CMSC414 Computer and Network Security

Introduction to Networking

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Credits: original slides from instructors and staff from CS161 at UC Berkeley. Blue slides will not be tested.

Today: Intro to Networking

- Internet: A global network of computers

- OSI model: A layered model of protocols
  - Stands for “Open Systems Interconnection model”

What’s the Internet?

- **Network**: A set of connected machines that can communicate with each other
  - Over a **protocol**, a set of rules for communication

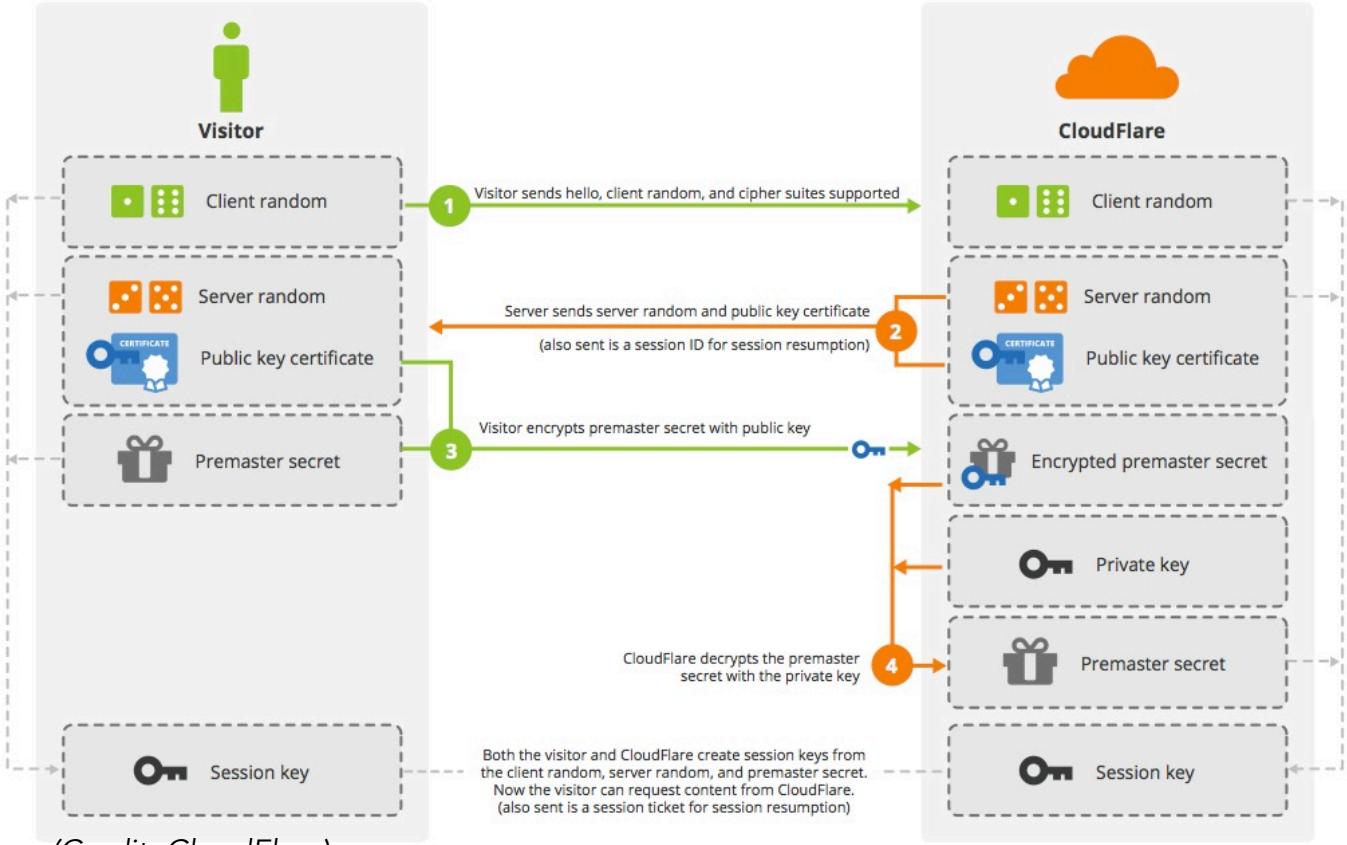
- **Internet**: A global network of computers
  - Web
  - SSH
  - Internet of Things: TV, Watch, Game Consoles, …

Protocols

- A **protocol** is an agreement on how to communicate that specifies syntax and semantics
  - *Syntax:* How a communication is specified and structured (format, order of messages)
  - *Semantics*: What a communication means (actions taken when sending/receiving messages)

SSL Handshake (RSA)

Handshake



(Credit: CloudFlare)

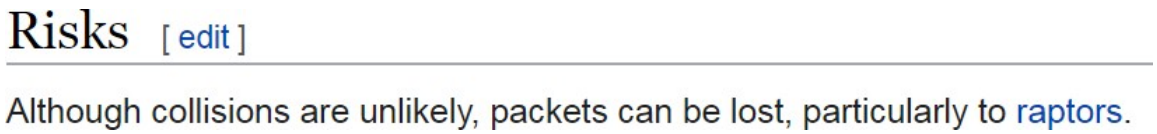
Internet Analogy: Mail

What’s the goal of the Internet?

- Move data from one location to another
- Analogy: I write a message on a piece of paper. How do I send this message to you?
- Solution: Postal system

Building block 1: Something That Moves Data

- The Internet is built on technology that moves bits across space
- Voltages on wires, wireless technology, radio waves, etc.

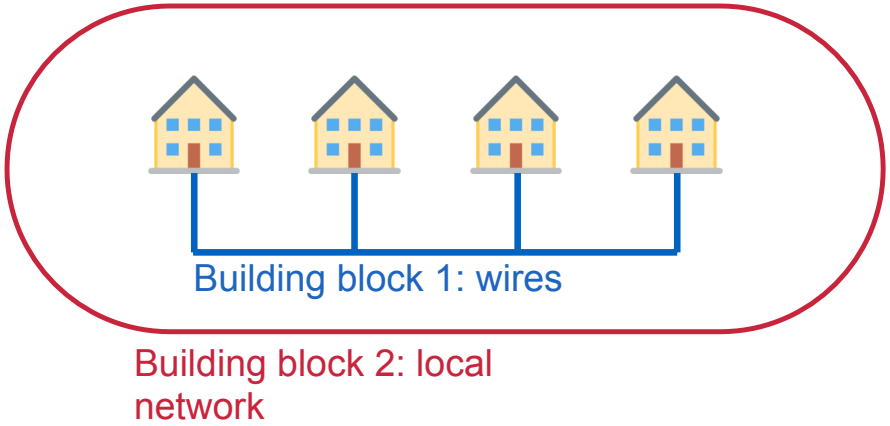


Risks [edit]

Although collisions are unlikely, packets can be lost, particularly to raptors.

