Introduction to Computer Networks

Computer Networks: a HW/SW Perspective

CS640

https://pages.cs.wisc.edu/~mgliu/CS640/S26/index.html

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Outline

- Last lecture
  - Course logistics
  - Computer network basics and design requirements
  - Intra-host v.s. Inter-host Communication
- Today
  - Computer networks: hardware infrastructure
  - Computer networks: software system
- Announcements
  - Lab1 will be released next week

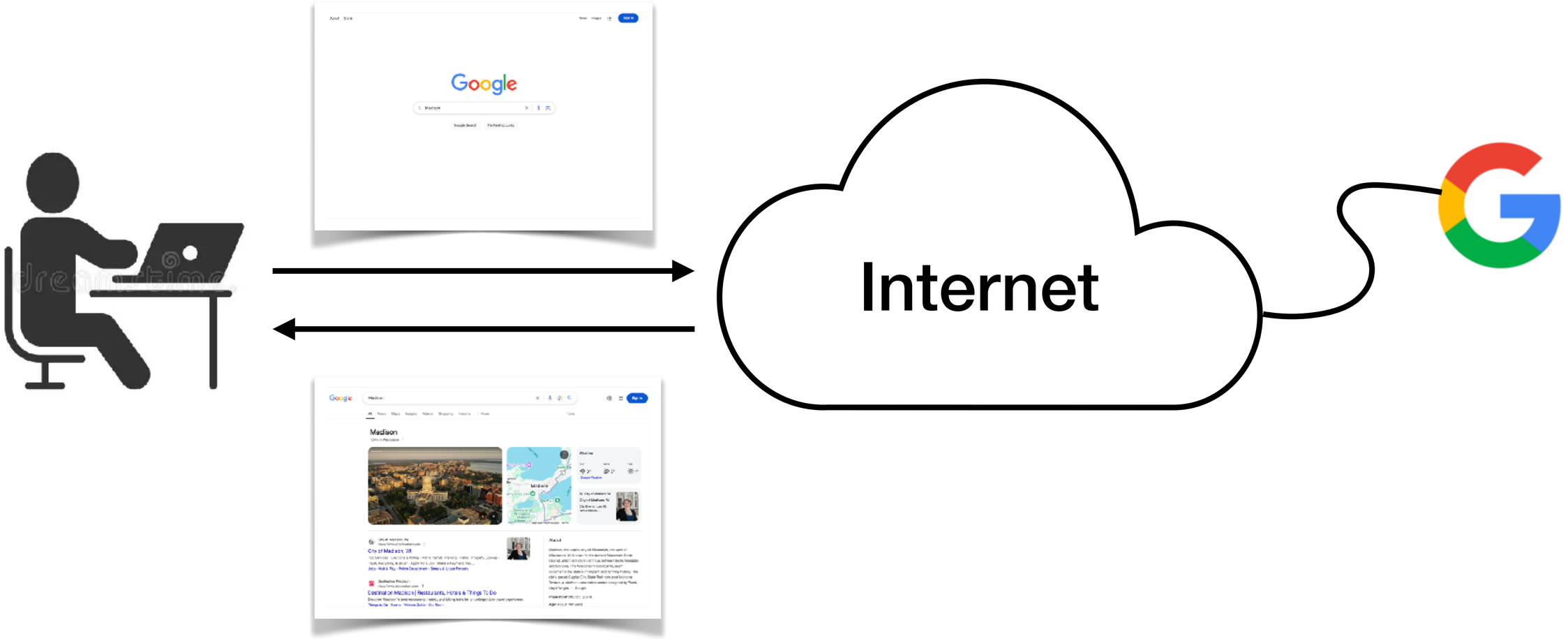
Recap

- Key Questions
  - What are computer networks?
  - What are the design requirements of computer networks?

- Terminology
  - (End)Host, Service, Communication Link
  - Router and Switch
  - Internet Service Provider (ISP)
  - Packet and Protocol

Networking Hardware @Host

- A host is a device that connects to the network
- A communication link is a physical media that carries data

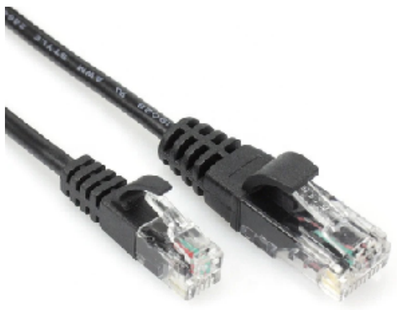


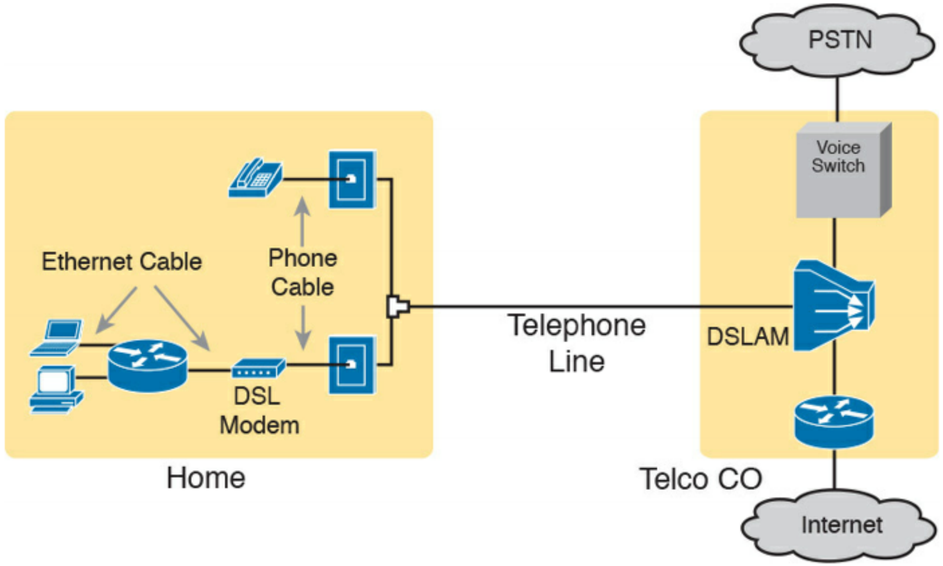
What are communication links exactly?

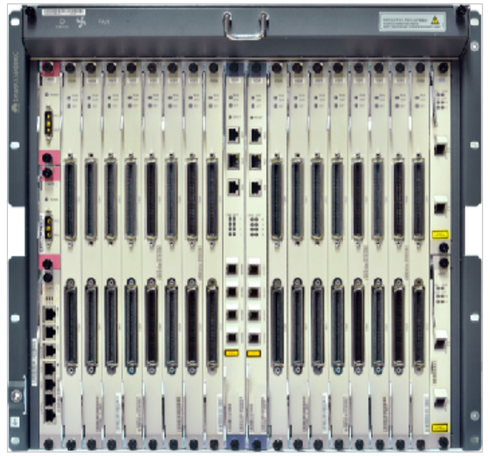
DSL @Home Network

- Digital subscriber line (DSL)
  - Local telephone company (telco) => Internet service provide (ISP)

- Digital subscriber line access multiplexer (DSLAM)
  - Locate at the cental office
  - Convert between digital data and analog signals







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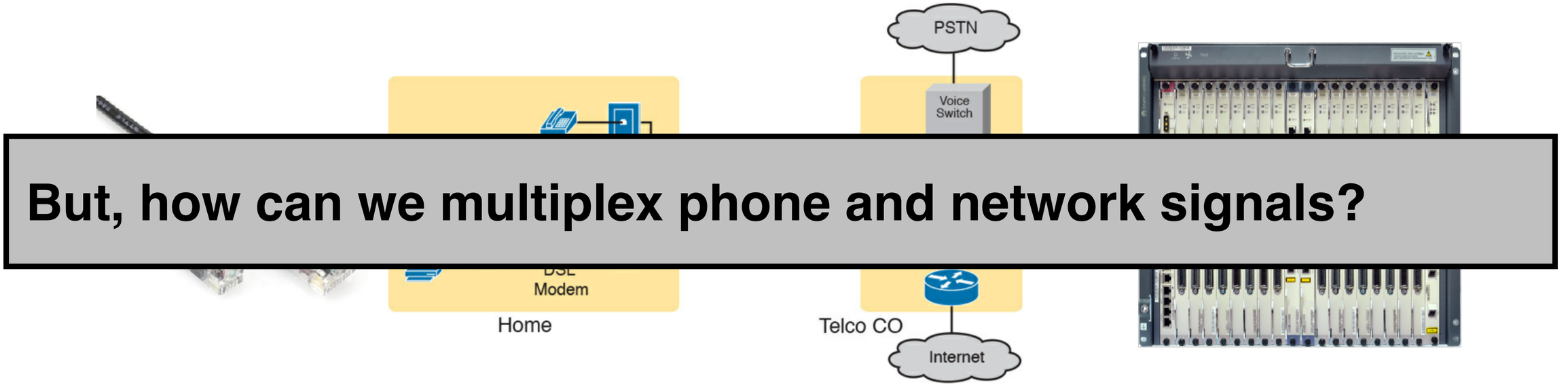


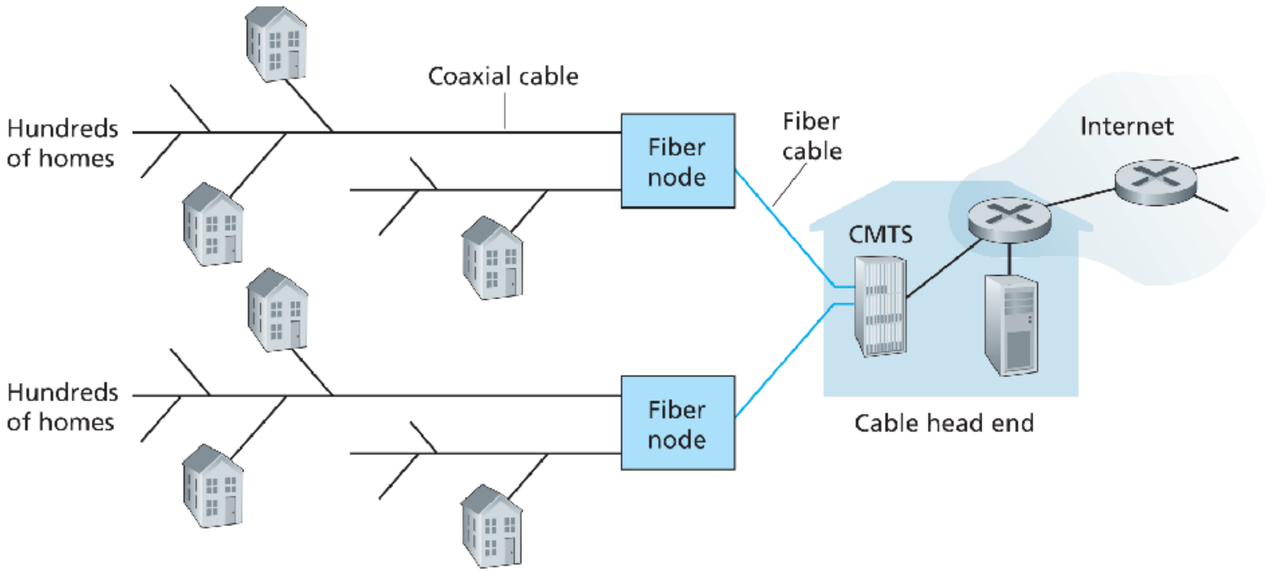
But, how can we multiplex phone and network signals?

Frequency-Division Multiplexing

- A splitter separates the signal
  - High-speed downstream channel: 50 kHz to 1MHz
  - Medium-speed upstream channel: 4 kHz to 50 kHz
  - Two-way telephone channel: 0 to 4 kHz
- Transmission rate
  - Mbps = Megabits per second
  - Downstream: 24Mbps and 52 Mbps
- Factors that affect the transmission rate
  - Distance, the degree of electrical interference, etc.

Cable @Home Network

- Coaxial cable
  - Television company => Internet service provide (ISP)
- Hybrid fiber coax (HFC)
  - A neighborhood junction supports 500-5000 homes
  - CMTS = Cable Modem Termination System



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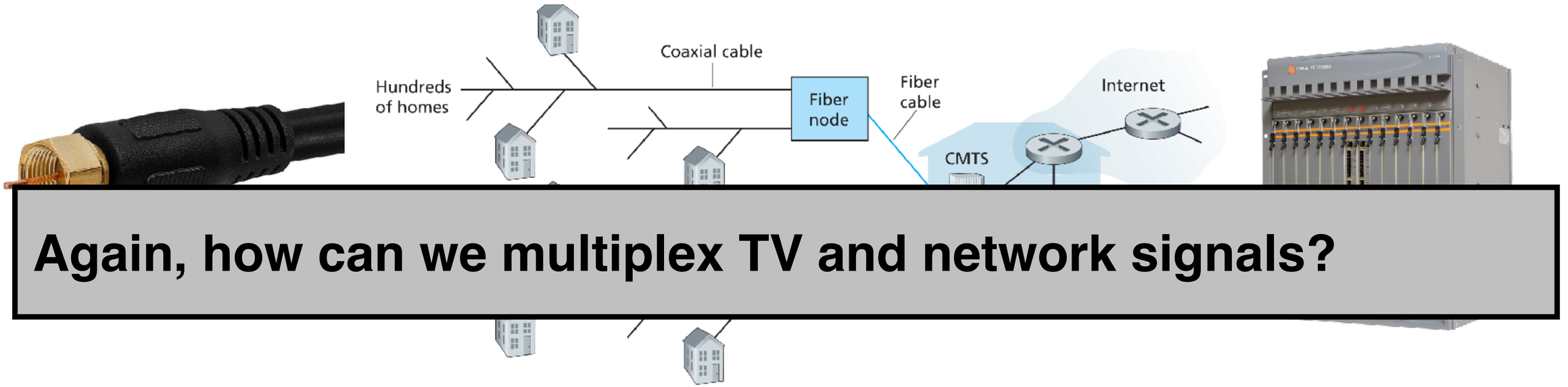


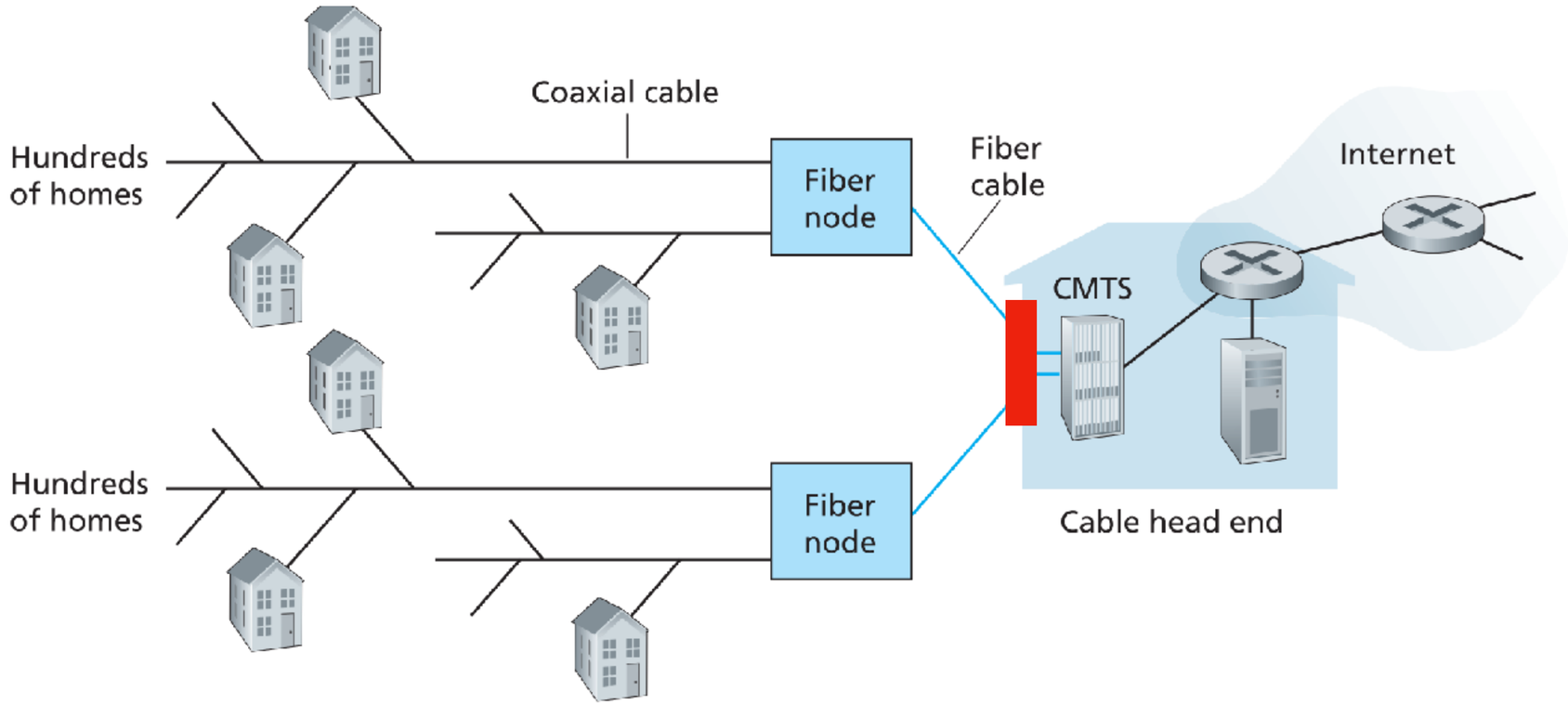
Again, how can we multiplex TV and network signals?

