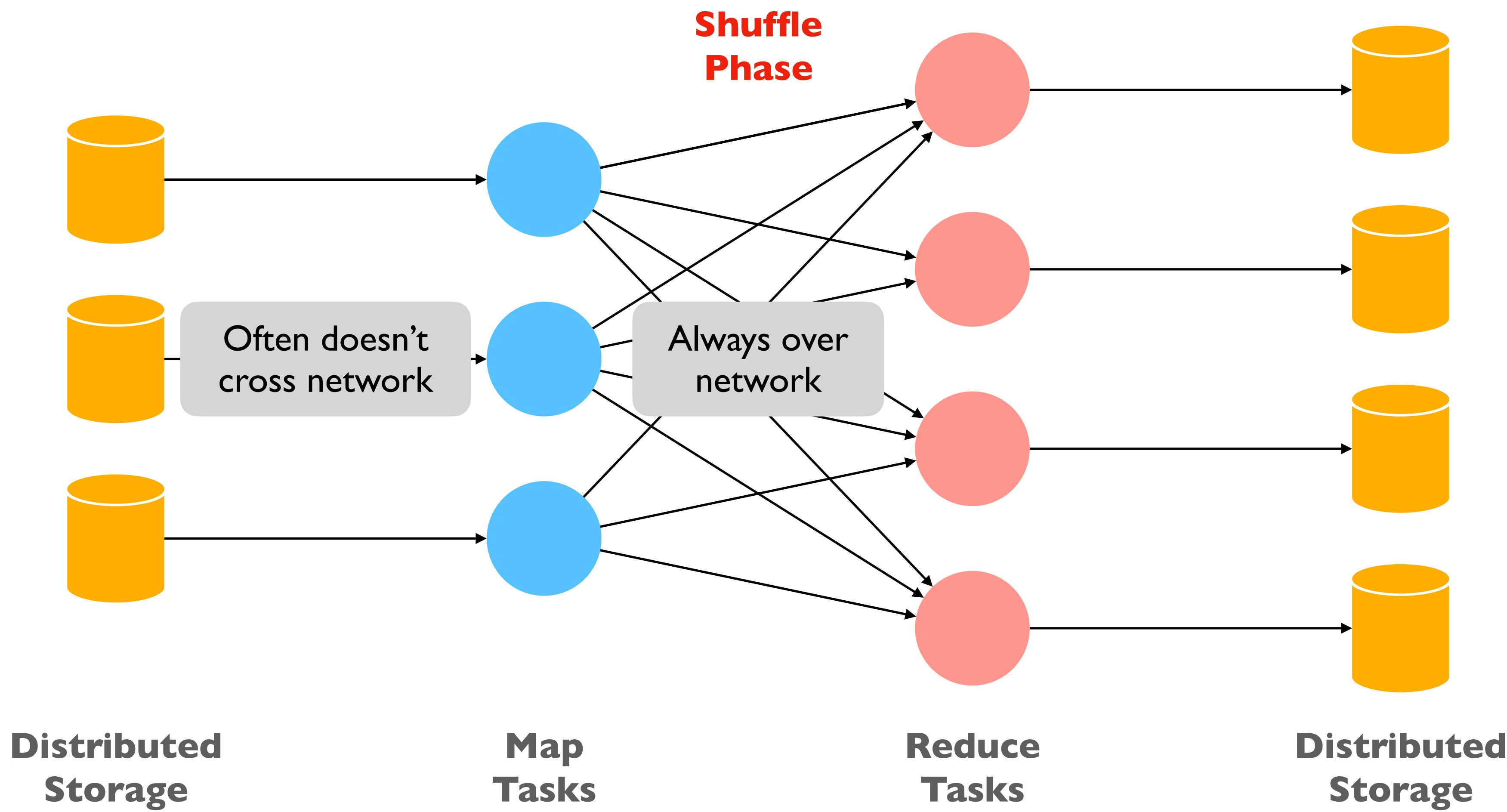
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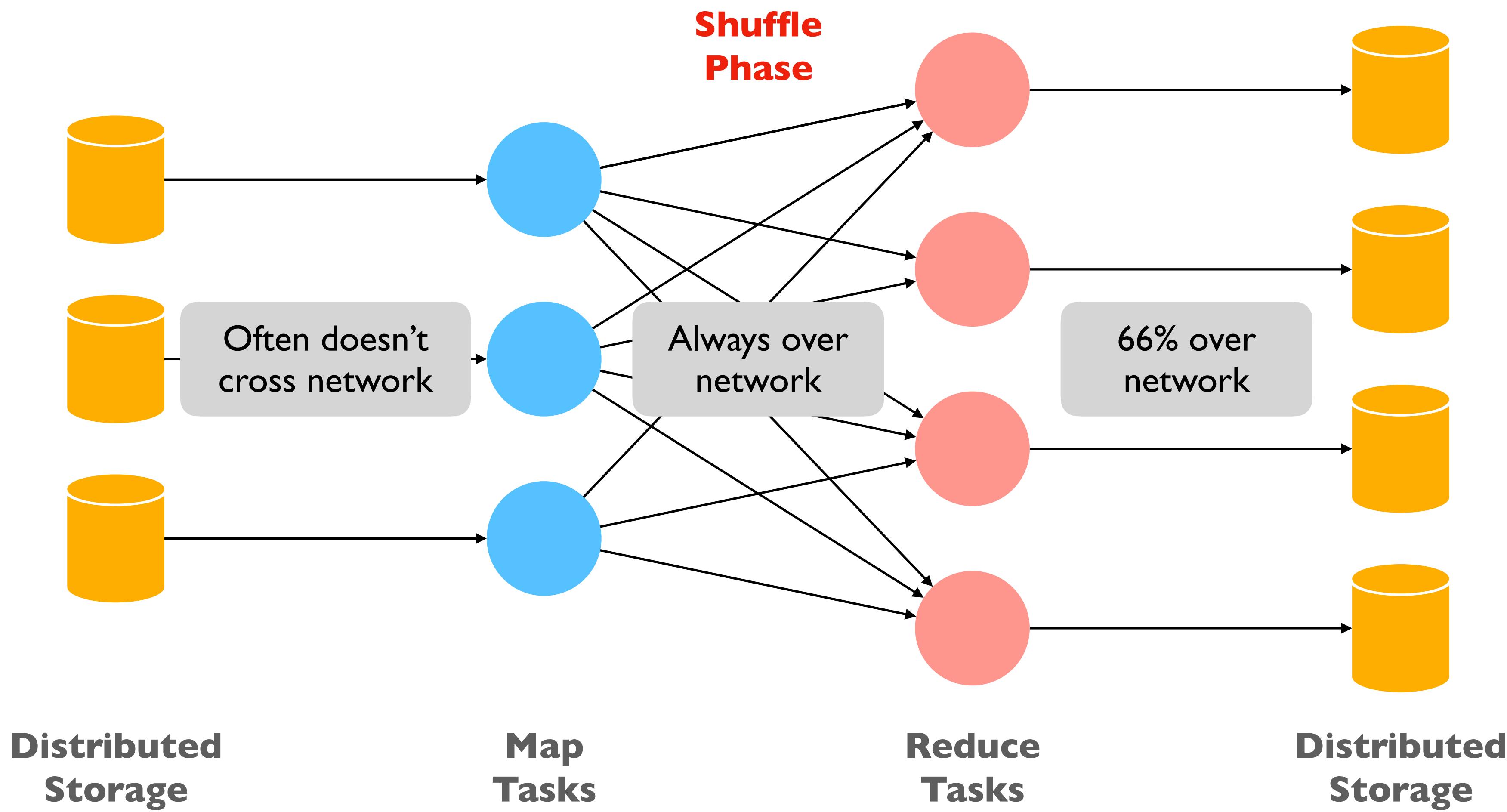
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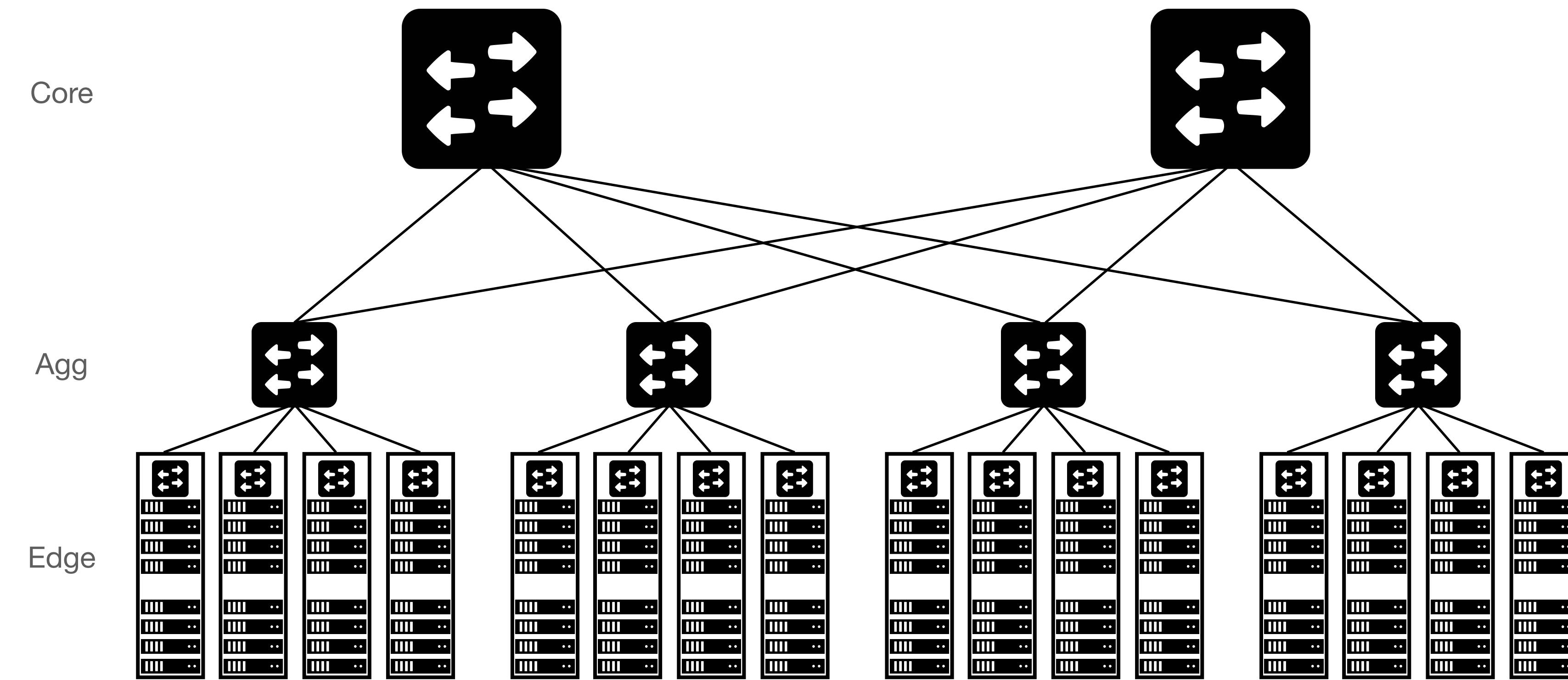
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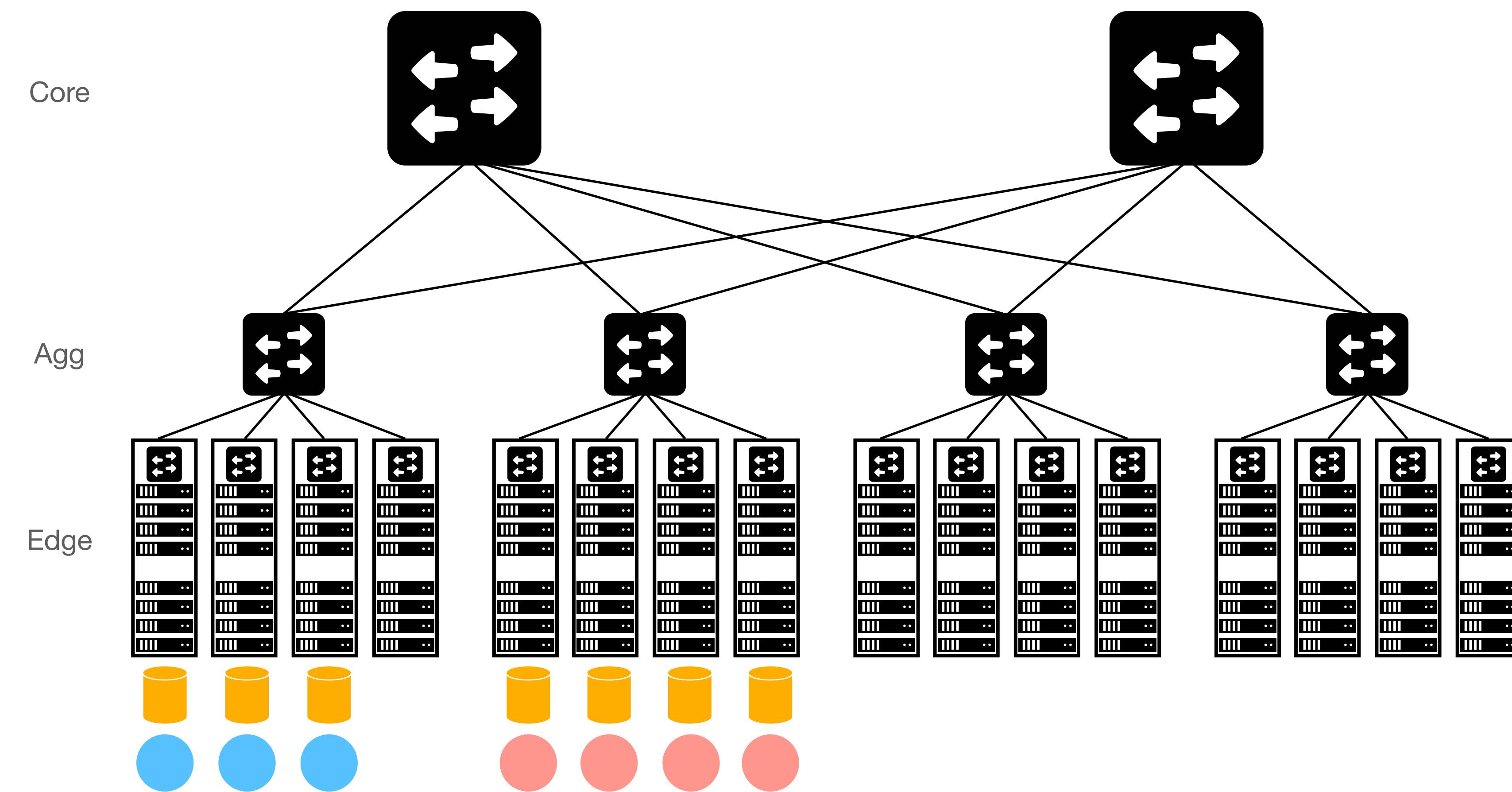
