

FIT1047 - Week 9

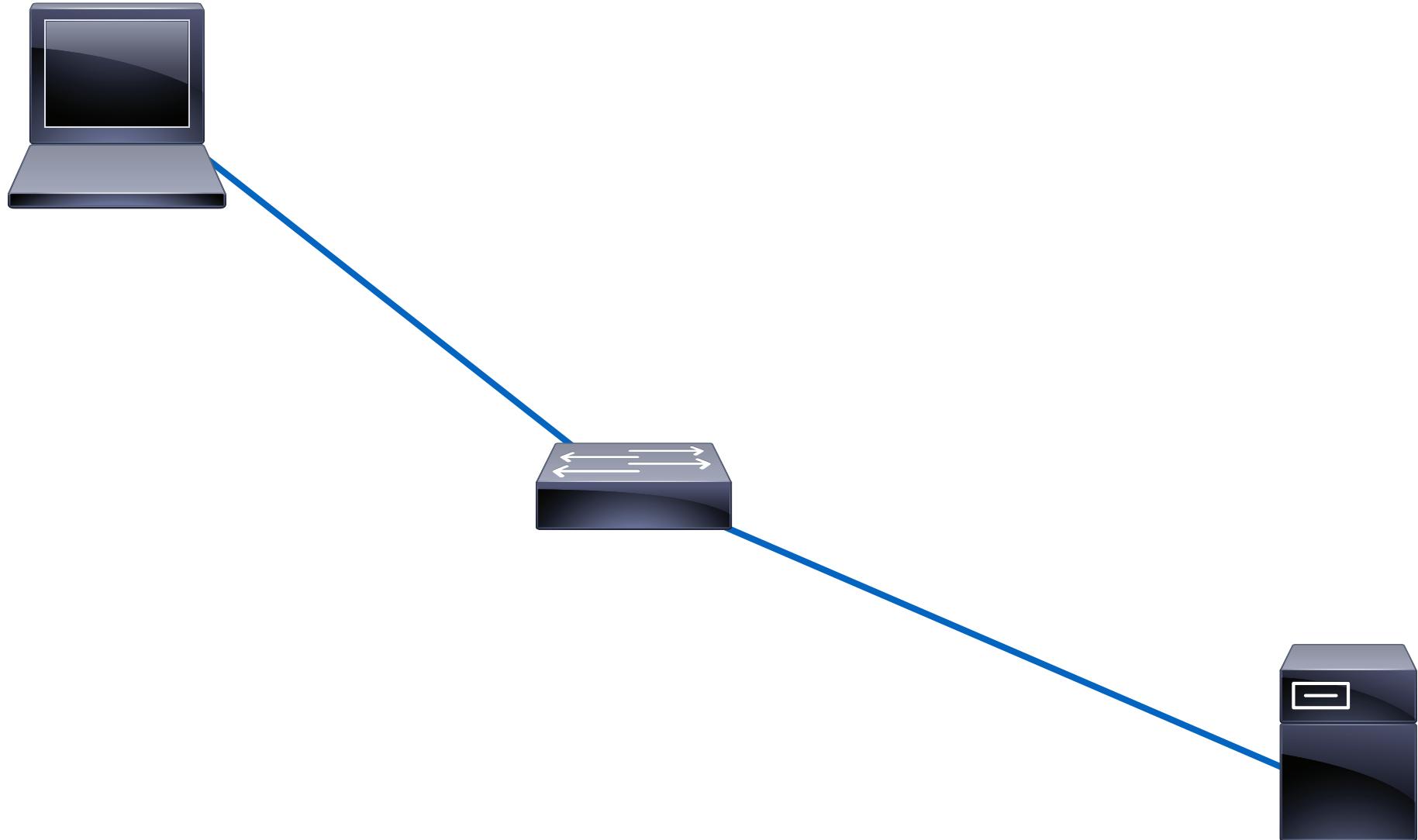
Networks: Physical and Data Link layers



Goals for this week

- Understand how messages can be transmitted over physical media such as copper cables, optical fibres or radio waves
- Look at Media Access Control (Data Link layer): when is a device allowed to transmit?
- Study the basic structure of Ethernet and WiFi networks

Basic LAN components



Basic LAN components

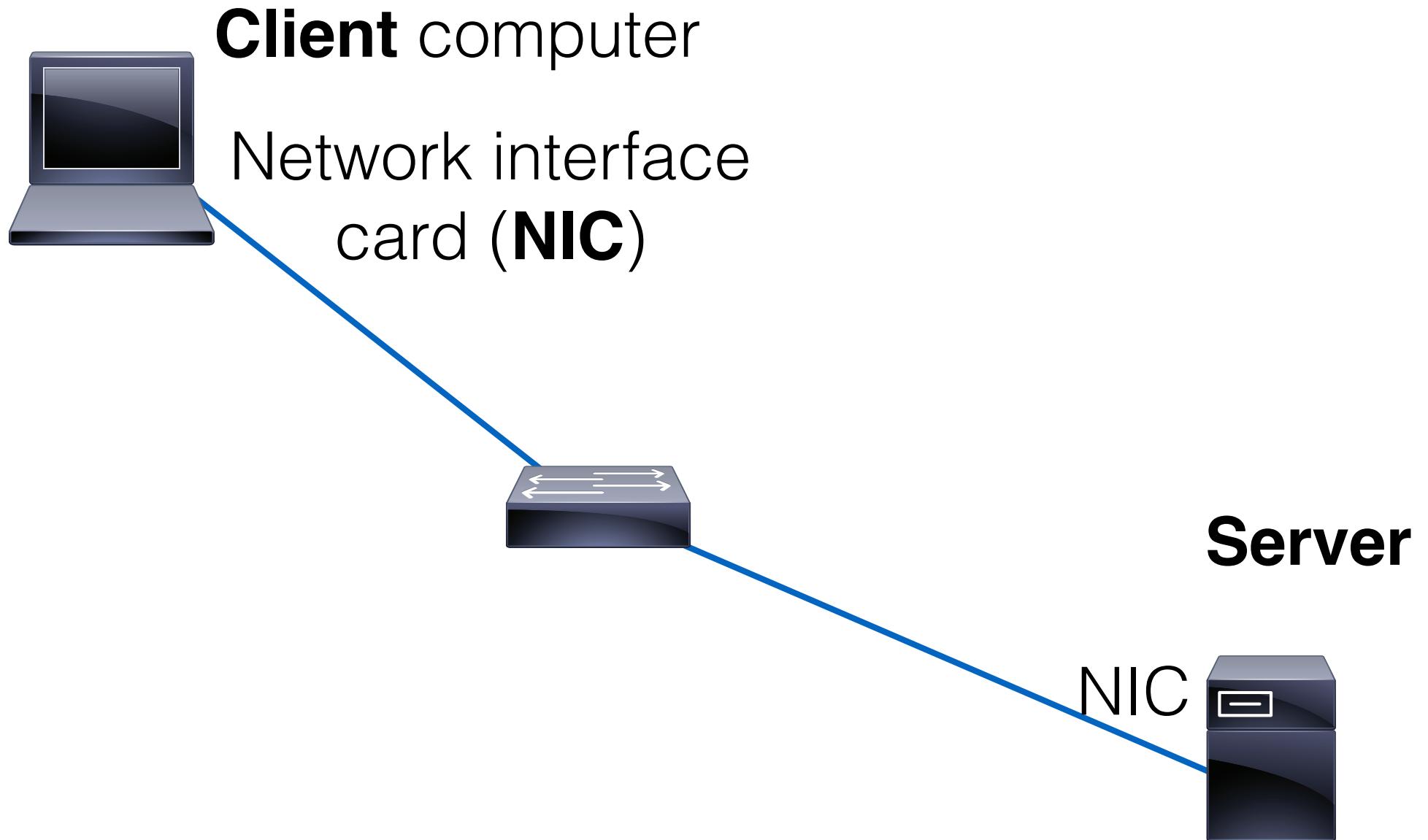
Client computer



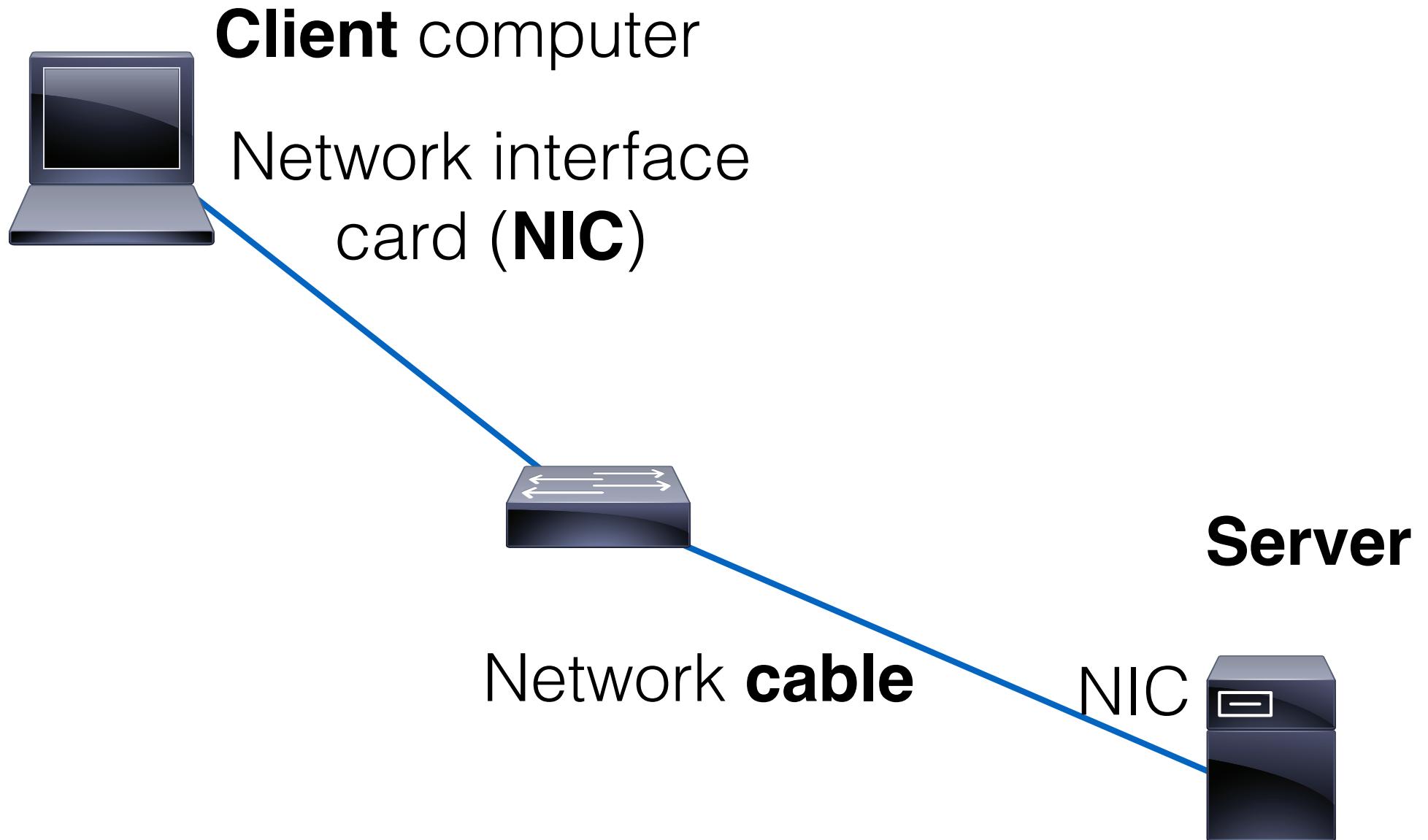
Server



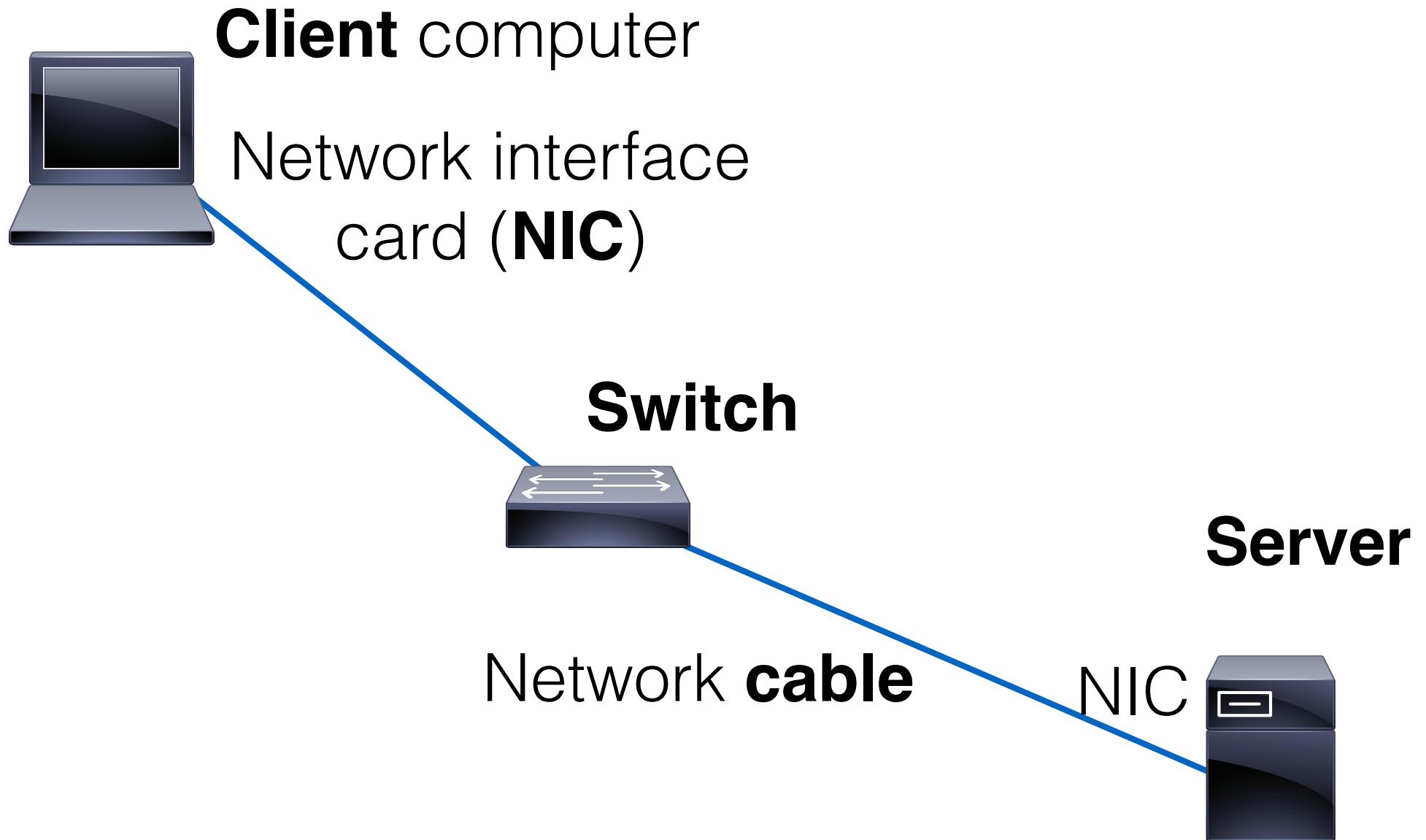
Basic LAN components



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Network interface card (NIC)

Implements physical and data link layer

- includes unique data link layer address (MAC address)
- provides physical connection to the network (socket or antenna)
- implements protocols (error detection, construction of frames, modulation or encoding etc)

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Connection to the computer

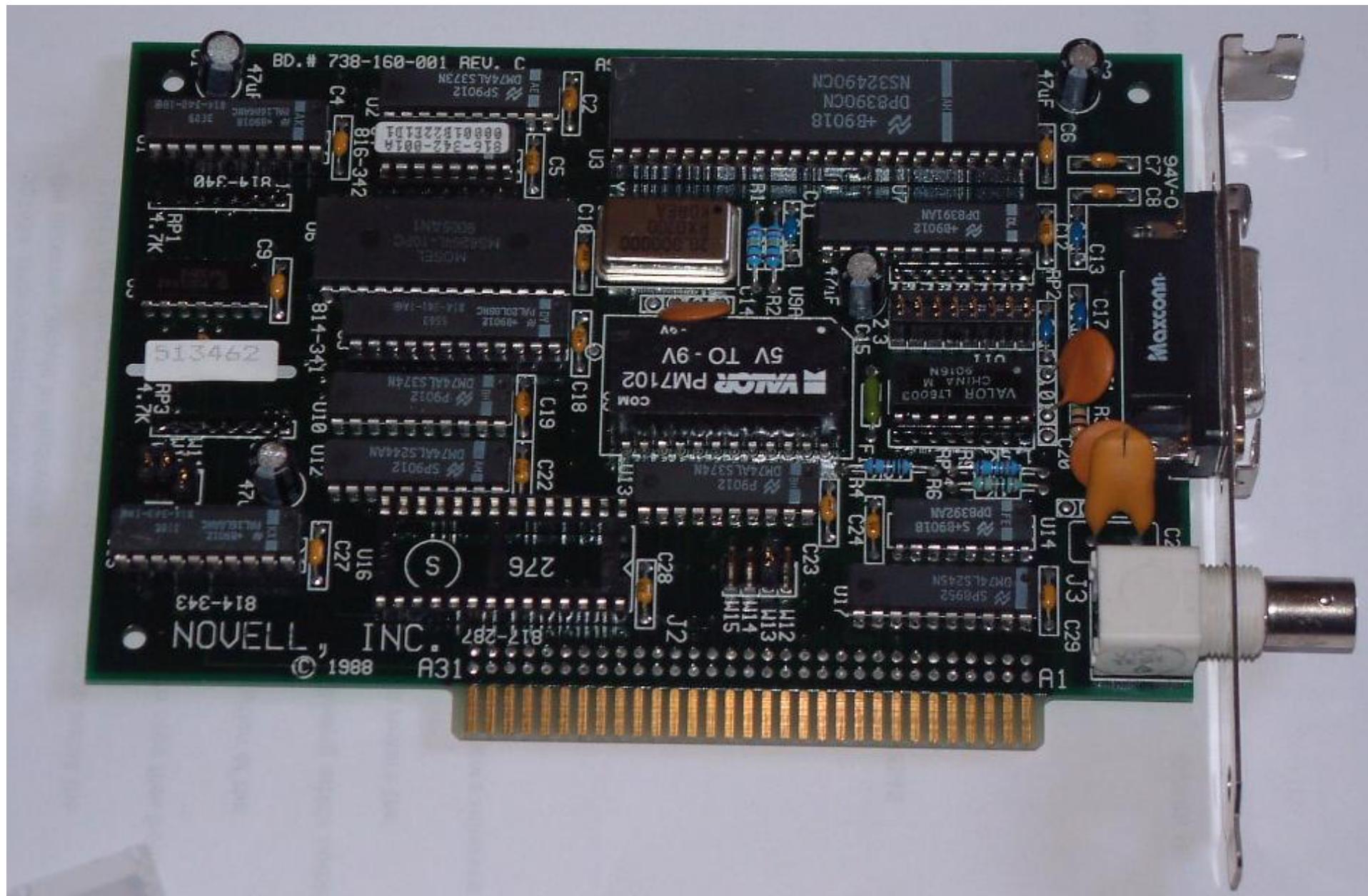
- often built into motherboards
- or connected via USB, PCI Express etc

Network interface card (NIC)

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Network interface card (NIC)



Network interface card (NIC)



Network Cables

Physical connection between network devices

Different types:

- UTP (unshielded twisted pair, most common type for LAN)
- STP (shielded twisted pair)
- Optical fibre (not yet common in LANs)
- Coaxial (only old LANs)

Network Cables

Name	Data Rate	Cables
10BASE-T	10Mbps	UTP cat 3 / cat 5
100BASE-T	100Mbps	UTP cat 5
1000BASE-T	1Gbps	UTP cat 5, 5e, 6
1000BASE-X	1Gbps	optic fiber (single mode or multi-mode)
10GbE	10Gbps	UTP cat 5e, 6, 7 optic fibre
40GbE	40Gbps	optic fiber

Physical layer

Physical media

- We transmit information using **physical signals**
- A signal travels through a **medium**:
 - **electrical** signals through e.g. copper wires
 - **radio waves** through “air” (or, really, space)
 - **light** signals through space or optical fibres

Digital vs Analog

- **Digital data:**
 - Discrete values (e.g. 0 and 1, or characters in the alphabet)
 - Discrete step from one symbol to the next

Digital vs Analog

- **Digital data:**
 - Discrete values (e.g. 0 and 1, or characters in the alphabet)
 - Discrete step from one symbol to the next
- **Analog data:**
 - Range of possible values (e.g. temperature, air pressure)
 - Continuous variation over time

Digital vs Analog

- Digital **signal**:
 - Waveform with limited number of **discrete states**

Digital vs Analog

- Digital **signal**:
 - Waveform with limited number of **discrete states**
- Analog **signal**:
 - Continuous, often **sinusoidal wave**
 - E.g. sound (pressure wave in air), light and radio (electromagnetic waves)

Transmission types

- analog signals for analog data:
 - e.g. analog FM radio
- digital signals for digital data:
 - e.g. old Ethernet, USB, the bus in a computer
- analog signals for digital data
 - e.g. modems, ADSL, Ethernet, WiFi, 4G, ...

digital transmission

Digital transmission

- Digital signals are typically transmitted through copper cables

Digital transmission

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- A digital signal encodes 0s and 1s into different **voltage levels** on the cable

Digital transmission

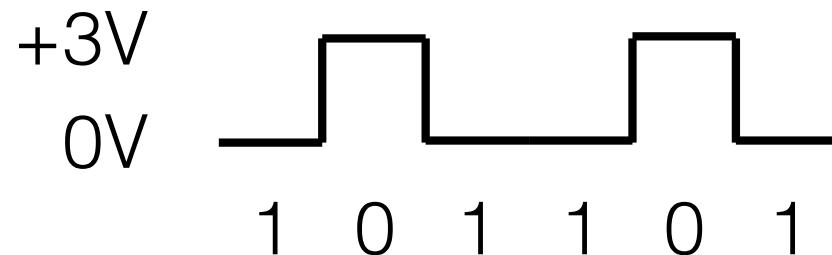
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Digital transmission

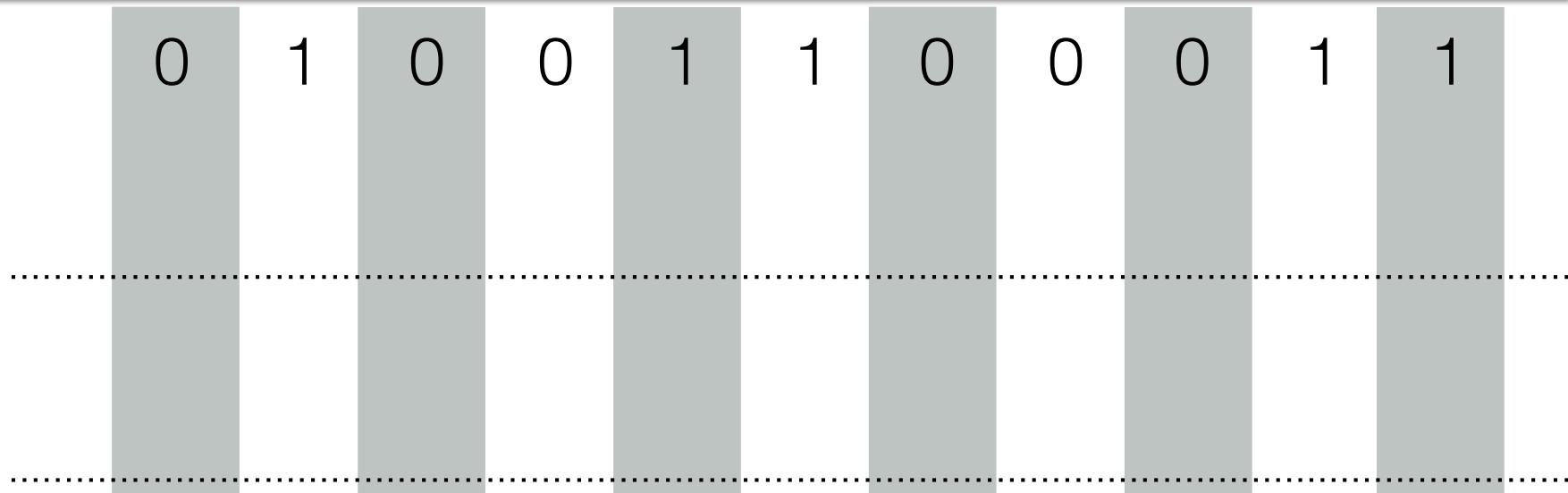
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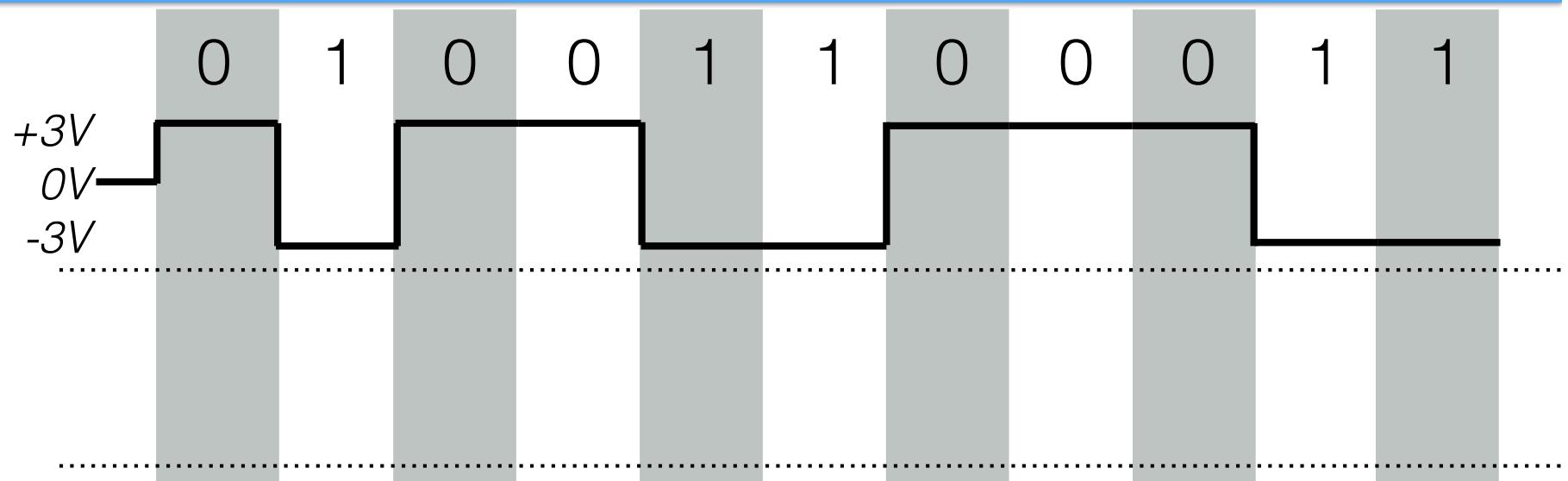


Digital transmission

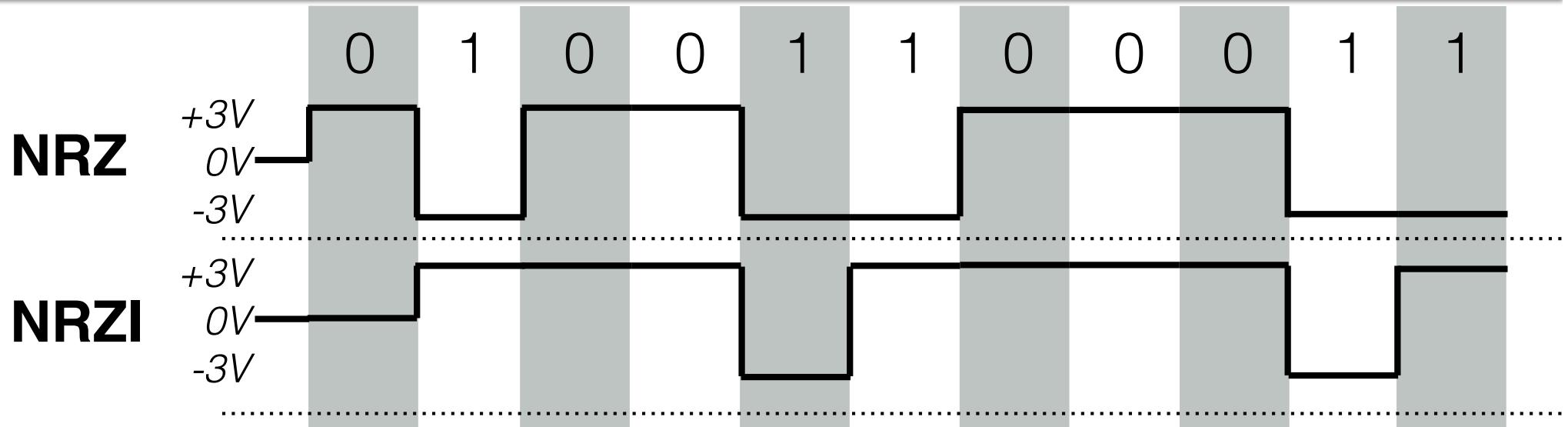


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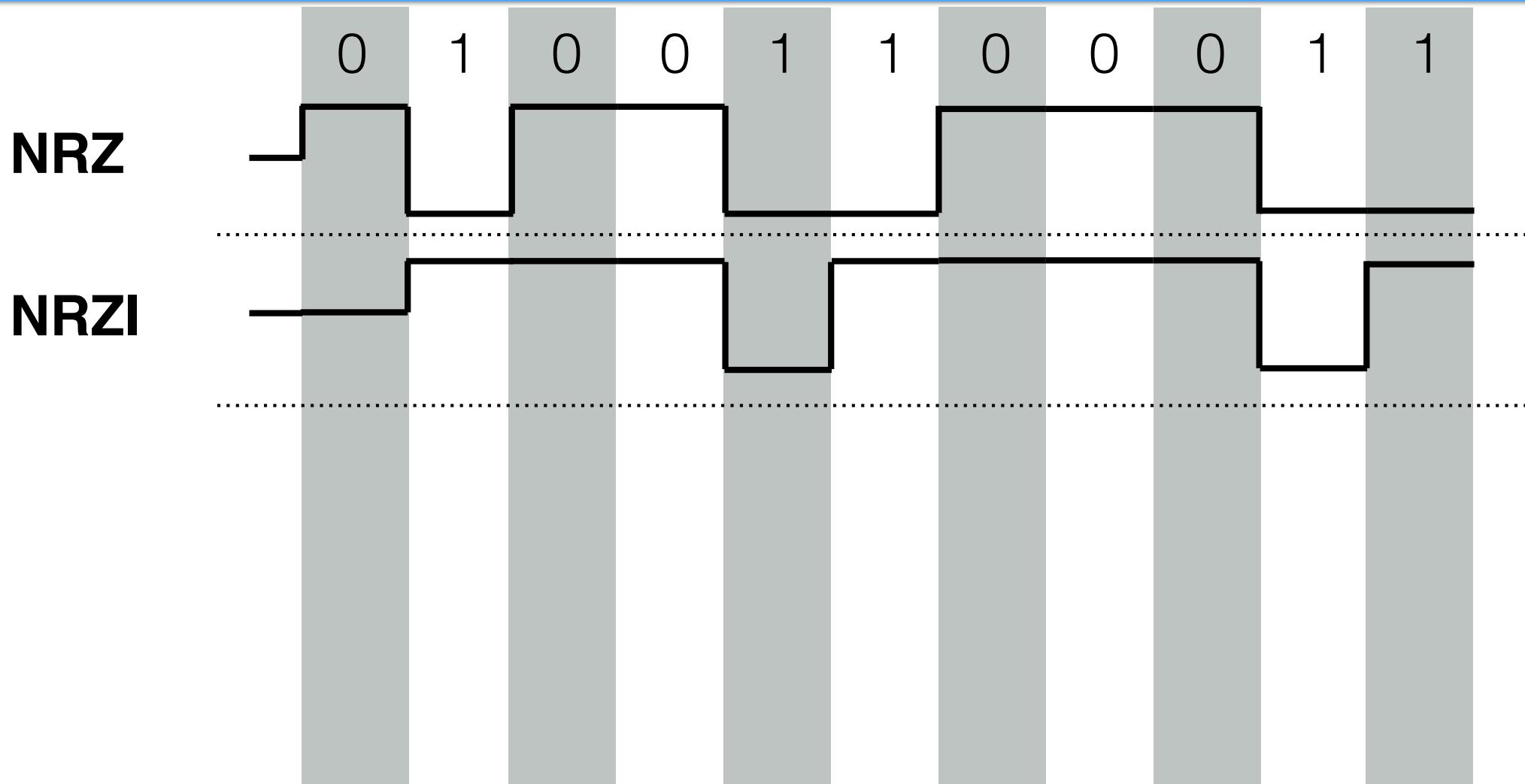
NRZ