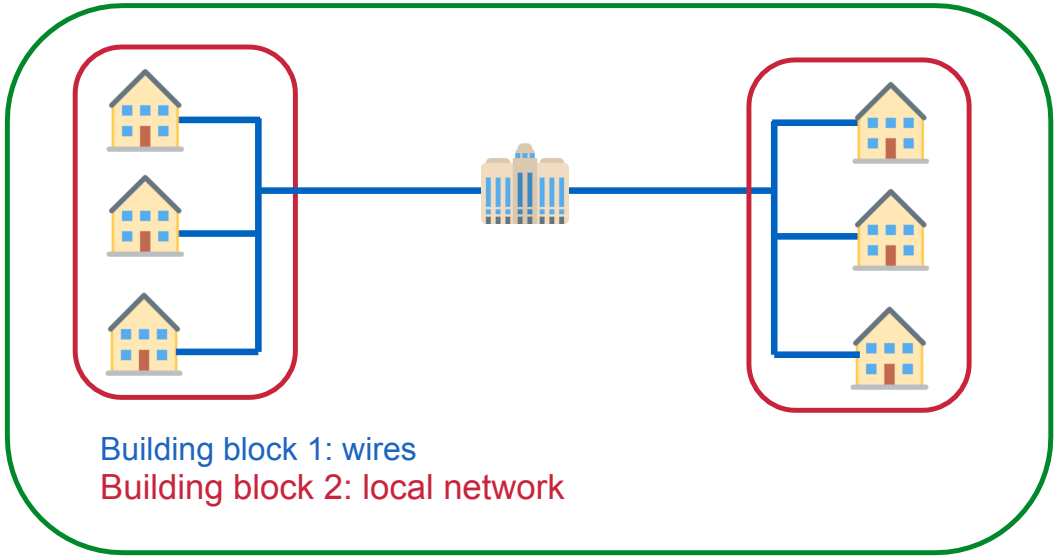
Building block 2: Talking to the Apartment Complex

- Using building block 1, we can link up people within a local apartment complex
- Forms a local area network (LAN)



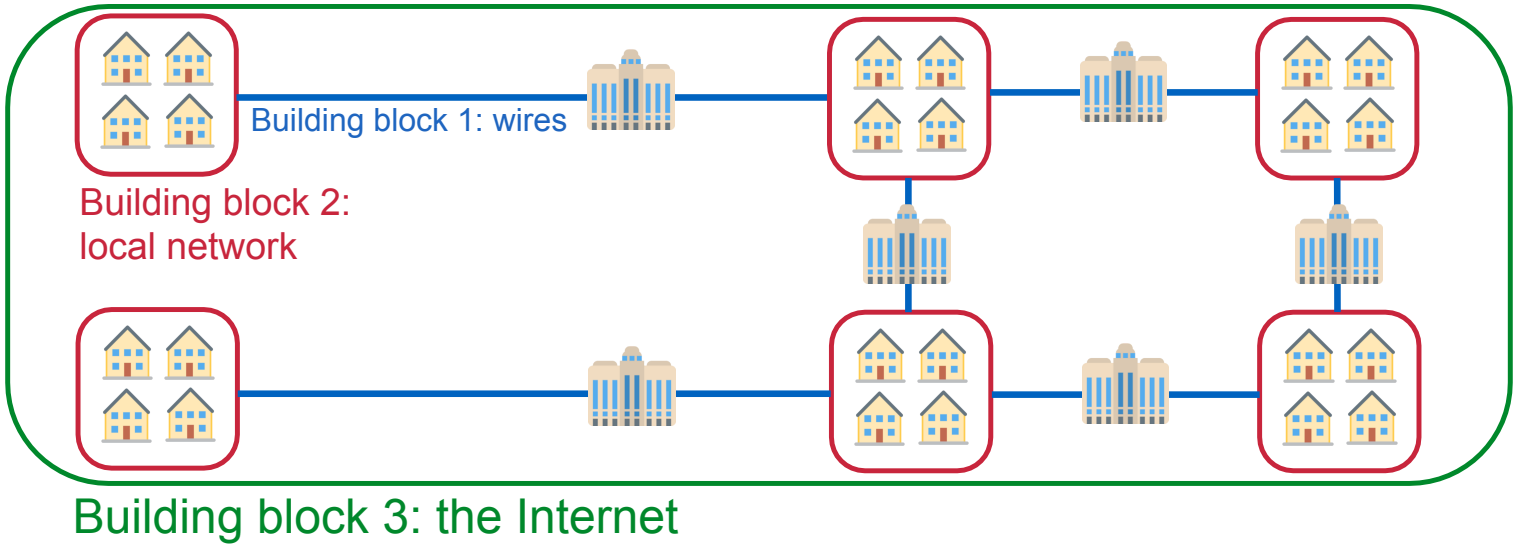
Building block 3: Post offices

- A post office connects two or more apartment complexes
- Forms a wide area network



Building block 3: The Internet

- Connect the entire world using post offices
- Messages may pass through multiple post offices before reaching destination



Layers of abstraction

Layer 3: Connect many local networks to form a global network

Layer 2: Create links in a local area

Layer 1: Move bits across space

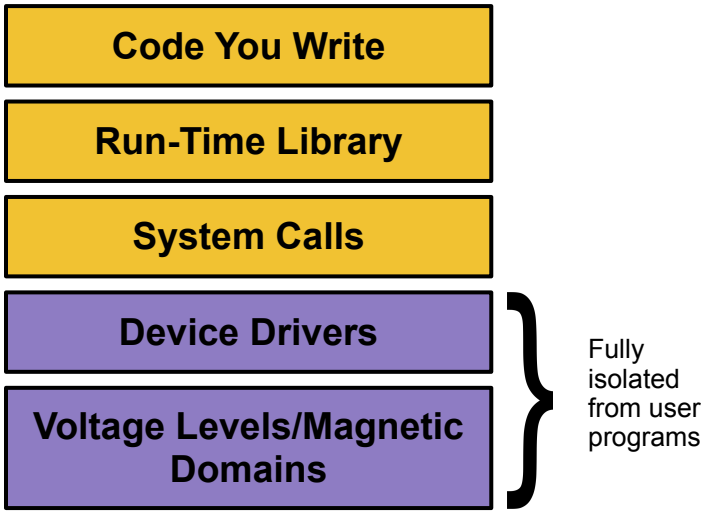
- A change in layer 1 implementation (wireless instead of wires) doesn't affect the other layers
- A change in layer 2 protocols doesn't affect the other layers

Layering: The OSI Model

Layering

- Internet design is partitioned into various layers. Each layer…
  - Has a protocol
  - Relies on services provided by the layer below it
  - Provides services to the layer above it

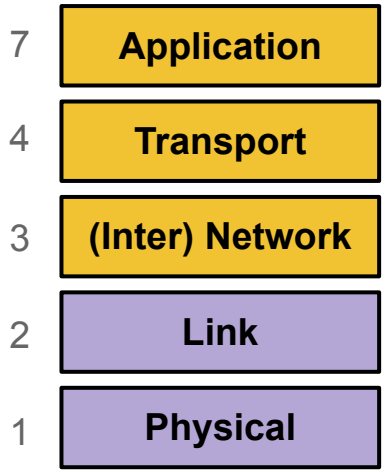
- Analogous to the structure of an application and the “services” that each layer relies on and provides



OSI Model

- **OSI model:** Open Systems Interconnection model, a layered model of Internet communication
  - Originally divided into 7 layers
    - But layers 5 and 6 aren't used in the real world, so we ignore them

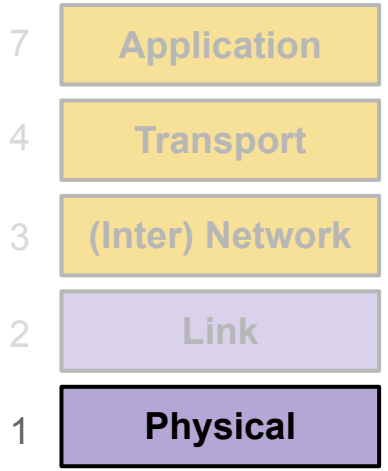
- Same reliance upon abstraction
  - A layer can be implemented in different ways without affecting other layers
  - A layer's protocol can be substituted with another protocol without affecting other layers