Cable Signal Multiplexing

- Frequency-Division Multiplexing
  - TV: 54MHz to 500 MHz
  - Network: 54MHz to 1GHz
  - Provision the channel with the frequency band
- Cable network has higher transmission rate than DSL
  - Downstream: 40 Mbps to 1.2 Gbps
  - Upstream: 30 Mbps to 100 Mbps
- Factors that affect the transmission rate
  - Media impairments, etc.

Cable: Shared Broadcast Medium

- Every packet from CMTS traverses every downlink
- Every packet from home traverses every uplink to CMTS



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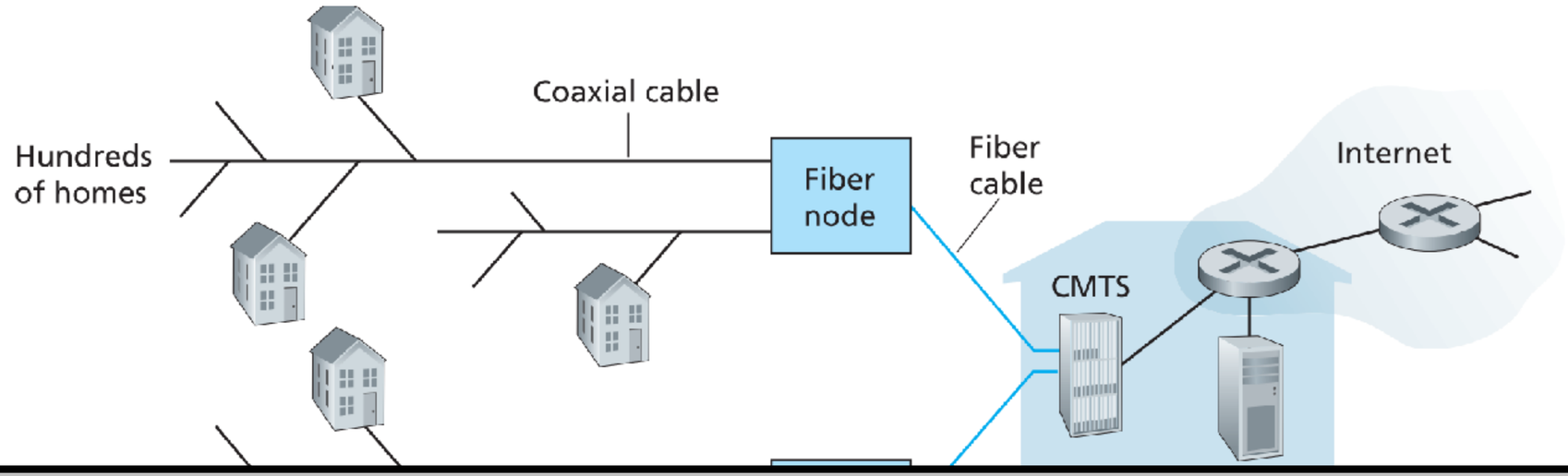

What is the downside?

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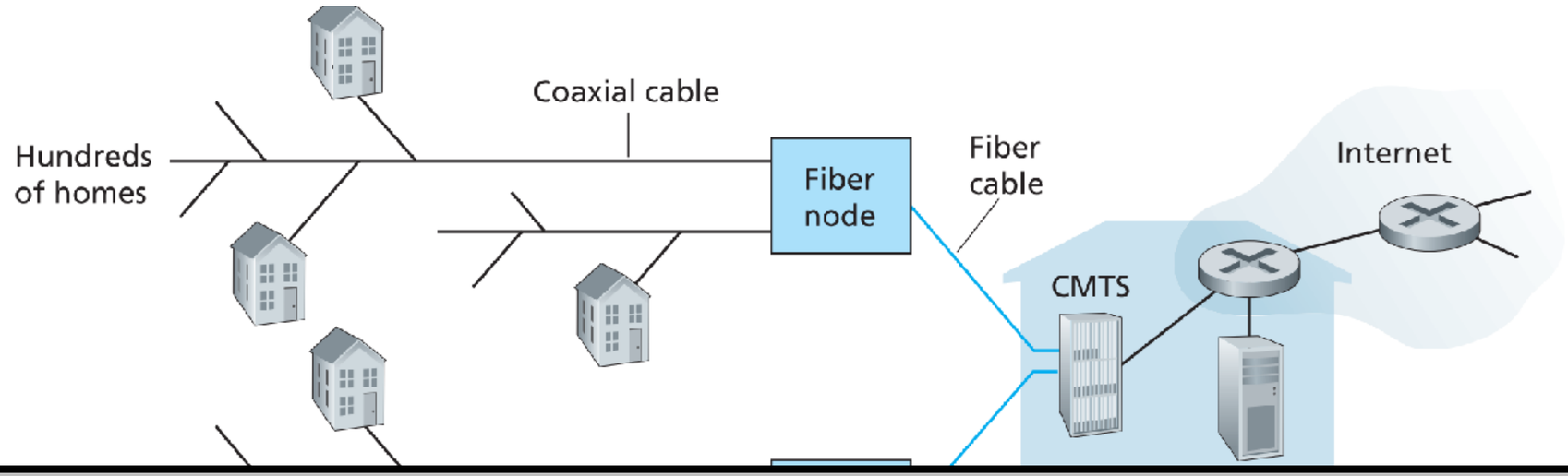
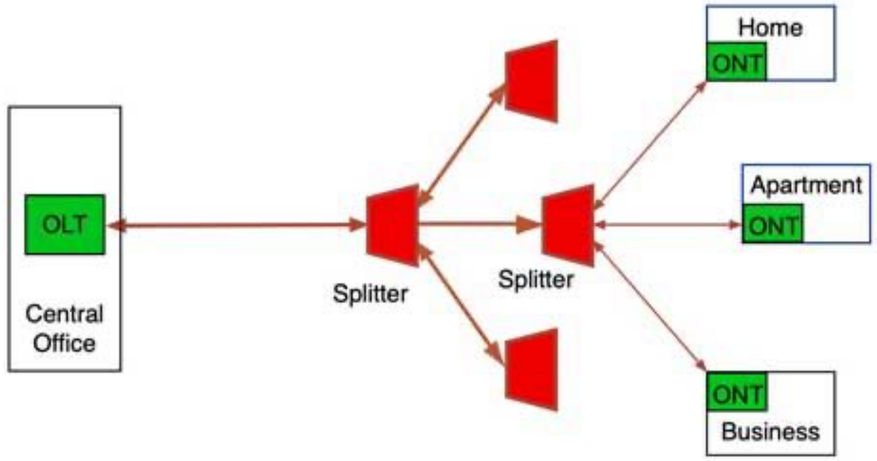


What is the downside?
Interference between concurrent downloads/uploads!

FTTH @Home Network

- FTTH = Fiber to the home
  - Active optical networks (AONs): long-range, e.g., 100km
  - Passive optical networks (PONs): short-range, e.g., 20km
- Hardware component
  - ONT (optical network terminator) @Home
  - OLT (optical line terminator) @Central office



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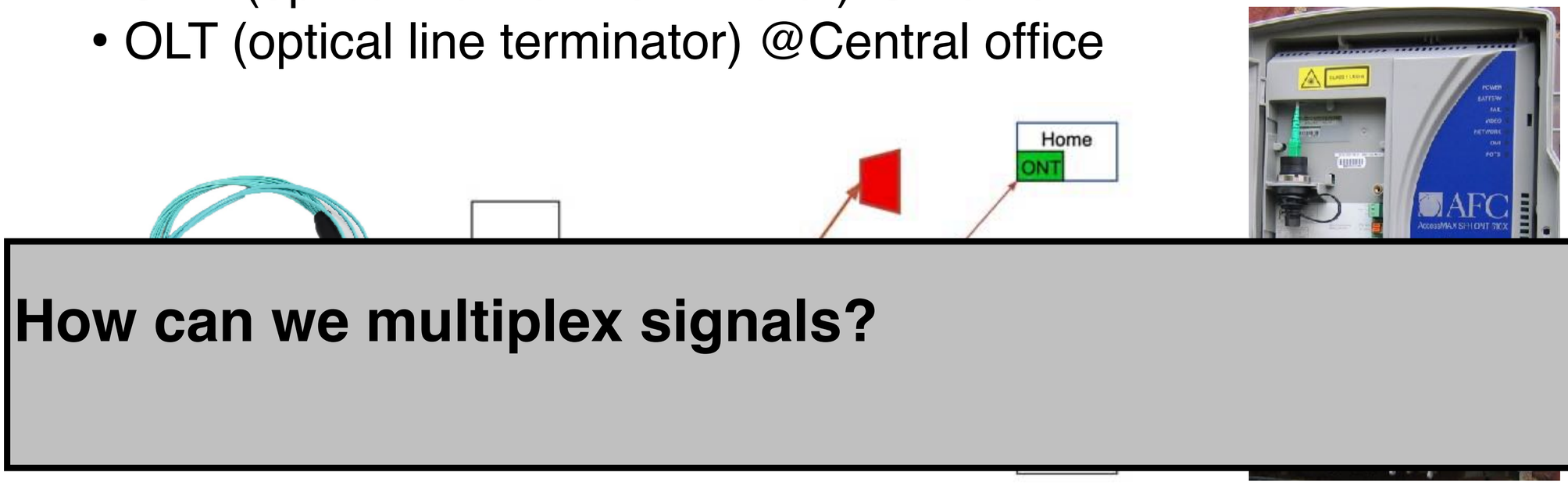

How can we multiplex signals?

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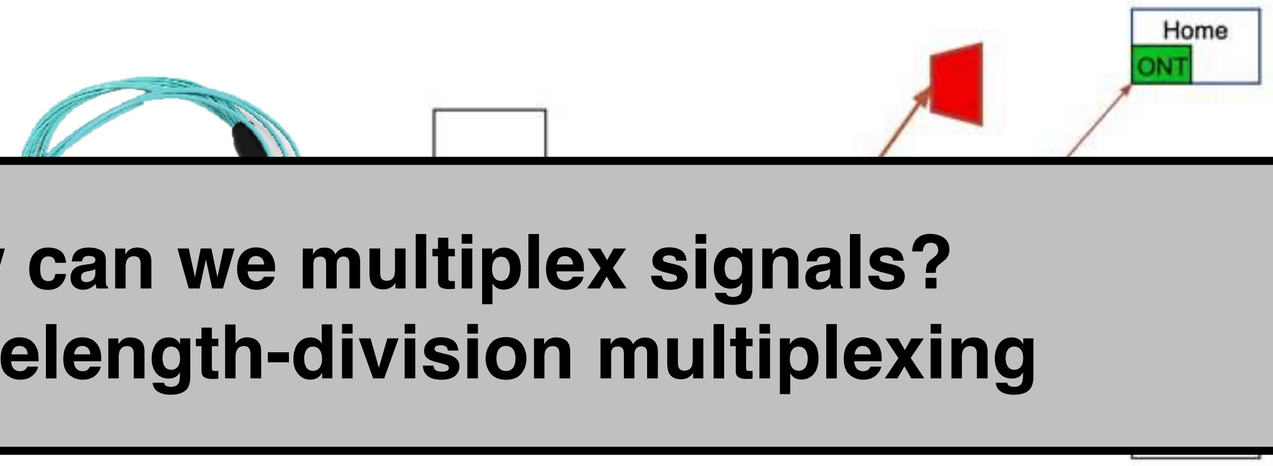
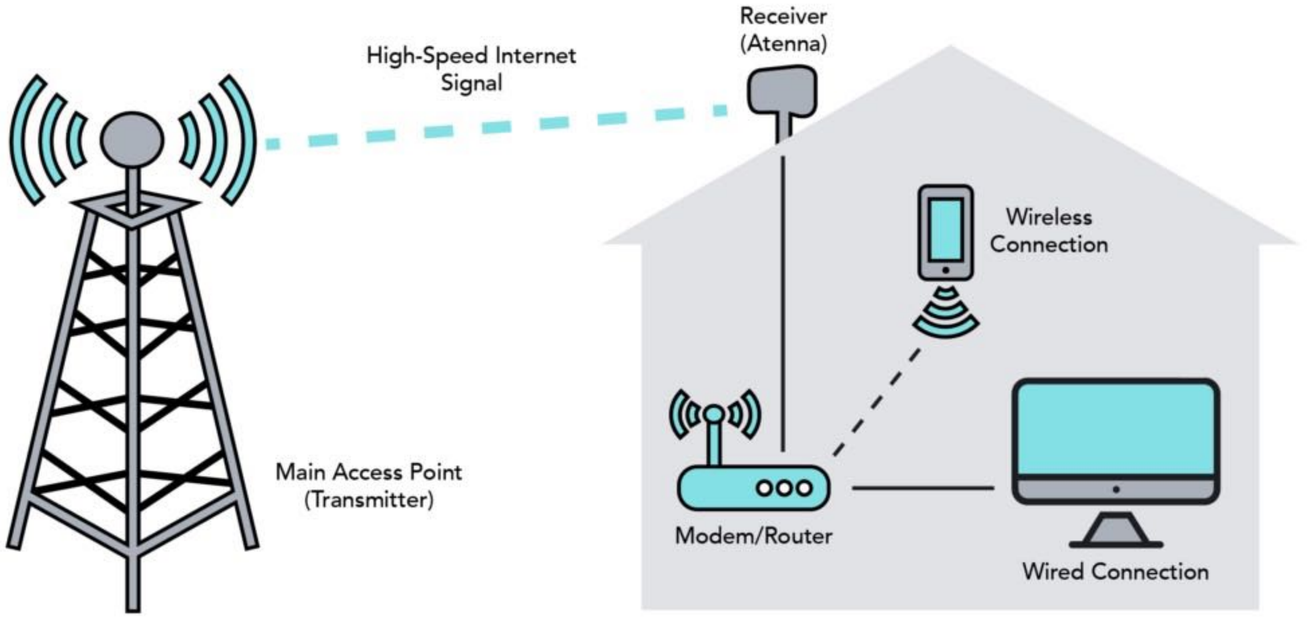