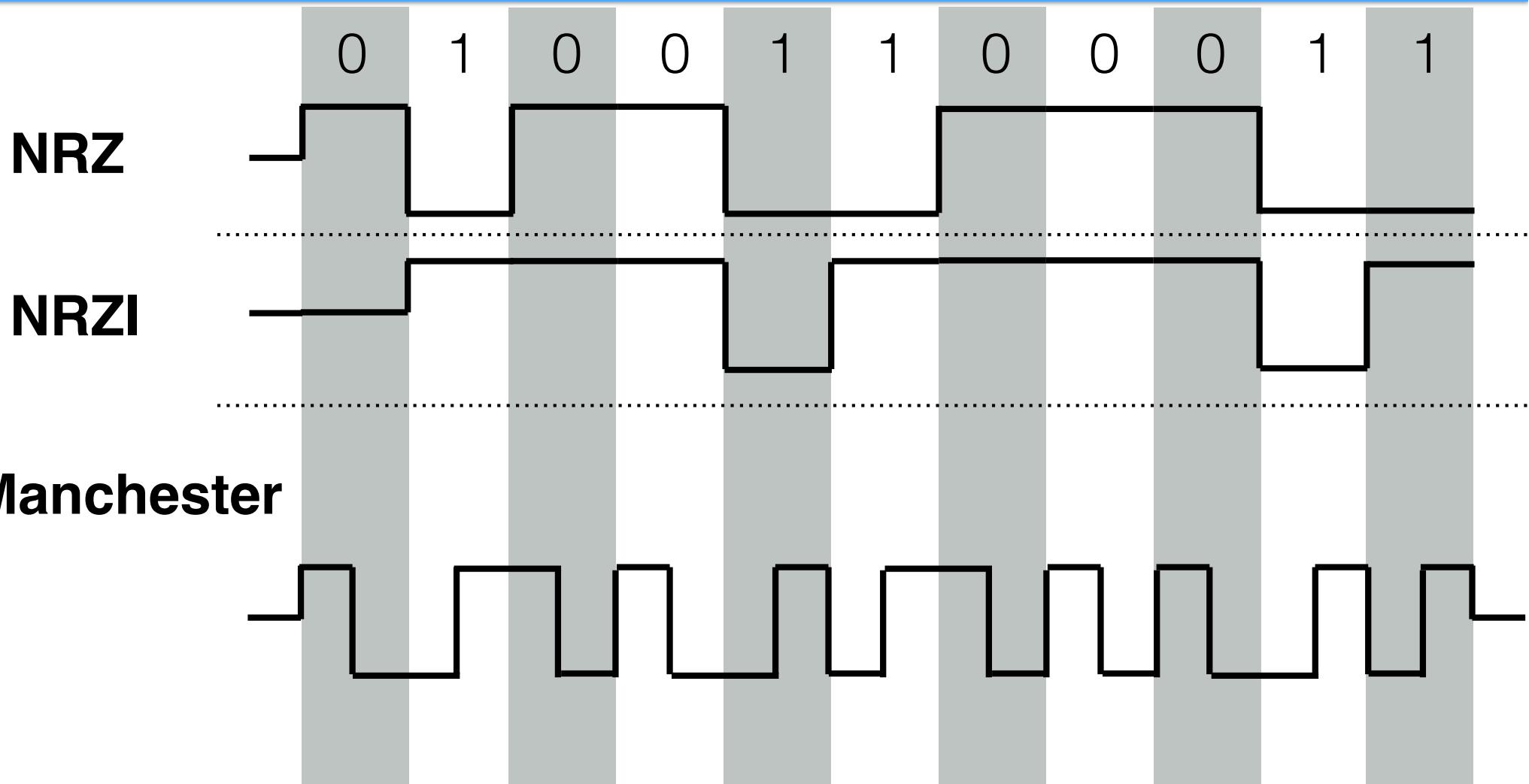
Digital transmission



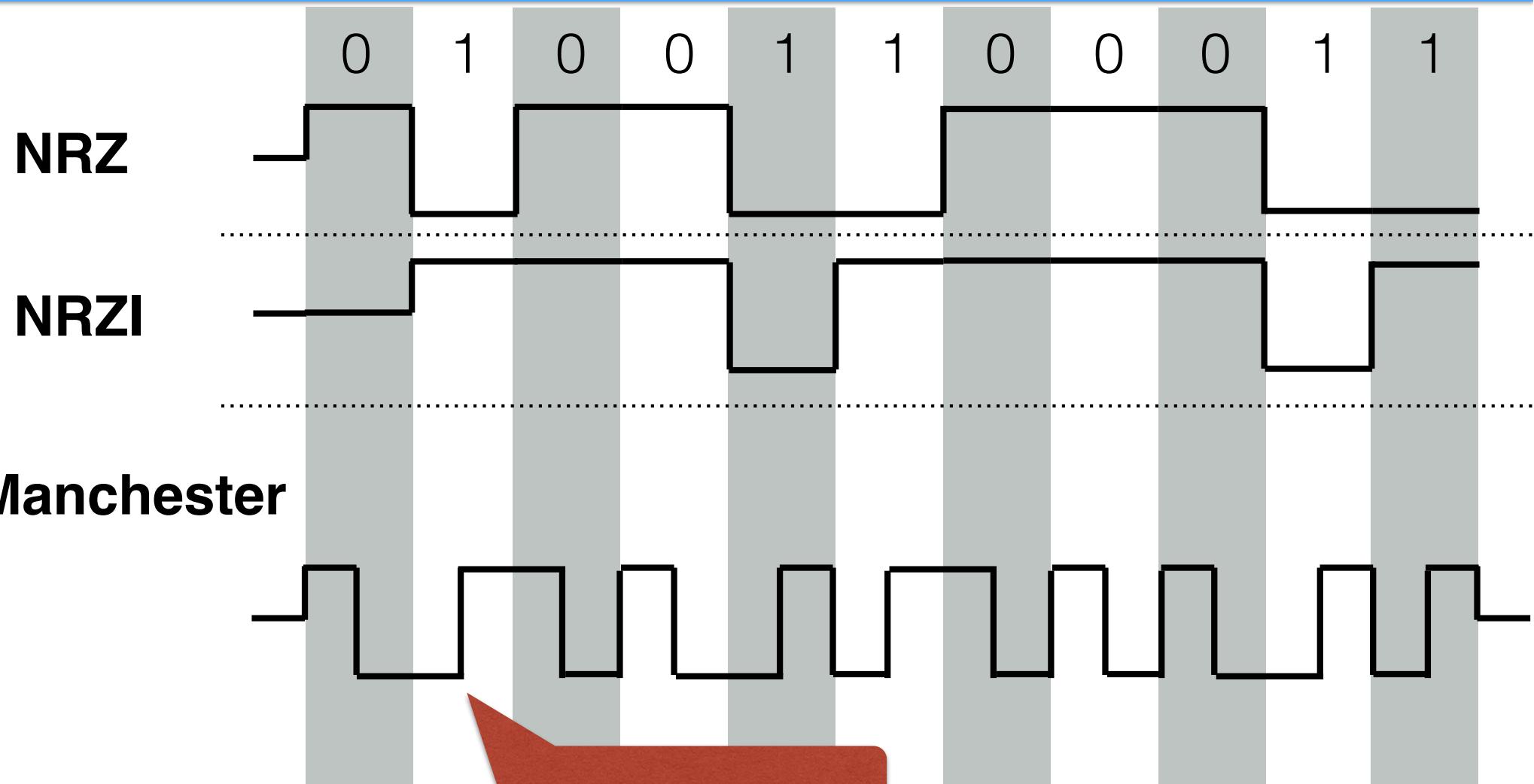
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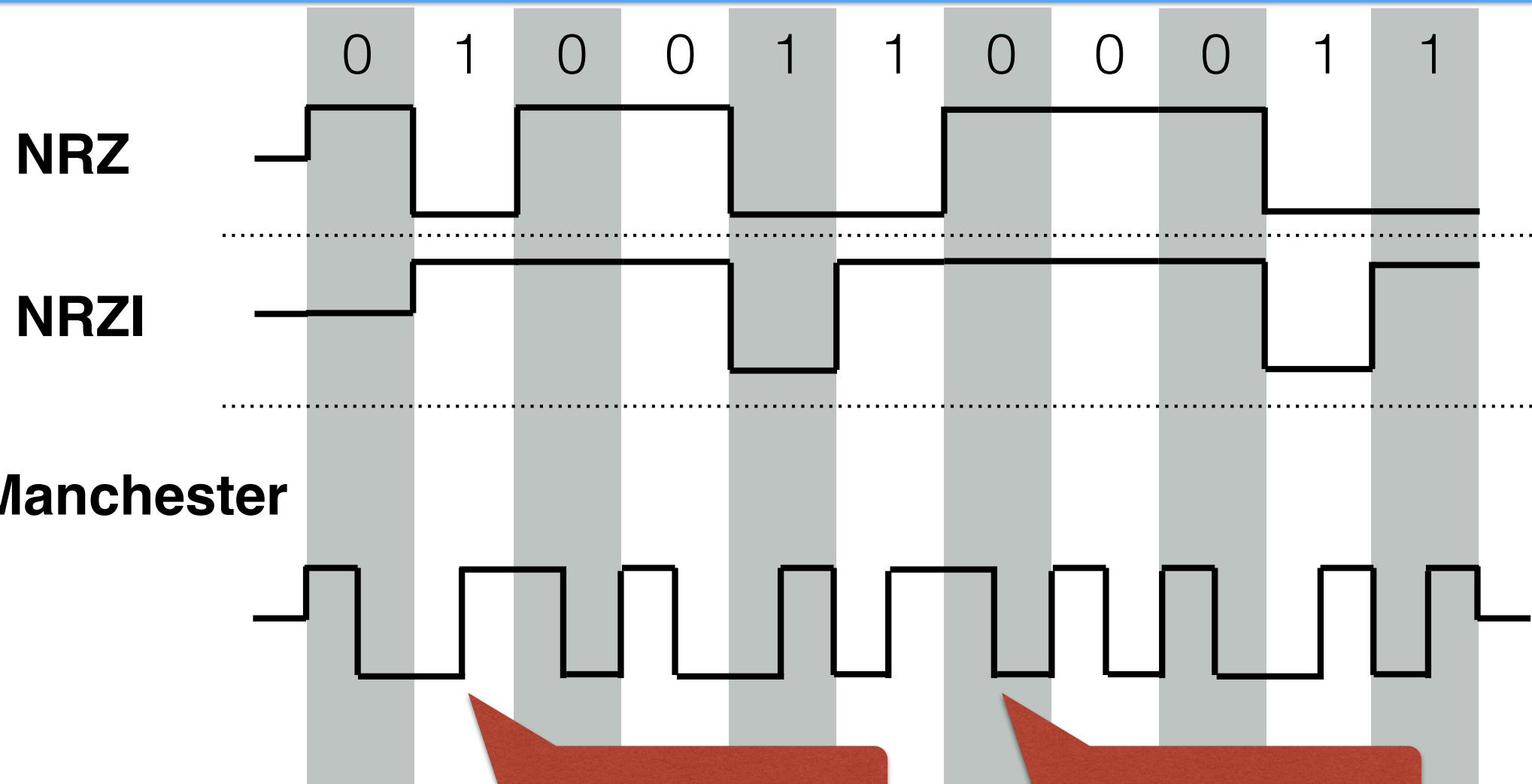


Digital transmission



low-to-high
in the middle of a
bit

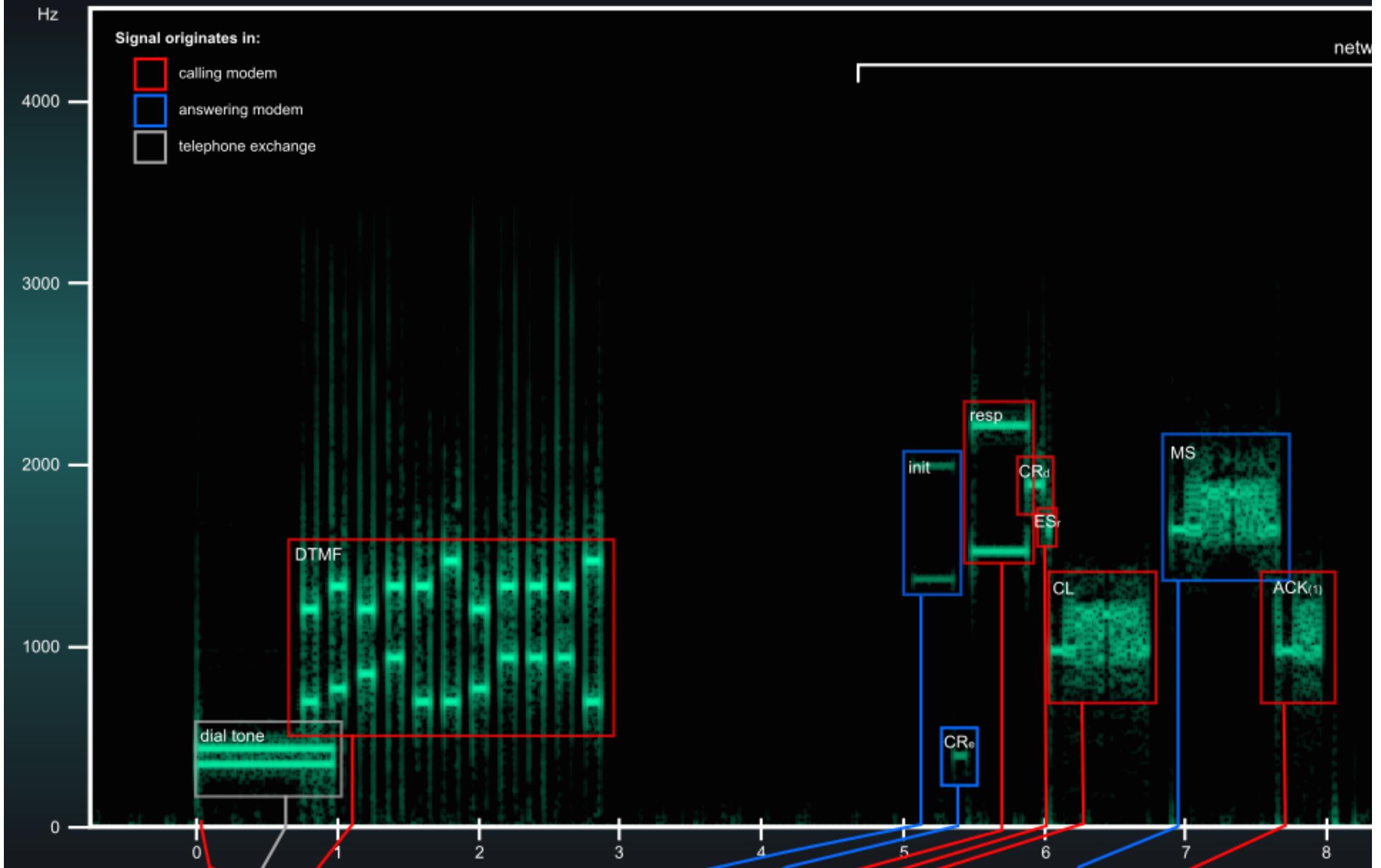
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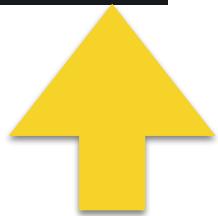
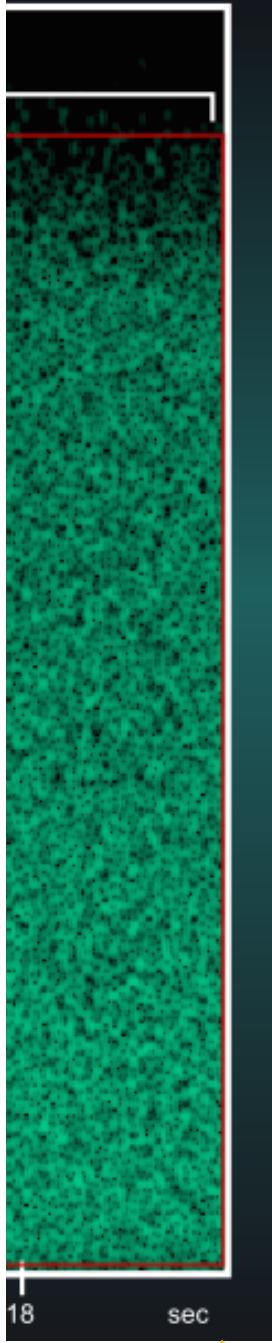


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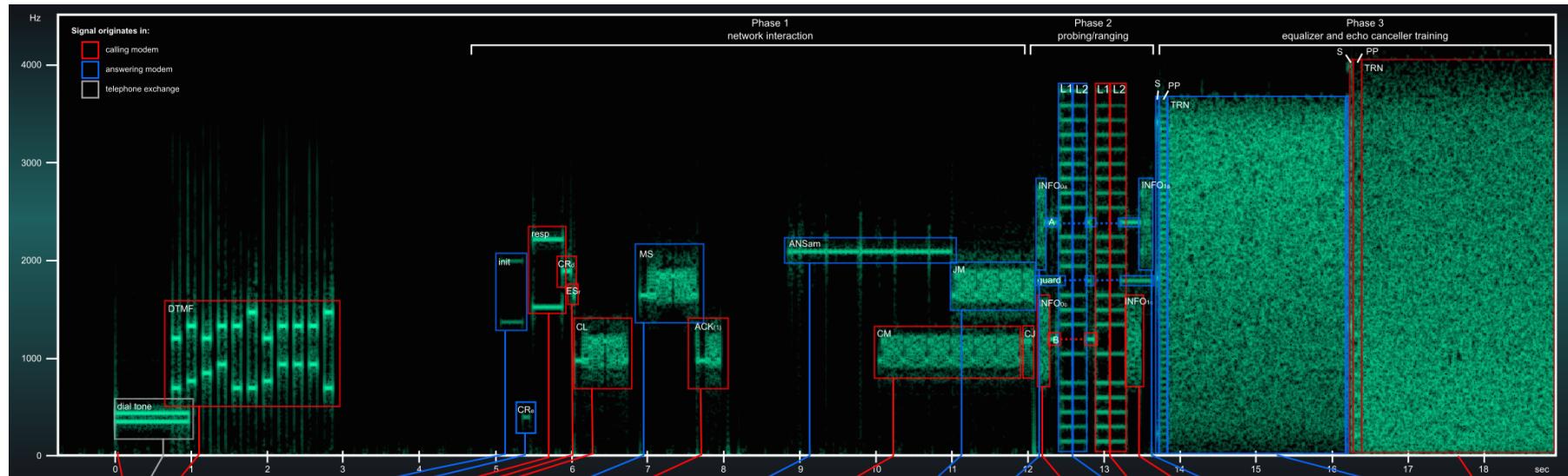
high-to-low in
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analog transmission



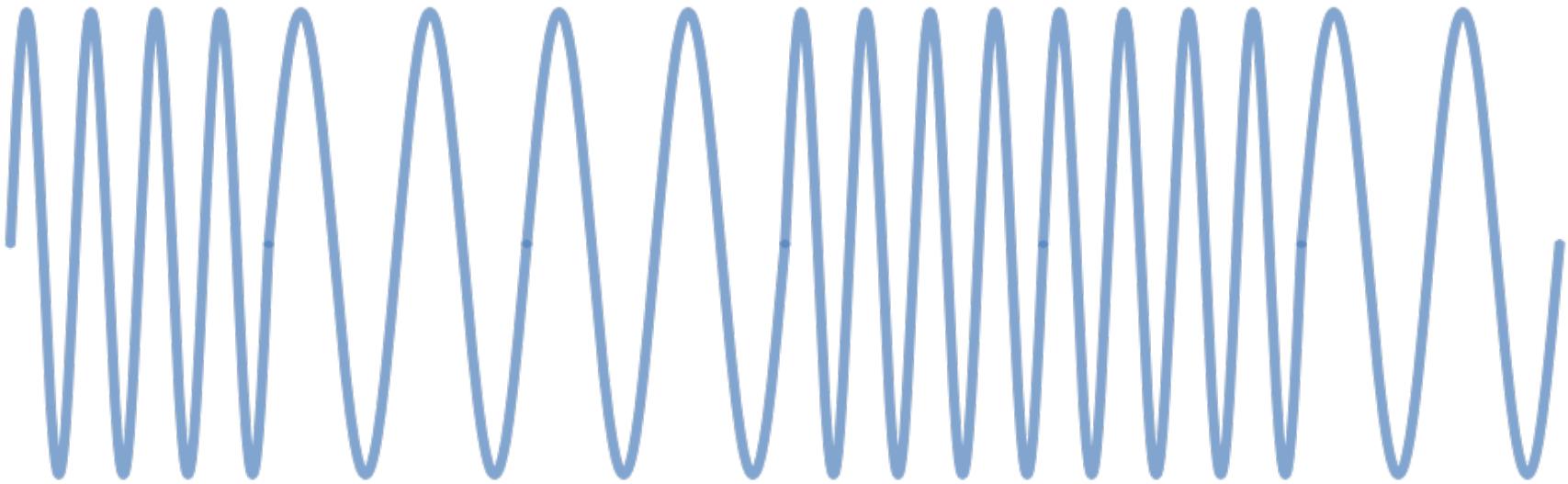


<http://www.windytan.com/2012/11/the-sound-of-dialup-pictured.html>

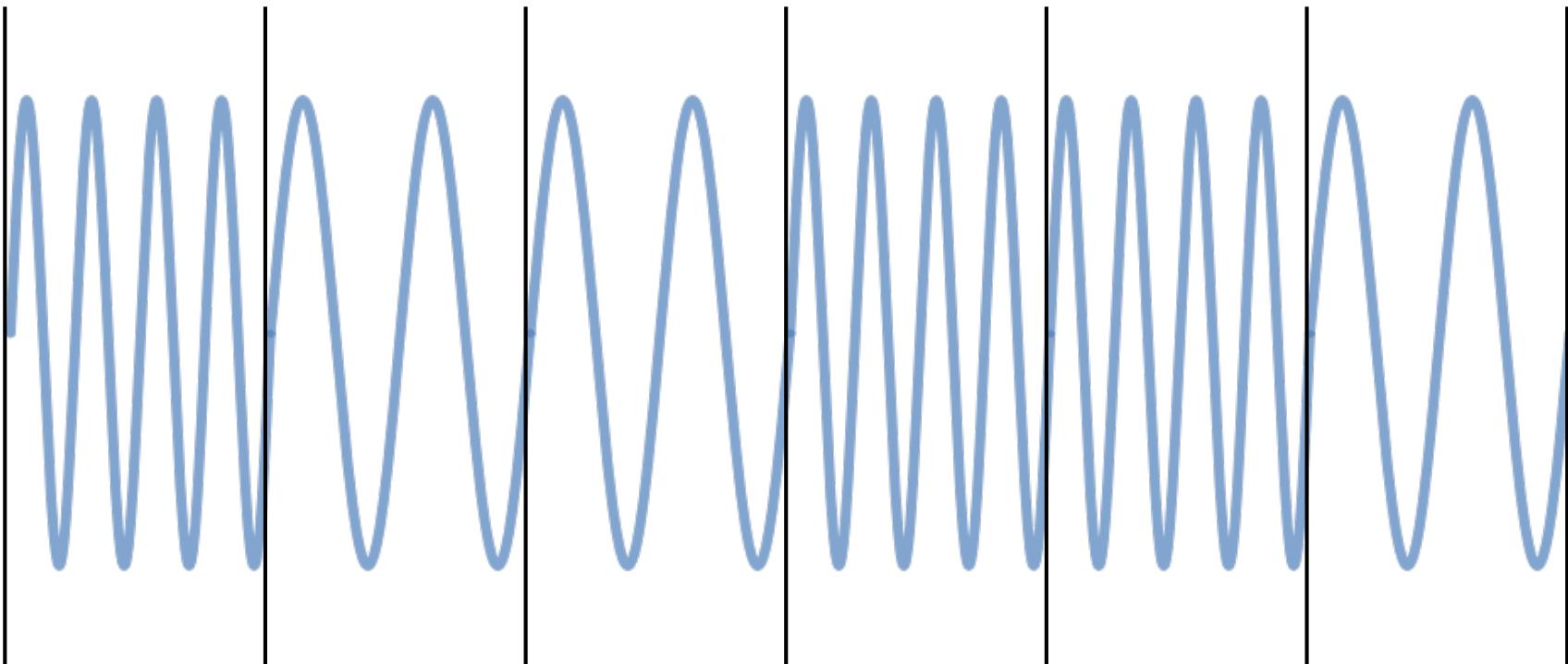


Frequency Modulation

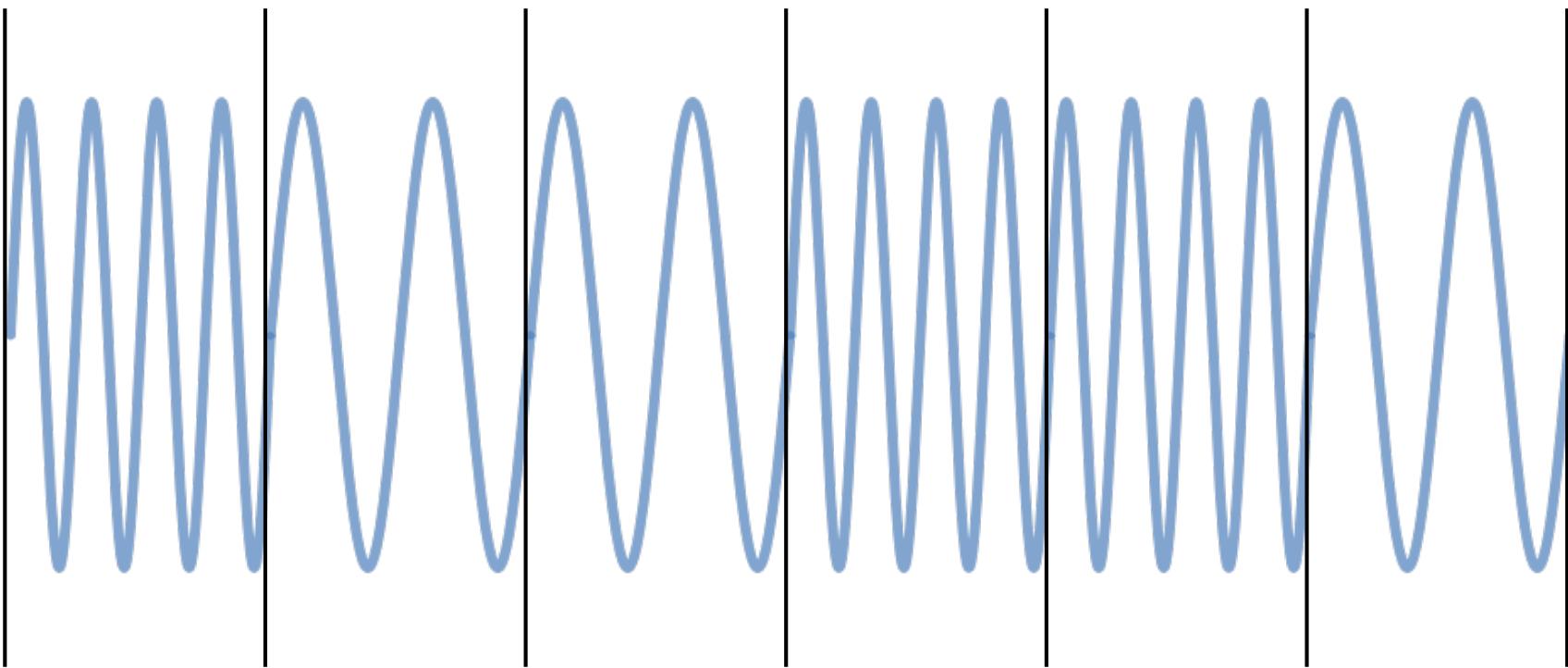
Frequency Modulation



Frequency Modulation



Frequency Modulation



1

0

0

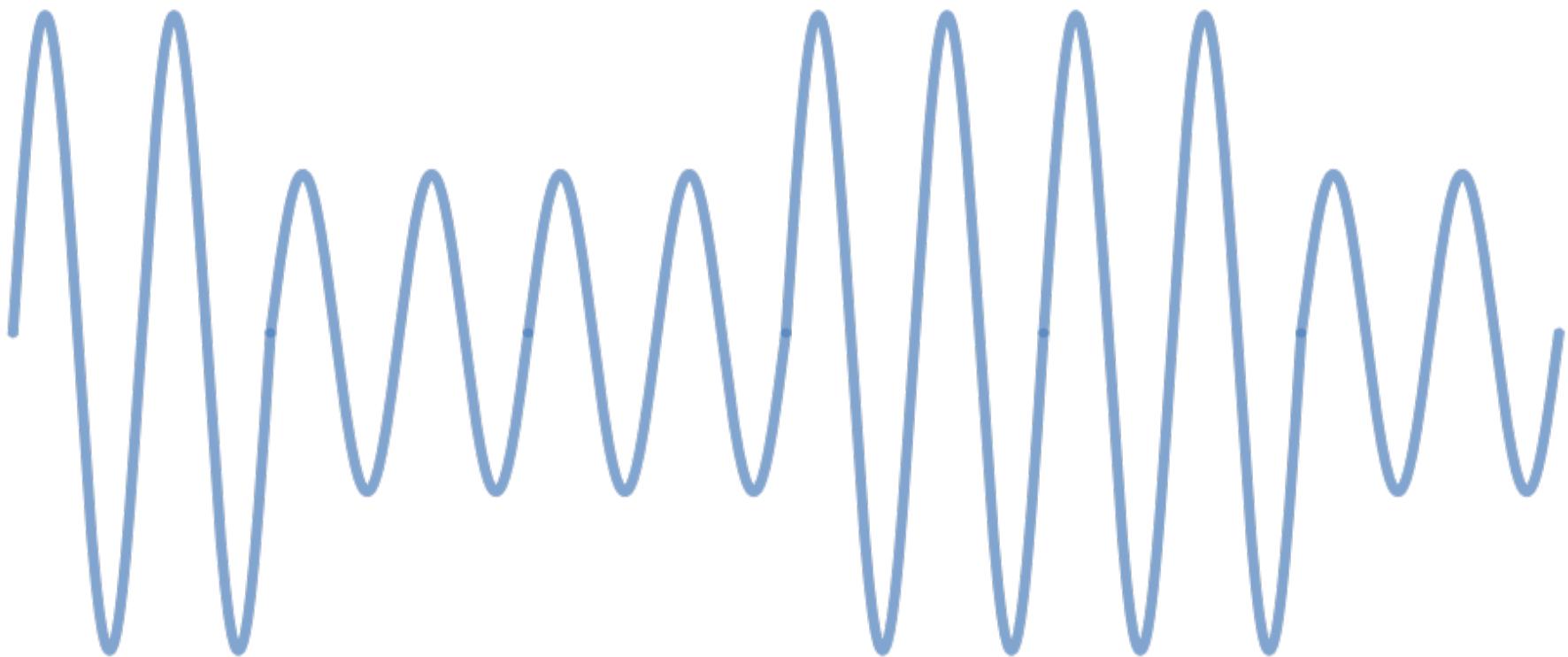
1

1

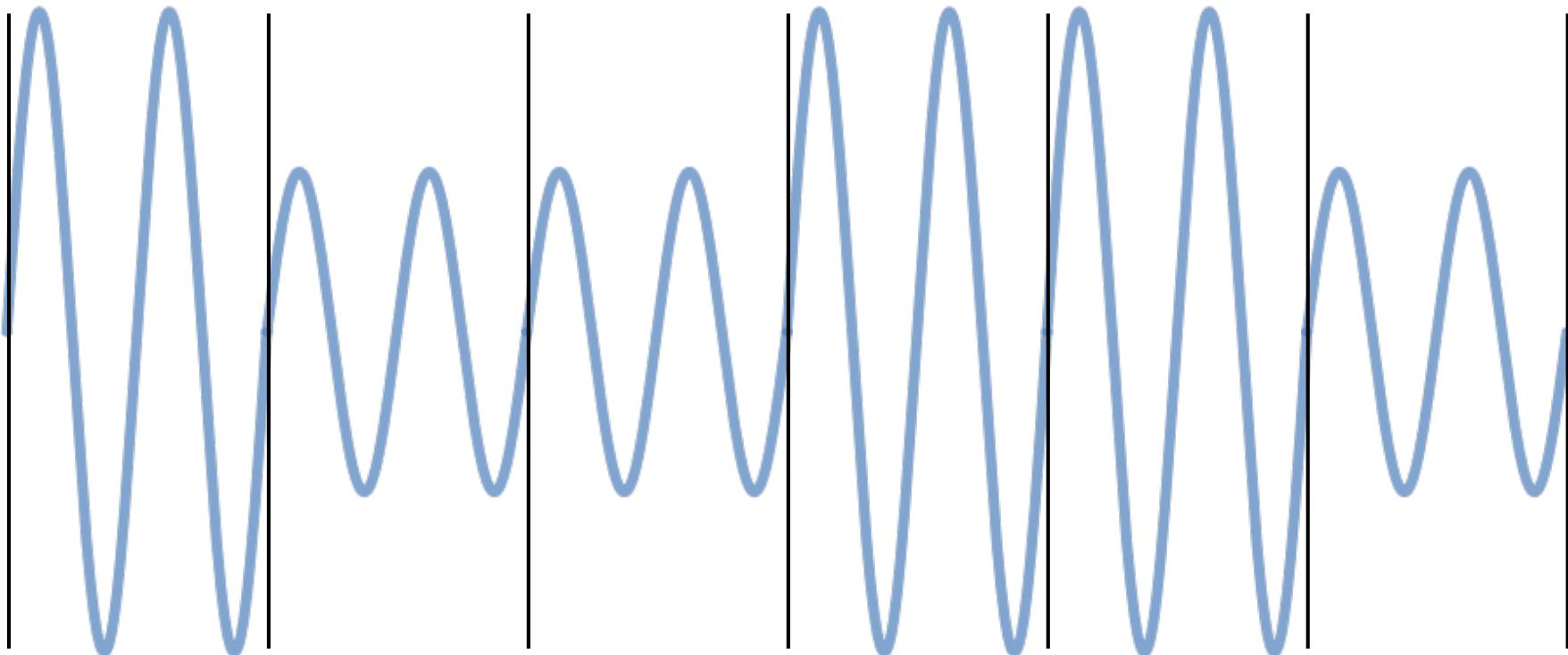
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Amplitude Modulation

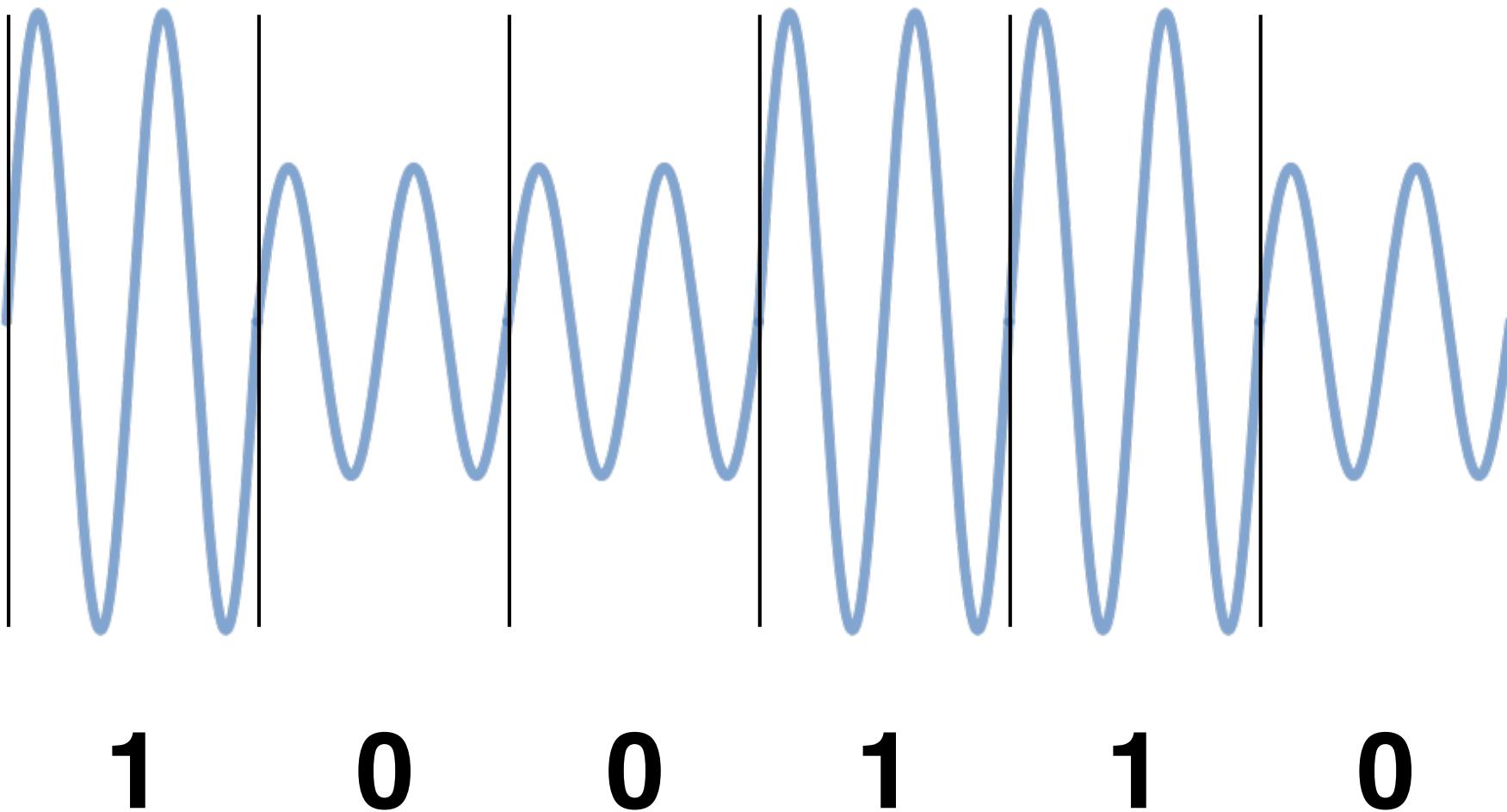
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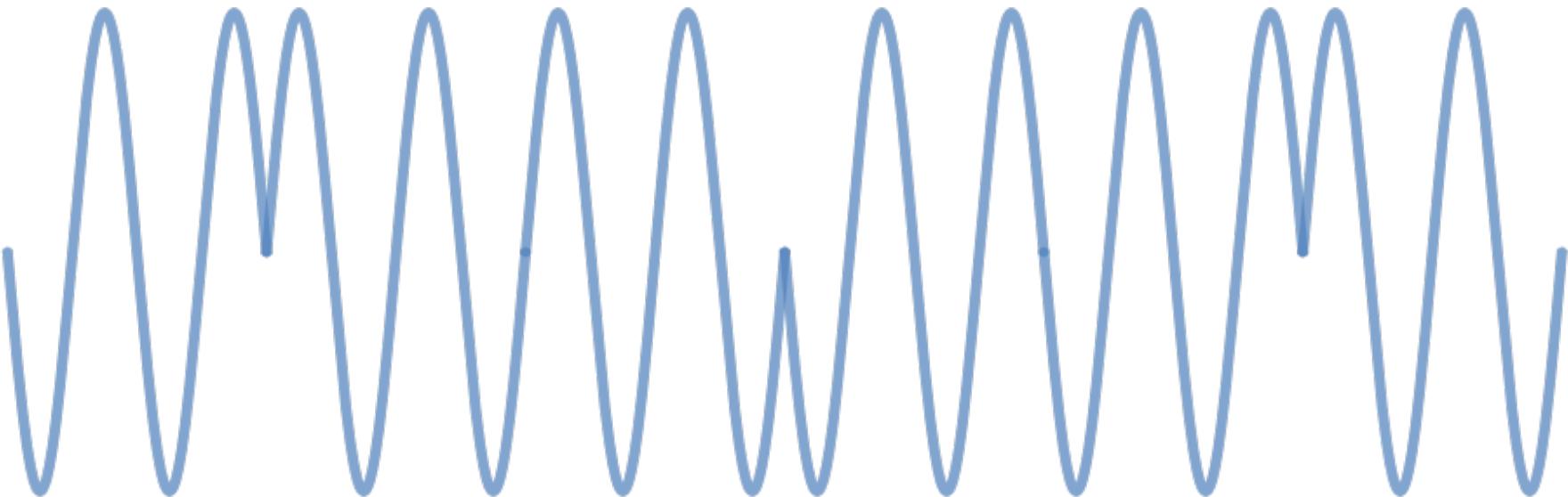


