Wireless Networks

CPSC 433/533, Spring 2021

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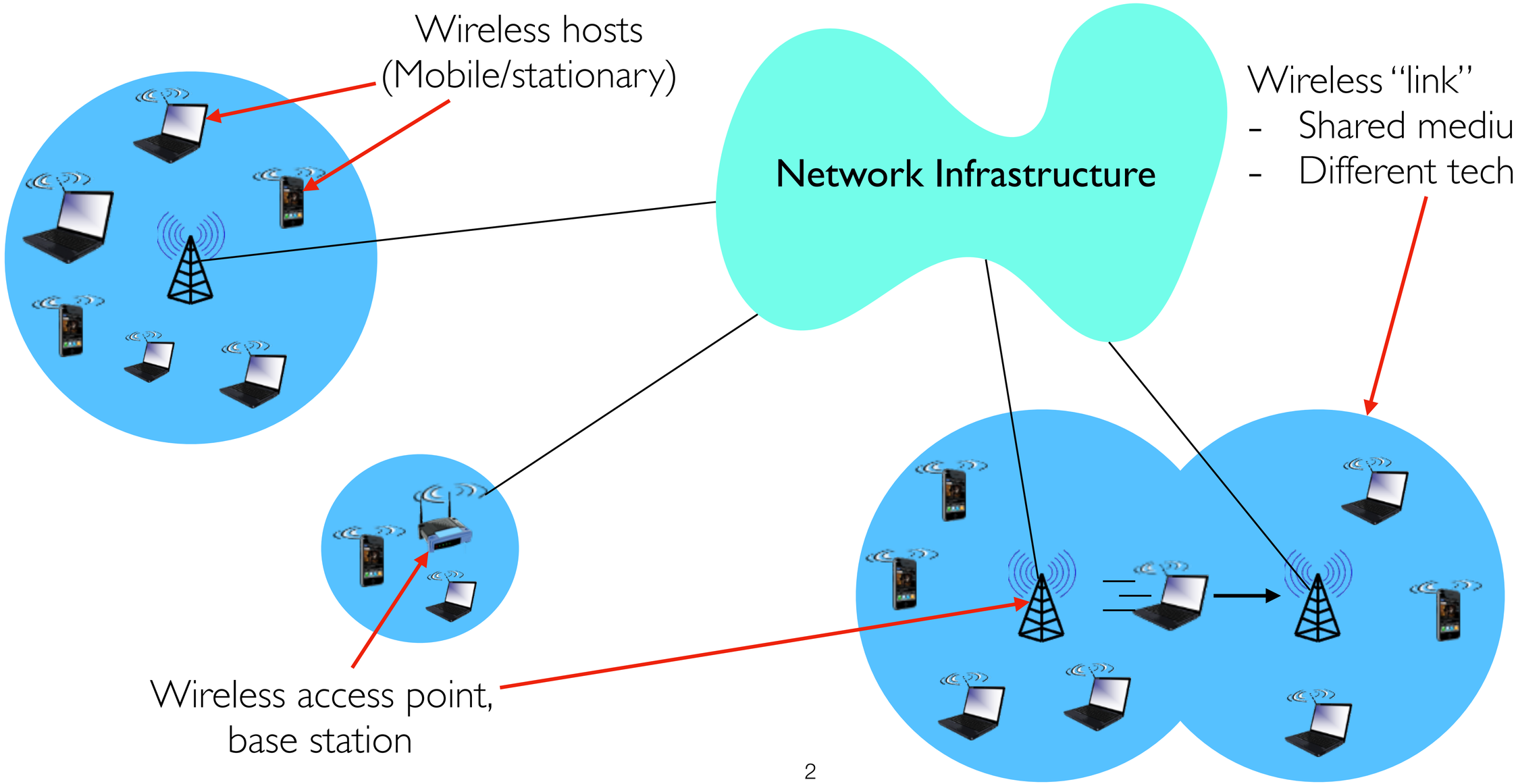
Elements of a Wireless Network



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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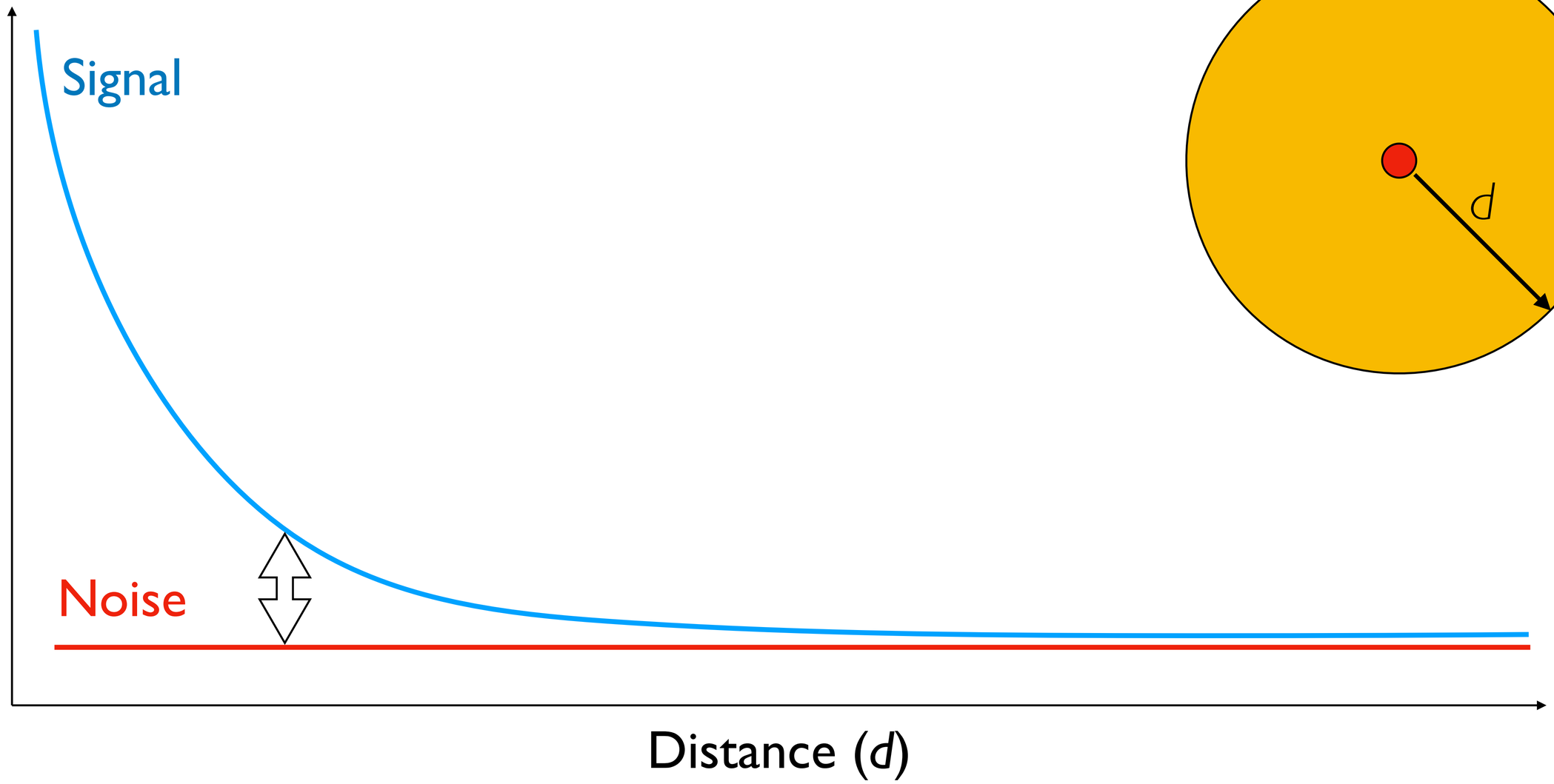
Common Wireless Standards

- **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, >1Gbps (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)

What makes wireless different?

- **Consider specific frequency band / wireless technology**
  - What makes it different from wired technologies?
- **A lot really…**
- **Broadcast medium**
  - Anybody in proxy can hear & interfere
- **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*

Signal and noise

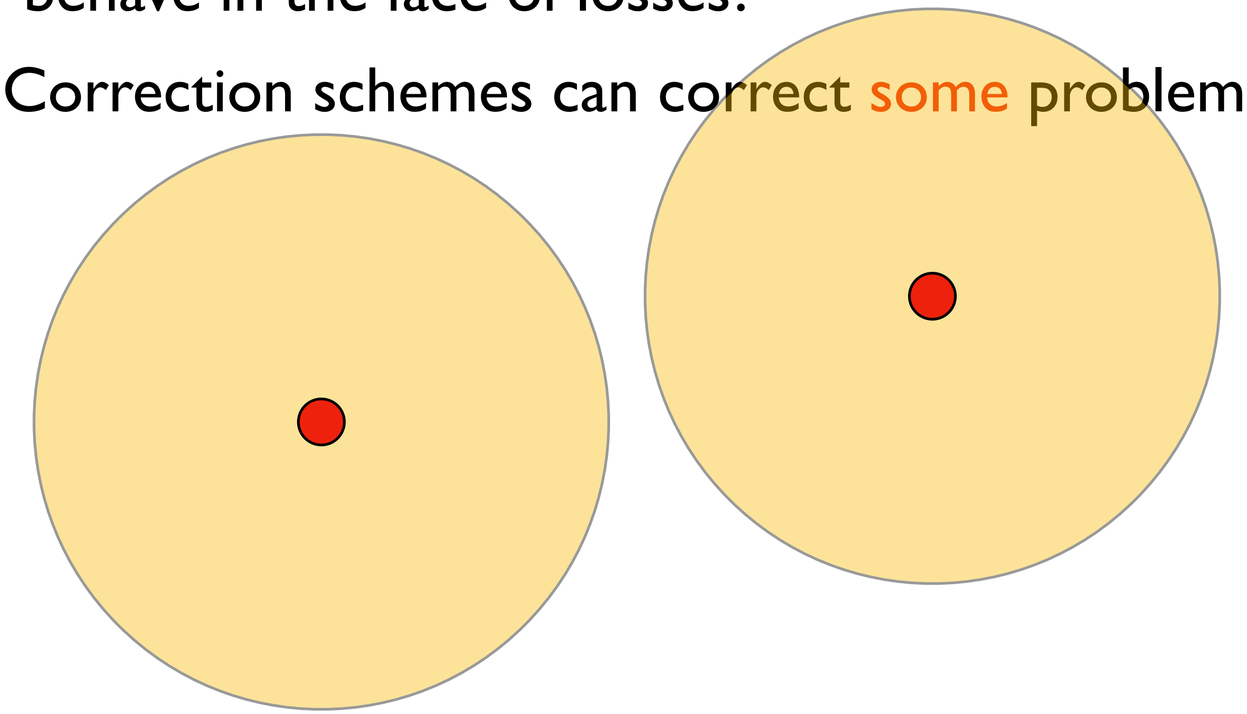


Signal-to-noise Ratio (SNR)

- Relative ratio of:
  - Strength of received signal, and,
  - Background noise
- Larger SNR = easier to extract signal from noise
- Lower SNR = higher Bit Error Rate (BER)
- Can’t we make the signal stronger then?
- Not always a good idea…

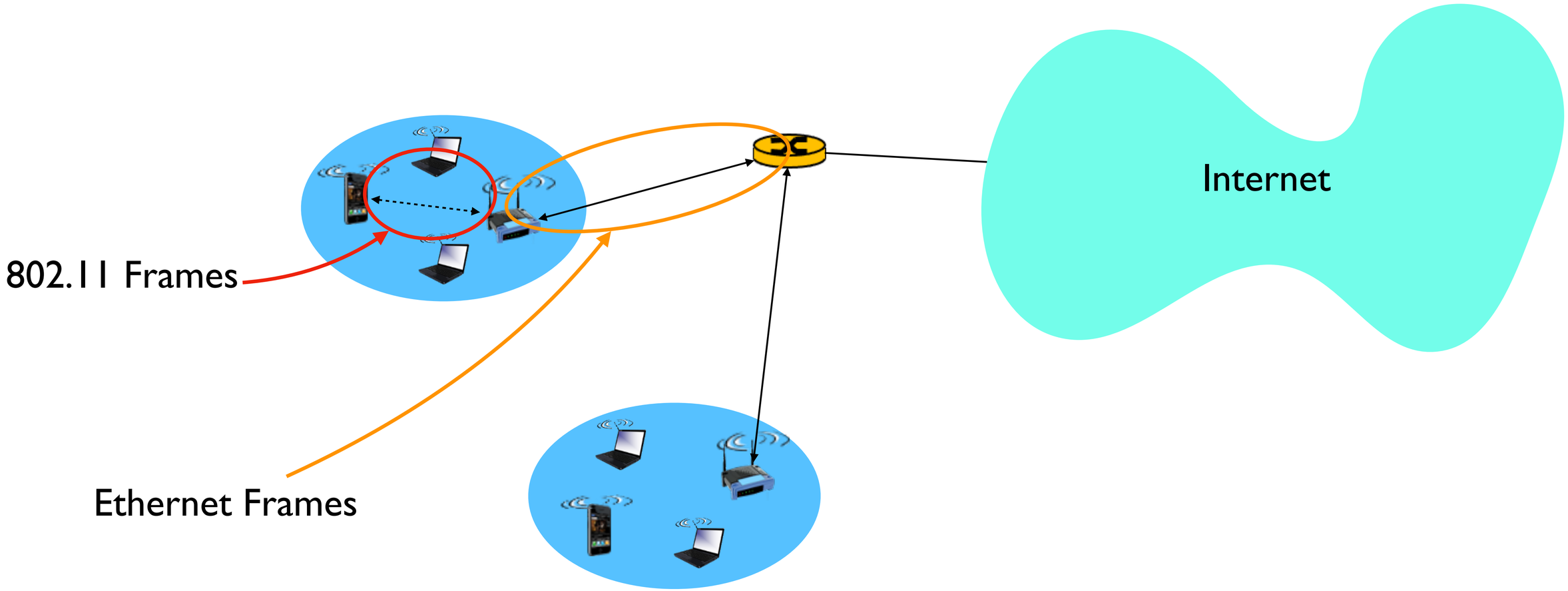
Signal-to-noise Ratio (SNR)

- Why isn't increasing SNR always a good idea?
  - Increased signal strength requires more power
  - Increases the interference range of the sender, so you interfere with more nodes around you
- 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

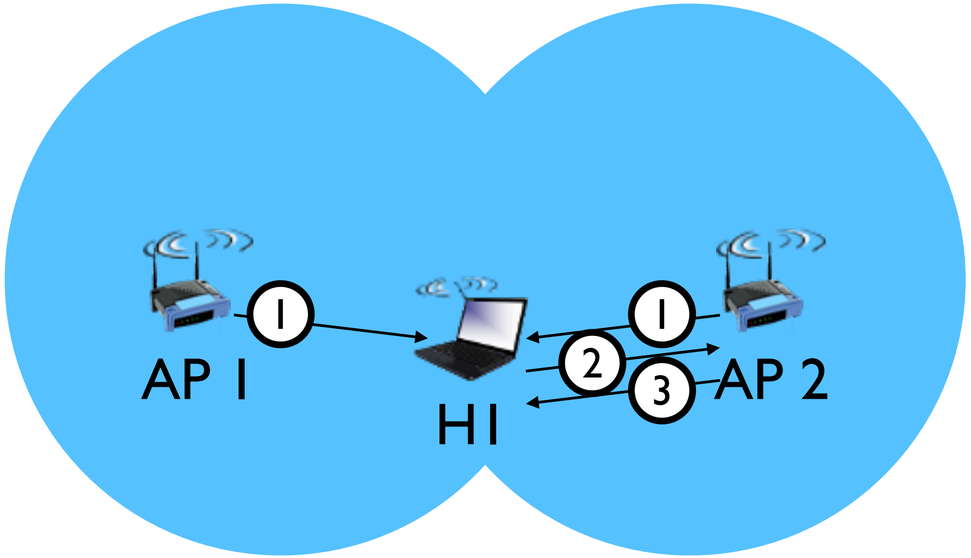


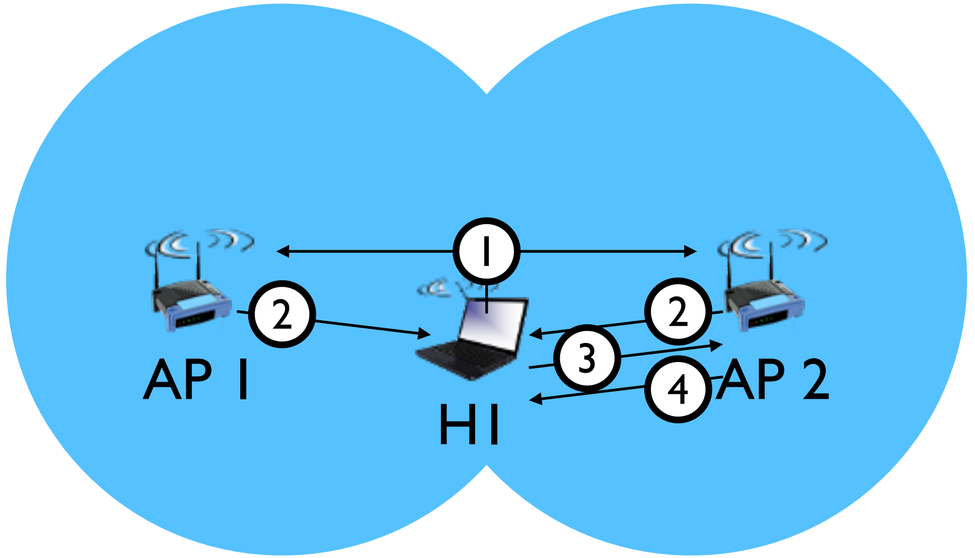
802.11: Channels & Association

- **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





Passive scanning:

(1) Beacon frames sent from APs

(2) Association request frame sent: H1 to selected AP

(3) Association Response frame sent from selected AP to H1

Active scanning:

(1) Probe request frame broadcast from H1

(2) Probe response frames sent from APs

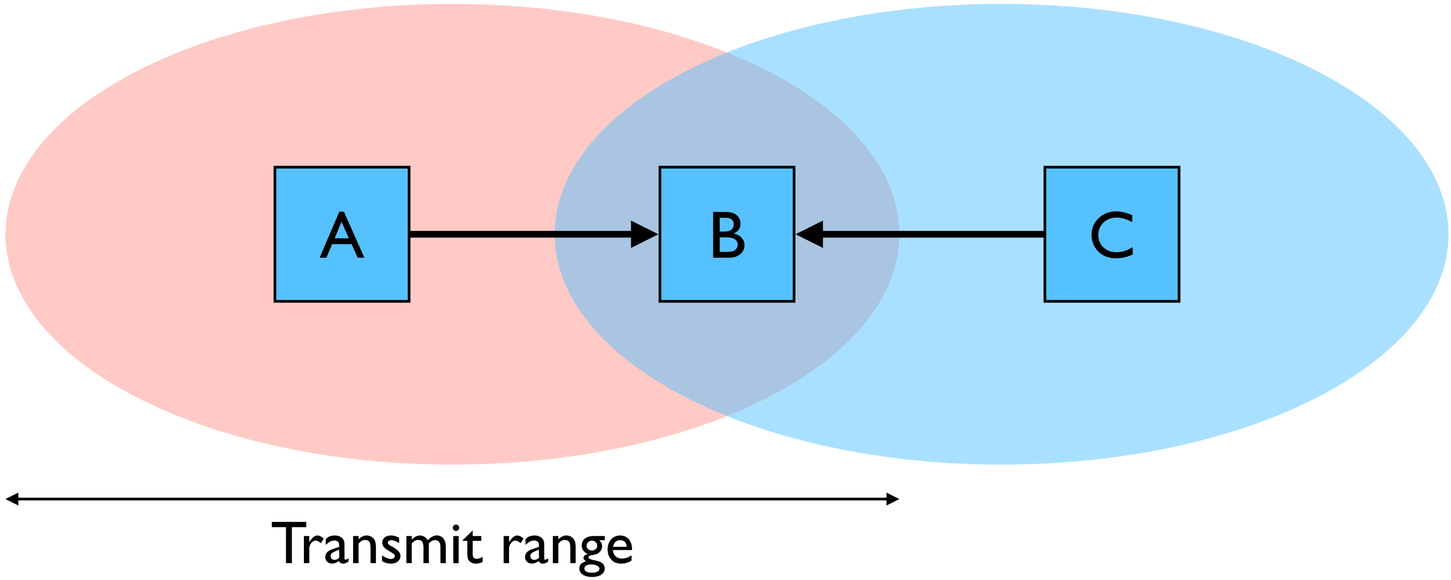
(3) Association request frame sent: H1 to selected AP2

(4) Association response frame sent from selected AP to H1

Wireless Multiple Access

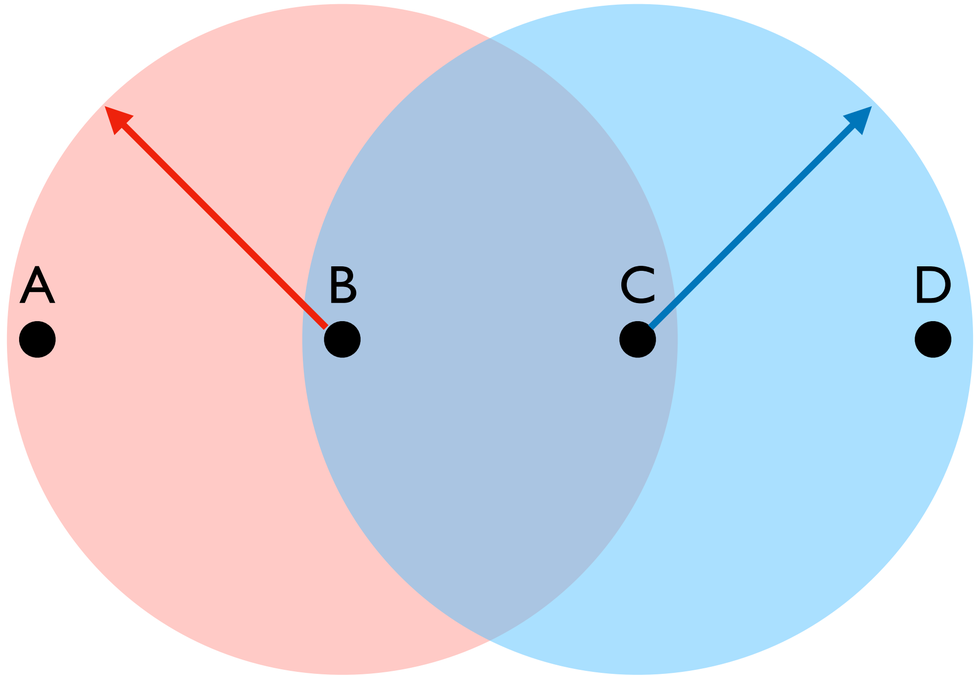
- **Recap: CSMA/CD in wired Ethernet**
  - *Carrier sense*: listen before you speak (wait for link to be idle)
  - *Collision detection*: listen while you speak (if garbled, stop & retry)
- **Carrier sense in wireless**
  - Sender can listen before sending
  - Is it always possible? No! Hidden terminals problem
  - Is it always useful? No! Exposed terminals problem
- **Collision detection in wireless**
  - Is it possible?

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



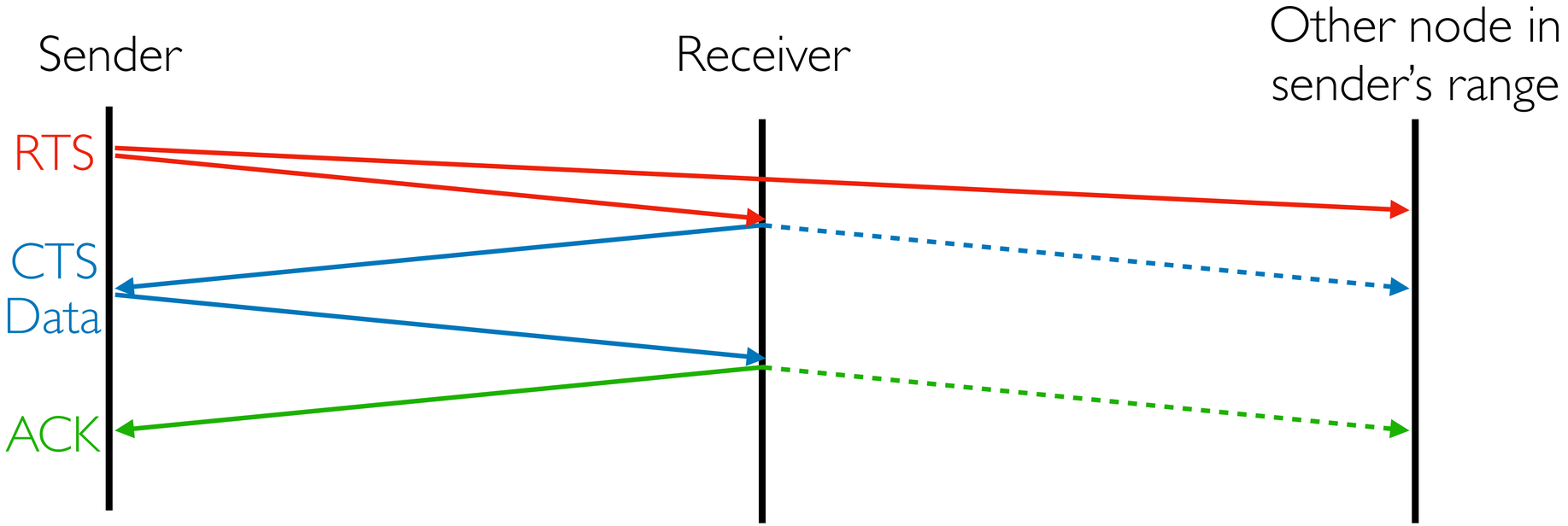
- B sends a packet to A
- C hears this and decides not to send a packet to D
  - *Even though this will not cause interference*
- Carrier sense would prevent a successful transmission

Questions?

What have we learned?