How can we multiplex signals?
Wavelength-division multiplexing

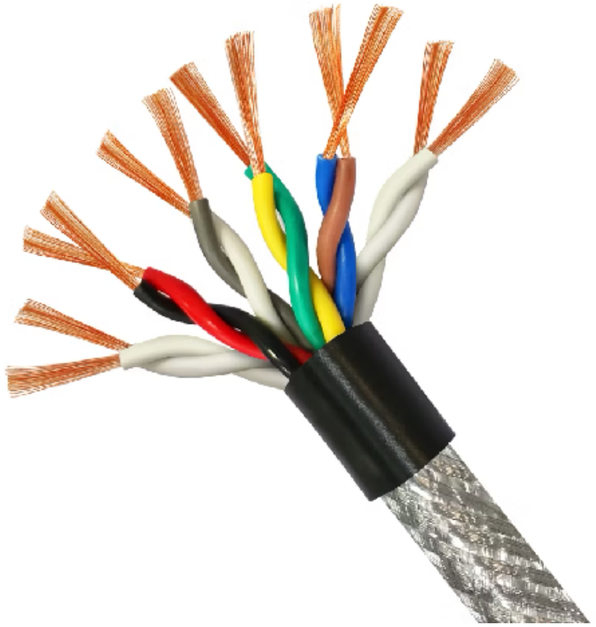
5G Fixed Wireless @Home Network

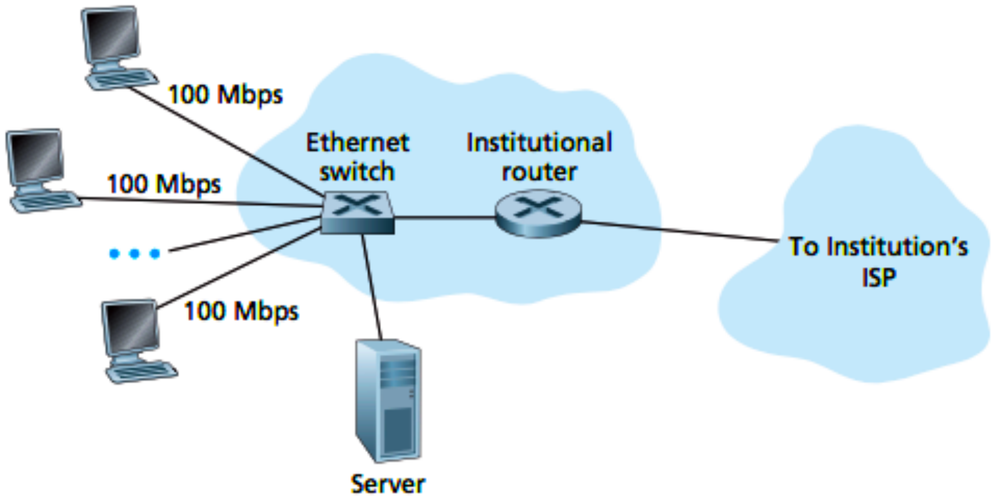
- Based on the Beam-forming technology
  - Teco company => Internet Service Provider (ISP)



Ethernet @Enterprise Network

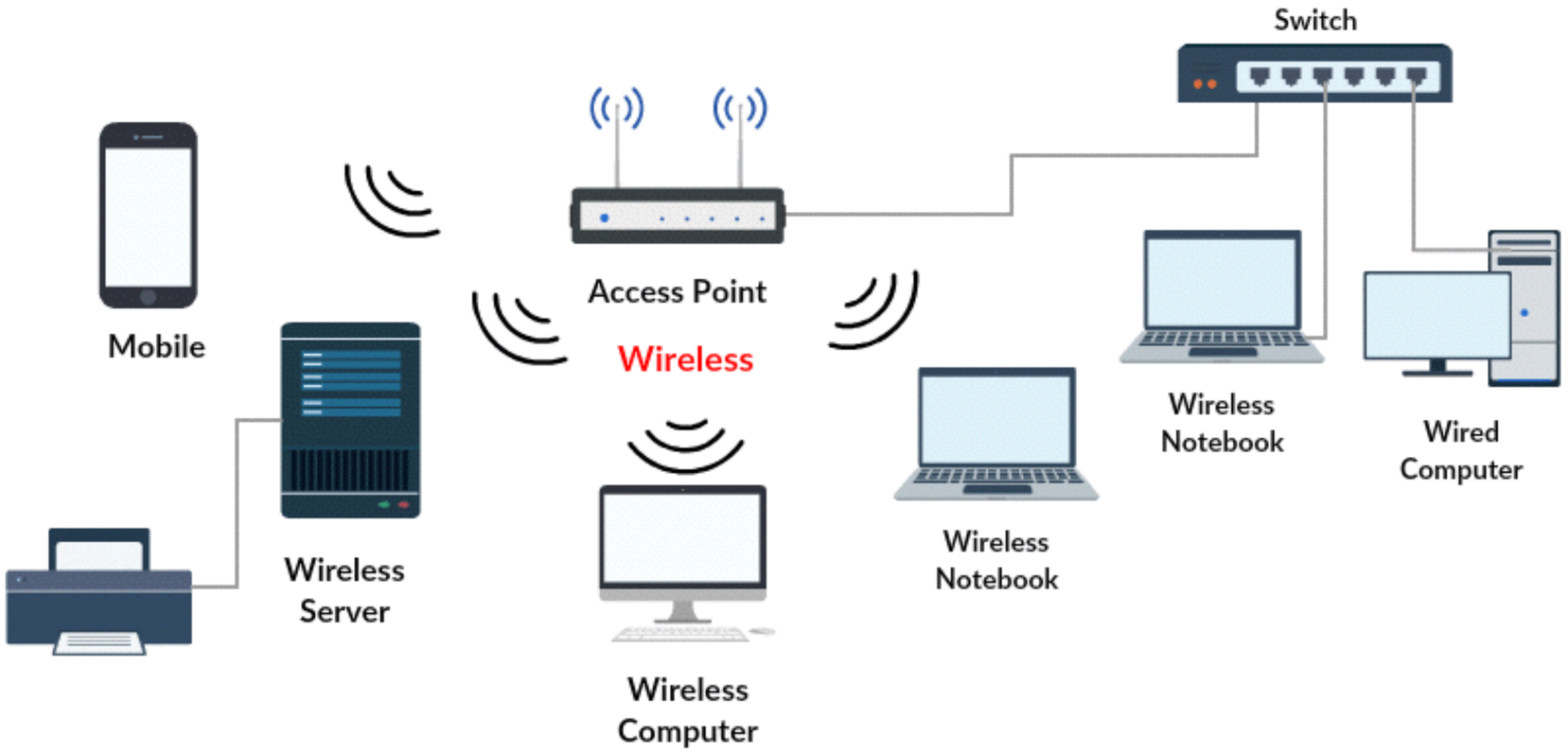
- The most widely used LAN technology
  - Invented by Robert Metcalfe, 2022 Turing Award
  - LAN = Local Area Network
  - Discuss extensively in this class





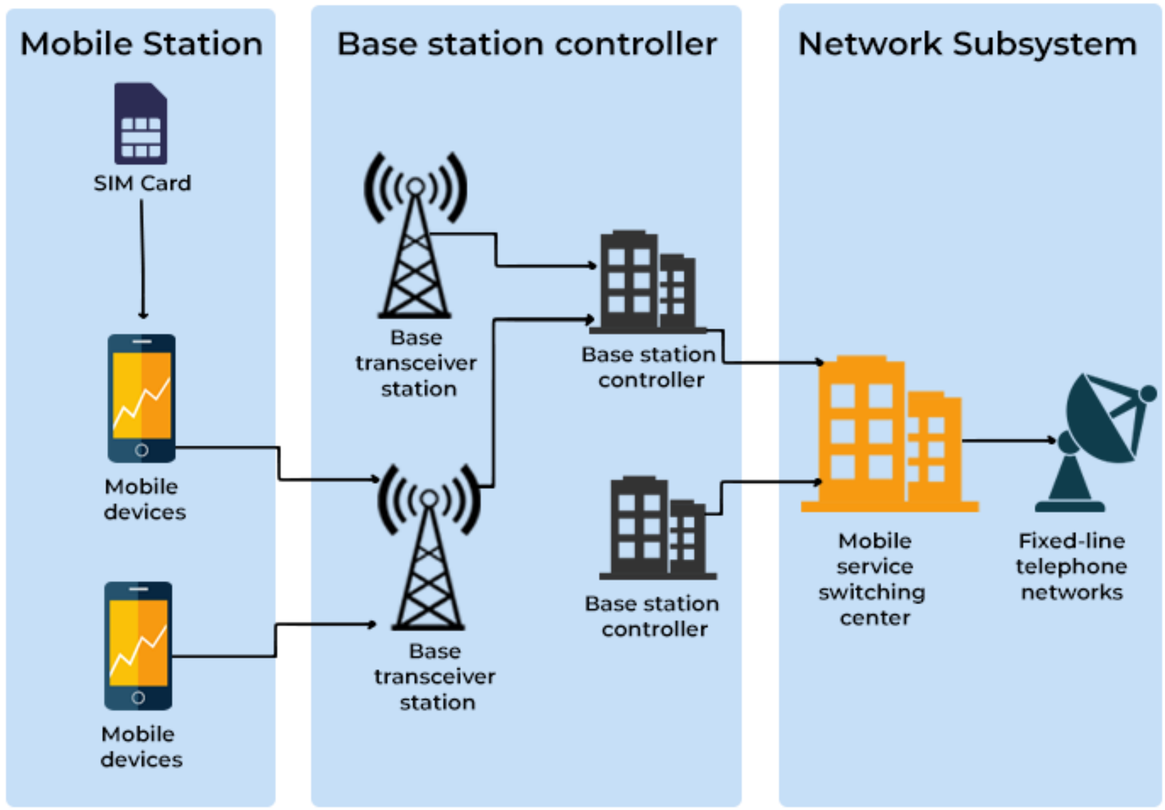
WiFi @Enterprise/Home Network

- Wireless access based on IEEE 802.11
  - Common radio frequency bands: 2.4GHz, 5GHz, and 6GHz



3G, LTE 4G, and 5G @Mobile Network

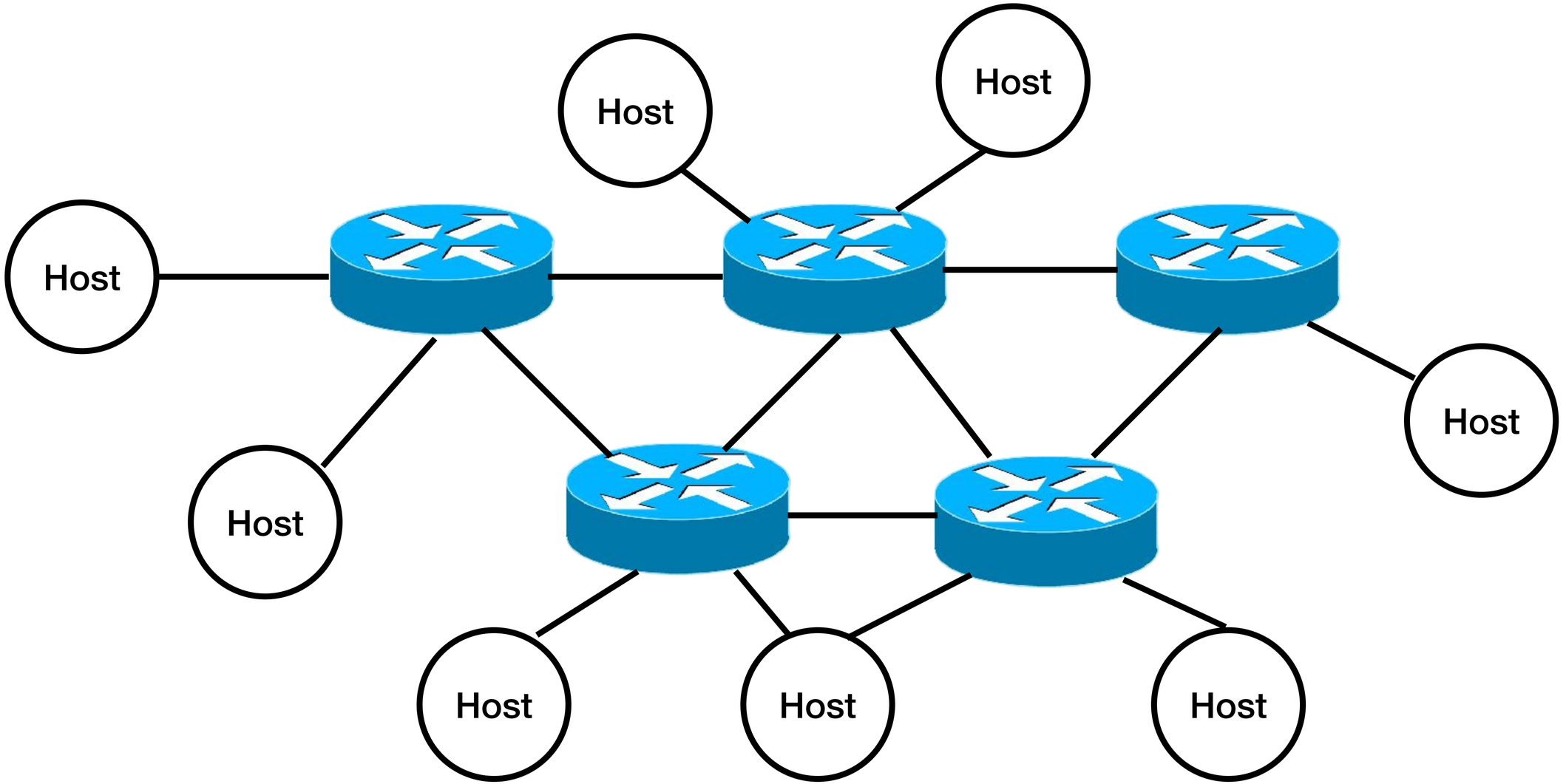
- The cellular network infrastructure is rising
  - https://5g.systemsapproach.org/index.html



Communication Link Summary

- The physical media can carry bits in many forms
  - Might not be the same as when you send them
  - Guided media and unguided media
- Guided media
  - The waves are guided along a solid medium
  - E.g., Coaxial cable, fiber-optical cable, twisted-pair copper wire, etc.
- Unguided media
  - The waves are propagated in the atmosphere or even outer space
  - E.g., wireless LAN, satellite channel, etc.
- Low capital cost, but high operational cost!