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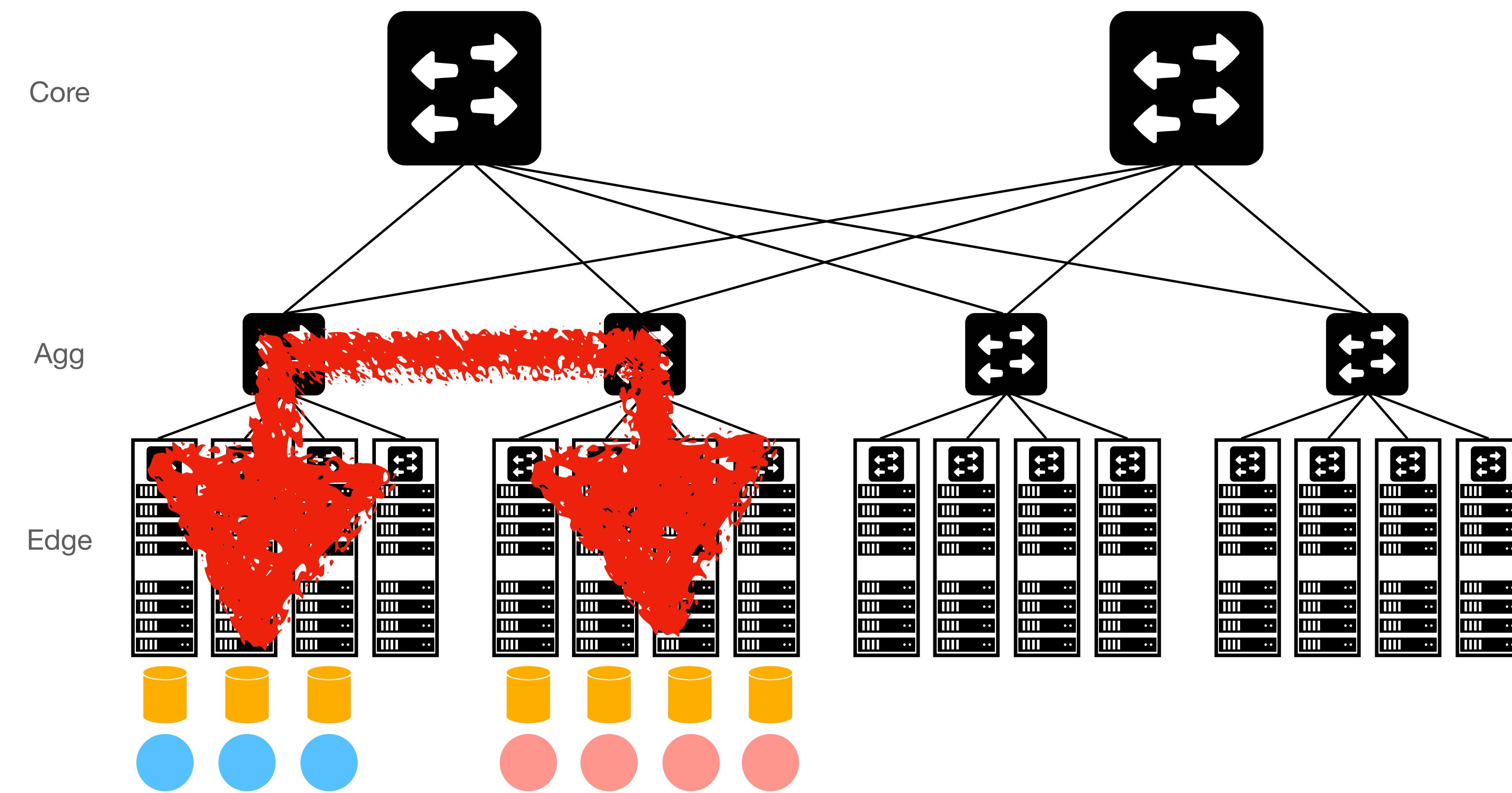
# “East-west” Traffic



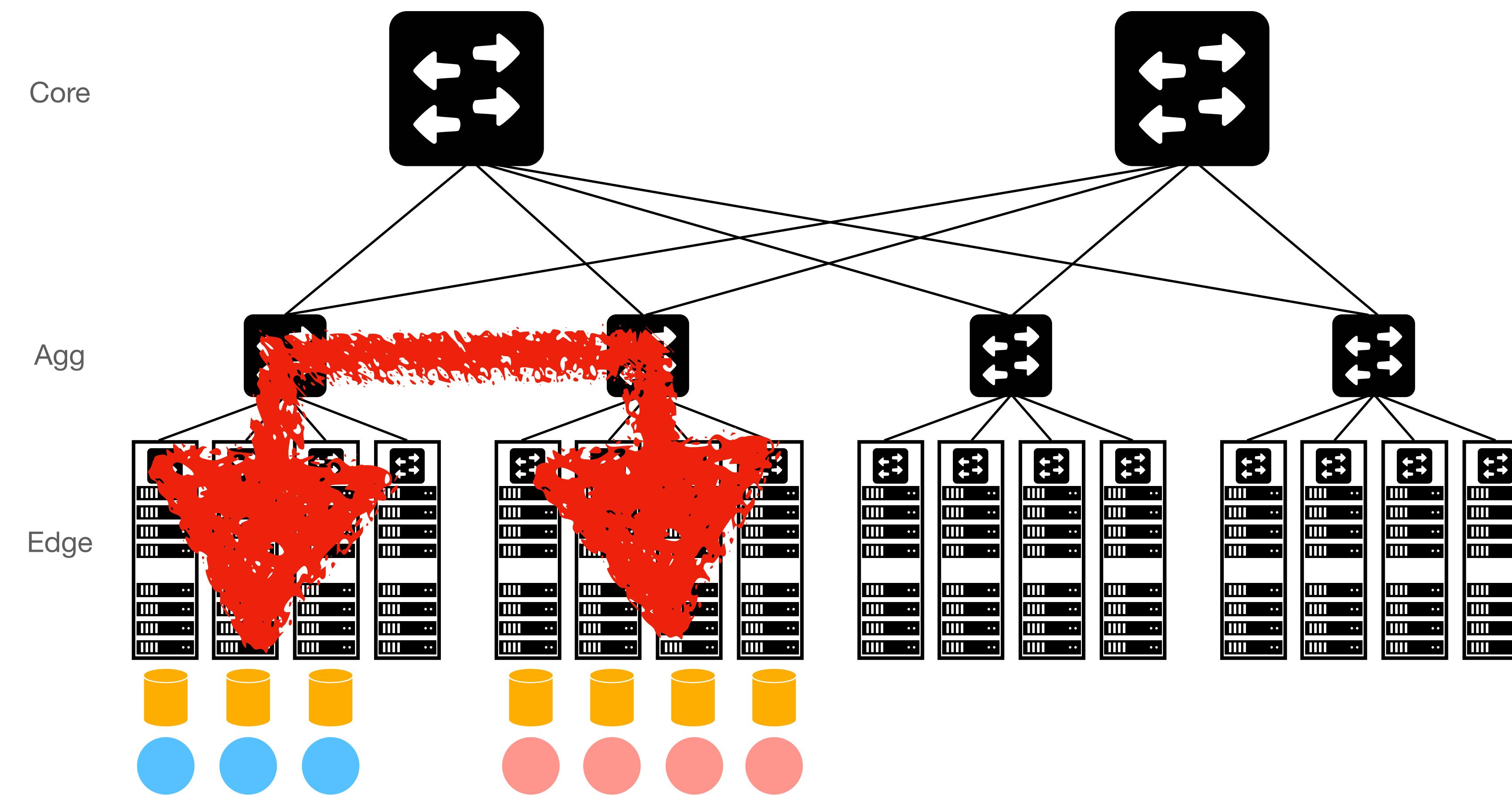
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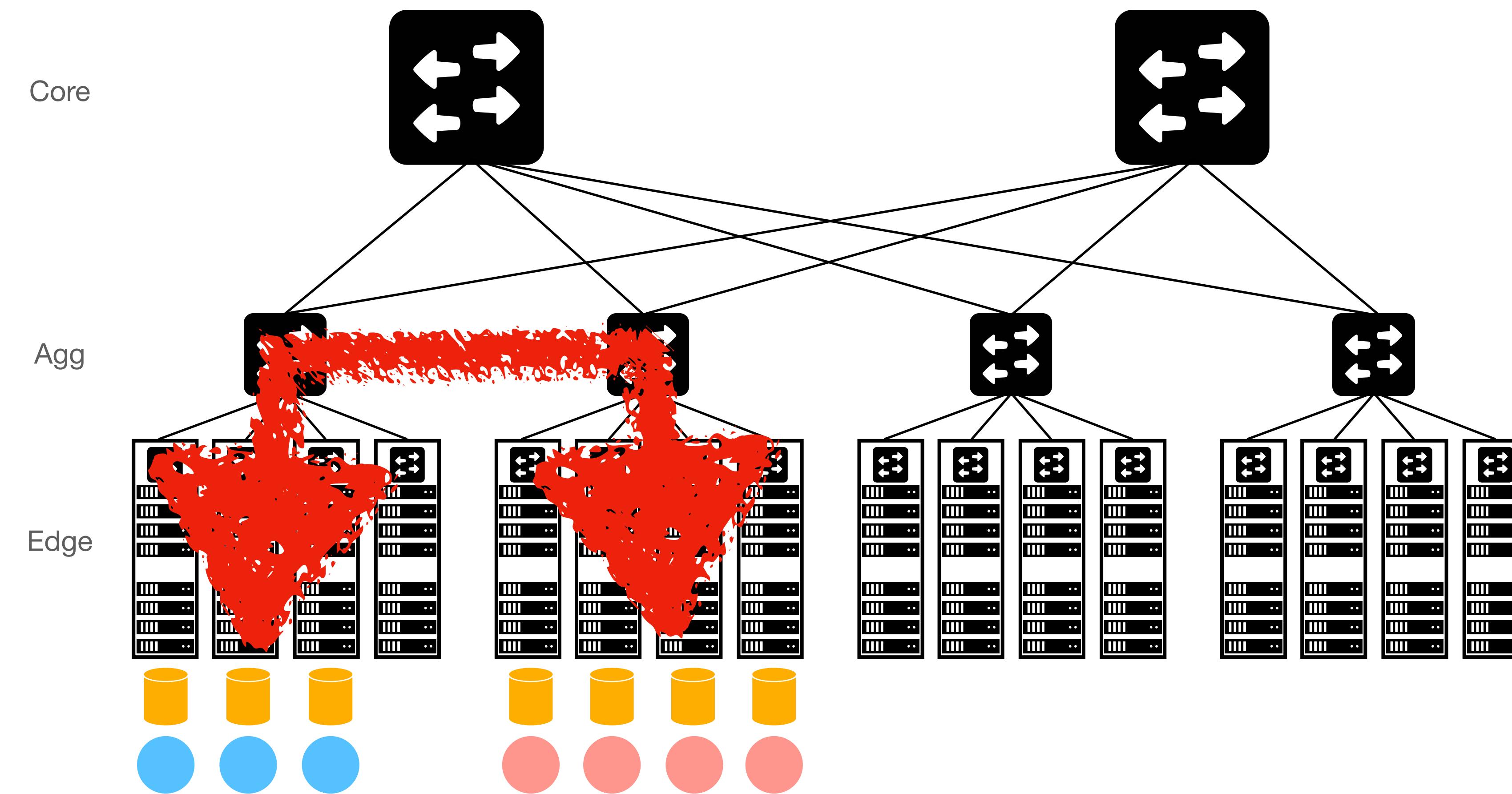


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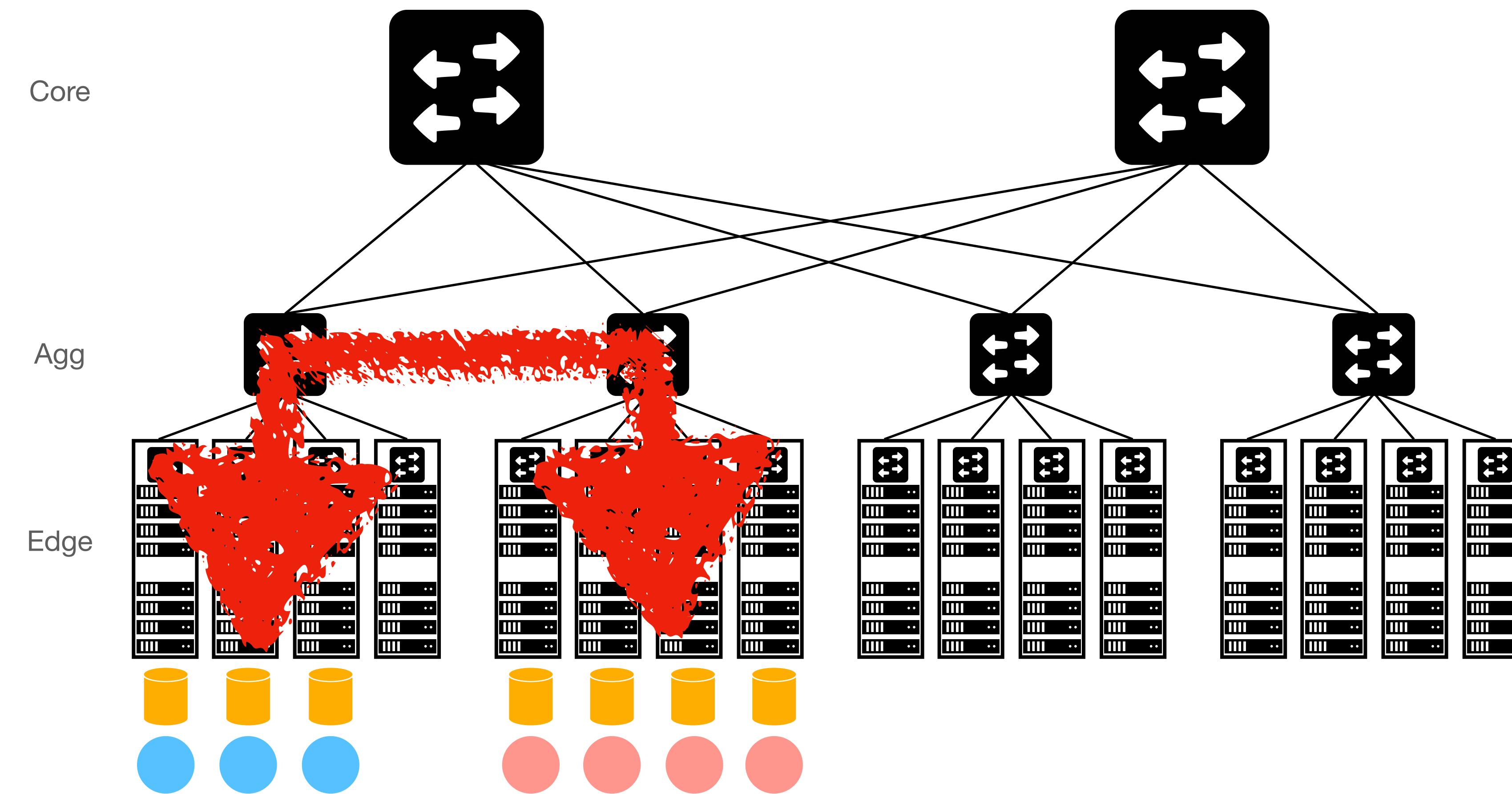
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# “East-west” Traffic