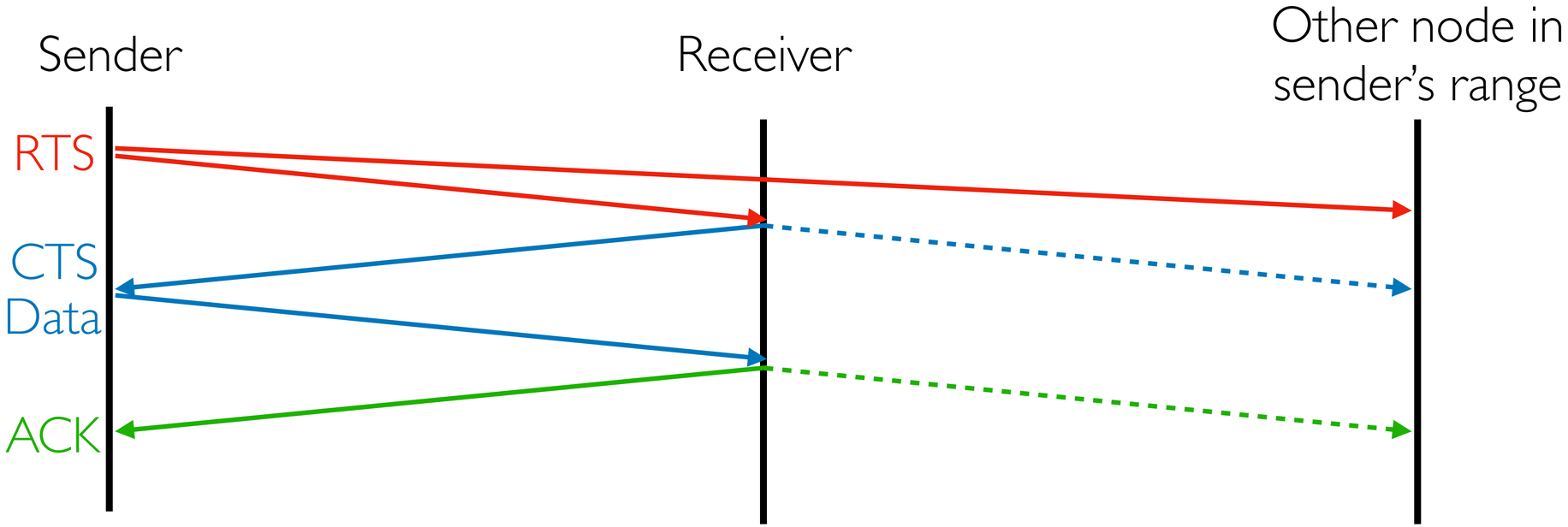
- ***No global collisions* due to path attenuation**
  - Different receivers hear different signals
  - Different senders reach different receivers
- ***Collisions are at receiver*, not sender**
  - Only care if receiver can hear sender clearly
  - Doesn't matter if sender can hear someone else (exposed 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



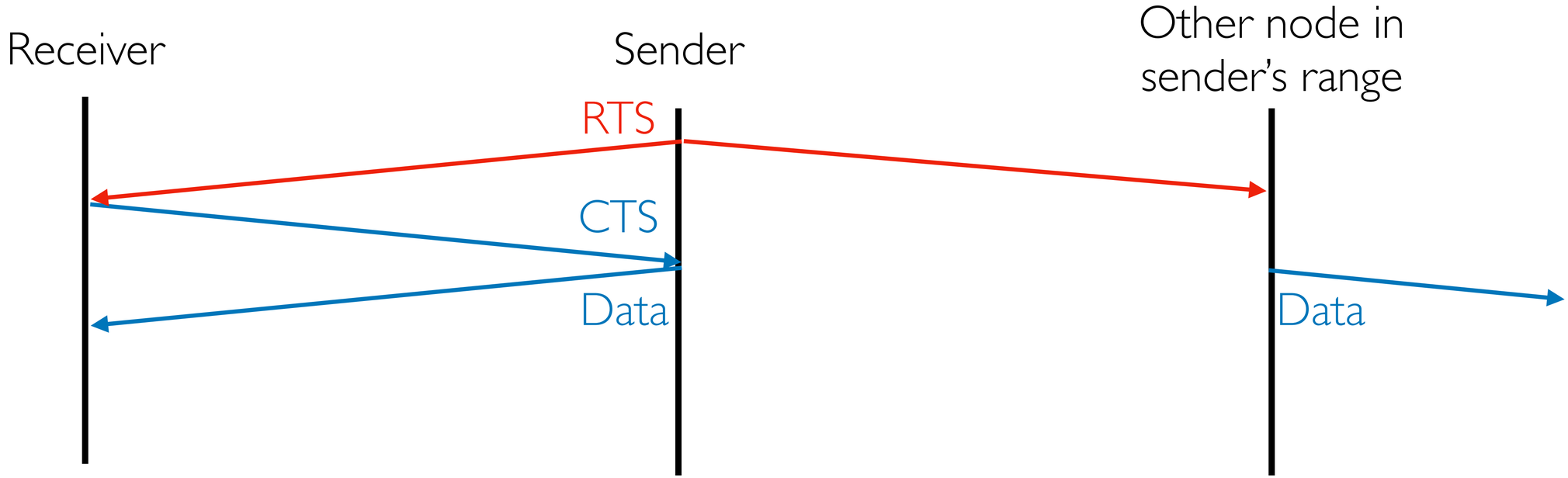
- **First exchange control frames before transmitting data**
  - Sender issues Request to Send (RTS), including length of data and destination
  - Receiver responds with Clear to Send (CTS)
  - If sender sees CTS for its own RTS, transmits data
  - Receiver sends an ACK; now other sender can send

Collision Avoidance: Note#1



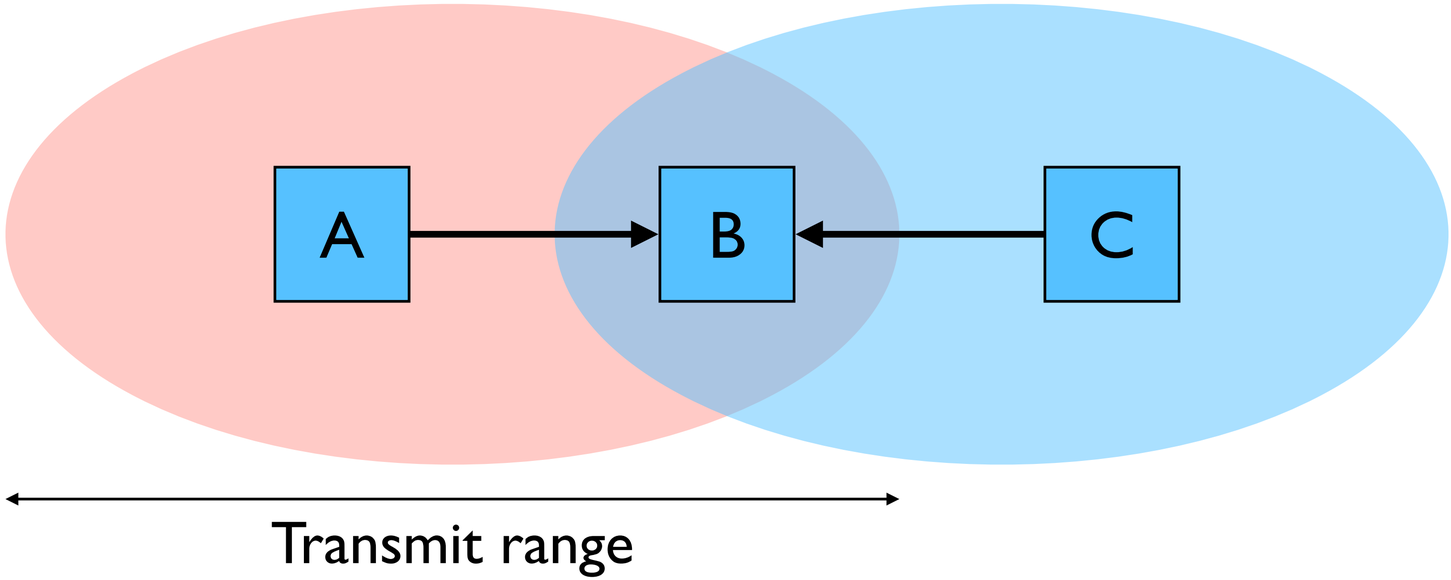
- When you hear a CTS, you keep quiet until scheduled transmission is over (hear ACK)

Collision Avoidance: Note#2



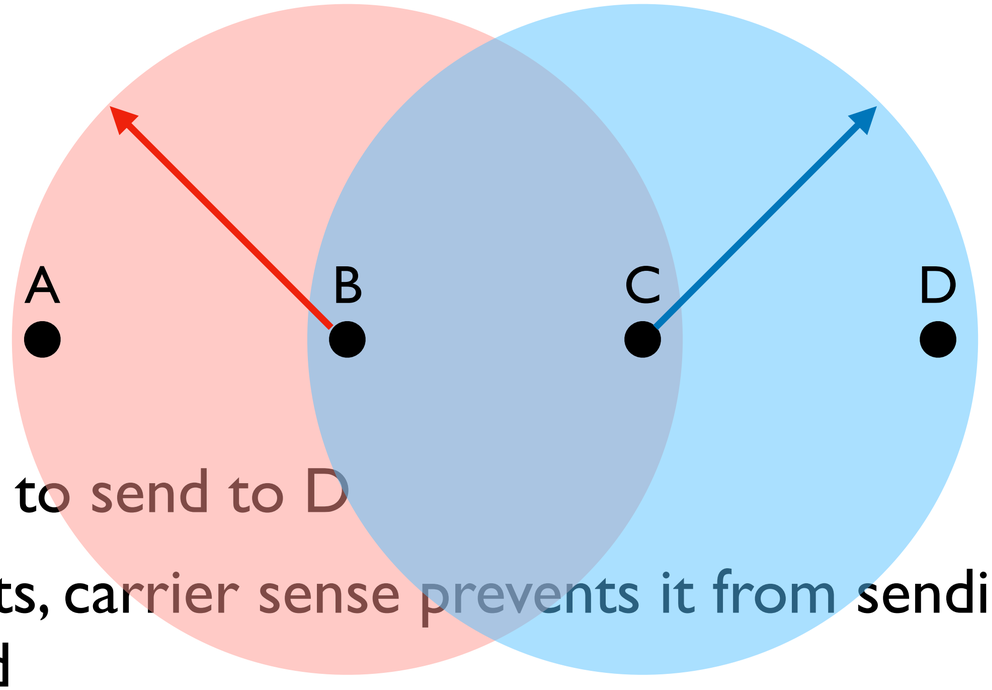
- **If other nodes hear RTS, but not CTS: *send***
  - Presumably, destination for first sender is out of node's range…

Hidden Terminals



- 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

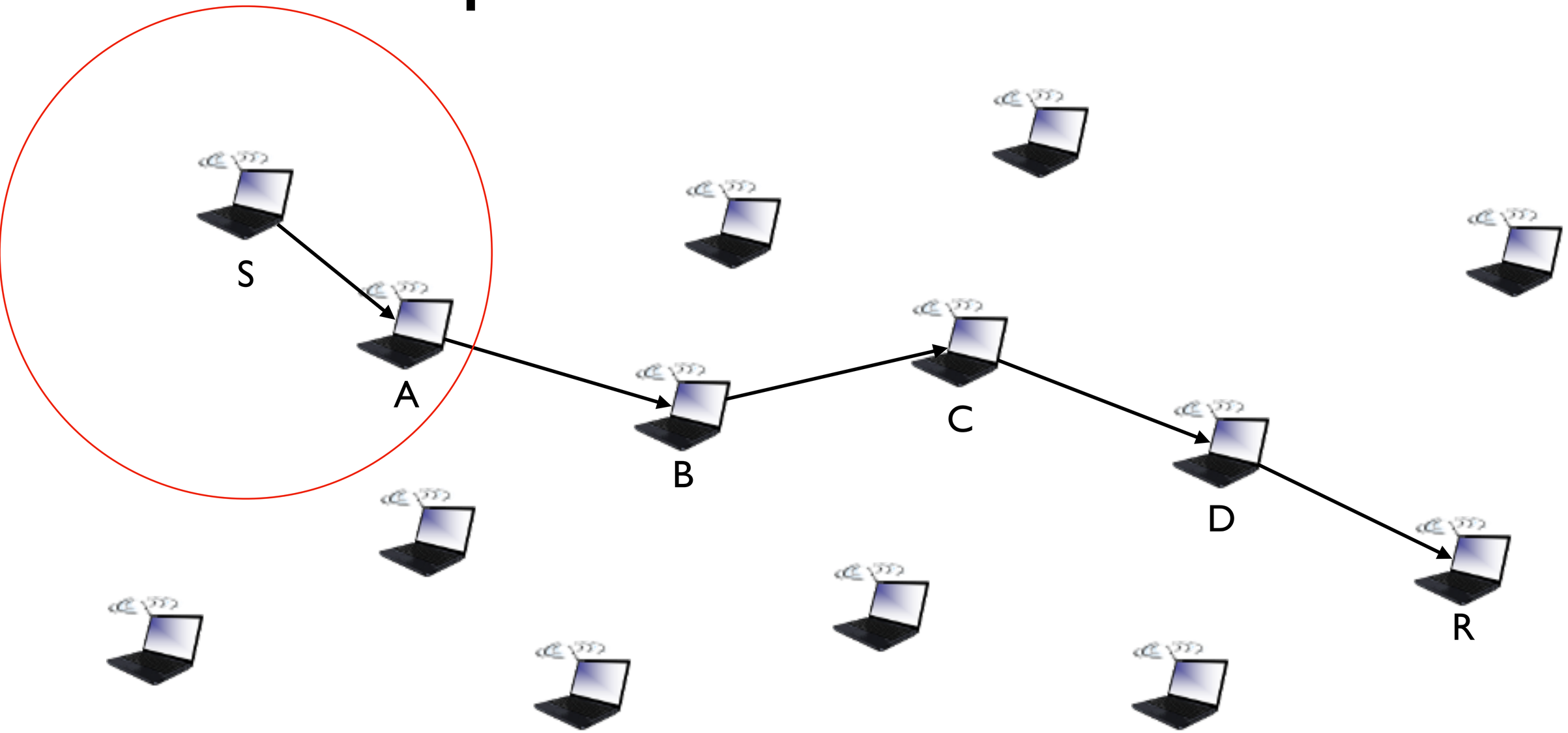
Exposed Terminals



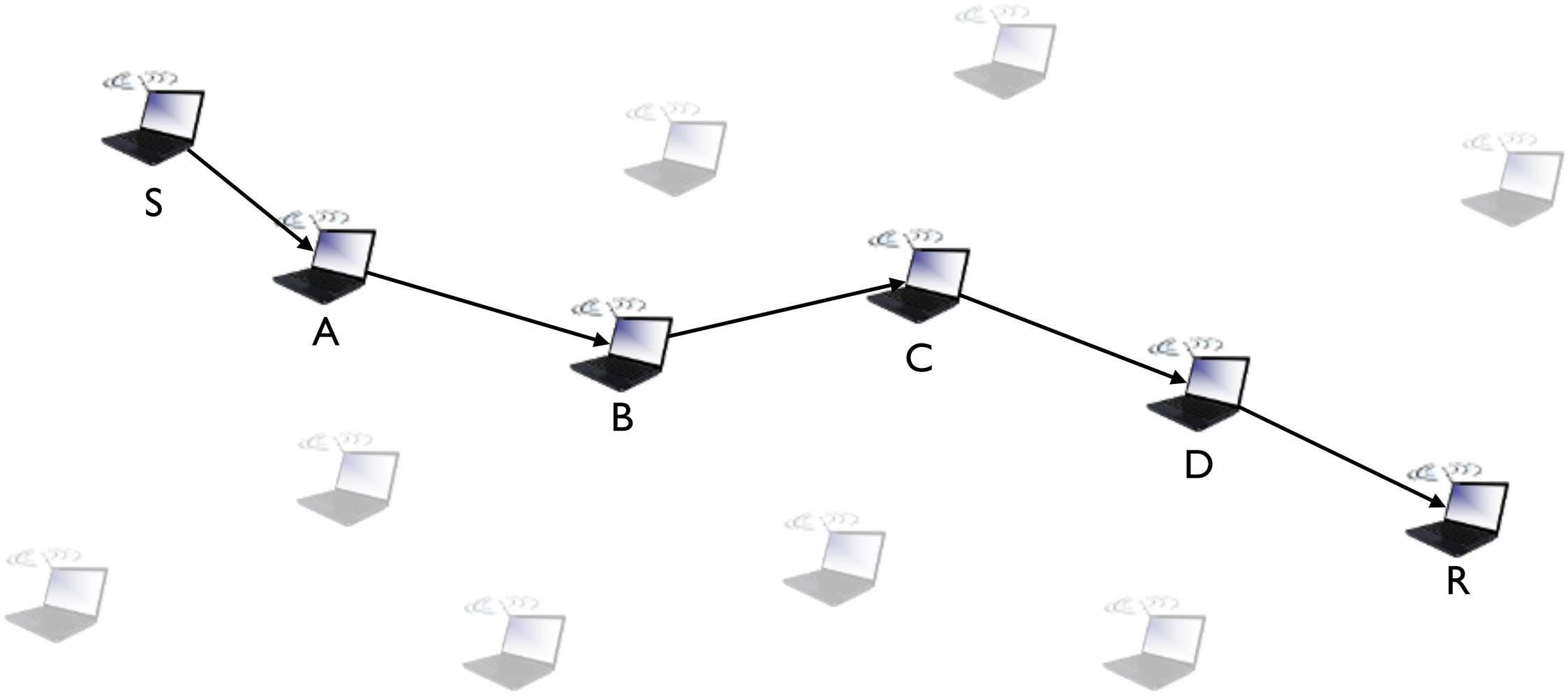
- B sending to A, C wants to send to D
- As C receives B's packets, carrier sense prevents it from sending to D, even though it wouldn't have interfered
- RTS/CTS can help
  - C hears RTS from B, but not CTS from A
  - C knows its transmission will not interfere with A
  - C is safe to transmit to D

Questions?

Multi-Hop Wireless Ad-hoc Networks



Multi-Hop Wireless Ad-hoc Networks



Multi-Hop Wireless Ad-hoc Networks

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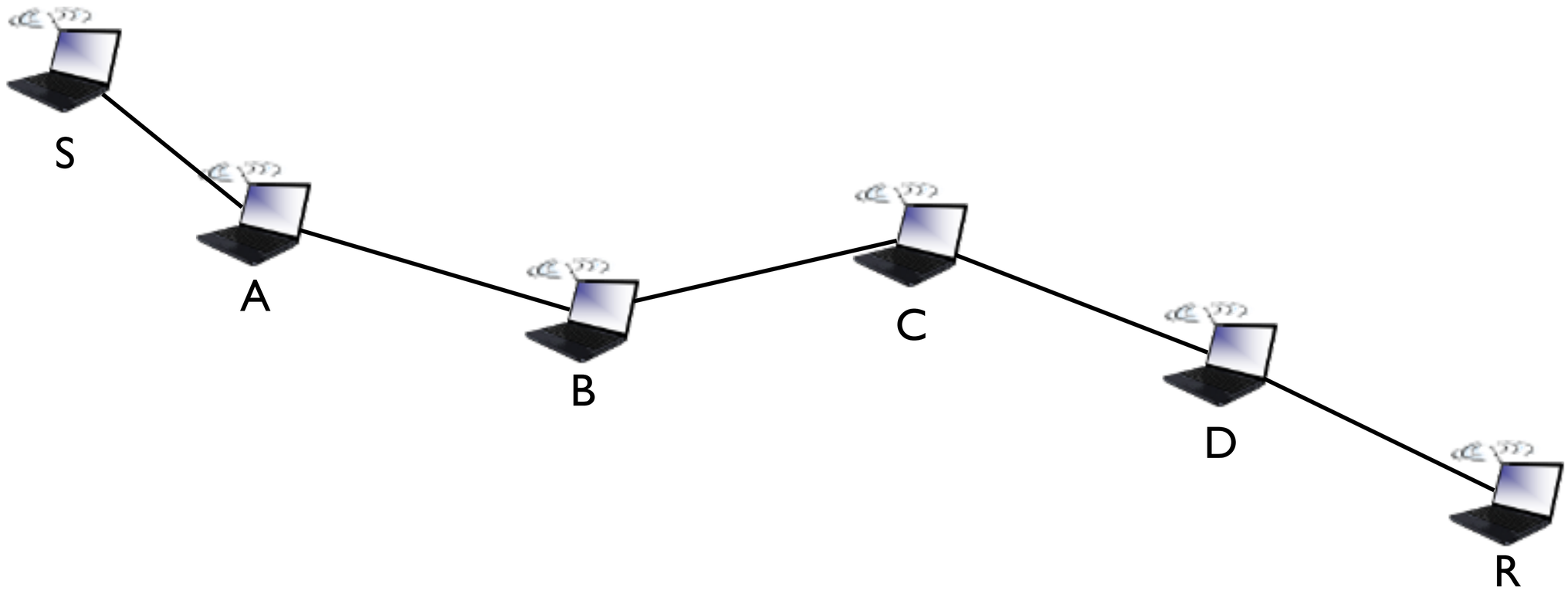

(Assume ideal world…)

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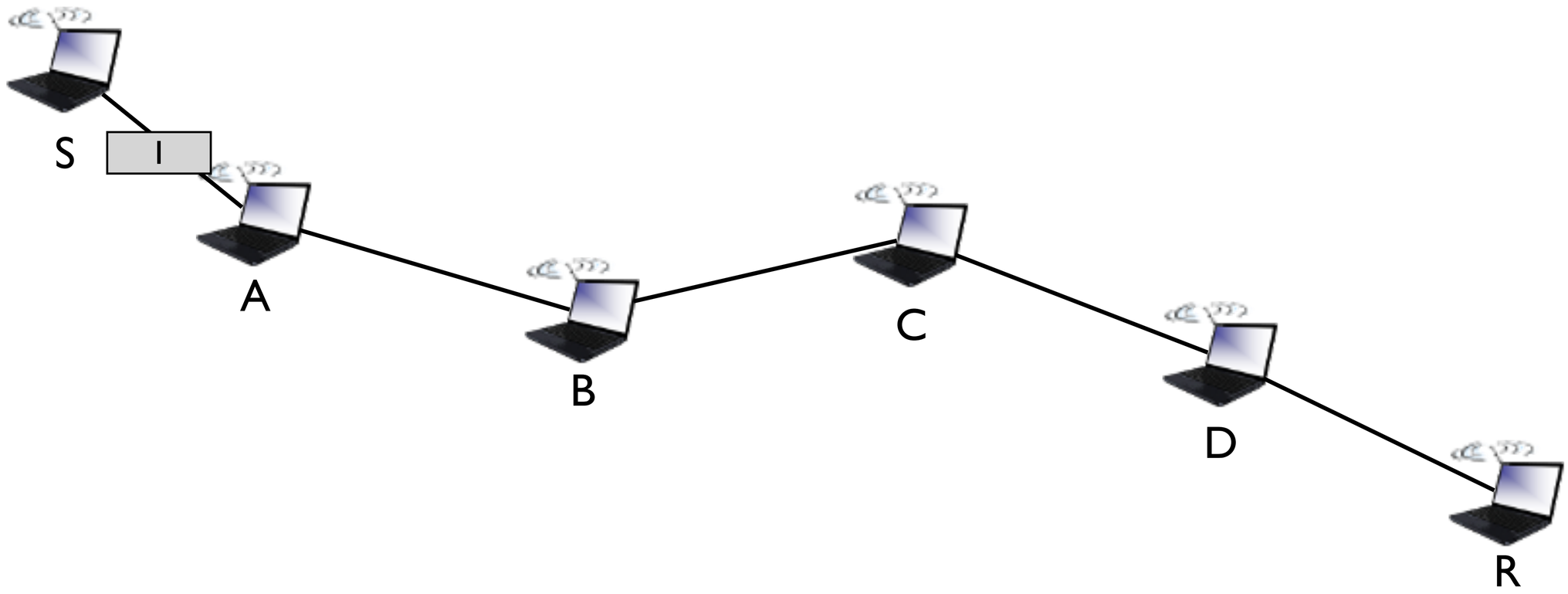

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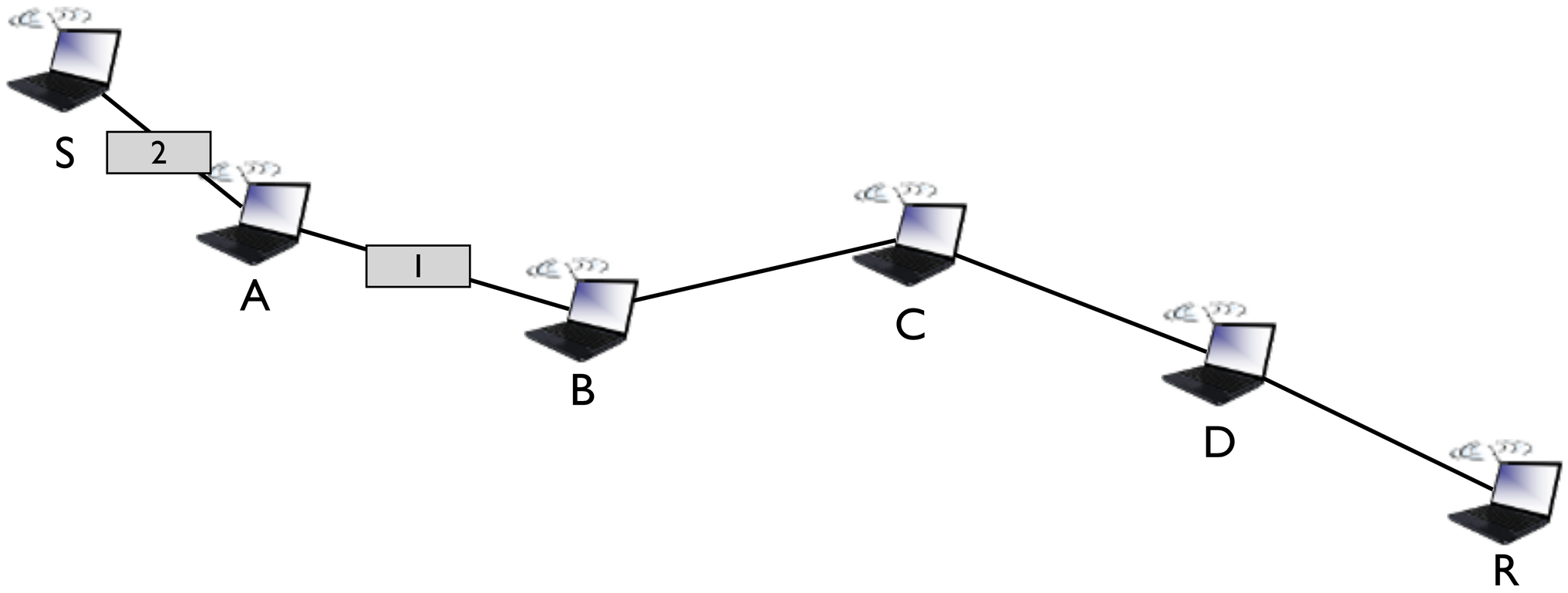

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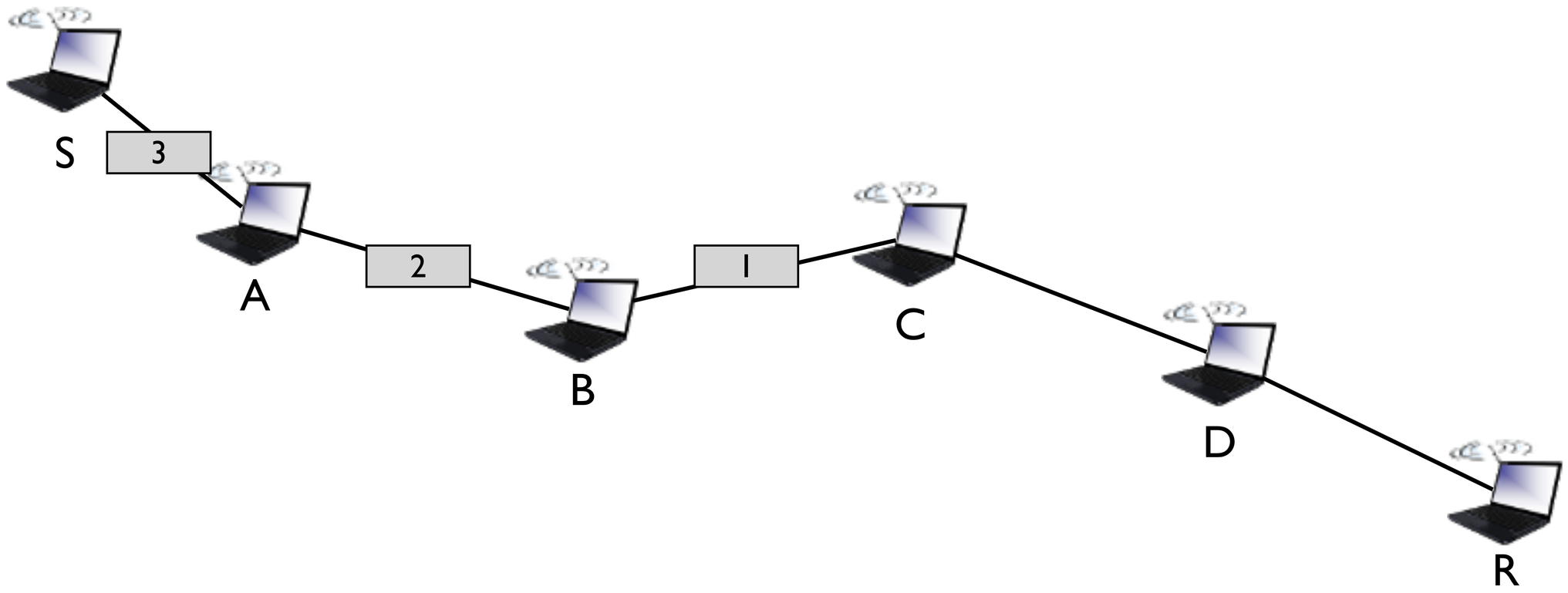