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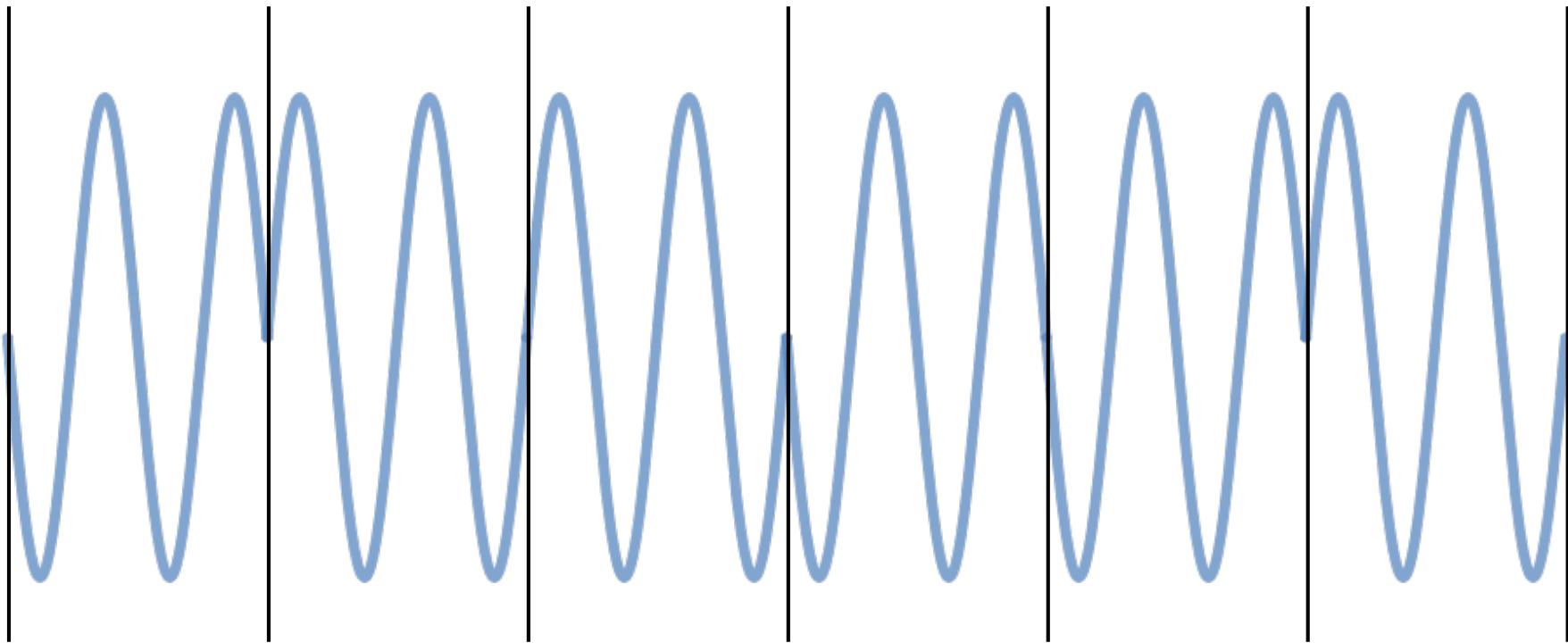


Phase Modulation

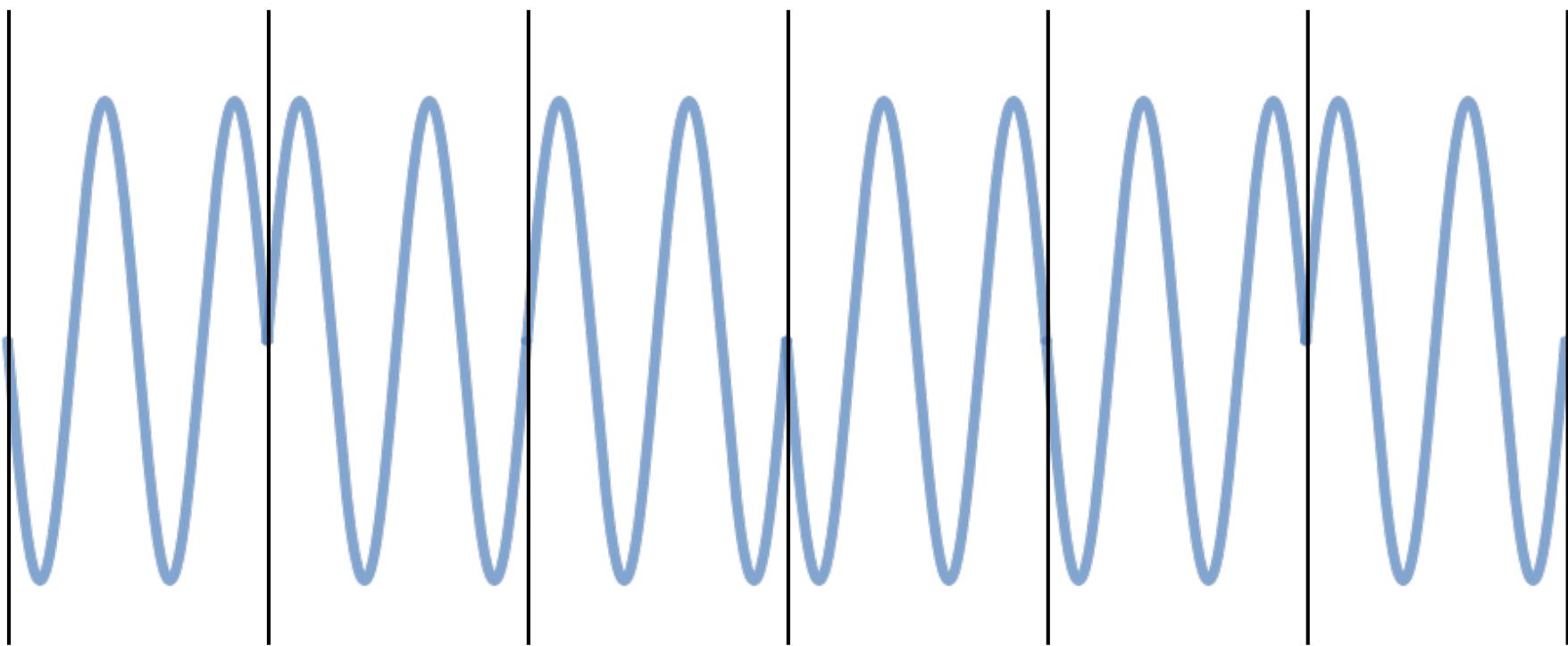
Phase Modulation



Phase Modulation



Phase Modulation



1

0

0

1

1

0

Data Link layer

Data Link Layer

- Now we've seen how we can convert digital data into a signal and back
- The data link layer
 - **controls** access to the physical layer
(MAC = Media Access Control)
 - **encodes/decodes** between frames and signals
 - implements **error detection**
 - **interfaces** to the network layer

Contention-based MAC

Any device can transmit at any time

- “first come first served”

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Collisions: two devices transmitting at the same time

- packets in a collision are damaged
- **avoid** collisions by carrier sensing
(listening on the network for transmission)
- **detect** collisions and re-transmit

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Used in Ethernet

Ethernet

Dominant LAN technology

- Standardised as IEEE 802.3
- used by almost all LANs
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Physical layer

- Originally 10Mbps over shared media coaxial cable
- Now mostly switched 100Mbps or 1Gbps over UTP
- Standards exist for optic fiber up to 100Gbps

Ethernet MAC

Media Access Control: CSMA/CD

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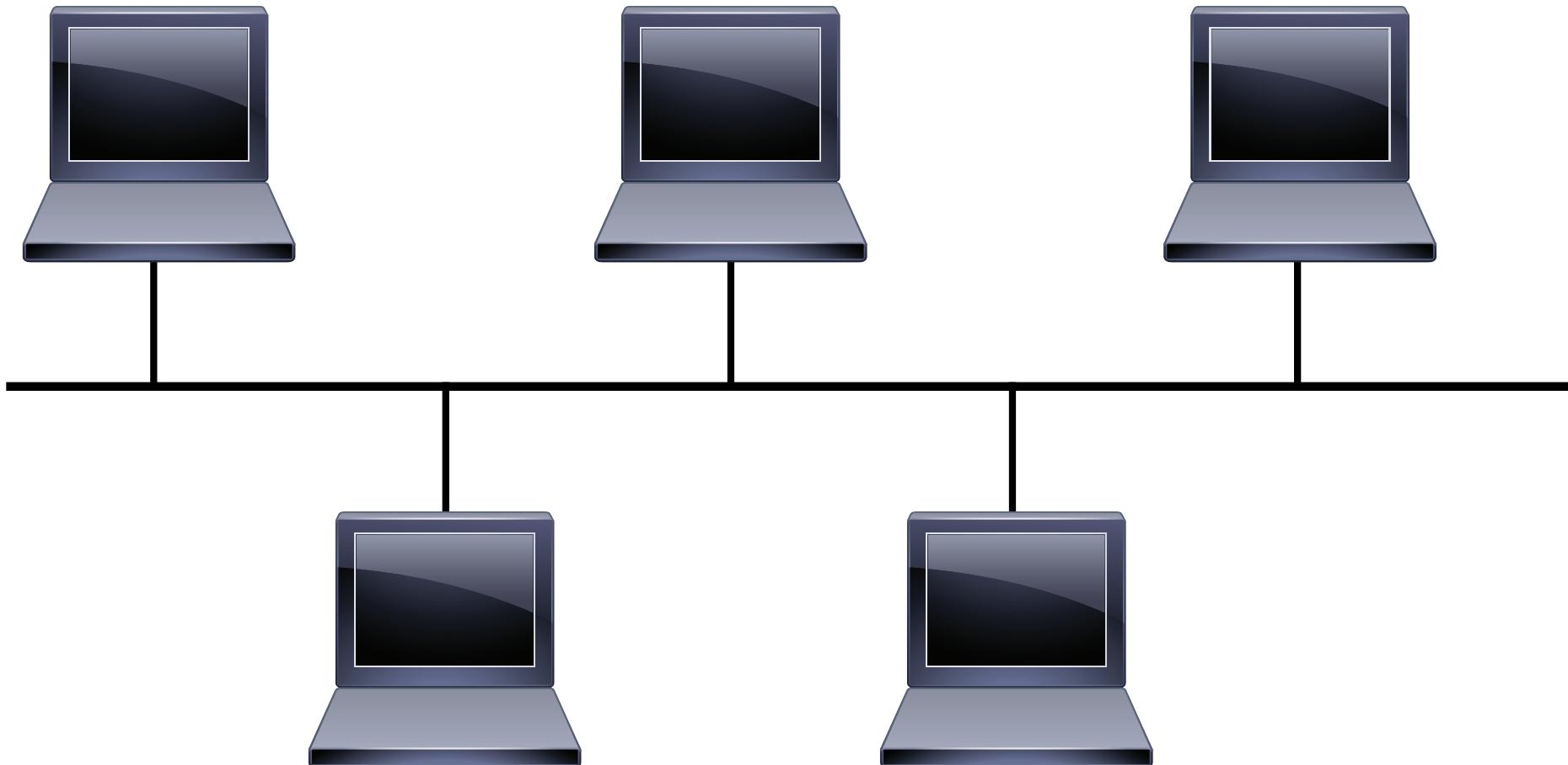
Ethernet MAC

Media Access Control: CSMA/CD

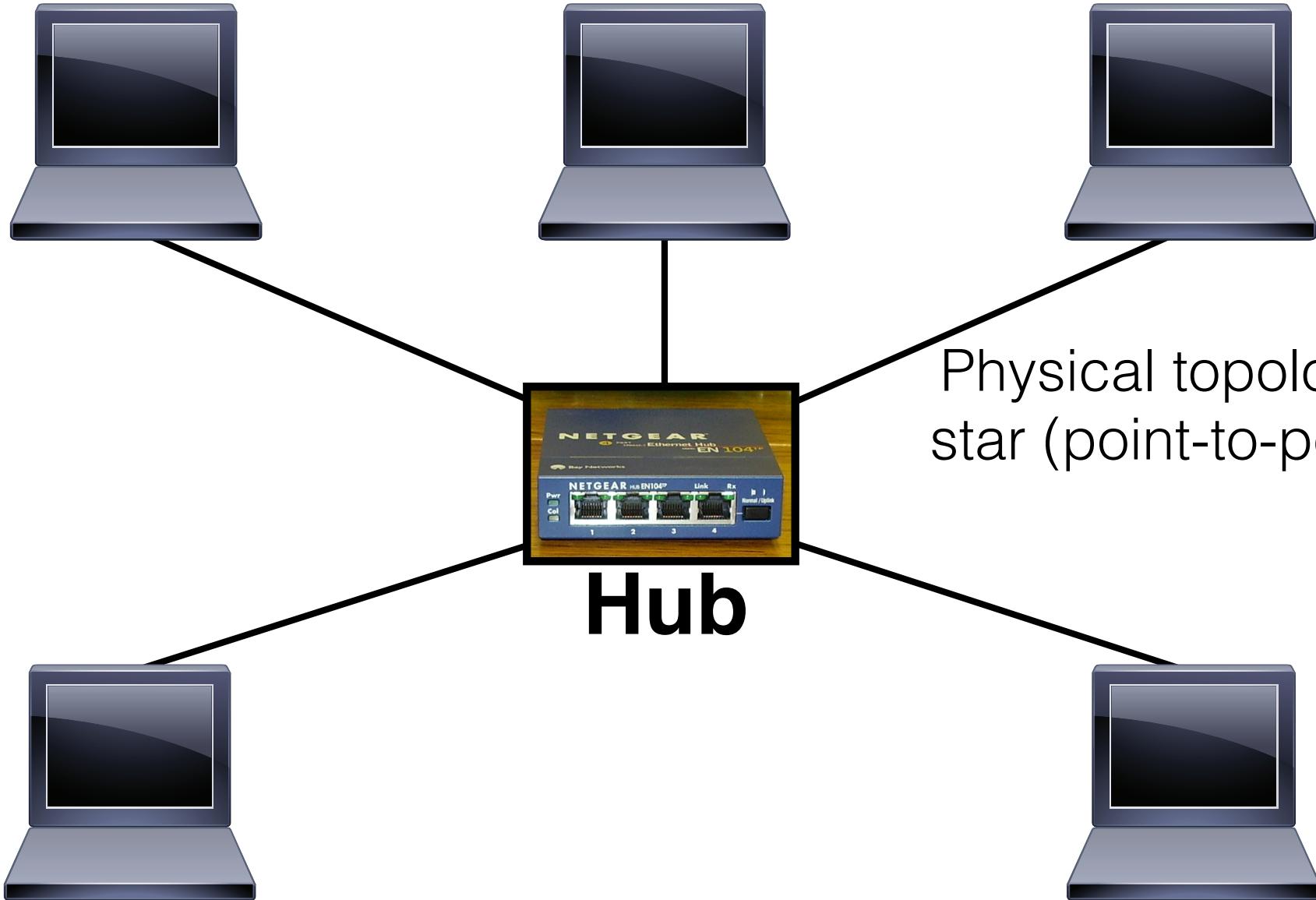
- Carrier Sense (**CS**):
listen on bus, only transmit if no other signal is "sensed"
- Multiple Access (**MA**):
several devices access the same medium
- Collision Detection (**CD**):
when signal other than own is detected:
 - transmit jam signal (so all other devices detect collision)
 - both wait random time before re-transmitting

Ethernet

Topology:
shared bus (multi-point)



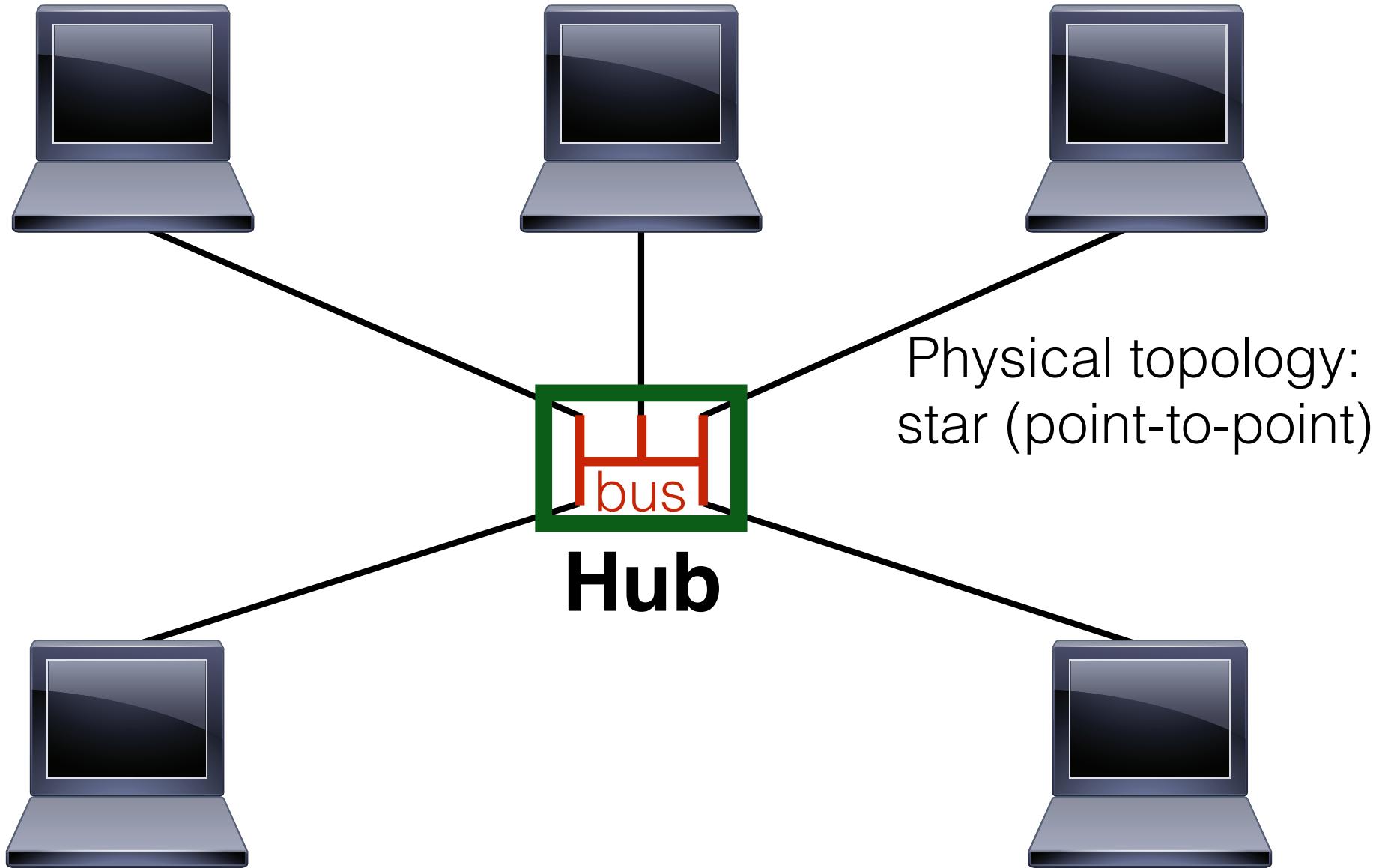
Ethernet



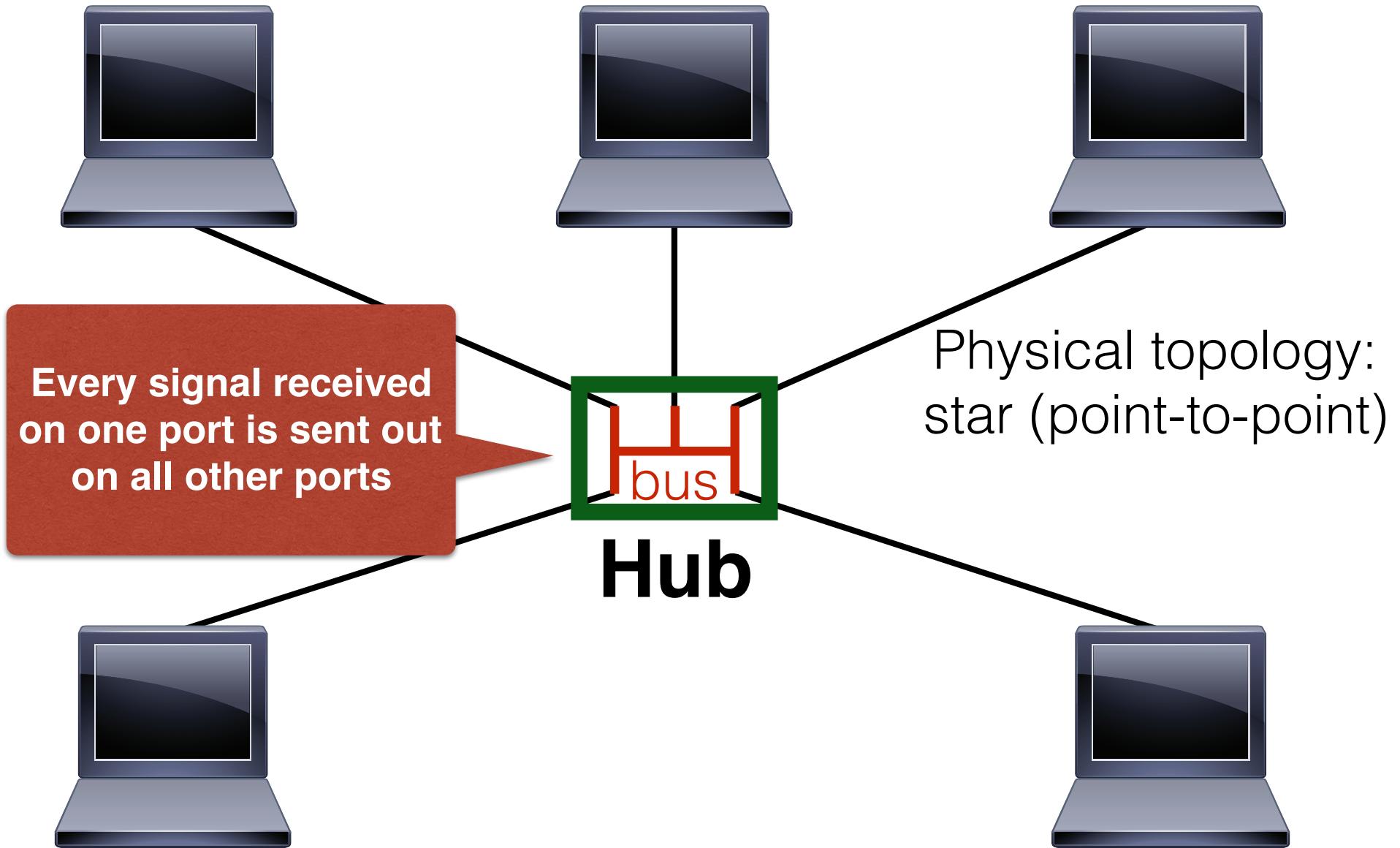
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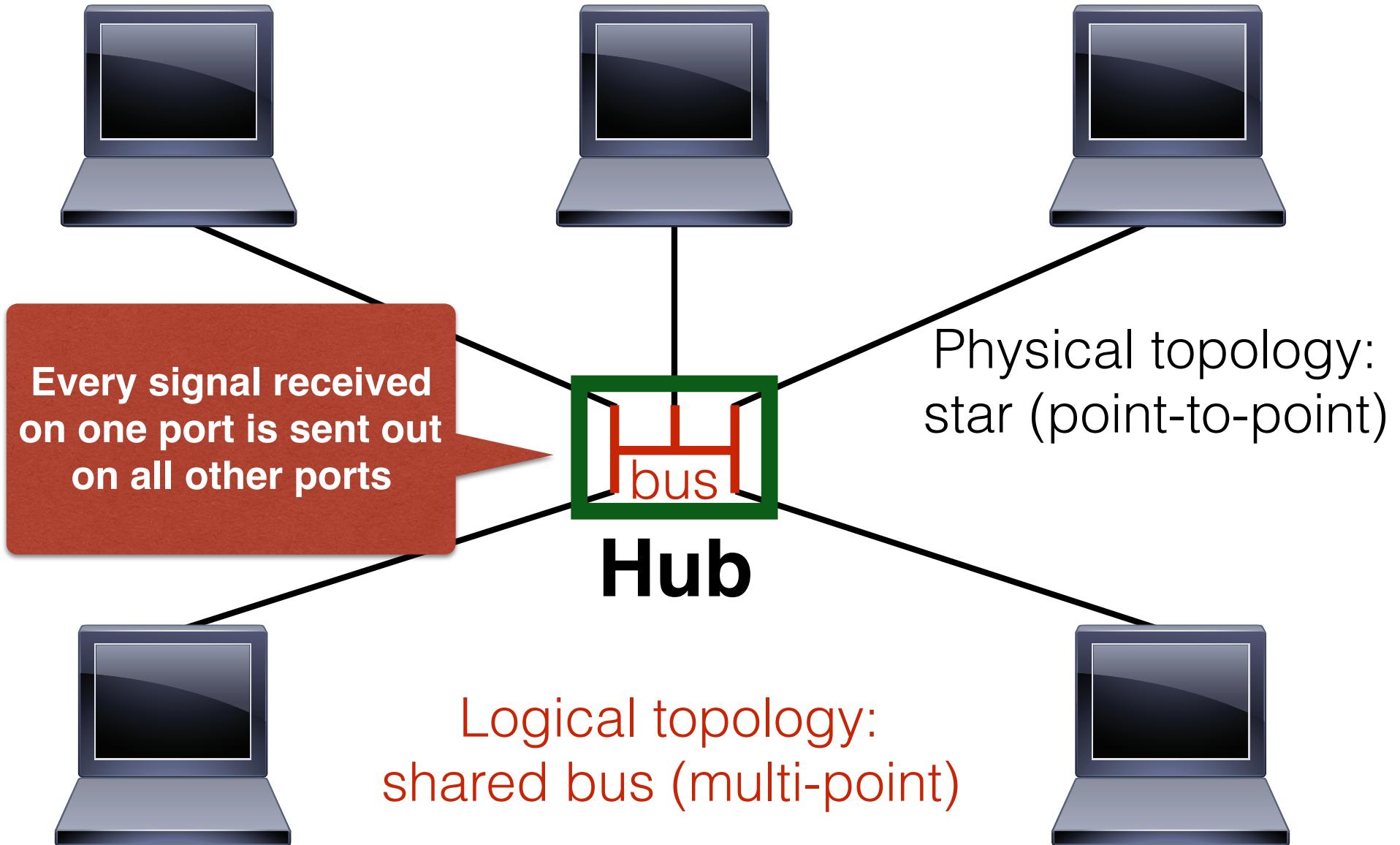
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Problems with Shared Ethernet

Half-duplex

- only one device can send at a time

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Limited network size

- CSMA/CD limits size of **collision domain**

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Solution: implement logical star topology!

Switched Ethernet

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Network switch

- looks like hub
- 16 to 24 ports for UTP cables
- **but:** circuit no longer shared!

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A switch is a layer 2 device

- reads MAC address of frame
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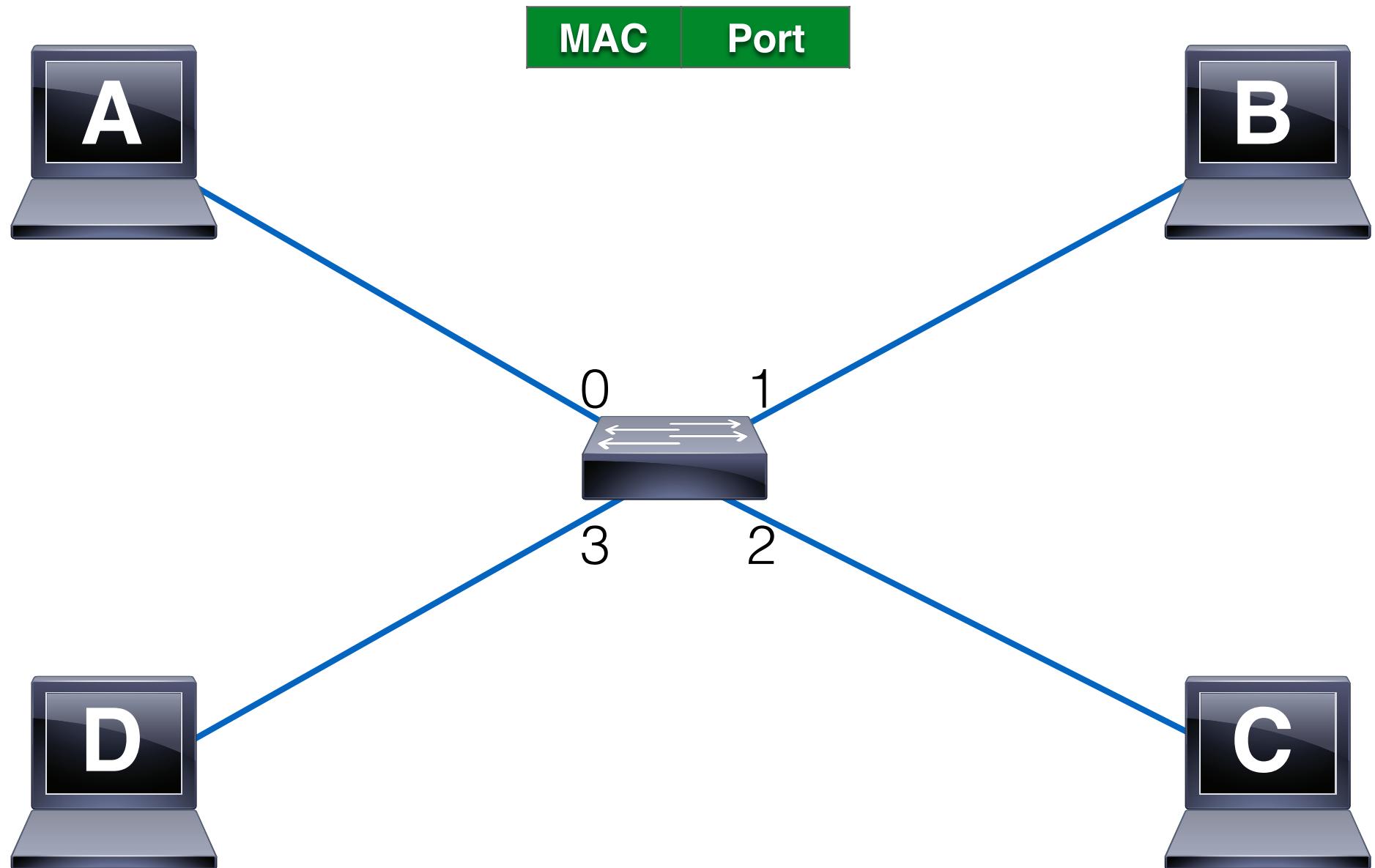
How does the switch know the destination port?

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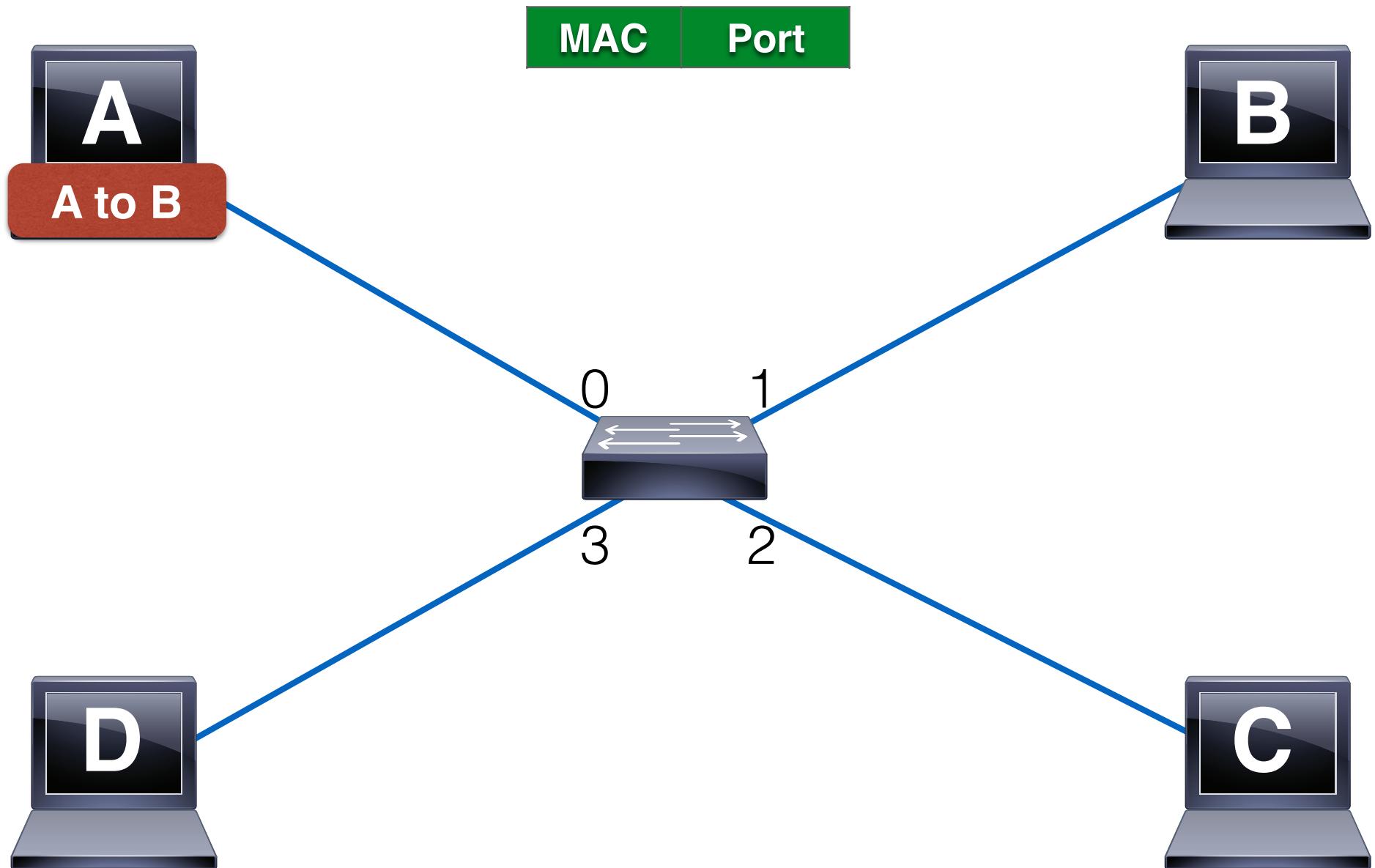
Networks: Physical and Data Link layers



