CSCI-1680

Building Links and (Local) Networks

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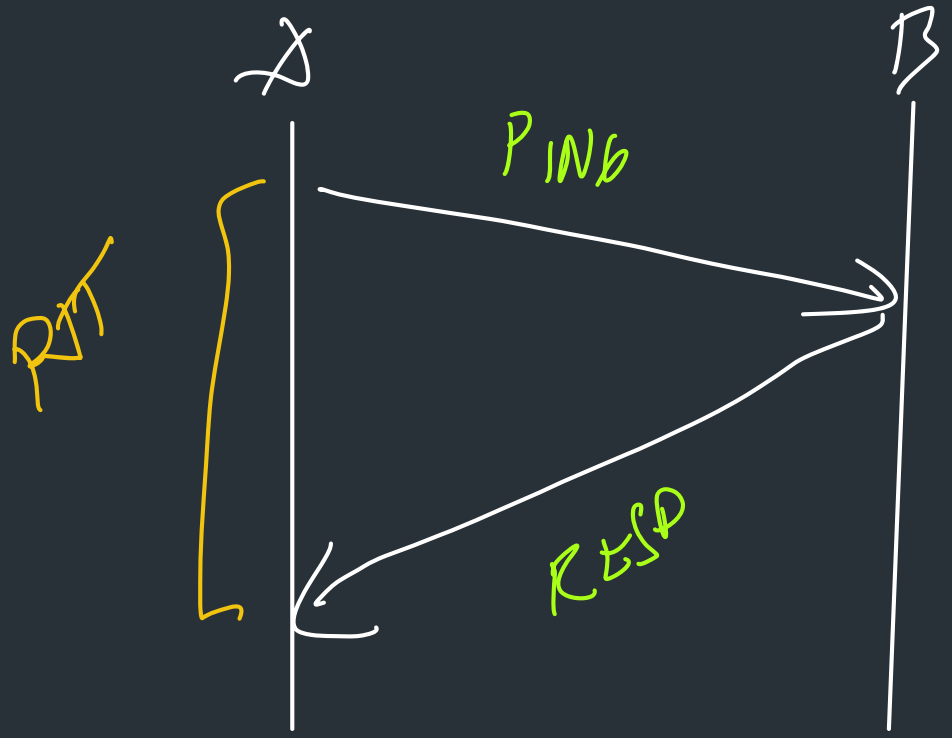
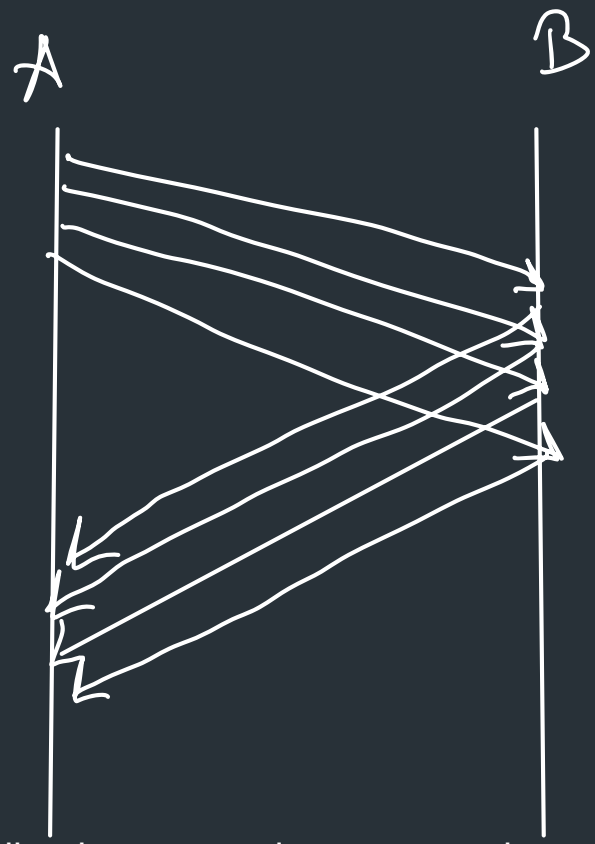
Based partly on lecture notes by Rodrigo Fonseca, David Mazières, Phil Levis, John Jannotti

Administrivia

- Snowcast due Tuesday (9/24) by 11:59pm EDT
- Look for announcement on Gradescope/testing soon
  - See our FAQ post for testing resources & common issues!

Last time: RTT vs. Throughput





For some applications, more important to have high *throughput*--using as much of the channel as possible (eg. file transfer)

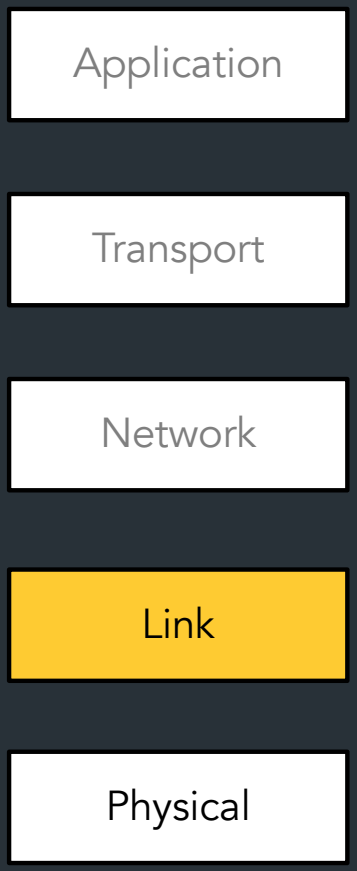
Today

Last time: how to send over a link

Today: how to build *small* network?

- How to share a link
- Case study/fundamental terms: Ethernet (and Wifi)
- How switching works

What does “link layer” mean?



Service: user-facing application.
Application-defined messages

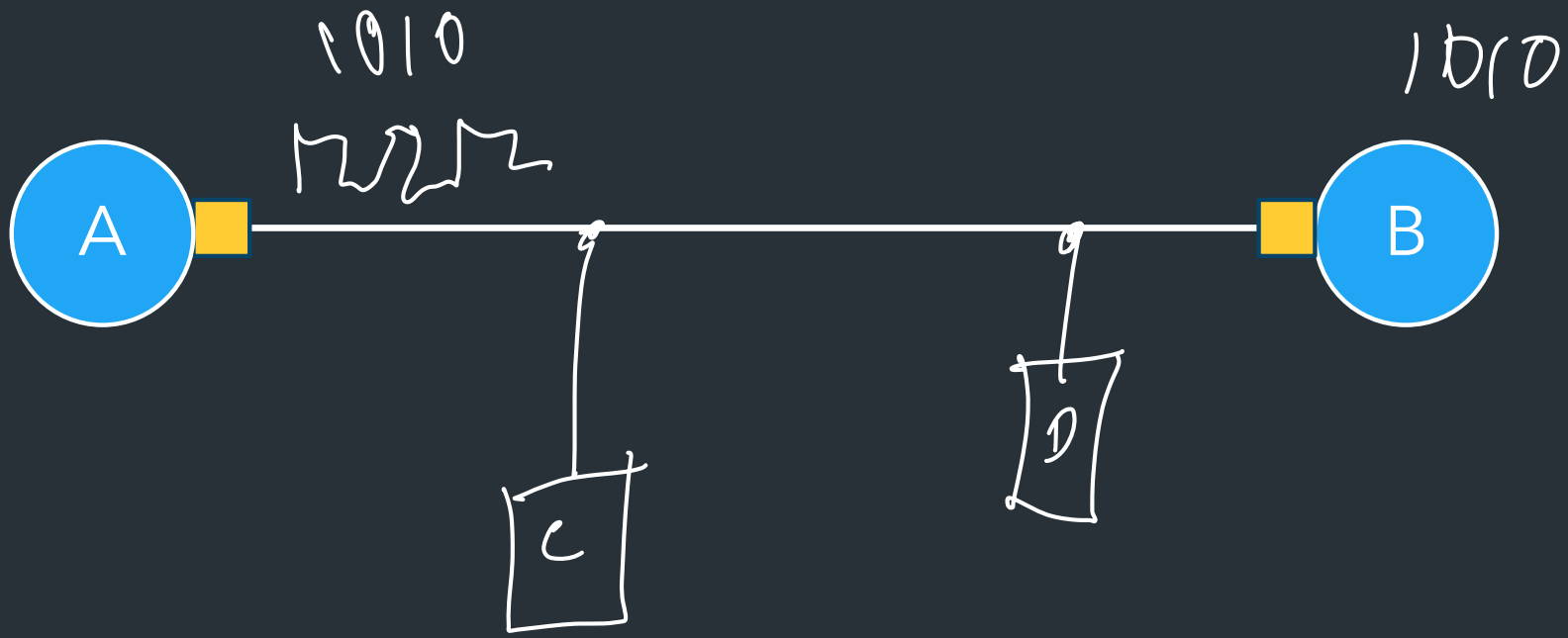
Service: multiplexing applications
Reliable byte stream to other node (TCP),
Unreliable datagram (UDP)