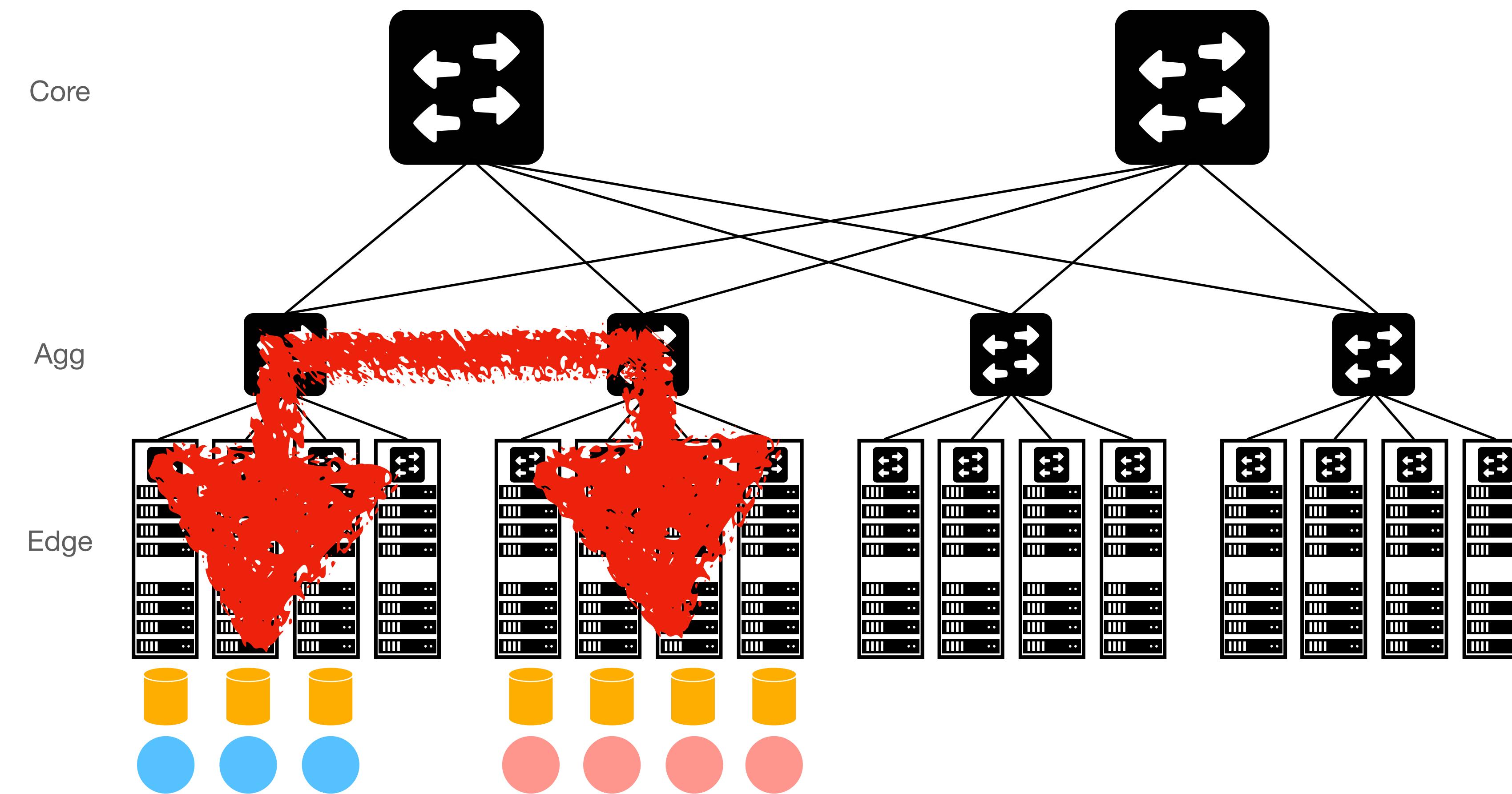
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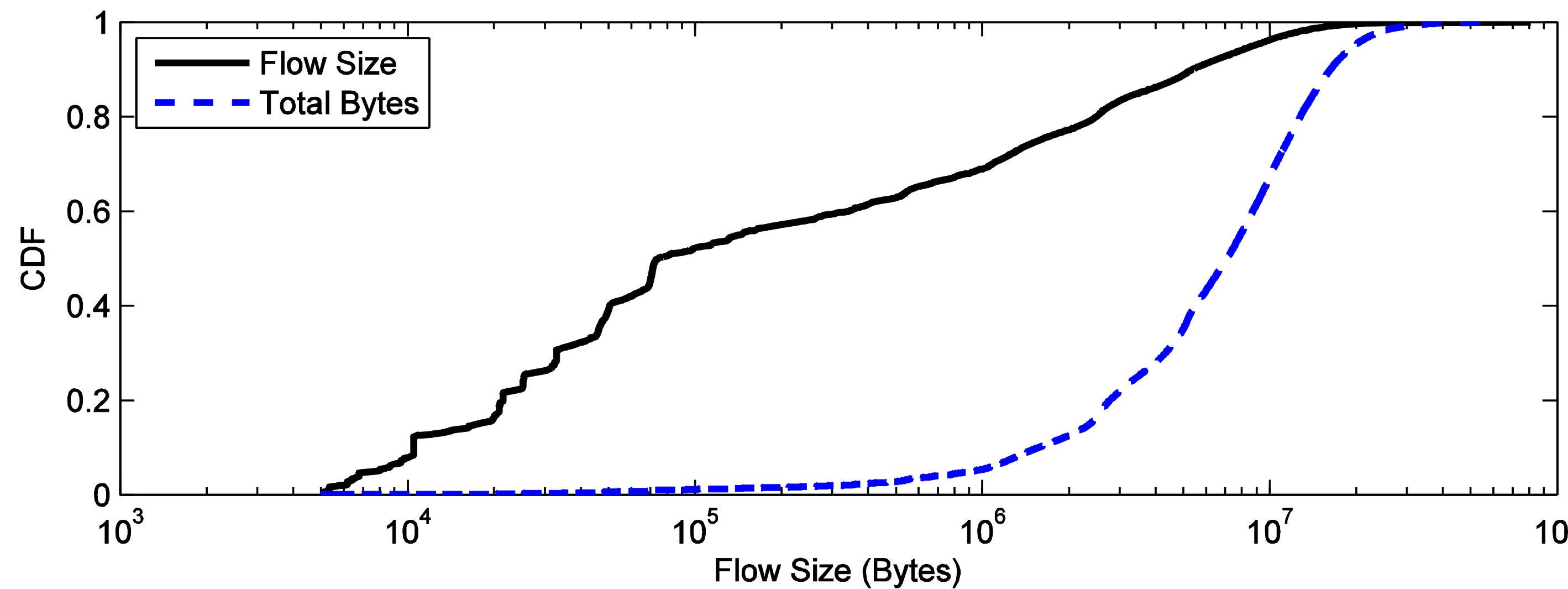
- Traffic between servers in the datacenter
  - Bandwidth intensive
  - $O(\text{mins})$
- Handled by map/reduce tasks, distributed filesystem

# Characterizing Traffic Pattern: “Elephant” & “Mice” Flows

- Microsoft [Alizadeh et. al. 2010]