A Conceptual Network Structure



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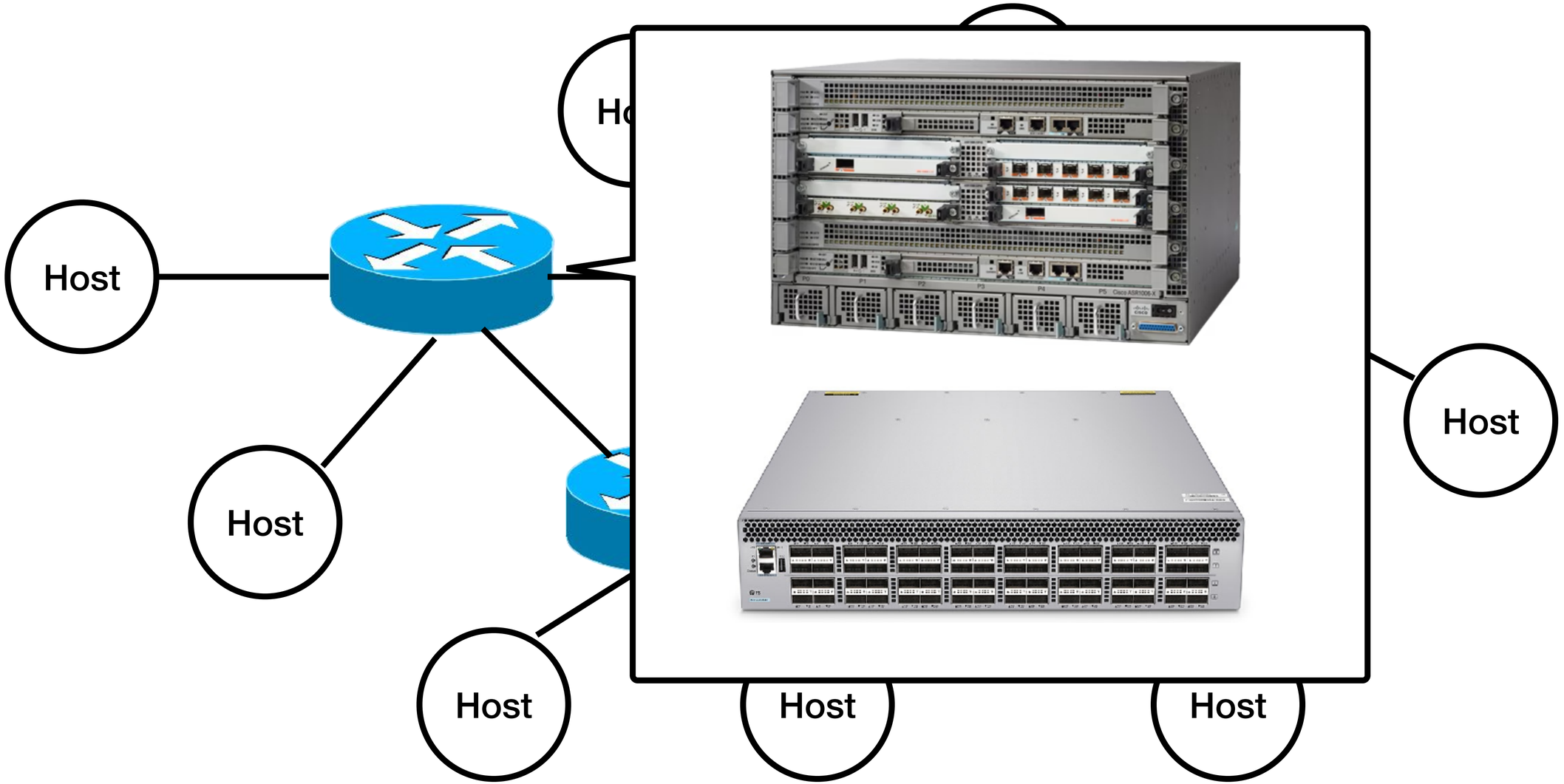
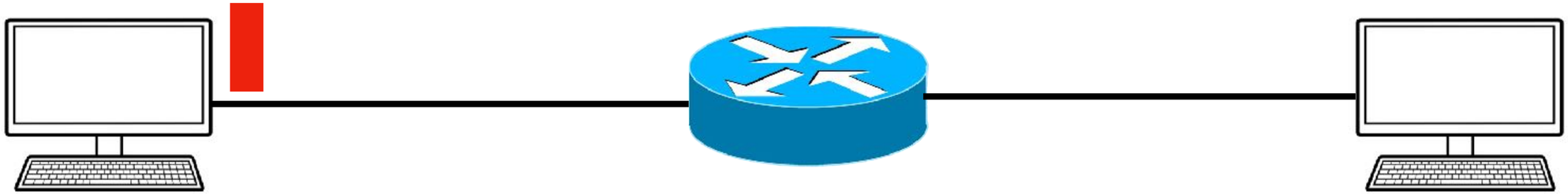


What does this networking hardware do?

Packet Switching



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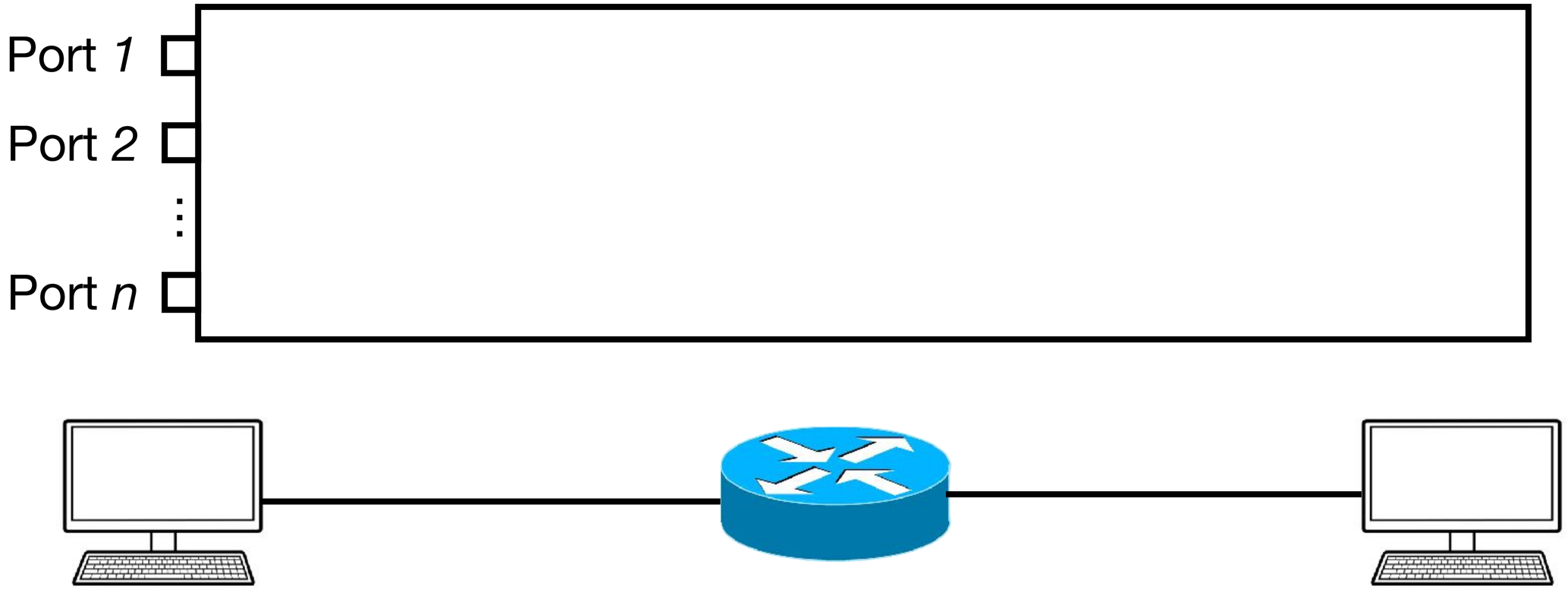

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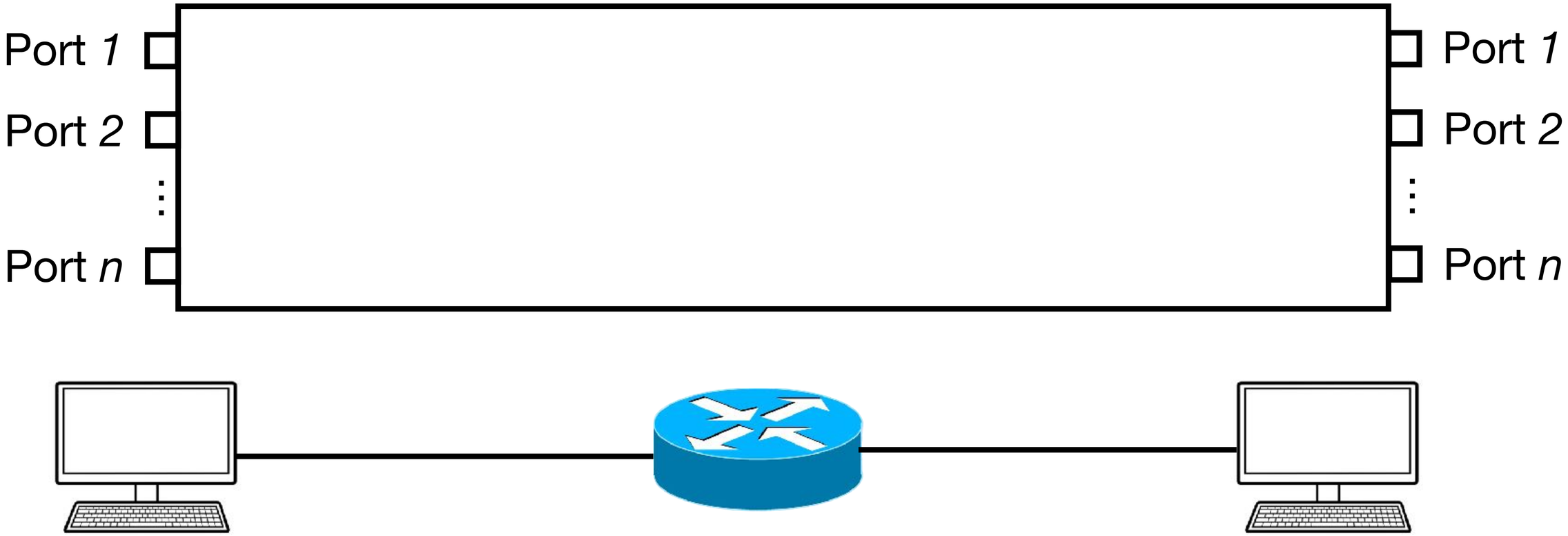

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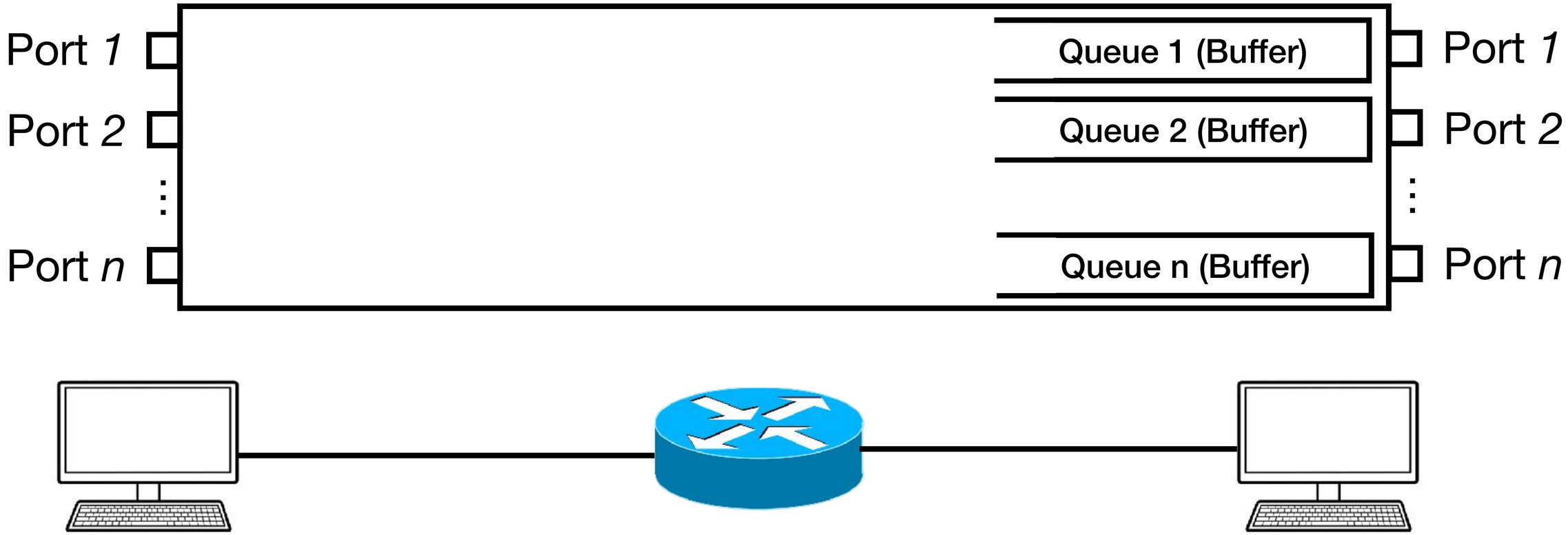

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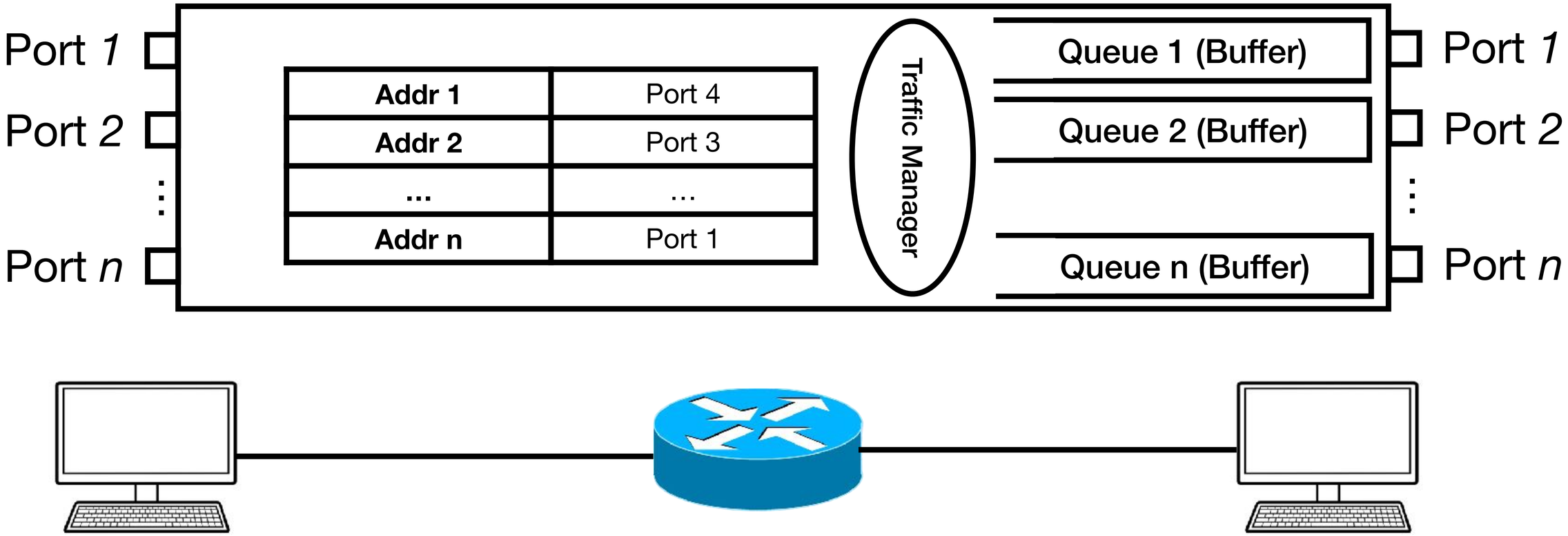