Service: move packets to any other node in the network
Internet Protocol (IP)

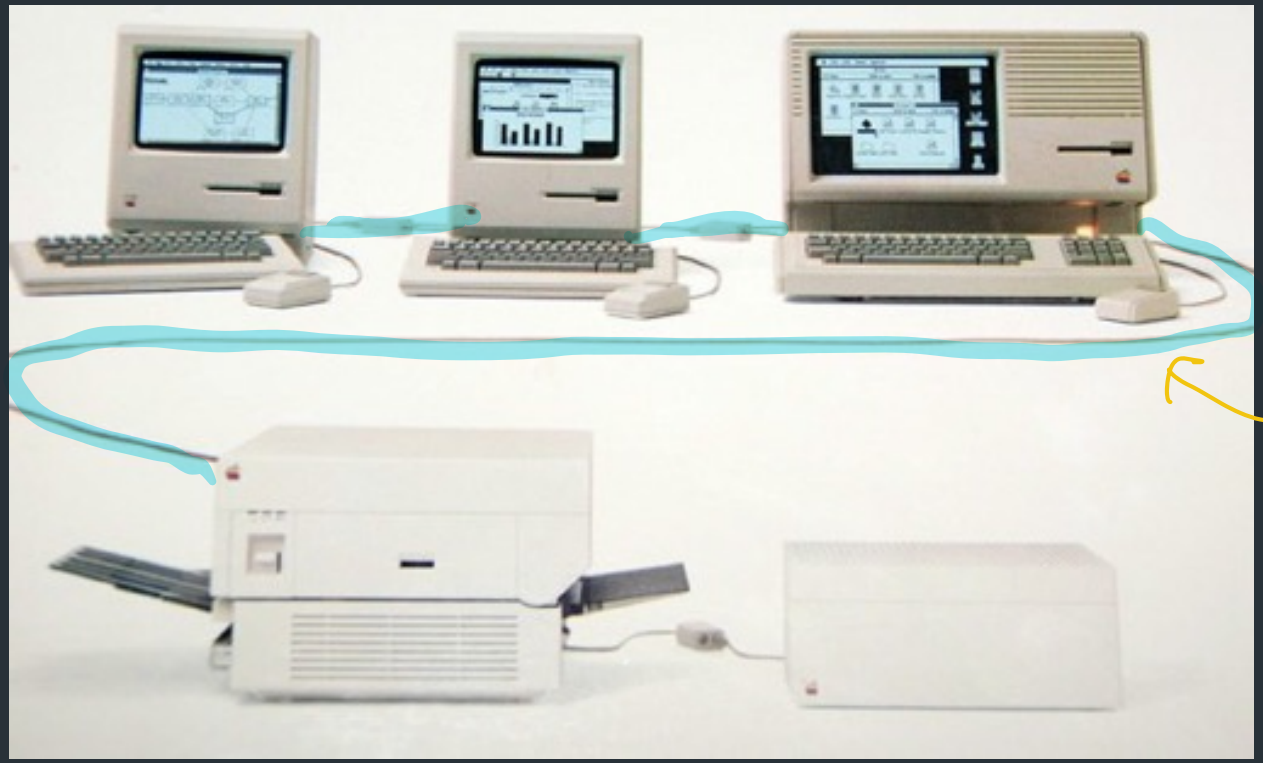
Service: move frames to other node across link.
May add reliability, medium access control

Service: move bits to other node across link

The main idea



Setting the scene

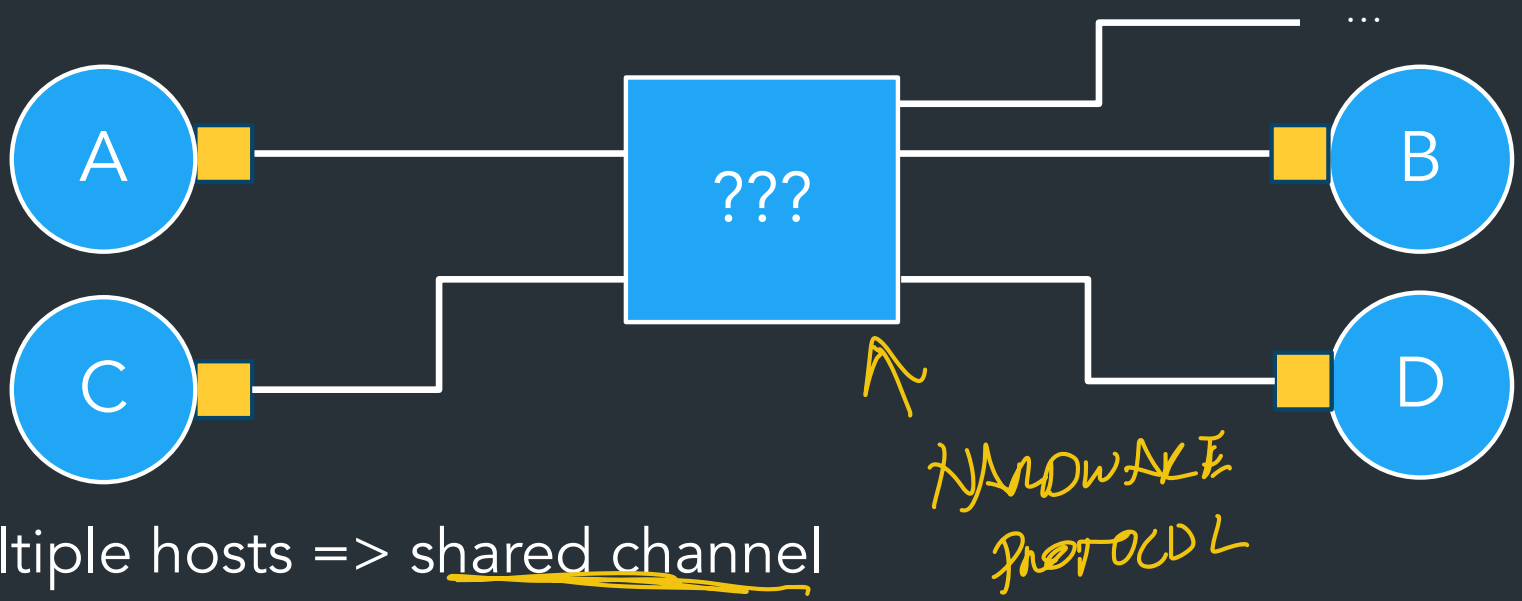


An AppleTalk network (1980s)

"Small" => Within a building, floor of office, etc

Related term: Local Area Network (LAN)

What does “link layer” mean?



- Multiple hosts => shared channel
- Need ways to allow “small” number of hosts to communicate

How to share the channel?