  - Web-search (north-south), data mining (east-west)

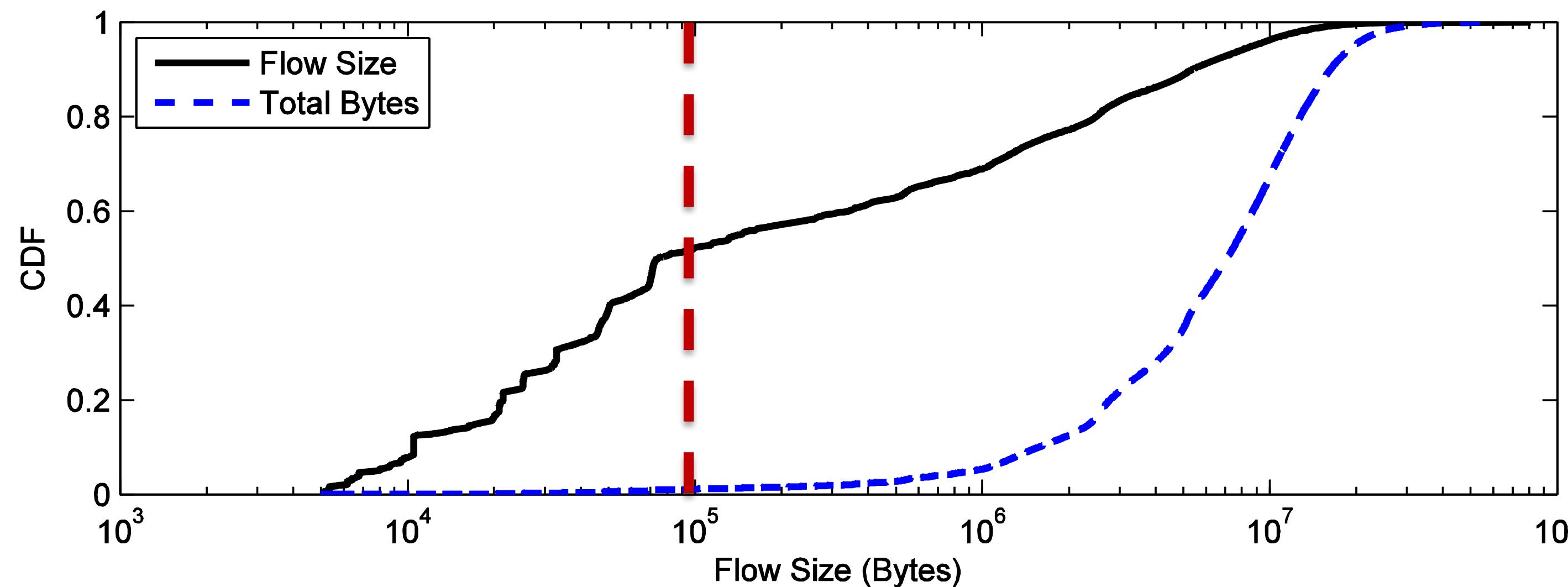
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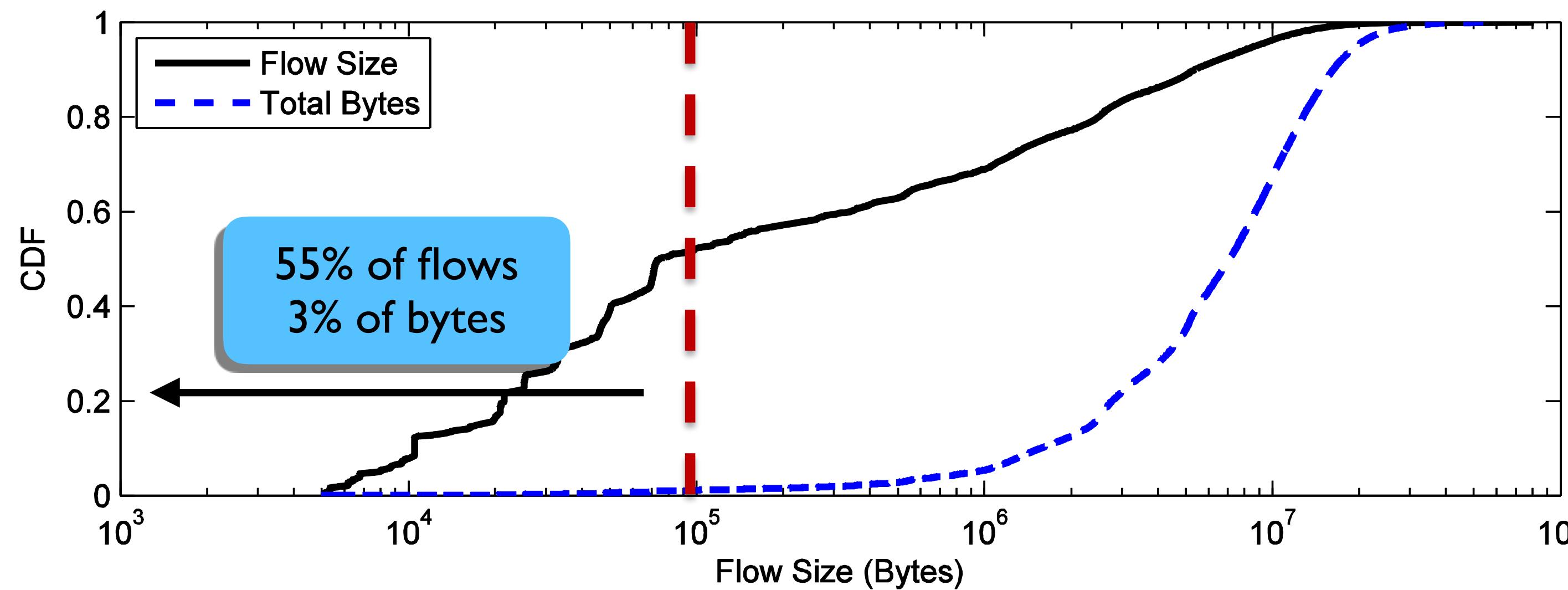
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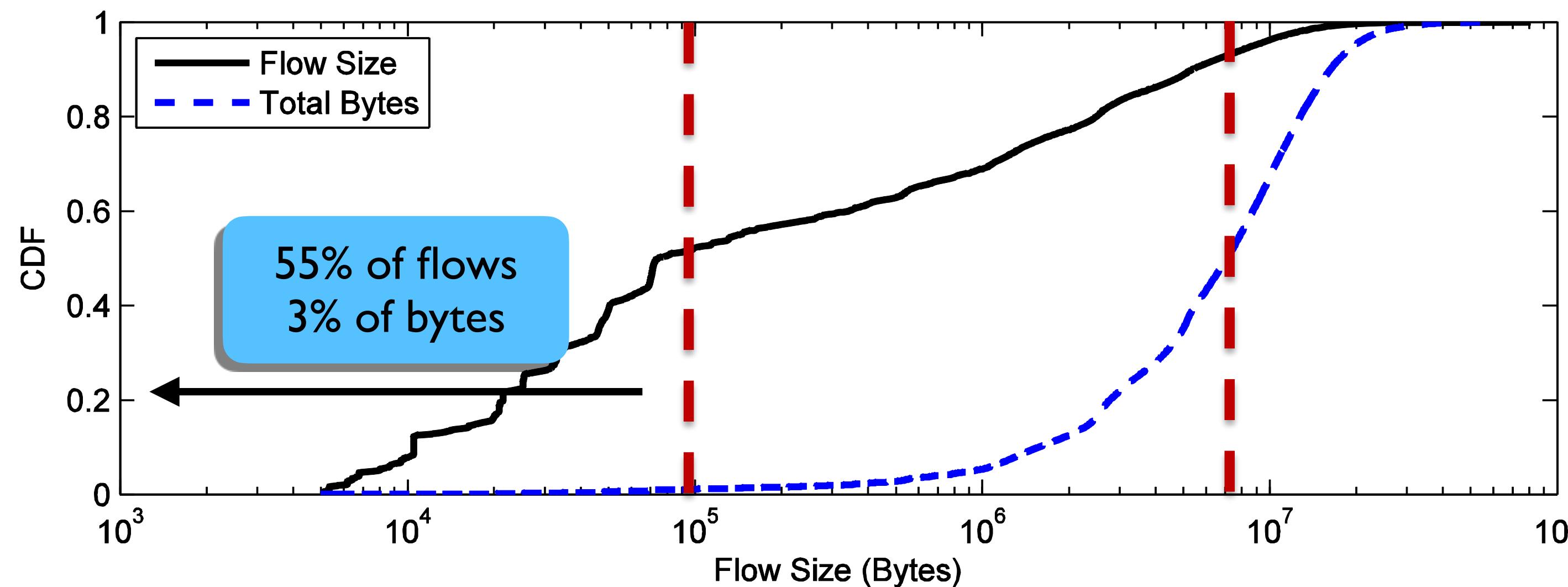