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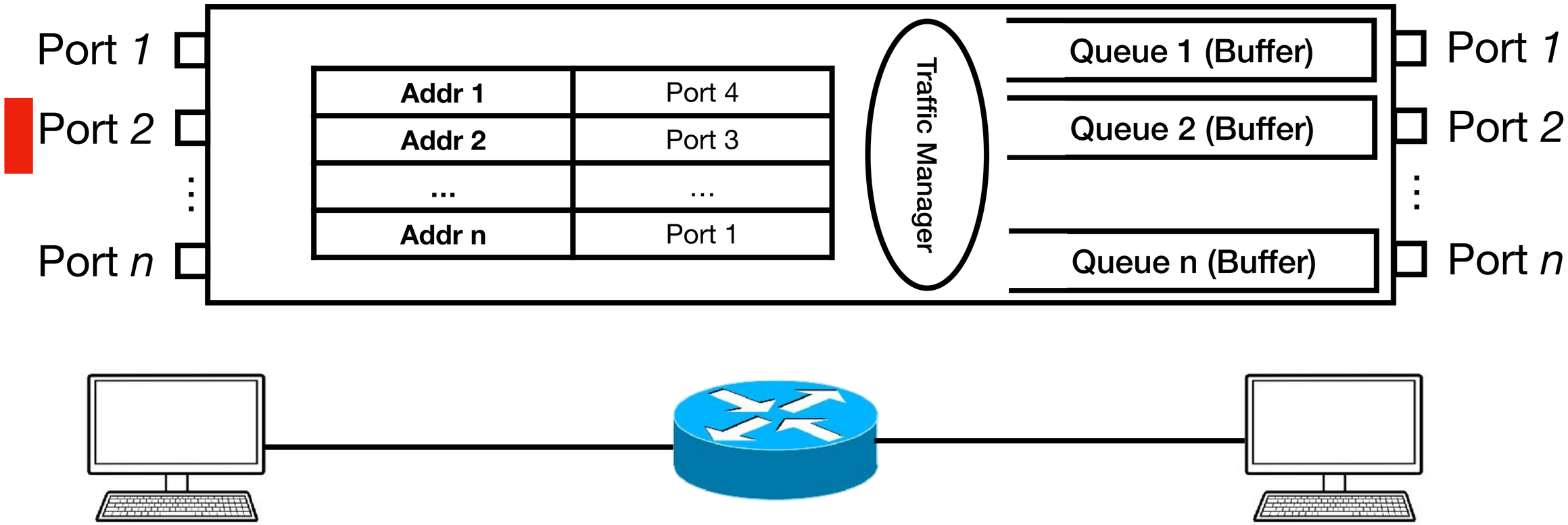
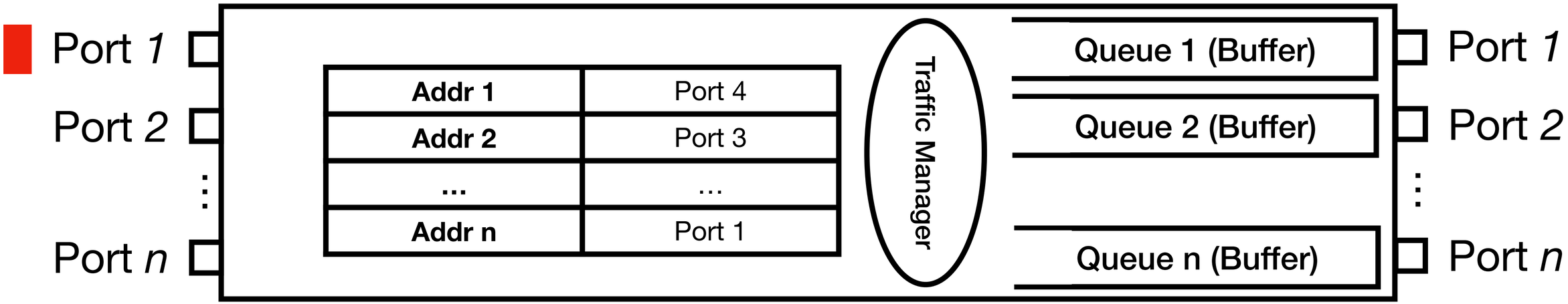


Store-and-Forward Transmission

- The hardware can only forward after receiving the entire packet
  - Packets need to be buffered!



Store-and-Forward Transmission

- The hardware can only forward after receiving the entire packet
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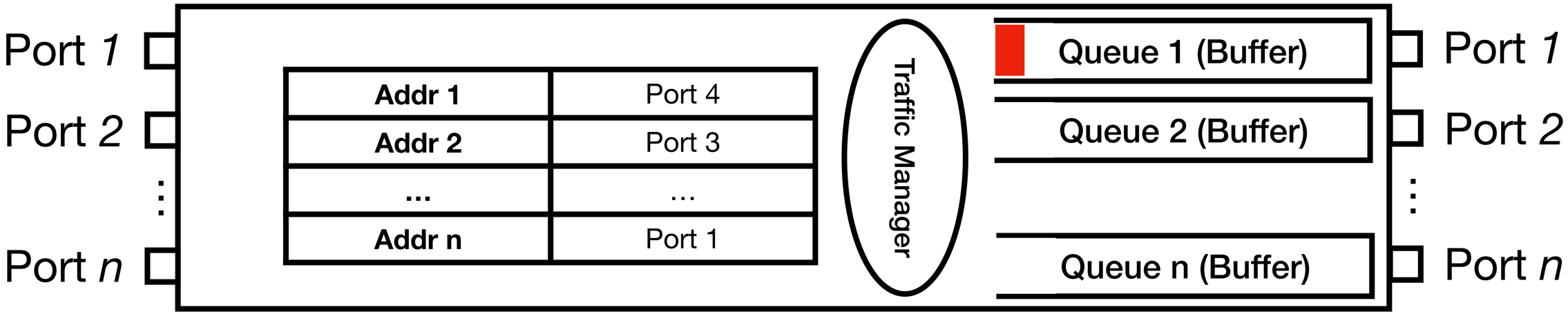
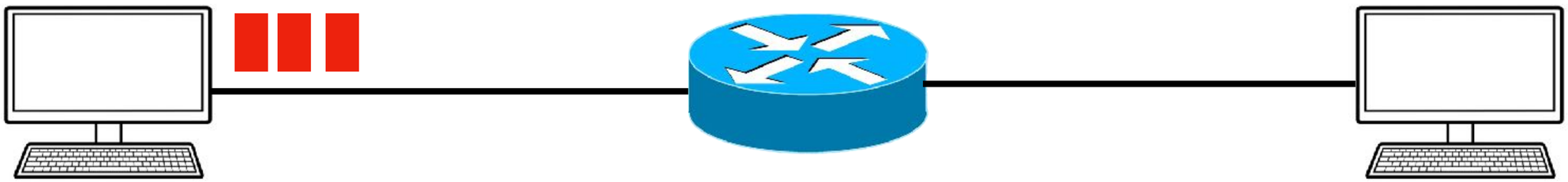
- Suppose a packet has *L* bits, and a switch transmits at *R* bits/sec
  - The switch takes *L/R* time to transmit the packet at the outbound port



End-to-End Transmission

- Suppose the sender transmits 3 packets to the receiver
  - The packet has *L* bits
  - All devices transmit at *R* bits/sec
  - The link is infinitely fast



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  - T = 2x *L/R*, the switch sends the 2nd pkt, the receiver gets the 1st one
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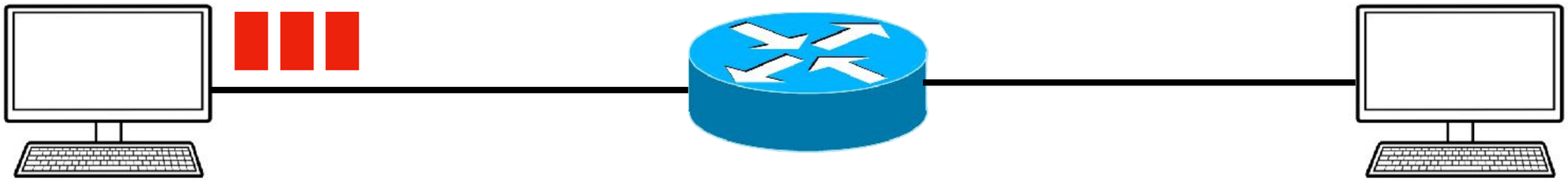

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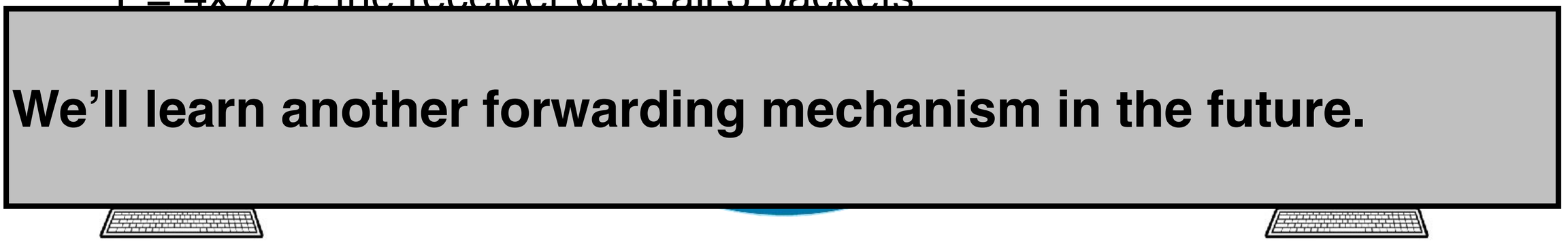
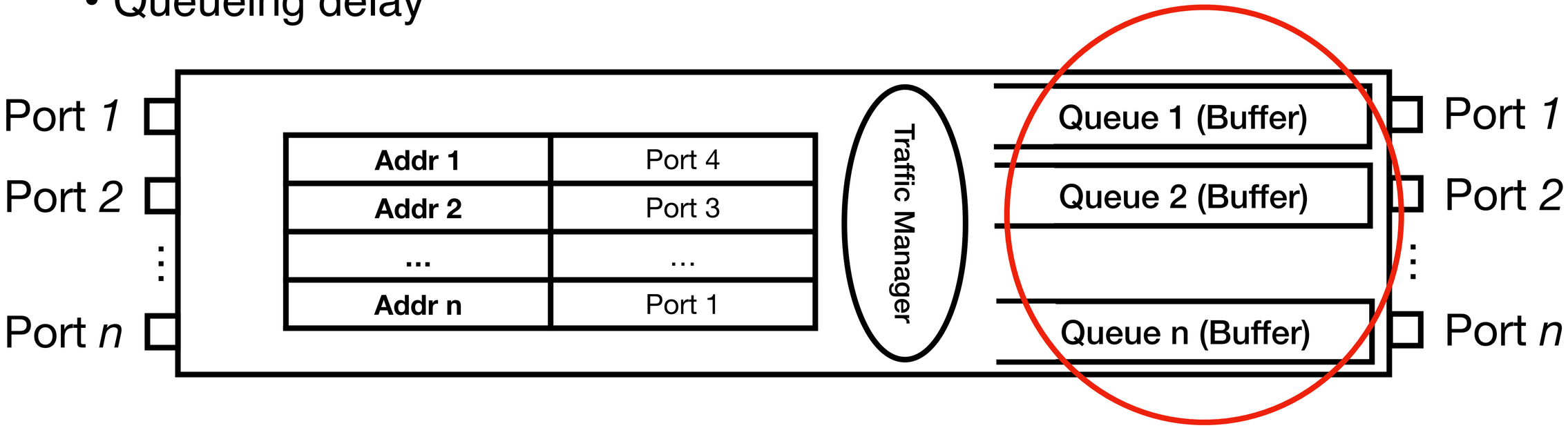


Queue is Fixed-Sized Buffer

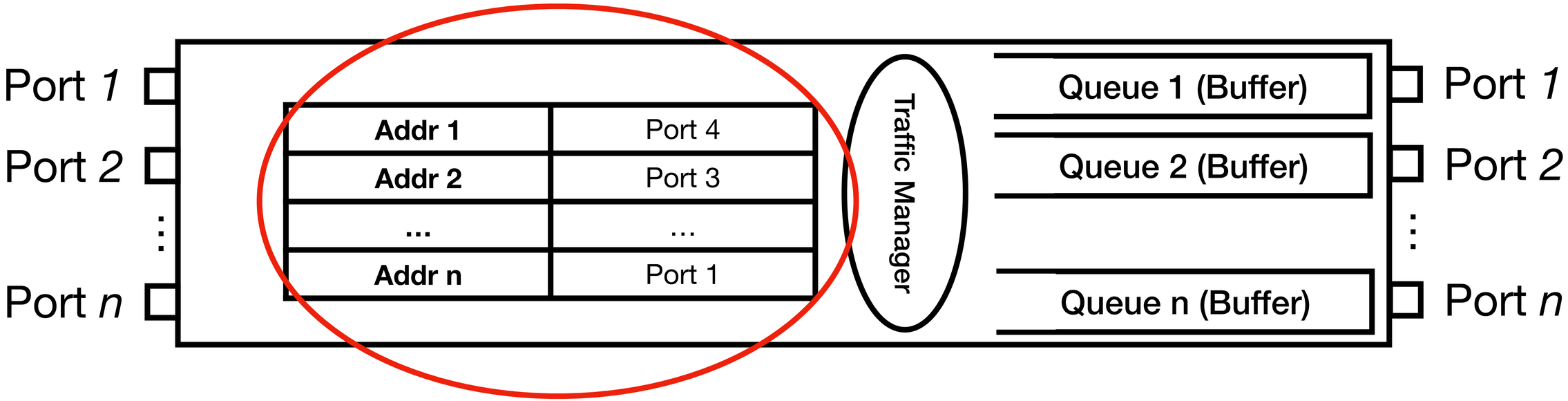
- The buffer capacity is limited
  - SRAM (Static random-access memory)
  - Fast, but hard to scale
- Packets are queued first, then dropped when becoming full
  - SRAM (Static random-access memory)
  - Queueing delay



Forwarding Table

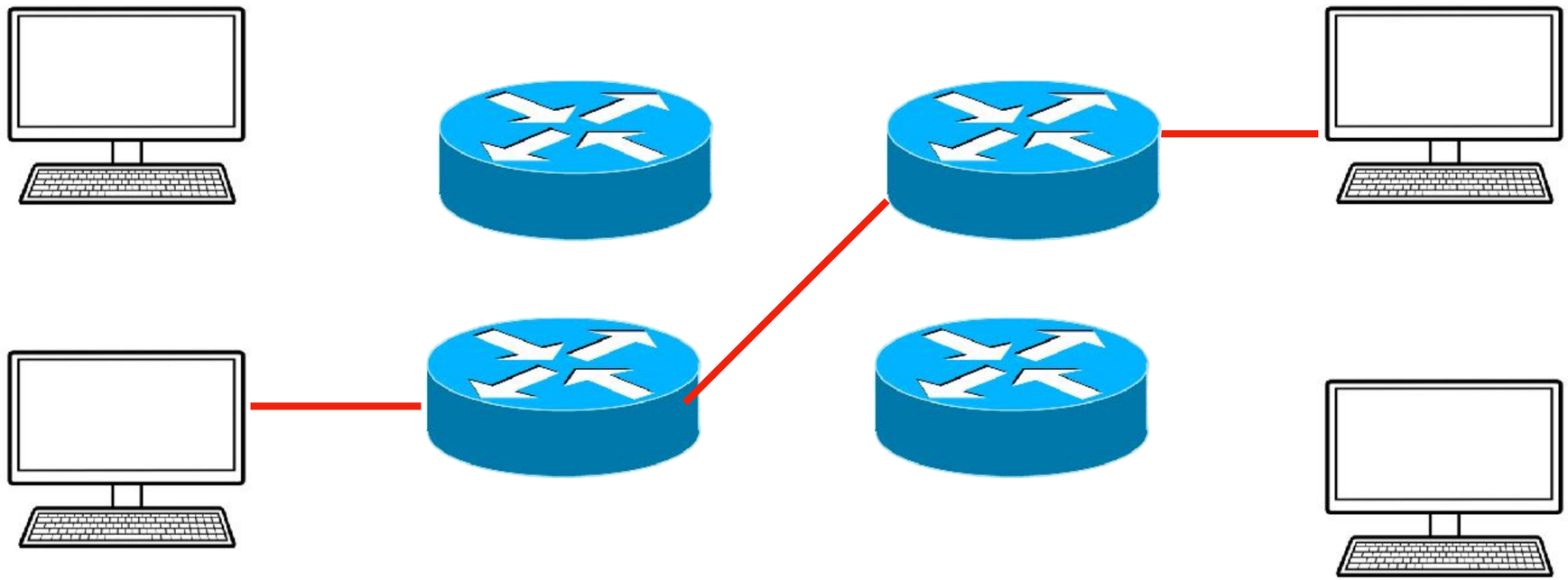
- Routing protocols fill in the following table
  - E.g., RIP, OSPF, etc.

- Forwarding Table
  - SRAM or TCAM (Ternary Content Addressable Memory)
  - Read/Write/Delete + Match (Query)



Circuit Switching

- Reservation-based system
  - Originally used in the telephone network
  - Communication can only happen after the end-to-end connection is ready



Multiplexing in Circuit Switching

- Frequency-division multiplexing (FDM)
  - The frequency spectrum is divided

- Time-division multiplexing (TDM)
  - The transmission time slot is divided

Packet Switching v.s. Circuit Switching

- Packet switching
  - Pros: suitable for real-time services
  - Cons: high utilization, simple

- Circuit switching
  - Pros: predictable performance
  - Cons: low resource usage

Packet Switching v.s. Circuit Switching

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  - Pros: suitable for real-time services
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- Circuit switching
  - Pros: predictable performance
  - Cons: low resource usage

Suppose there are 10 clients. One client is going to transmit 1000 100-bit packets, and the other nine are idle. Which switching is better?