=> Media access control: mechanism/protocol to share the channel

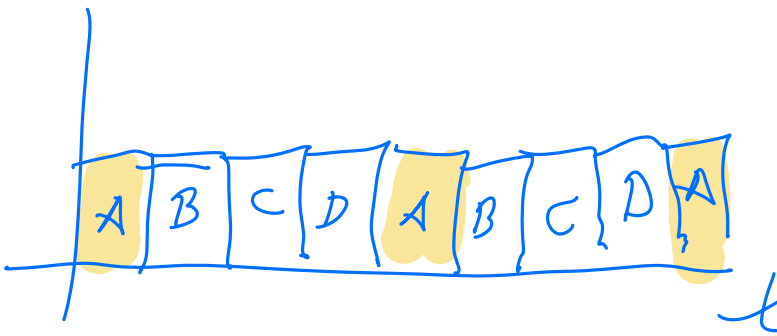
MAC strategies (the gist)

Idea: no more than one device can be "Talking" at a time
Protocol: "who can talk when?"

Two main types

1. **Partitioned access**: divide up the channel into fixed "slots"
eg. Time slices, small ranges of frequencies, ...

=> Fair to all hosts, but not efficient, doesn't have high utilization unless all hosts are using channel



2. Random access
=> No fixed slots, but some way to mediate multiple hosts talking

=> CSMA/CD

- 'Listen' for when other devices are talking, and wait for channel to be free
- "request to send" => send a tiny signal to ask to use the channel (usually a "leader")
- "Token-based"

=> Can achieve higher utilization, but not necessarily fair to all hosts (some ways to mitigate this)

High-level: MAC approaches

Partitioned Access: divide the channel into fixed slots

- Time Division Multiple Access (TDMA)
- Frequency Division Multiple Access (FDMA)
- …

Problems?

⇒ Hard to maximize channel *utilization*
(eg. what happens if only one person is talking?)

High-level: MAC approaches

Random Access: no fixed slots: "ask" to talk, or just talk and hope for the best

- Carrier Sense Multiple Access / Collision Detection (CSMA/CD)
- Carrier Sense Multiple Access / Collision Avoidance (CSMA/CA)
- RTS/CTS (Request to Send/Clear to Send)
- Token-based
- …

Problems?

⇒ Hard to maintain "fairness"
(eg. one host dominating channel)

Why does this matter?

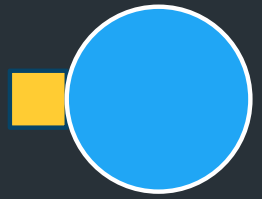
Different types of links solve these problems differently

- Ethernet (wired) vs. Wifi (wireless)
- Affects throughput, reliability, etc.

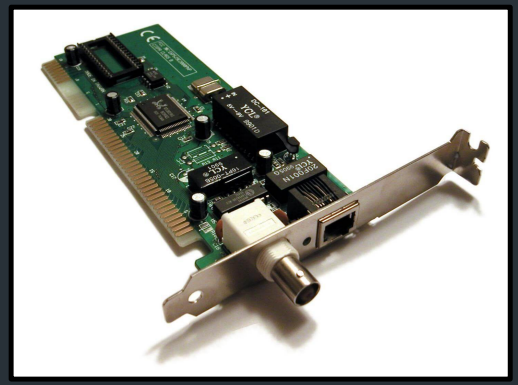
Understand why different links operate differently
=> How we build the Internet from them

How does a device use a link?

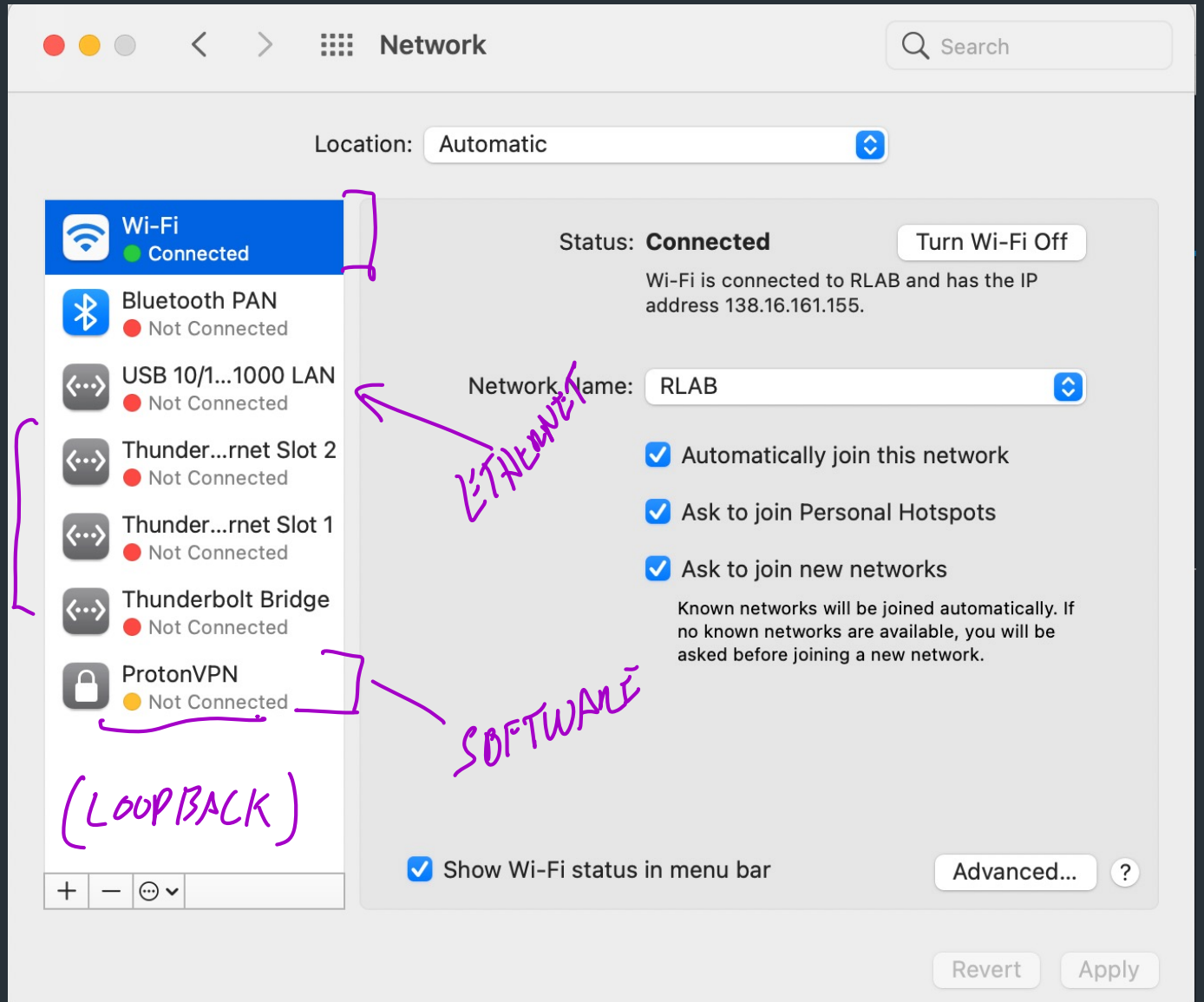
Interface: device that connects something to the network



=> OS abstraction for a link
=> Hardware in the interface actually "talks" on the channel
    => Network Interface Card (NIC)

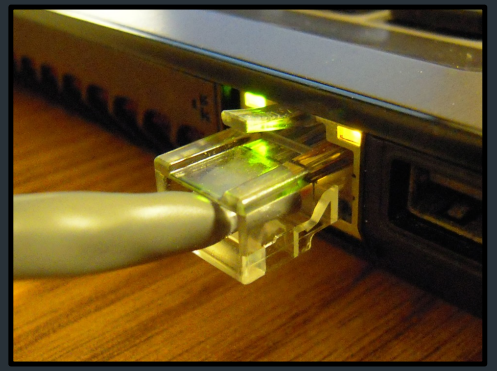


Examples:
- Loopback interface (lo): Virtual interface, for localhost
- Physical: Wifi, ethernet, bluetooth, etc.