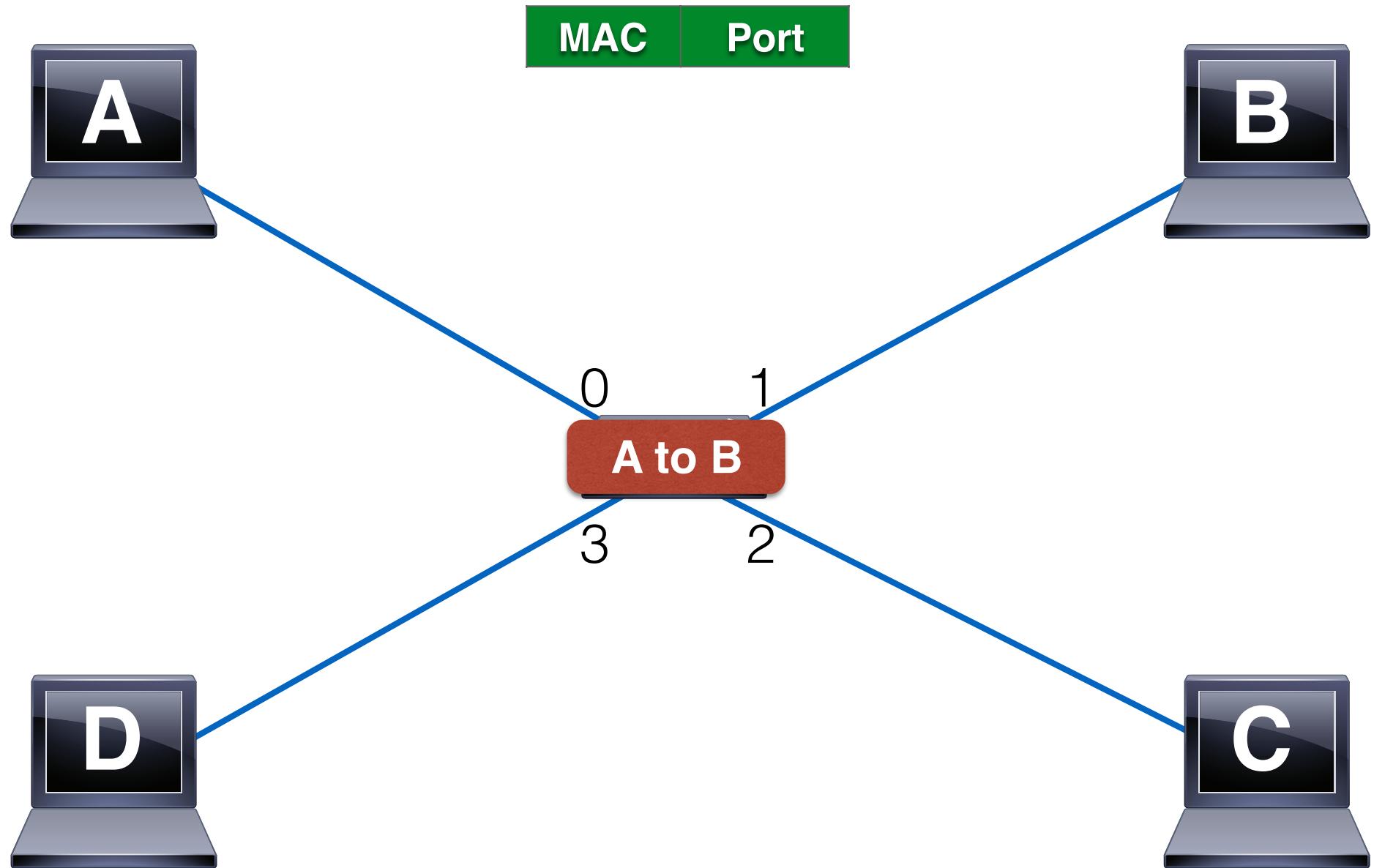
Switch Forwarding Table



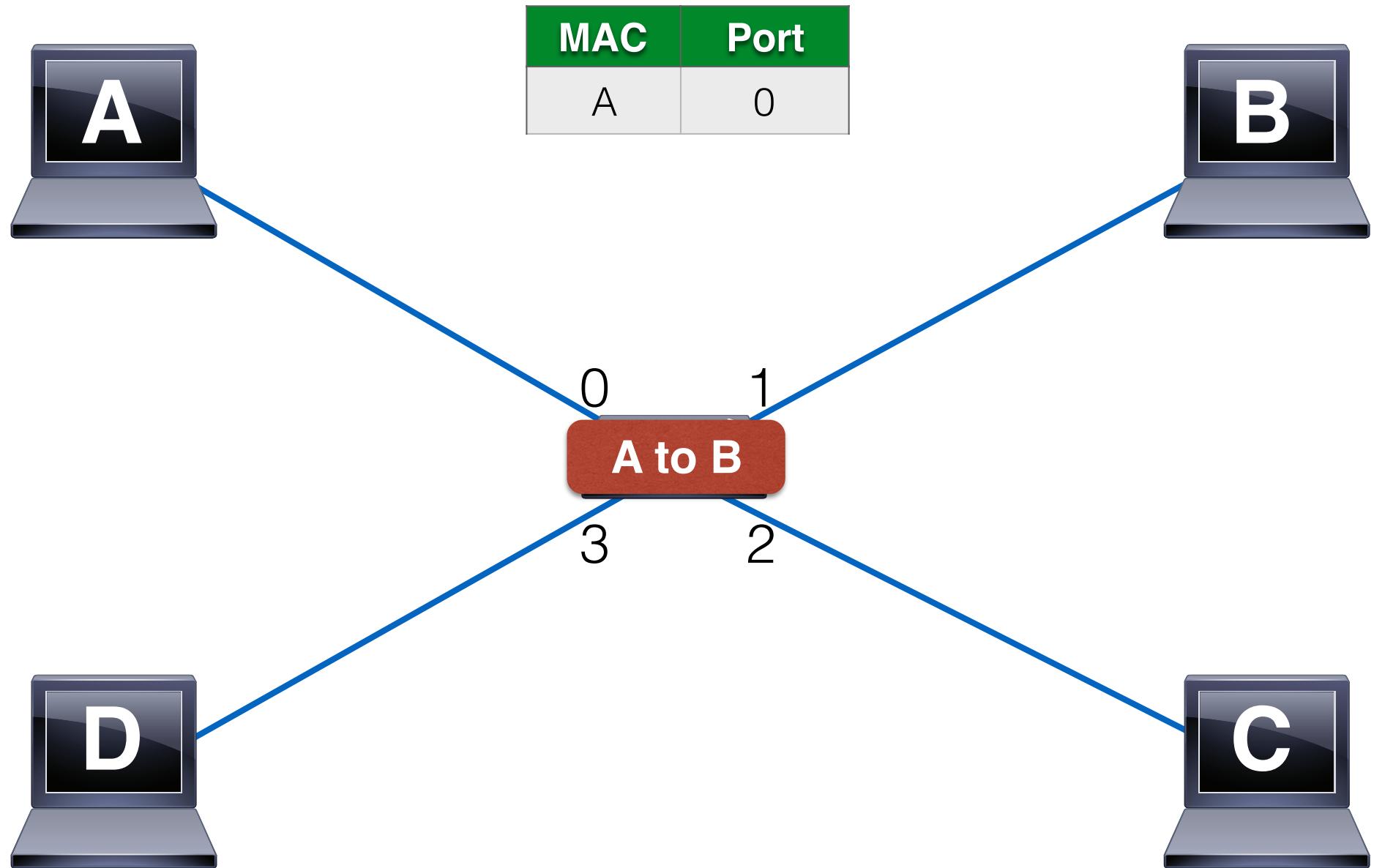
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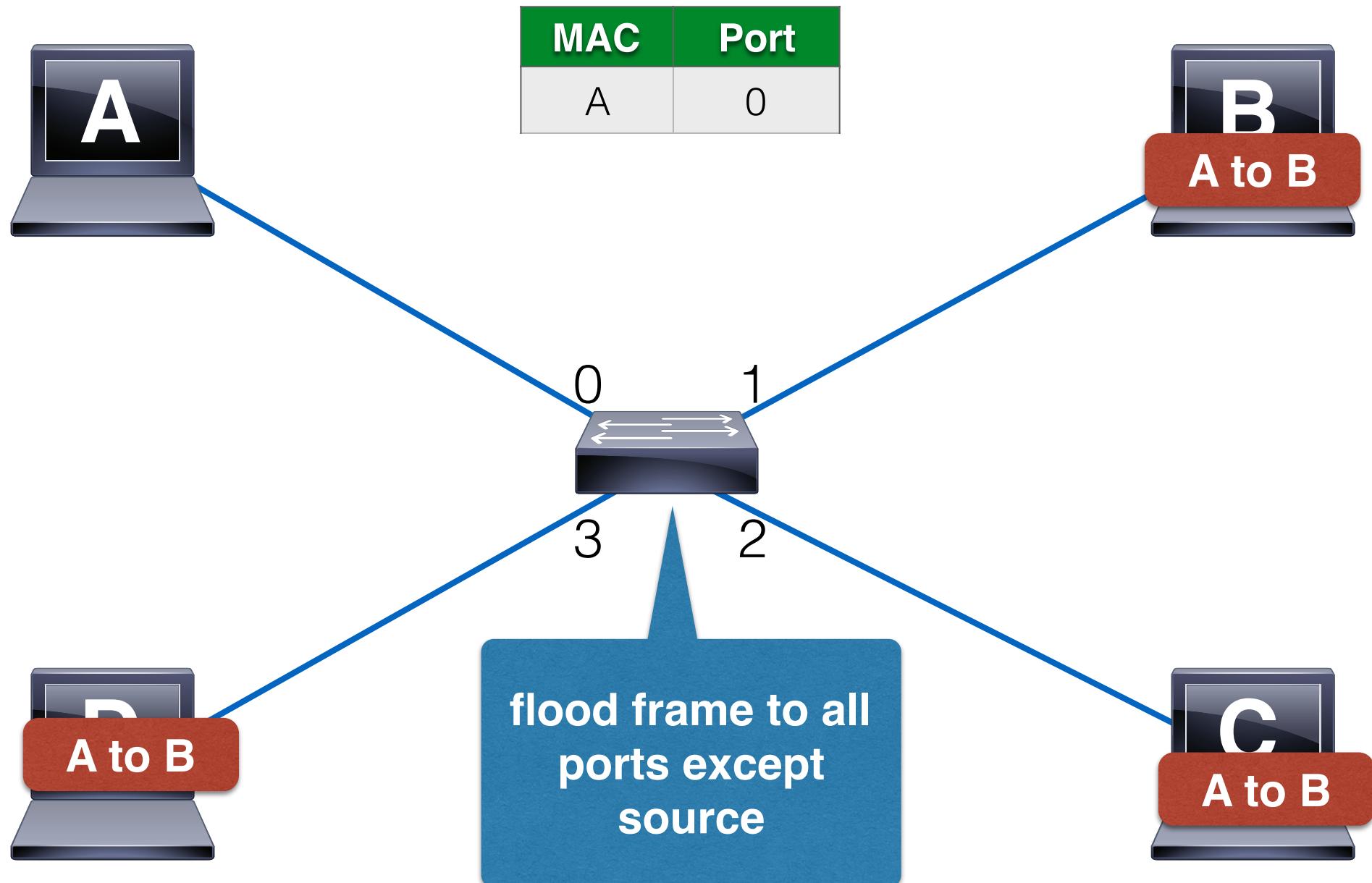
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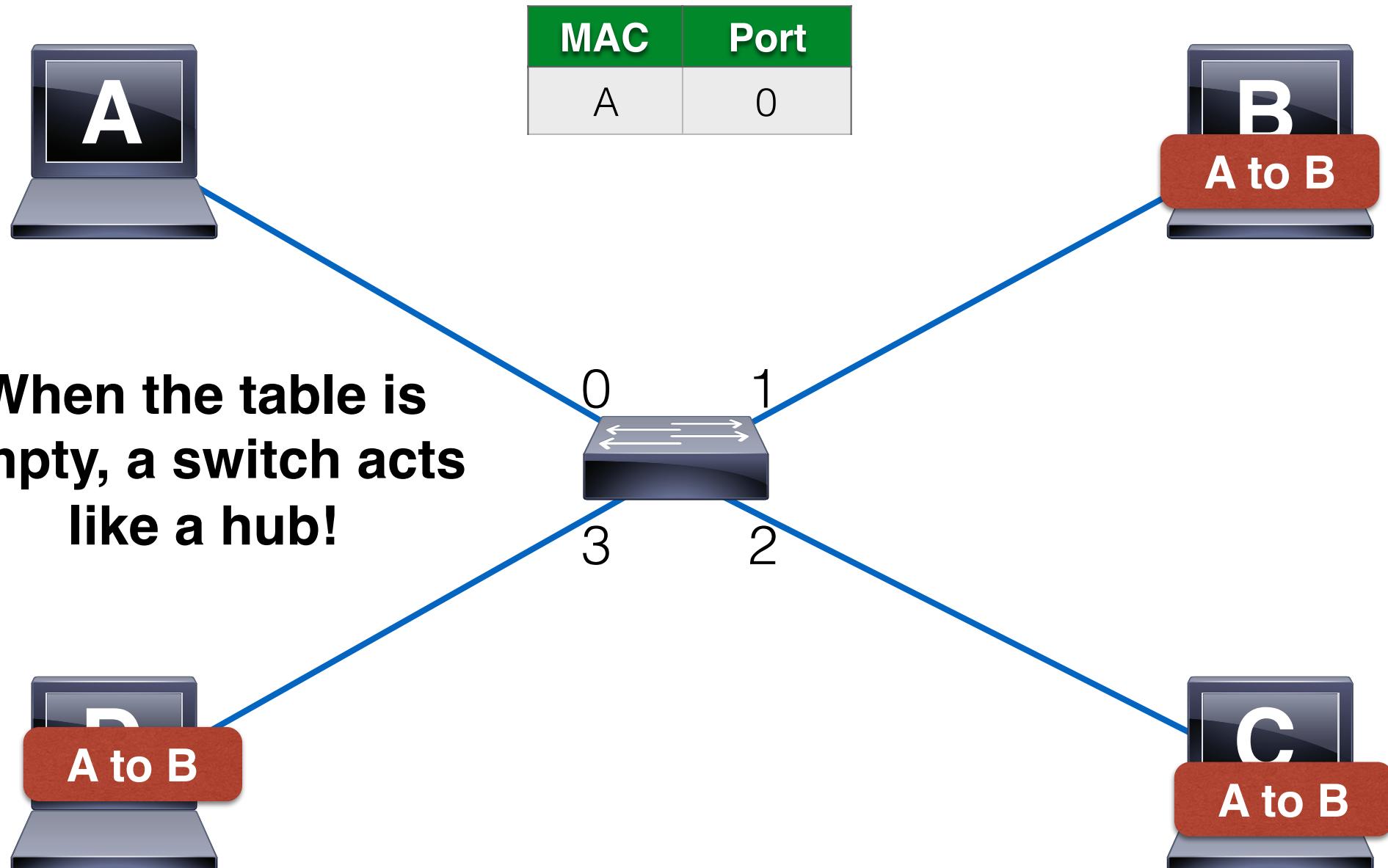
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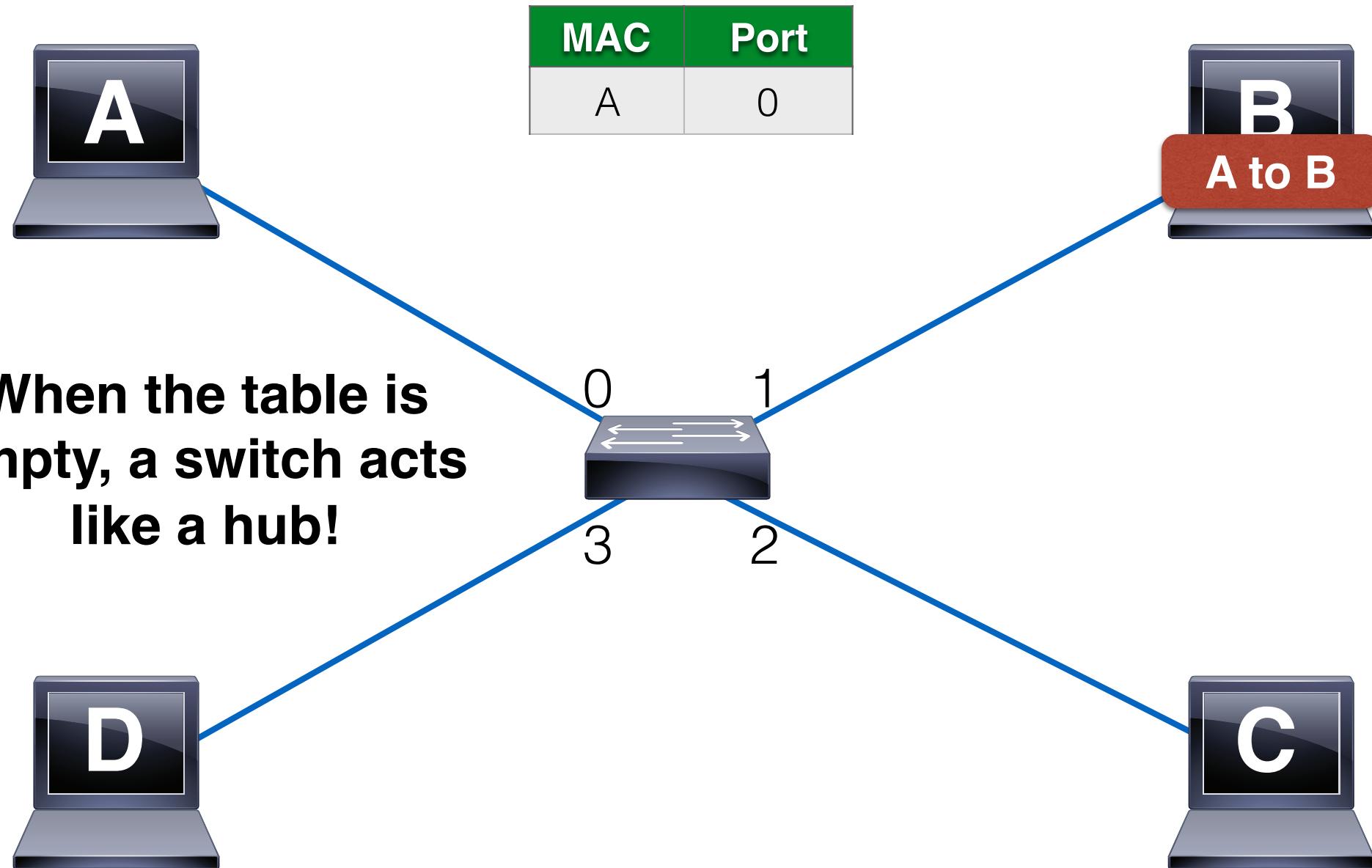
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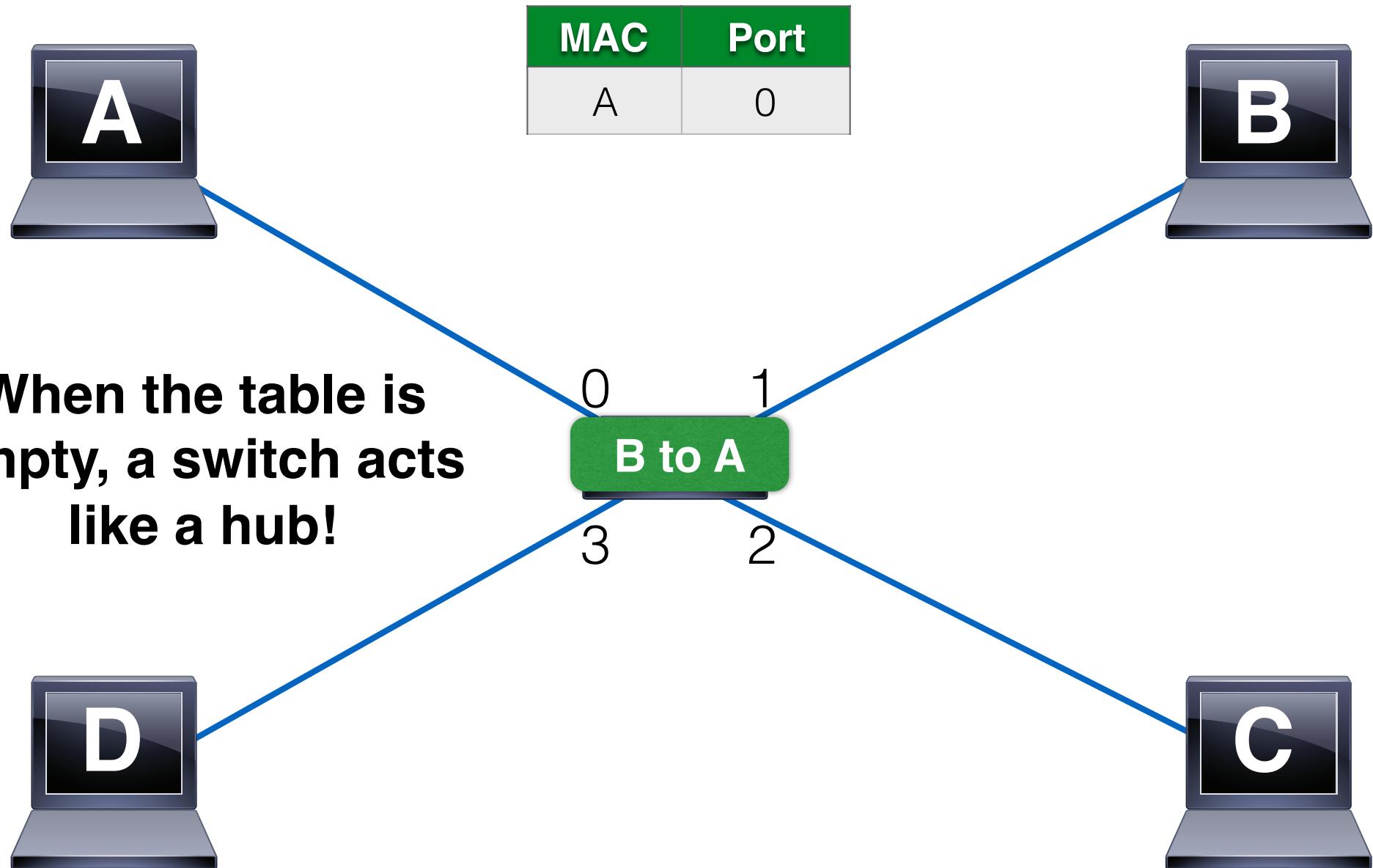
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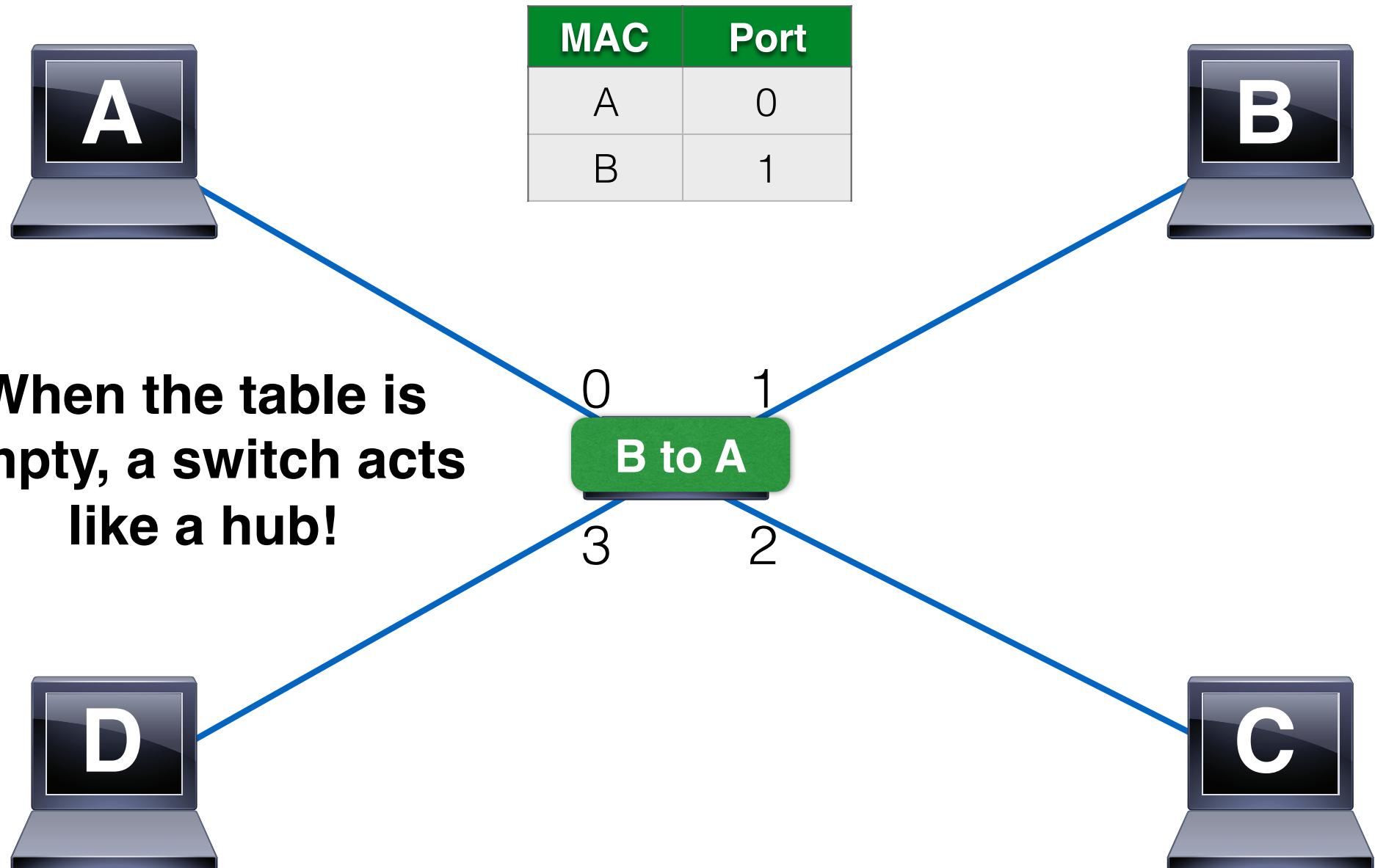
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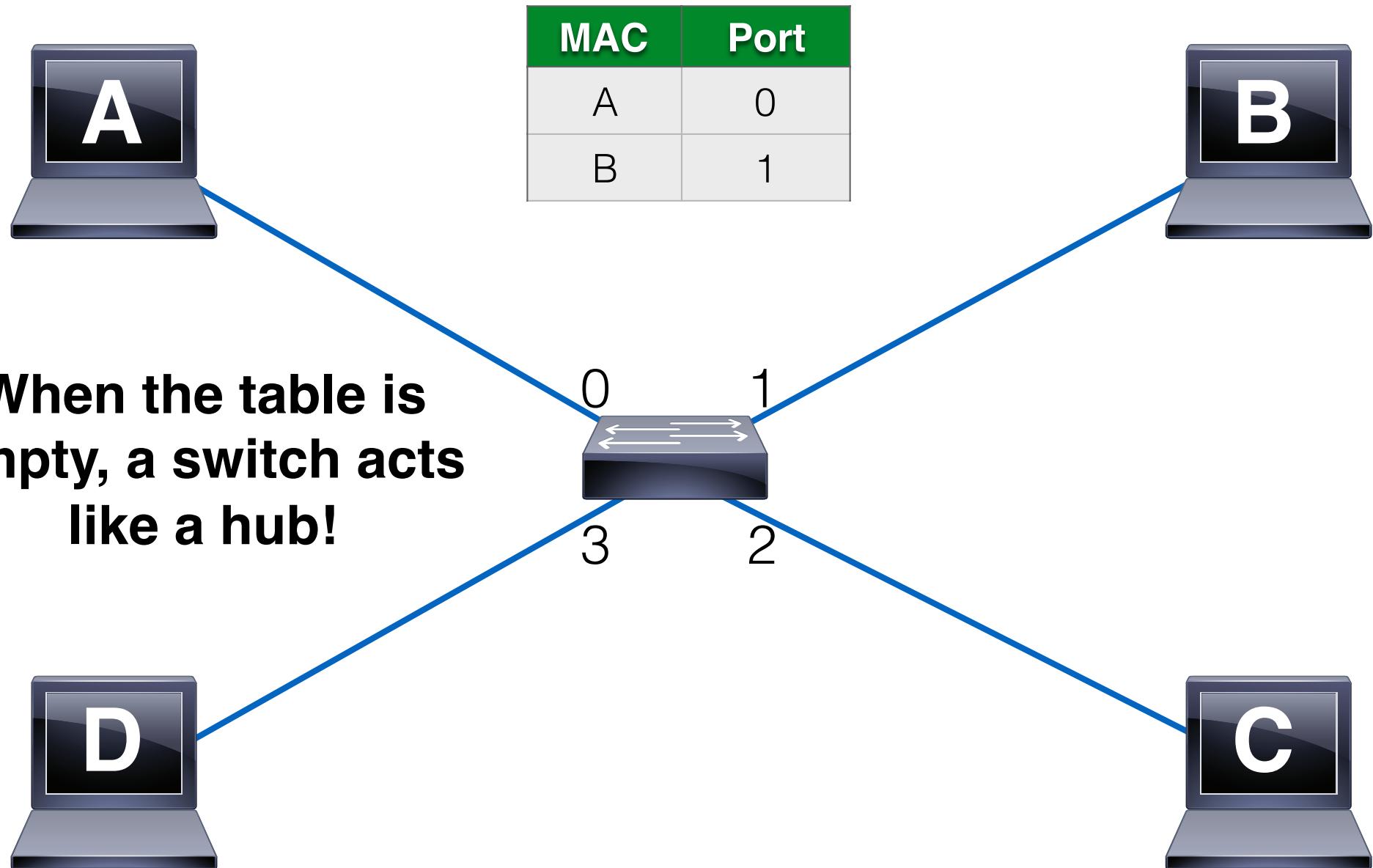
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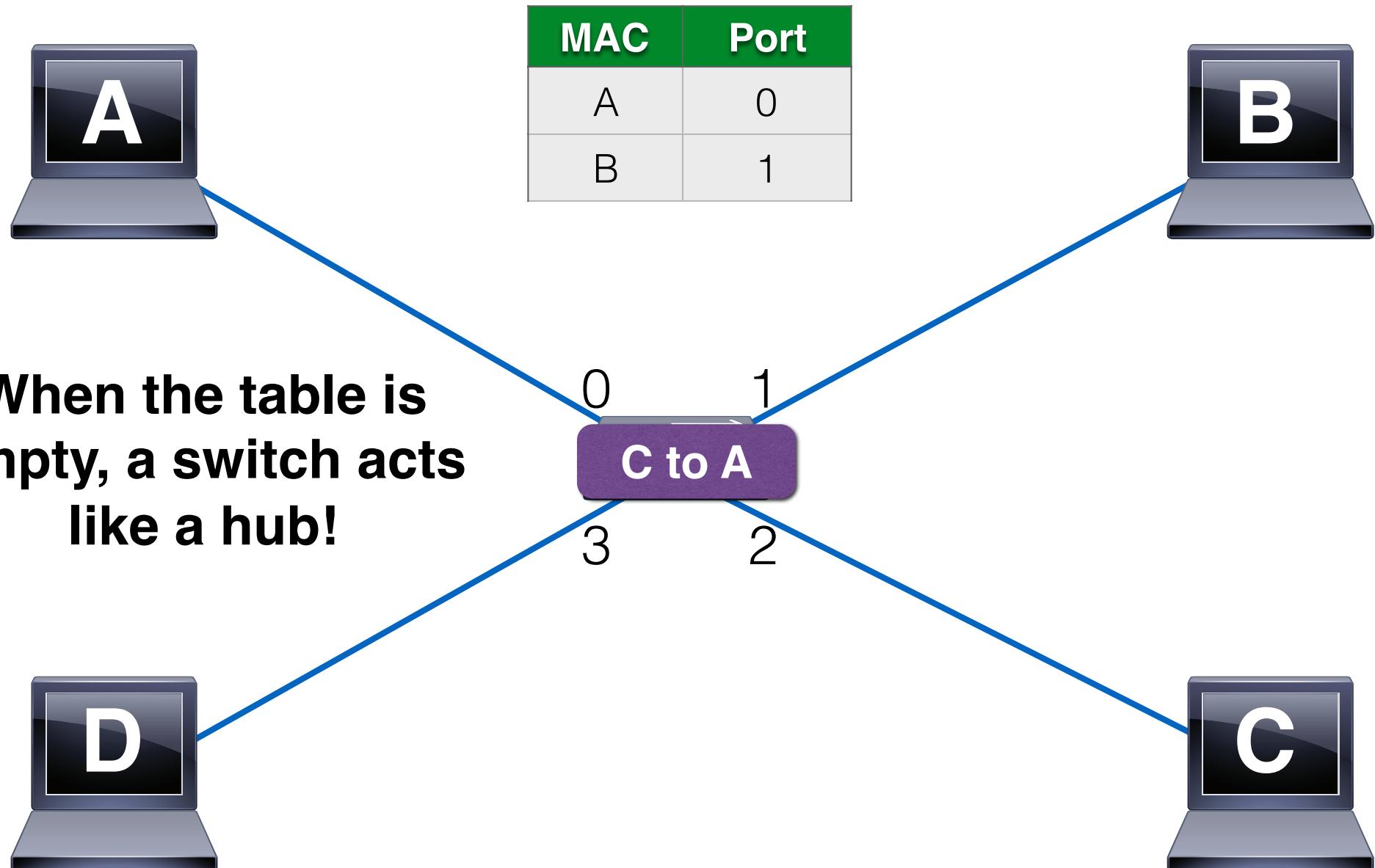
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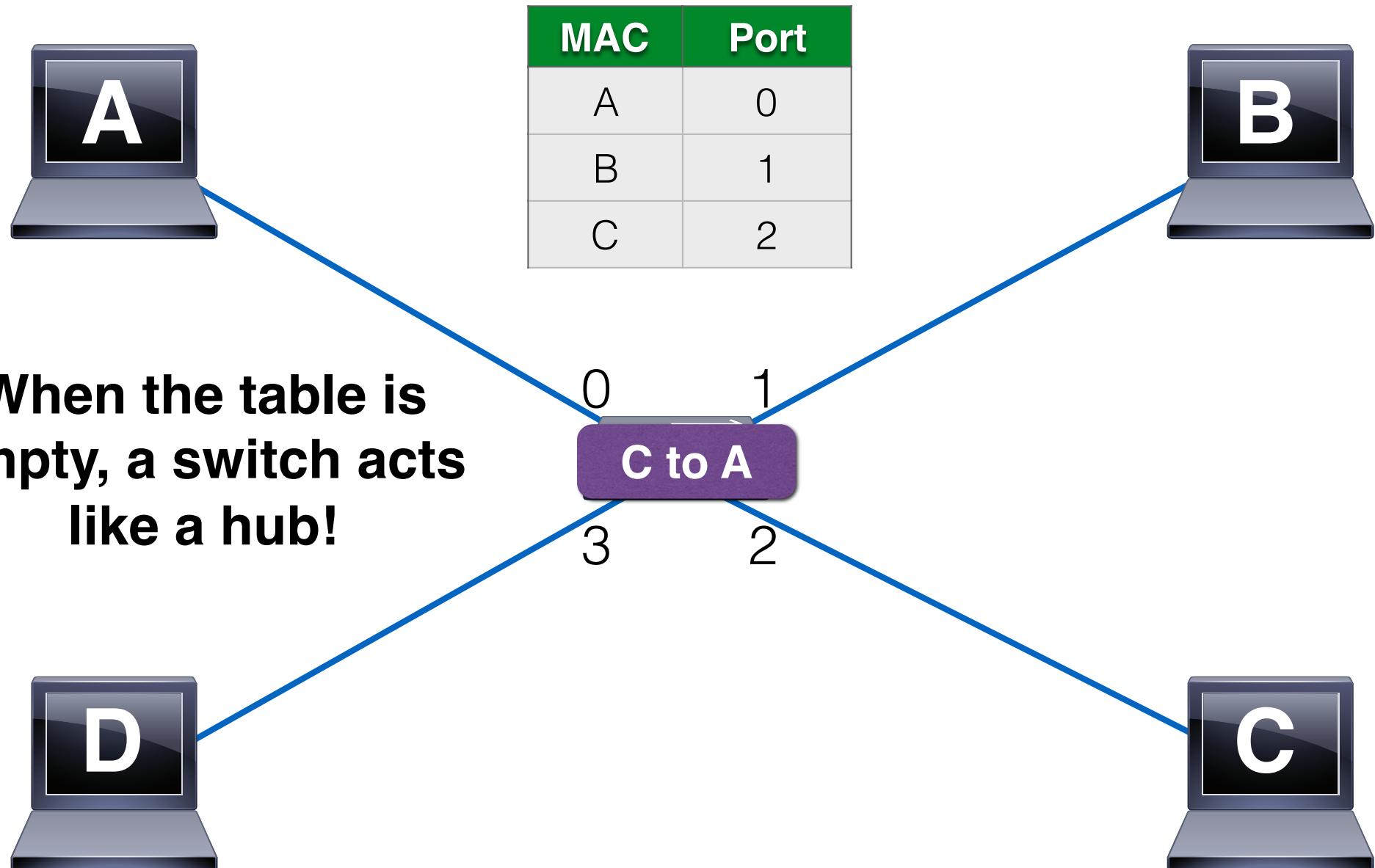
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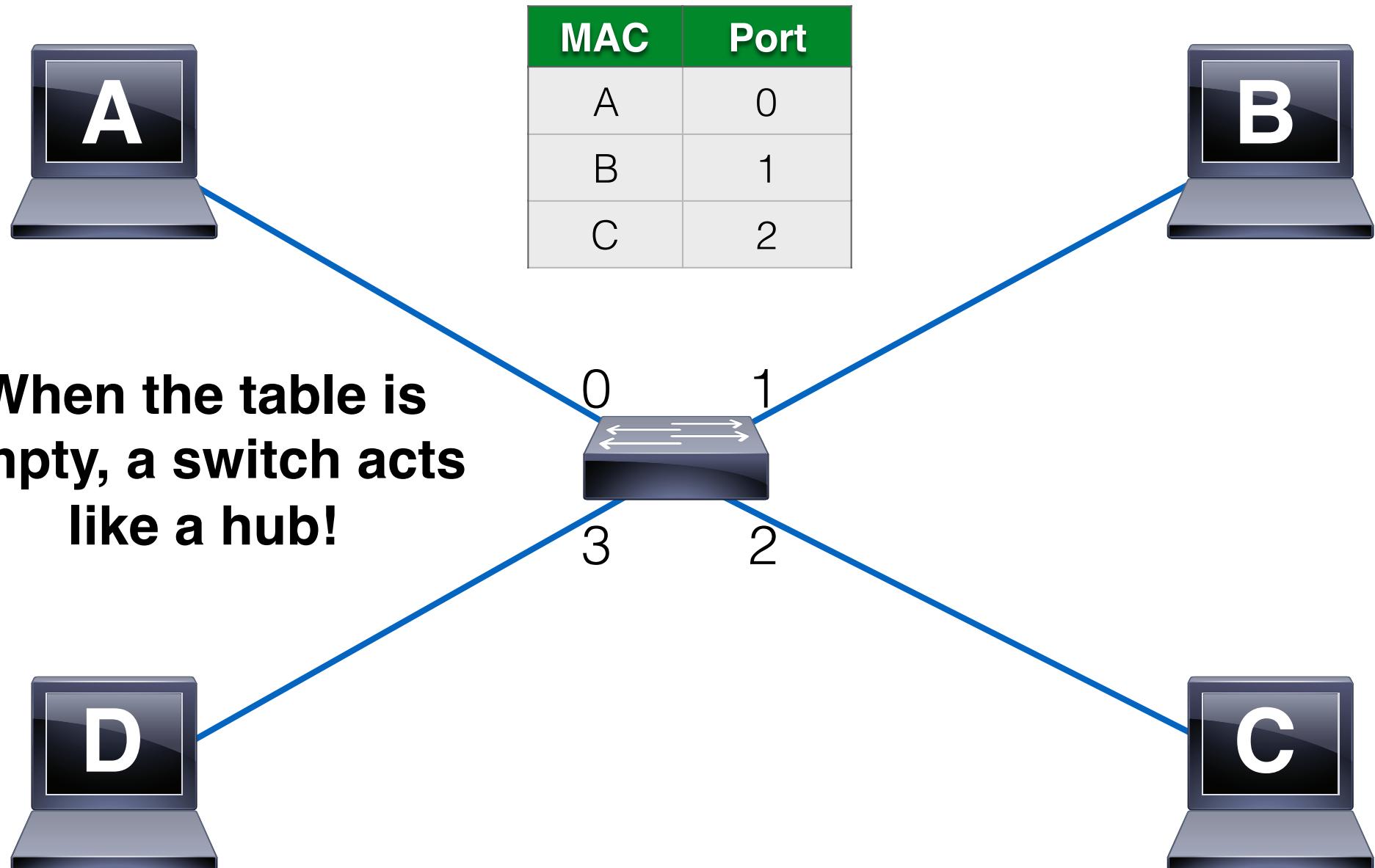
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Switch Forwarding Table