Layer 1: Physical Layer

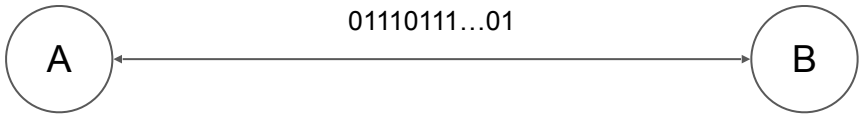
- **Provides**: Sending bits from one device to another
  - Encodes bits to send them over a physical link
    - Patterns of voltage levels
    - Photon intensities
    - RF modulation

- Examples
  - Wi-Fi radios (IEEE 802.11)
  - Ethernet voltages (IEEE 802.3)

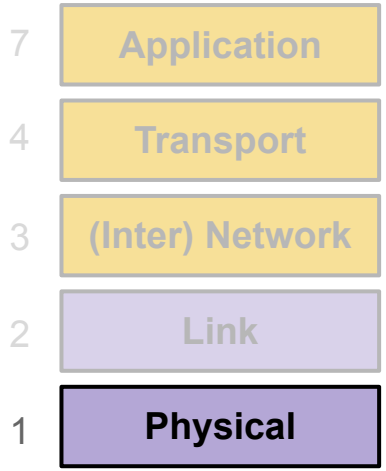


Layer 1: Physical Layer

Physical layer: “How do I transmit this sequence of 0’s and 1’s from A to B?”



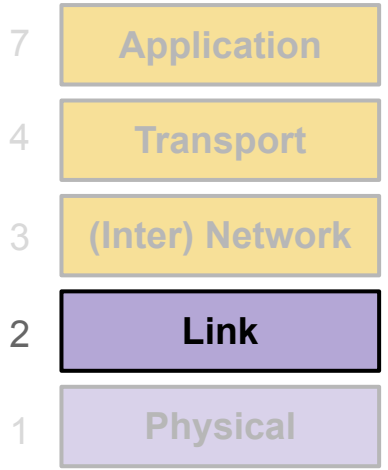
Next: How do we talk to more than one device?



Layer 2: Link Layer

- **Provides**: Sending frames directly from one device to another
  - **Relies upon**: Sending bits from one device to another
  - Encodes messages into groups of bits called “frames”

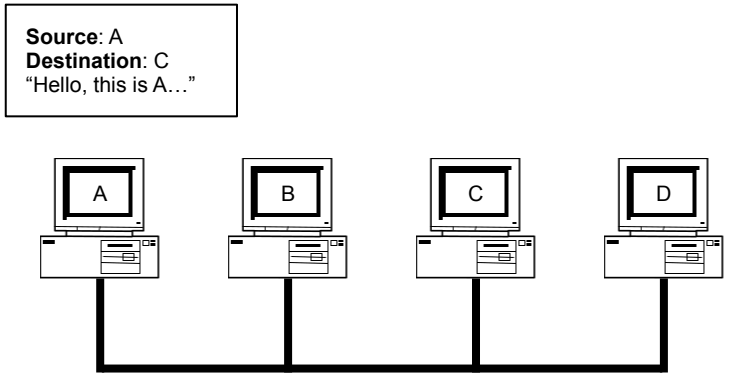
- Examples
  - Ethernet frames (IEEE 802.3)



Layer 2: Link Layer

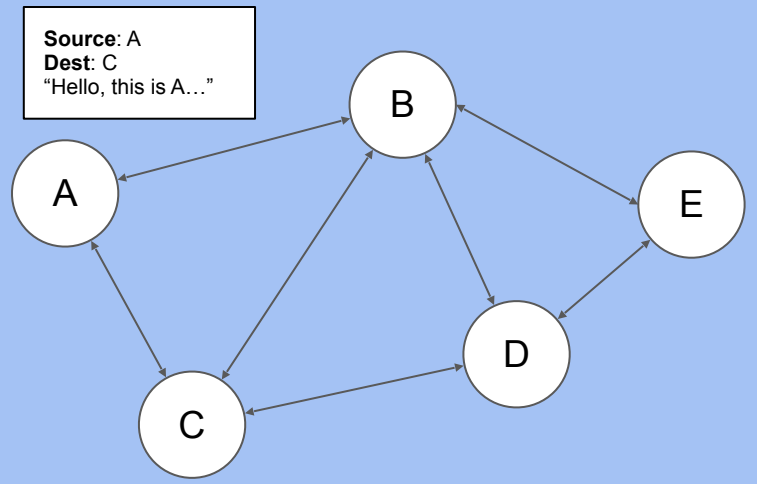
- **Local area network (LAN)**: A set of computers on a shared network that can directly address one another
  - Consists of multiple physical links

- Frames must consist of at least 3 things:
  - Source (“Who is this message coming from?”)
  - Destination (“Who is this message going to?”)
  - Data (“What does this message say?”)



Layer 2: Link Layer

- In reality, computers aren't all connected to the same wire
  - Instead, local networks are a set of point-to-point links
- However, Layer 2 still allows direct addressing between any two devices
  - Enabled by transmitting a frame across multiple physical links until it reaches its destination



Ethernet and MAC Addresses

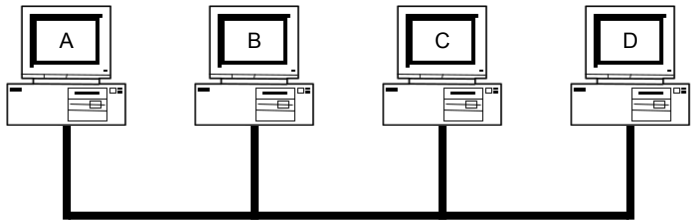
- **Ethernet**: A common layer 2 protocol that most endpoint devices use

- **MAC address**: A 6-byte address that identifies a piece of network equipment (e.g. your phone's Wi-Fi antenna)
  - Typically represented as 6 hex bytes: **13:37:ca:fe:f0:0d**
  - The first 3 bytes are assigned to manufacturers (i.e. who made the equipment)
    - This is useful in identifying a device
  - The last 3 bytes are device-specific

Layer 2: Link Layer

Link layer: “How do I transmit this frame from A to C, making sure that no one else thinks the message is for them?”

Source: A
Dest: C
“Hello, this is A…”



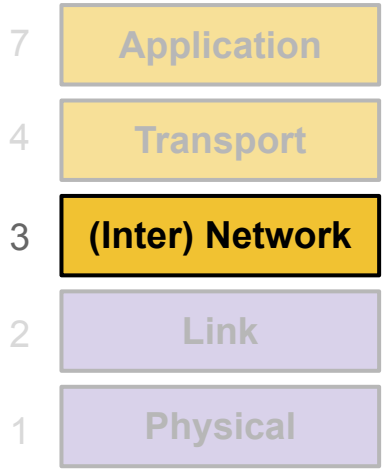
7	Application
4	Transport
3	(Inter) Network
2	**Link**
1	Physical

Next: How do we address every device in existence?