Network
Search
Location: Automatic
Wi-Fi
Connected
Bluetooth PAN
Not Connected
USB 10/1...1000 LAN
Not Connected
Thunder...rnet Slot 2
Not Connected
Thunder...rnet Slot 1
Not Connected
Thunderbolt Bridge
Not Connected
ProtonVPN
Not Connected
(LOOPBACK)
ETHERNET
SOFTWARE
Status: Connected
Turn Wi-Fi Off
Wi-Fi is connected to RLAB and has the IP address 138.16.161.155.
Network Name: RLAB
Automatically join this network
Ask to join Personal Hotspots
Ask to join new networks
Known networks will be joined automatically. If no known networks are available, you will be asked before joining a new network.
Show Wi-Fi status in menu bar
Advanced...
?
Revert
Apply

Example: Ethernet

Ethernet



Dominant wired LAN technology, has evolved significantly over time

- Original version (1983): 10Mbps
- Now (commonly): 1Gbps
- Also: 10Gbps, 40Gbps, …

New developments in physical media, encodings, hardware => higher speeds over time

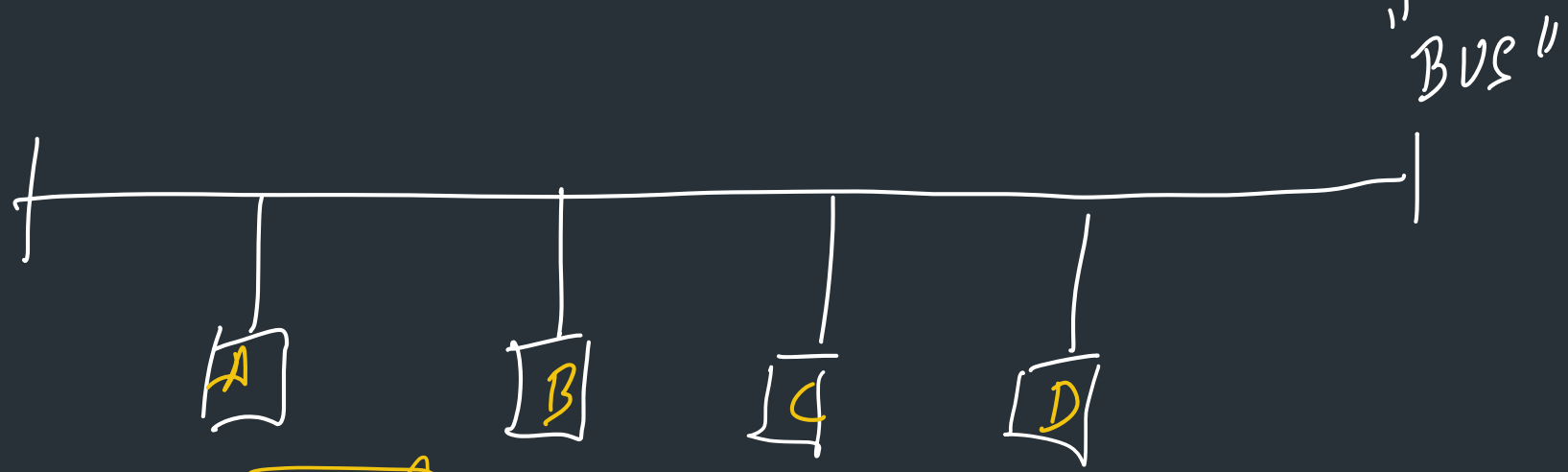
Ethernet: software viewpoint

- Logically all hosts are connected to each other

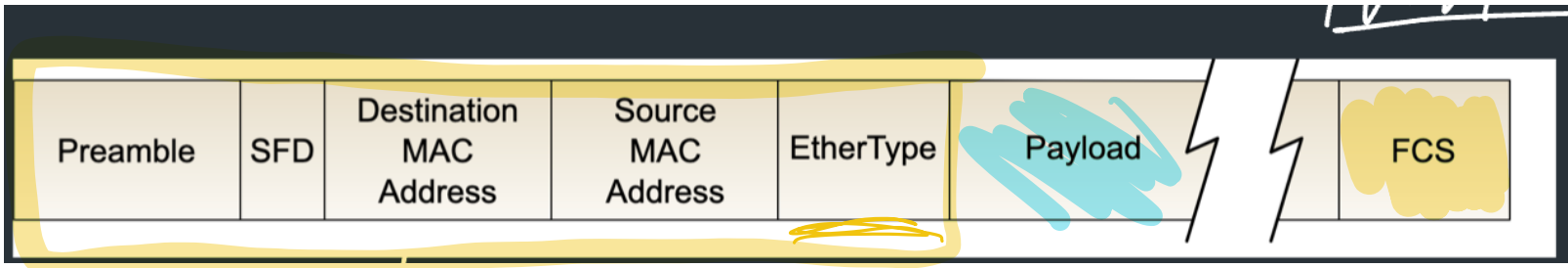
- All hosts have an "ethernet address" ("mac address")
  => Globally-unique identifier

- If you know a host's ethernet address, you can send to it

Ethernet: Historical version



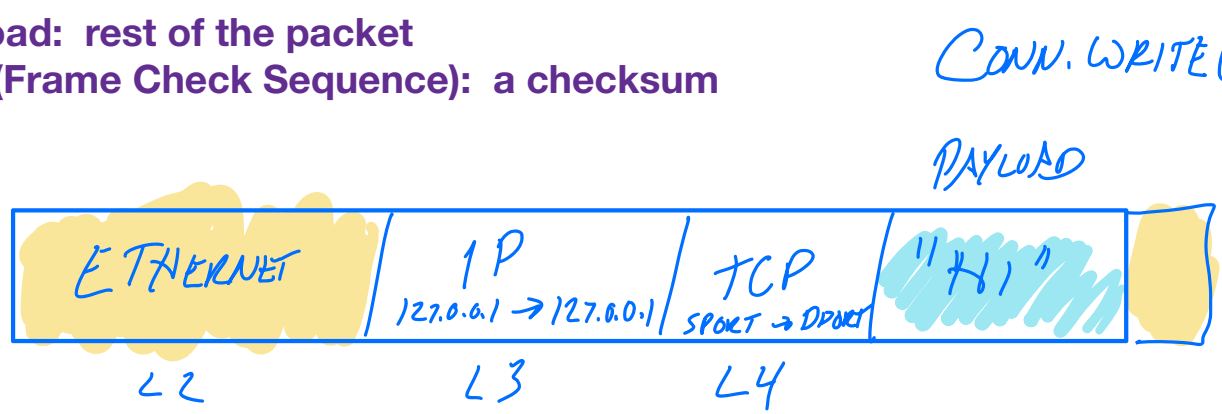
Every host has an address => Every host is connected to every other host"
When you want to send, send packet on bus
Every host can see signals on the wire — PROBLEM? YUP.
If you see a packet for your address, process packet, otherwise ignore



Destination address: where packet is going
Source address: where packet is coming from

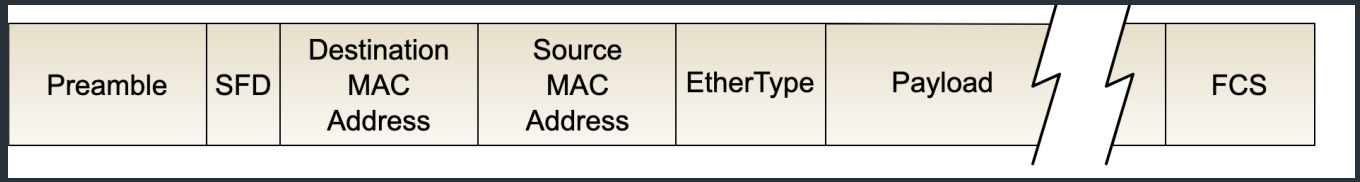
EtherType: type of data that's in the payload