Switch Forwarding Table



Switches and MAC

Full-duplex circuits

- point-to-point connection between computer and switch
- no collisions possible

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But frames may still be sent at the same time

- e.g. A sends to B while C sends to D
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Switches and MAC

Full-duplex circuits

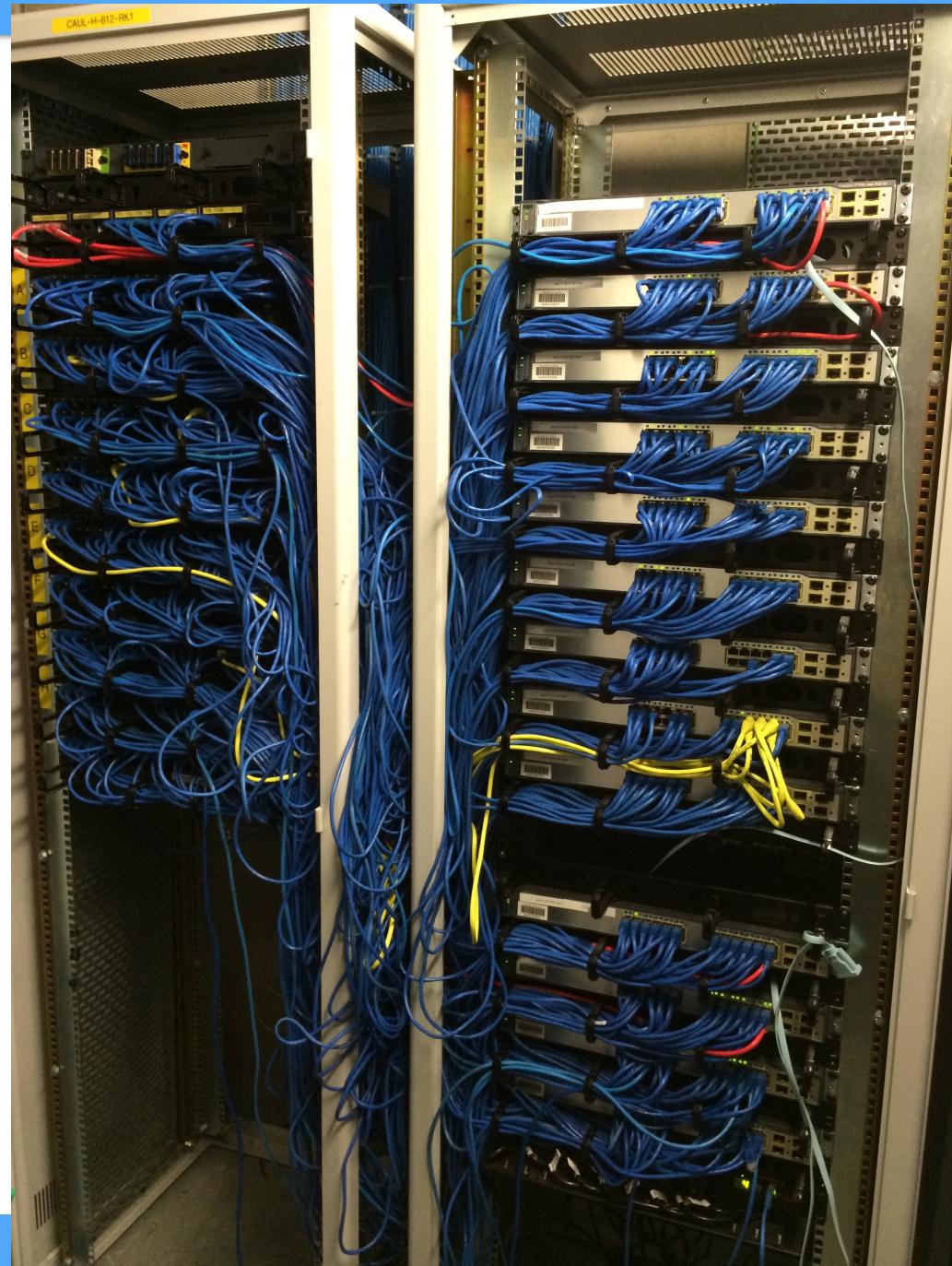
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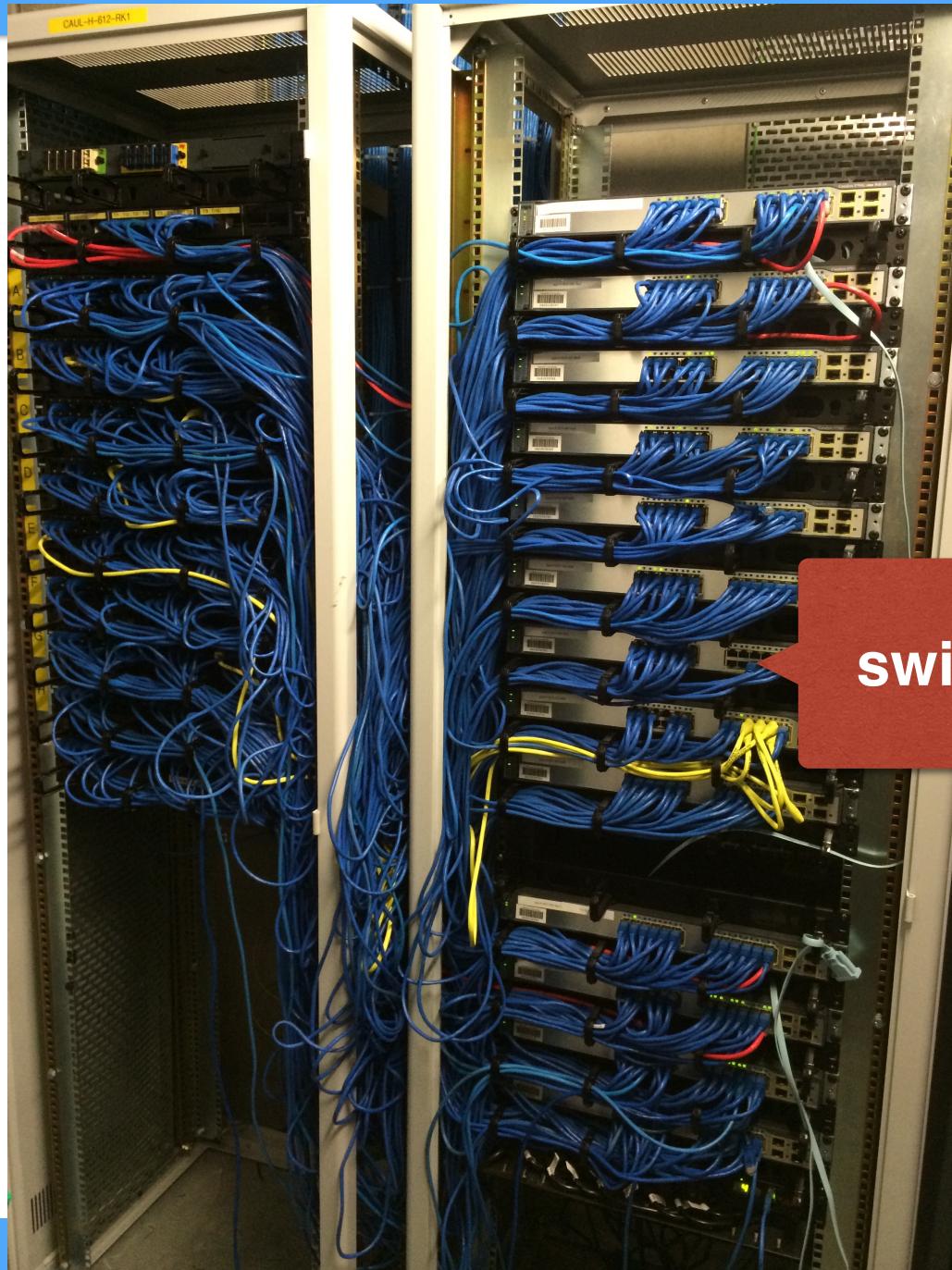
Switched Ethernet runs at up to 95% capacity, compared to 50% for shared Ethernet!

Rack-mounted switches



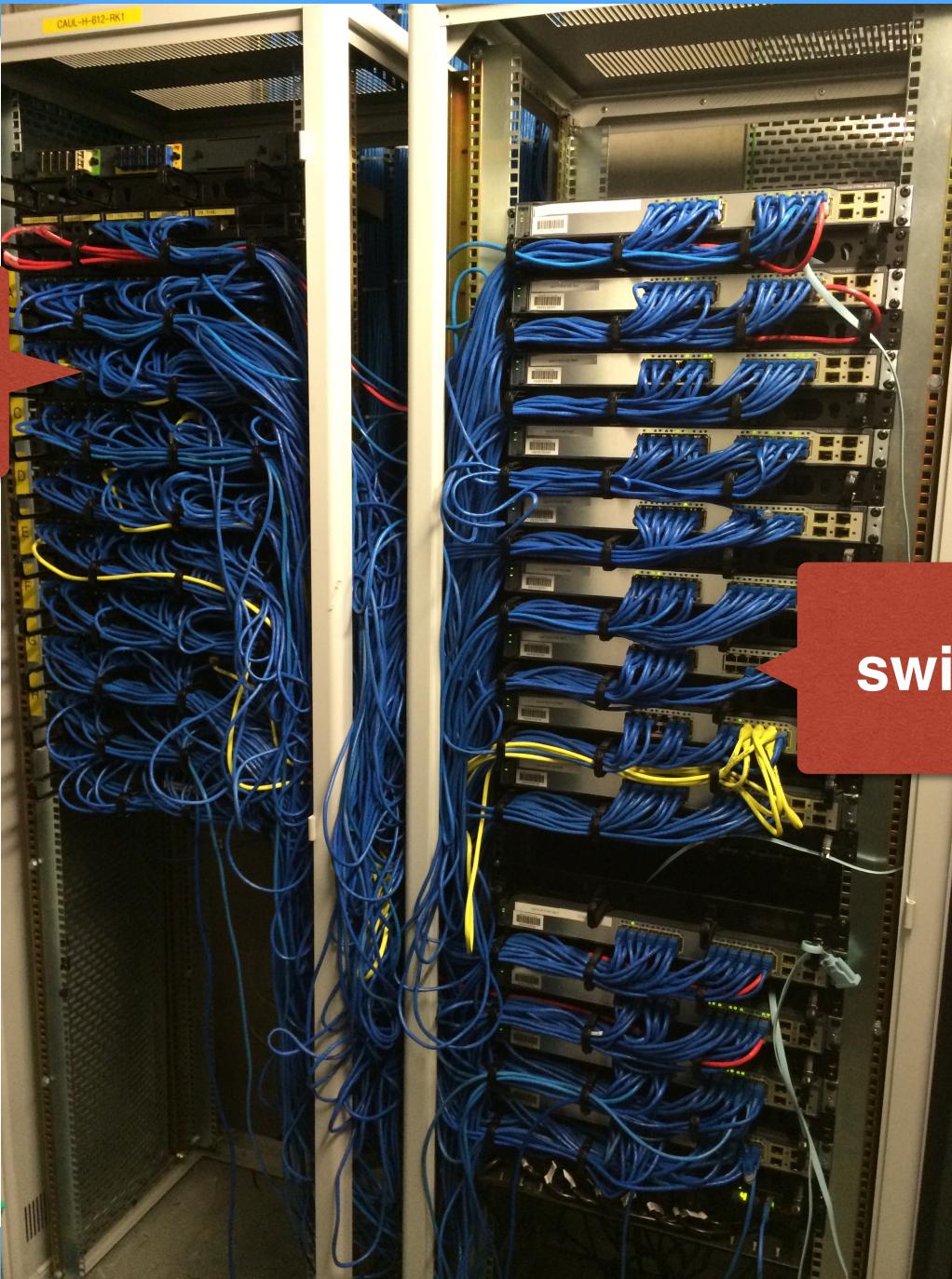
Monash
communications
cabinet, Caulfield,
Bldg. H level 6

Rack-mounted switches



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Rack-mounted switches



Rack-mounted switches



Wireless Local Area Networks

Why WiFi?

Wireless LANs

- eliminate cables (heritage buildings, rented apartments, ...)
- allow for more flexible network access
- facilitate mobile workers (e.g. hospital)

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Basic setup

- WLAN NICs connect to Access Points (APs) using radio frequencies
- APs are connected to wired LANs (or backbones)

WLAN Technology

Wi-Fi (or “Wireless Ethernet”)

- IEEE 802.11 family of standards
- Original standard from 1997-1999 (802.11a, 802.11b)
- Widely used: 802.11g (2003), 802.11n (2009)
- Latest: 802.11ac

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Other wireless LAN technologies

- WiMAX (802.16)
- Bluetooth (802.15), also called WPAN (Wireless Personal Area Network)

WLAN Radio Frequencies

Most WLANs use the 2.4GHz and/or 5GHz range

- high frequencies allow for large bandwidth
- but higher frequencies have stronger attenuation

WLAN Radio Frequencies

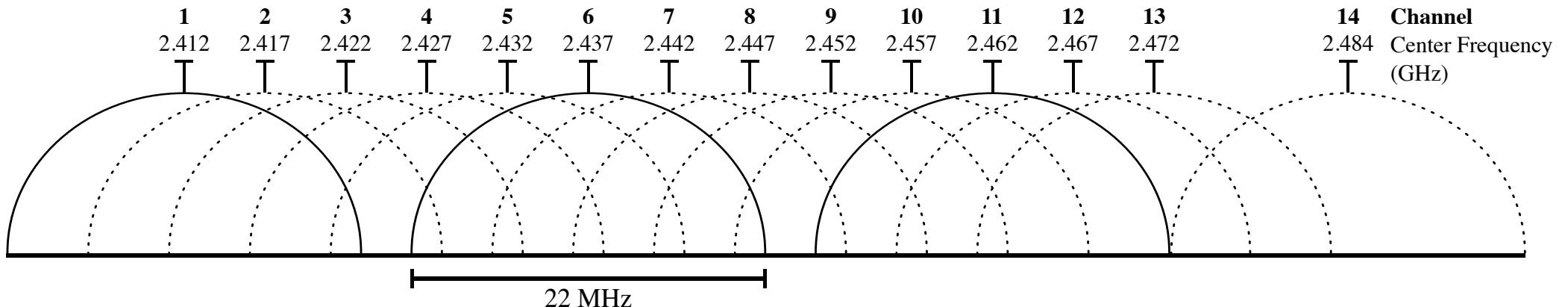
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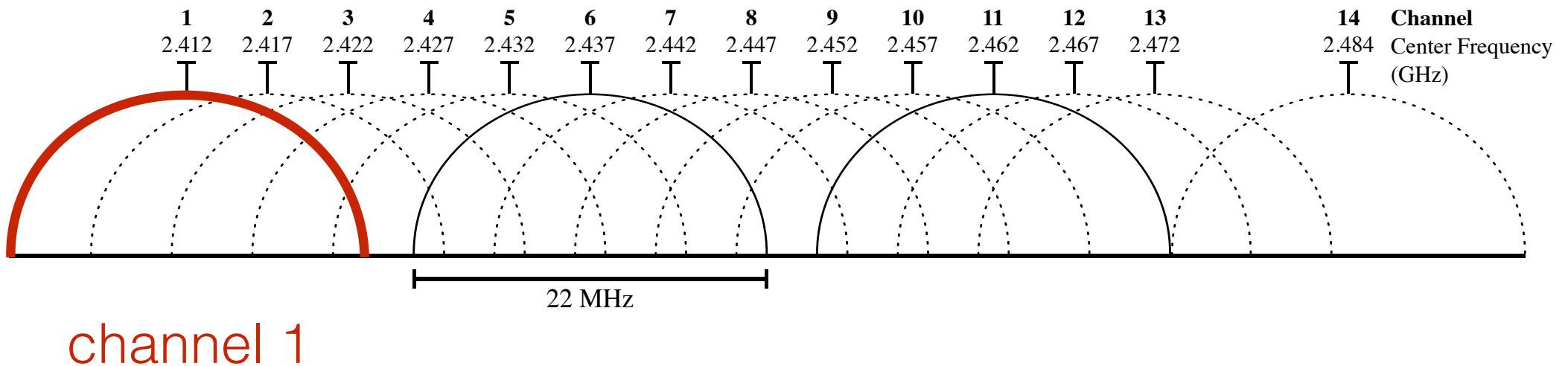
WLAN channels

- Networks in the same area should not use the same frequencies
- WLAN spectrum is divided into **channels**, each network is set to a different channel

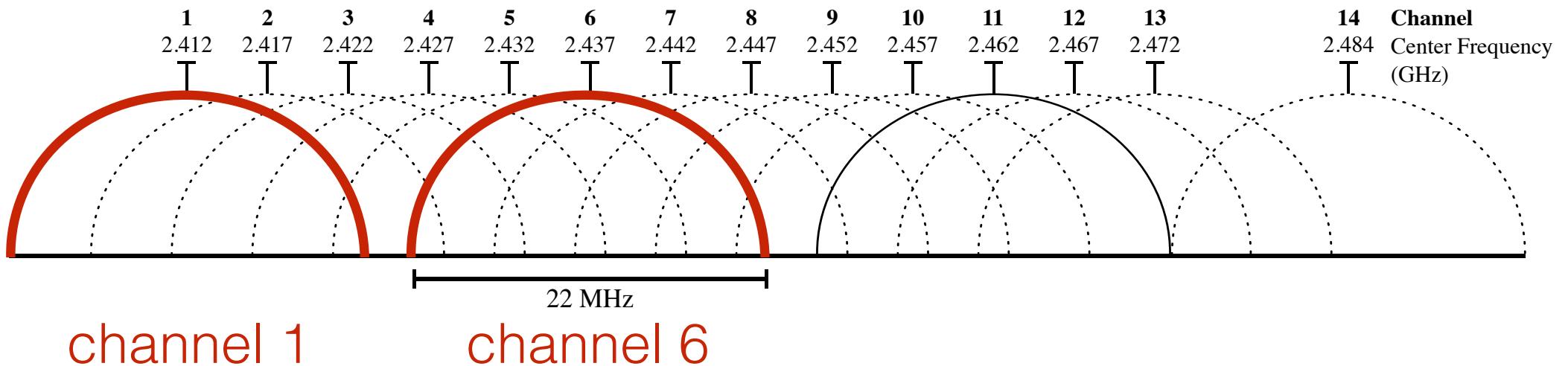
WLAN channels (802.11n)



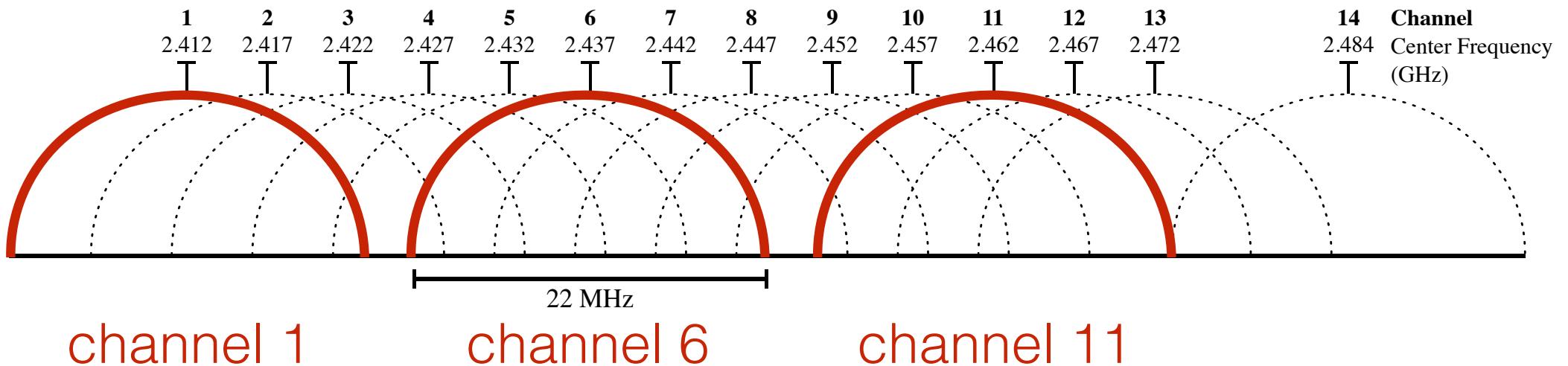
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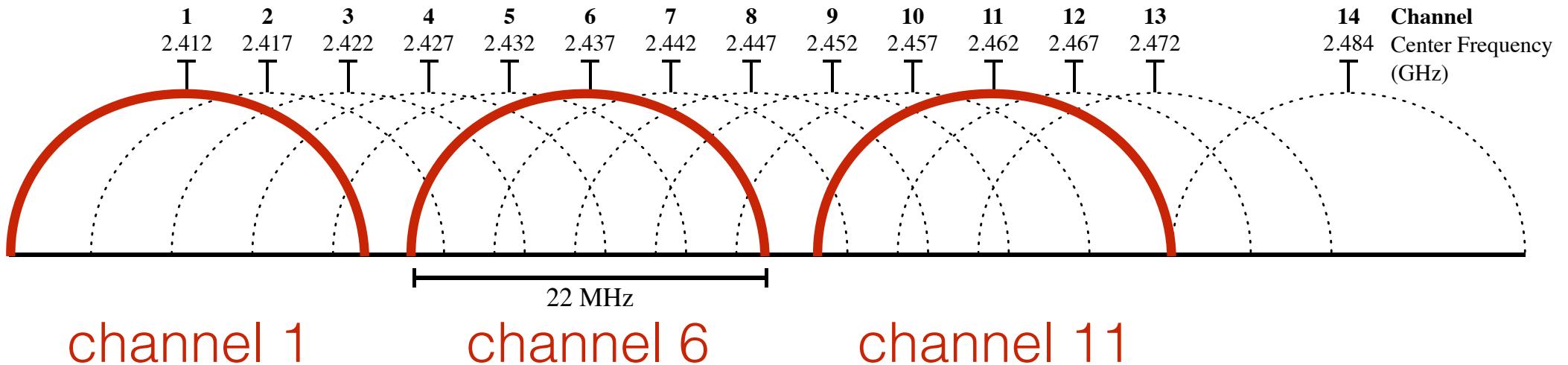
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WLAN channels (802.11n)



2.4GHZ band

- 2.4000-2.4835 GHz
- 13 channels, each 22 MHz wide
- But channels overlap! Only 5 MHz apart

CSMA/CA Media Access Control

All devices in a WLAN share the medium

- use the same channel (frequency band)
- need to deal with collisions

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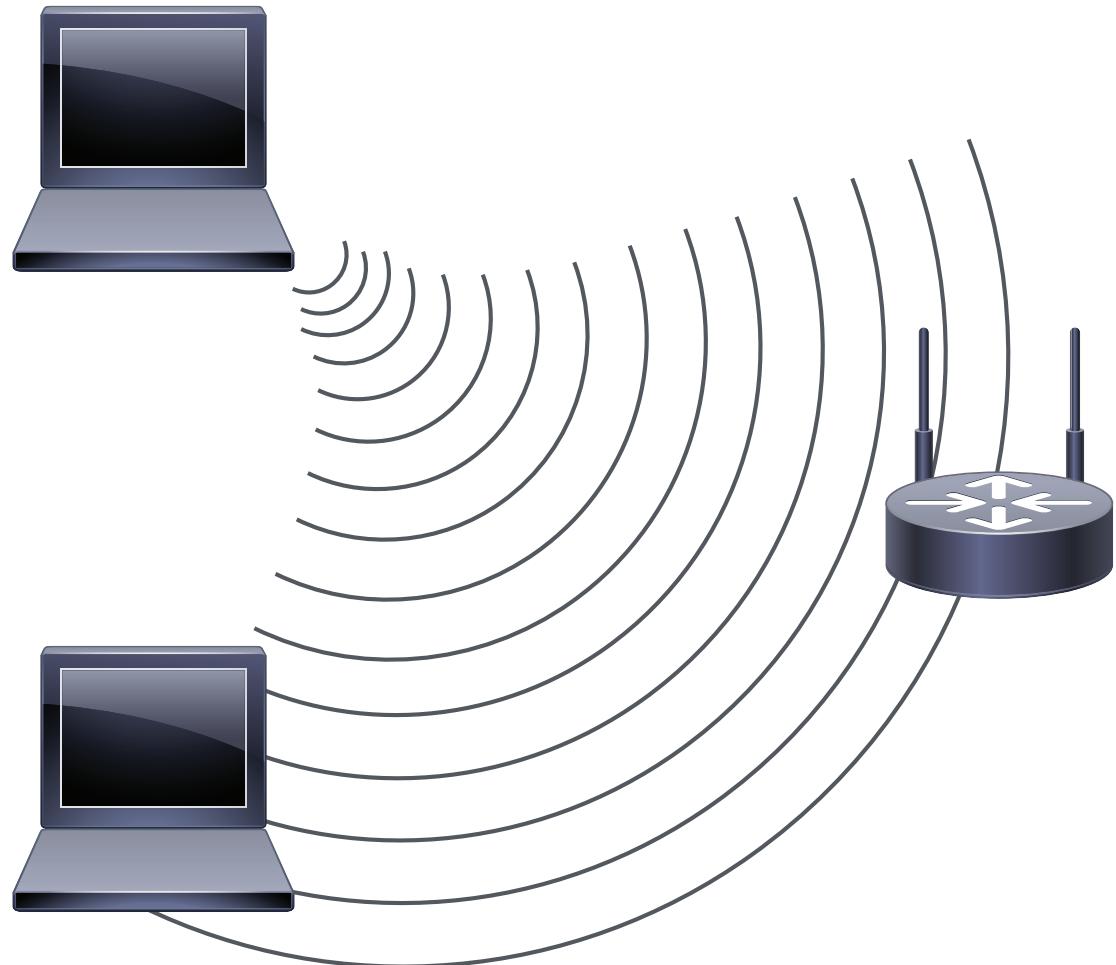
CSMA/CA

- Carrier Sense, Multiple Access
- Collision Avoidance
- Compare to 802.3: Collision Detection
- Devices try to **actively avoid** collisions