Switching Summary

- An abstract switch machine
  - Input/Output ports, forwarding table, buffer, and traffic manager
  - Buffers have limited capacity
  - Forwarding tables are constructed by routing protocols

- Packet and circuit switching are two fundamental schemes
  - Packet switching: on-demand
  - Circuit switching: reservation-based

What software do we need for computer networks?

What are the design requirements of computer networks?

#1: Anytime and anywhere connectivity
#2: Always-on correctness
#3: Reasonable performance
#4: Low cost
#5: Tolerable security

A computer network should realize:

#1: Scalable and correct data movement
#2: Reliable bits delivery
#3: Resource multiplexing
#4: Performance maximization
#5: Access control

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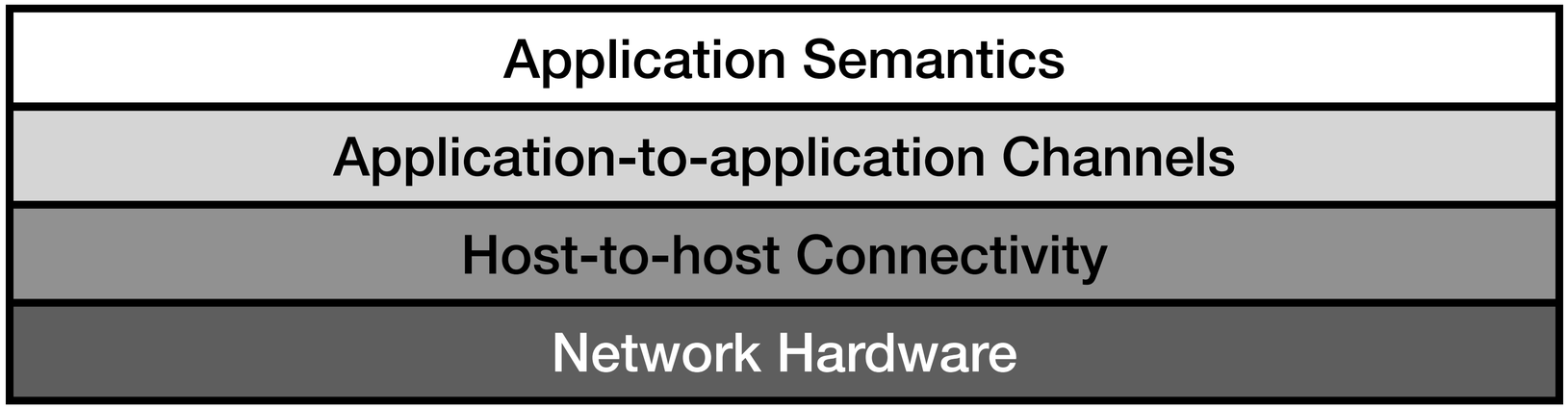
} **Too hard!**

Layering

- A modular approach to building networks by abstractions
  - Introduce multiple levels of abstractions
  - Each layer focuses on different functionalities



Layering

- A modular approach to building networks by abstractions
  - Introduce multiple levels of abstractions
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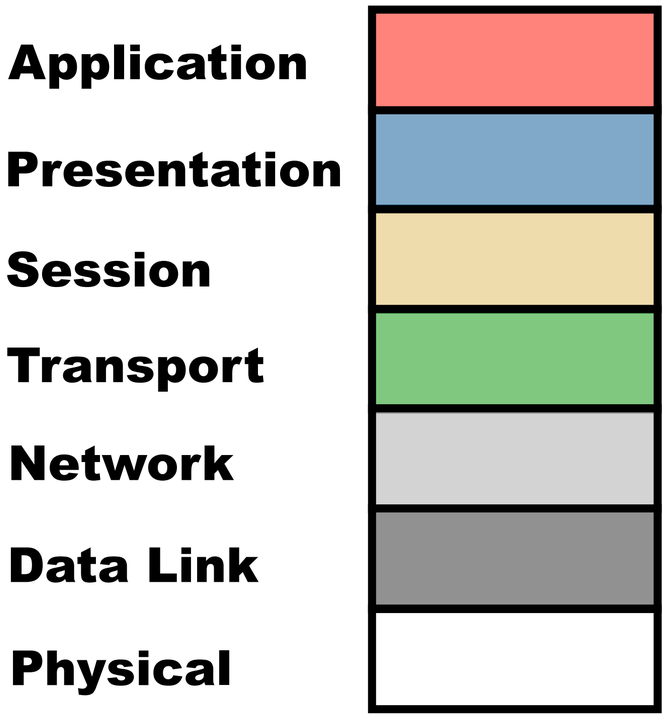
A **protocol** defines the format and the order of messages exchanged between two or more communication entities, as well as the actions taken on the transmission and/or receipt of a message or other event.

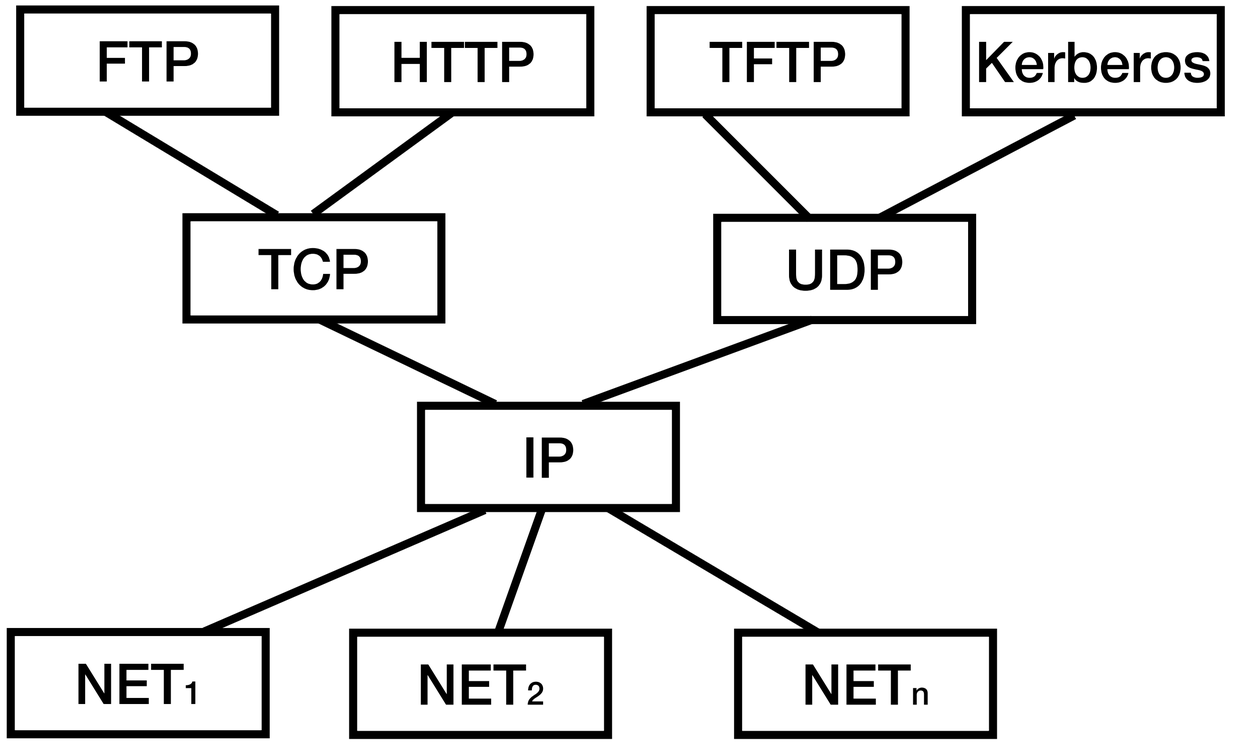
- *Vertical view: an interface to high-level protocols*
- *Horizontal view: a peer interface to a counterpart*

Protocol Stack

- OSI = Open System Interconnection



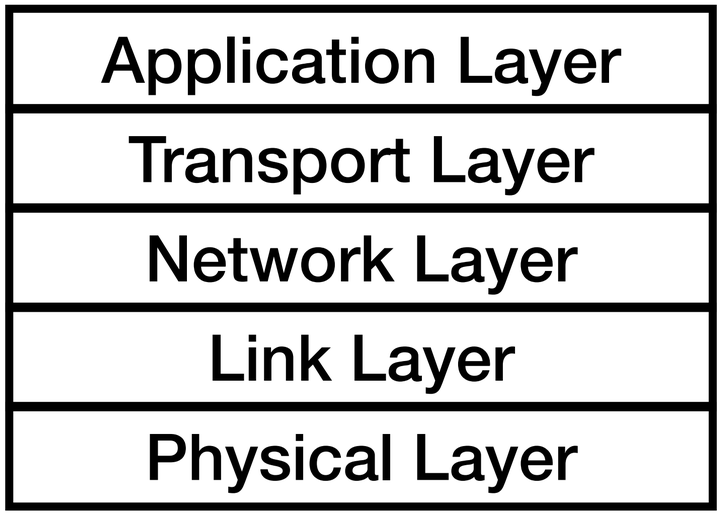
OSI model



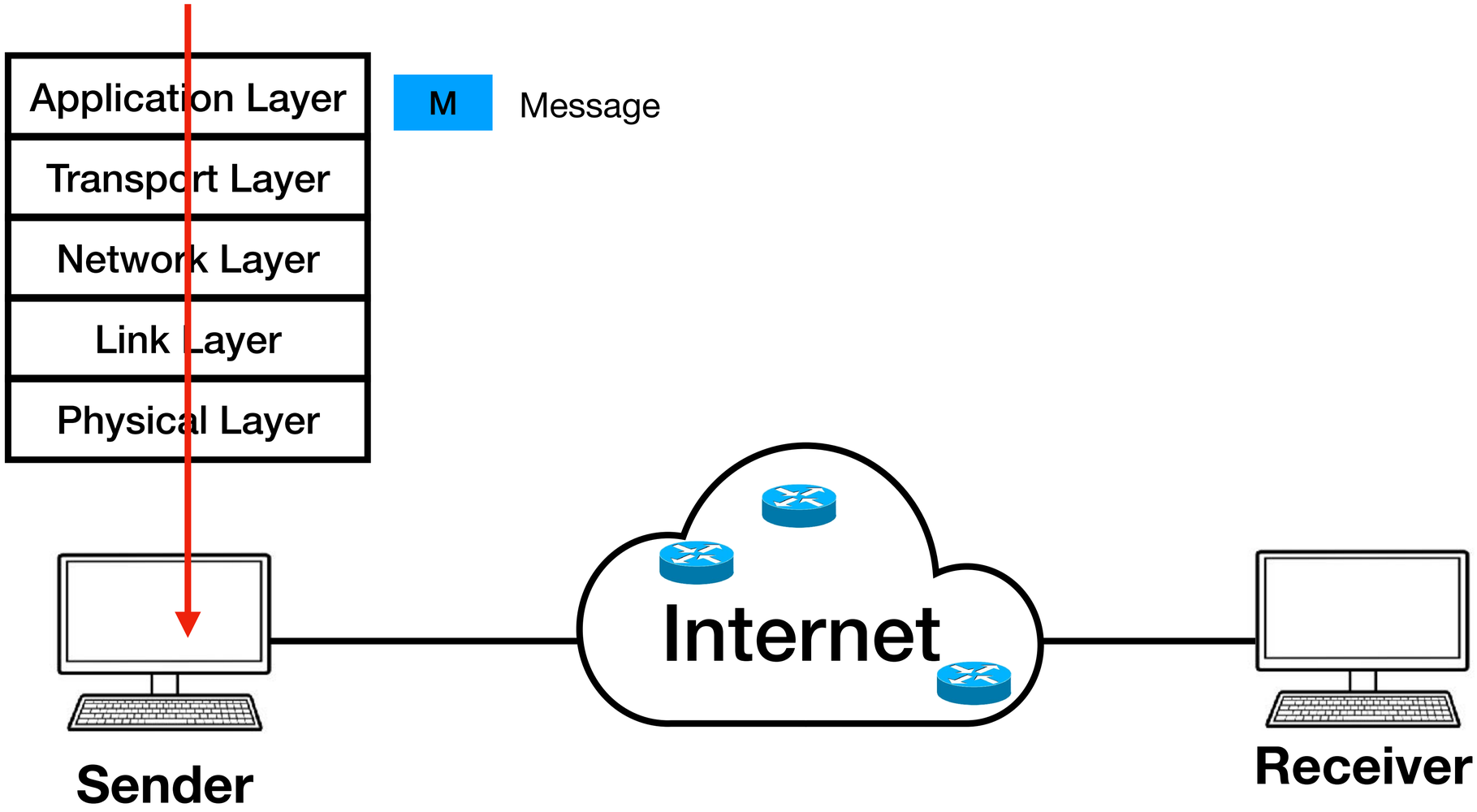
TCP/IP

Five-layer Internet Stack

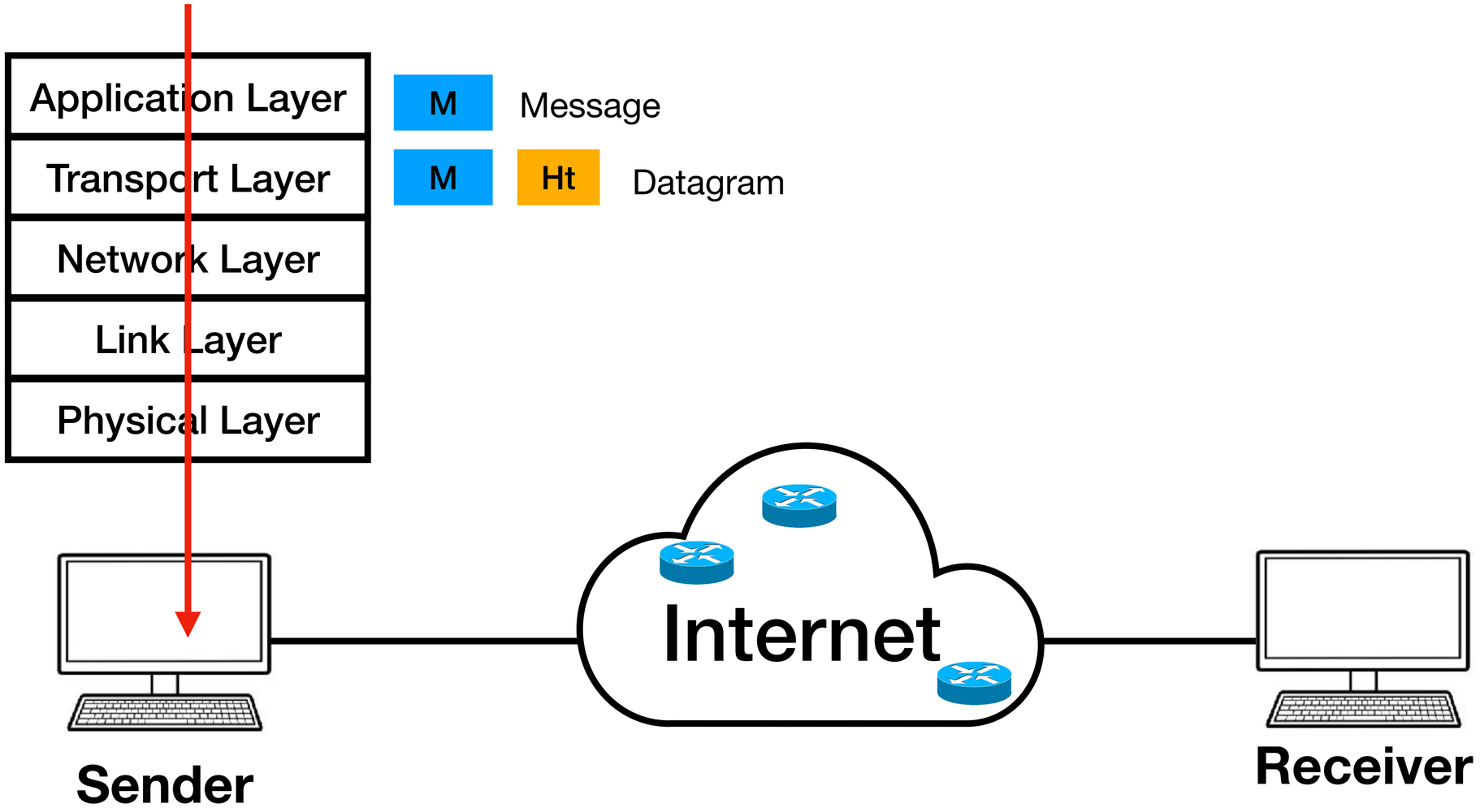
- We'll focus on this stack in this class