Layer 3: Network Layer

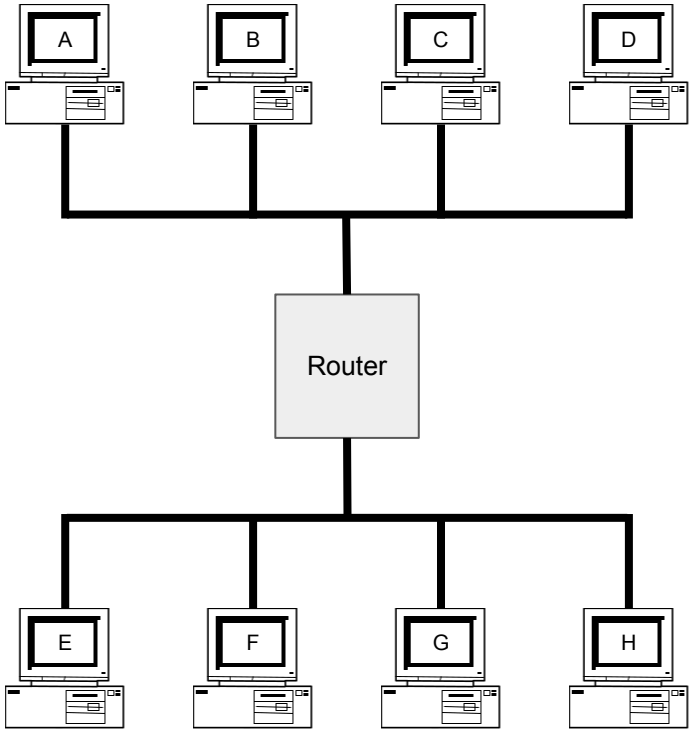
- **Provides**: Sending packets from any device to any other device
  - **Relies upon**: Sending frames directly from one device to another
  - Encodes messages into groups of bits called “packets”
  - Bridges multiple LANs to provide global addressing

- Examples
  - Internet Protocol (IP)

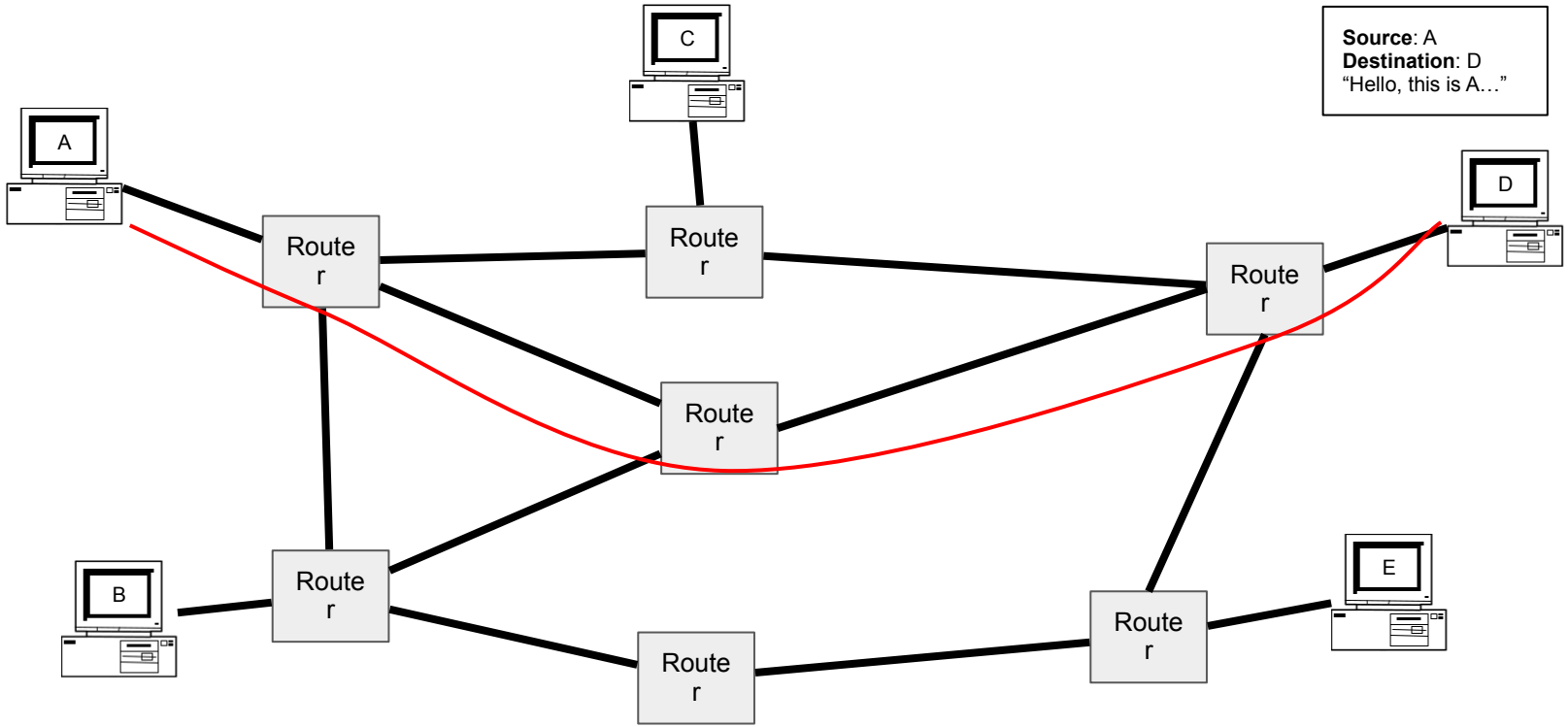


Layer 3: Network Layer

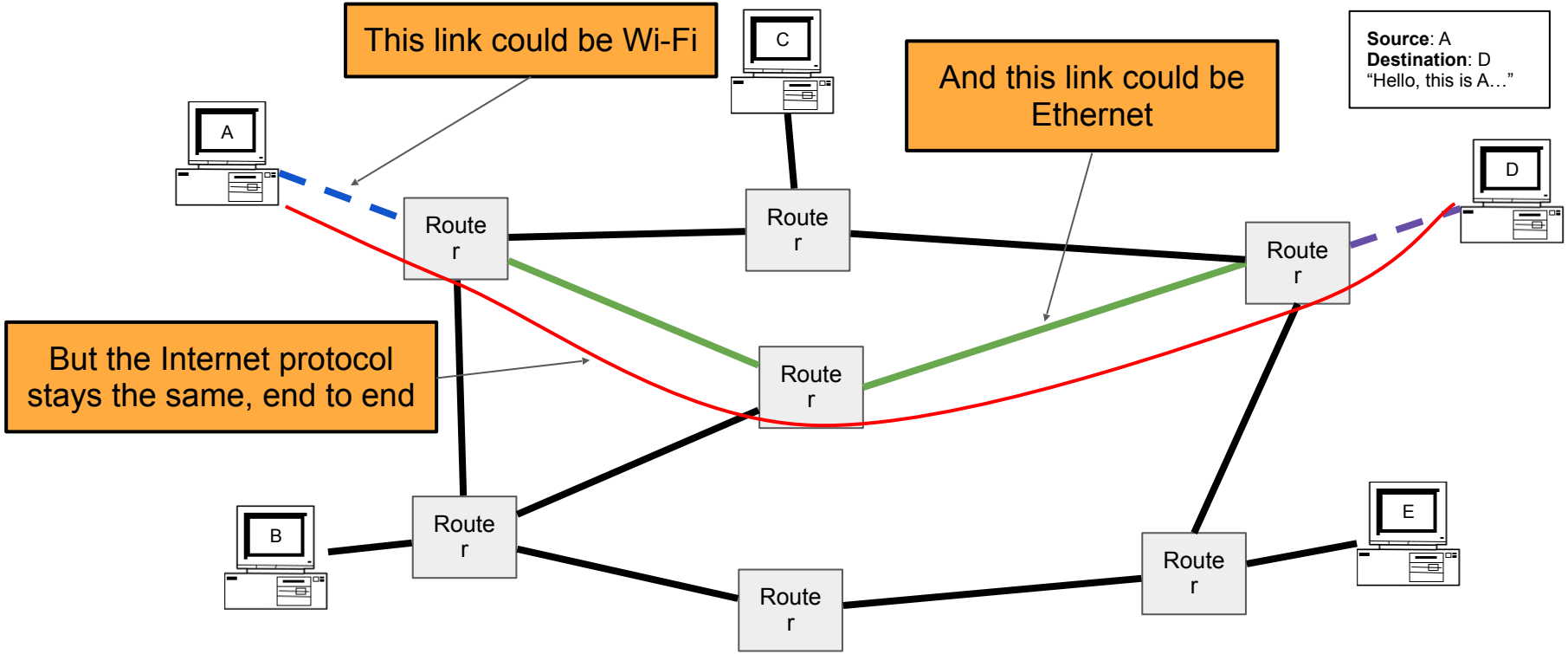
- Recall the ideal layer 2 model: All devices can directly address all other devices
  - This would not scale to the size of the Internet!
- Instead, allow packets to be **routed** across different devices to reach the destination
  - Each hop is allowed to use its own physical and link layers!