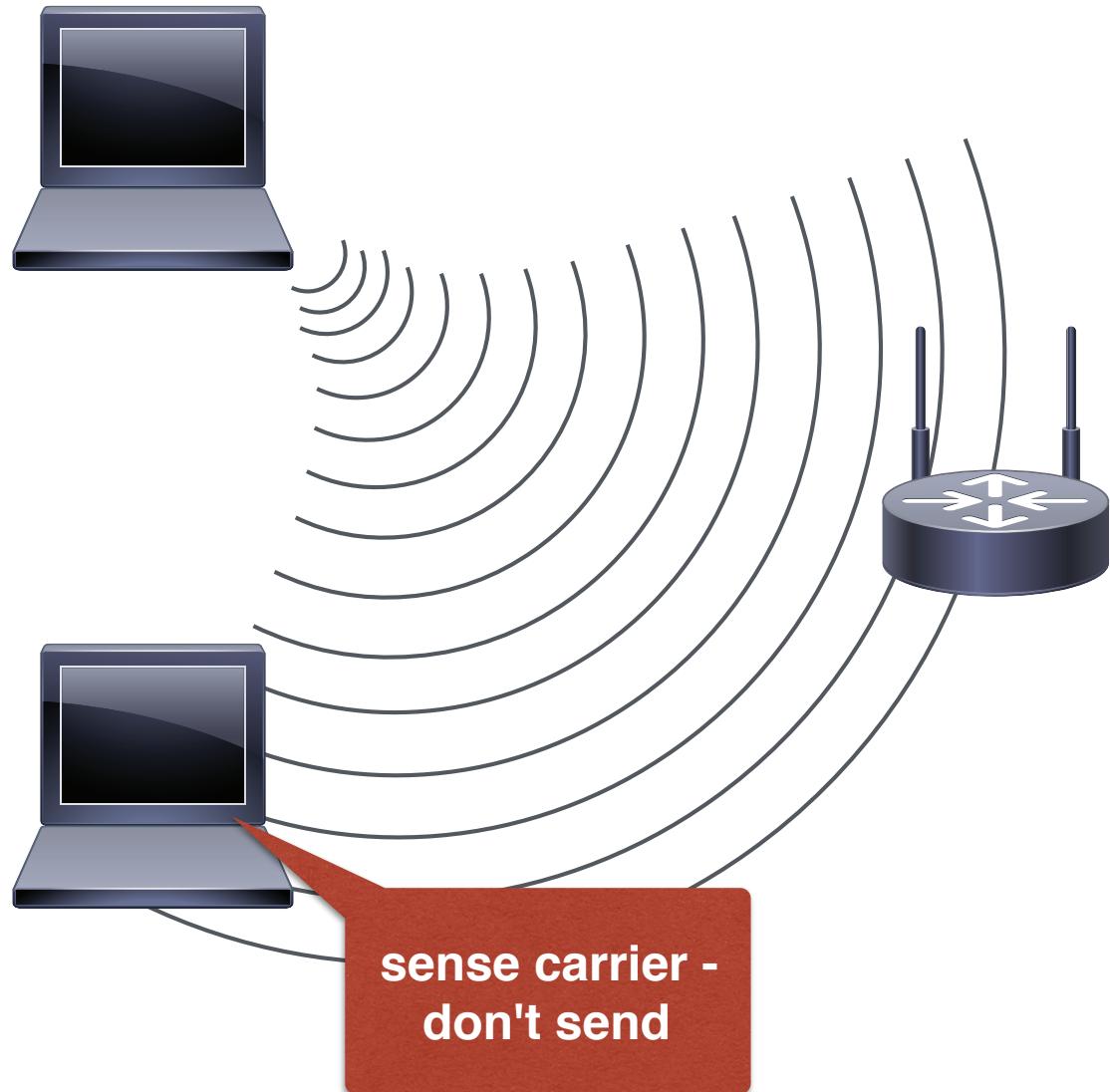
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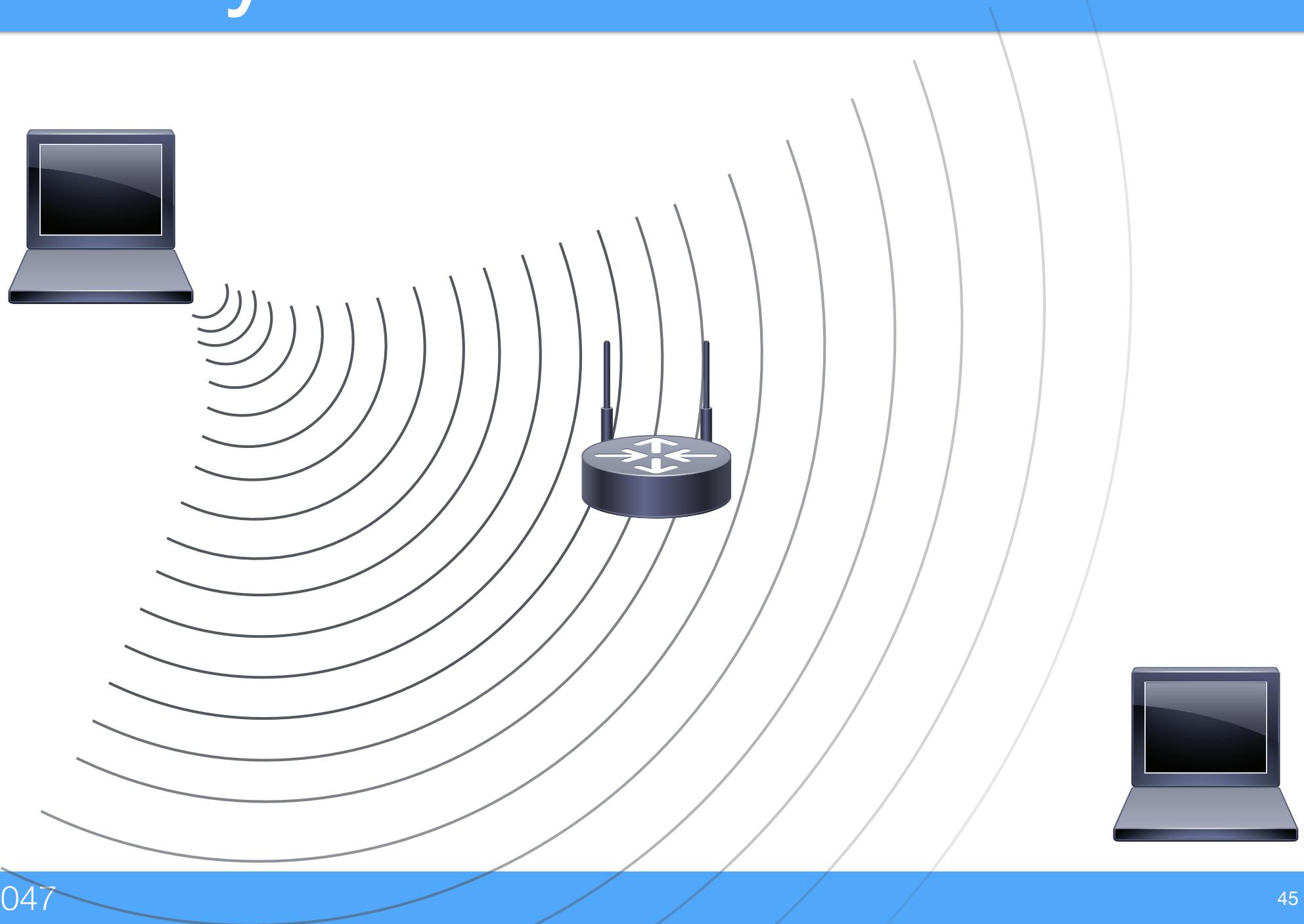
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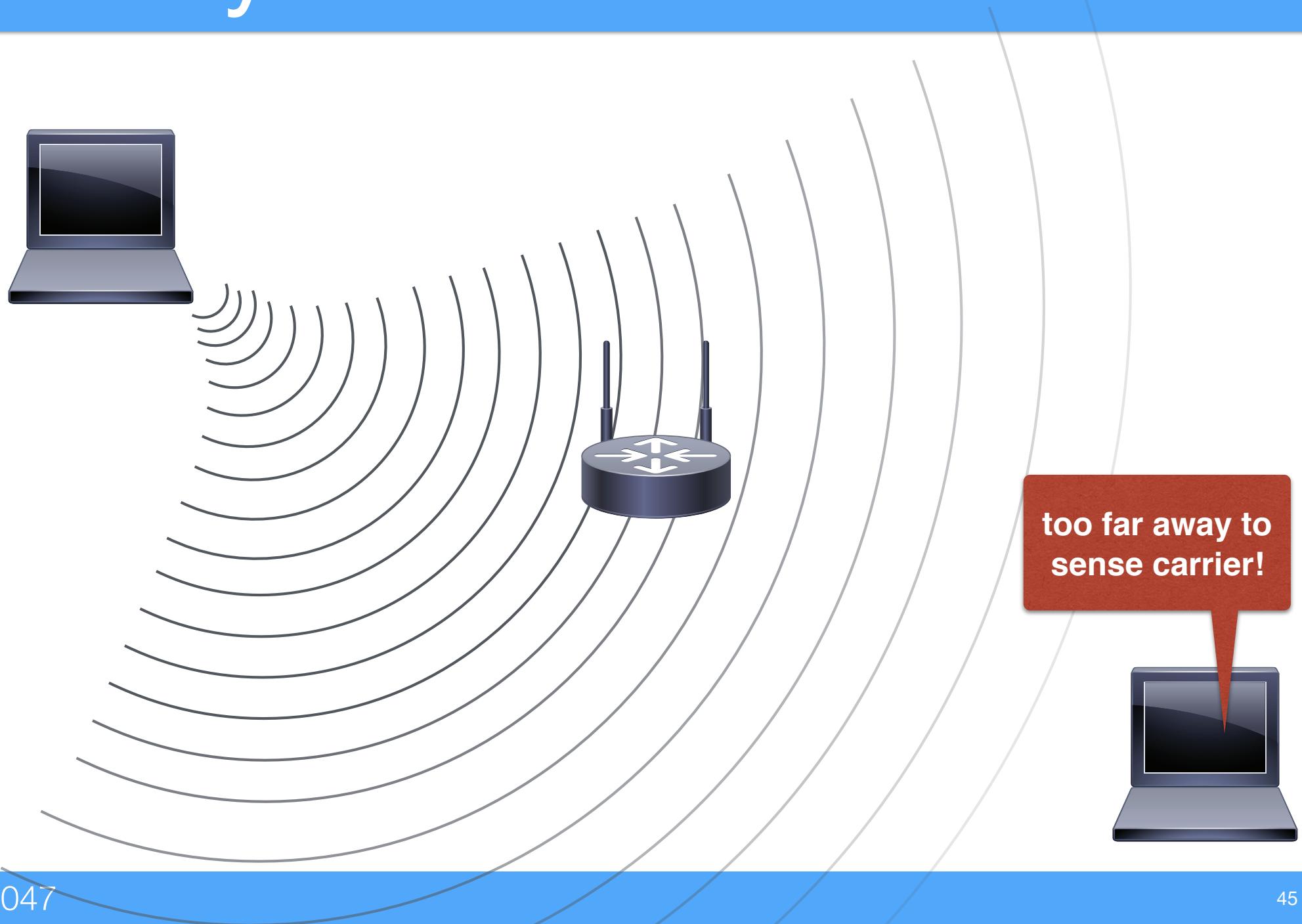
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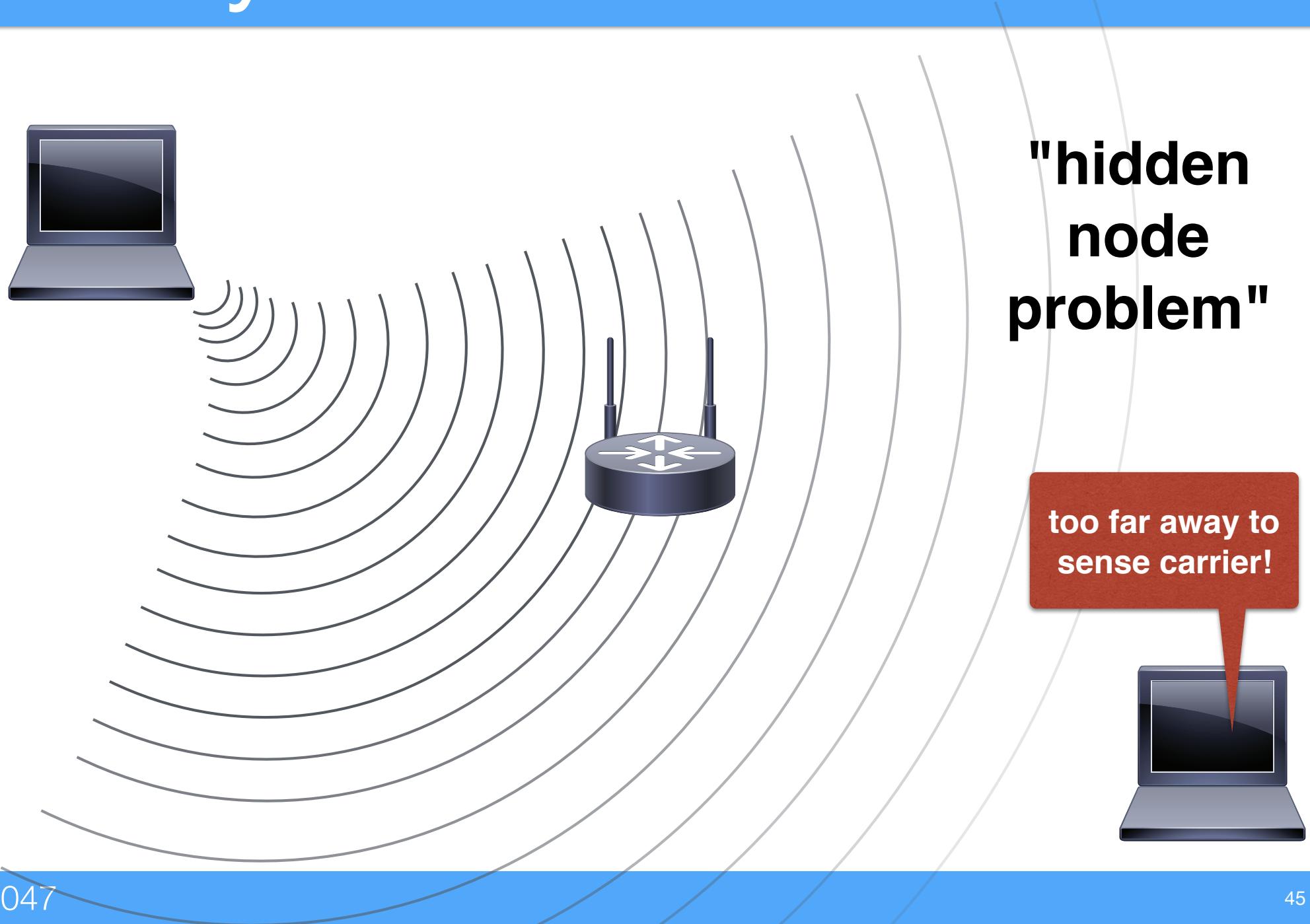
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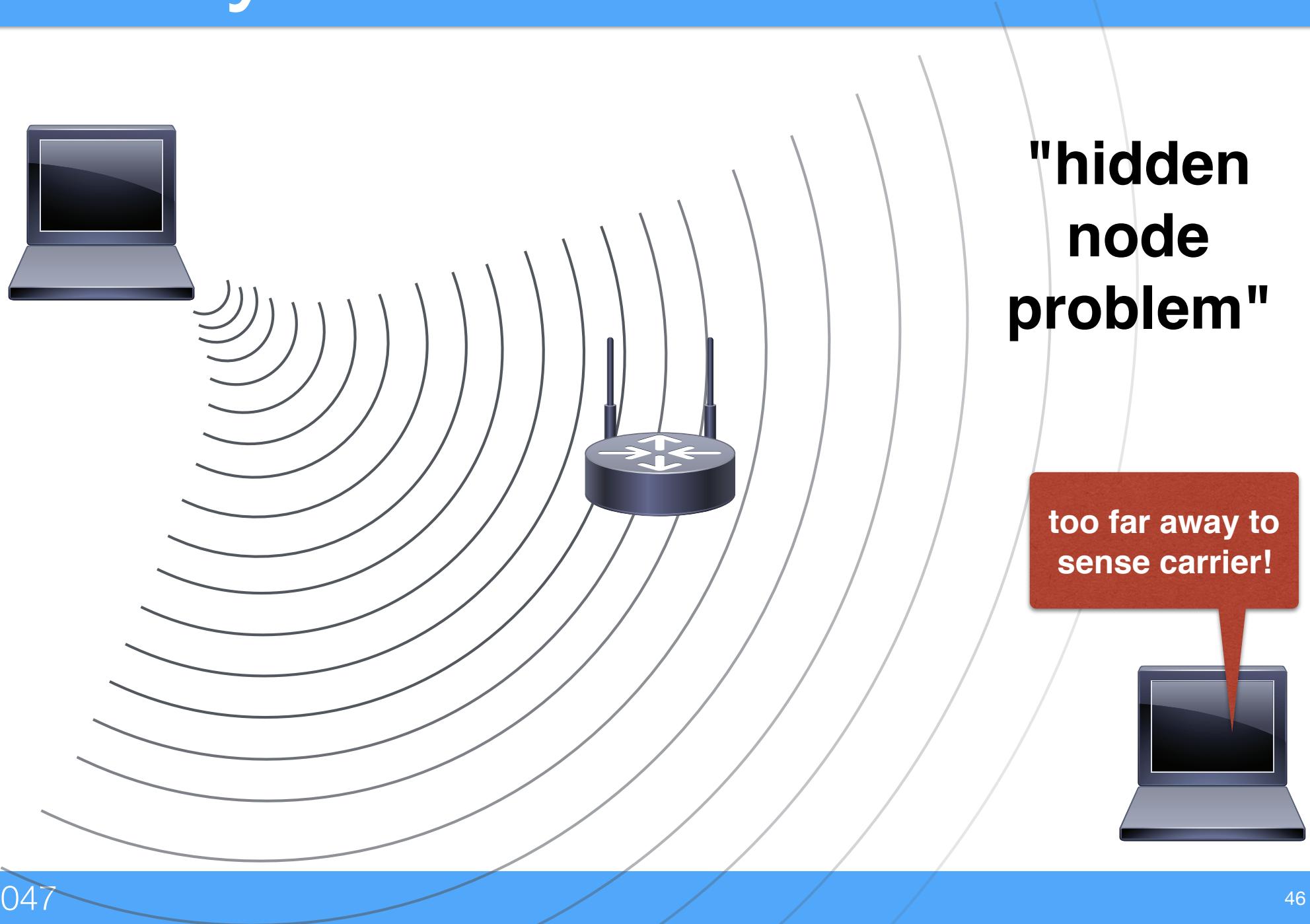
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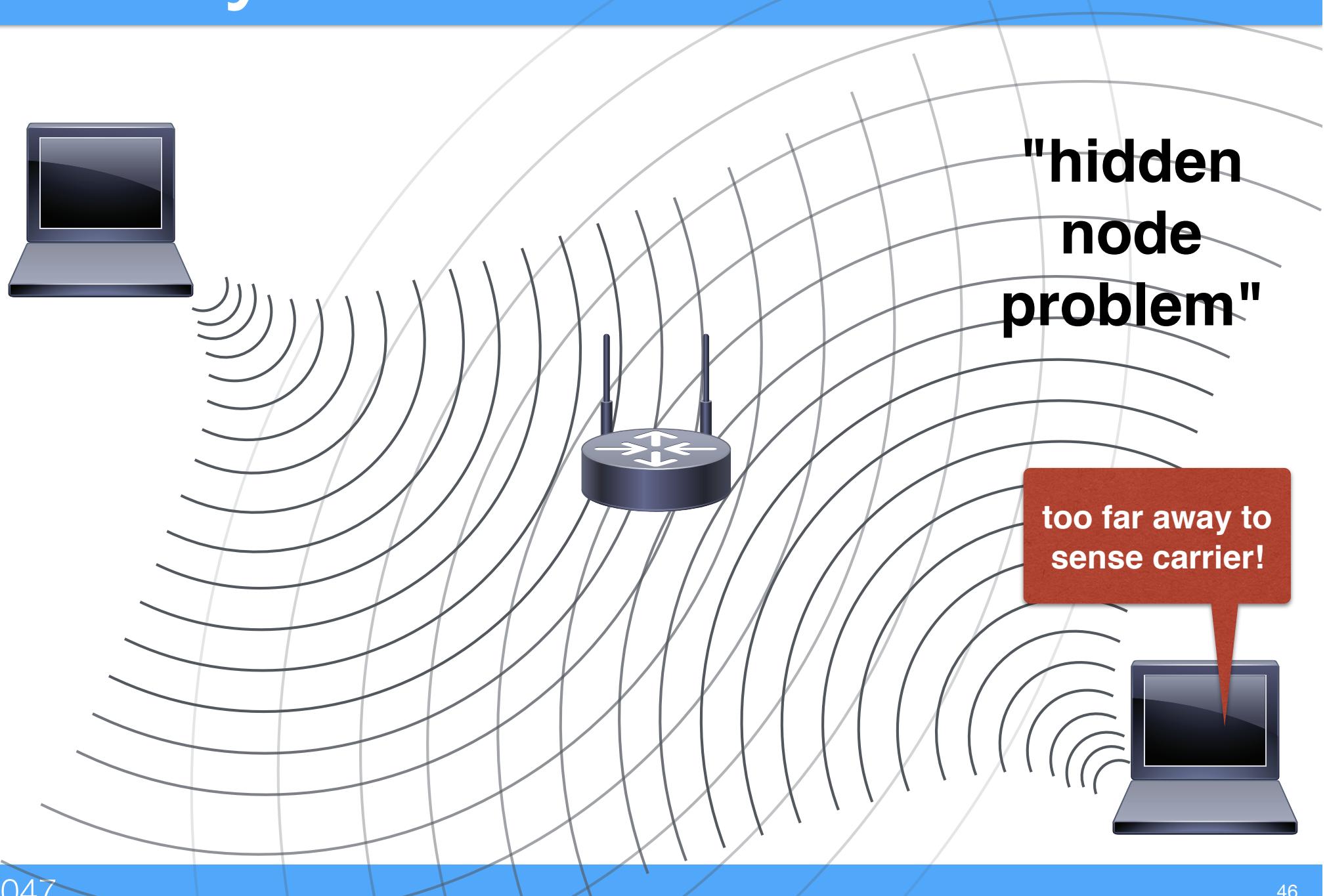
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Two solutions: ARQ + Controlled Access

802.11 uses stop-and-wait ARQ

- ARQ = Automatic Repeat ReQuest
- AP sends ACK (acknowledgement) after receiving a frame
- devices only send next frame after receiving ACK for previous frame, otherwise re-send original

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802.11 *may use controlled access*

- device can send "Request To Send" (RTS)
- only transmit frame if AP sends "Clear To Send" (CTS)

802.11 ARQ

Hidden node problem

- collision detection not reliable
- instead, receiver needs to ACK every frame

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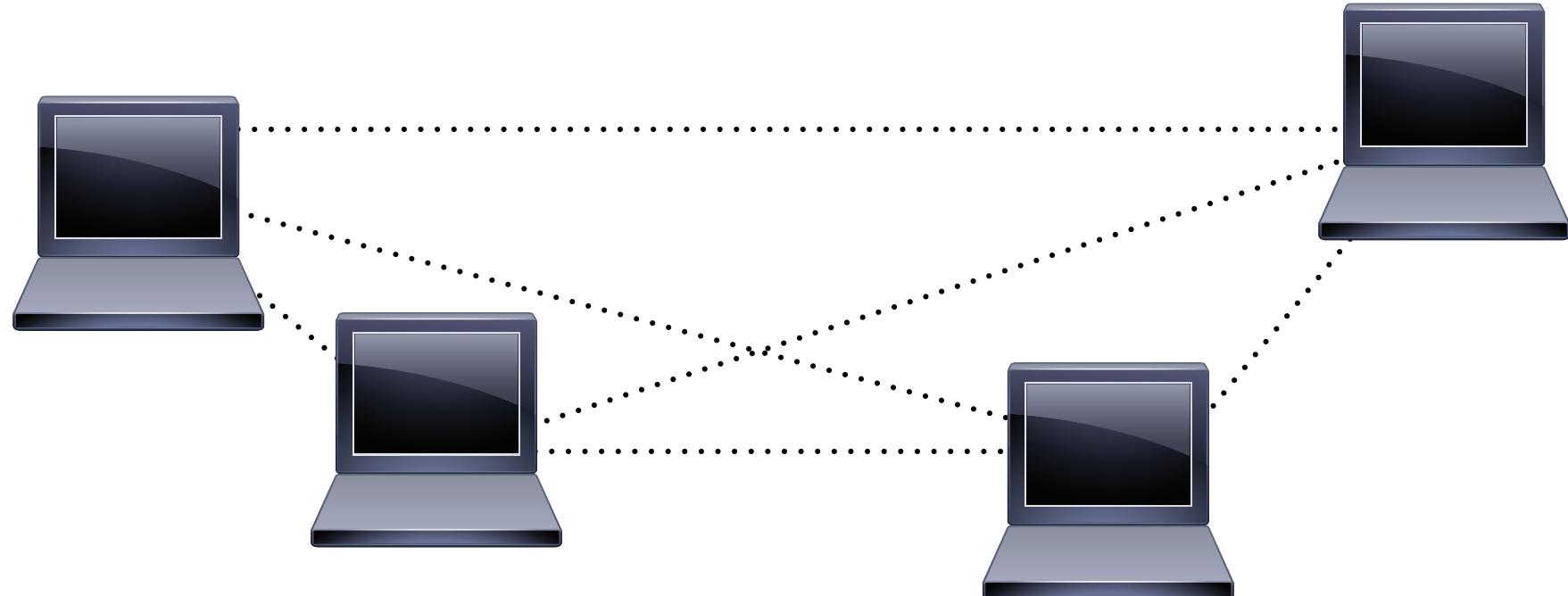
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Solution: exponential back-off

- 1st collision: everybody waits 0 or 1 time unit
- 2nd: everybody waits between 0 and 3 time units
- 3rd: everybody waits between 0 and 7 time units...

WLAN Topology

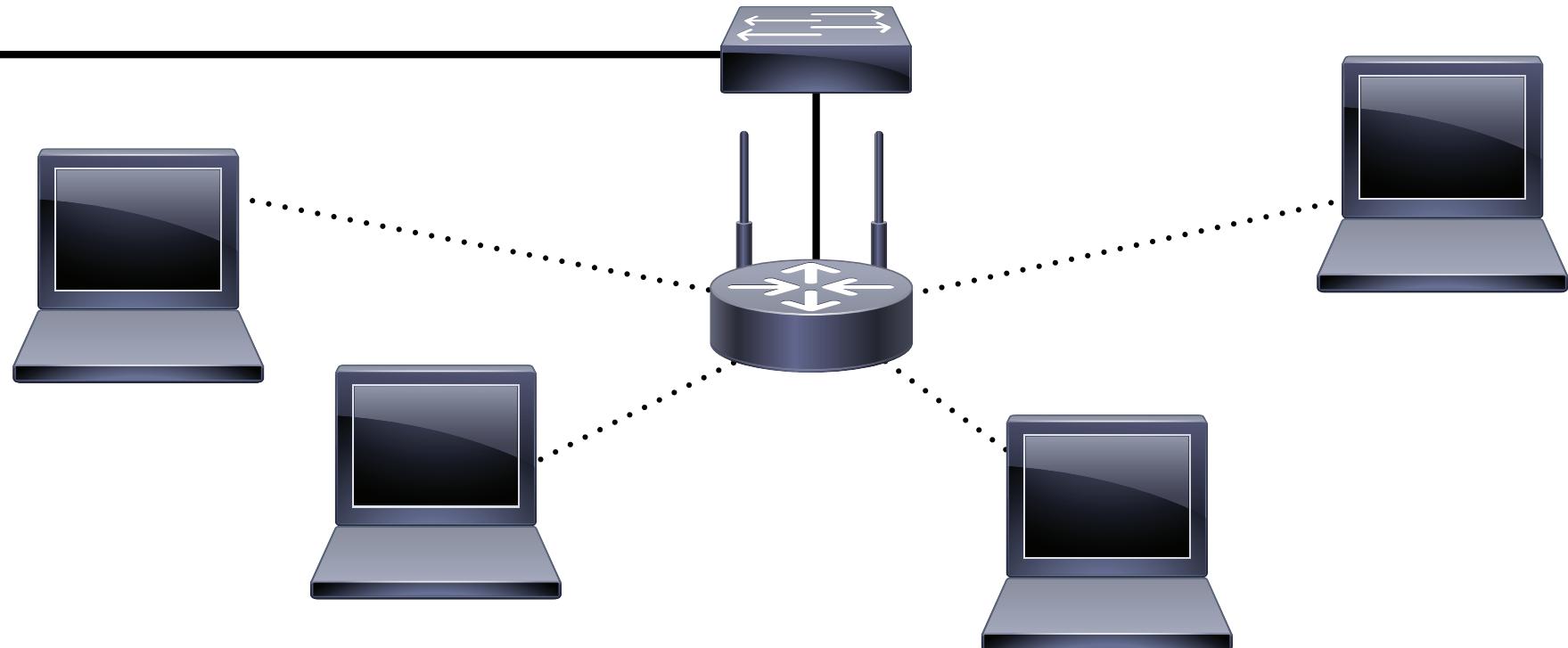
Basic Service Set (BSS)



Independent BSS

- **ad-hoc** network
- devices communicate directly with each other

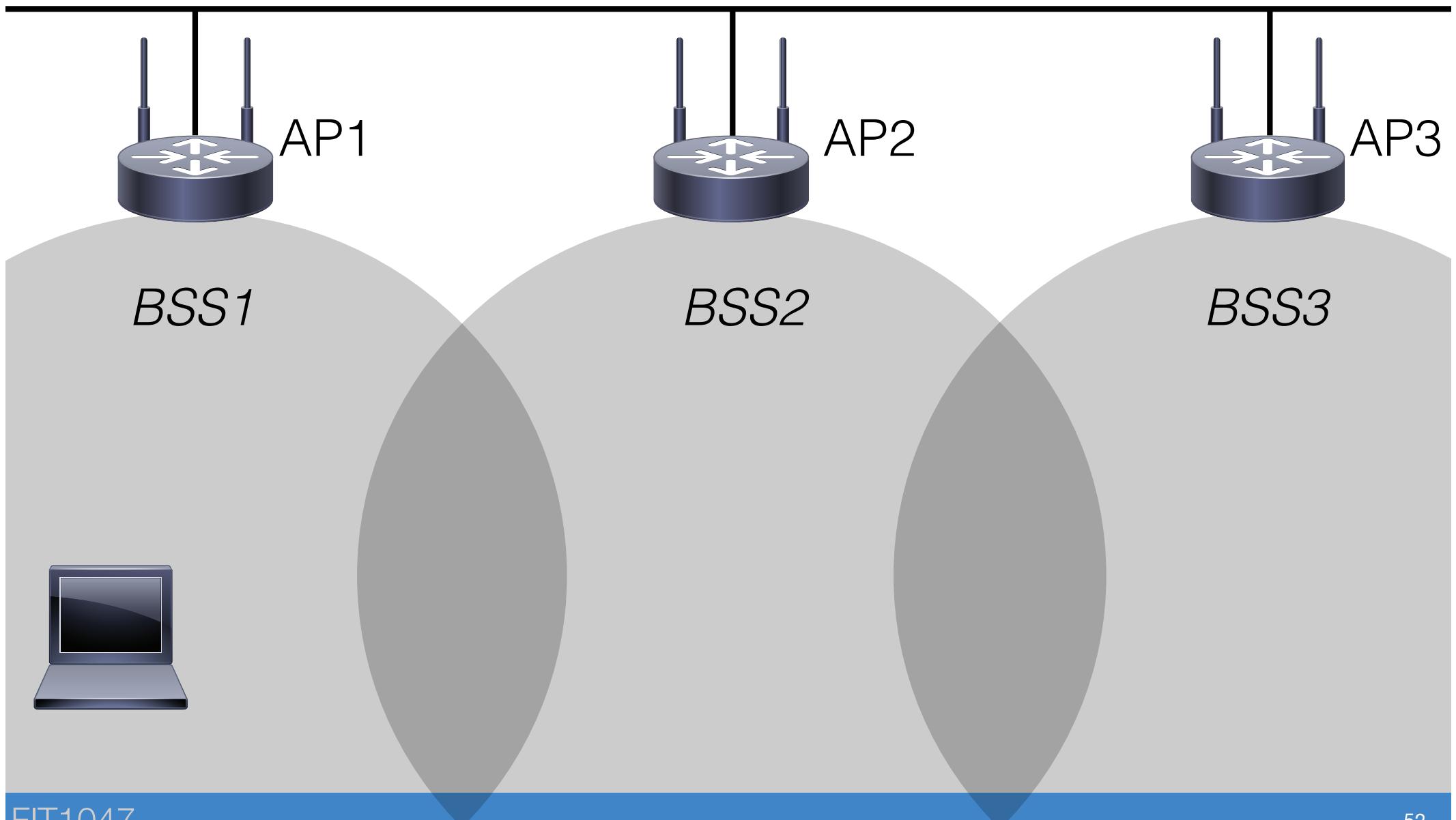
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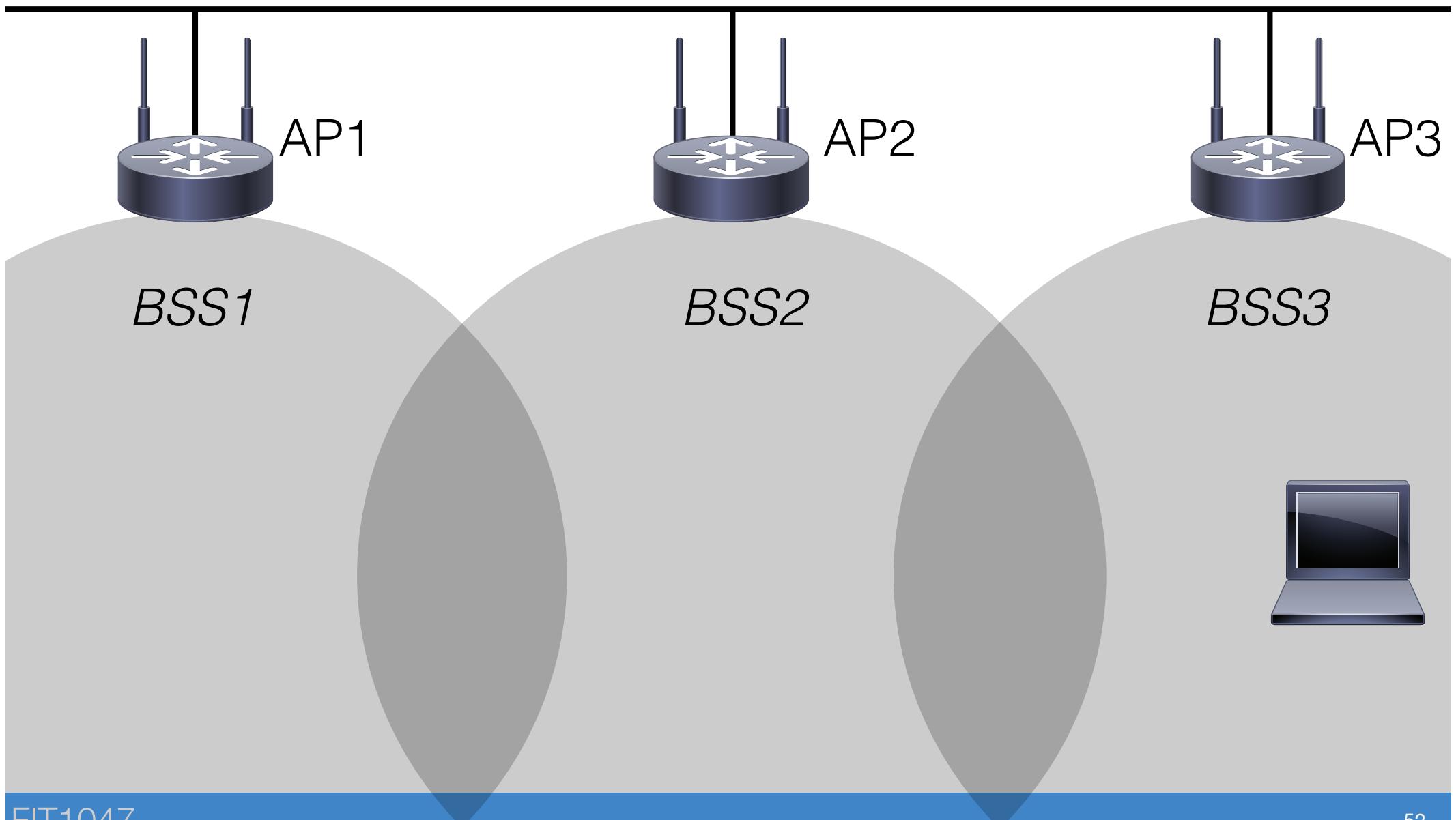
Infrastructure BSS

- all devices communicate with one Access Point (AP)
- AP connects to LAN
- all devices communicate **via** the AP

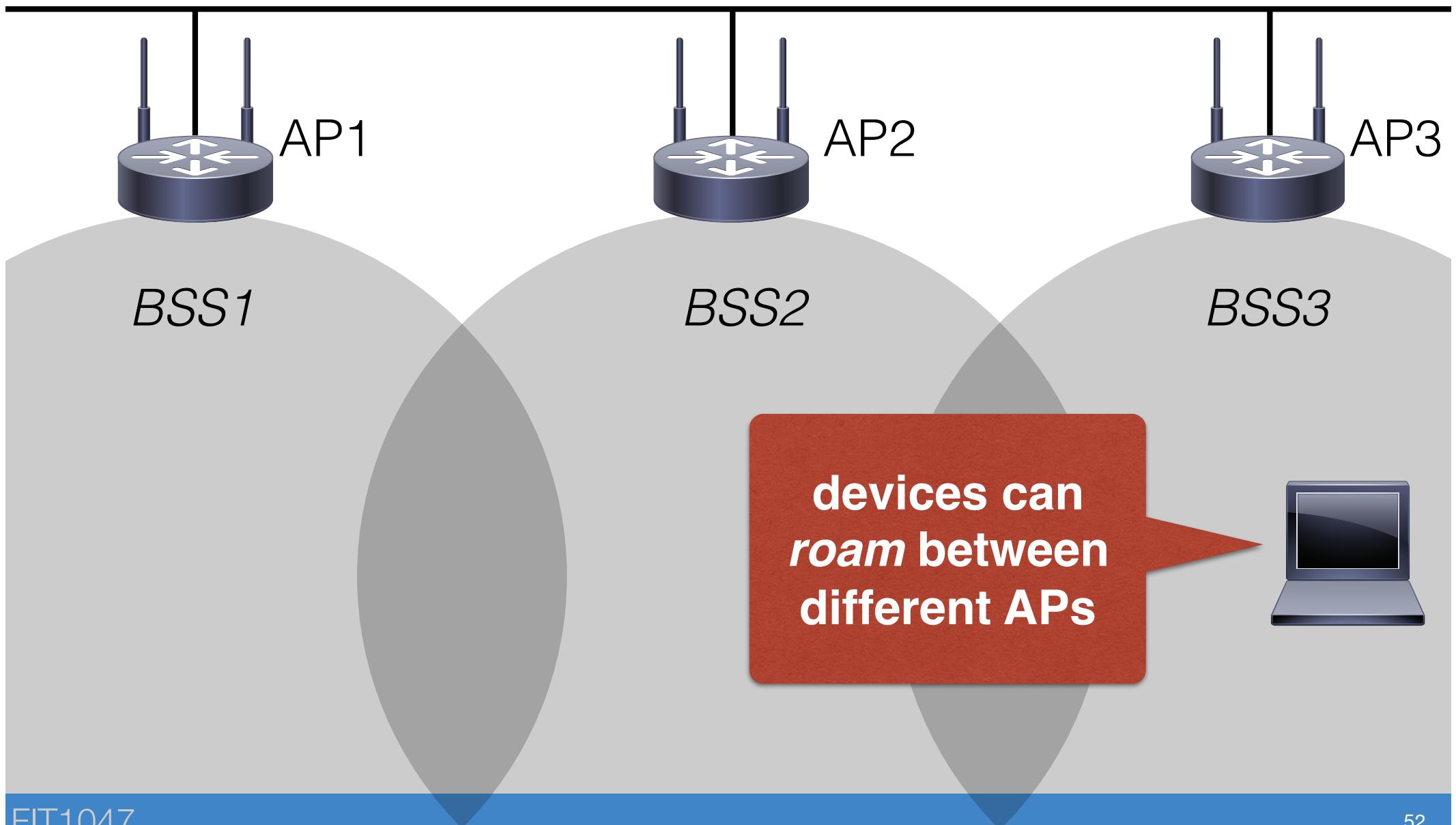
Extended Service Set (ESS)



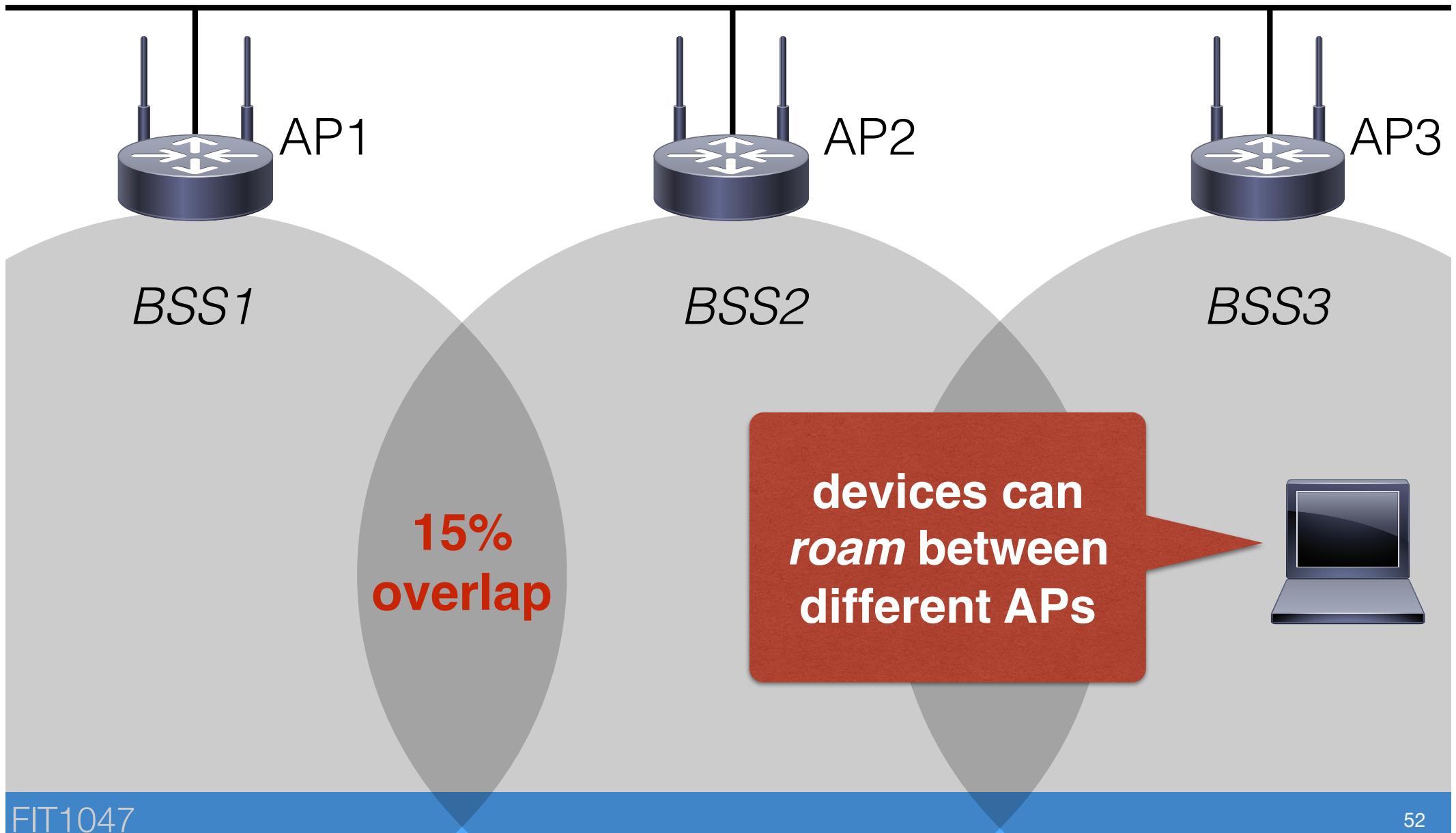
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Extended Service Set (ESS)

Extends range of mobility

- set of infrastructure BSSs
- APs communicate to forward traffic between BSSs
- APs communicate via **distribution system (LAN)**
- devices see a **single layer 2** connection