Data Encapsulation



Data Encapsulation



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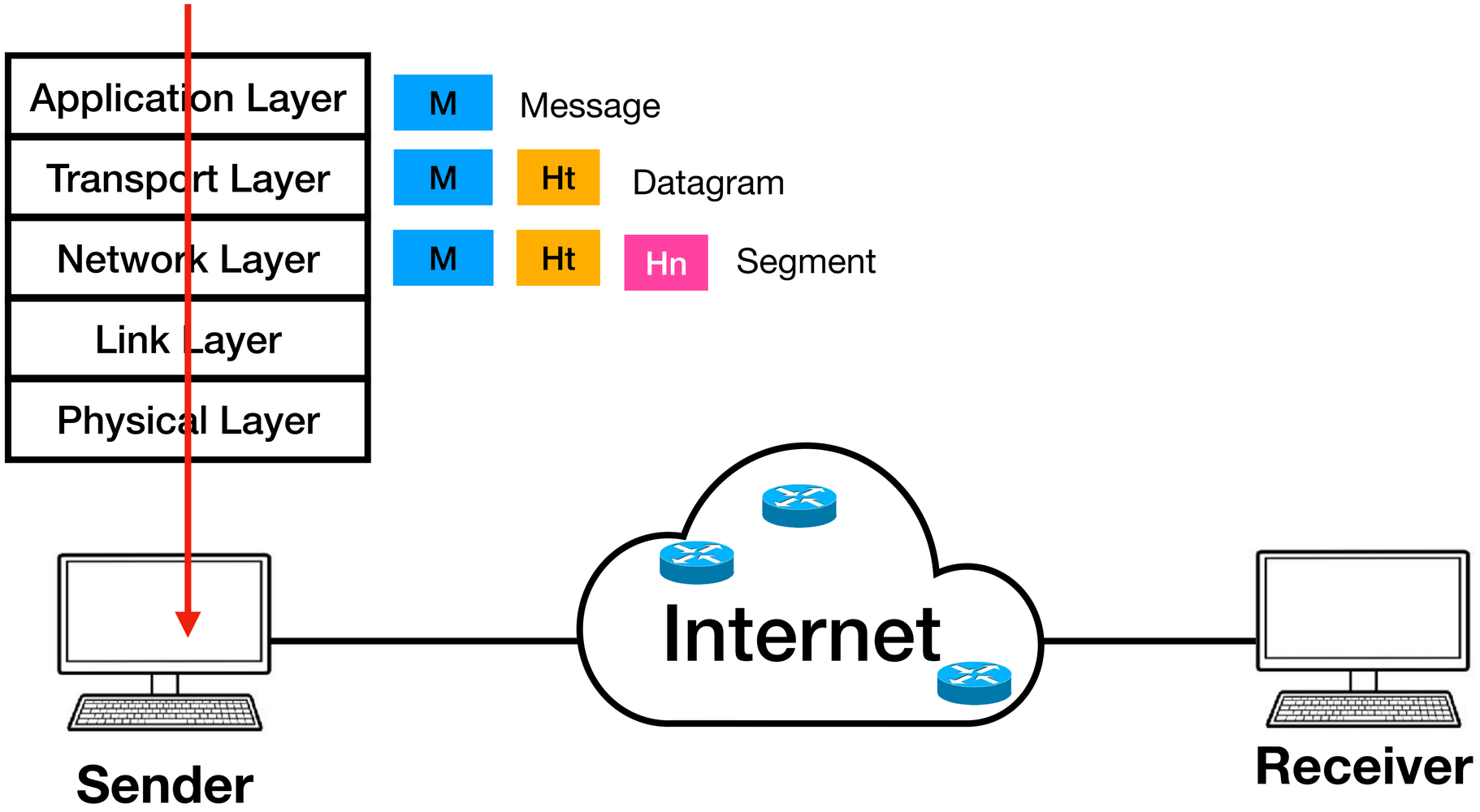

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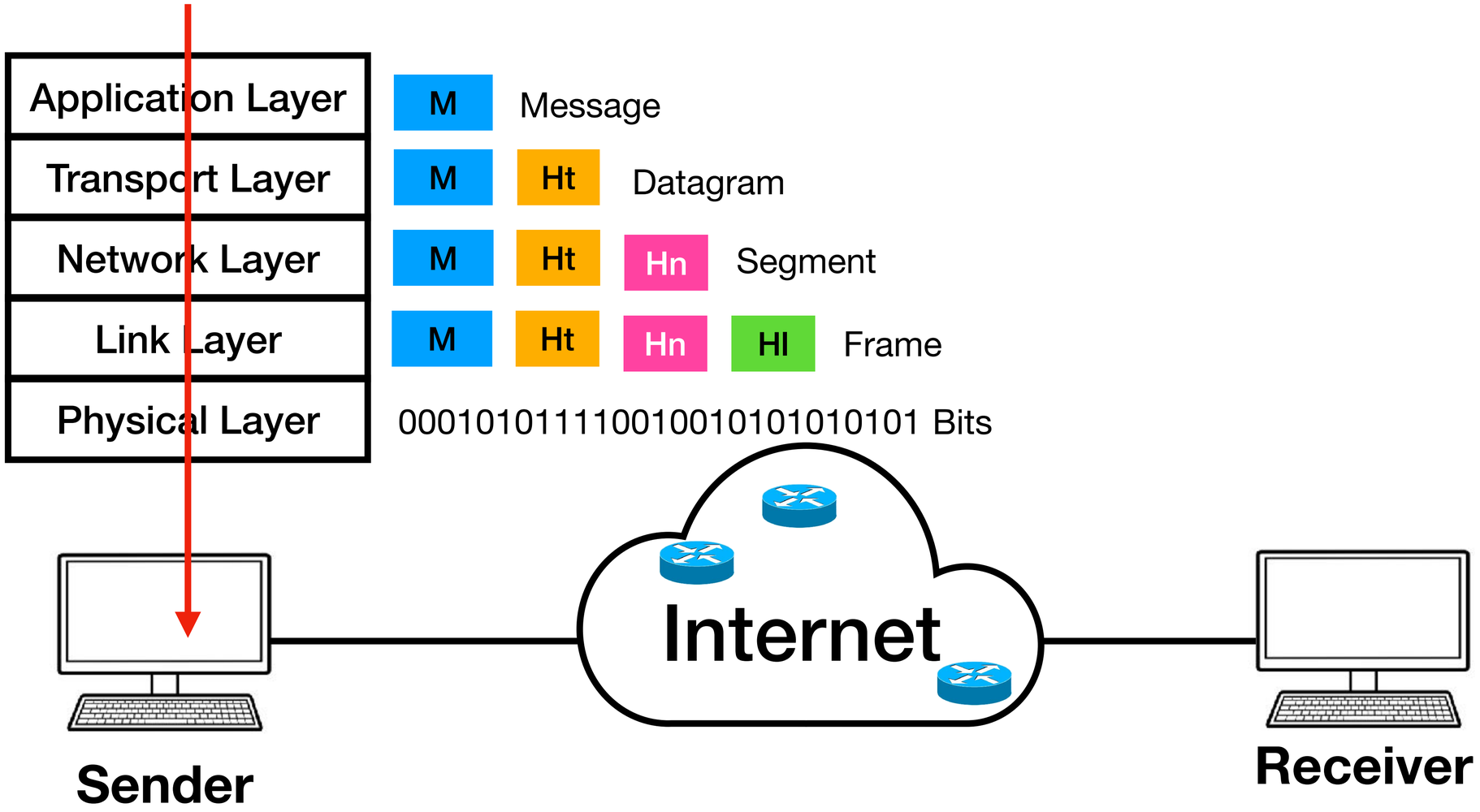

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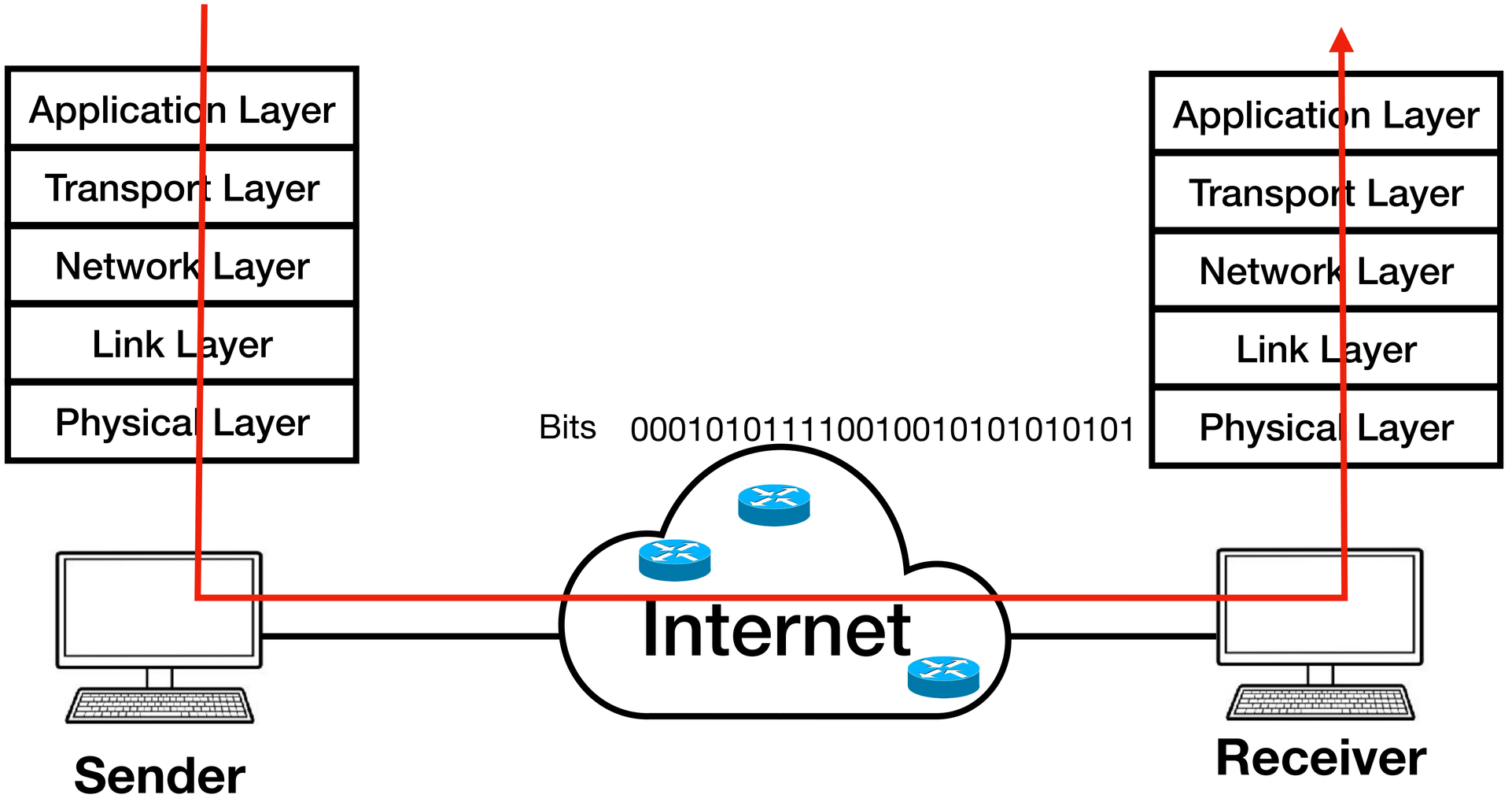

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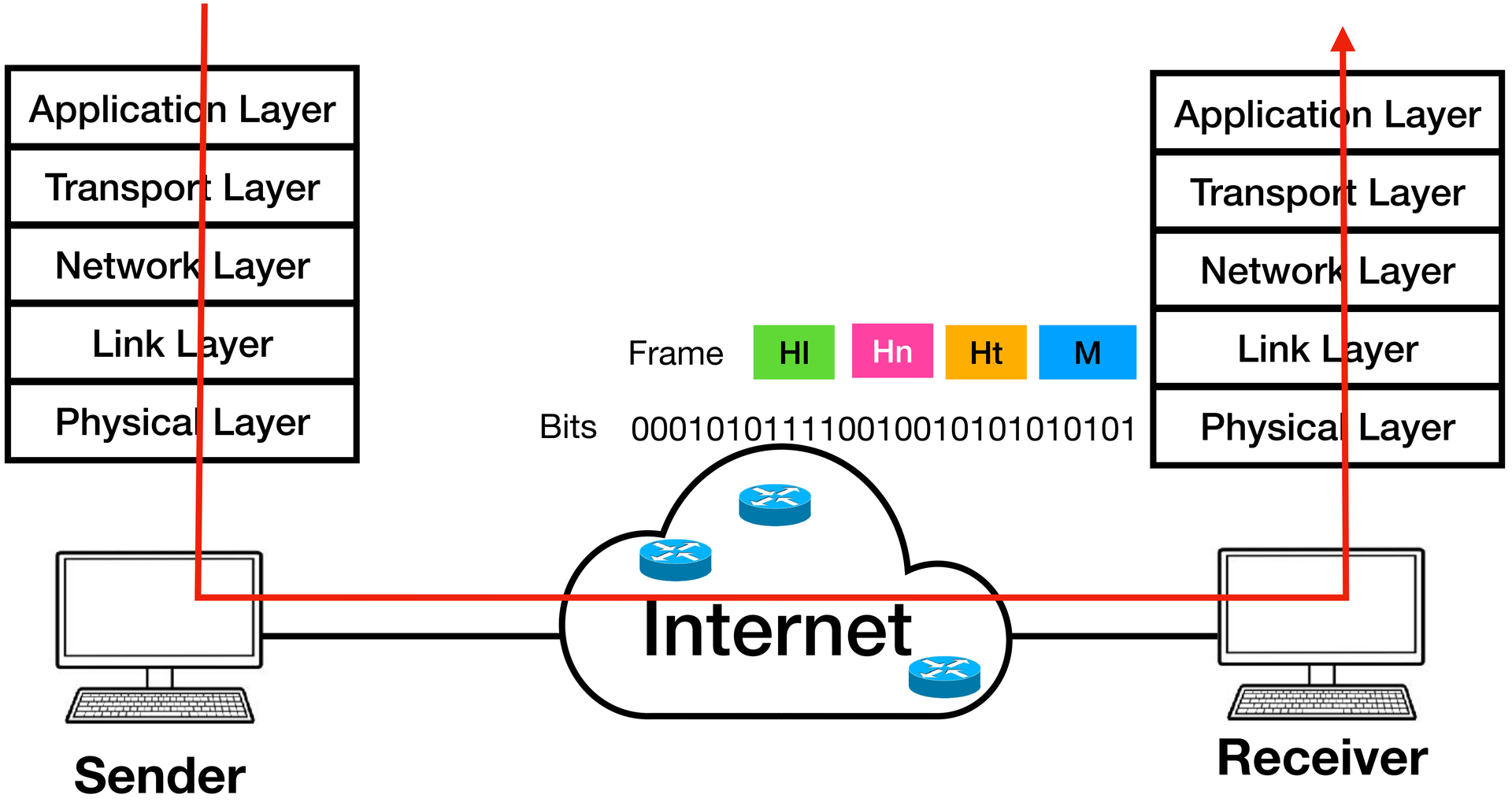