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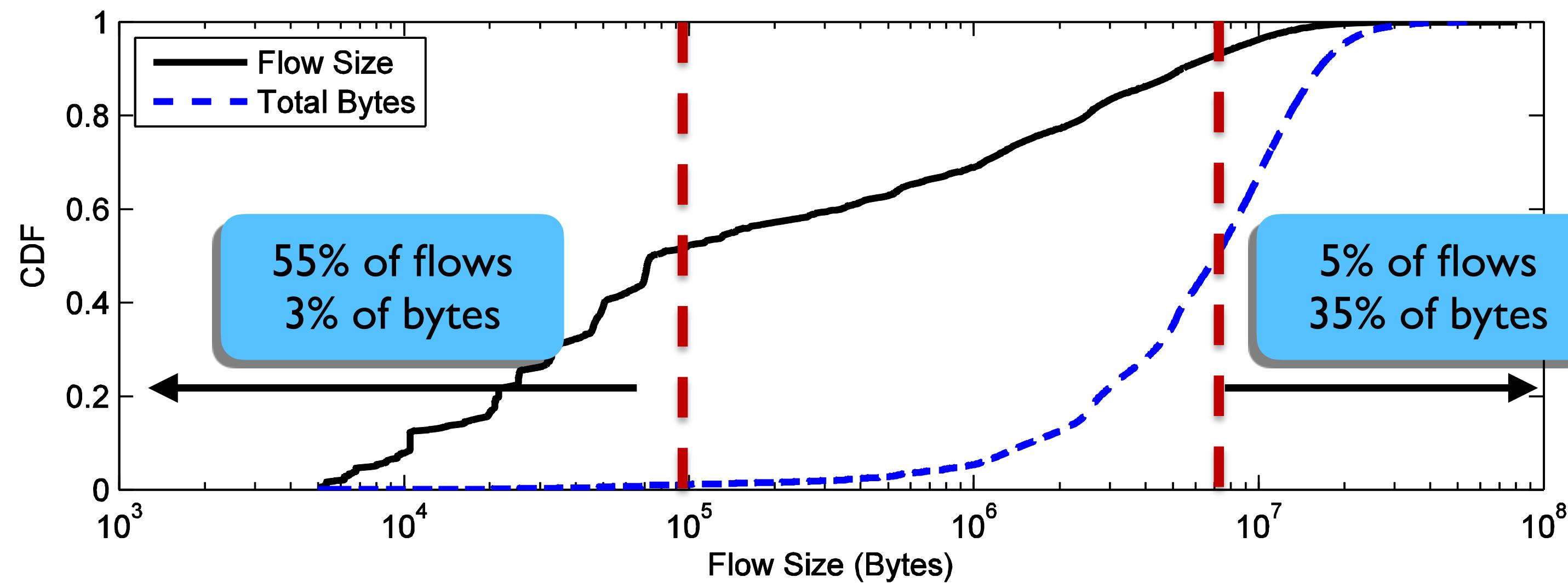
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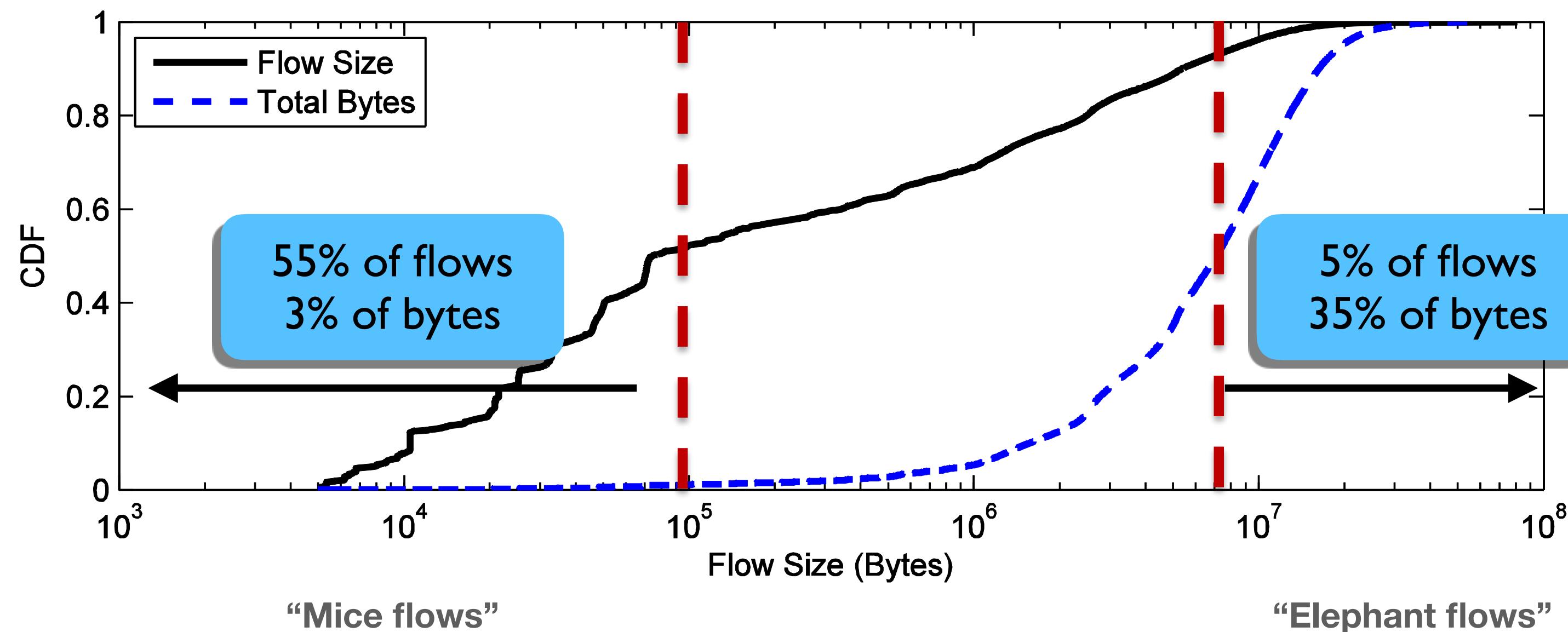
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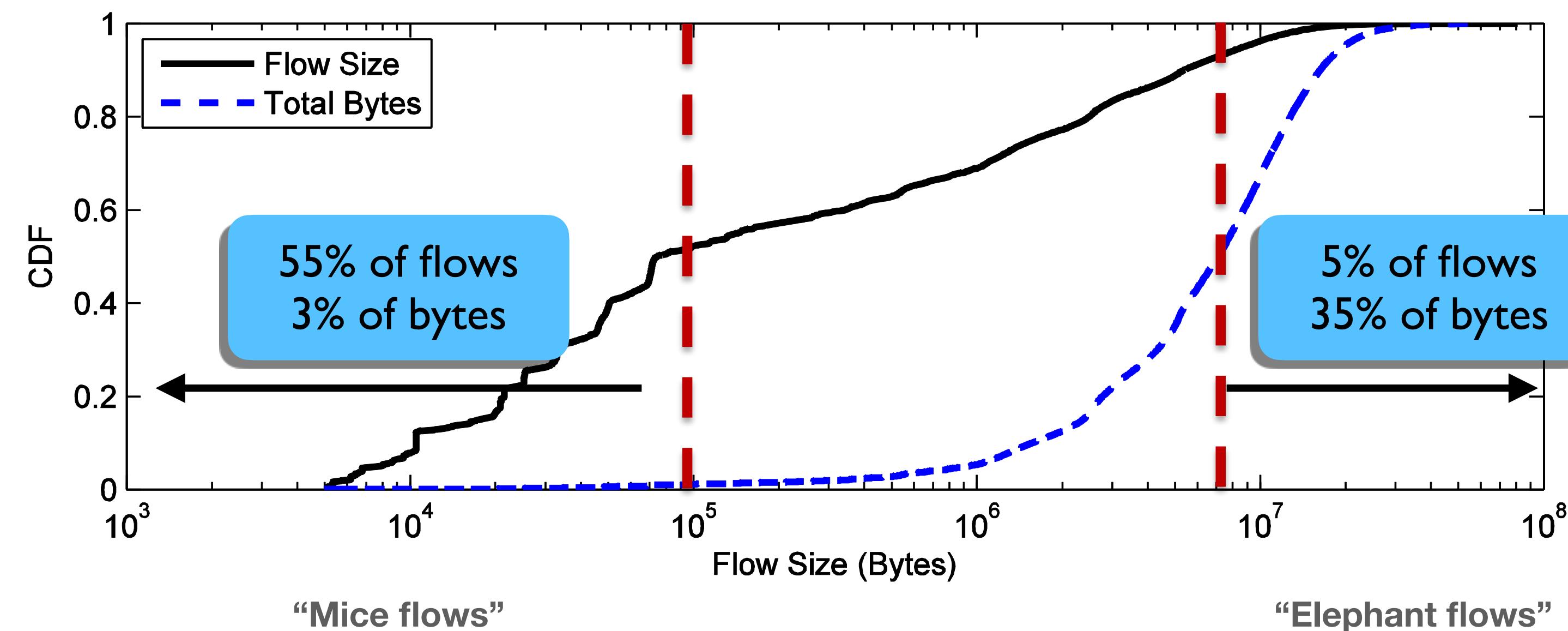
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**Research:** How do you design the network protocols for such traffic?