Payload: rest of the packet
FCS (Frame Check Sequence): a checksum



What's a checksum? Helps check for errors
- Sender compute small value, like hash of packet => send this with the packet
- Receiver hashes packet on arrival. If receiver's hash != hash in packet, message was corrupted in transit

Ethernet: the header

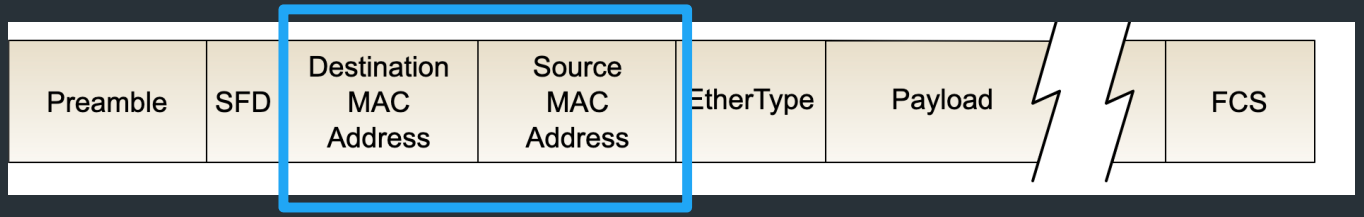


- Source address: where packet is from
- Destination address: where packet is going
  - ⇒ Devices ask: "Is this my packet?" "Where should I send this packet?"

Other stuff

- Preamble: when a packet starts
- FCS: Frame Check sequence (checksum)

Ethernet Addresses (mac addresses)



Globally unique, 48-bit address per interface

00:1c:43:00:3d:09 (Samsung adapter)

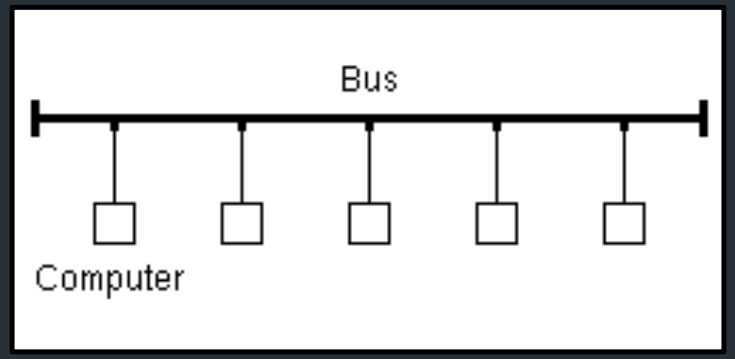
First 24 bits: Registered to manufacturers

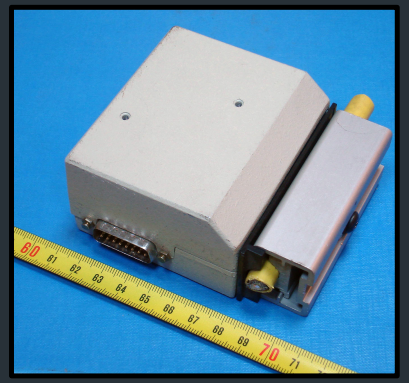
=> Other protocols have adopted this address format (eg. Wifi, Bluetooth, …)

=> Nowadays, we call them “mac addresses” or “hardware addresses”

Ethernet's evolution

Originally, a shared medium with all hosts





- Basic idea: all hosts can see all frames, read a frame if it matches your hardware address
- Implications?

RANDOM ACCESS

=>Can have collisons!

Classical Ethernet: Problems

Problem: all hosts in the same "collision domain"

=> All hosts could cause collisions with all others

Transmit algorithm

- If line is idle, transmit immediately
- Max message size: 1500 bytes
- If line is busy: wait until idle and transmit immediately

"Wait until idle" => wait for some time t, if line is busy after t, wait 2*t, keep increasing exponentially until time out

=> Exponential backoff

"Delay and try again later"

Sketch: In Ethernet

- *n*th time: $k \times 51.2\mu s$, for $k = U\{0..(2^{\min(n,10)}-1)\}$
  - 1st time: 0 or 51.2μs
  - 2nd time: 0, 51.2, 102.4, or 153.6μs
- Give up after several times (usually 16)

=> Exponential backoff: a useful, general technique

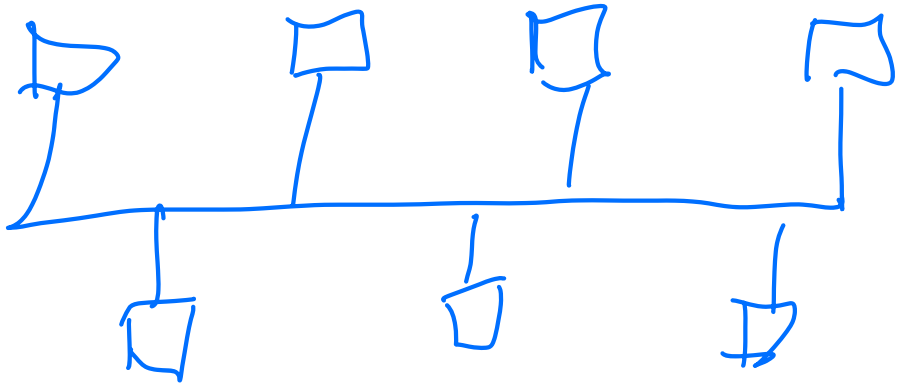
Does this scale?

Ethernet Recap

- Service provided: send frames among stations with specific addresses
- All nodes in the same “collision domain”

EARLY ETHERNET:

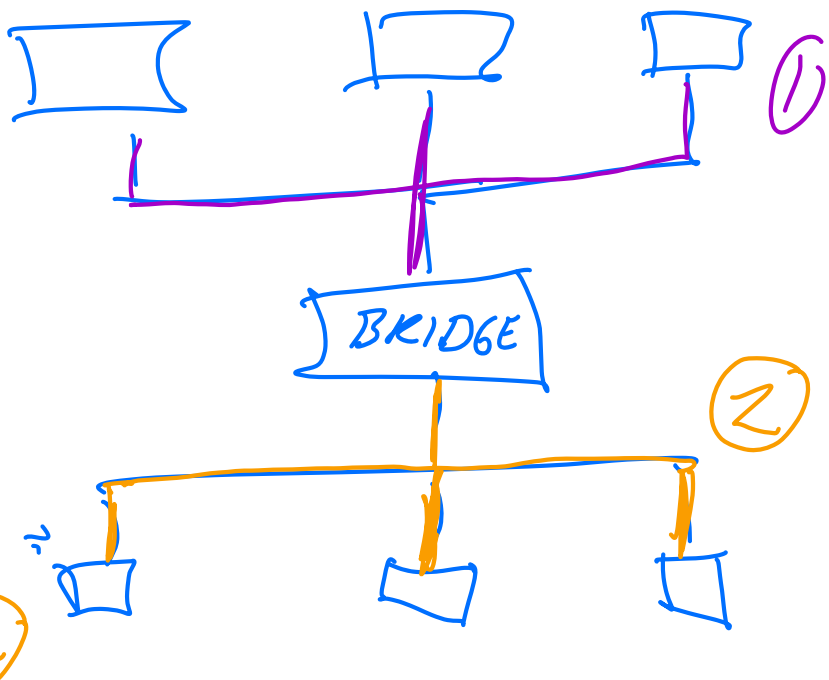
ALL HOSTS ON SAME COLLISION DOMAIN



DOESN'T SCALE

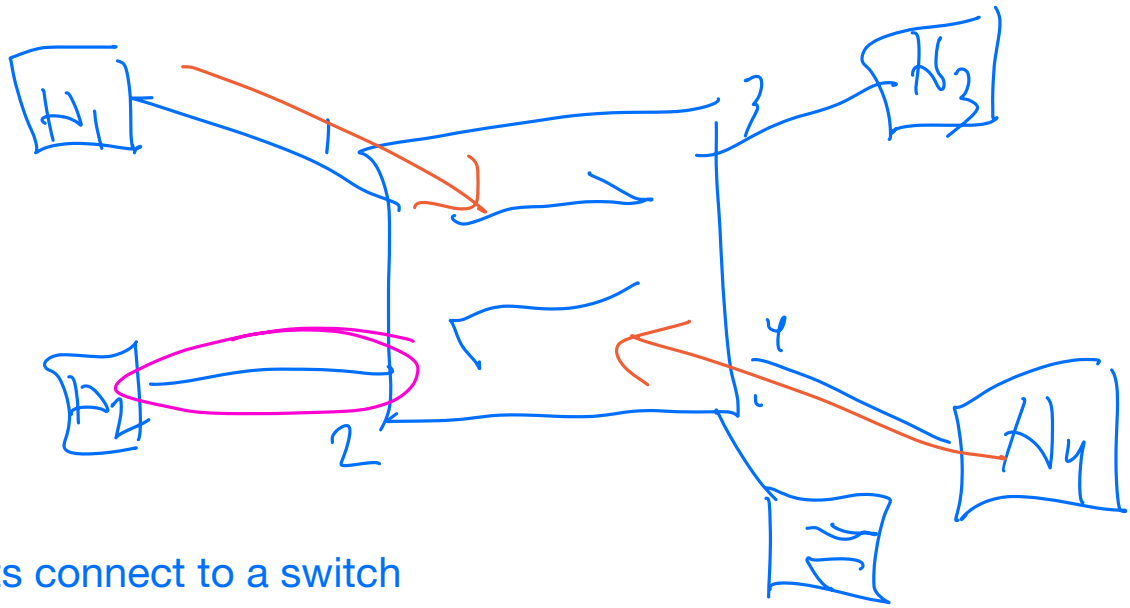
- WANT ABILITY TO SEPARATE COLLISION DOMAIN WHILE STILL BEING ABLE TO TALK TO EVERYONE.

EARLY WAY: BRIDGES
- CONNECT TWO NETWORKS
- ONLY FORWARD BETWEEN ① ↔ ② IF NECESSARY



HERE: ONE LAN, 2 COLLISION DOMAINS ① ②

Modern way: an Ethernet switch

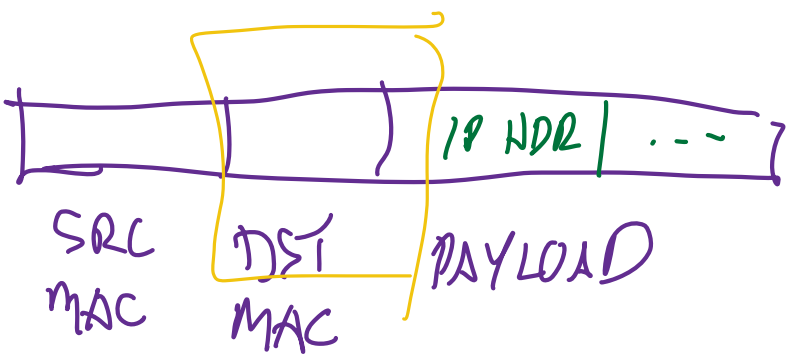


All hosts connect to a switch
Collision domain is just the host-switch link

=> In modern times, both sides of one link can transmit/receive at the same time (full duplex)
=> Really hard to have a collision

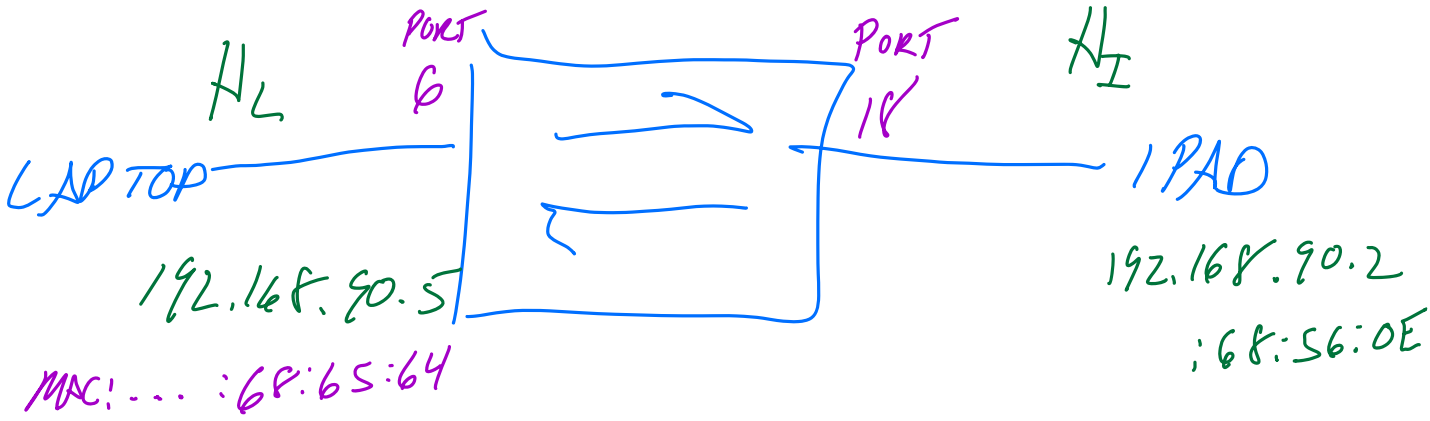
Switch receives frames, looks at destination address
- Decides which port to send packet to
- Queue up packets until the destination port is idle

=> Lots of engineering involved in how to design a switch to do this quickly, queue efficiently



MAC learning: as packets are sent, switch builds a table of mac addresses it has seen before, remembers the port used

(More info in next couple of pages)



MAC	PORT
LAPTOP	6
IPAD	18

Switch "learns" which host is on which port

Switch has table: <mac address, port>

Fills the table based on packets that it sees
=> Source address on packet tells it what to put in table

When switch doesn't know what to do, it sends packets to all ports ("flood")

If there's an entry in the table, switch can send packet to only the port associated with that host

Modern way: switching

Switch: network device that forwards frames (packets) between *ports*

- All hosts connect to a switch
- Collision domain is host-switch
- Switch buffers packets, forwards to destination when its port is idle

How to know which devices is on which port?

MAC Learning

- Switches "learn" which host lives on which port by watching traffic
- If you don't know, flood to all ports!

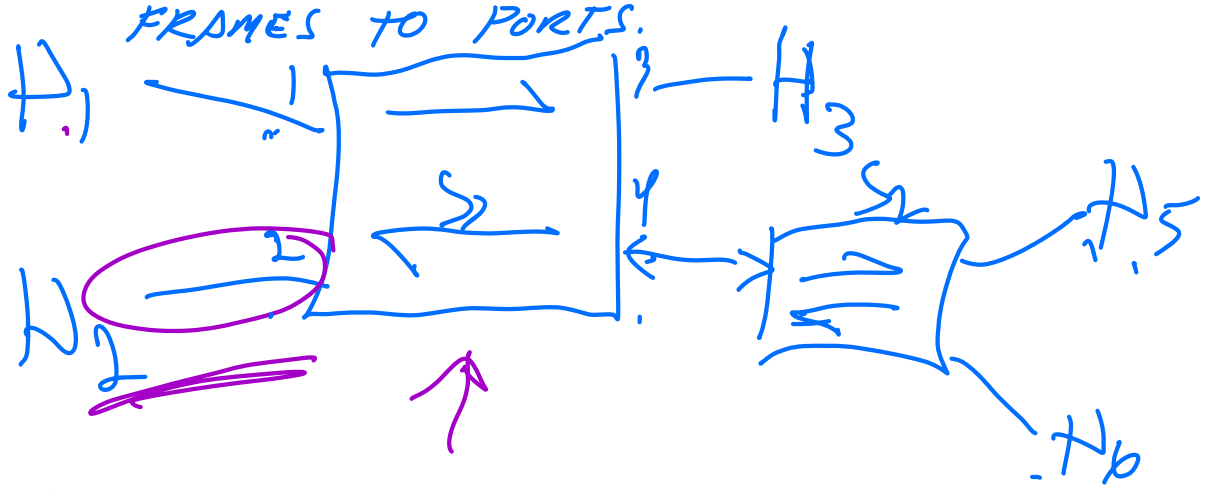
SOME SECURITY PROBLEMS
– CAN "SPOOF" (FORGE) ADDRESS
– CAN FILL TABLE.