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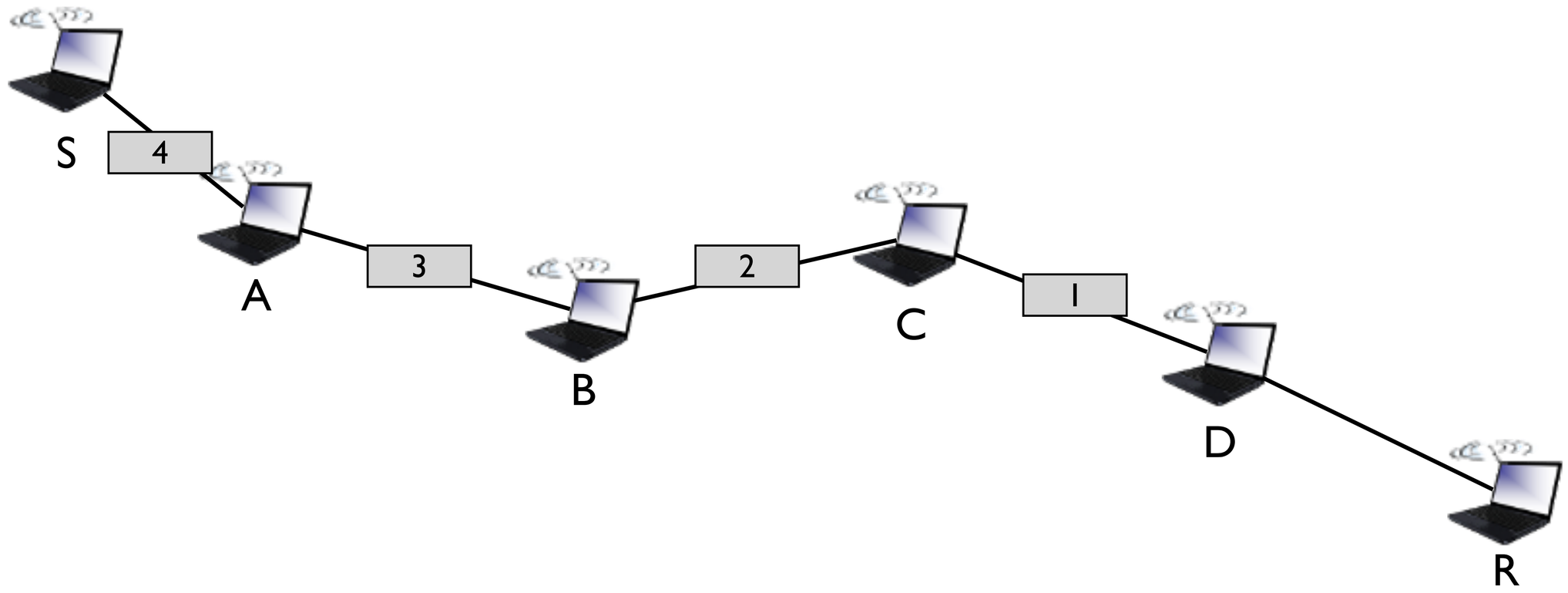

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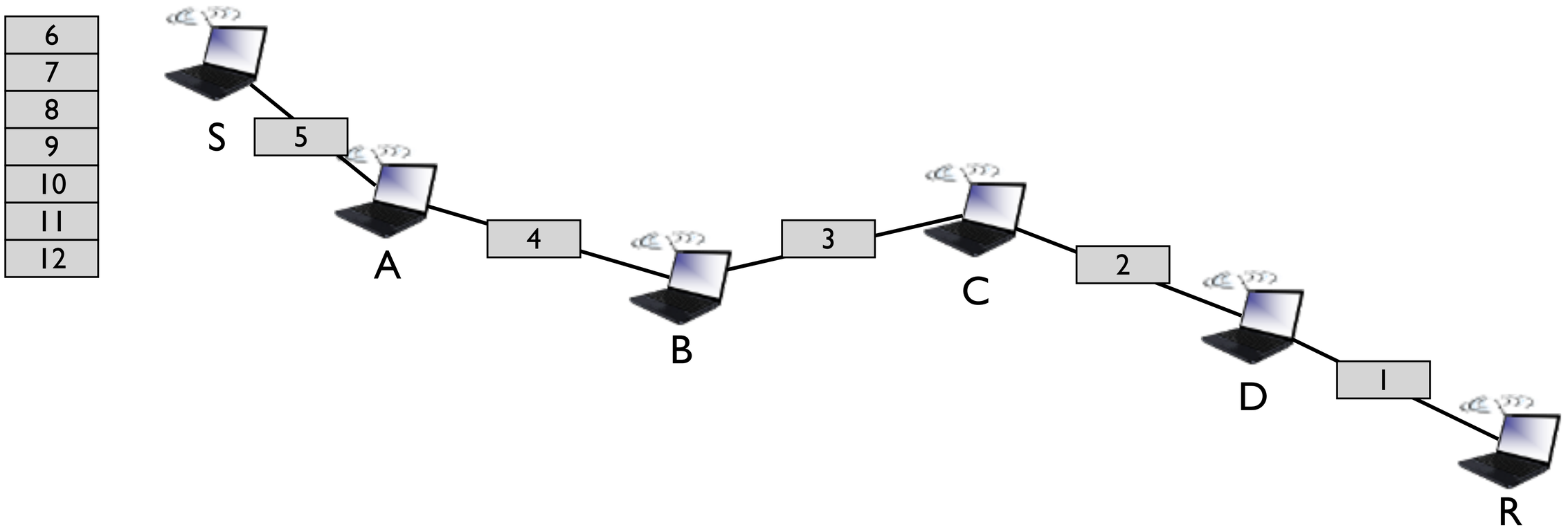

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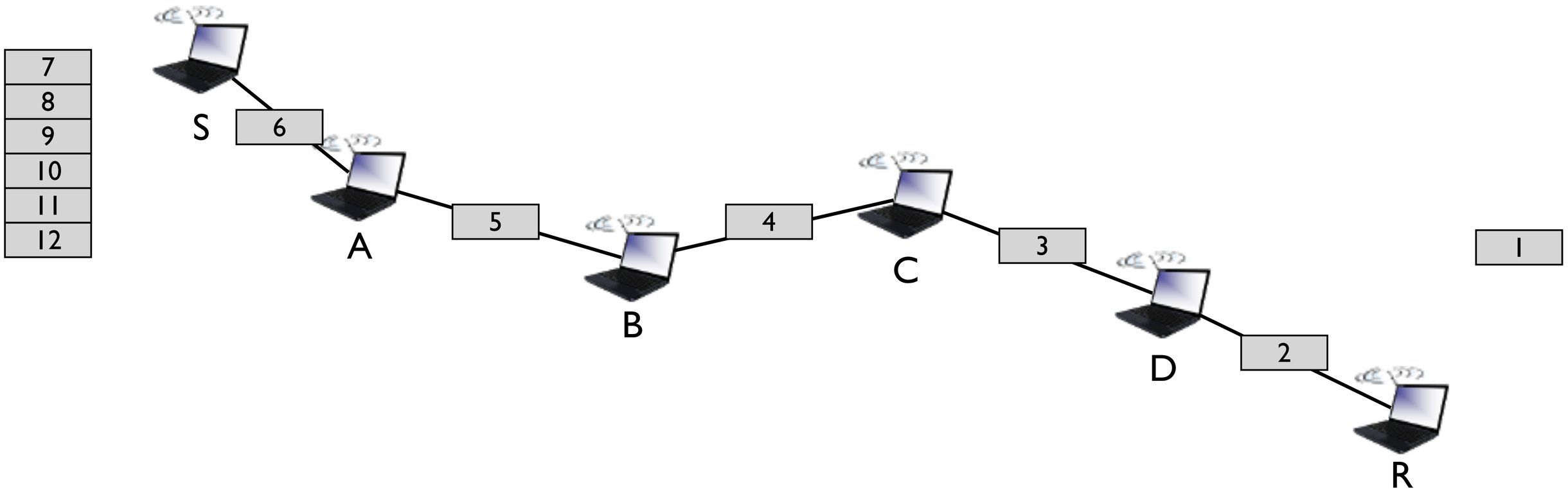

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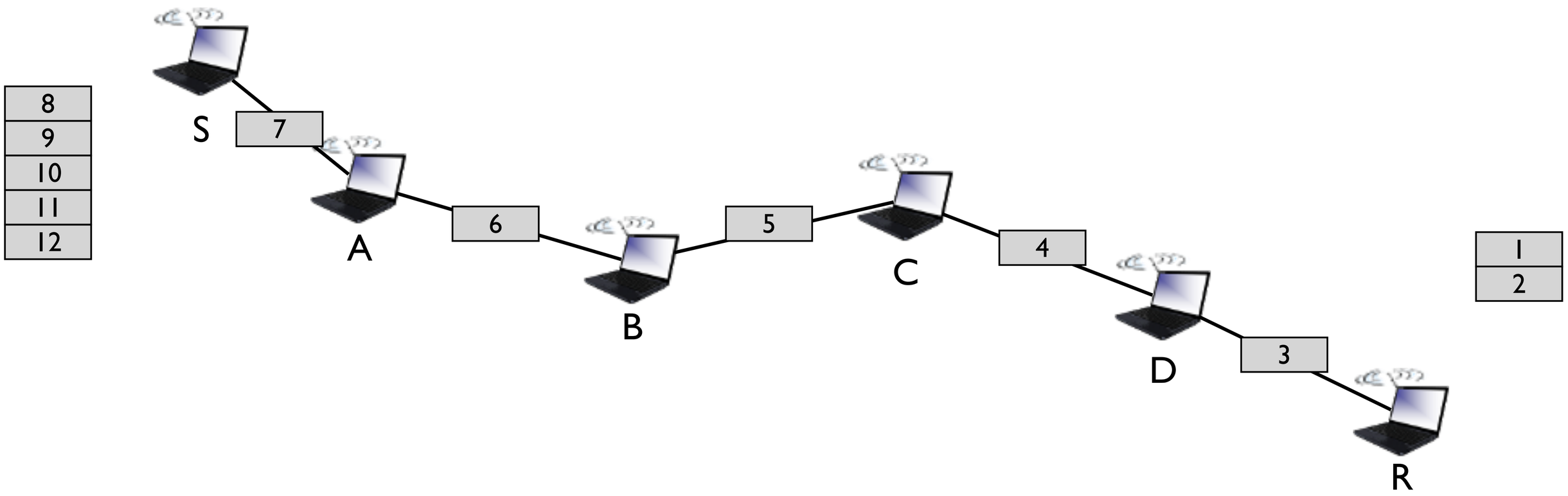

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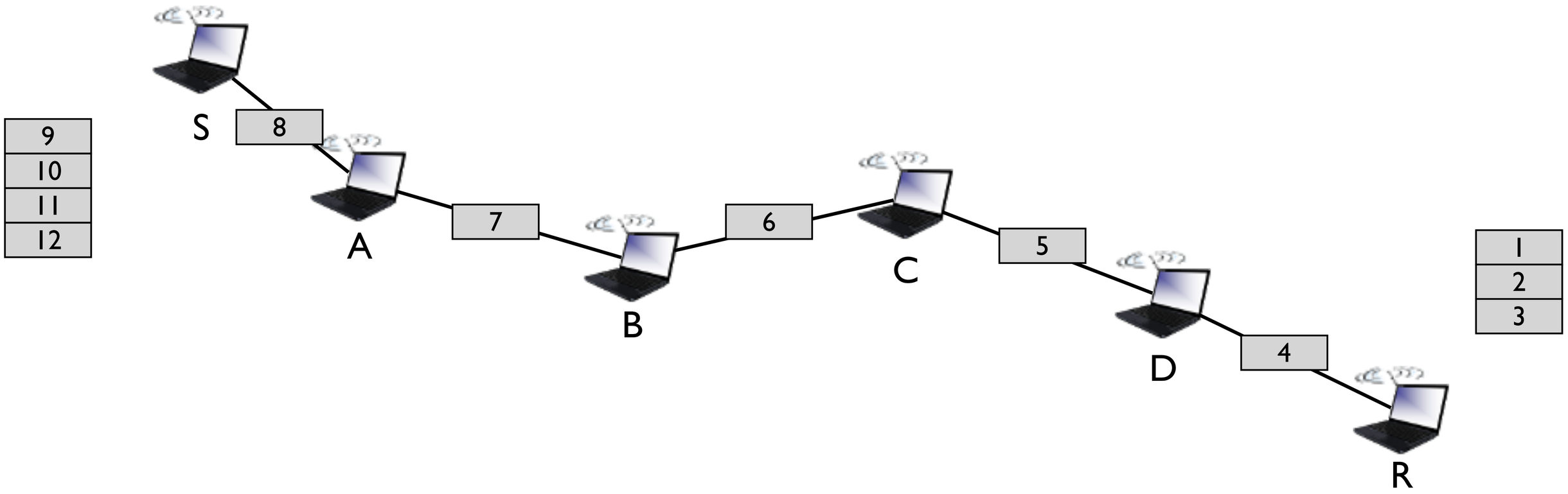

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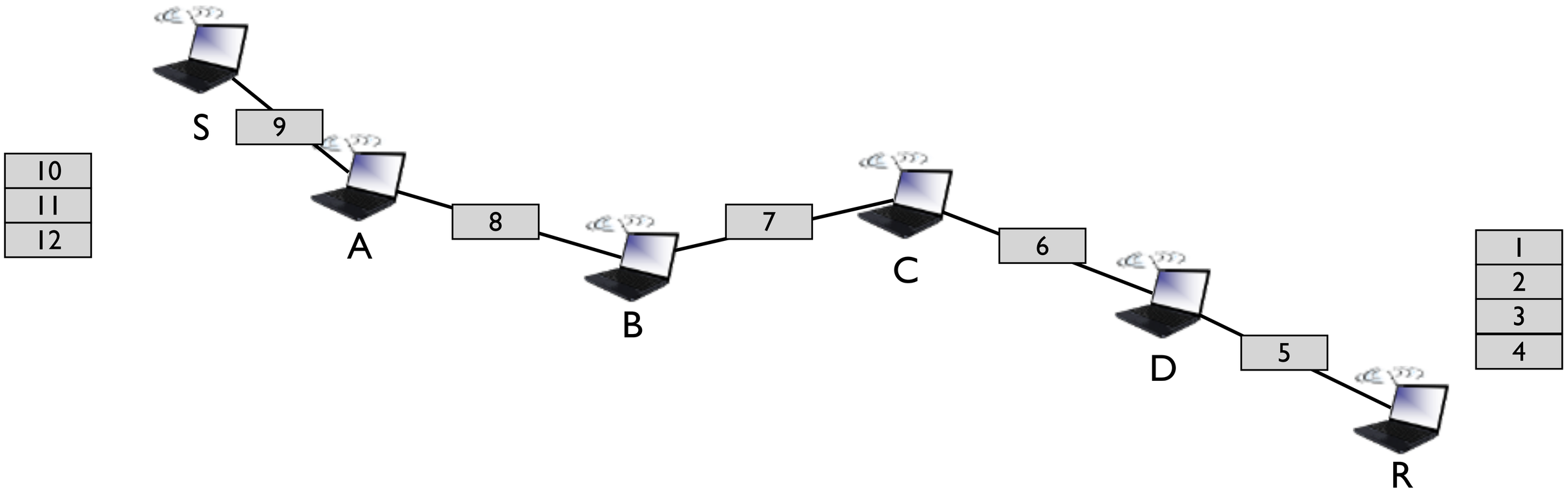

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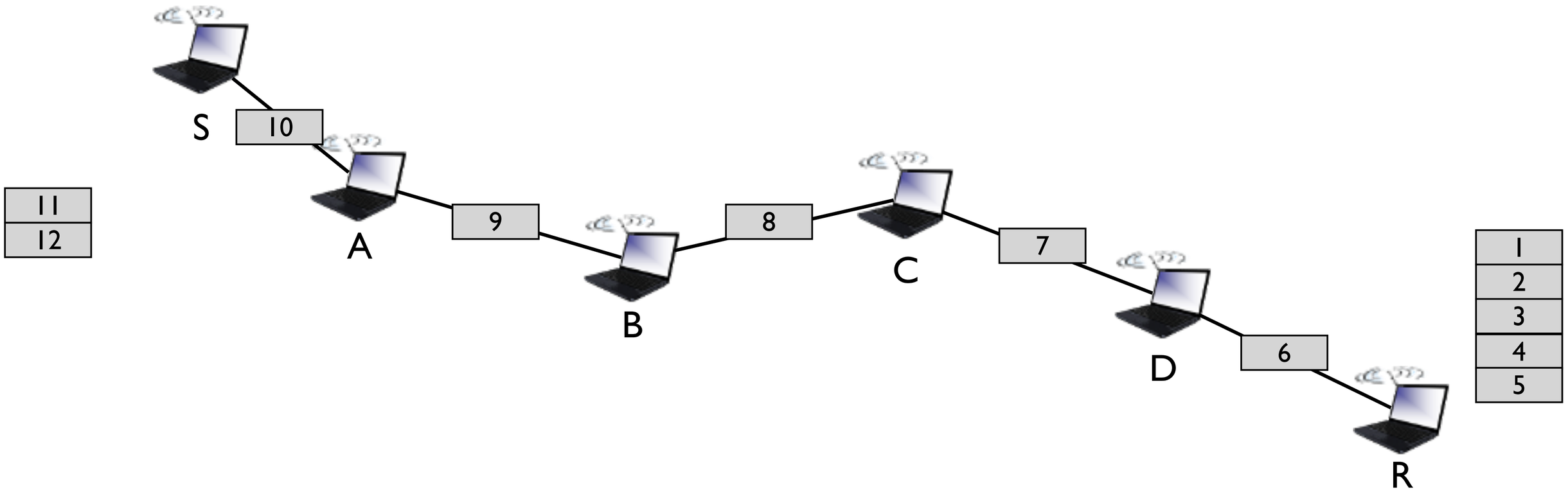

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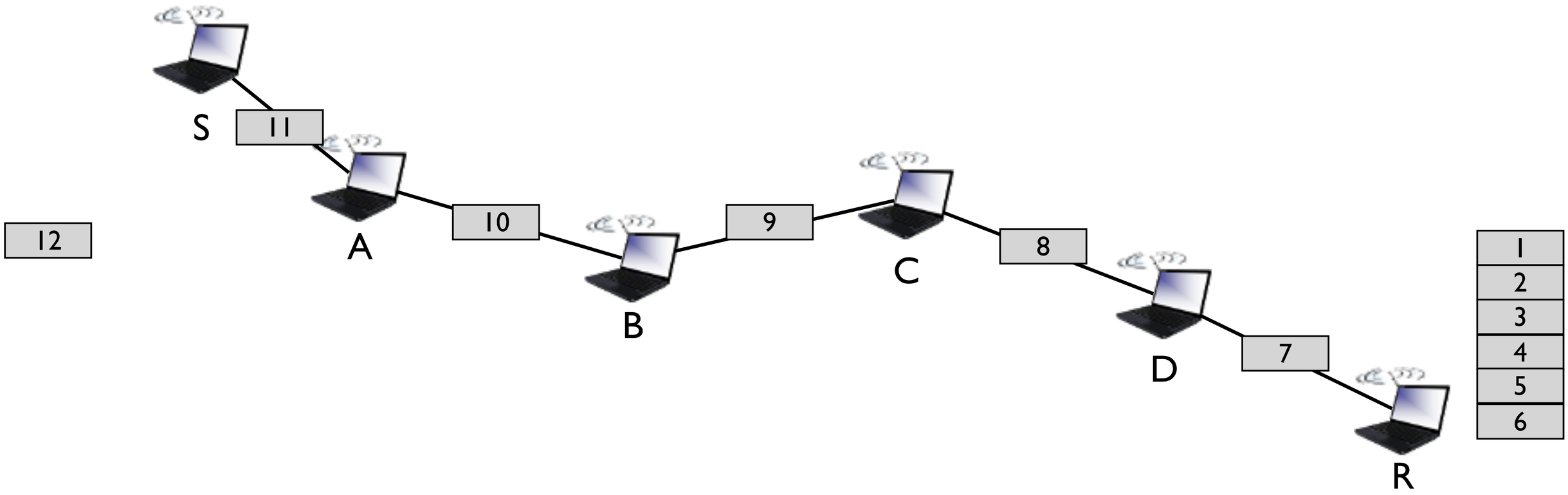

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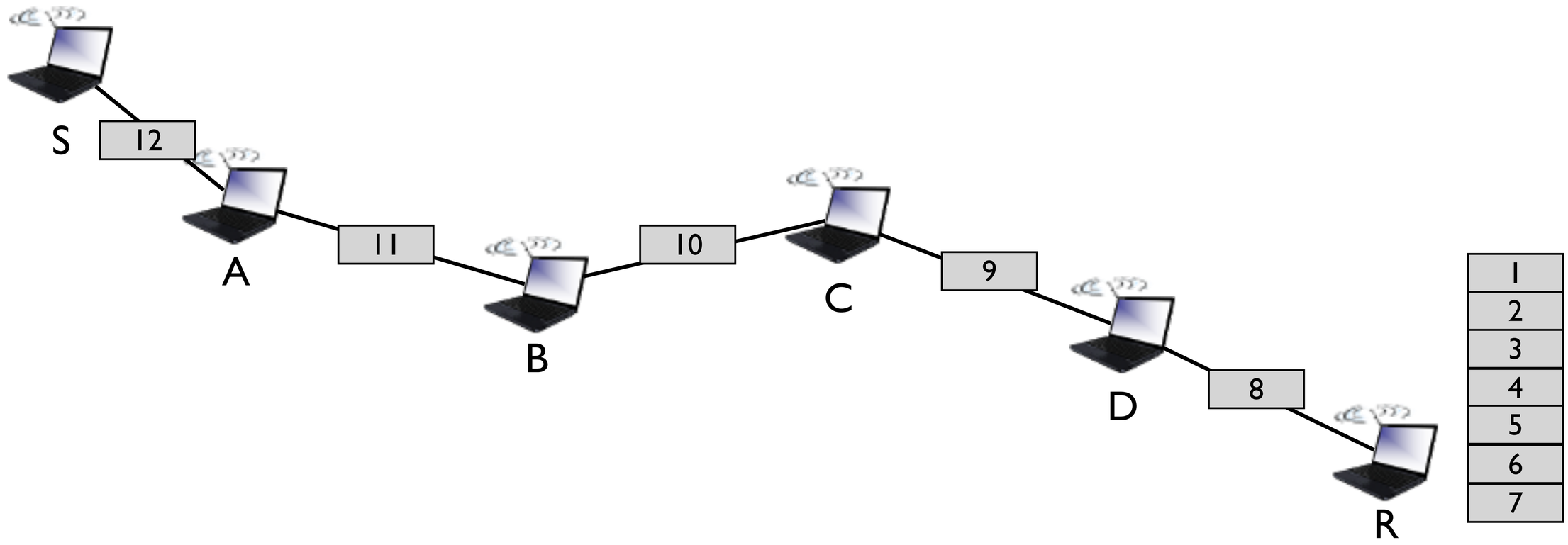

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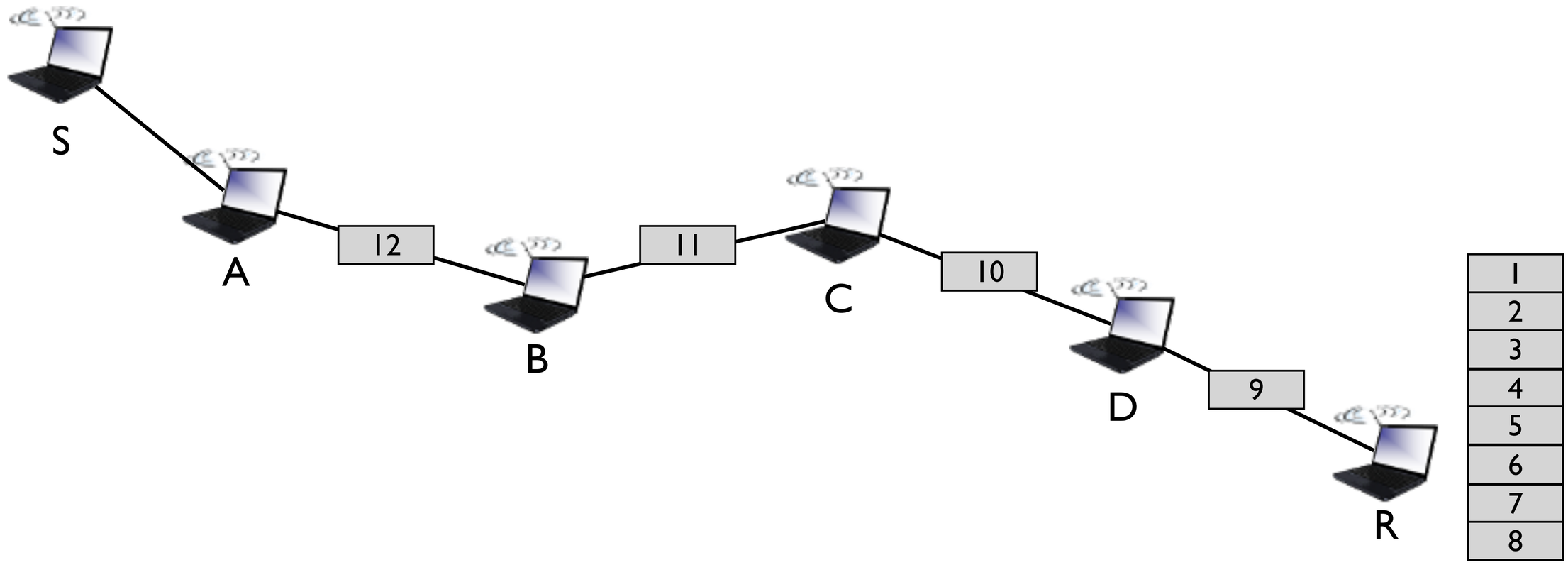

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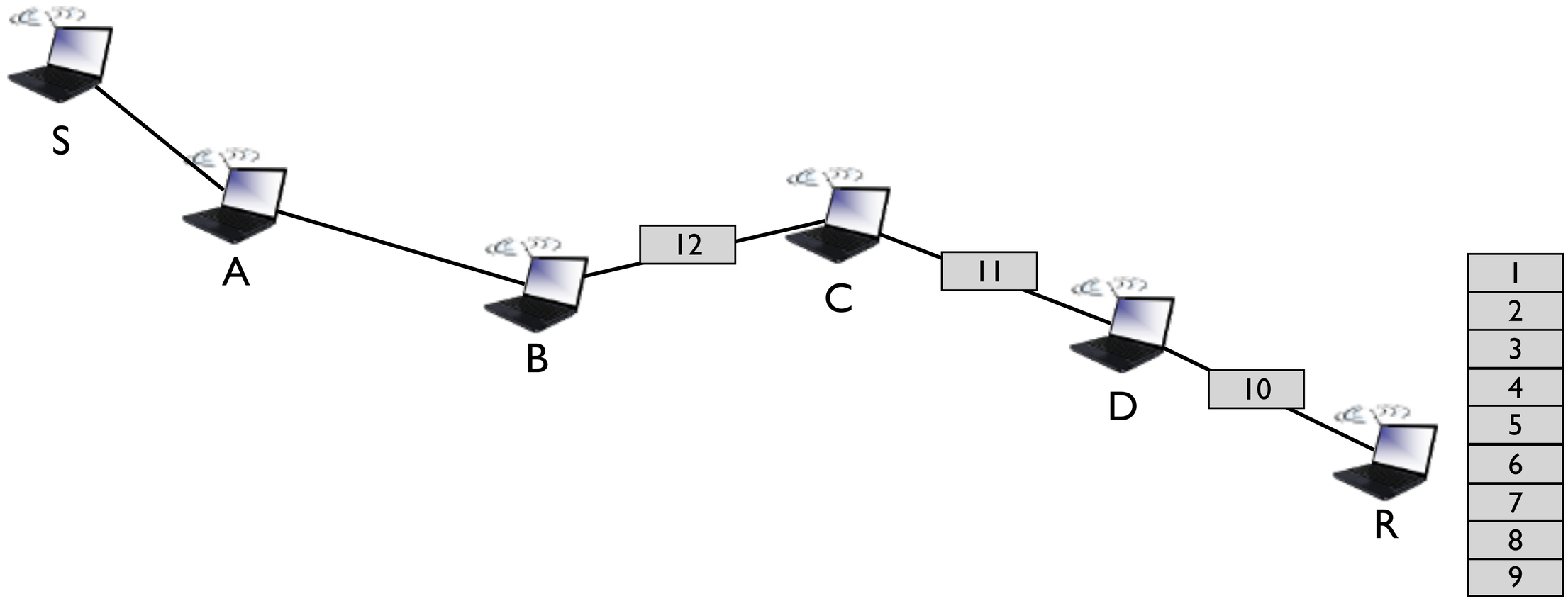