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- Low latency is critical (for north-south)
  - Also worst-case (“tail”) latency

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- Low latency is critical (for north-south)
  - Also worst-case (“tail”) latency
- High bandwidth any-to-any communication (east-west)
  - ‘Bisection bandwidth’

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- Partition network into two equal parts

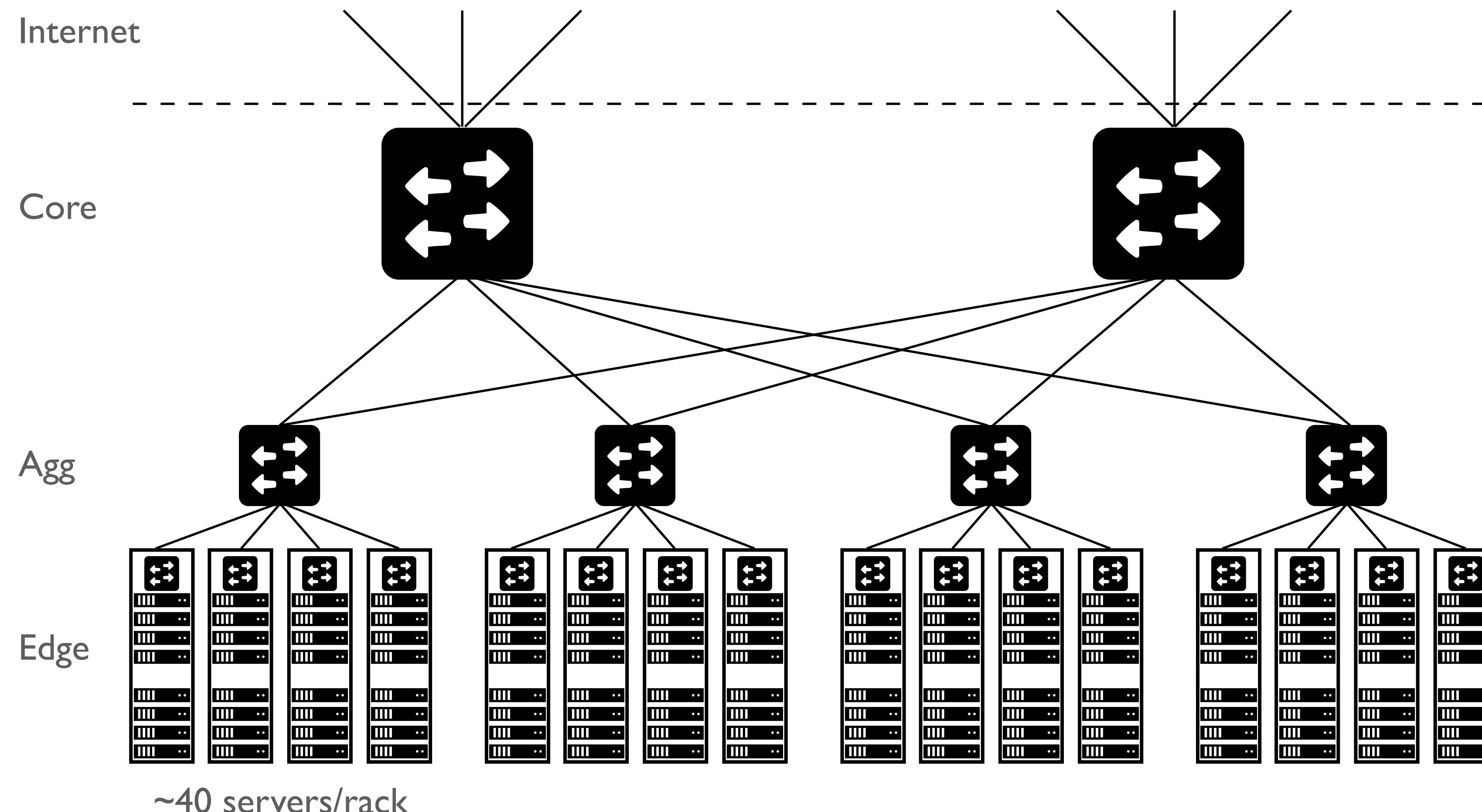