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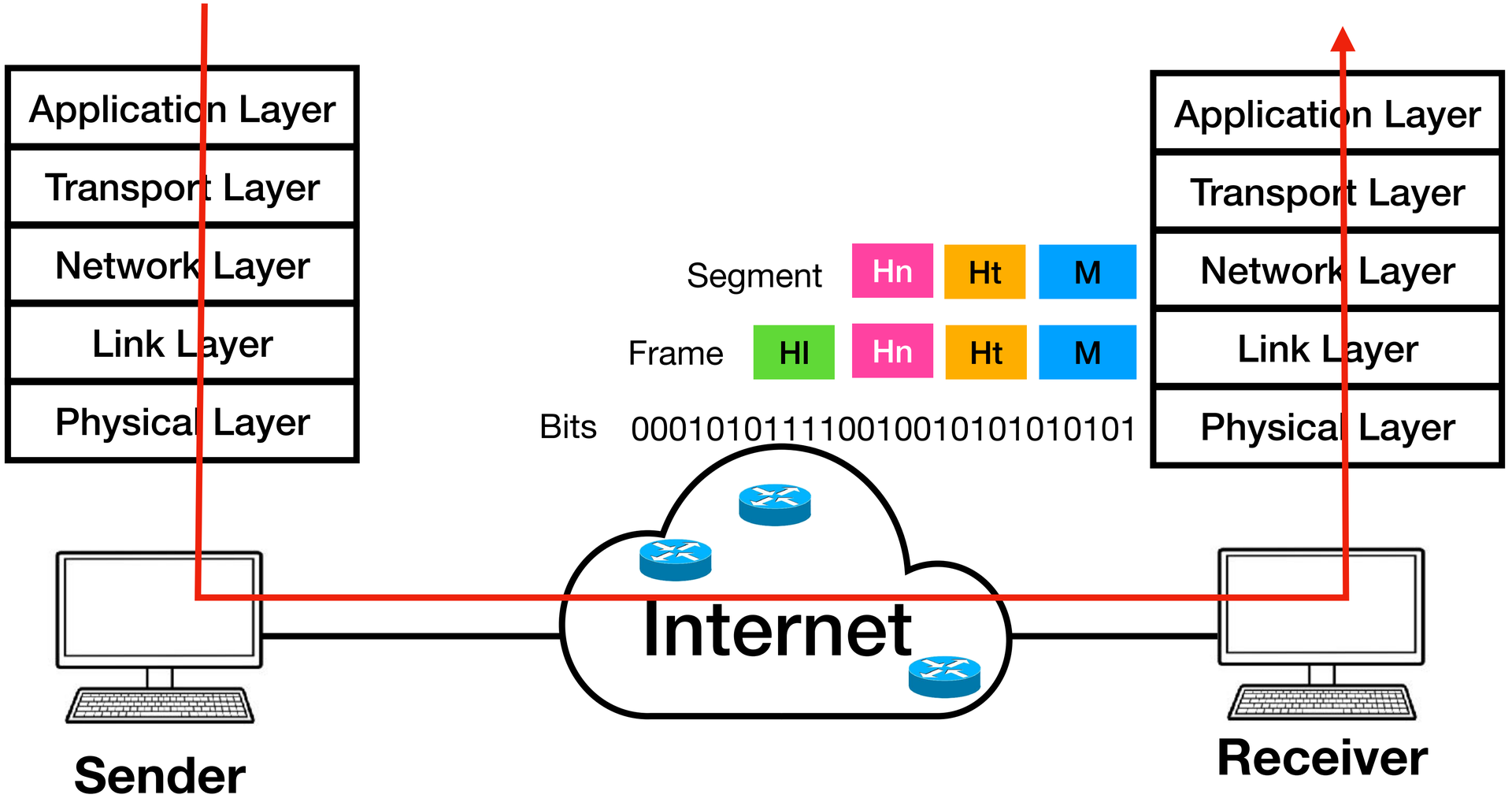

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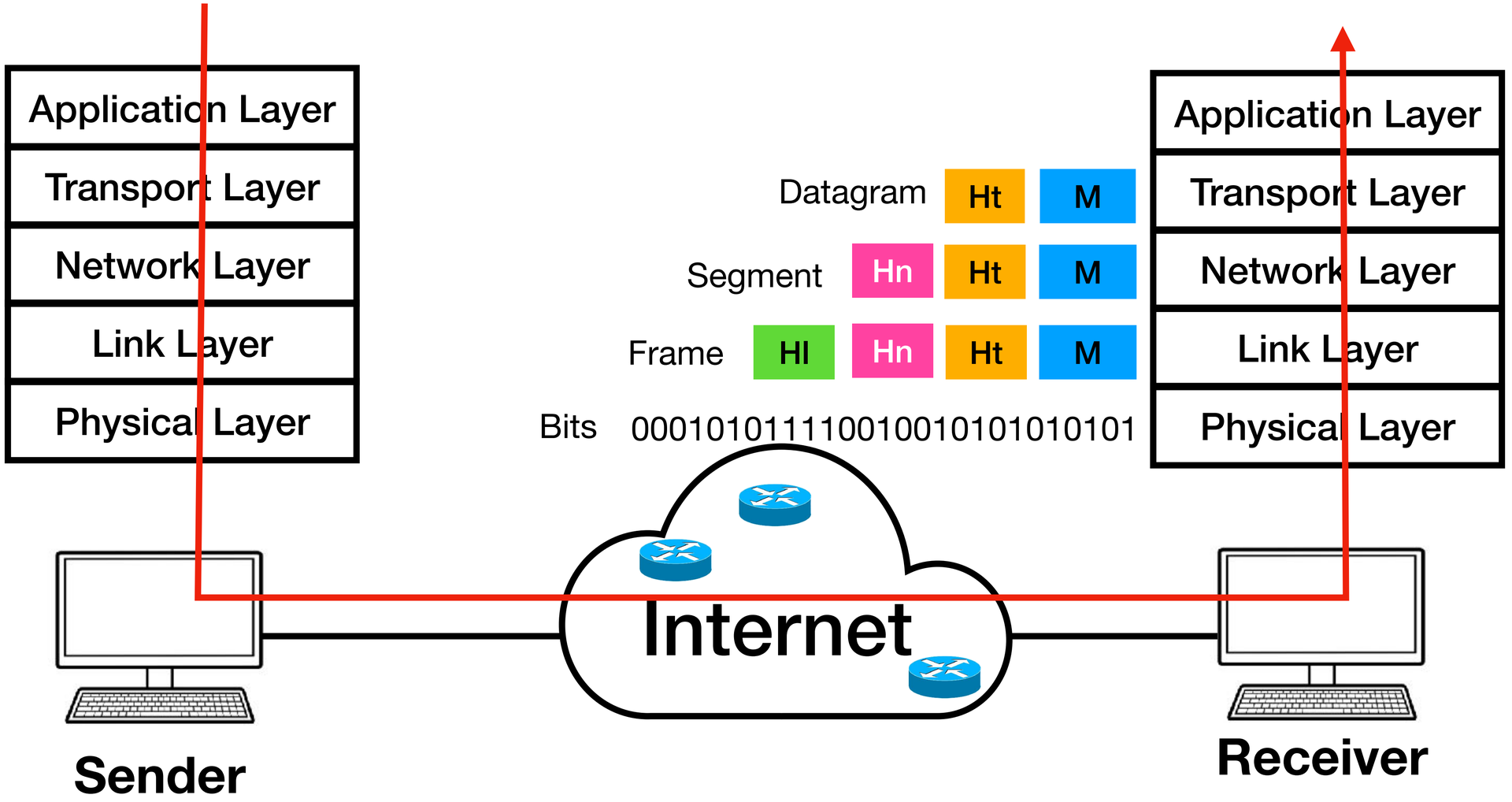

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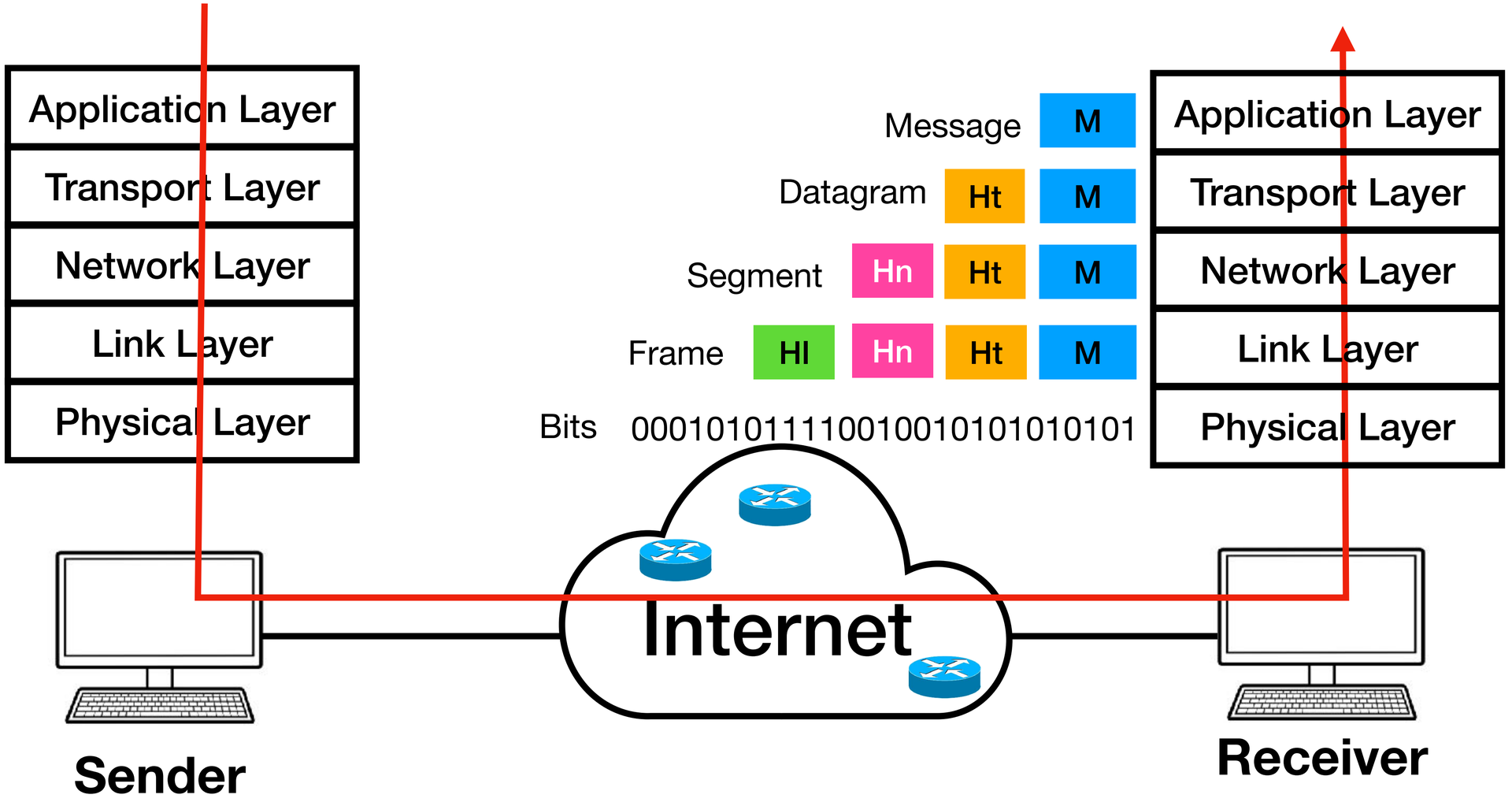
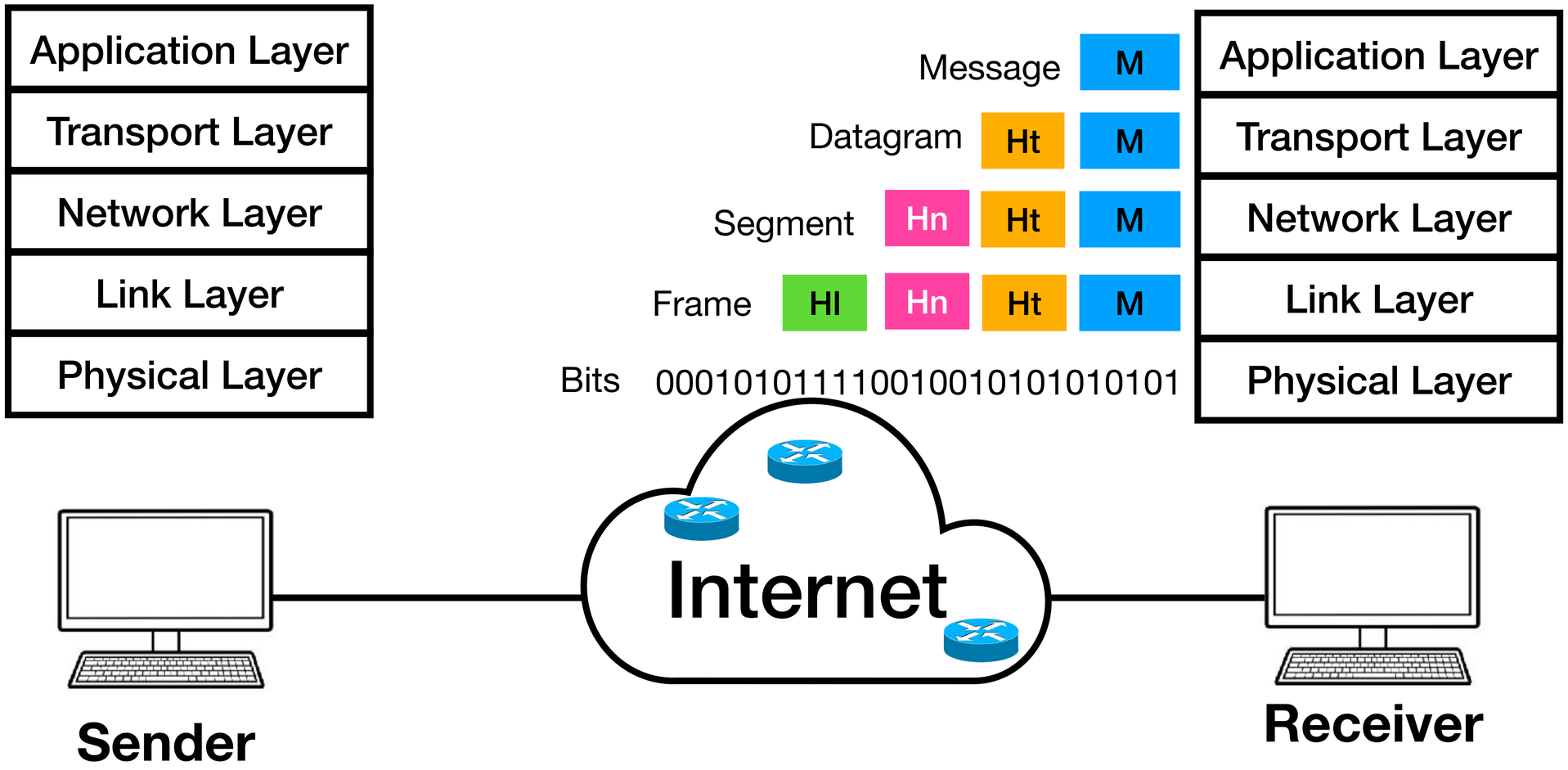


Learning Strategy

- We'll take a **bottom-up** approach to learn



Summary

- Today
  - Computer networks: hardware infrastructure
  - Computer networks: software system

- Next lecture
  - Computer networks: performance anlaysis