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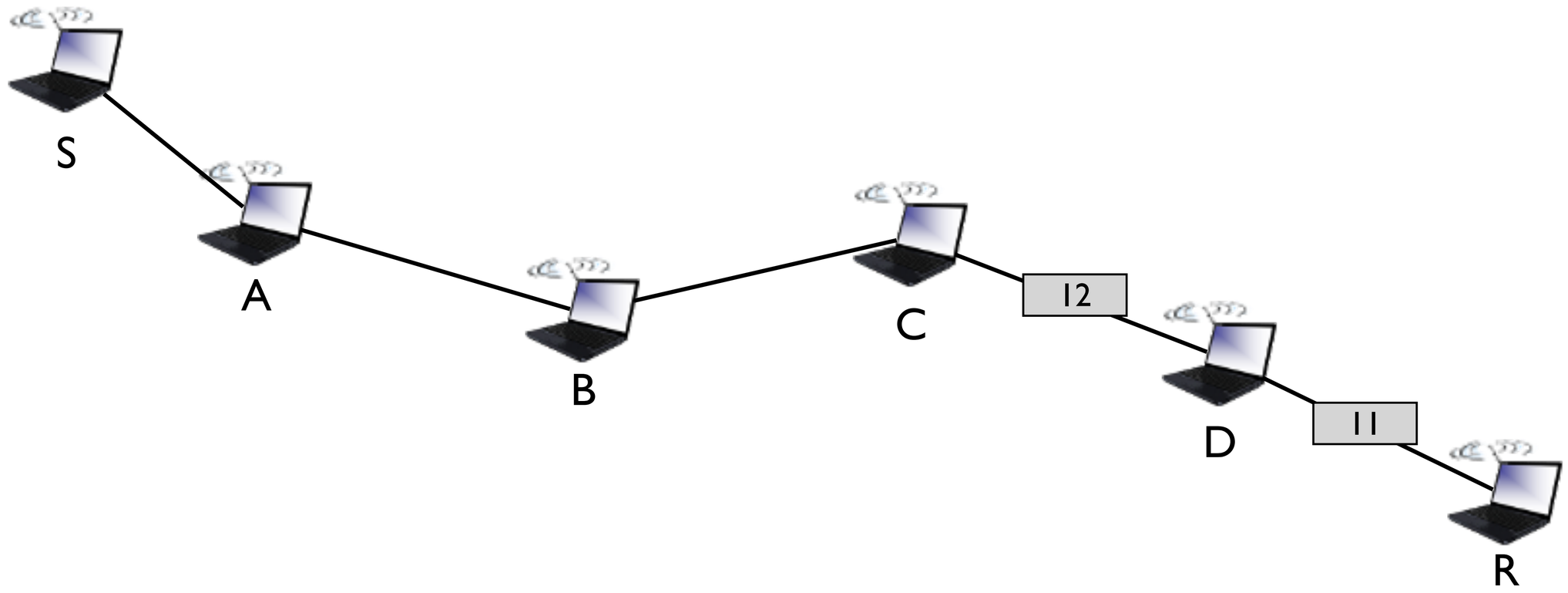

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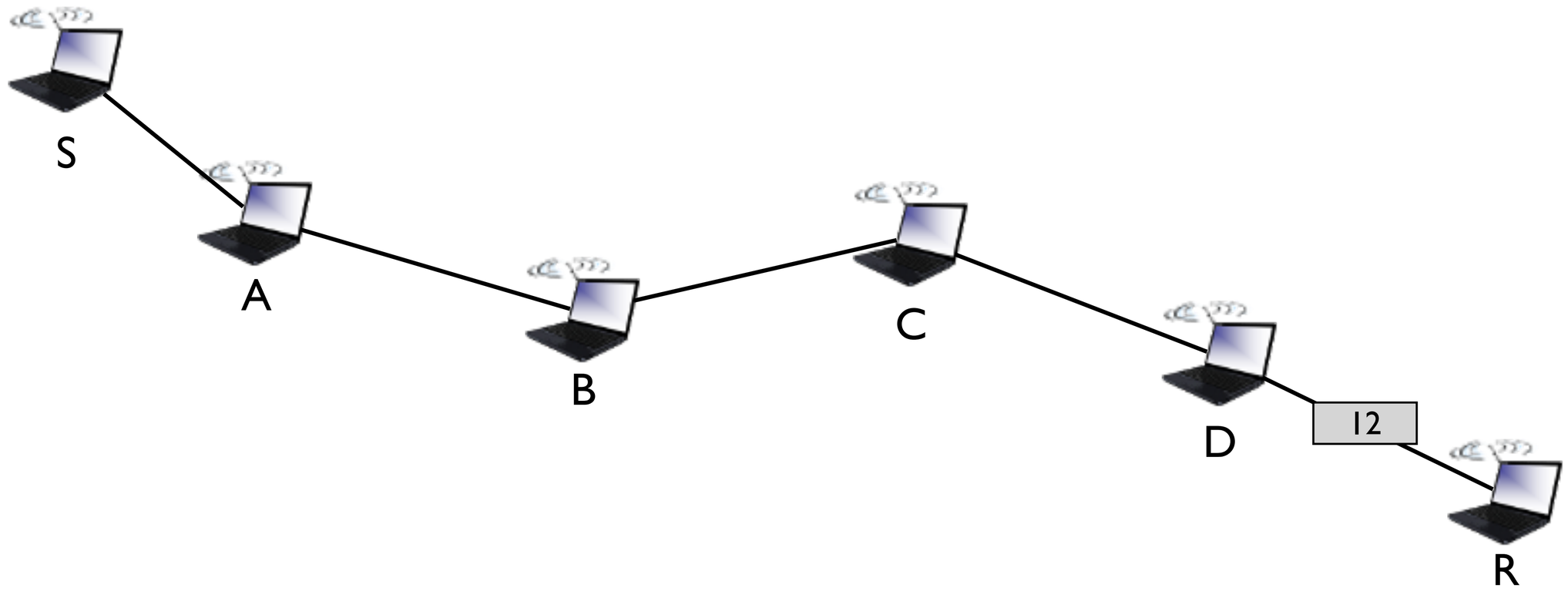

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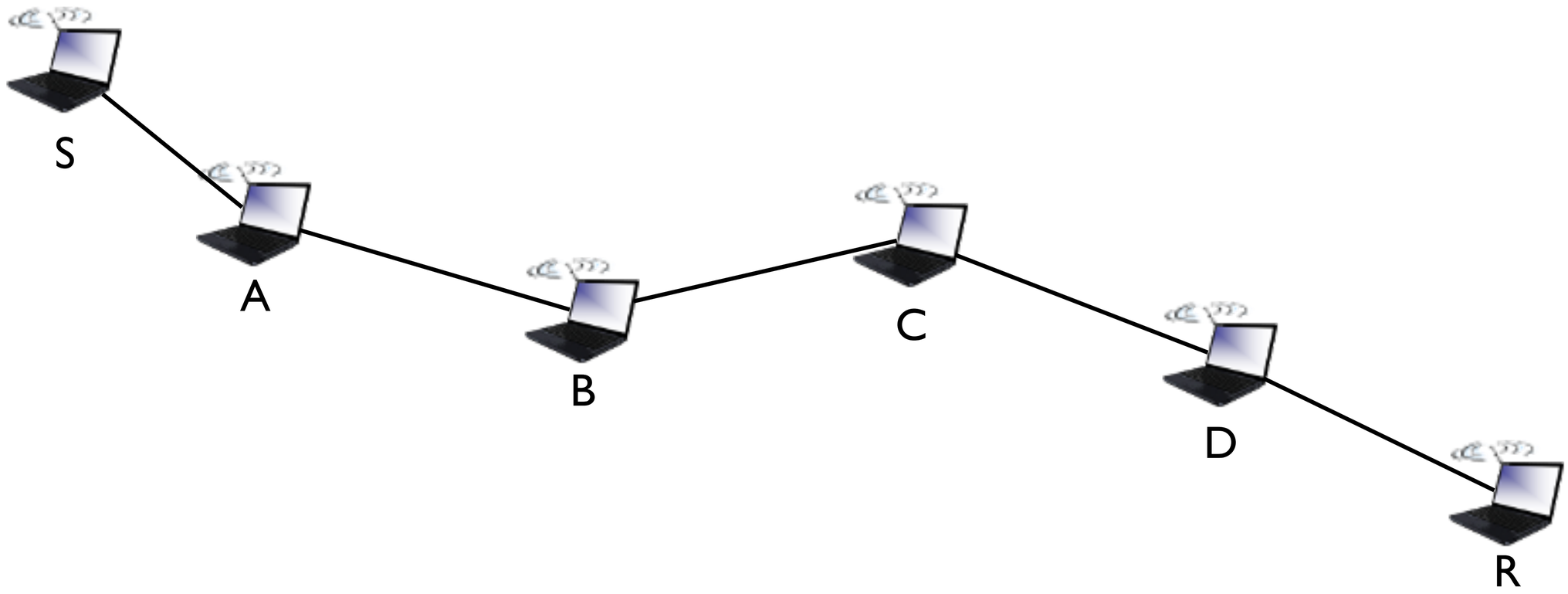

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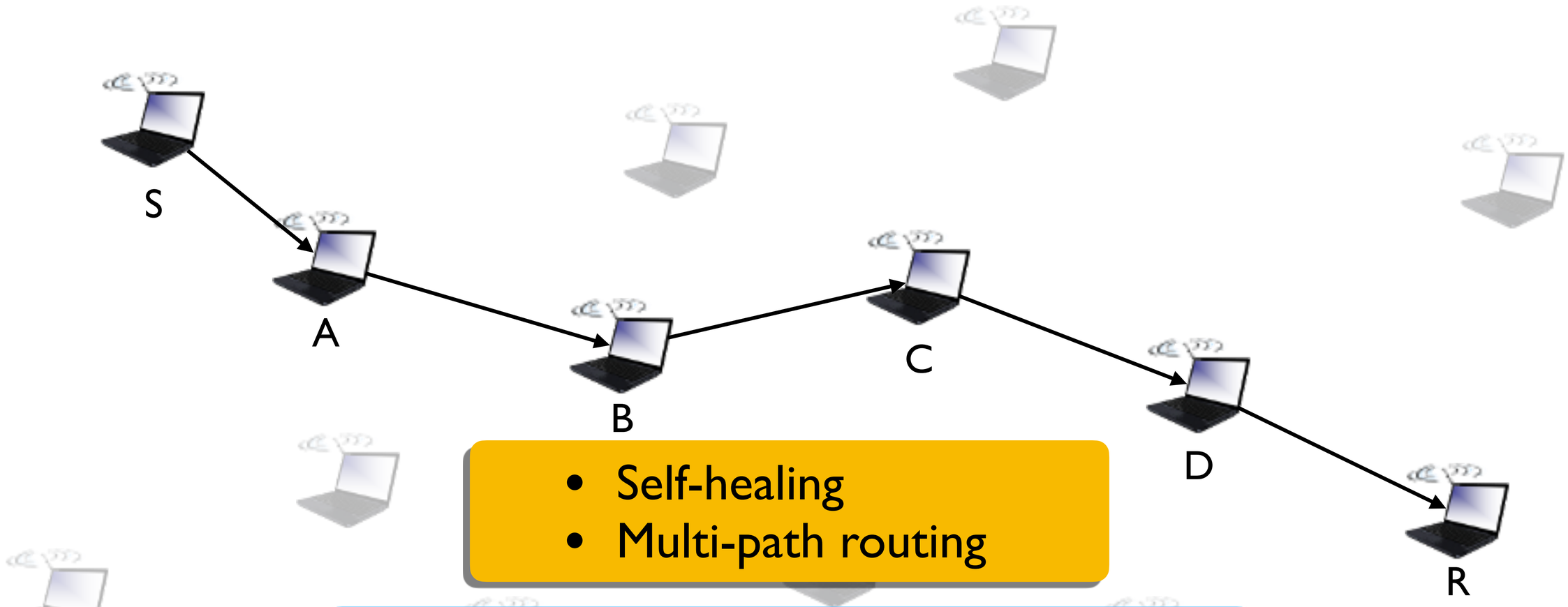

- Self-healing
- Multi-path routing

End of cellular companies & ISPS??

What do **you** think really happens?

Multi-Hop Wireless Ad-hoc Networks

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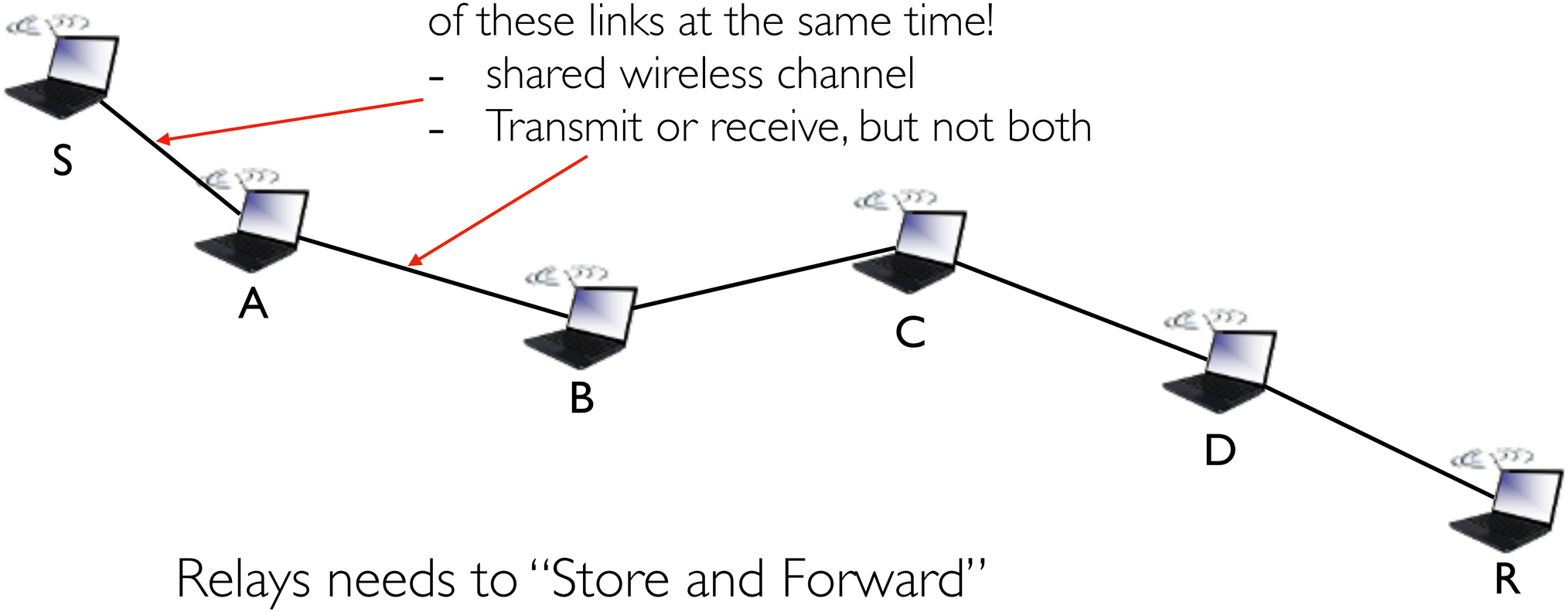
(Reality check…)

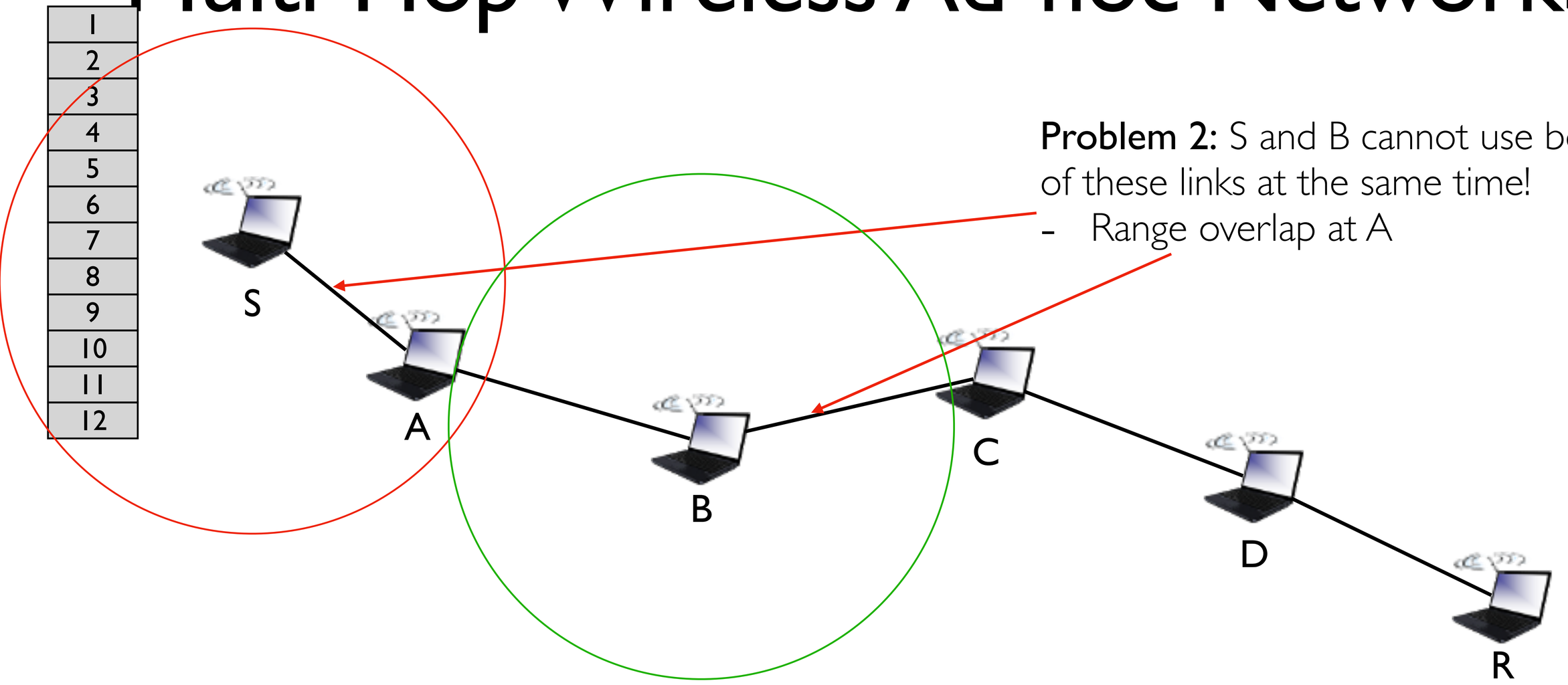
Problem 1: node A cannot use both of these links at the same time!

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



Relays needs to "Store and Forward"

Multi-Hop Wireless Ad-hoc Networks



Problem 2: S and B cannot use both of these links at the same time!

- Range overlap at A

Multi-Hop Wireless Ad-hoc Networks

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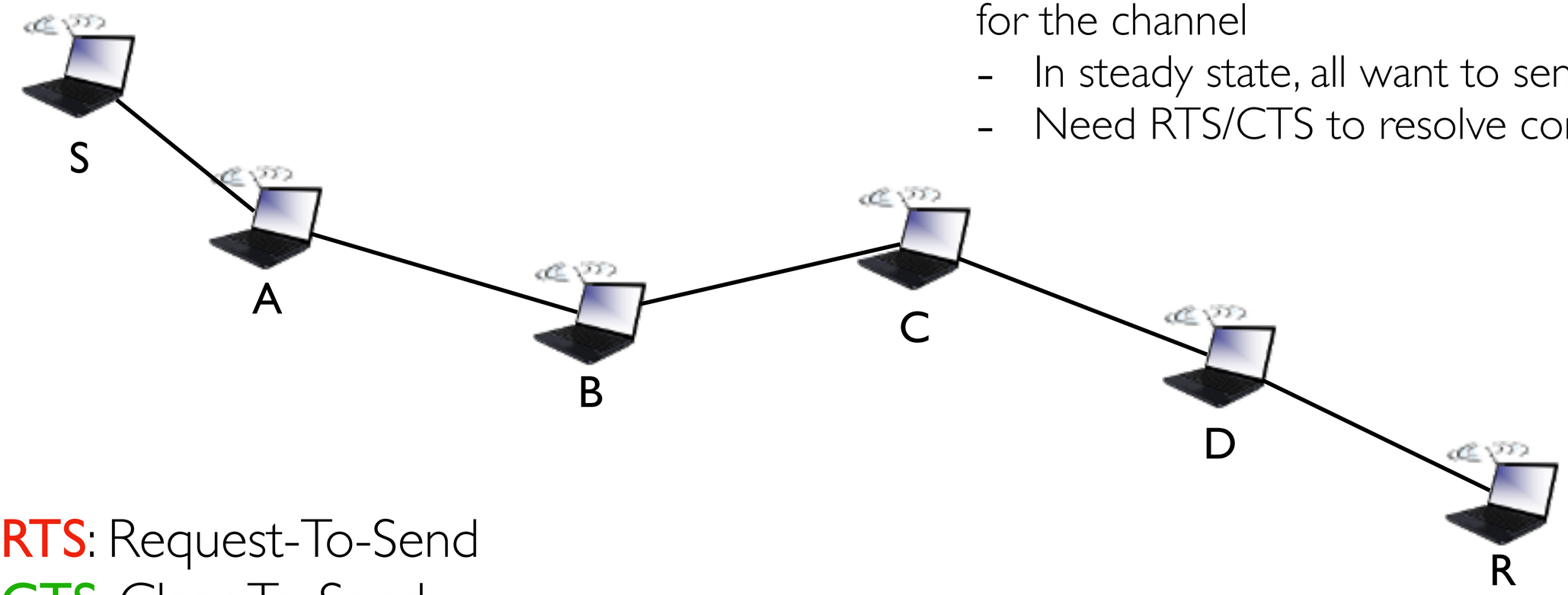


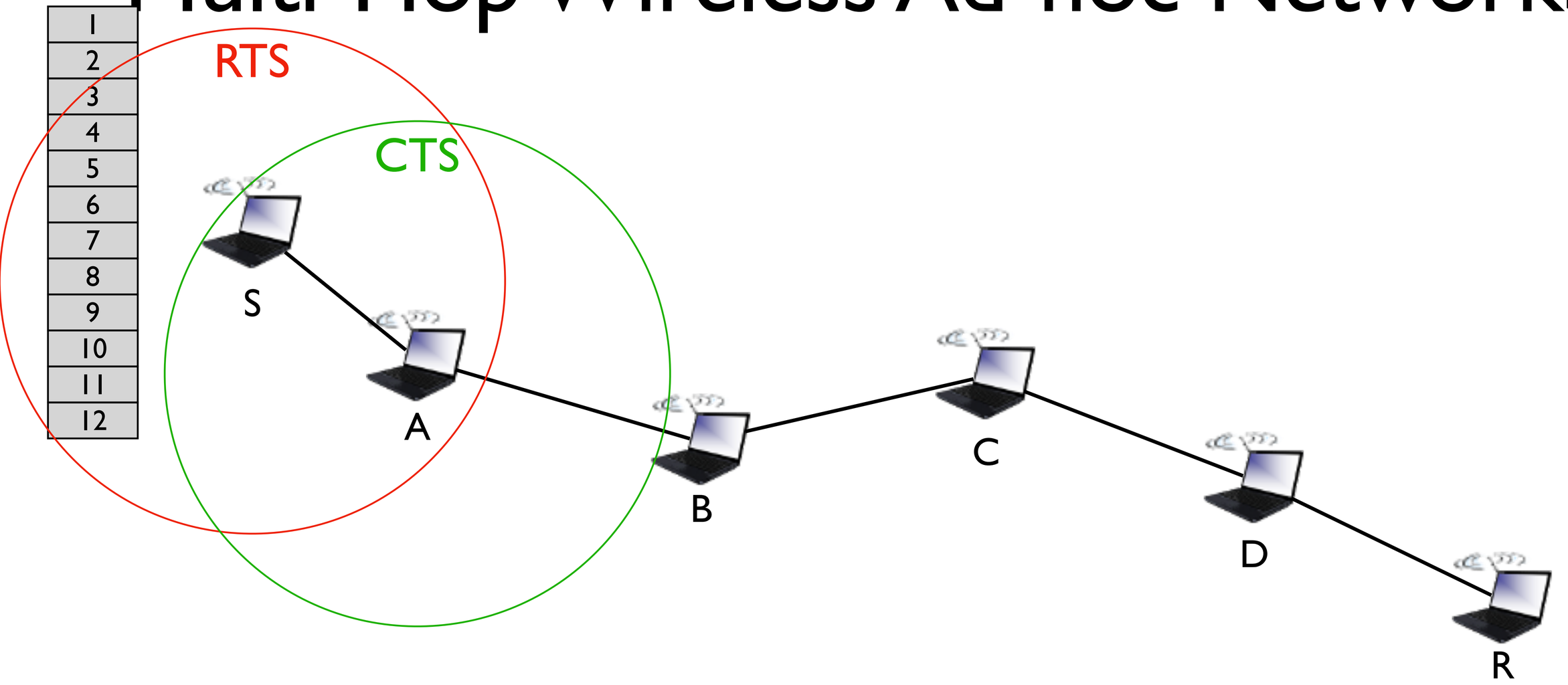
Problem 3: LOTS of contention for the channel

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

RTS: Request-To-Send

CTS: Clear-To-Send

Multi-Hop Wireless Ad-hoc Networks



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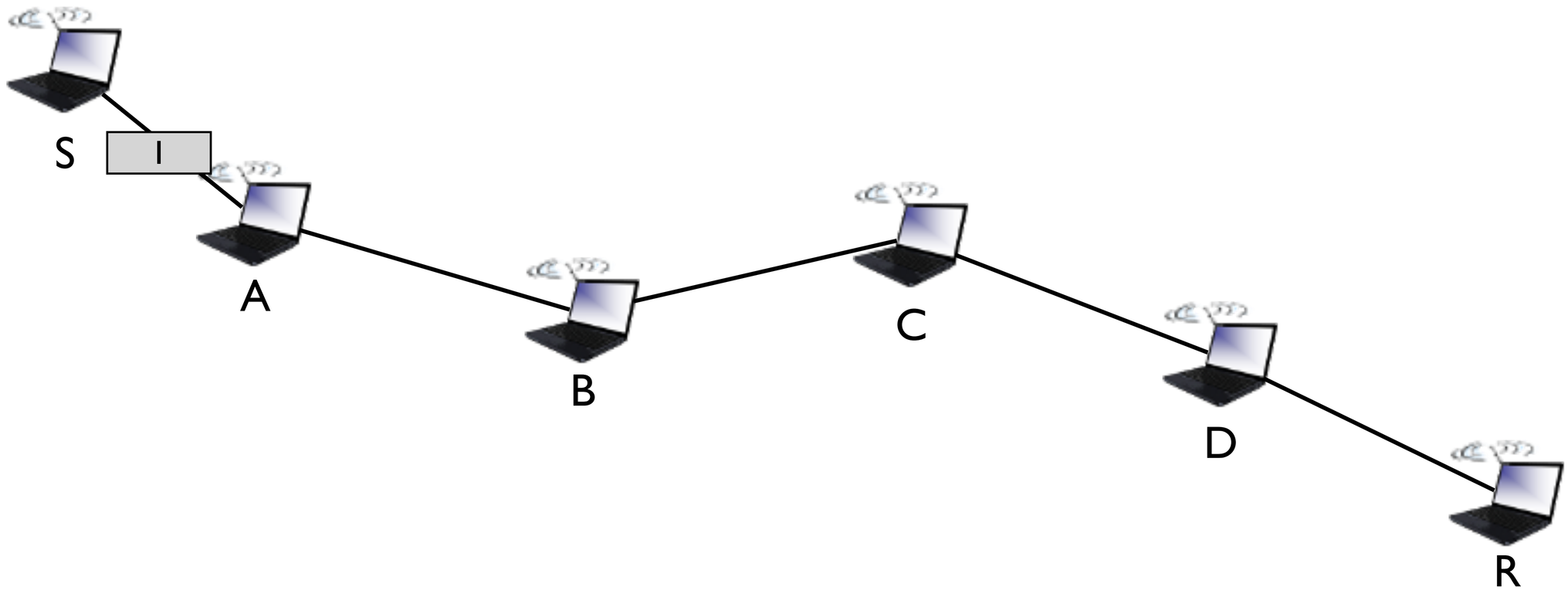