Layer 3: Network Layer



Layer 3: Network Layer



Layer 3: Network Layer

- Packets must consist of at least 3 things:
  - Source (“Who is this message coming from?”)
  - Destination (“Who is this message going to?”)
  - Data (“What does this message say?”)
  - Similar to frames (layer 2)

- Packets may be fragmented into smaller packets
  - Different links might support different maximum packet sizes
  - Up to the recipient to reassemble fragments into the original packet

- Each router forwards a given packet to the next hop
  - We will cover how a router knows how to forward—and attacks on it—in the future

- Packets are not guaranteed to take a given route
  - Two packets with the same source and destination may take different routes

Internet Protocol (IP)

- **Internet Protocol (IP)**: The universal layer-3 protocol that all devices use to transmit data over the Internet

- **IP address**: An address that identifies a device on the Internet
  - IPv4 is 32 bits, typically written as 4 decimal octets, e.g. **35.163.72.93**
  - IPv6 is 128 bits, typically written as 8 groups of 2 hex bytes: **2607:f140:8801::1:23**
    - If digits or groups are missing, fill with 0's, so **2607:f140:8801:0000:0000:0000:0001:0023**
  - Globally unique from any single perspective
    - For now, you can think of them as just being globally unique
  - IP addresses help nodes make decisions on where to forward the packet

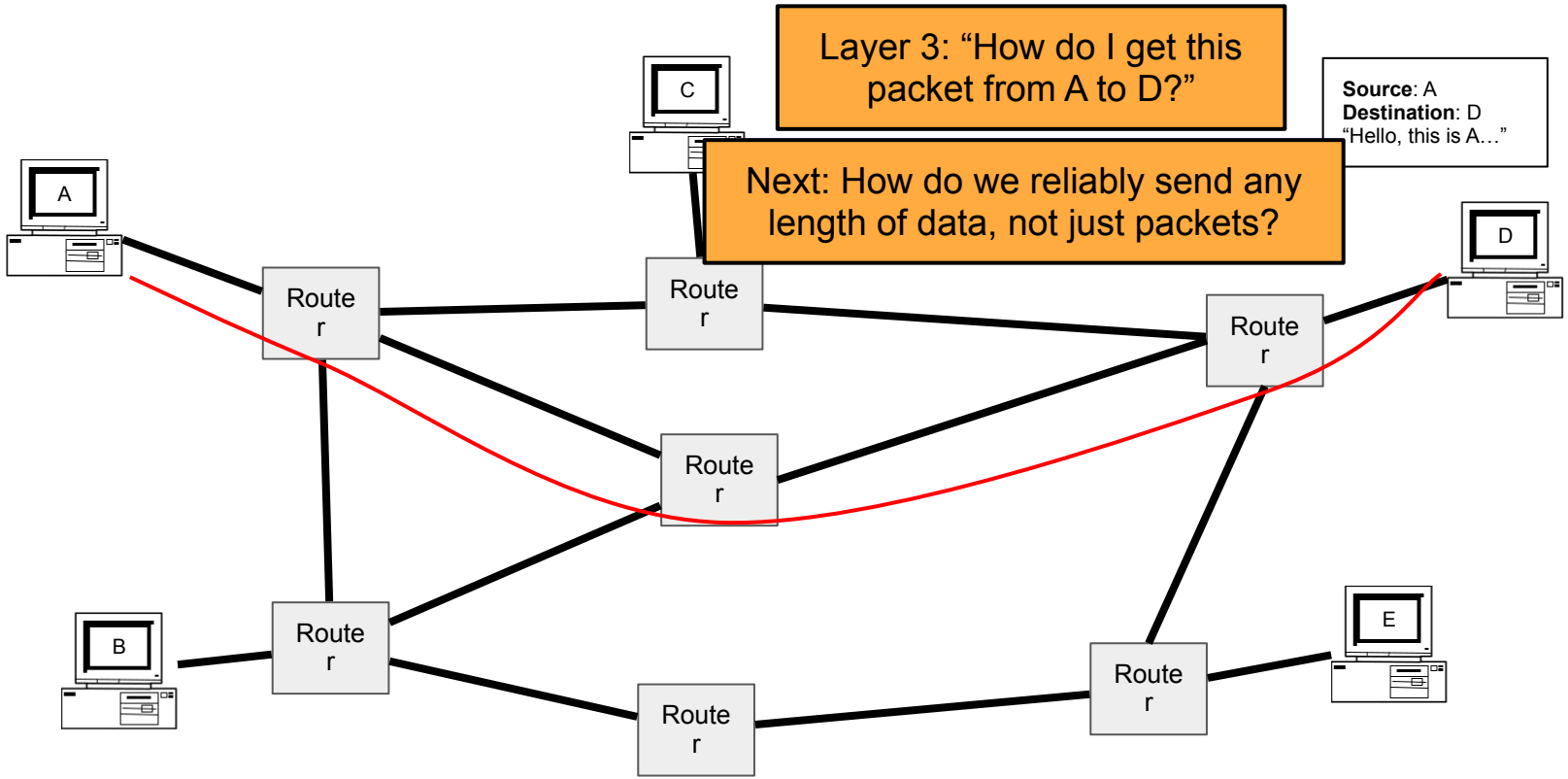
Reliability

- **Reliability** ensures that packets are received correctly or, if random errors occur, not at all
  - This is implemented with a checksum
  - However, there is no cryptographic MAC, so there are no guarantees if an attacker modifies packets

- IP is *unreliable* and only provides a **best effort** delivery service, which means:
  - Packets may be lost (“dropped”)
  - Packets may be corrupted
  - Packets may be delivered out of order