REALLY JUST A CACHE!

MAC learning is just an optimization vs. old version
(but a pretty good one…)

MODERN ETHERNET: SWITCHES

SWITCH: NETWORK DEVICE THAT FORWARDS FRAMES TO PORTS.



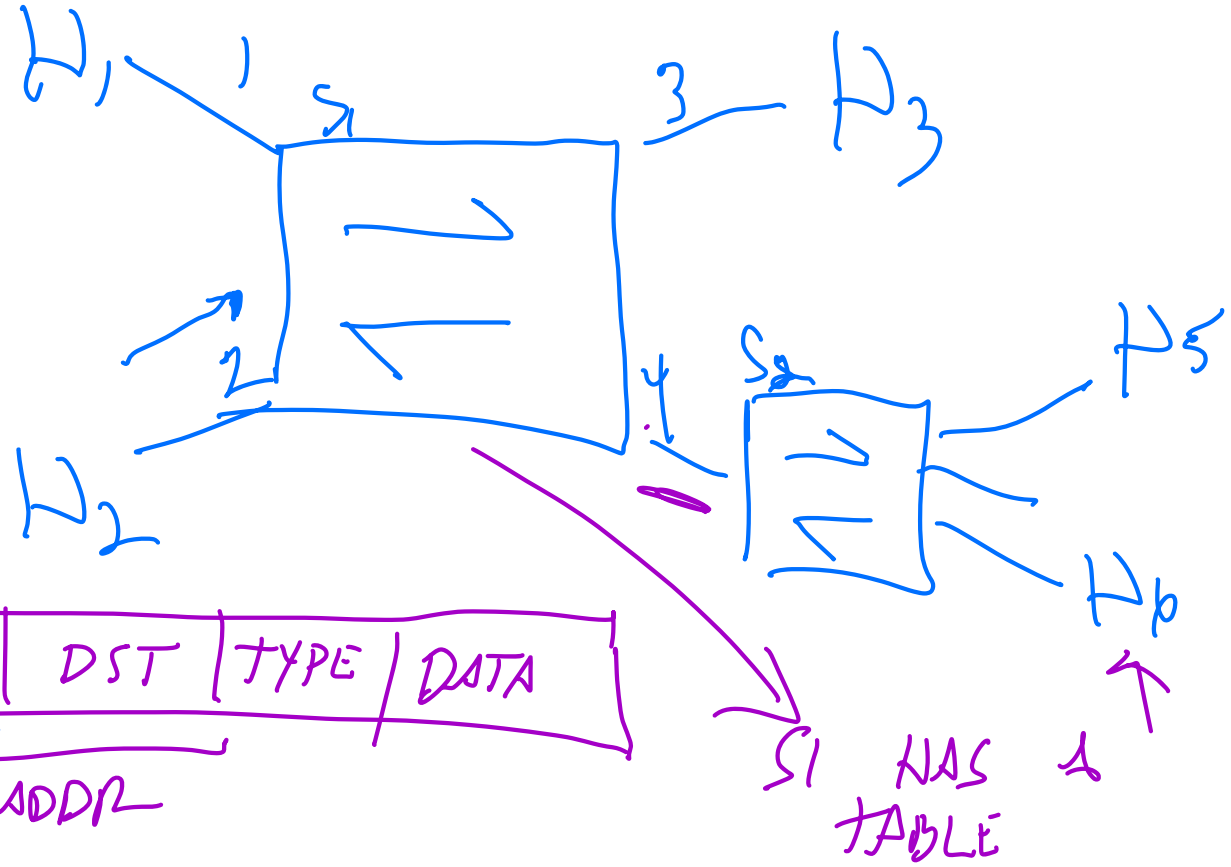
- ALL HOSTS CONNECT TO A SWITCH

- COLLISION DOMAIN IS JUST THE LINK OF HOST – SWITCH.
  - IN MODERN TIMES, BOTH SIDES OF A LINK CAN TRANSMIT AT SAME TIME.
  - SWITCH CAN STORE FRAMES + ONLY FORWARD TO A PORT WHEN IT'S IDLE.
    ⇒ REALLY HARD TO HAVE A COLLISION

- SWITCH RECEIVES FRAME, LOOKS AT DEST ADDRESS, DECIDES WHICH PORT ON WHICH TO SEND FRAME

"MAC LEARNING":
- SWITCHES "LEARN" WHICH HOST(S) LIVES ON WHICH PORT
  - IF DON'T KNOW, FLOOD TO ALL PORTS!
    ⇒ JUST AN OPTIMIZATION VS. OLD VERSION!

MAC LEARNING: NOW IT WORKS.