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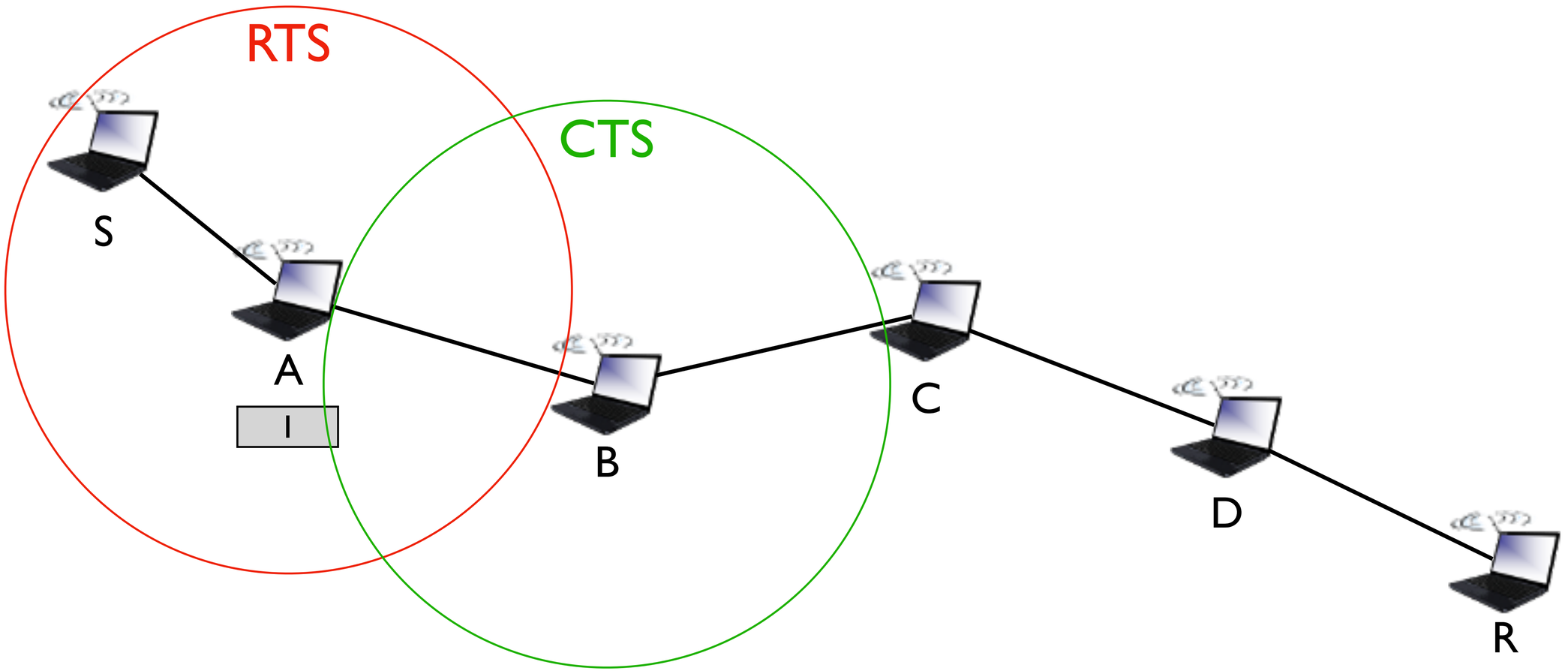

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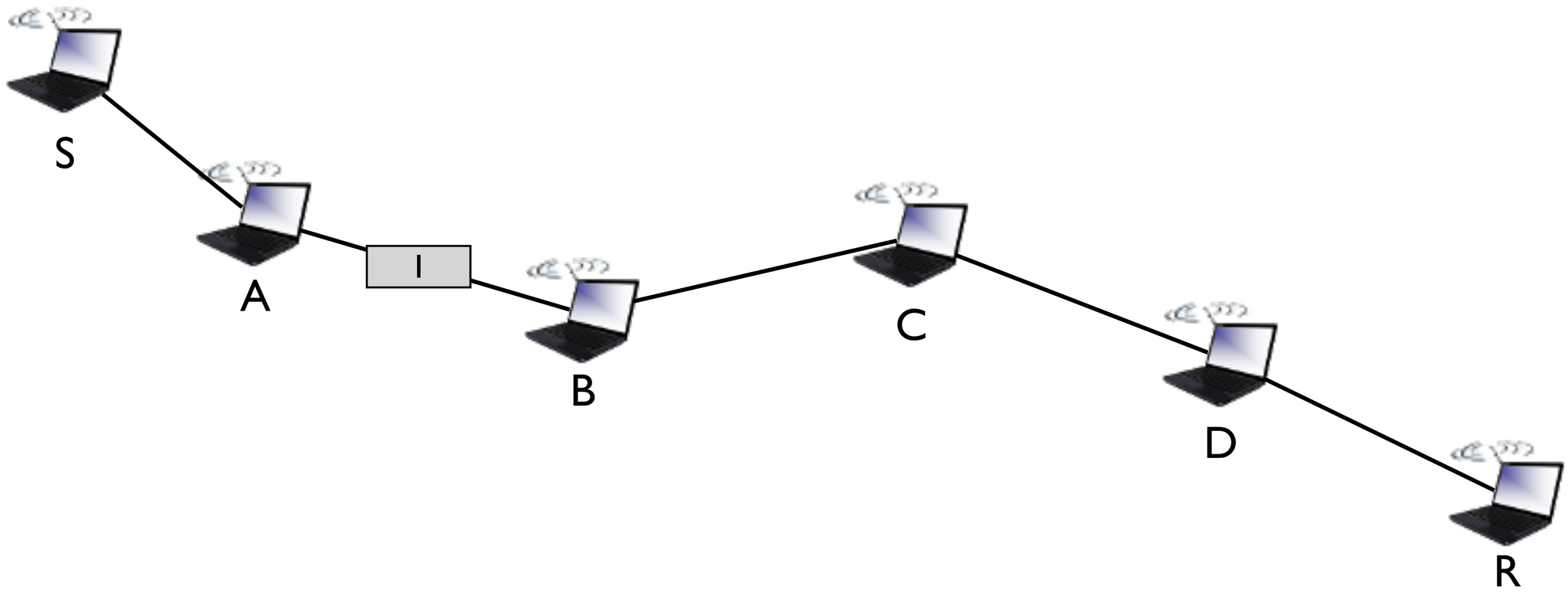

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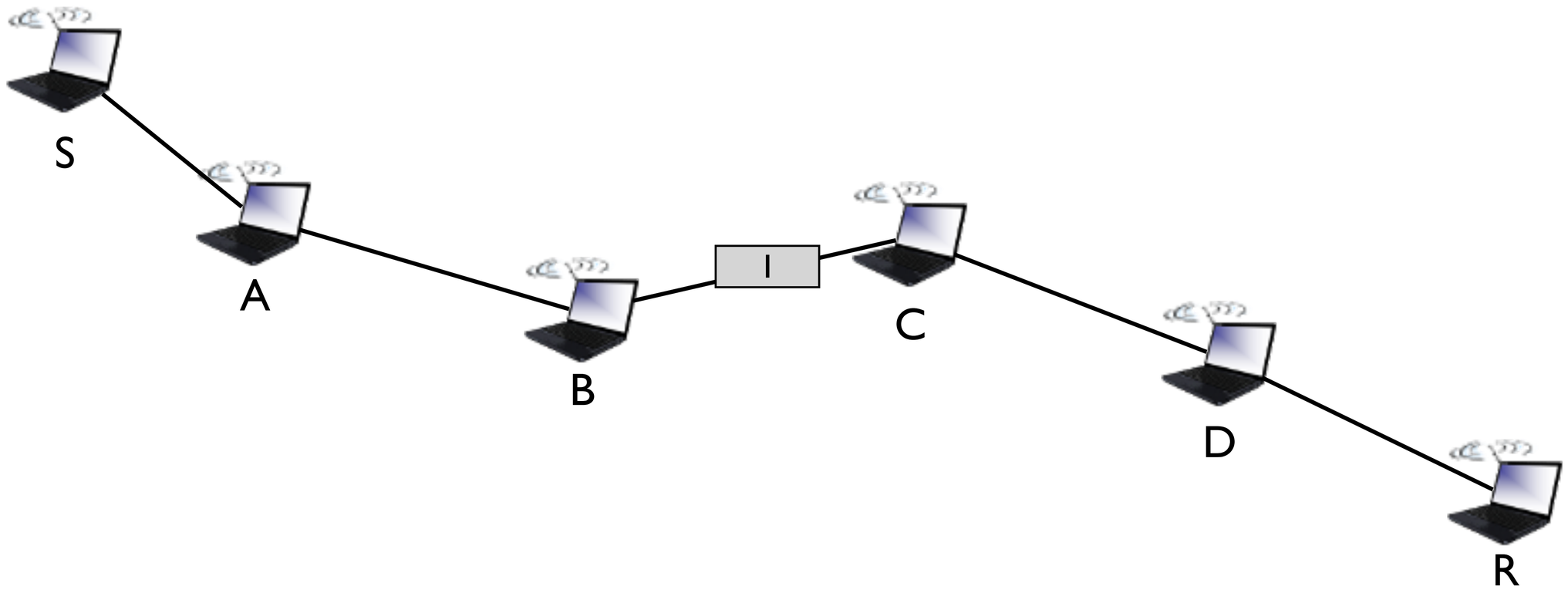

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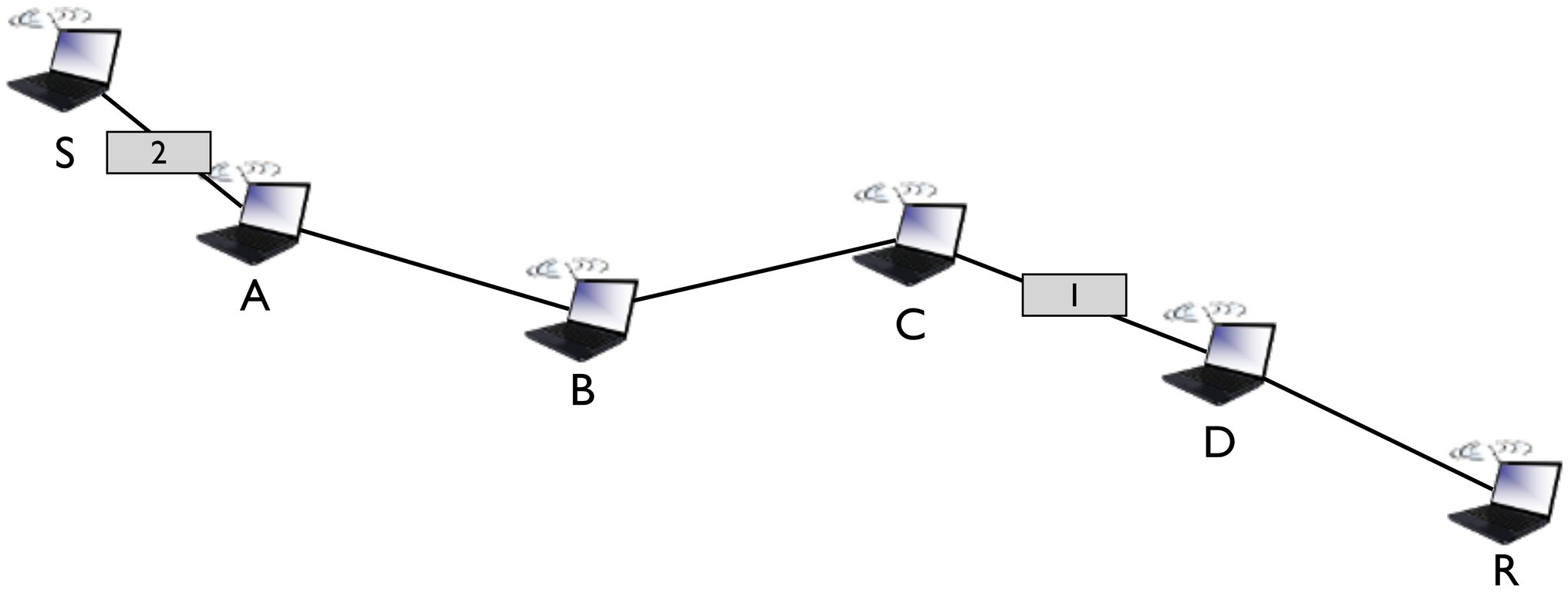

Multi-Hop Wireless Ad-hoc Networks

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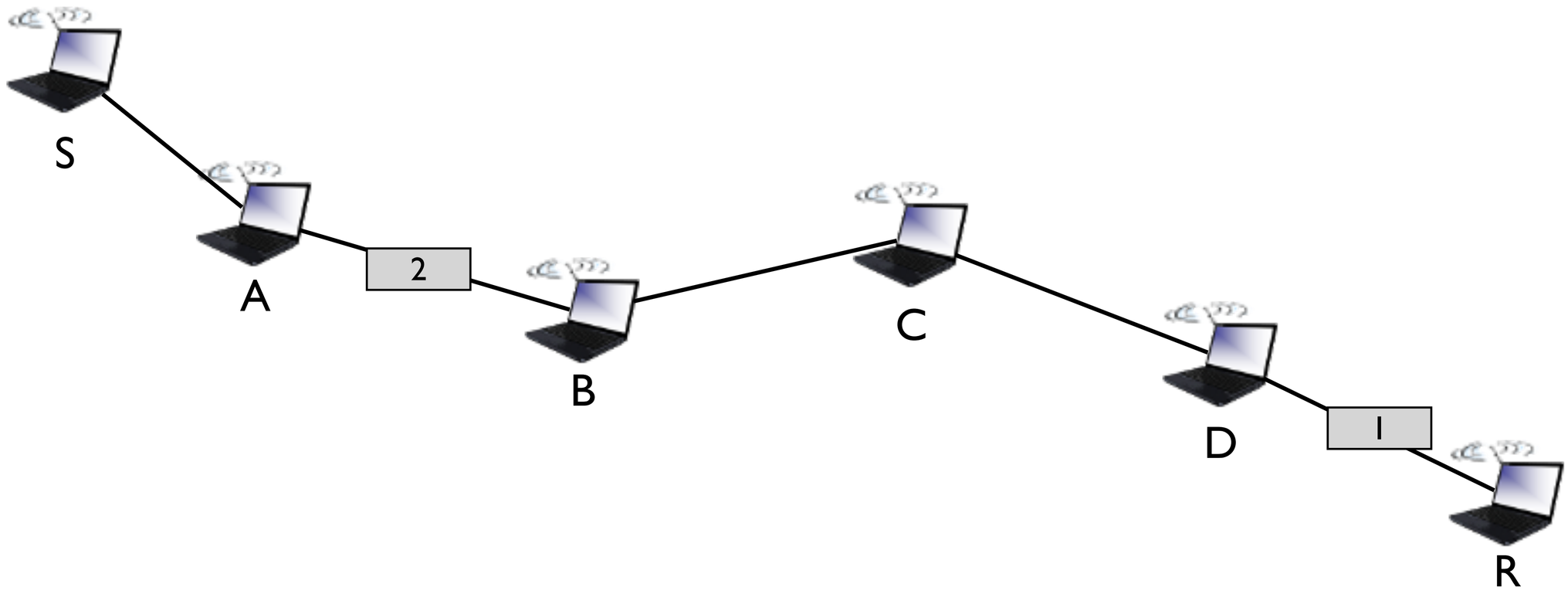

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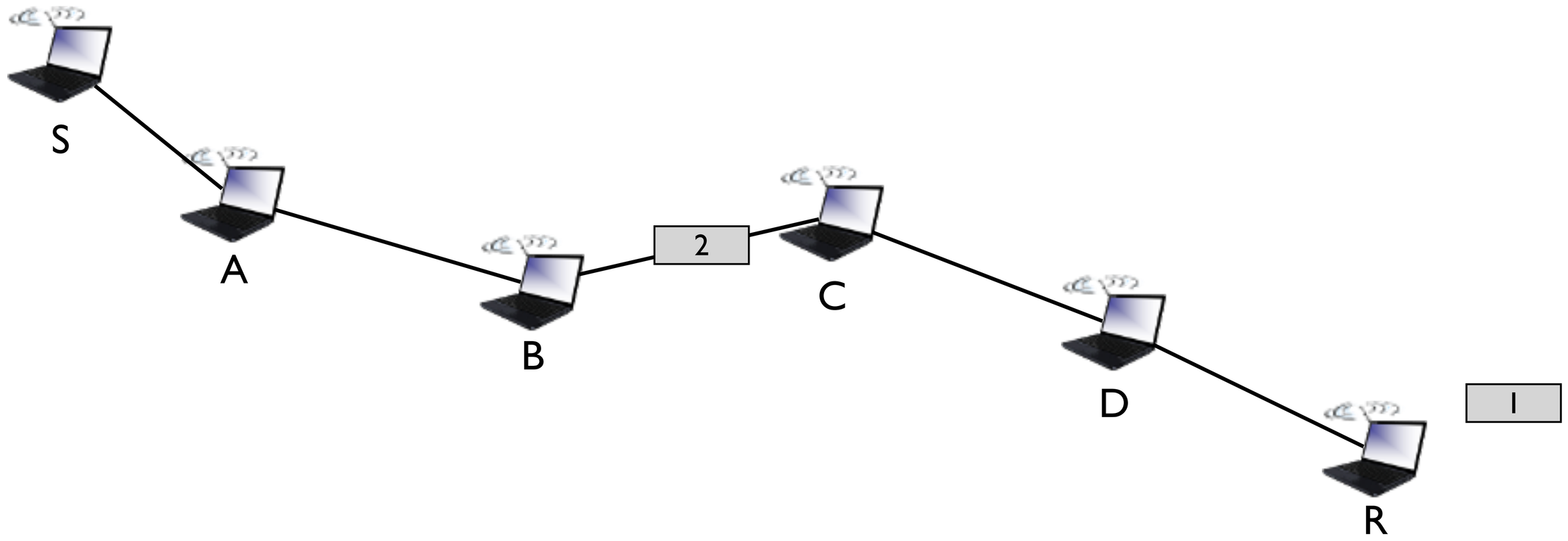
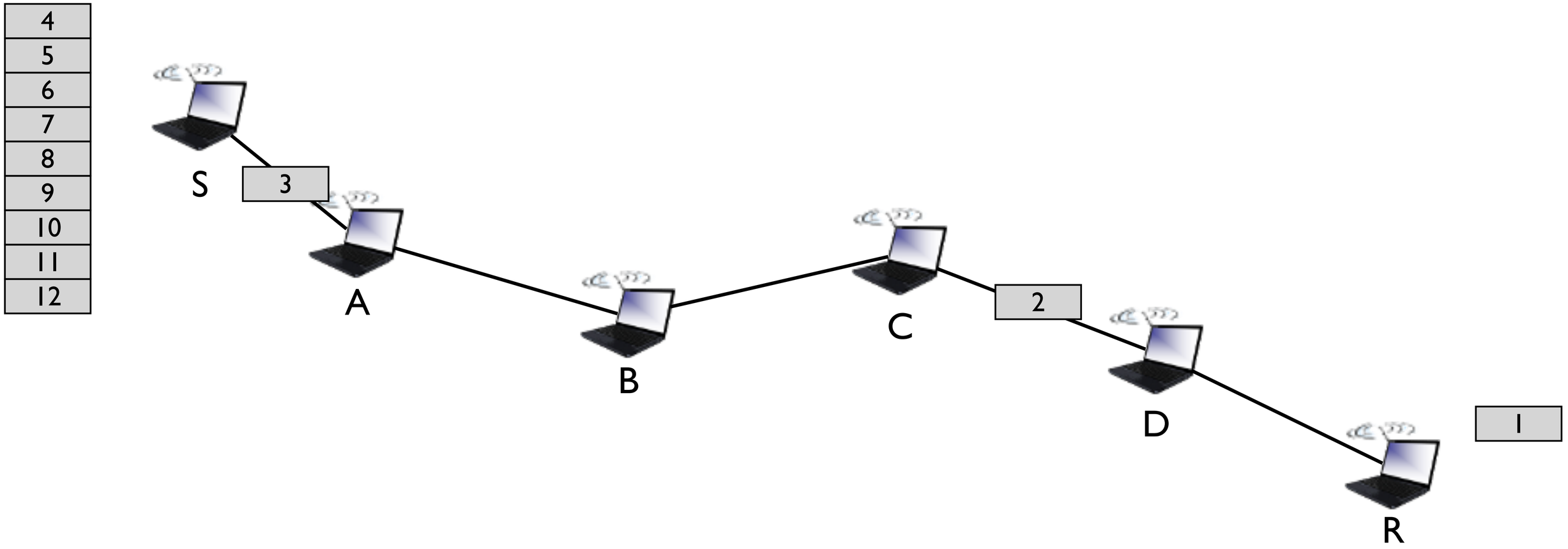


Multi-Hop Wireless Ad-hoc Networks



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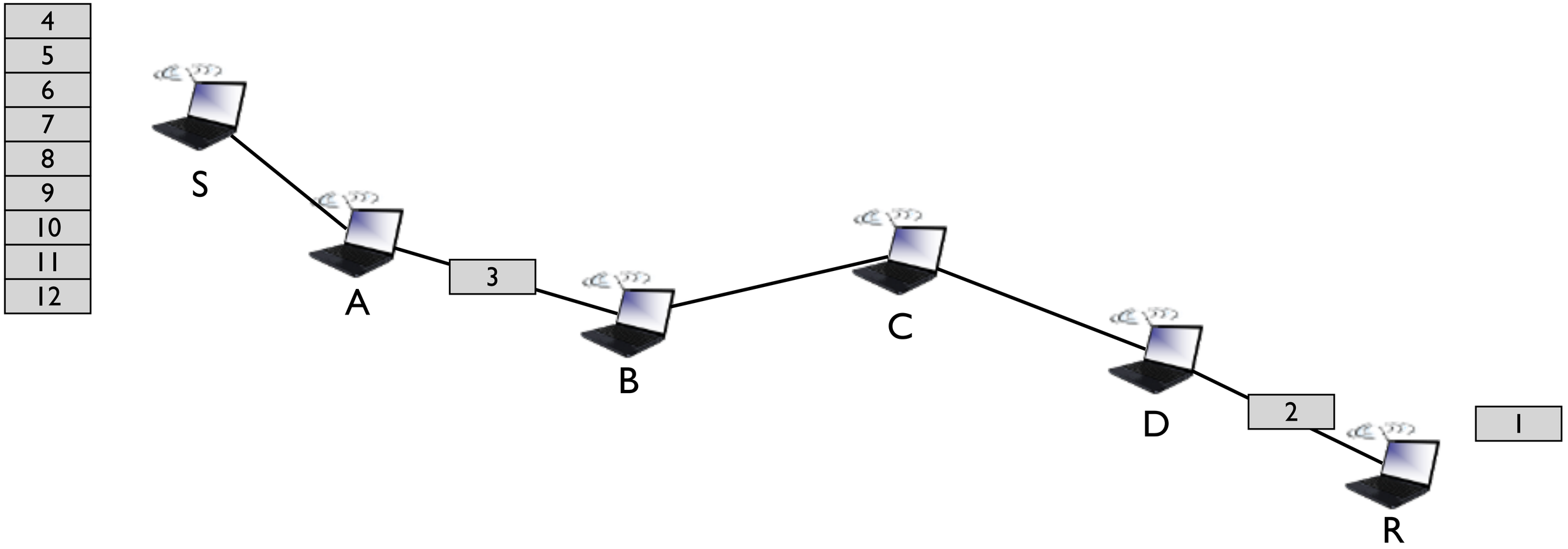

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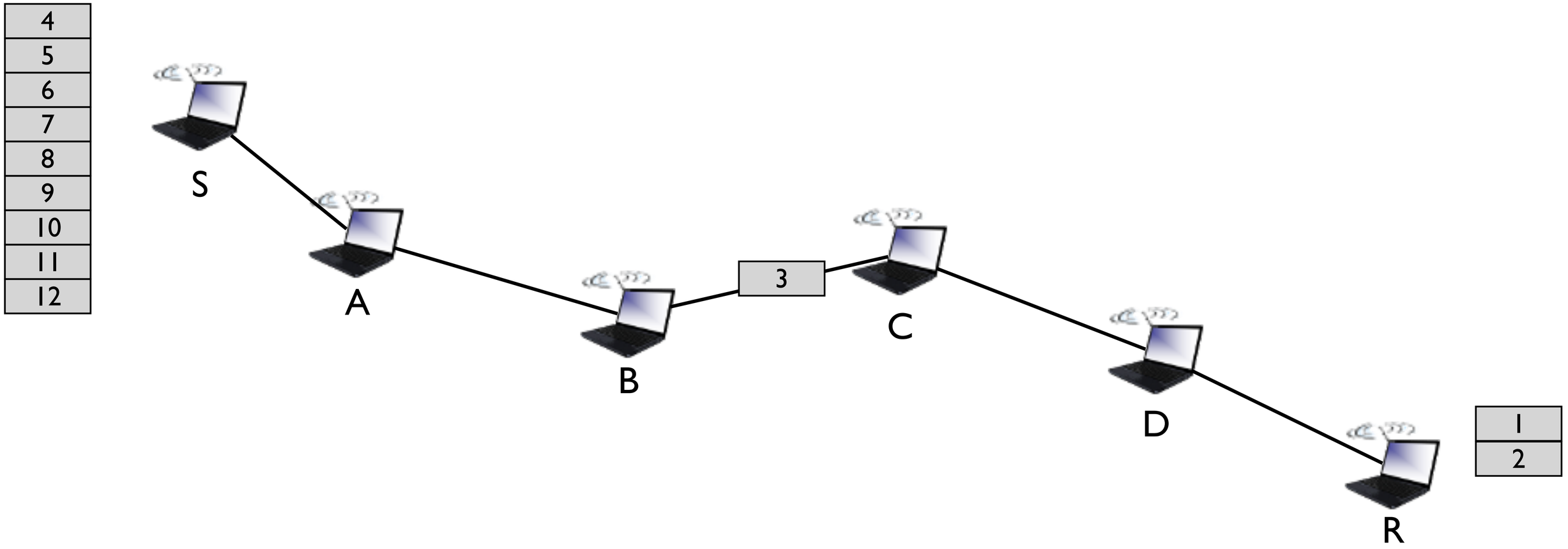
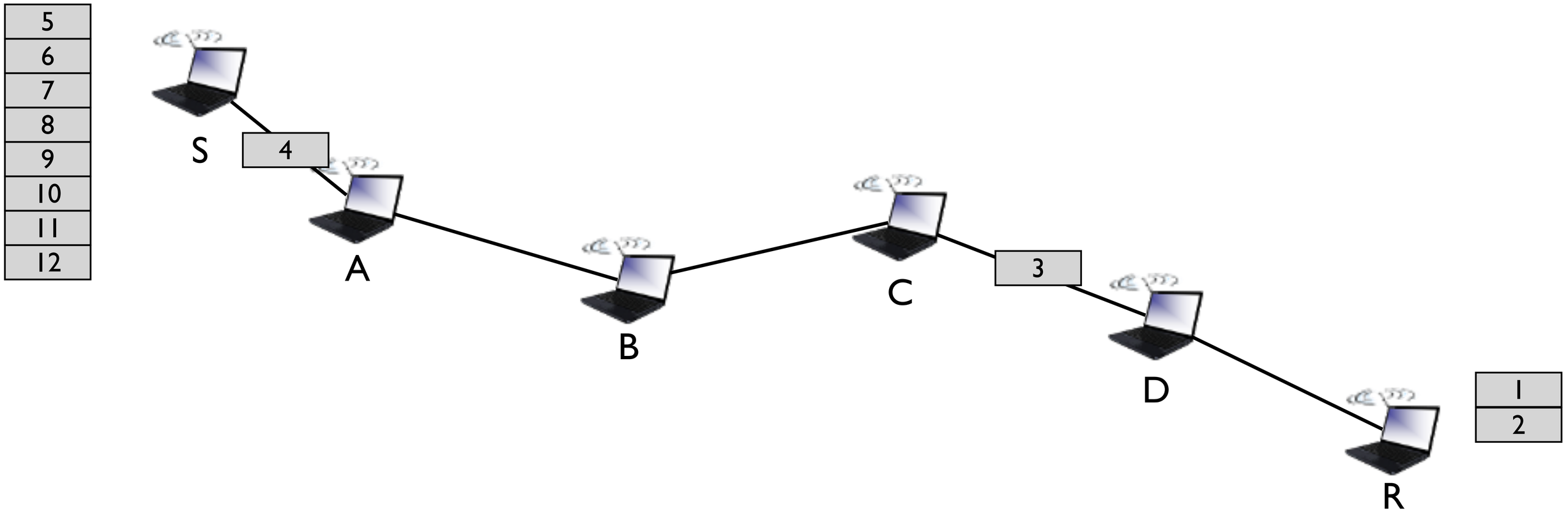