- It is up to higher level protocols to ensure that the connection is reliable

Layer 3: Network Layer

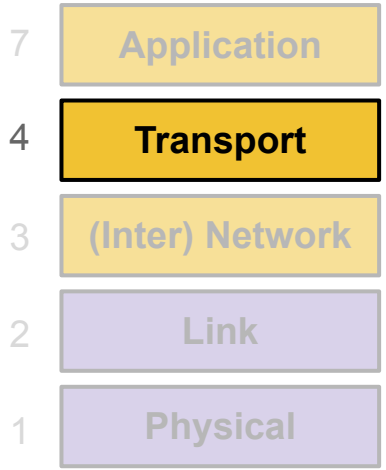


Layer 4: Transport Layer

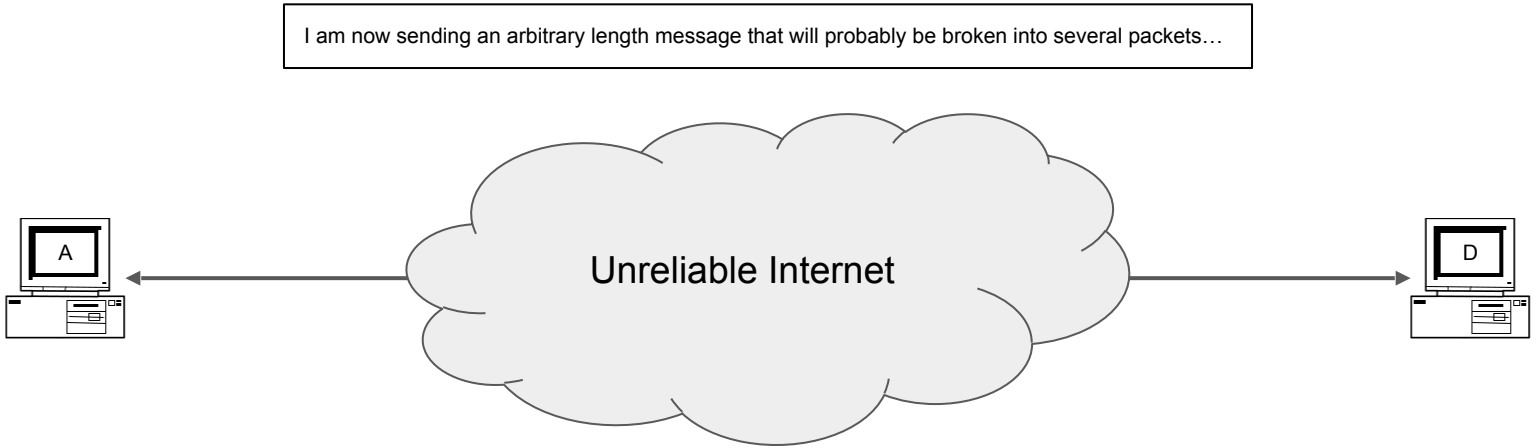
- **Provides**: Transportation of variable-length data from any point to any other point
  - **Relies upon**: Sending packets from any device to any other device
  - Builds abstractions that are useful to applications on top of layer 3 packets

- Useful abstractions
  - **Reliability**: Transmit data reliably, in order
  - **Ports**: Provide multiple “addresses” per real IP address

- Examples
  - **TCP**: Provides reliability and ports
  - **UDP**: Provides ports, but no reliability



Layer 4: Transport Layer

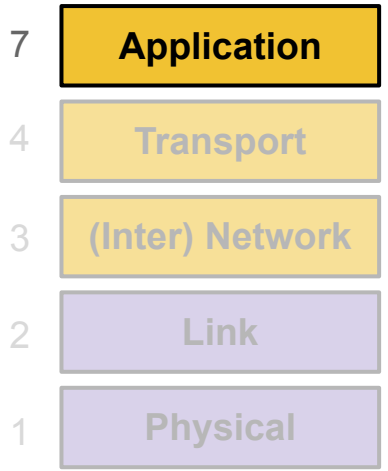


Layer 4: “How do I transport this arbitrary data over an unreliable medium?”

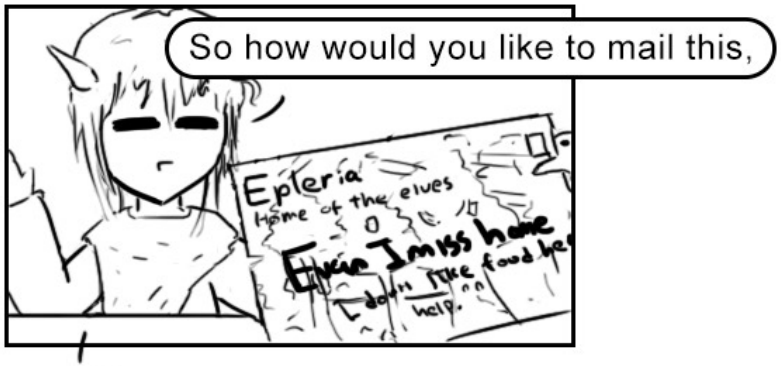
Layer 7: Application Layer

- **Provides**: Applications and services to users!
  - **Relies upon**: Transportation of variable-length data from any point to any other point

- Every online application is Layer 7
  - Web browsing
  - Online video games
  - Messaging services
  - Video calls (Zoom)



Headers


So how would you like to mail this,
Epteria
home of the elves
I miss home

Example: Sending Mail

Alice

I am hungry.

Bob

Example: Sending Mail

Alice

Send to: Bob

I am hungry.

Bob

Example: Sending Mail

Alice

Mail to: 123 Bob St

Send to: Bob

I am hungry.

Bob

Example: Sending Mail

Alice

Bob

Mail to: 123 Bob St

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I am hungry.

Example: Sending Mail

Alice

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Send to: Bob

I am hungry.

Example: Sending Mail

Alice

Bob

I am hungry.

Example: Sending Mail

Each layer communicates with each other, relying on abstractions below them!

Alice

Bob

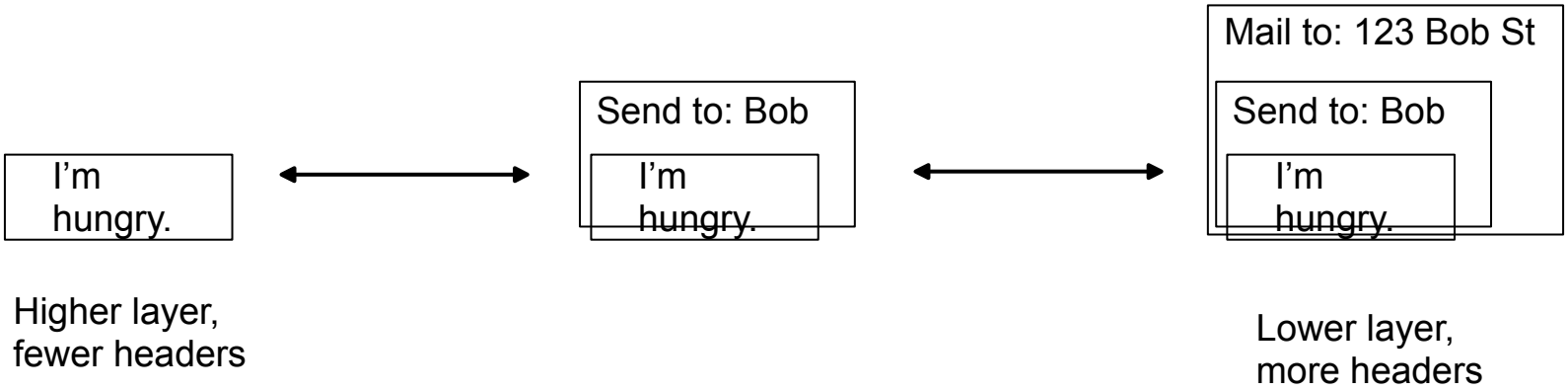
Relies upon: Sending messages to people

Provides: Sending messages to people
Relies upon: Sending messages to addresses

Provides: Sending messages to addresses

Layers of Abstraction and Headers

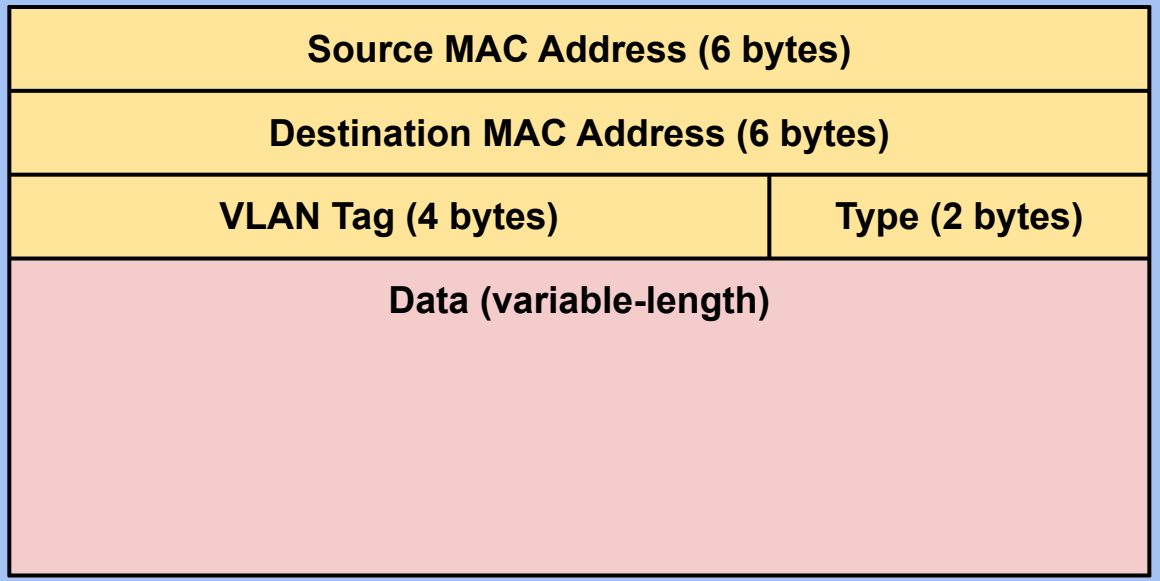
- As you move to lower layers, you wrap additional headers around the message
- As you move to higher layers, you peel off headers around the message