SRC	DST	TYPE	DATA

MAC ADDR

S1 HAS A TABLE

MAC ADDR →	PORT
H_2	2
H_5	4
H_6	4

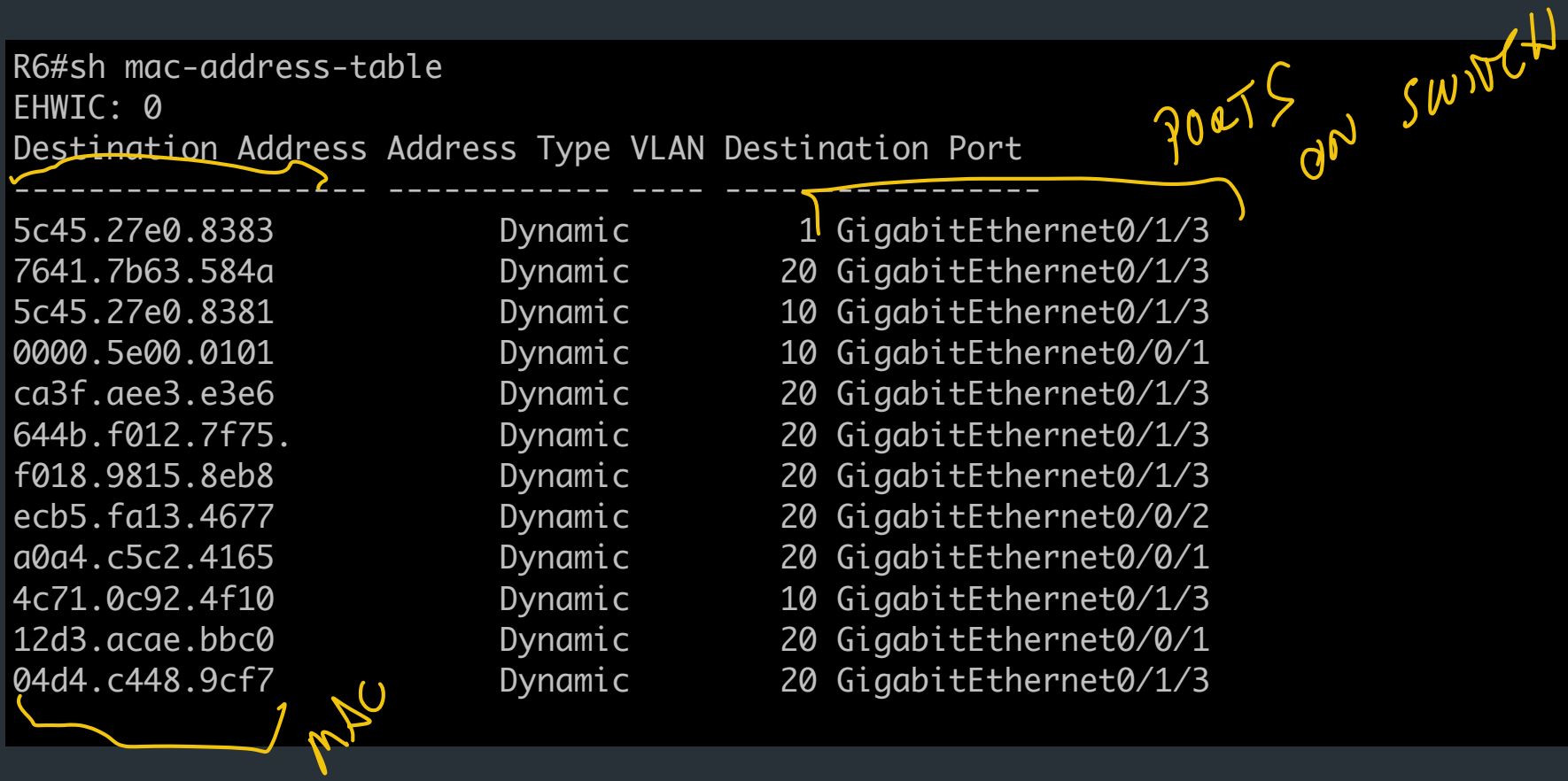
$H_2 \rightarrow H_3$ ON PORT 2

IF TABLE IS EMPTY
=> FLOOD

$H_5 \rightarrow H_2 \Rightarrow$ SEND TO PORT 2

MAC table example

```
R6#sh mac-address-table
EHWIC: 0
Destination Address Address Type VLAN Destination Port
------------------- ------------ ---- --------------------
5c45.27e0.8383           Dynamic    1 GigabitEthernet0/1/3
7641.7b63.584a           Dynamic   20 GigabitEthernet0/1/3
5c45.27e0.8381           Dynamic   10 GigabitEthernet0/1/3
0000.5e00.0101           Dynamic   10 GigabitEthernet0/0/1
ca3f.aee3.e3e6           Dynamic   20 GigabitEthernet0/1/3
644b.f012.7f75.          Dynamic   20 GigabitEthernet0/1/3
f018.9815.8eb8           Dynamic   20 GigabitEthernet0/1/3
ecb5.fa13.4677           Dynamic   20 GigabitEthernet0/0/2
a0a4.c5c2.4165           Dynamic   20 GigabitEthernet0/0/1
4c71.0c92.4f10           Dynamic   10 GigabitEthernet0/1/3
12d3.acae.bbc0           Dynamic   20 GigabitEthernet0/0/1
04d4.c448.9cf7           Dynamic   20 GigabitEthernet0/1/3
```



What if you WANT to talk to multiple hosts?

This is still possible! Separating collision domains means we don't need to do this unless necessary.

There are special Ethernet addresses to reach multiple hosts
- Broadcast address: send to all hosts
- Multicast: send to a certain group of hosts

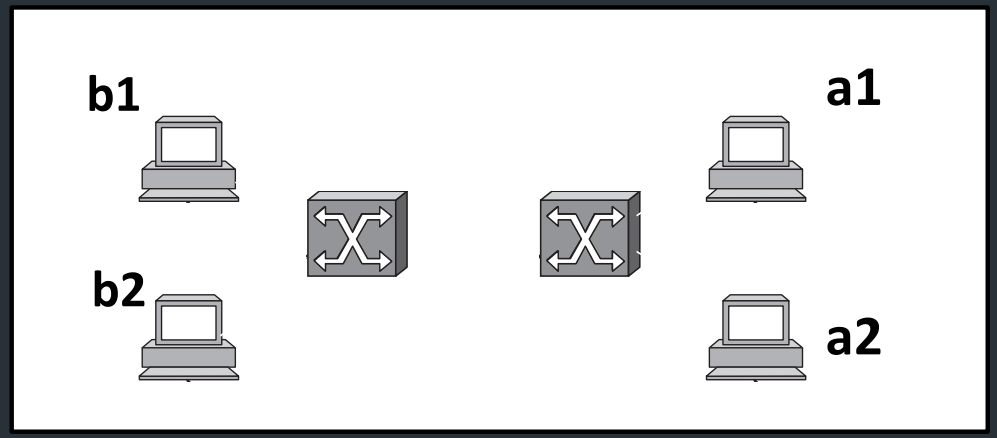
Attack on a Learning Switch

- Eve: wants to sniff all packets sent to Bob
- Same segment: easy (shared medium)
- Different segment on a learning bridge: hard
  - Once bridge learns Bob's port, stop broadcasting
- How can Eve force the bridge to keep broadcasting?
  - Flood the network with frames with spoofed src addr!

Also: VLANs

Consider: Company network, A and B departments

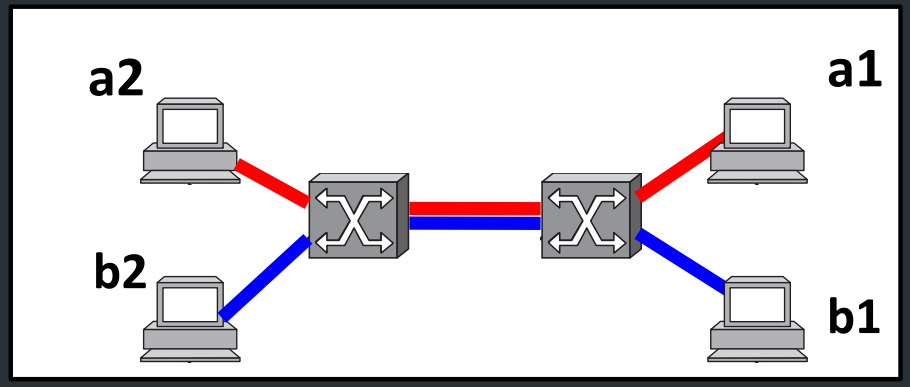
- Broadcast traffic does not scale
- May not *want* traffic between the two departments
- What if employees move between offices?



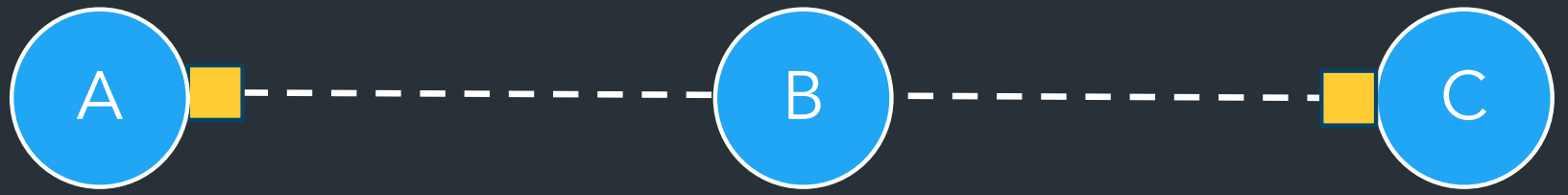
VLANs

- Solution: Virtual LANs
  - Assign switch ports to a VLAN ID (color)
  - Isolate traffic: only same color
  - Some links may belong to multiple VLANs

=> Easy to change, no need to rewire



How does this all change with wifi?



Can’t detect collisions anymore!

=> Carrier Sense Multiple Access / Collision Avoidance

=> Try to send: if you don’t hear back, assume collision (and maybe retry)