Multi-Hop Wireless Ad-hoc Networks



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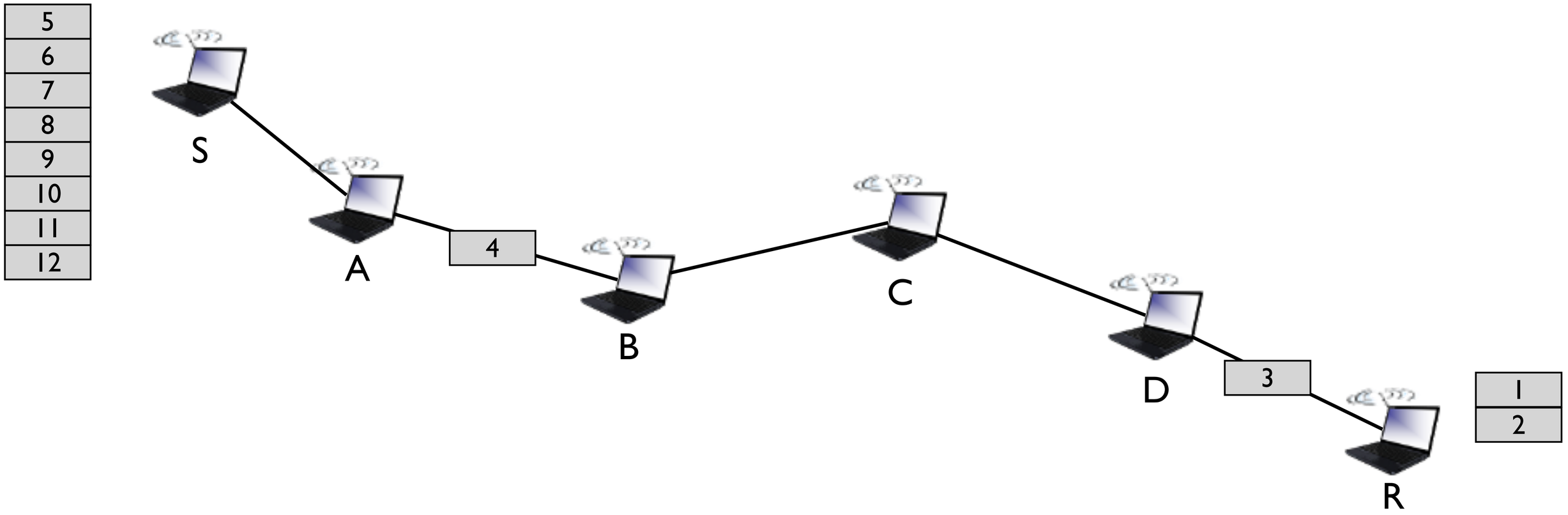

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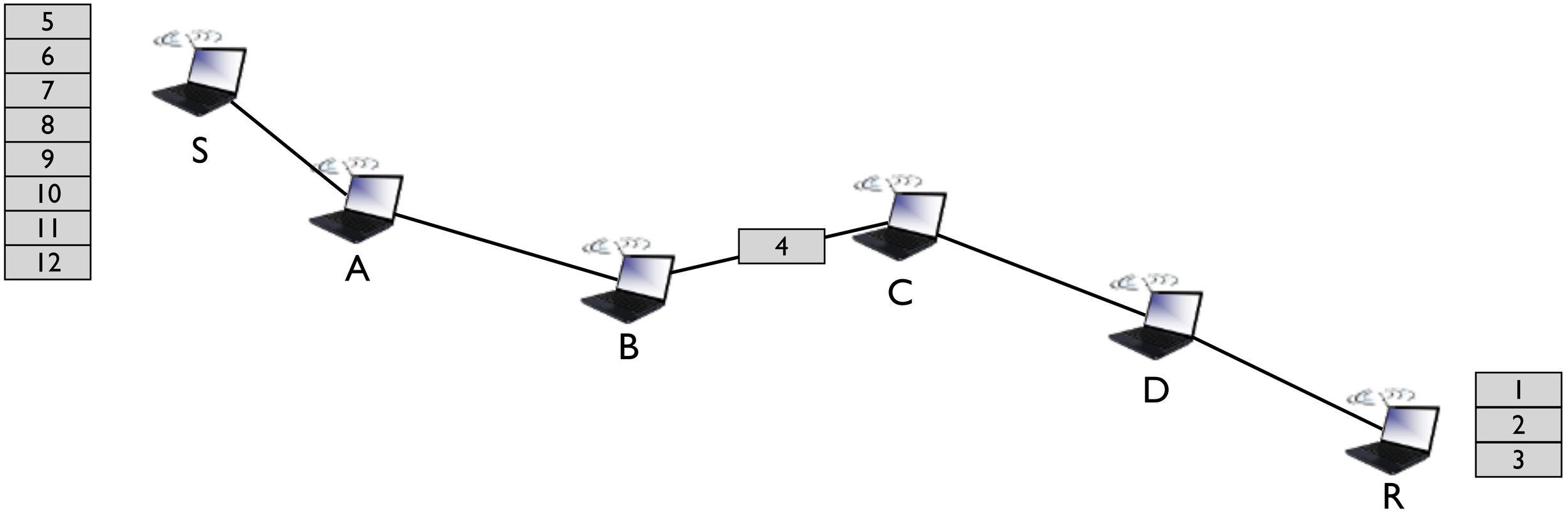

Multi-Hop Wireless Ad-hoc Networks

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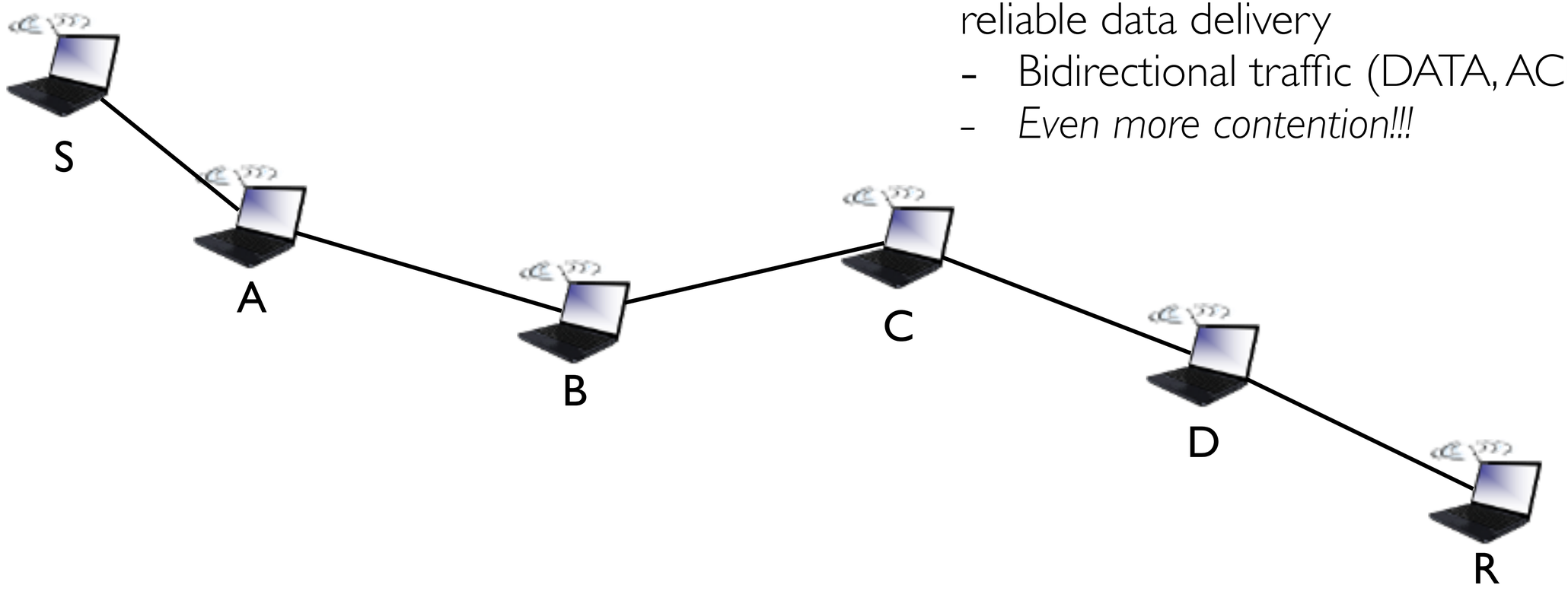

Problem 4: TCP uses ACKs to indicate reliable data delivery

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

Multi-Hop Wireless Ad-hoc Networks

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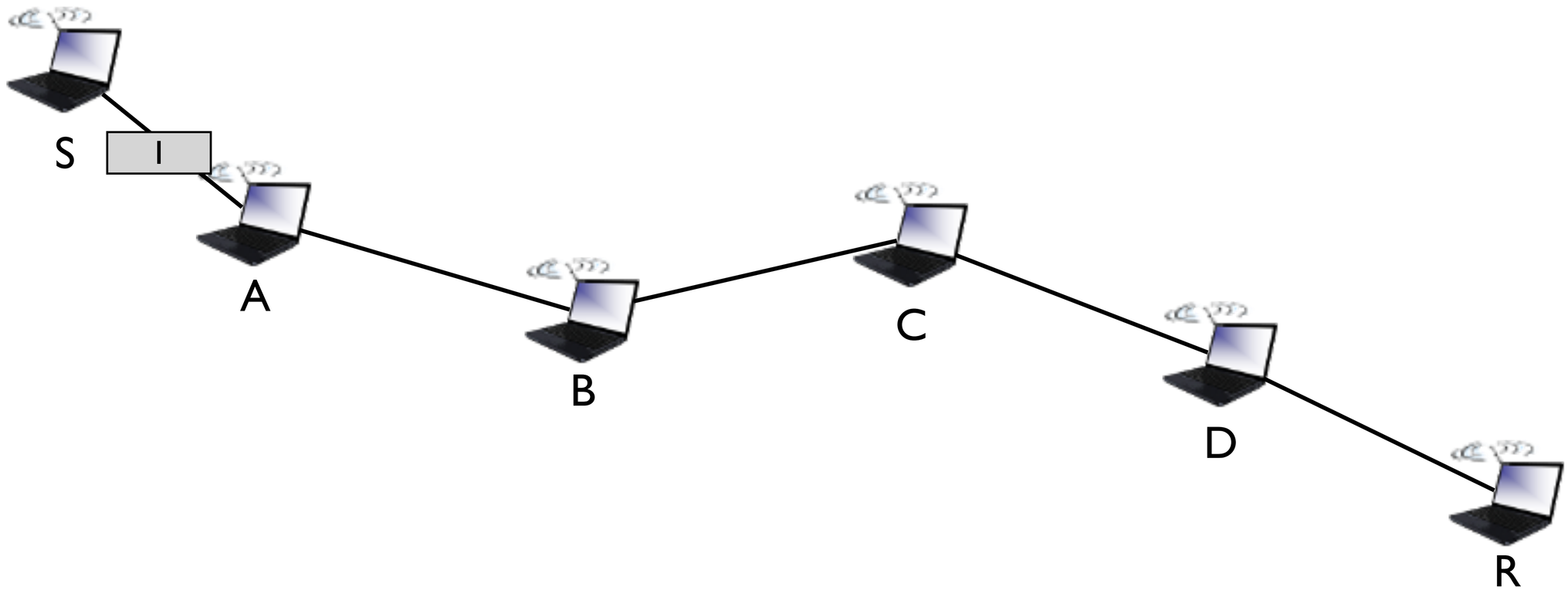

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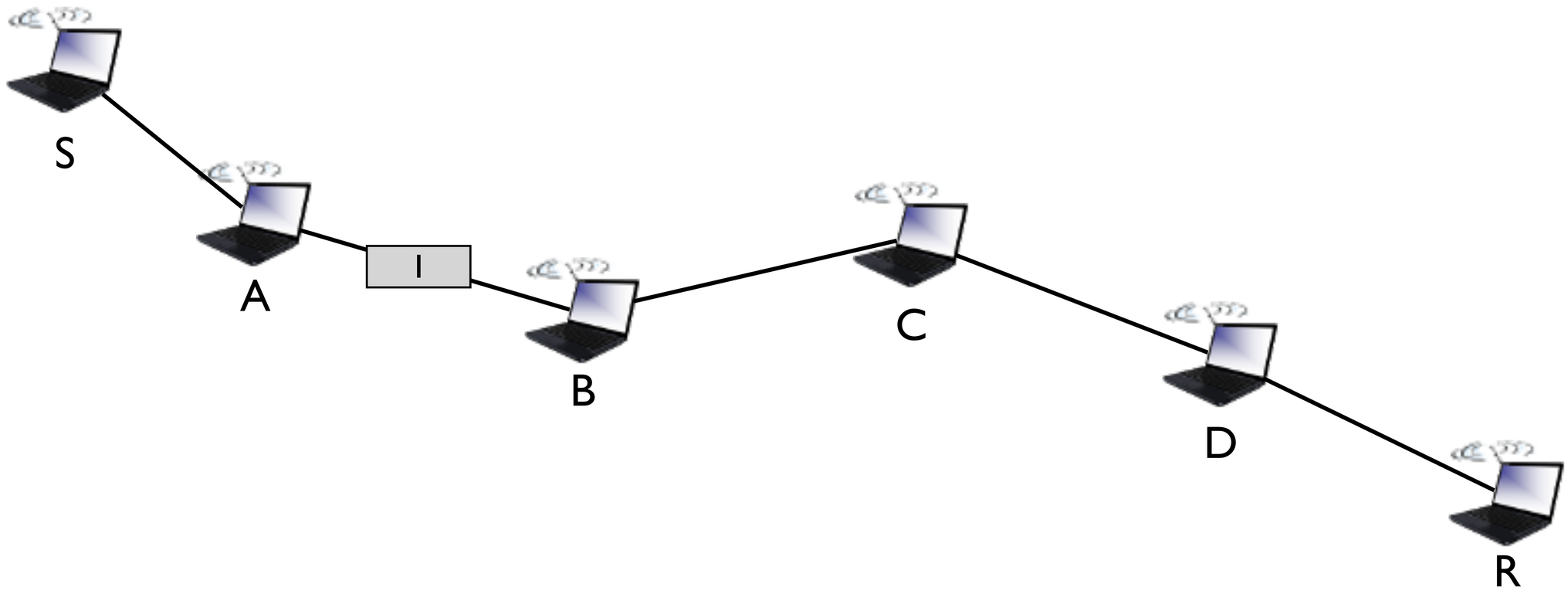

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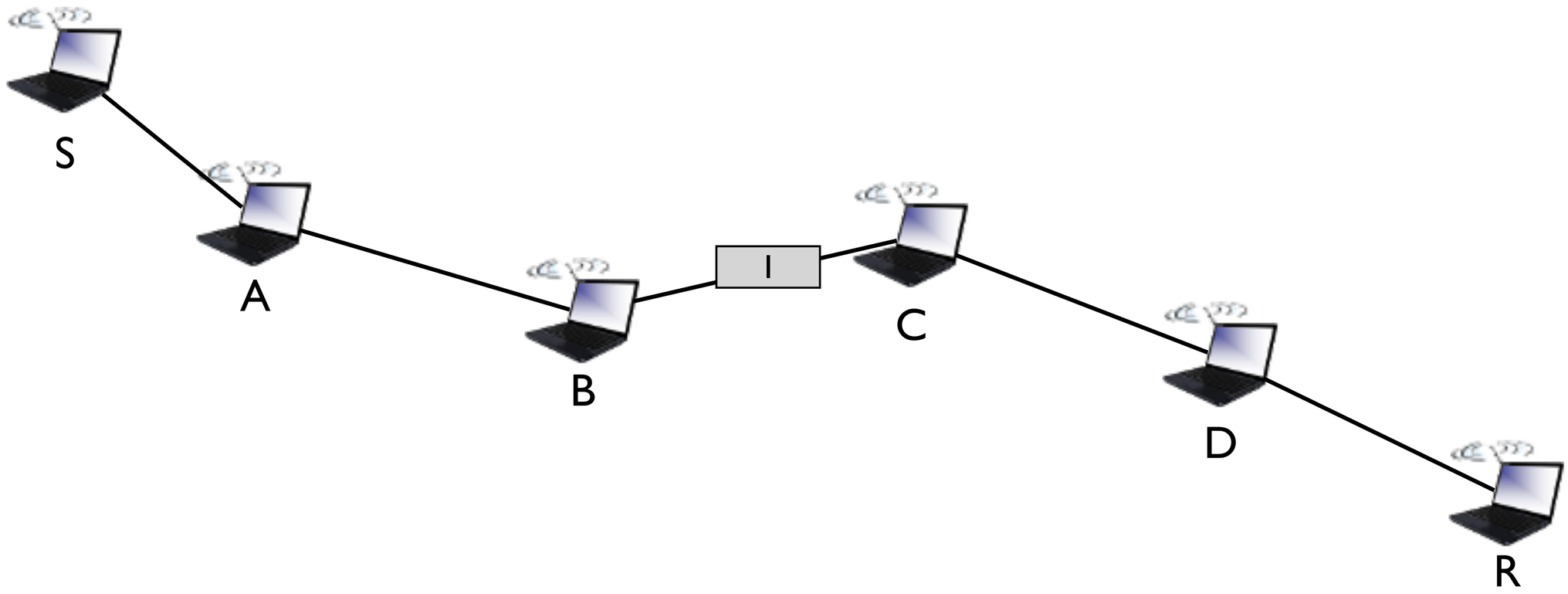

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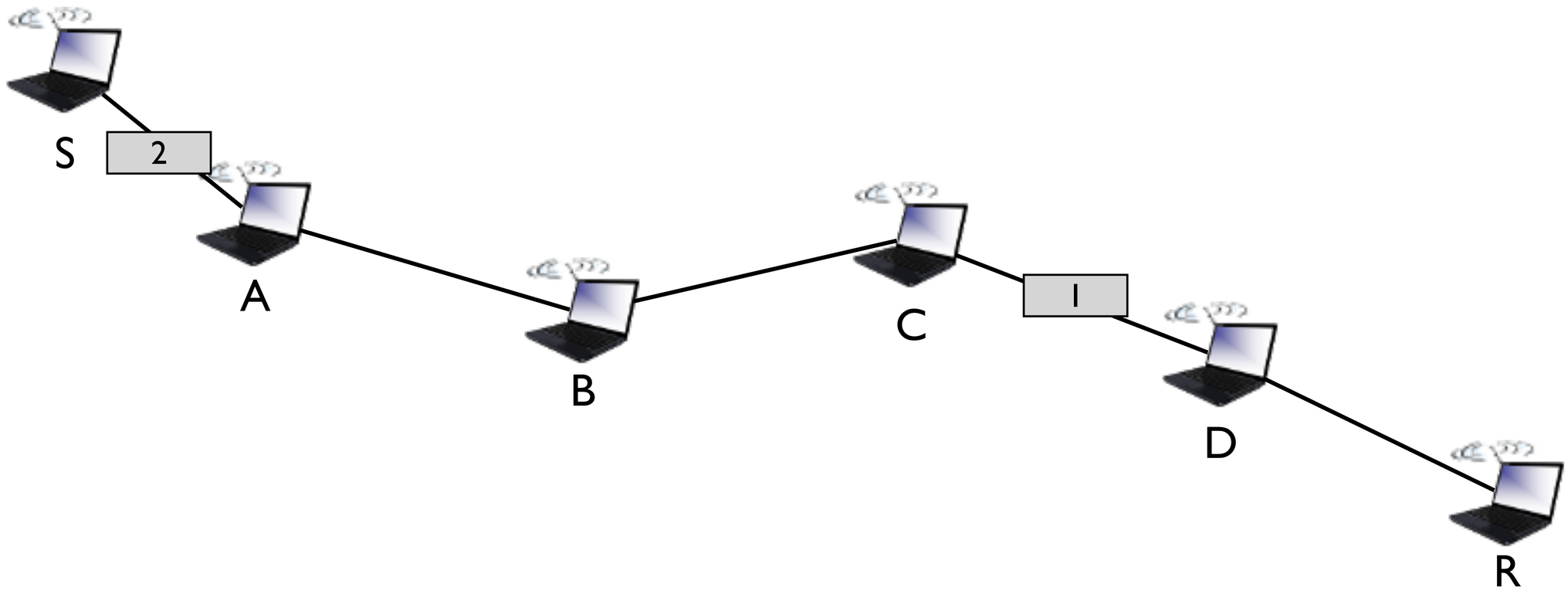

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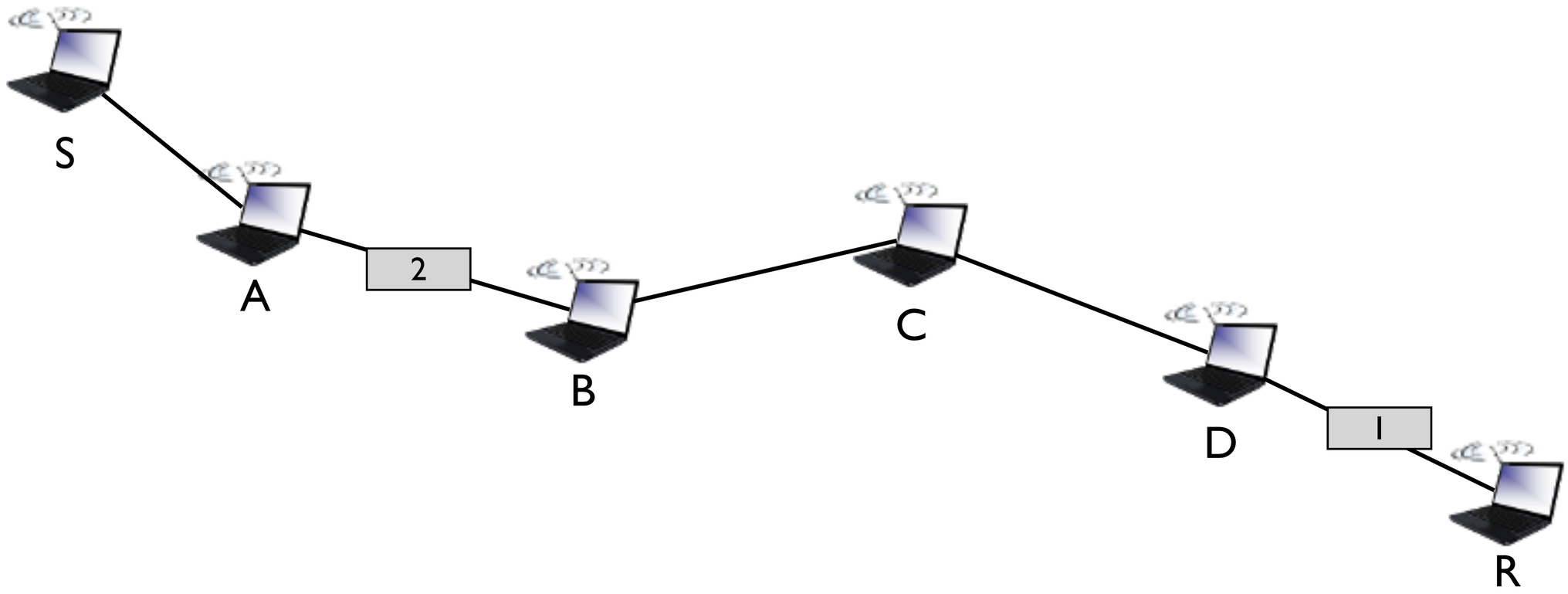

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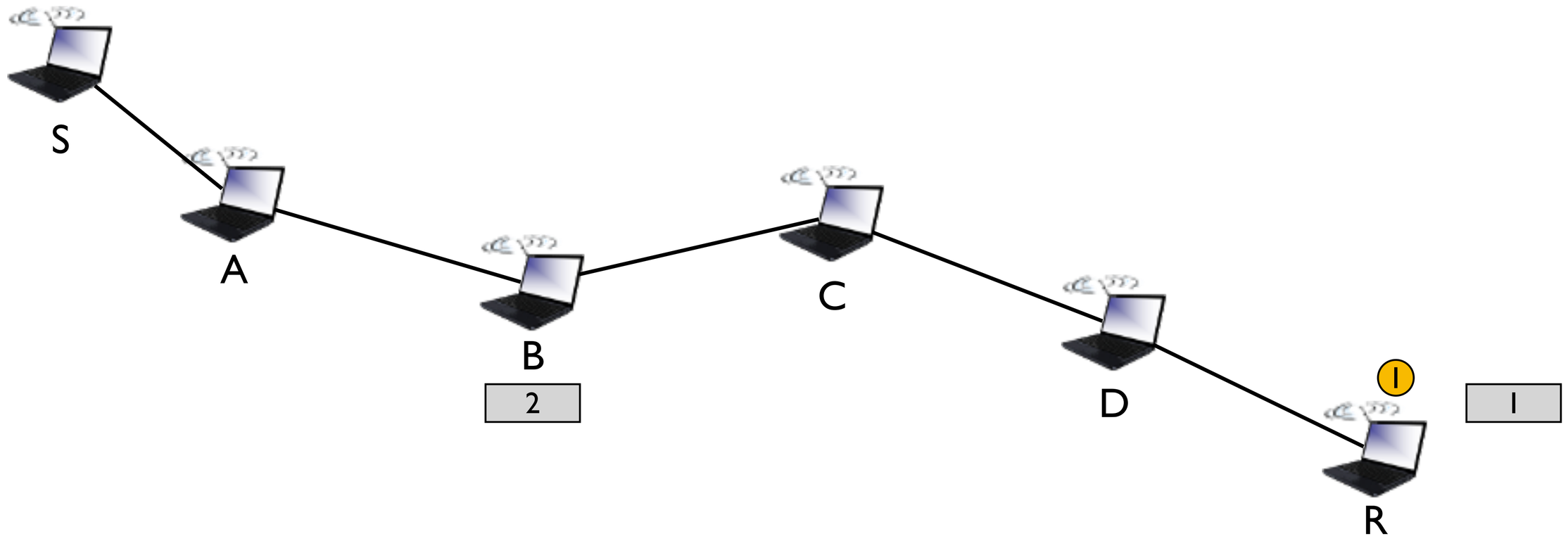