Layers of Abstraction and Headers

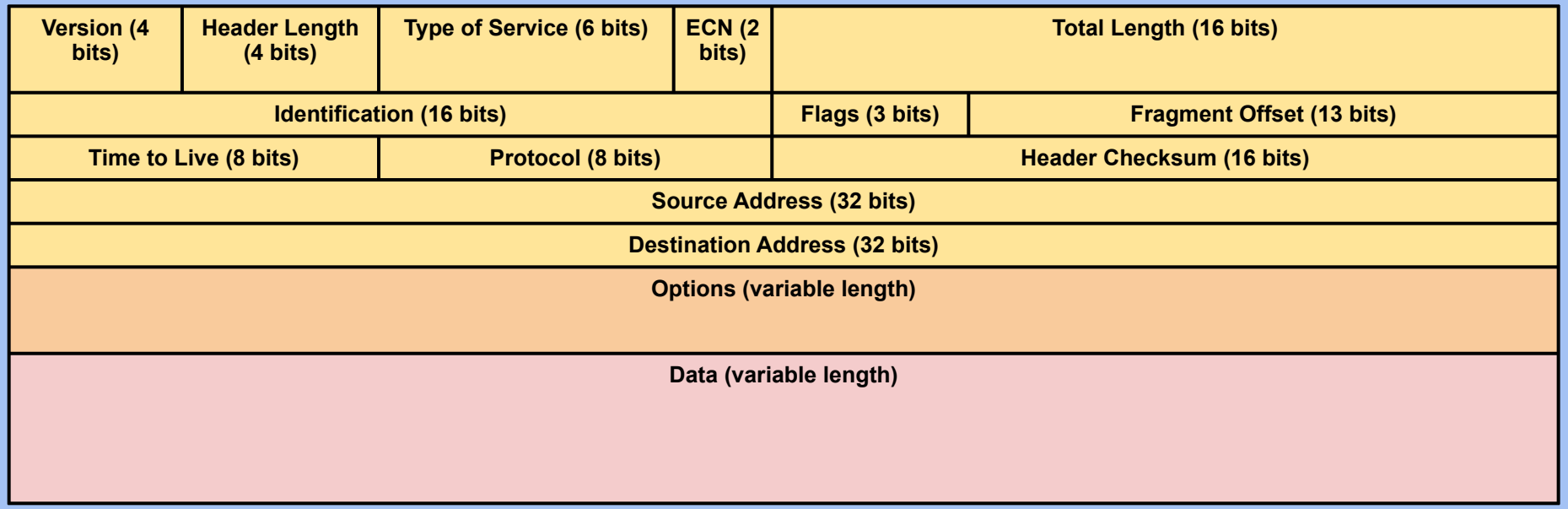
- As you move to lower layers, you wrap additional headers around the message
- As you move to higher layers, you peel off headers around the message
- When sending a message we go from the highest to the lowest layer
- When receiving a message we go from the lowest to highest layer