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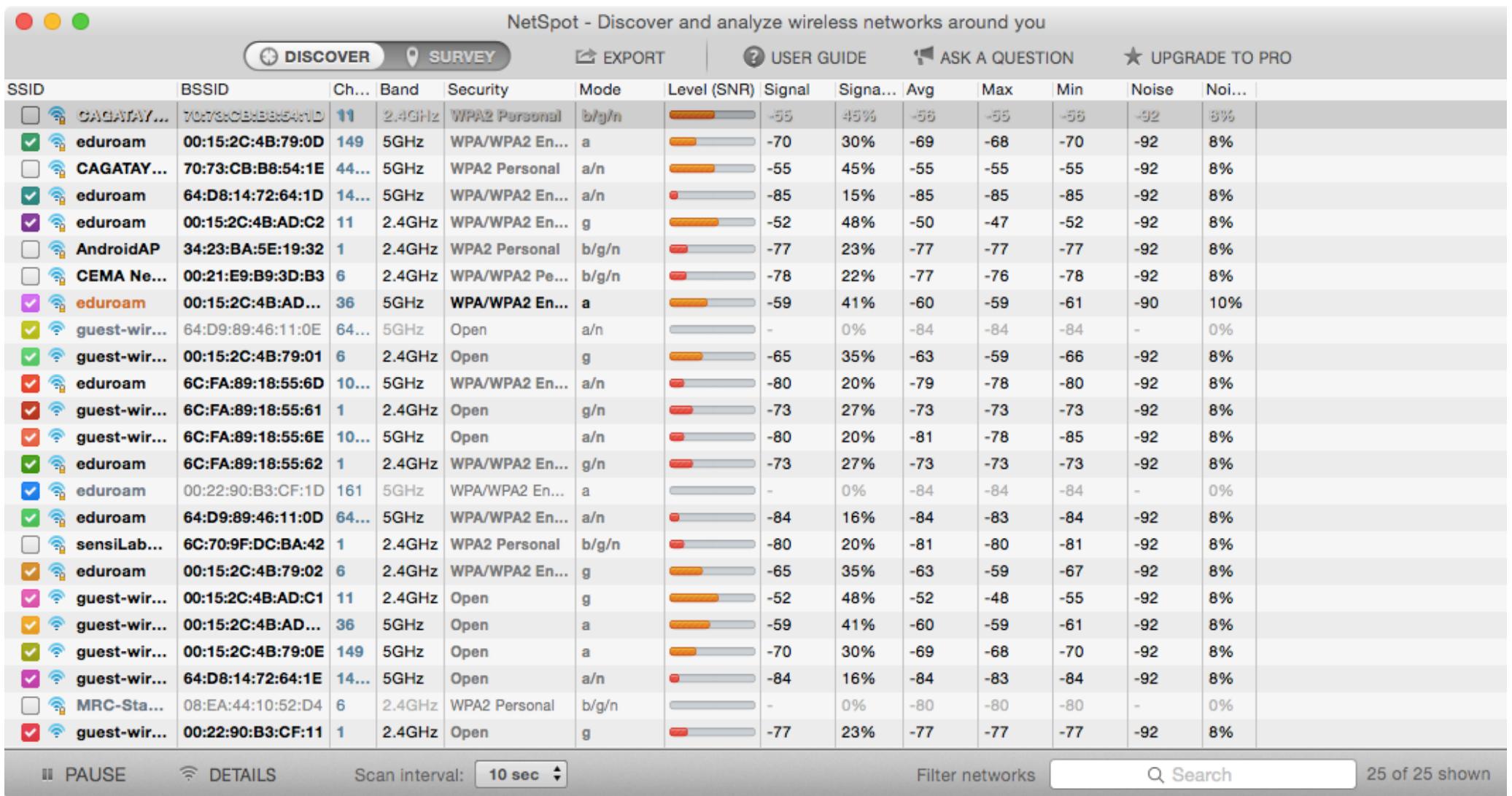
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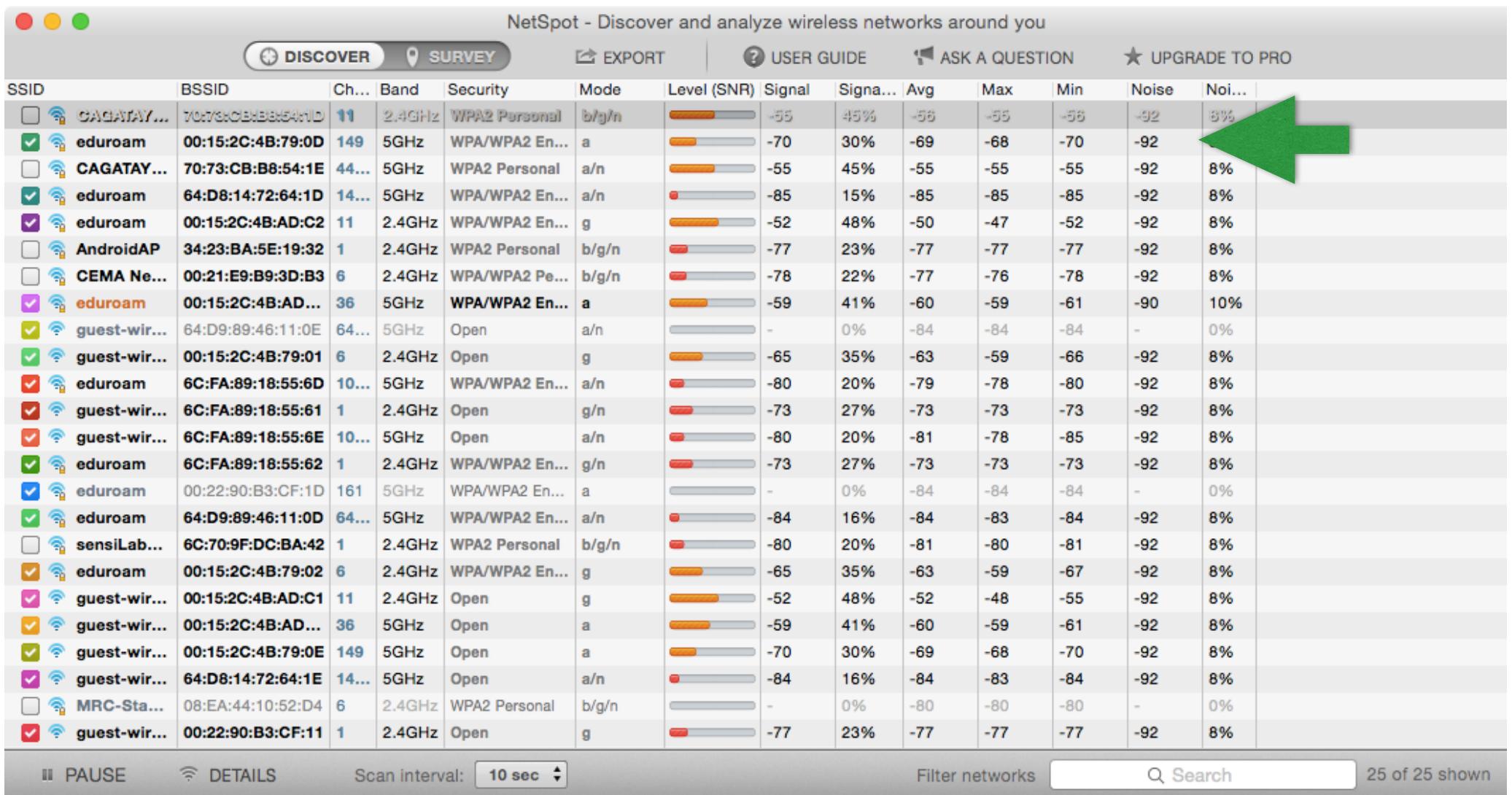
Roaming between different ESSs

- not possible in 802.11 protocol
- requires higher-level protocol, e.g. Mobile IP

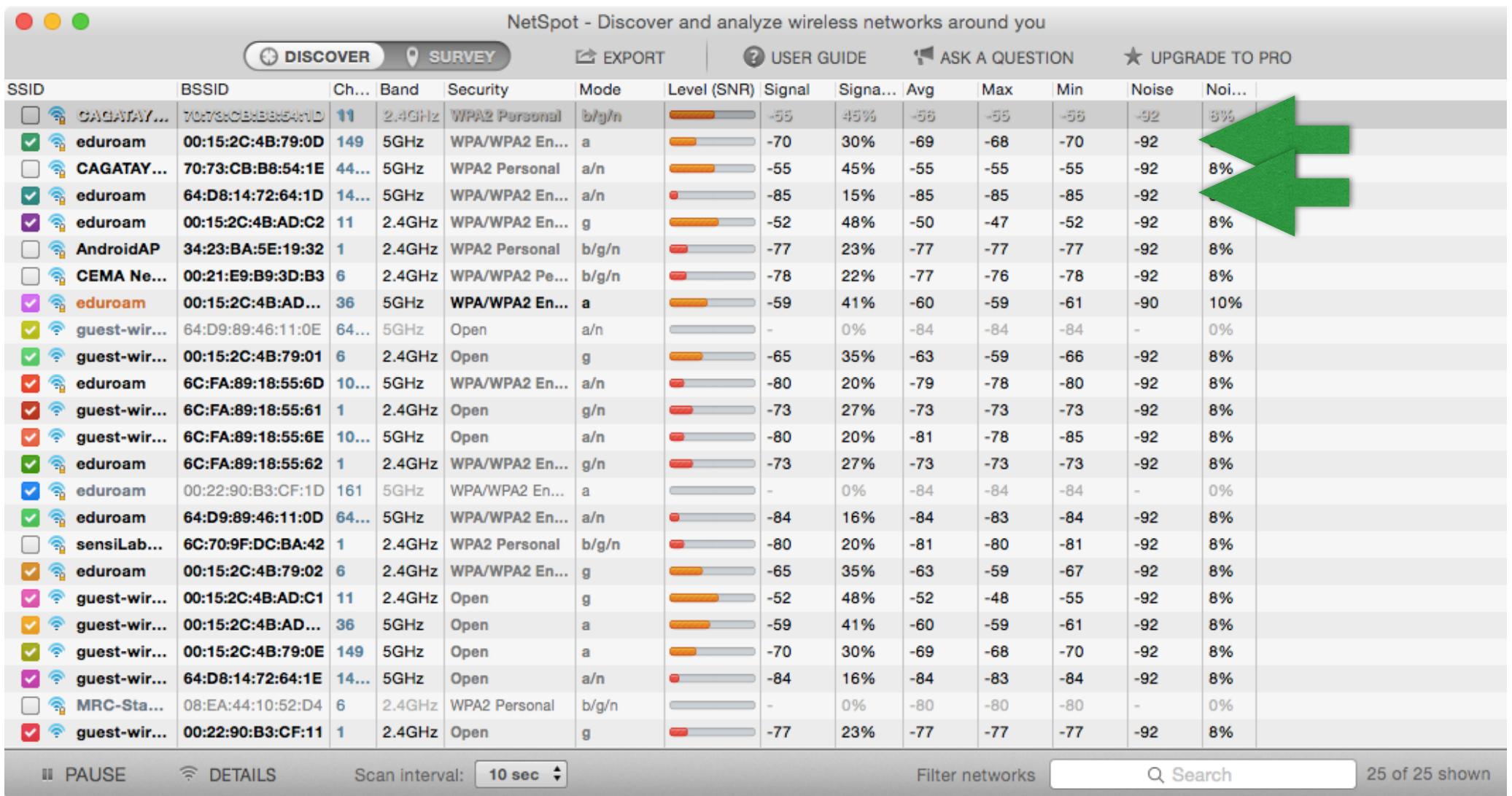
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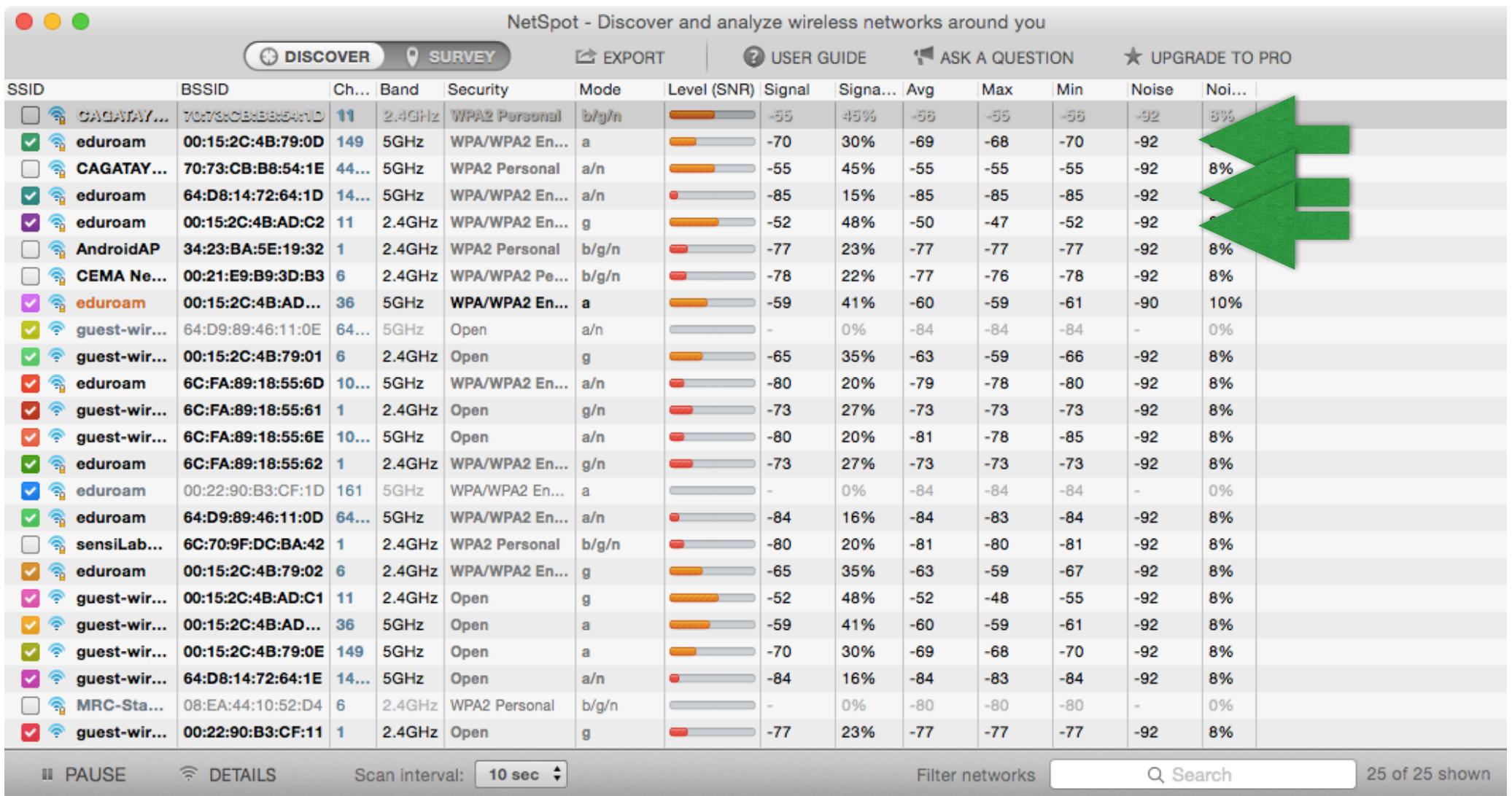
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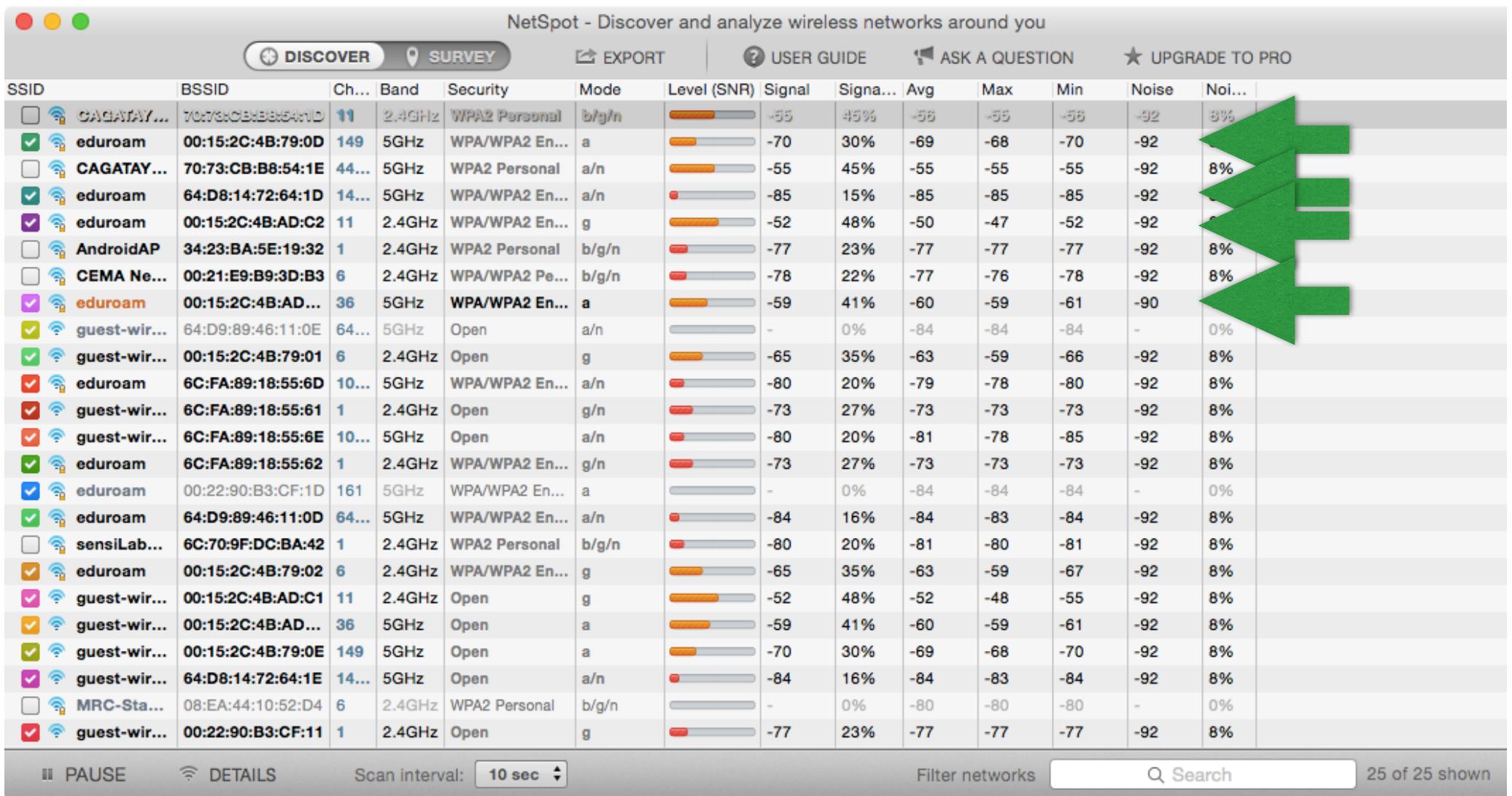
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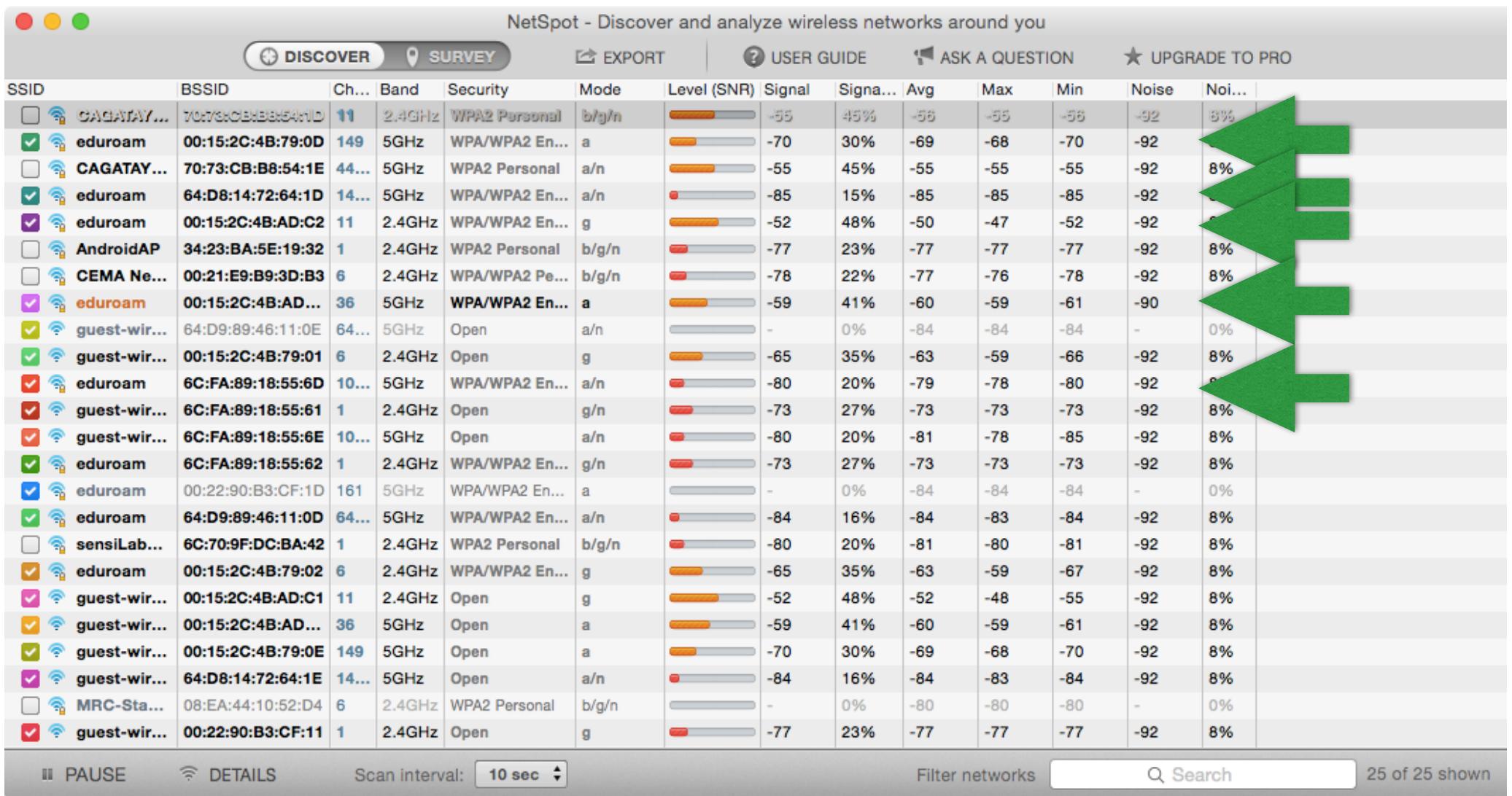
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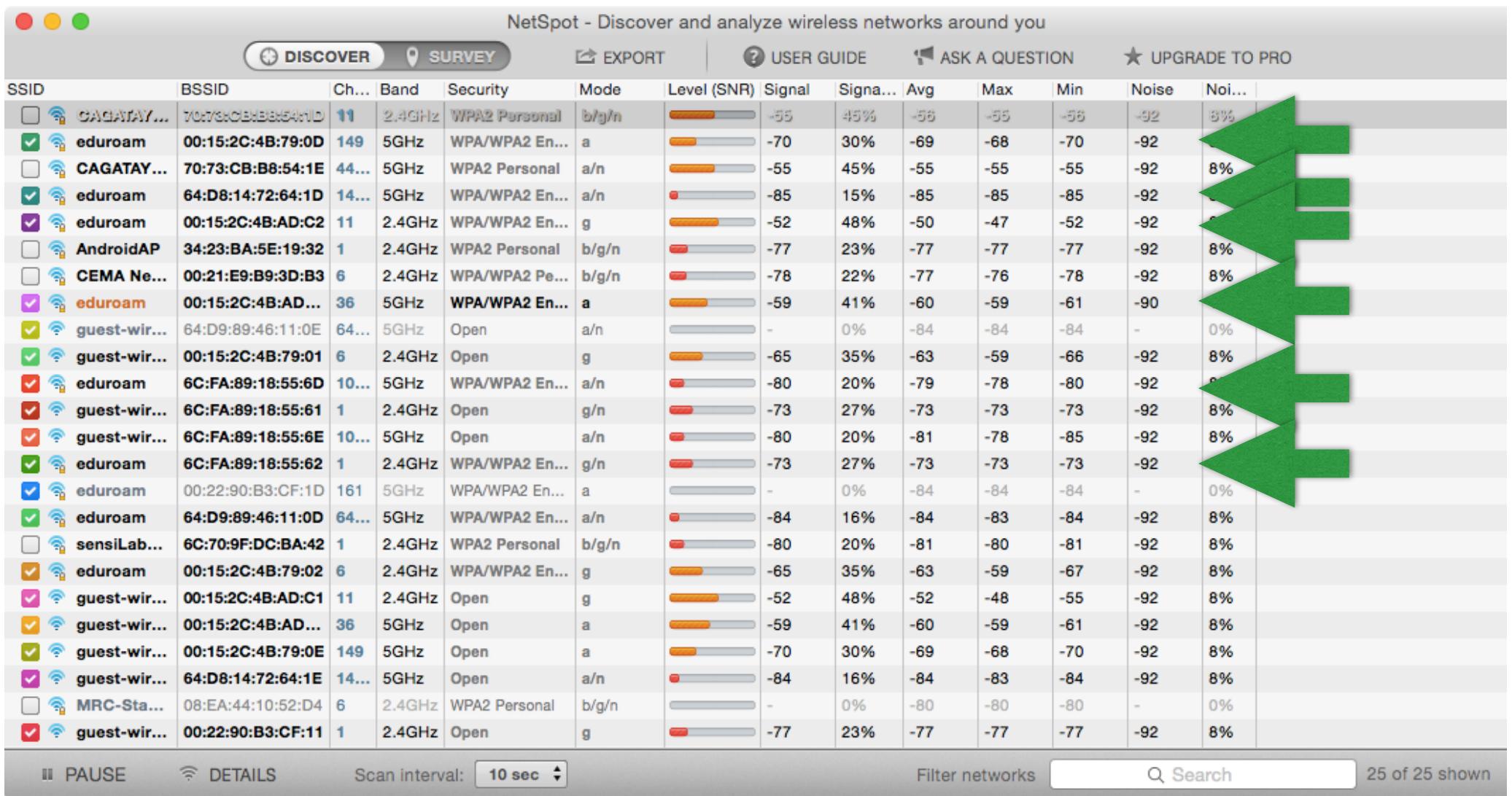
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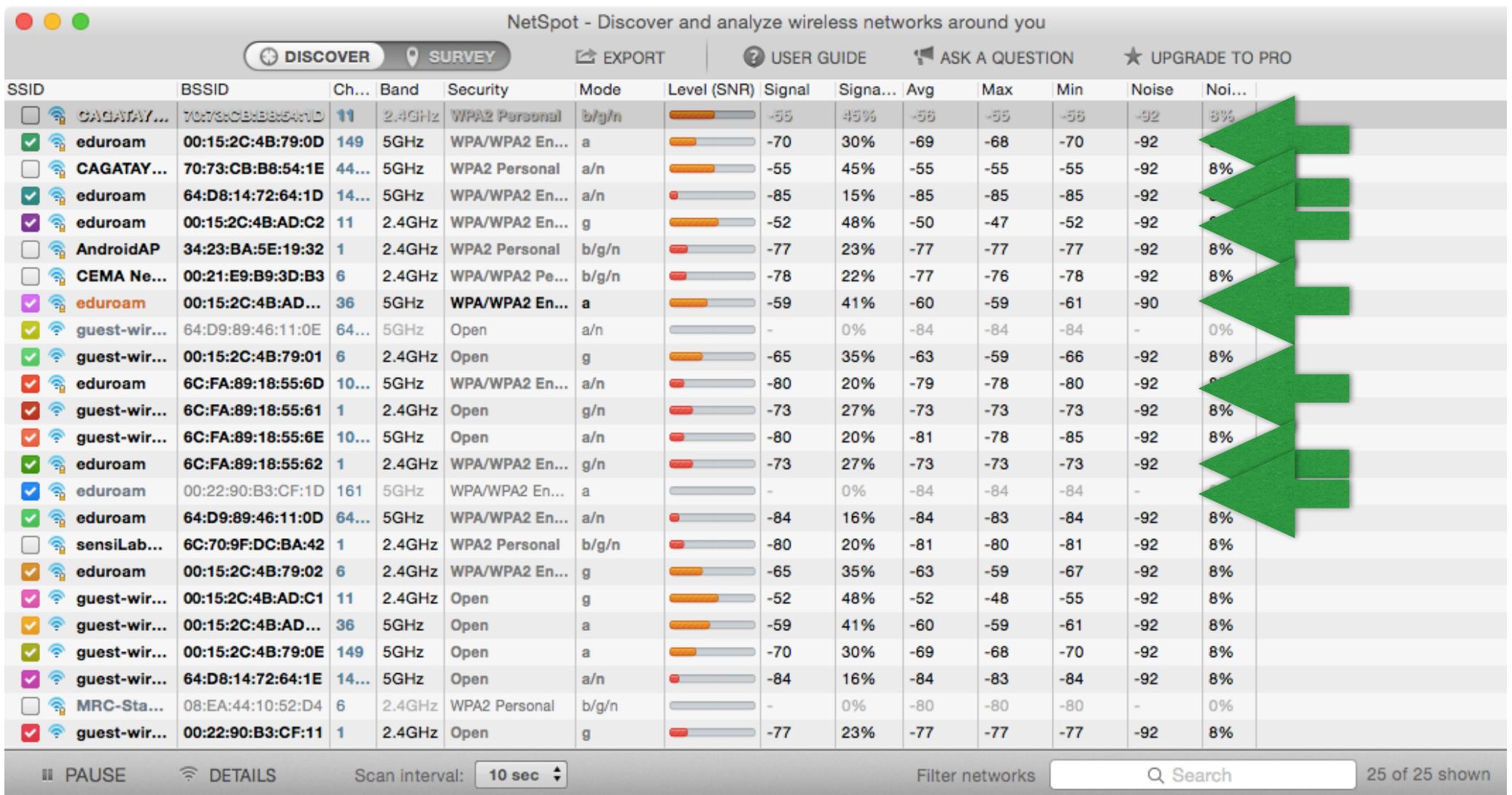
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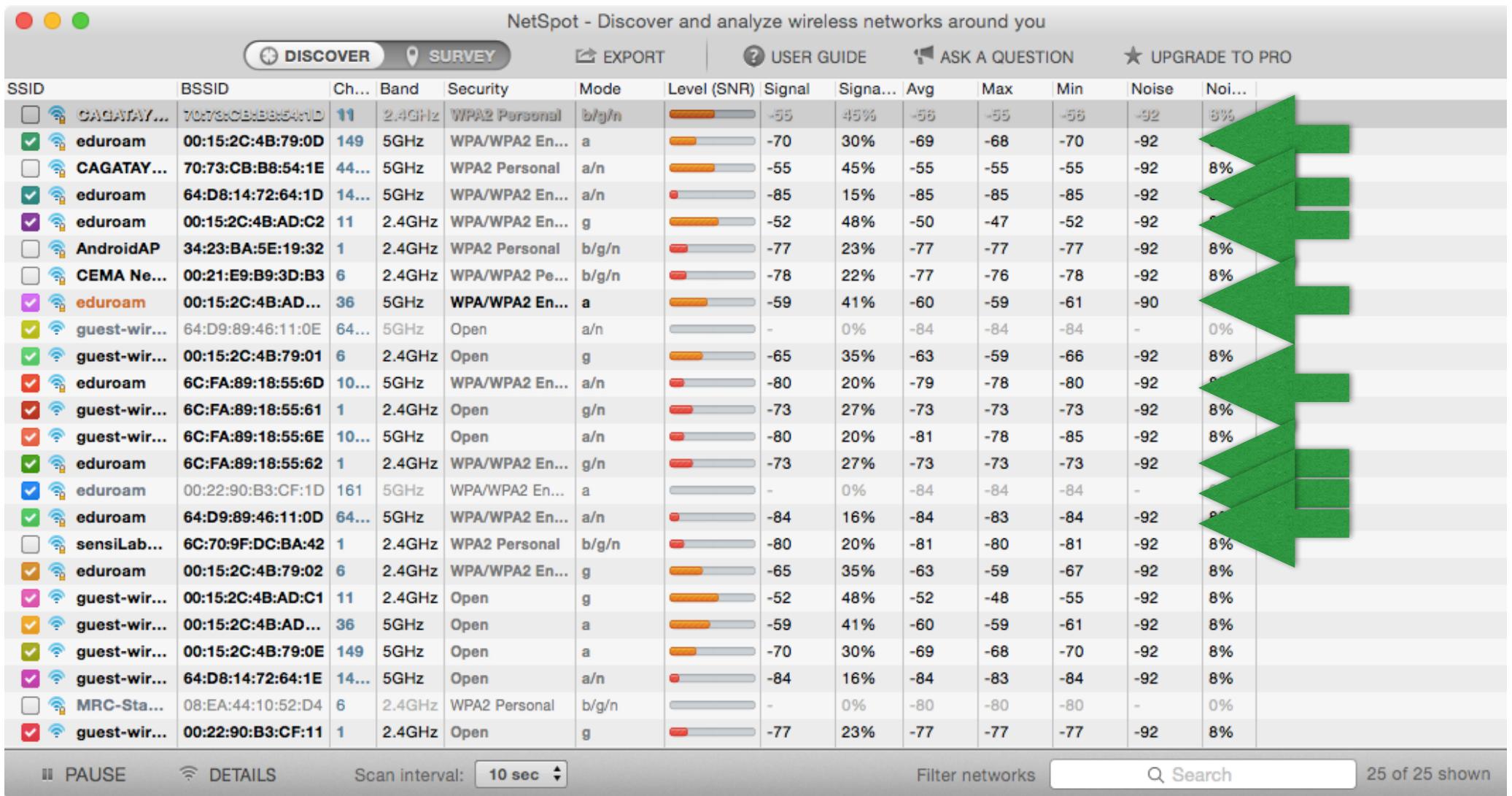
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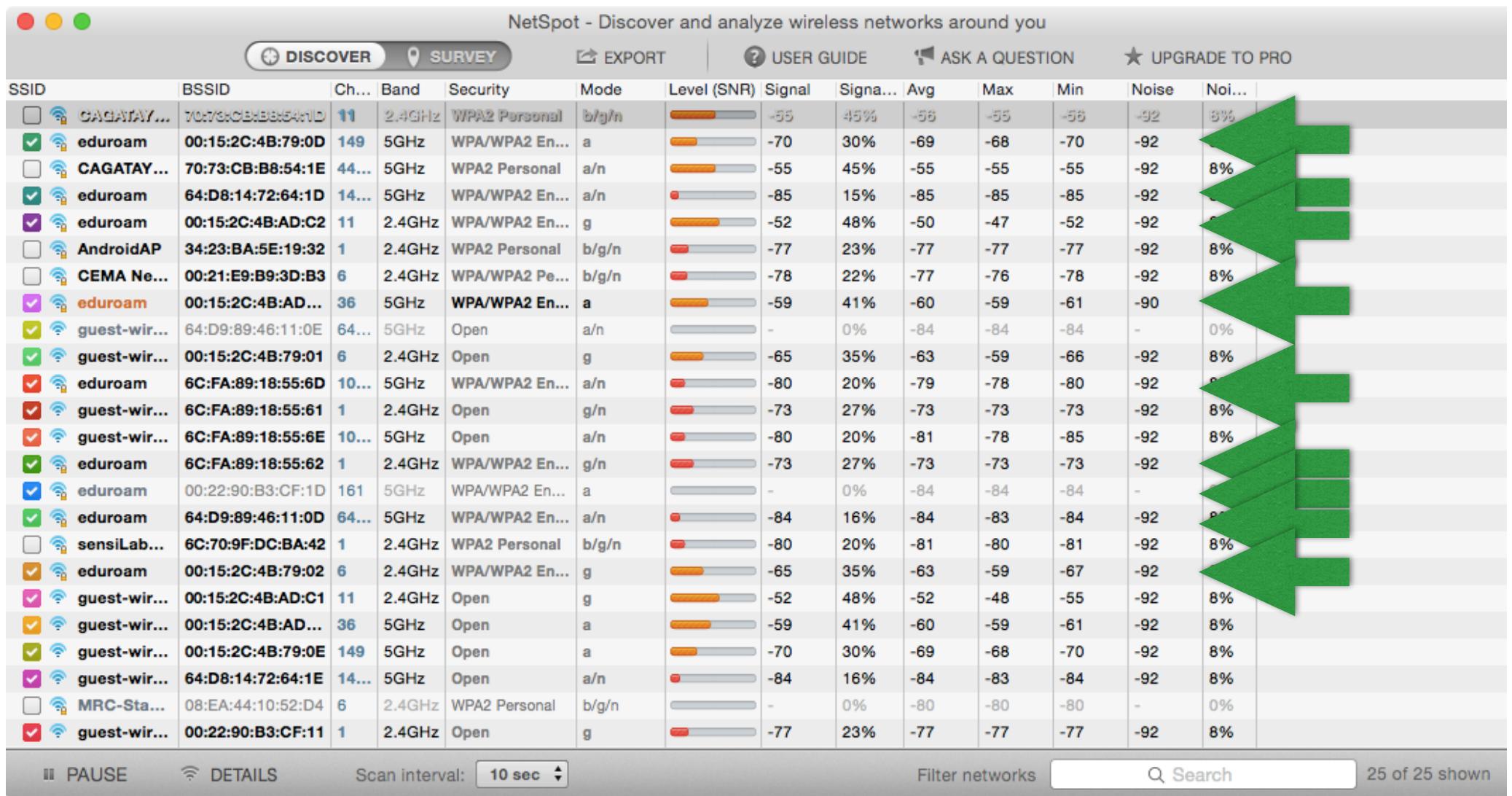
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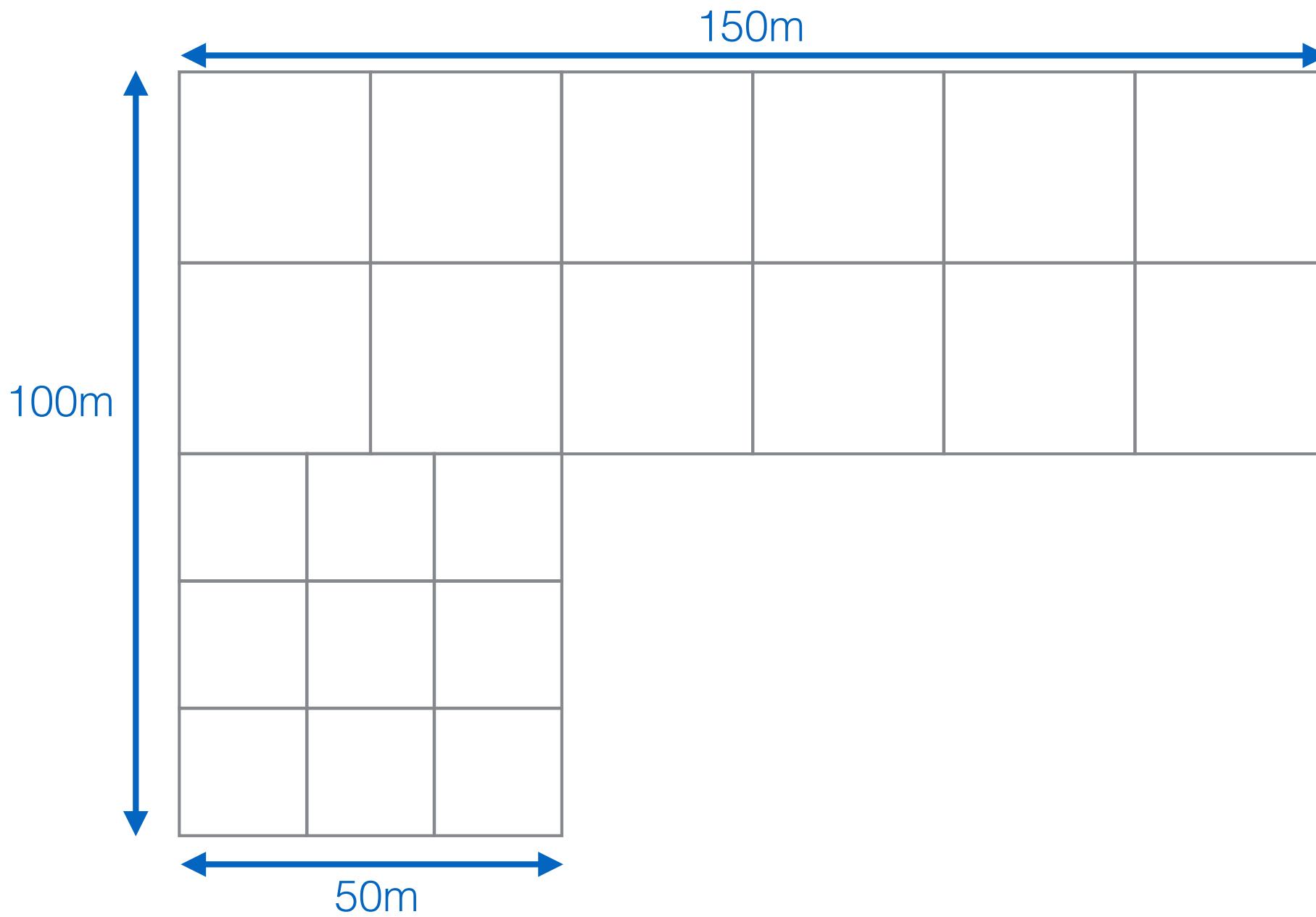
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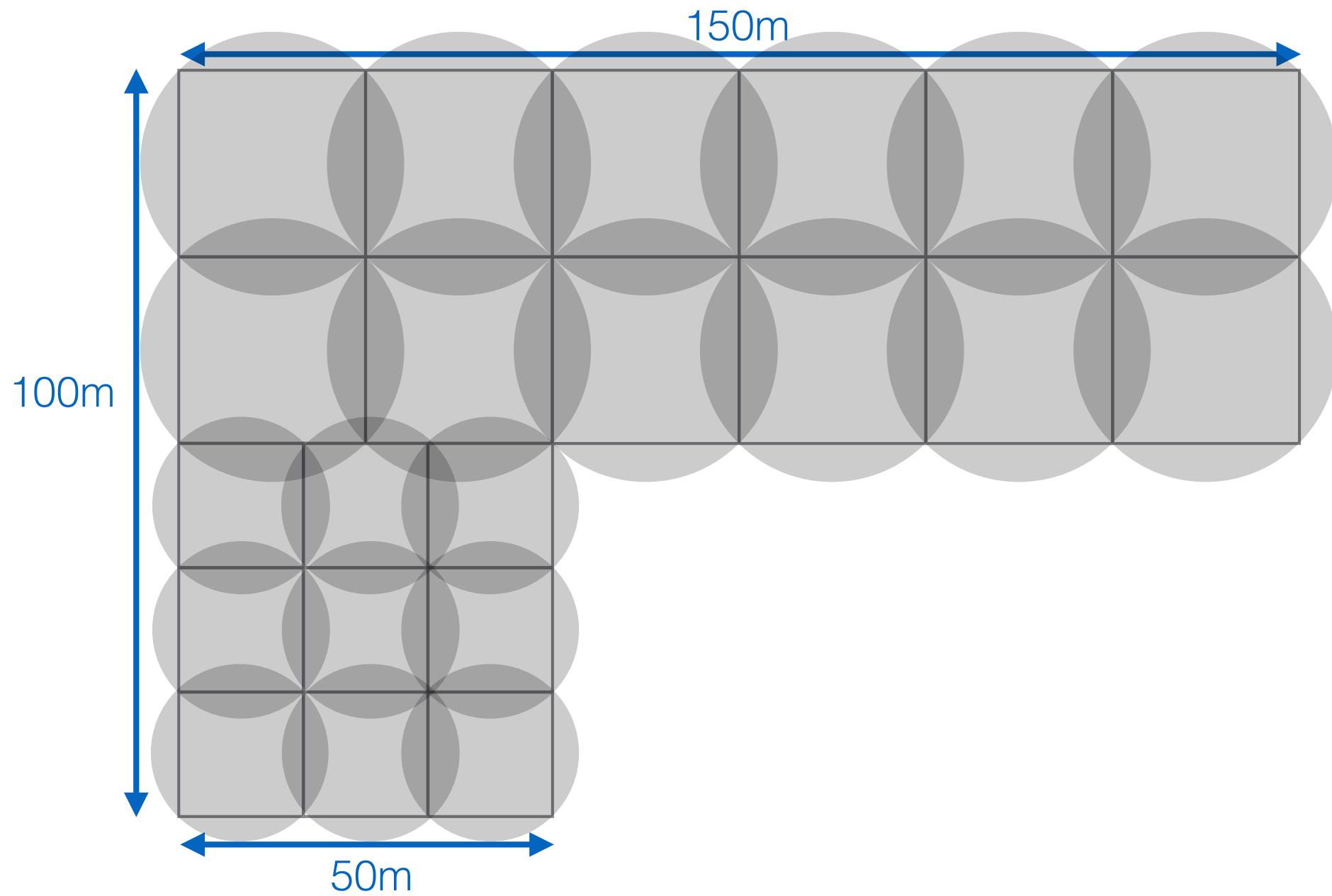
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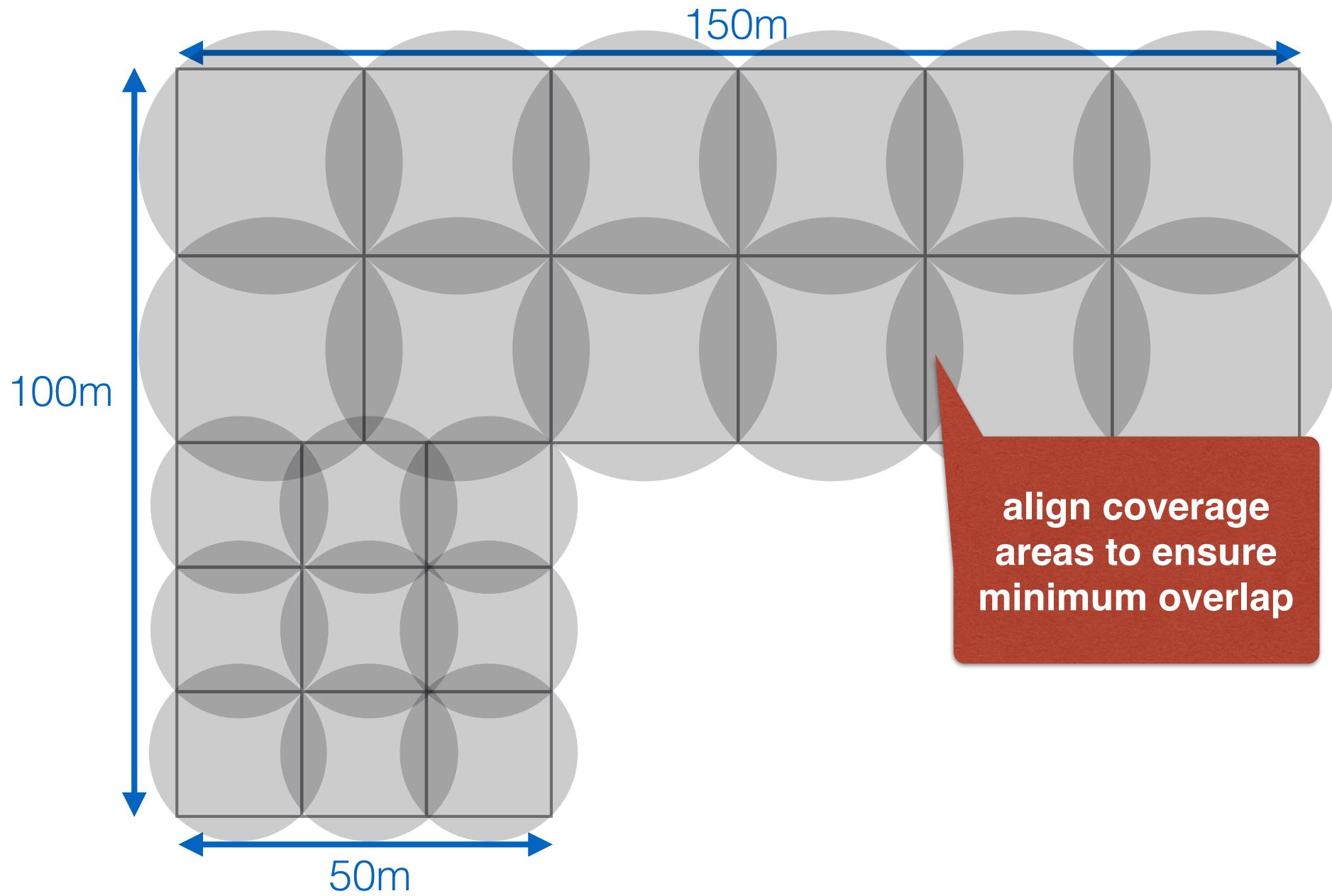
Planning Example