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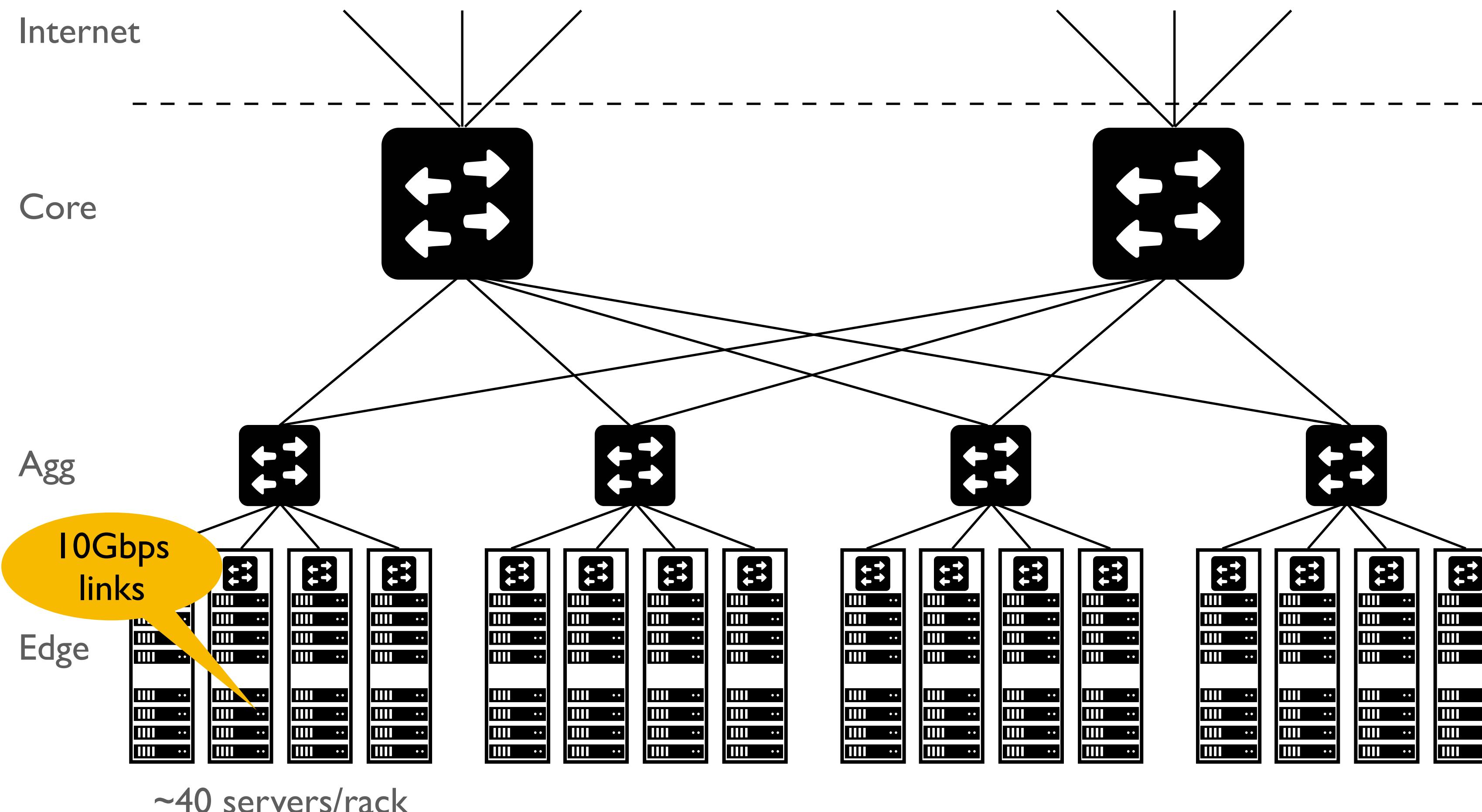
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- Partition network into two equal parts
- Minimum bandwidth between the partitions is the *bisection bandwidth*
- *Full bisection bandwidth:* bisection bandwidth in an  $N$ -node network is  $N/2$  times the bandwidth of a single access link
  - Nodes of *any* two halves can communicate at full speed with each other

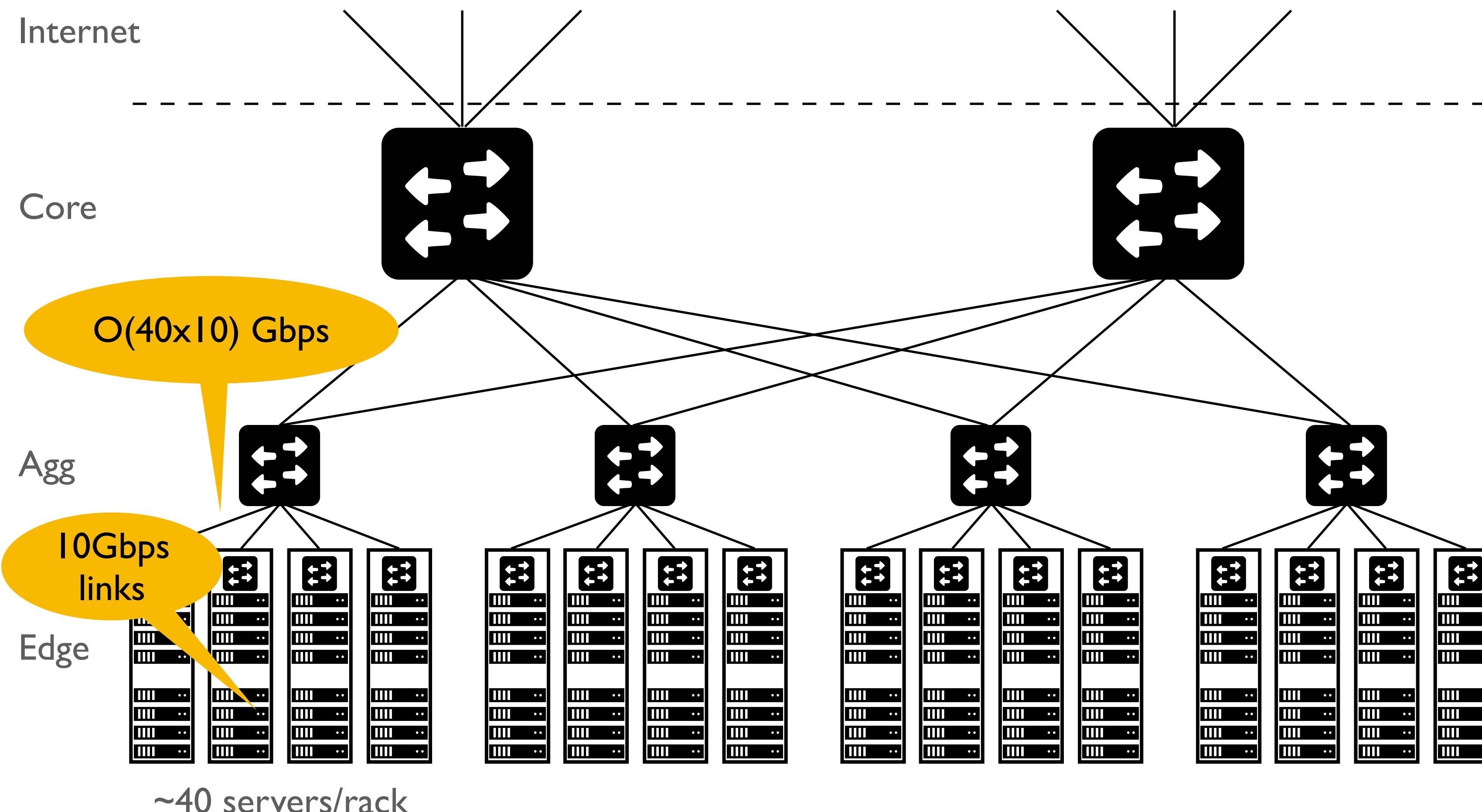
# Achieving Full Bisection Bandwidth



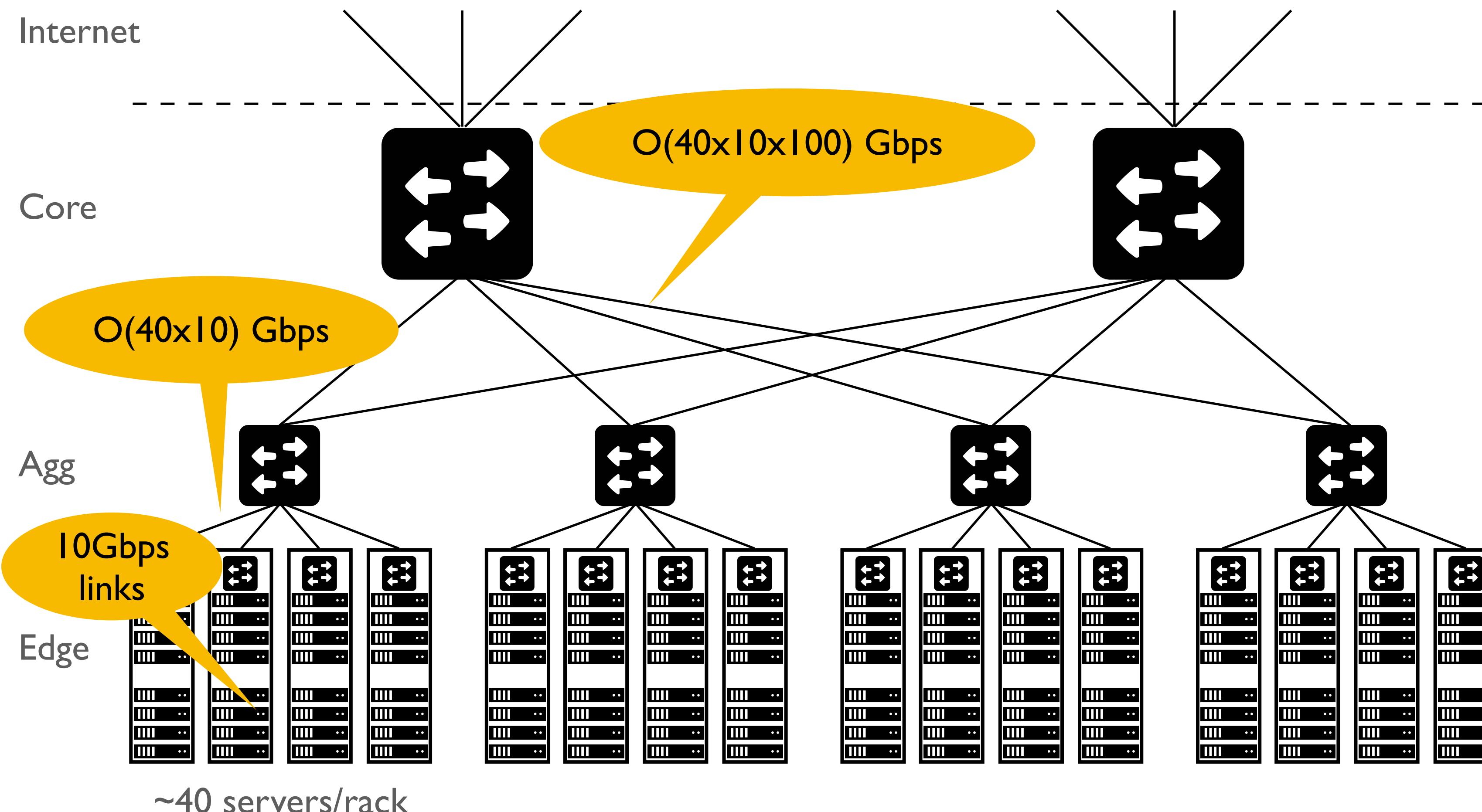