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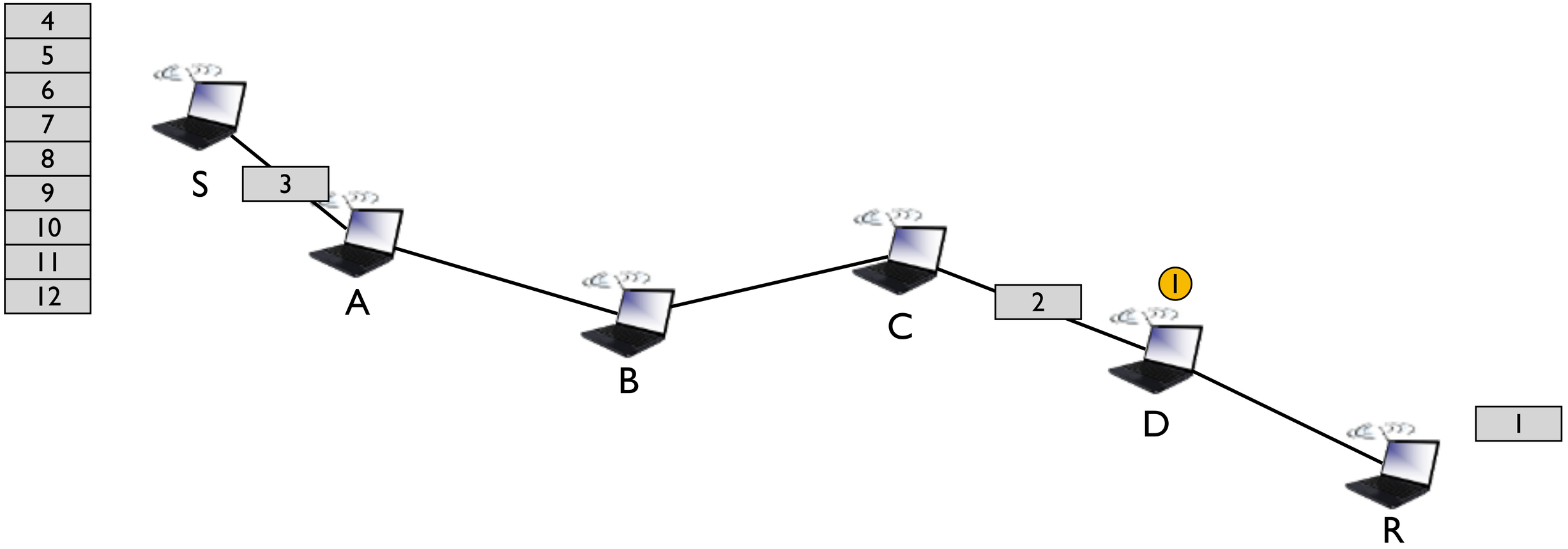

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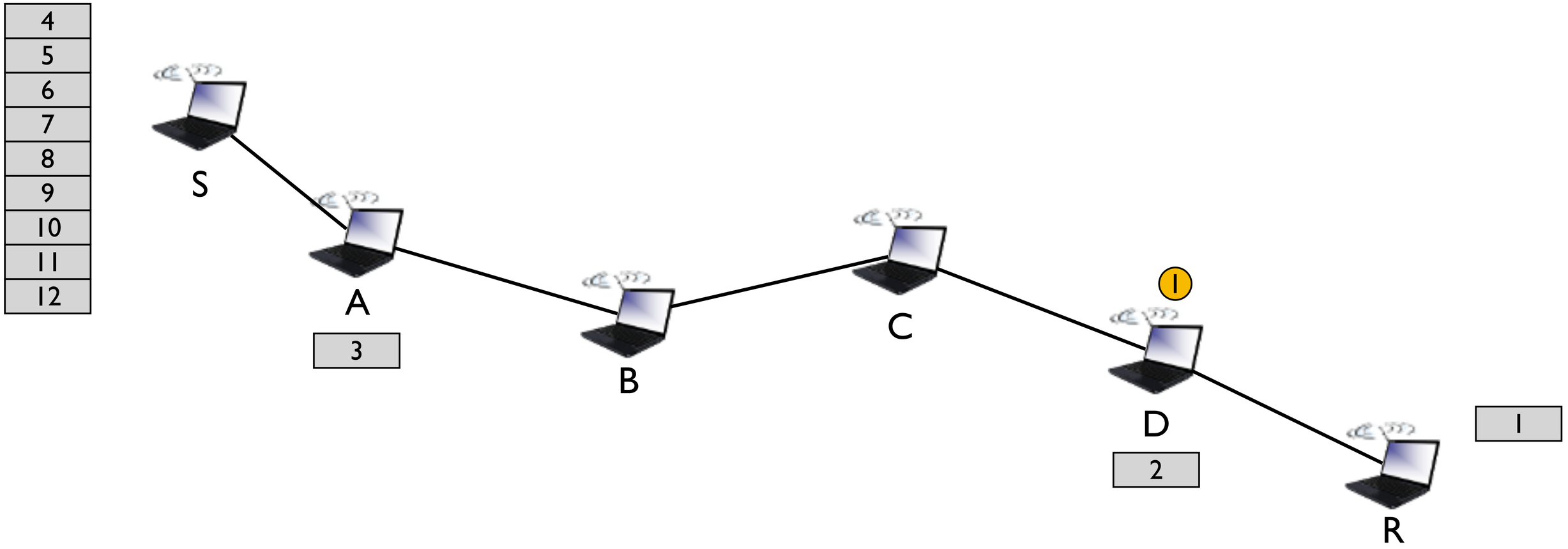

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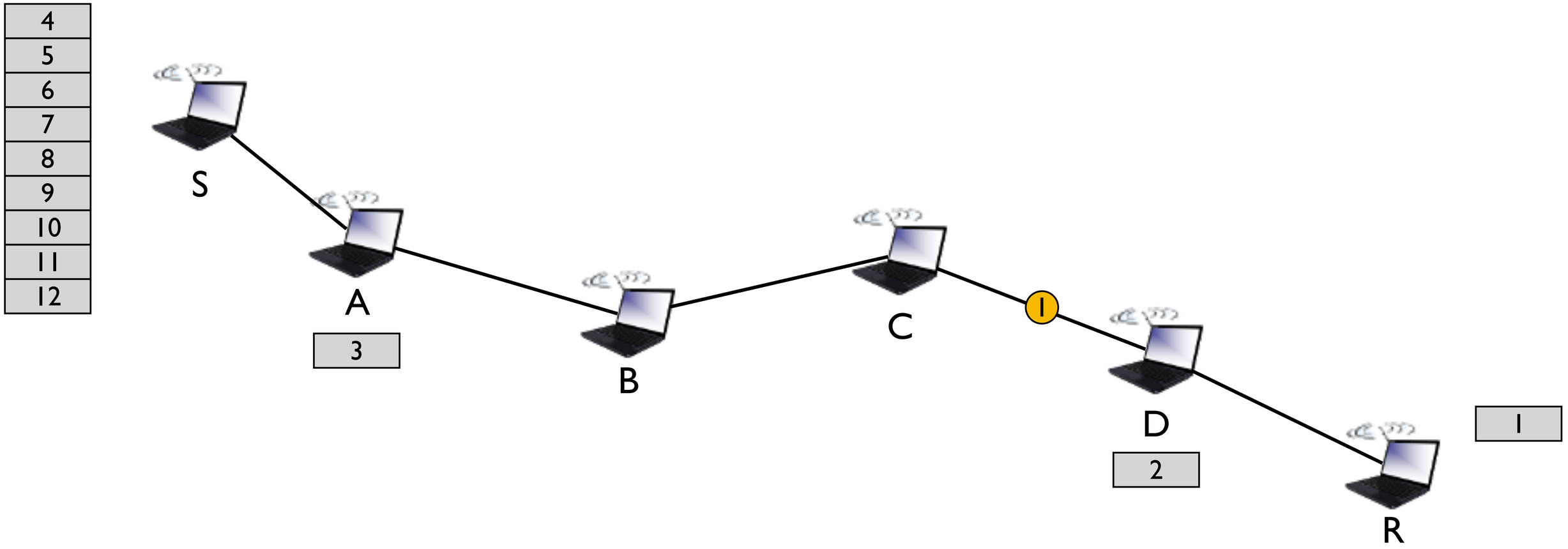

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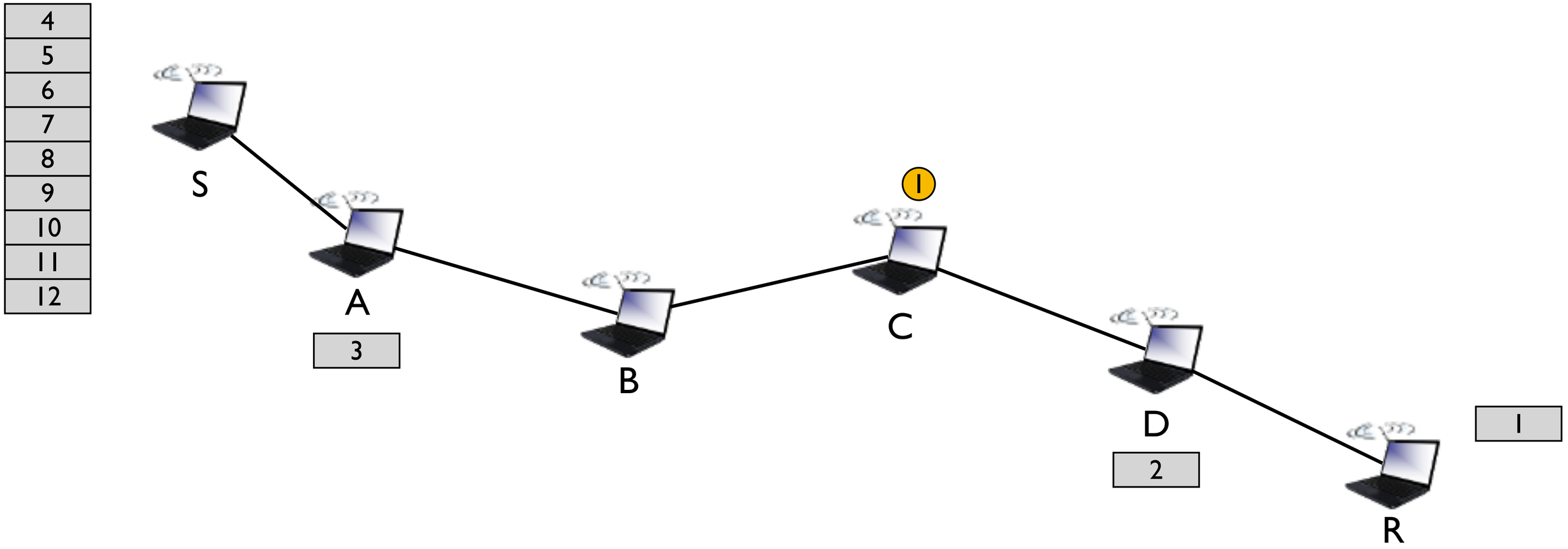

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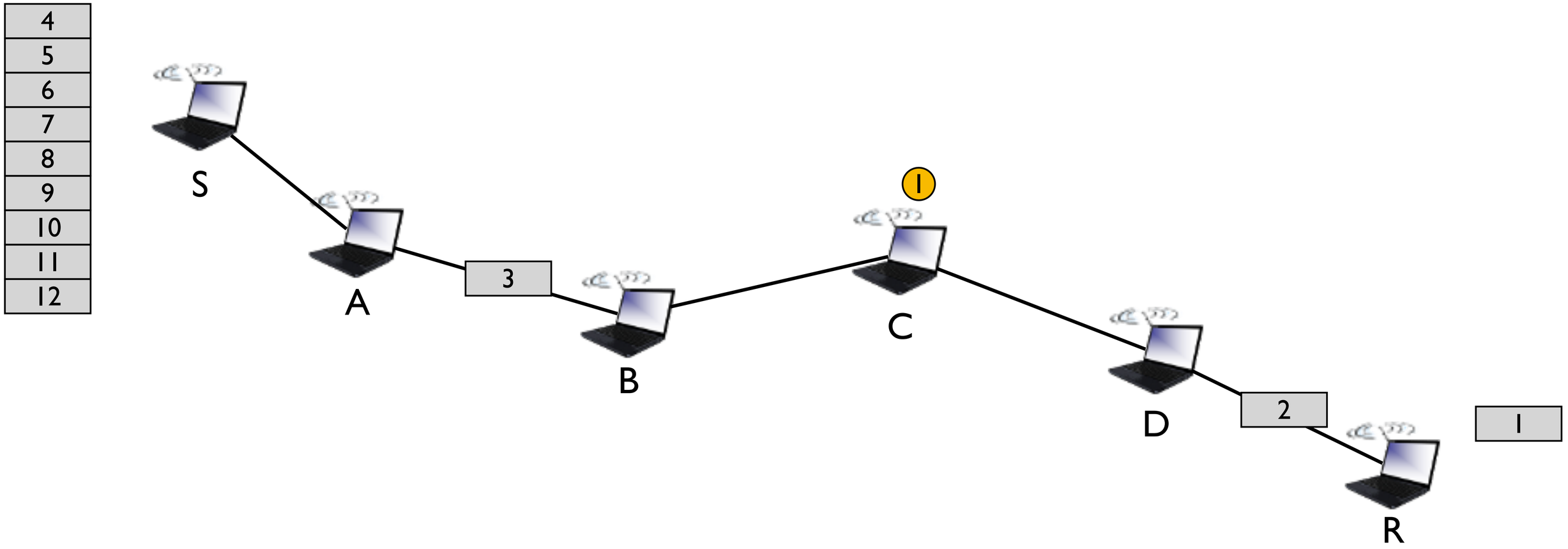

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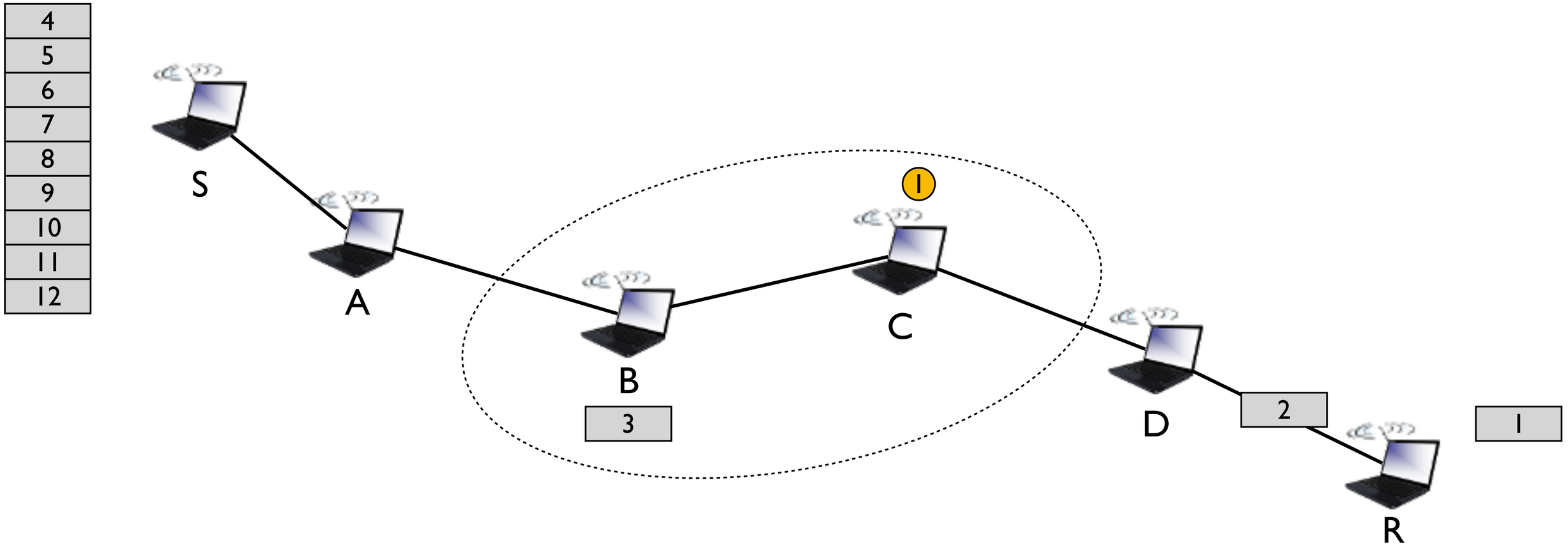

Lesson

- **Multi-hop wireless is hard to make efficient**
- **Store and forward**
  - Halves the bandwidth for every hop
  - Doubles the latency for every hop
  - Increases interference
- **Horrible idea for Internet access**
- **Even worse for interactive applications**
  - Such as Zoom

Summary

- **Wireless is a tricky beast**
  - Distributed multiple access problem
  - Hidden terminals
  - Exposed terminals
  - Current protocols sufficient, given over-provisioning
- **Multi-hop even more complicated**

Questions?

Datacenter Networks

CPSC 433/533, Spring 2021

Anurag Khandelwal

What you should understand…

- **What is a datacenter network**
  - Scale, service-model, application characteristics
- **What makes it different?**
  - Characteristics, goals (w.r.t. Internet), degrees of freedom
- **How do we achieve goals by exploiting freedom?**
  - Topology redesign, L2/L3 redesign, L4 redesign
  - We will look at some approaches, not all

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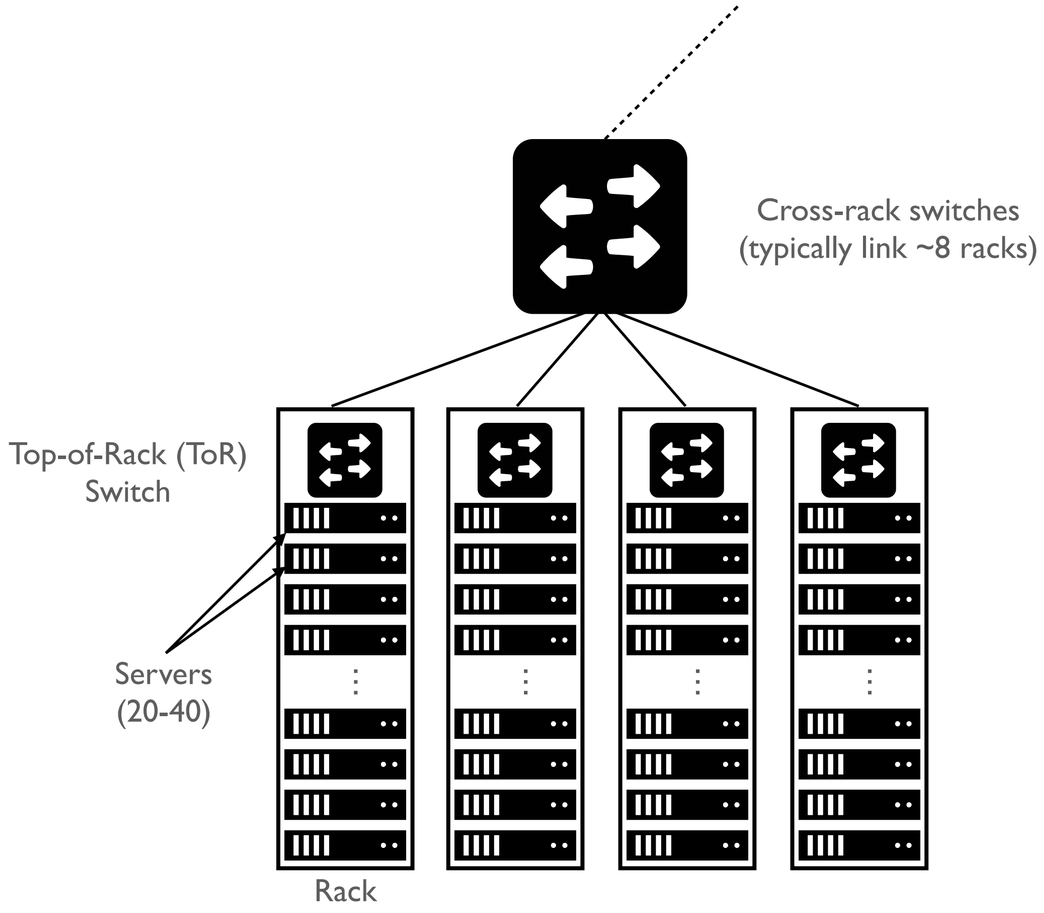
What goes into a datacenter (network)?



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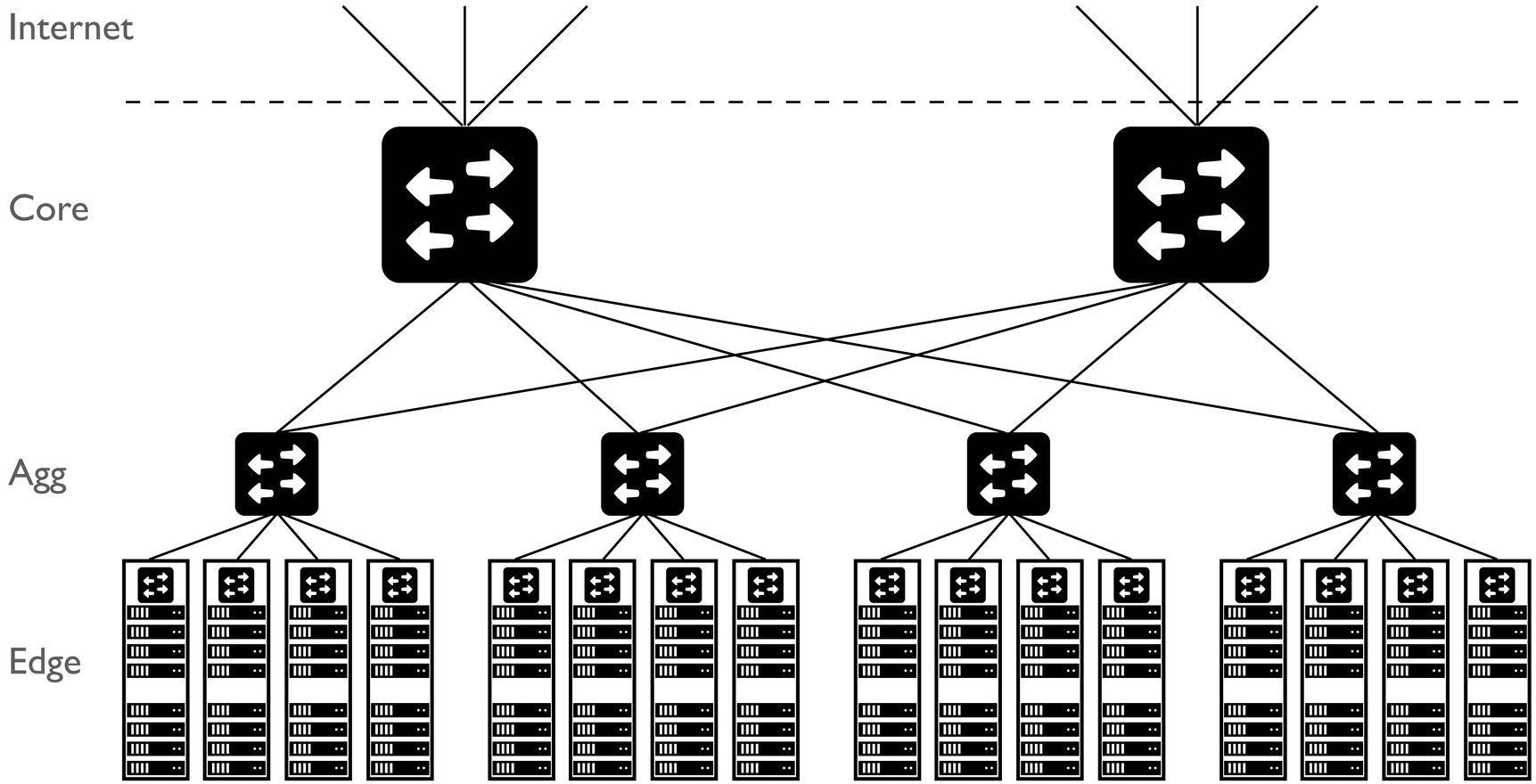


- ToR switches connected by **‘Aggregation switches’**
  - 2x redundancy for fault-tolerance
- DCN connected to the internet via **‘Core switches’**
  - **Note:** blurry boundary b/w core and aggregation
- Other (better) topologies:
  - Fat-tree, Clos, Jellyfish, …

What goes into a datacenter (network)?

- Servers organized in racks
- Each rack has a 'Top of Rack' (ToR) switch
- 'Aggregation switches' interconnect ToR switches
- Connected to the outside via 'core' switches
  - *Note: blurry line between aggregation and core*
- With 2x redundancy for fault-tolerance

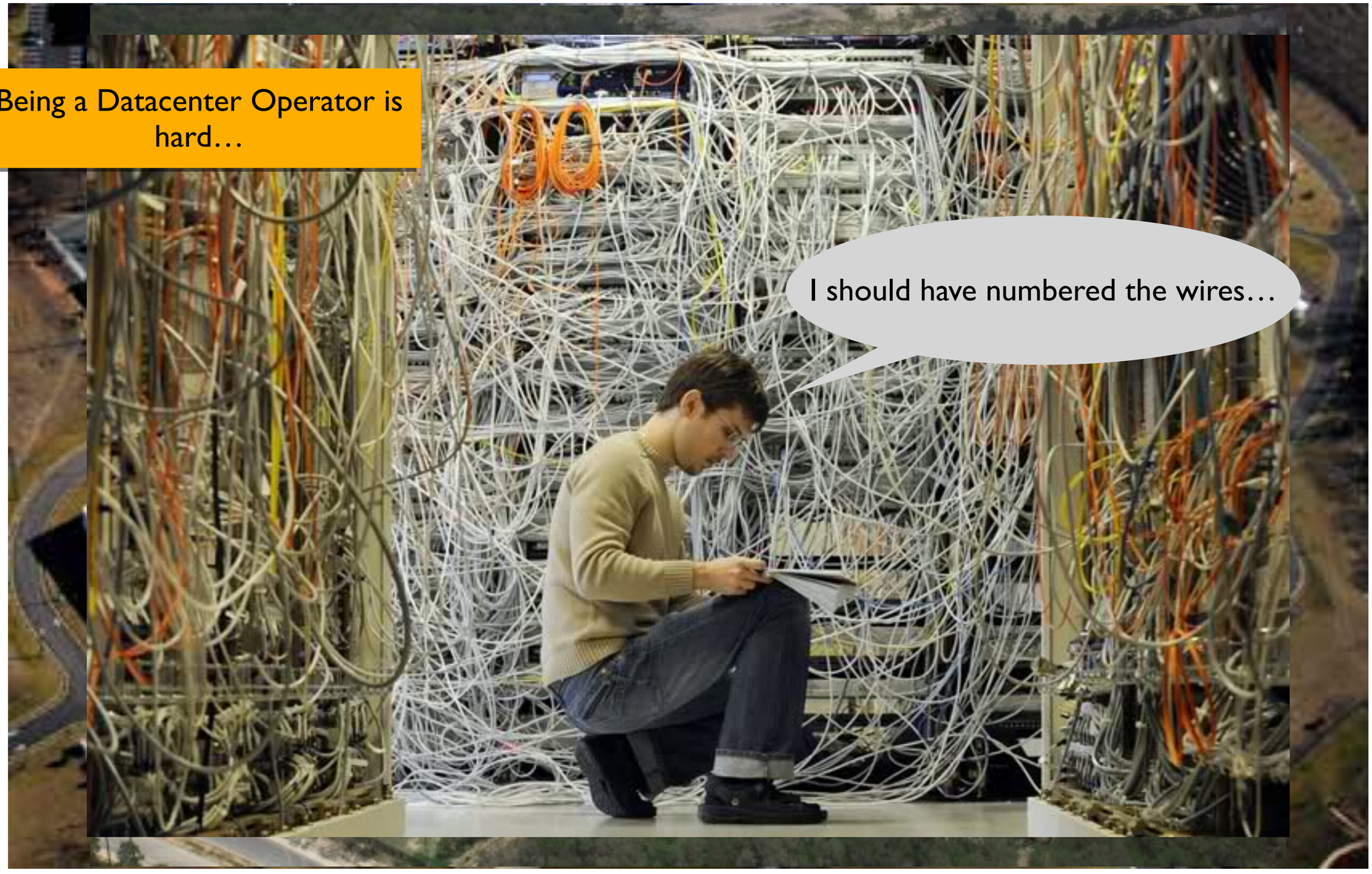
Key Features of a DCN

- **Scale**

- **Service model**
  - *Public* clouds (jargon: SaaS, PaaS, DaaS, IaaS, …)
  - Multi-tenancy

- **Application characteristics**
  - Large-scale computations (“big data”)
  - Customer-facing, revenue generating services

SCALE!