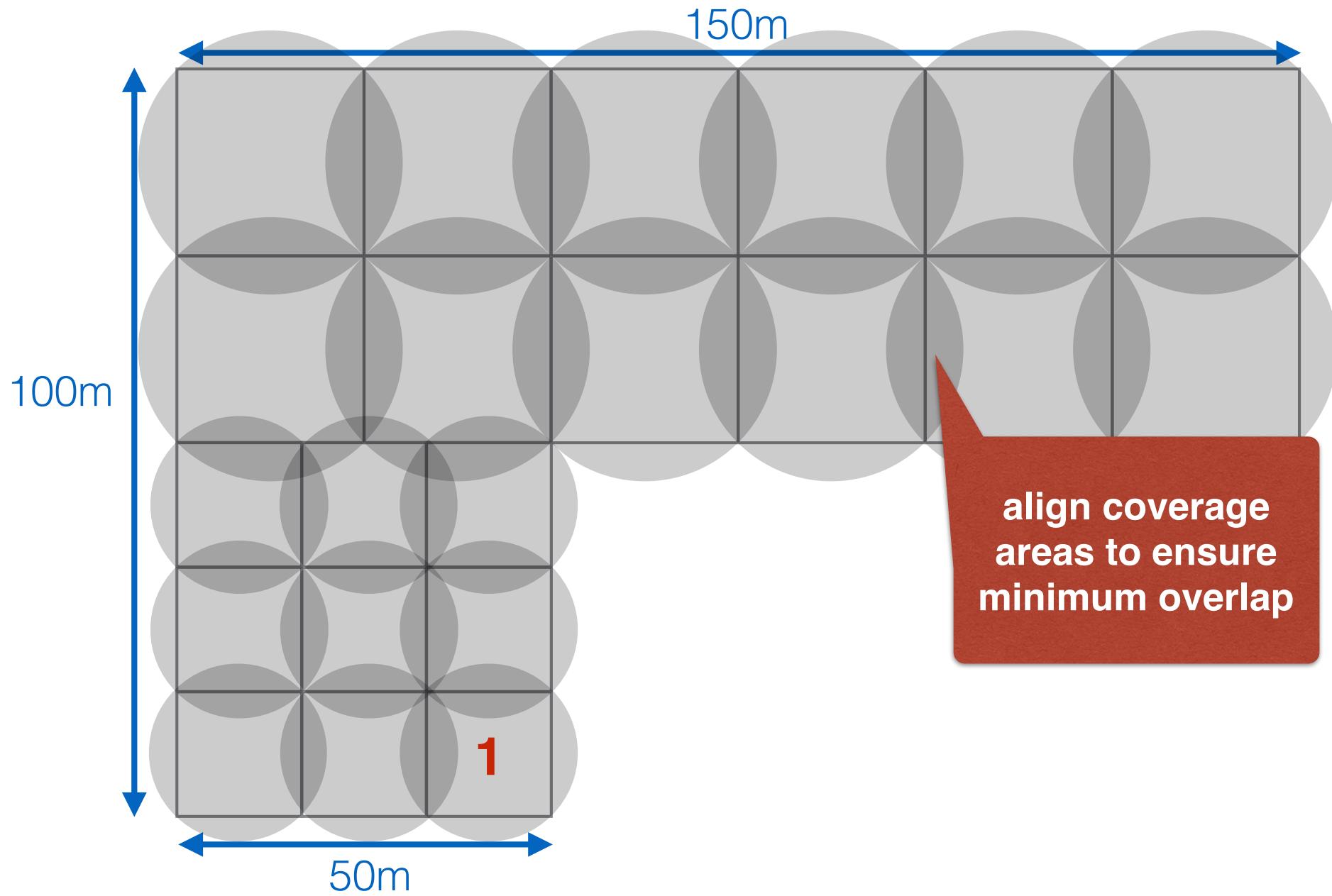
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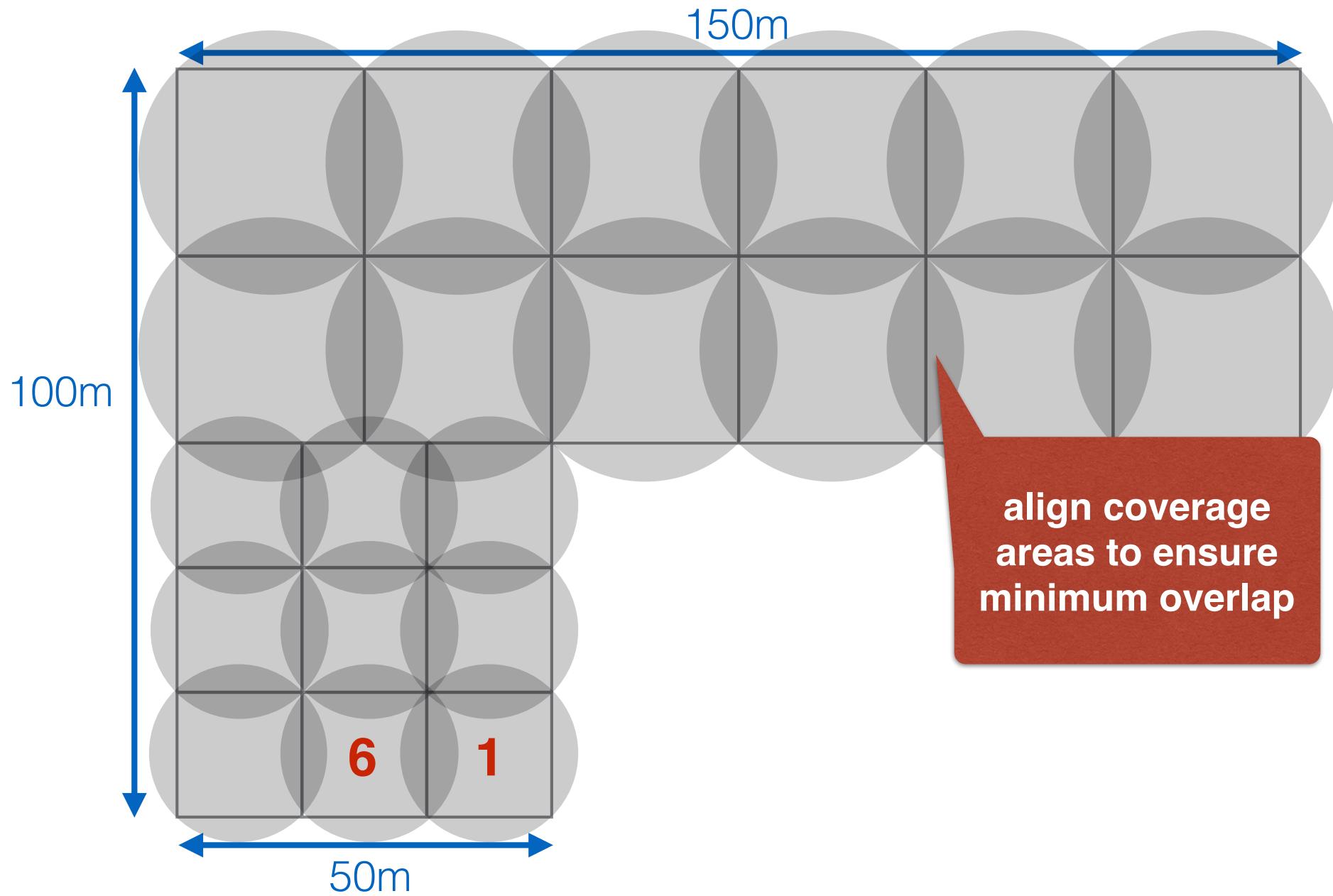
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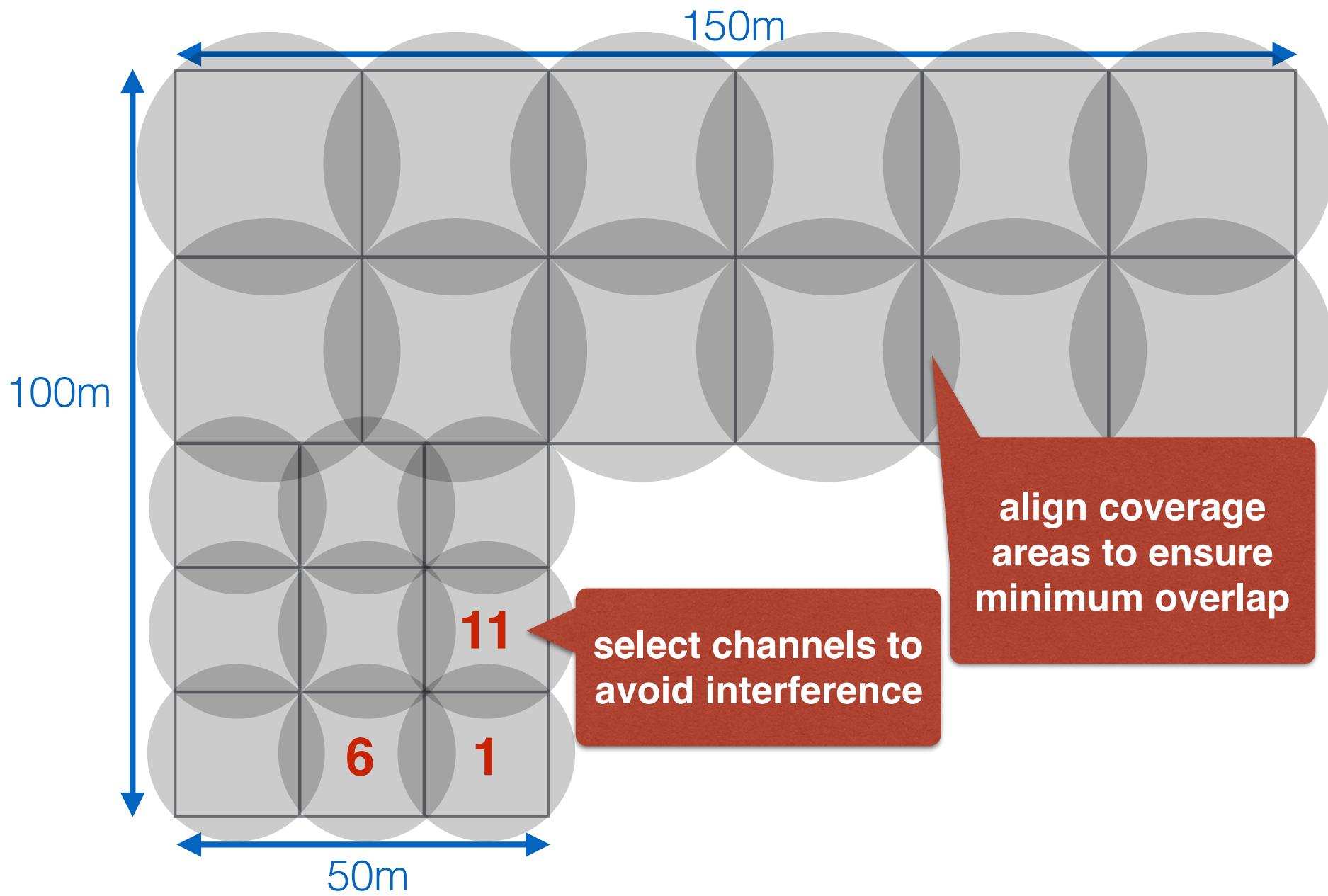
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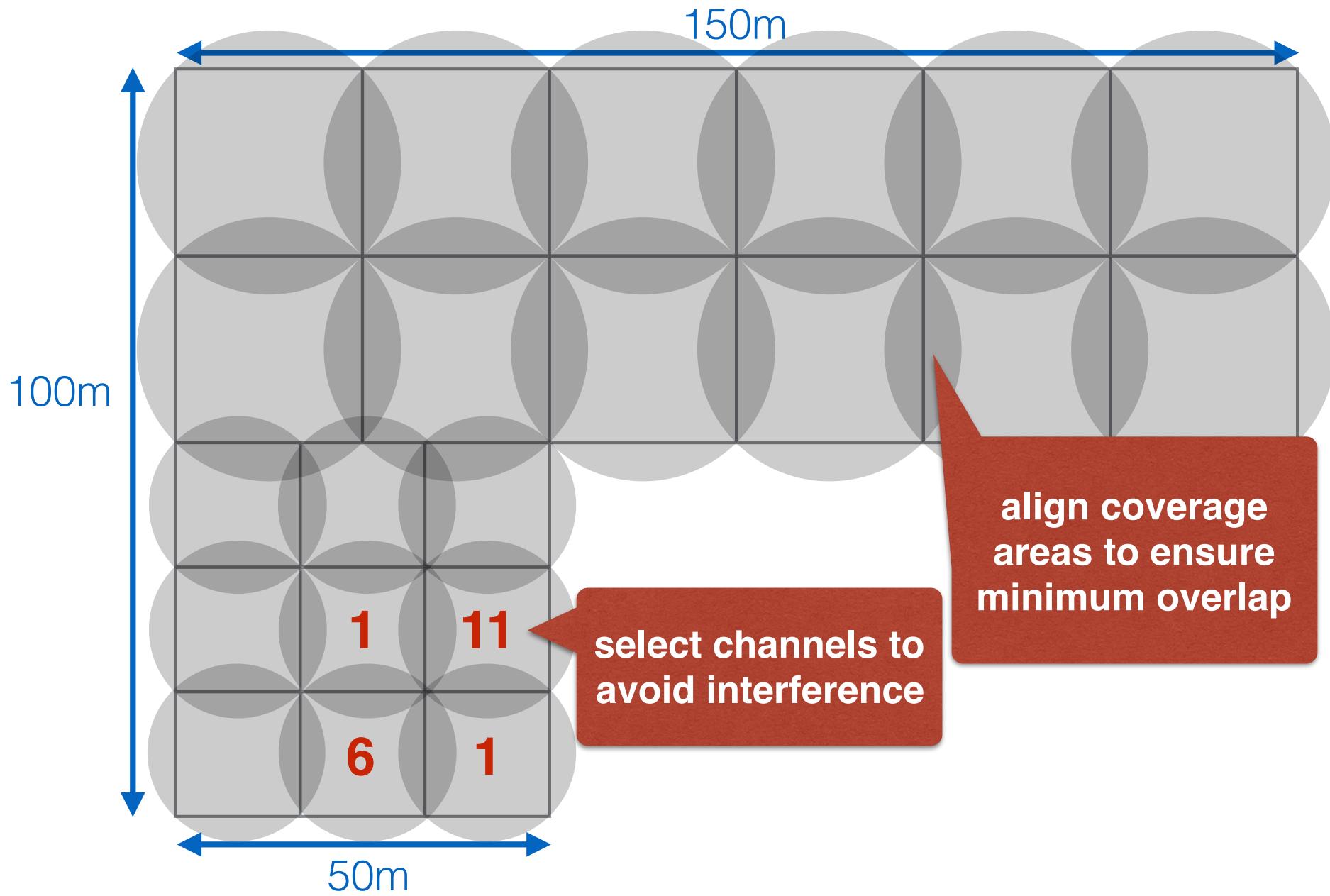
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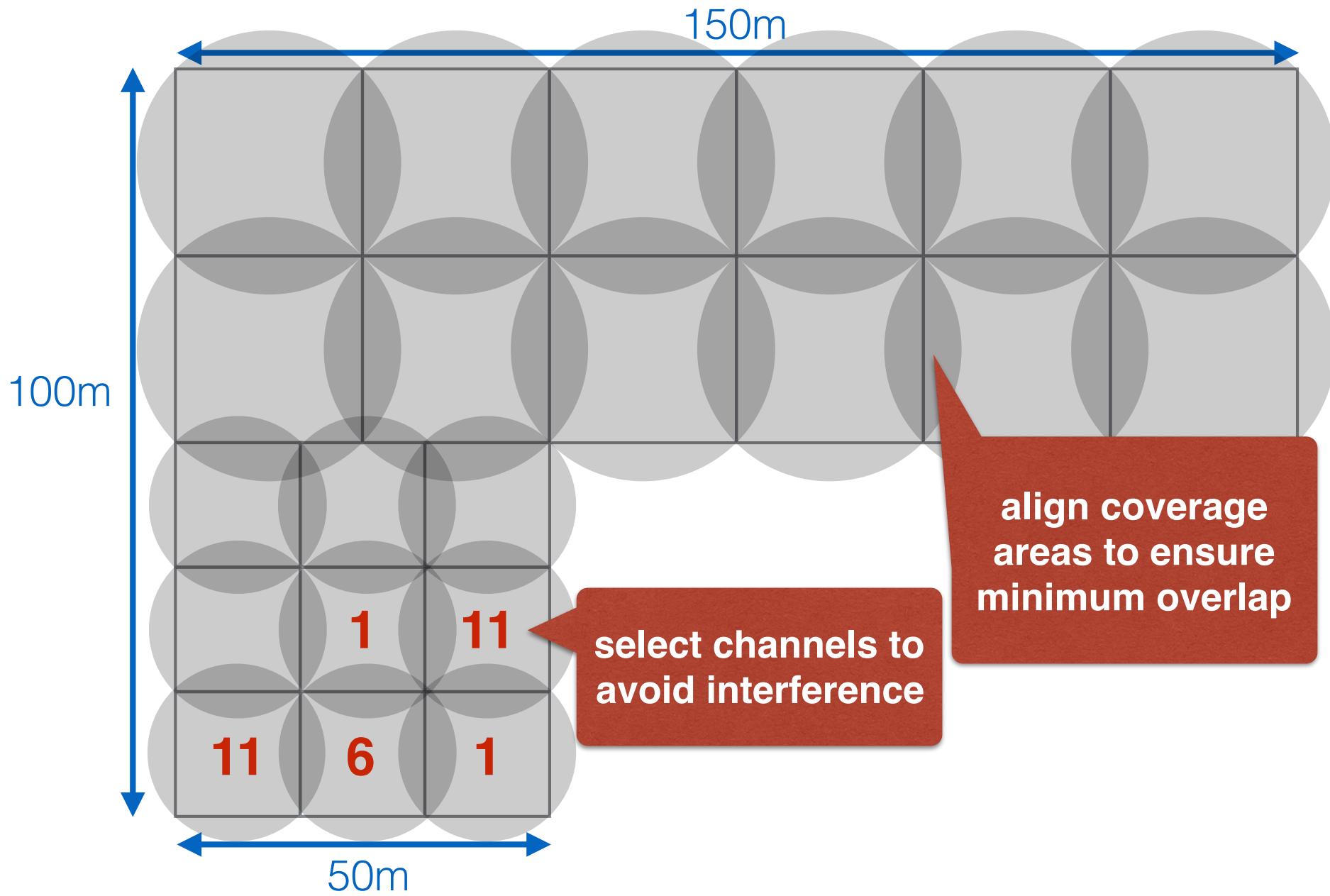
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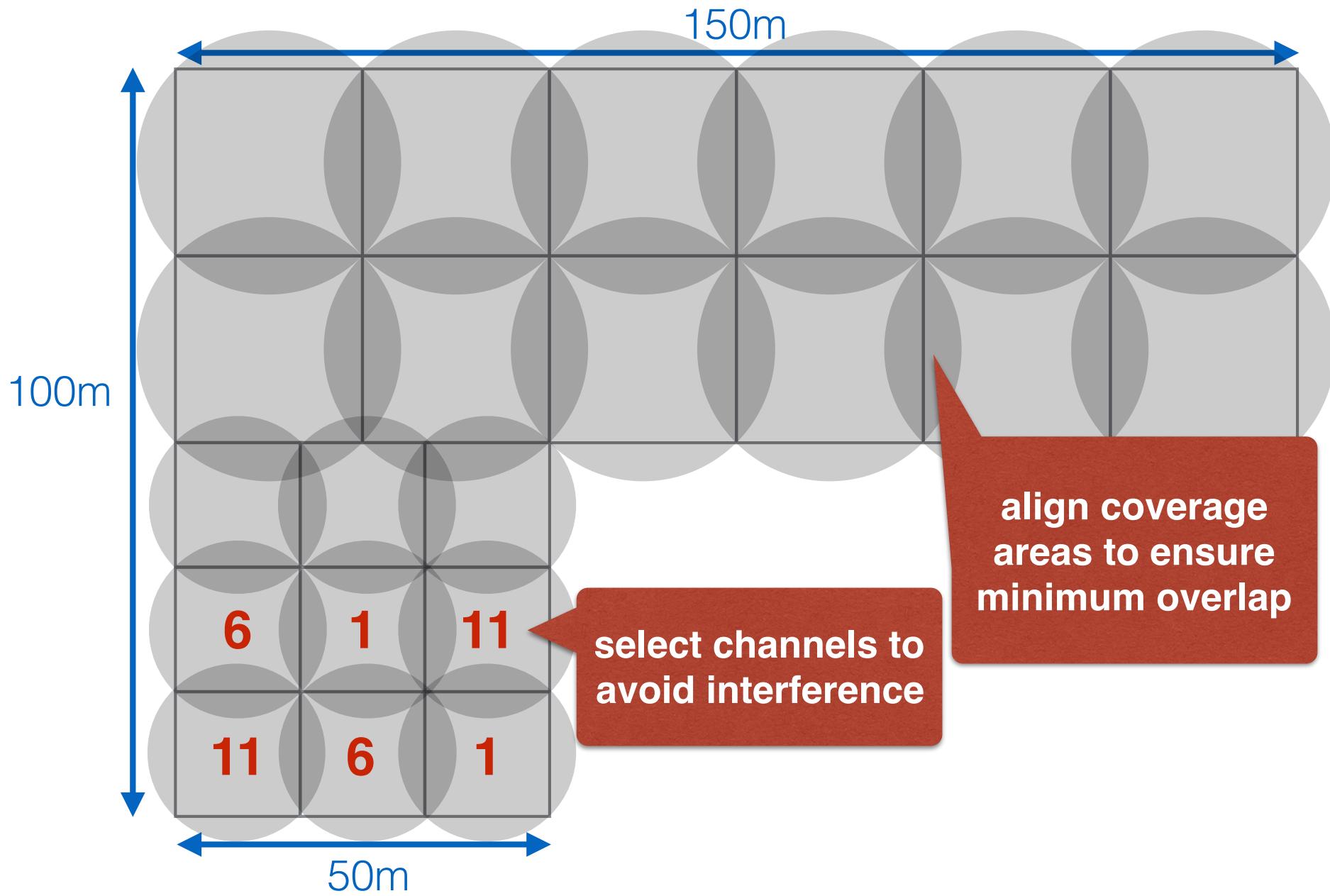
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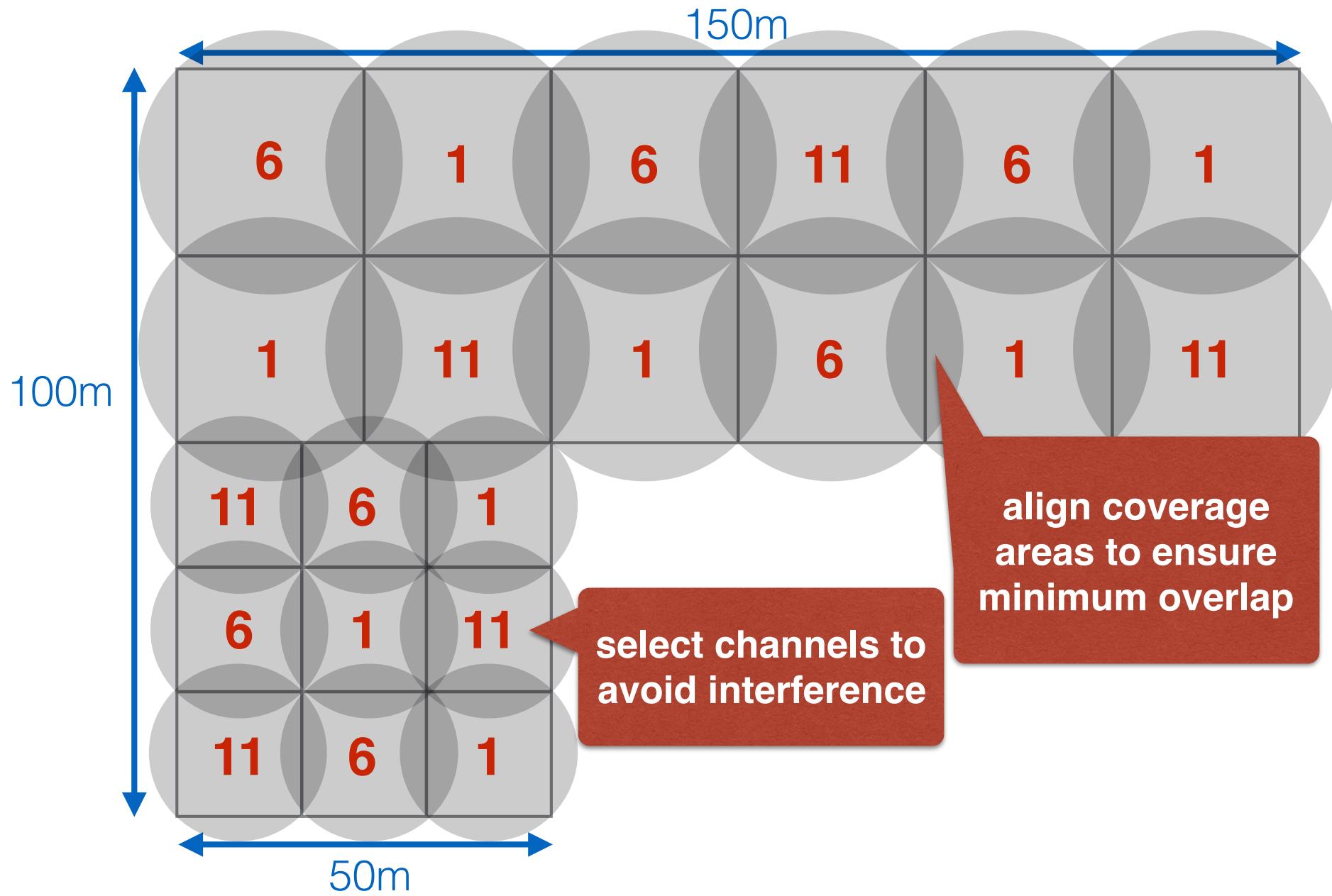
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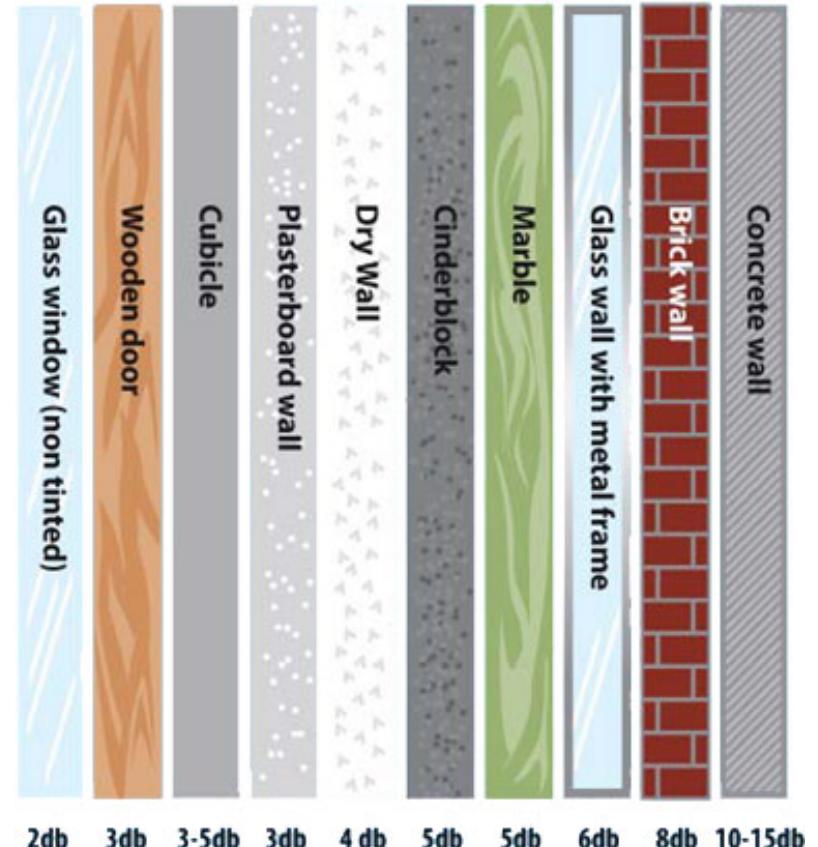
Planning Example



Attenuation

Walls can introduce significant attenuation.

- 3db means signal strength halves
- 6db means 1/4
- these values are for 2.4GHz, attenuation is even higher in 5GHz



Source: <http://www.liveport.com/wifi-signal-attenuation>

Summary

Physical layer:

- Media: copper cables, optical fibres or radio waves
- modulate digital data onto digital or analog signals

Data link layer:

- Media access control (CSMA/CD and CSMA/CA)
- Ethernet as the dominant LAN technology
- Wireless LANs