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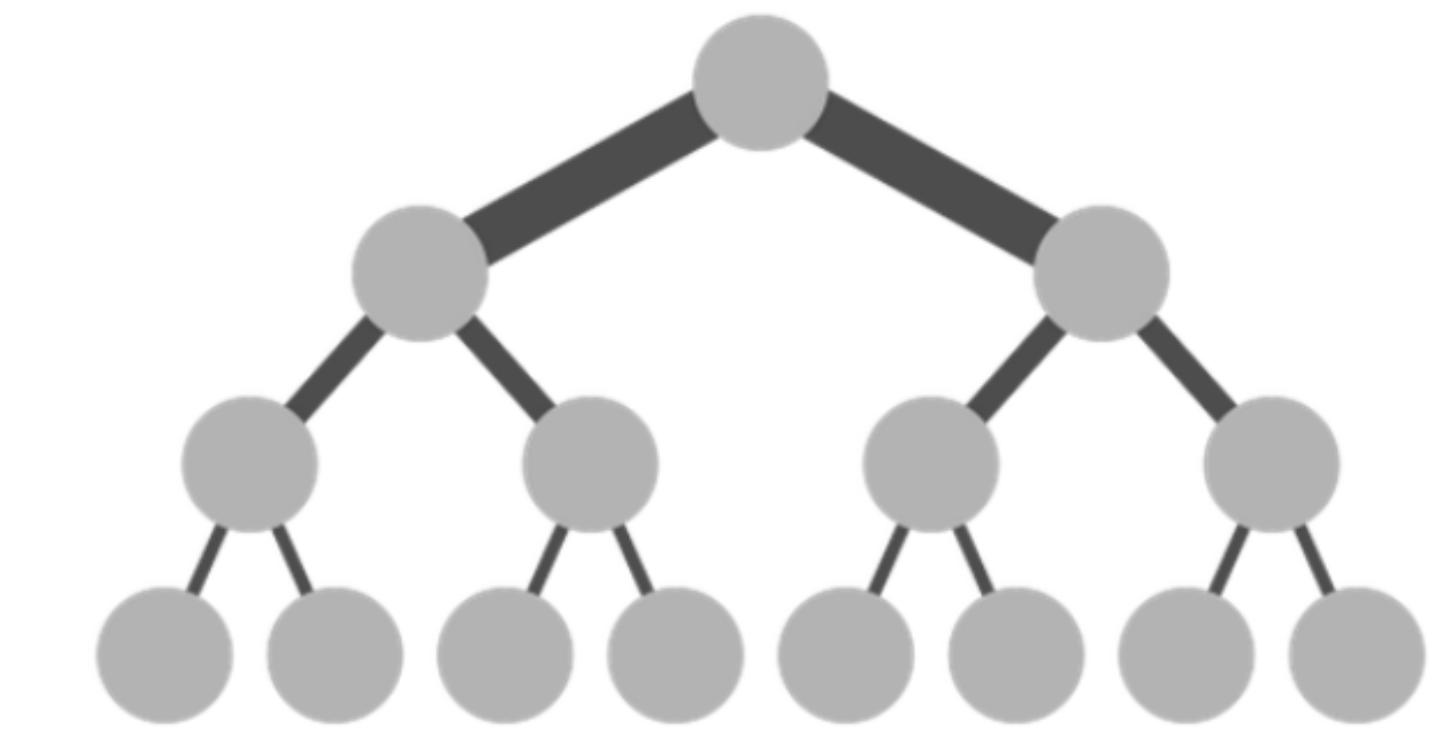
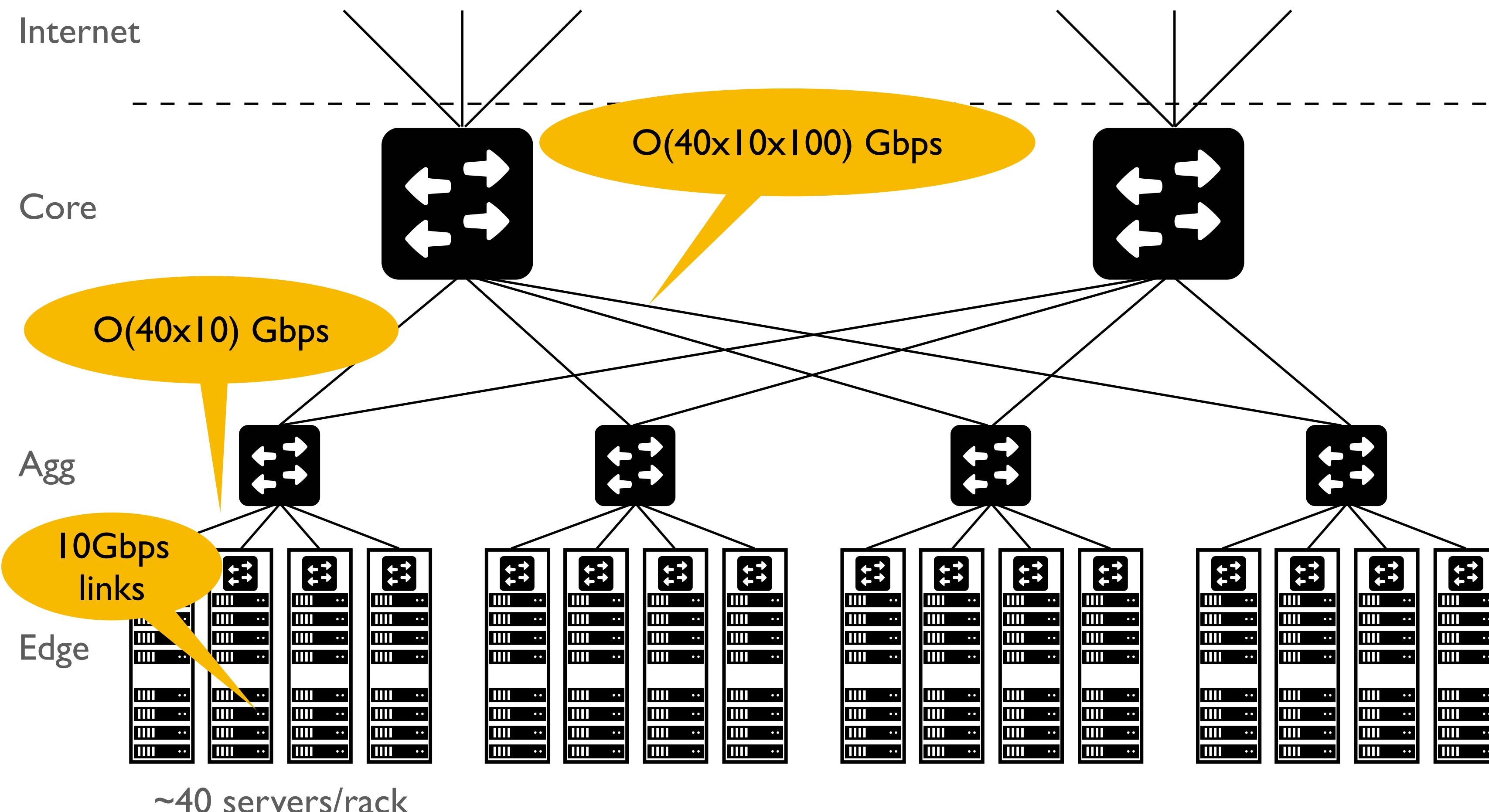
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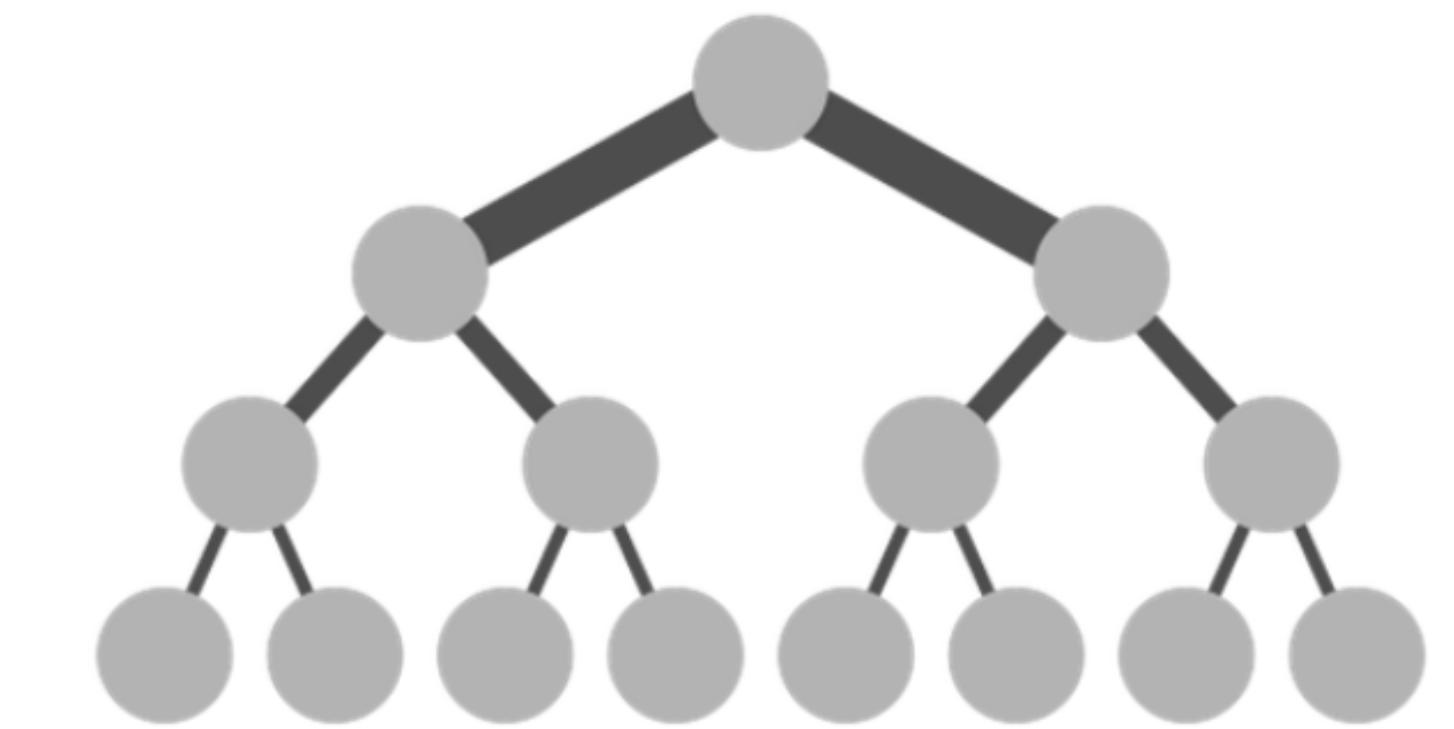
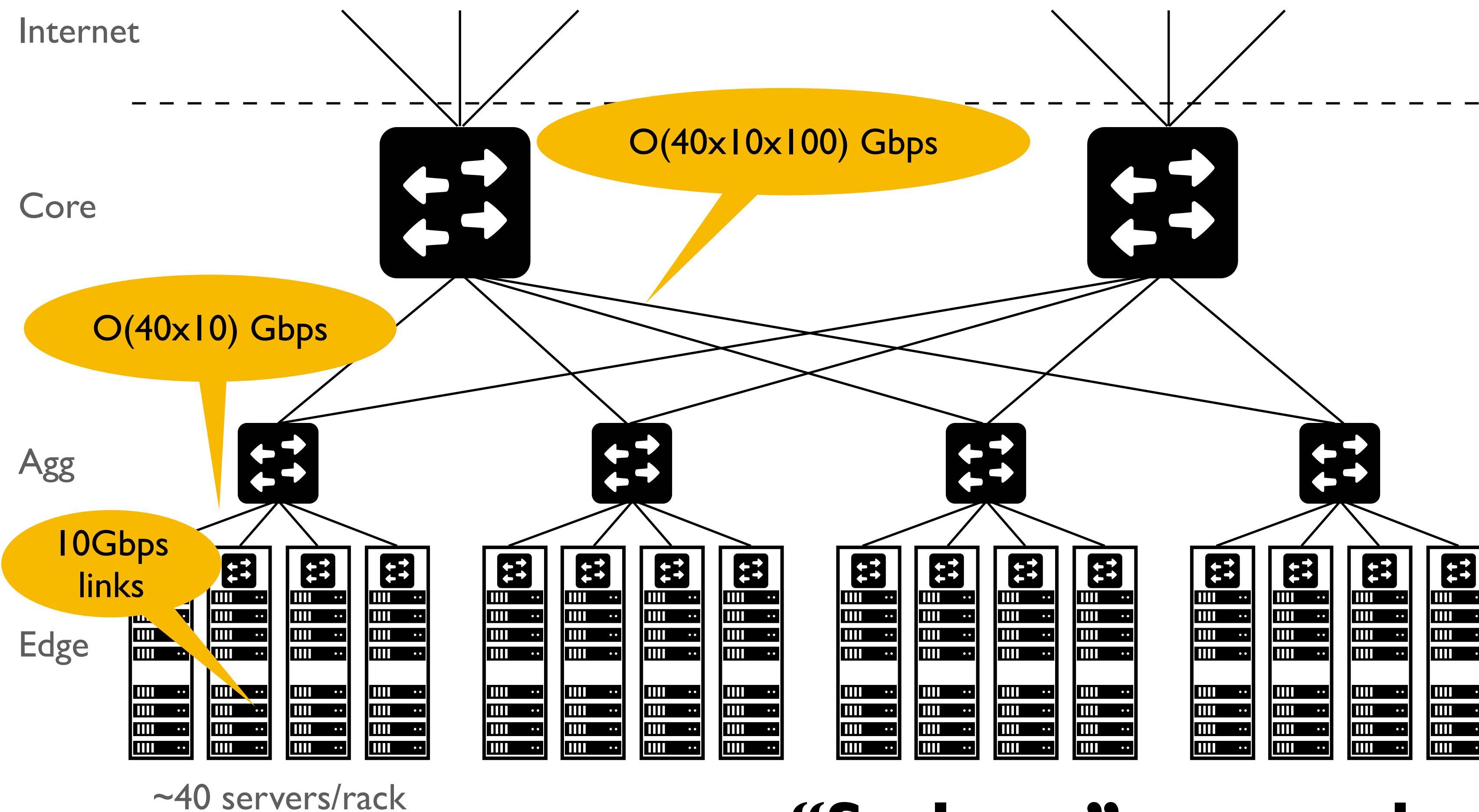
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- Challenge: “Scaling up” a traditional tree topology is expensive!
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- Solutions?
  - Later...

# Questions?