Being a Datacenter Operator is hard…
I should have numbered the wires…

How Big are Datacenters Anyway?

- > 1million servers/site [Microsoft/Amazon/Google]
- > $1billion to build a site [Facebook]
- > $20million/month/site operational costs [Microsoft]

But only O(10-100) sites

Implications of Scale

- **Need scalable designs (duh)**
  - E.g., avoid flooding
- **Low cost designs:**
  - E.g., use commodity technology
- **High utilization (efficiency): e.g., >80% average utilization**
  - Contrast: average utilization on the Internet links often ~30%
- **Tolerate frequent failure**
  - Large number of (low cost) components
- **Automate**

Service Model: Rise of Public Cloud

- **Pre-2006 world**
  - Amazon had huge datacenters that only ran @ 10% capacity for most of the year
  - Why?

Christmas shopping

amazon

aws

Today: 12% of total Amazon revenue

Yes, Andy?

Jeff Bezos

Andy Jassy

Why don't we rent out our unused capacity?

Public Cloud & Infrastructure as a Service

- Users (**“tenants”**) **“rent”** out servers
- Gives rise to **multi-tenancy**: multiple tenants must now share the infrastructure
- *Network as a shared resource:* How does this affect users? Cloud providers?

Implications of Service Model

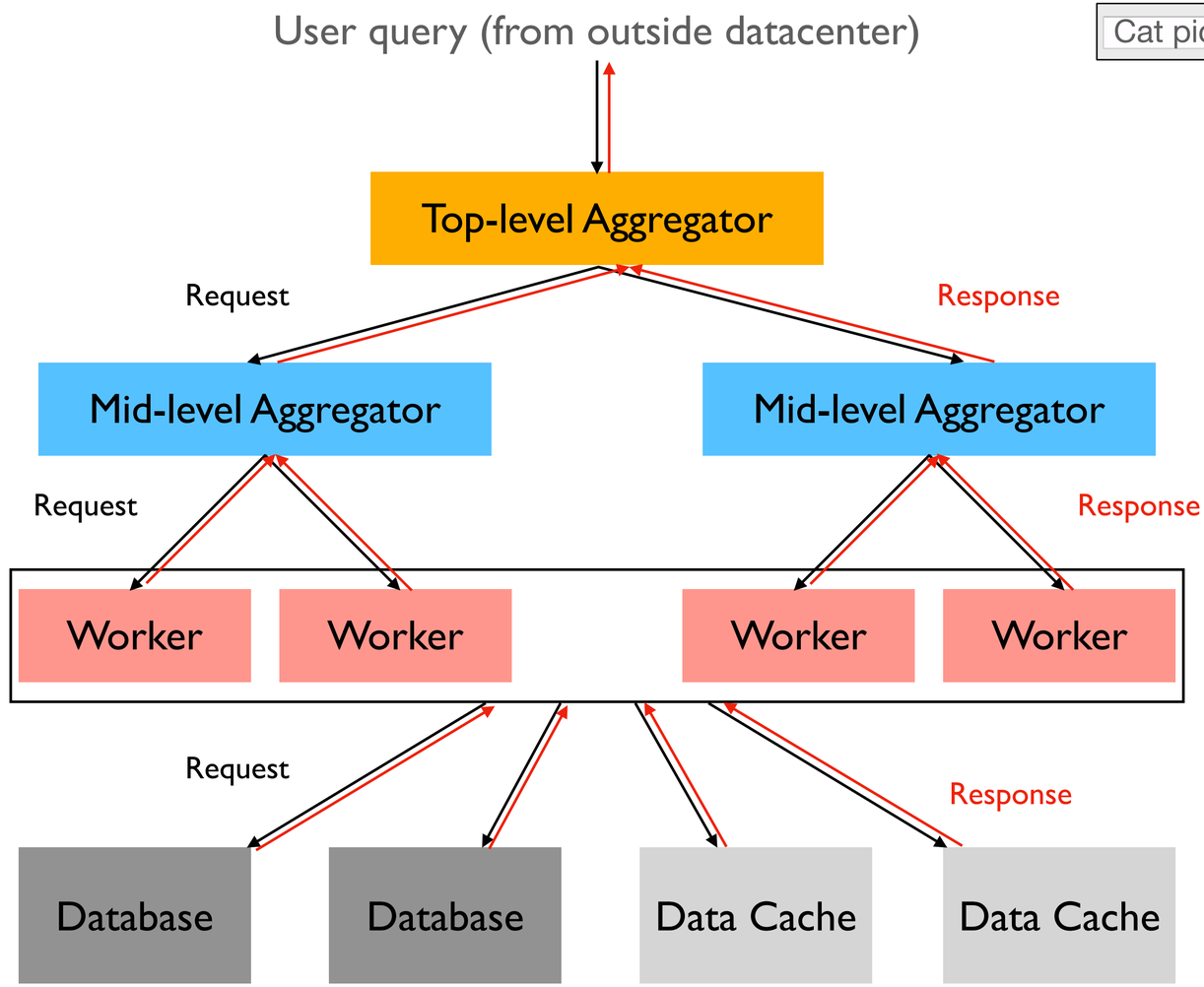
- **Compare with Internet:**
  - Performance guarantees
  - Isolation guarantees
  - Portability
- **How?**
  - "Network virtualization" (SDN): Later…

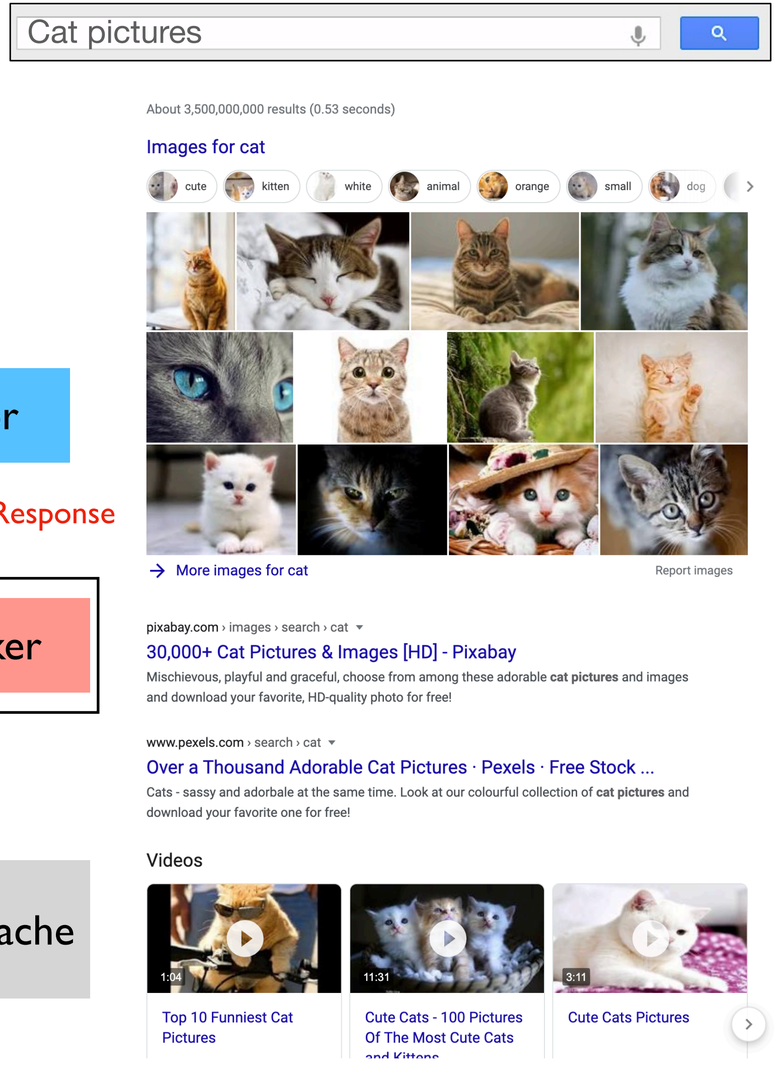
Application Characteristics

- Common Theme: **Parallelism**
  - Application decomposed into tasks
  - Running in parallel on different servers
- **Two common paradigms (not exhaustive)**
  - Partition-Aggregate
  - Map-Reduce

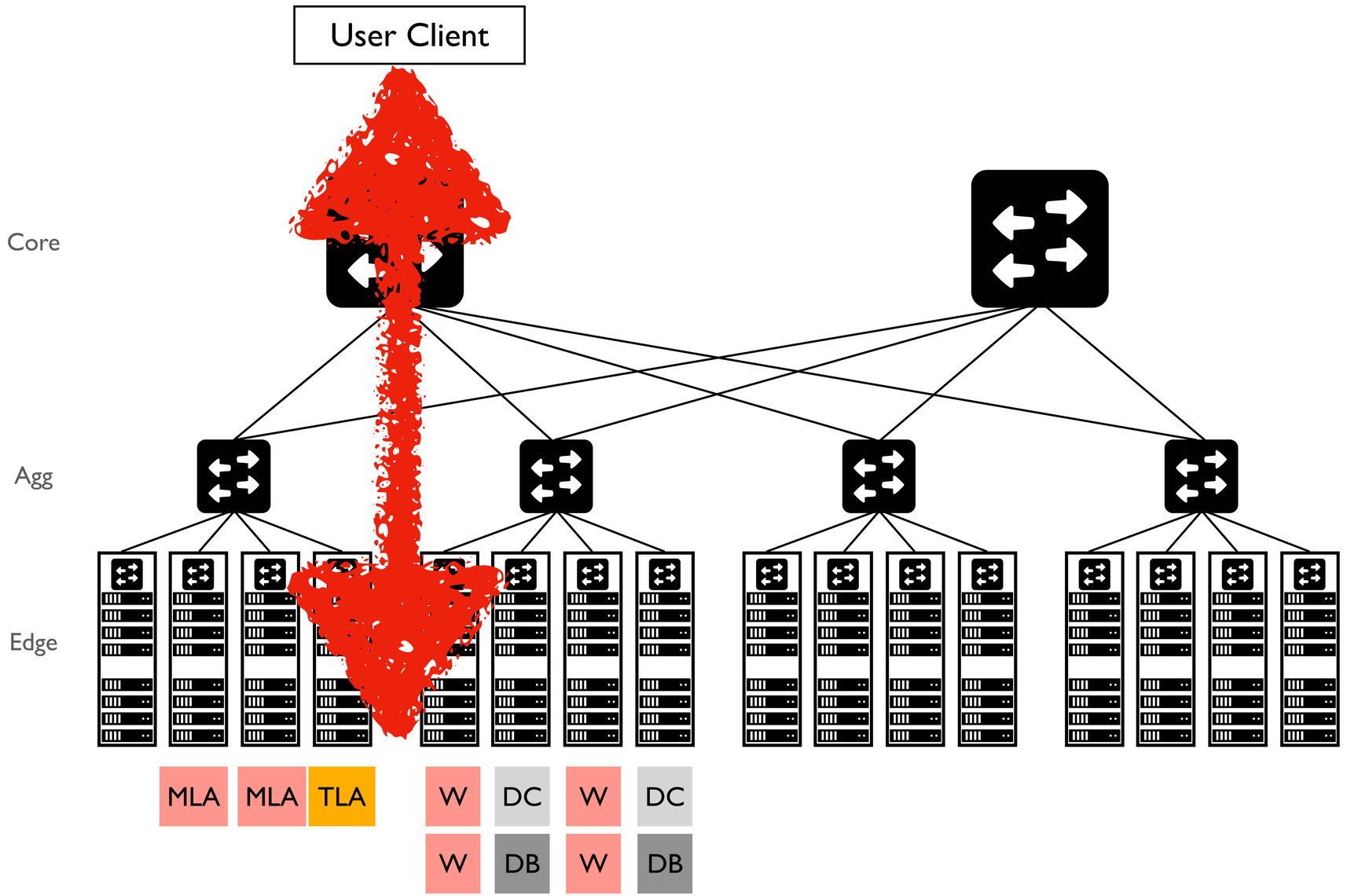
Workload: Partition Aggregate

Most communications over network



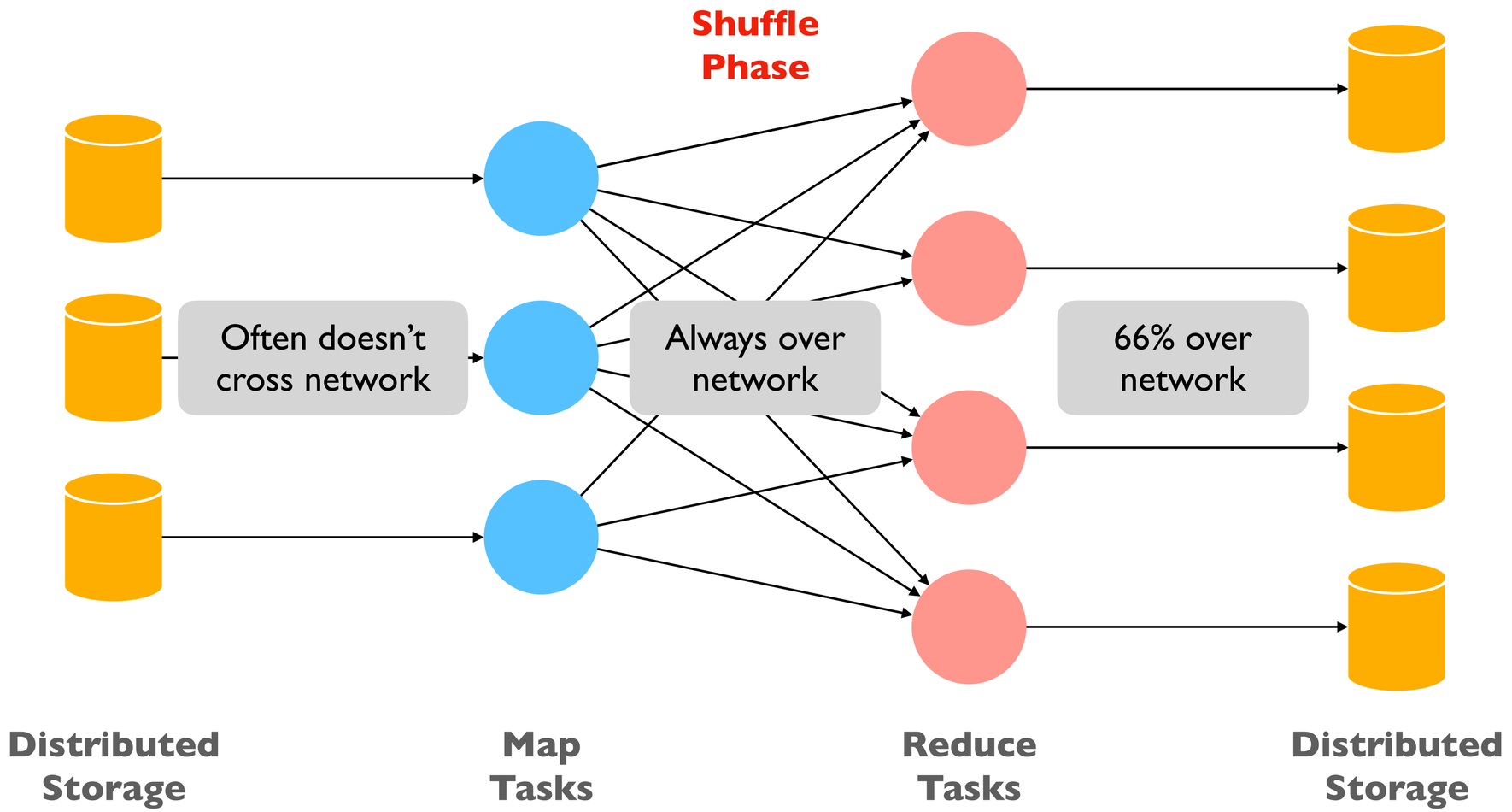


"North-South" Traffic

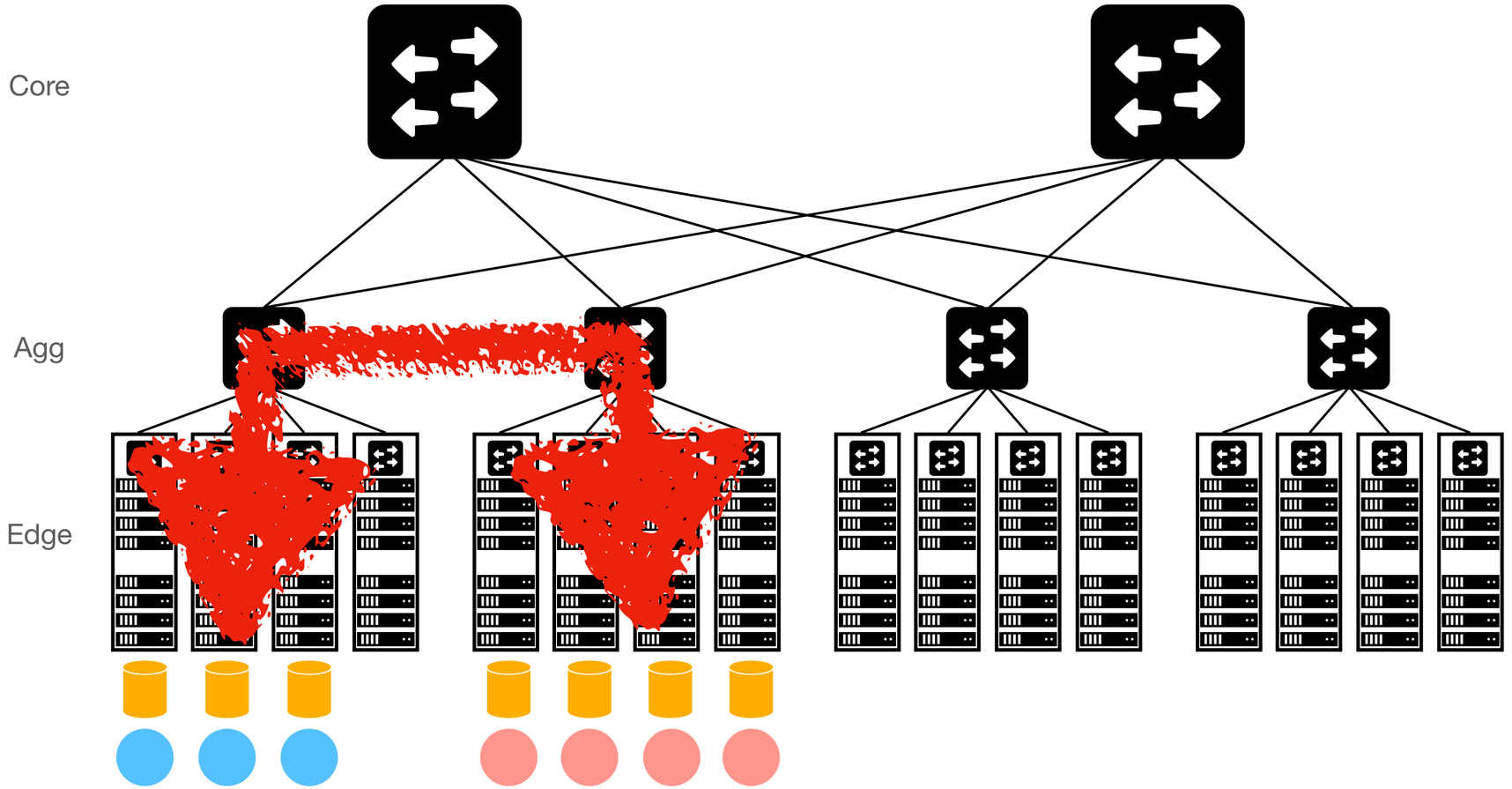


- Interactive query-response exchange b/w external clients & datacenter
  - *Latency sensitive*
  - *O(milliseconds)*
- Handled by worker/aggregator tasks, databases & caches

Workload: Map Reduce



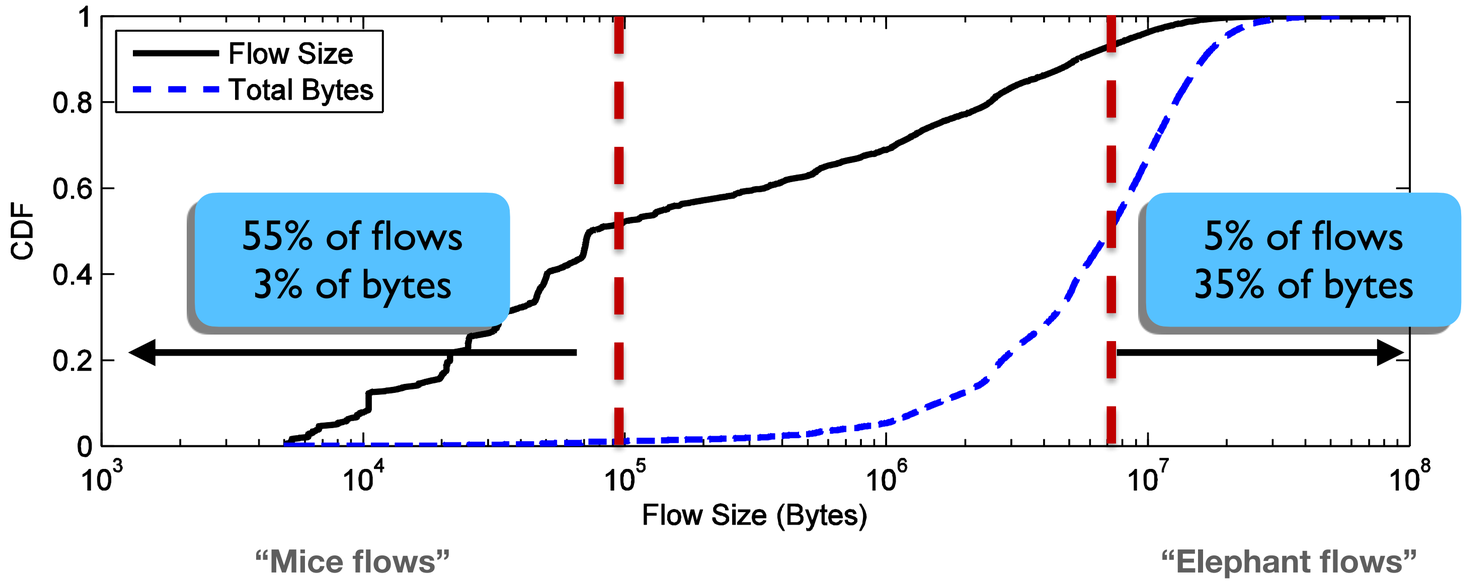
"East-west" Traffic



- Traffic between servers in the datacenter
  - *Bandwidth intensive*
  - *O(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)



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

Implications of Application Characteristics

- **Low latency is critical (for north-south)**
  - Also worst-case ("tail") latency

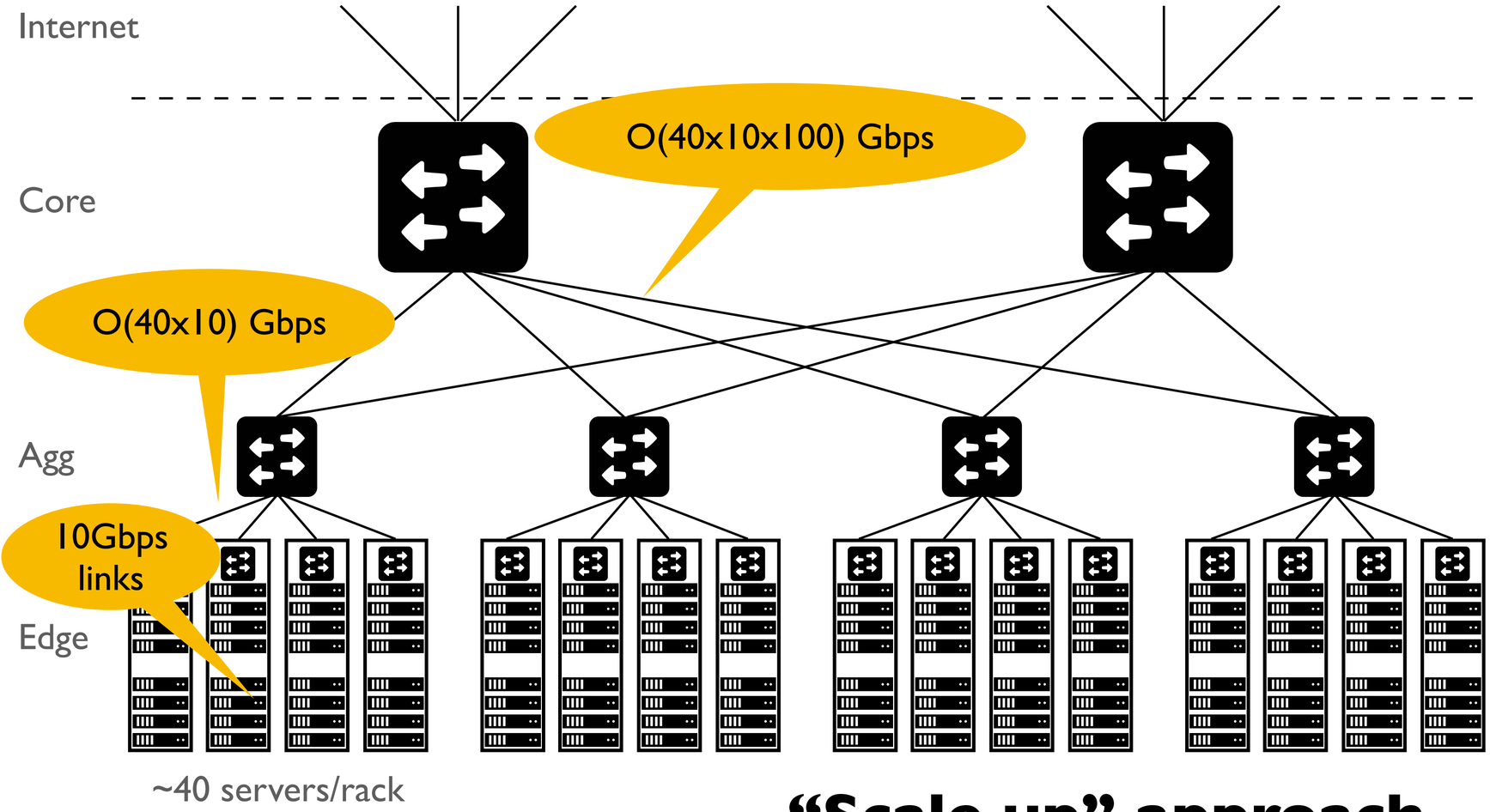
- **High bandwidth any-to-any communication (east-west)**
  - "Bisection bandwidth"

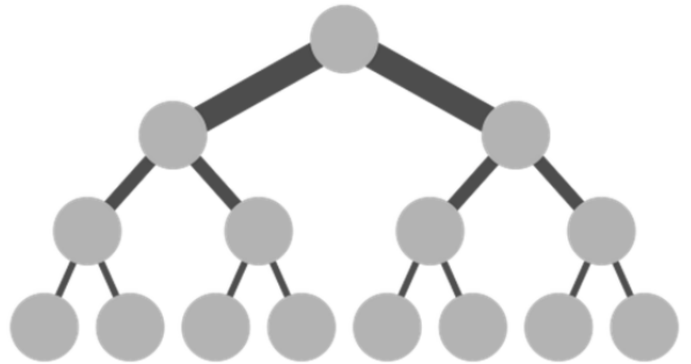
Bisection Bandwidth

- 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





“Scale up” approach

Achieving Full Bisection Bandwidth

- **Challenge: "Scaling up" a traditional tree topology is expensive!**
  - Requires non-commodity / impractical / link and switch components

- **Solutions?**
  - Later…

Questions?