Layer 2 Header



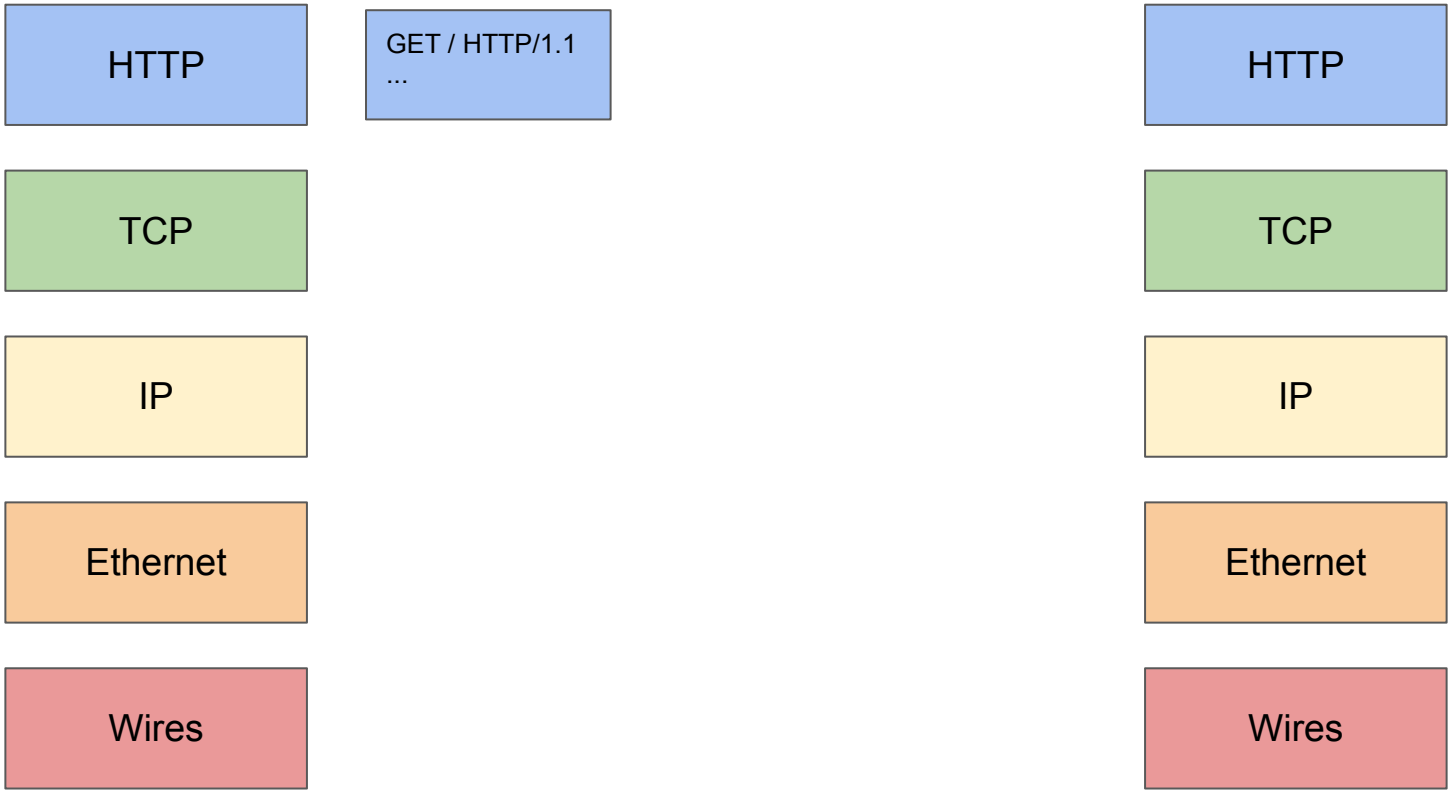
Ethernet and MAC address headers

Layer 3 Header



IPv4 header

Example: HTTP Request



Example: HTTP Request

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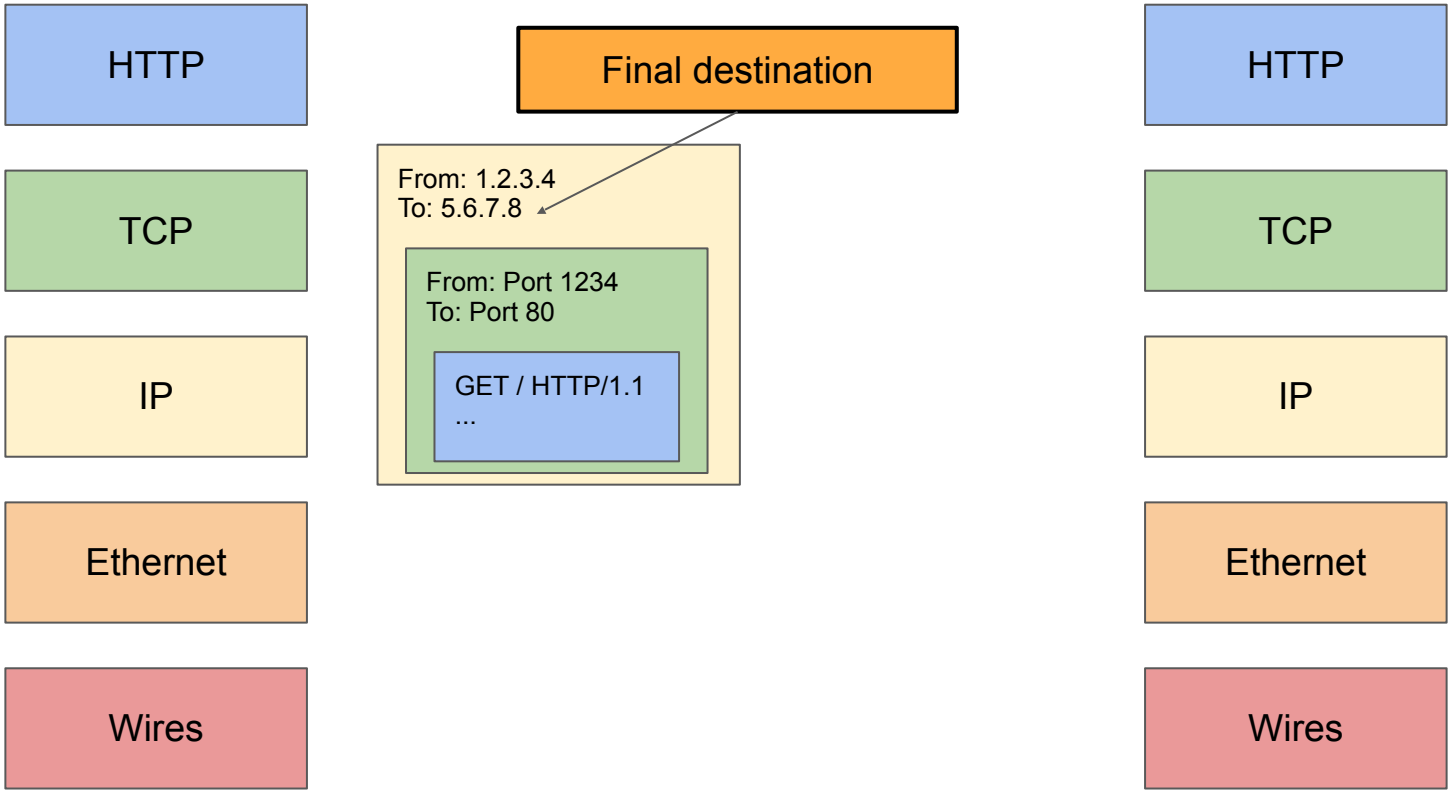

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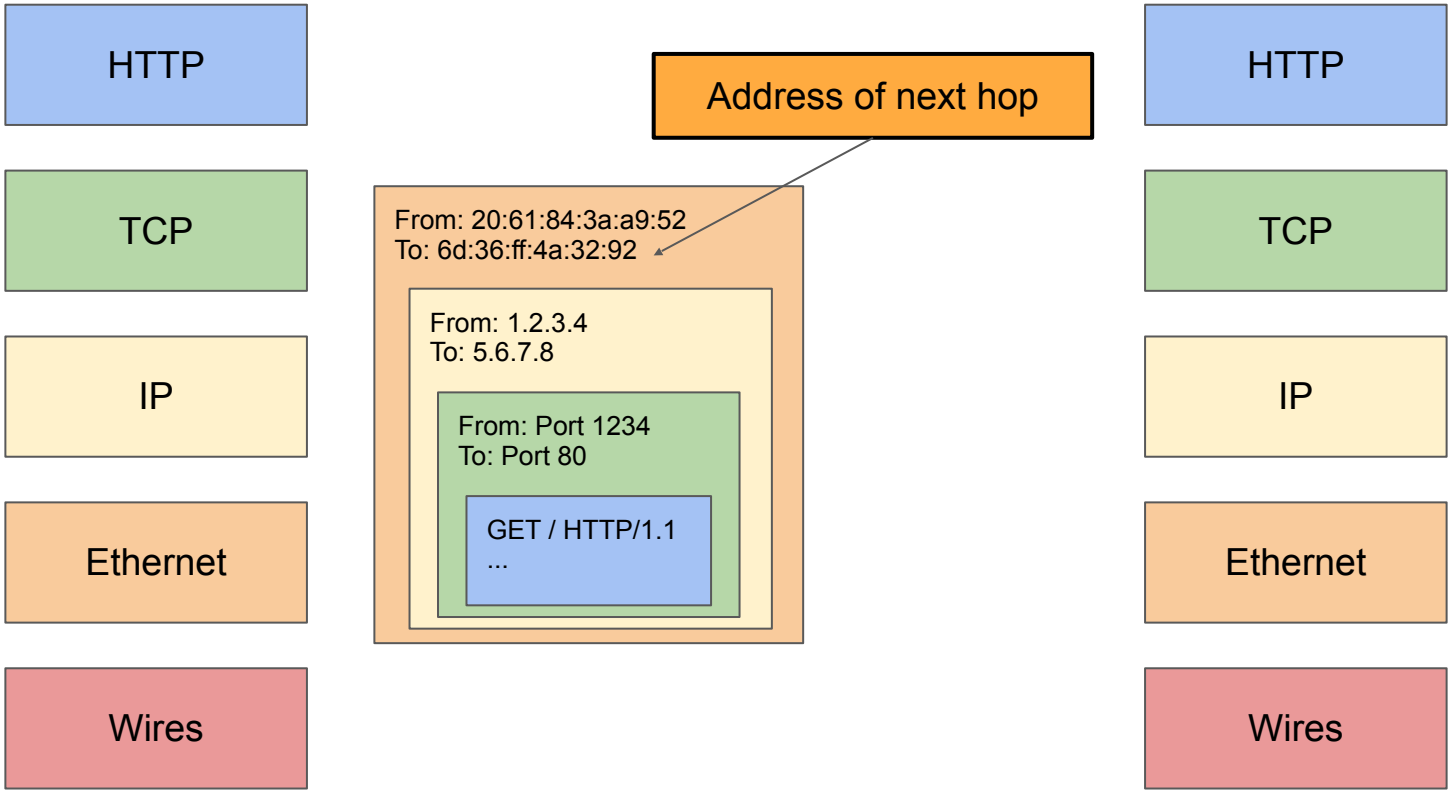

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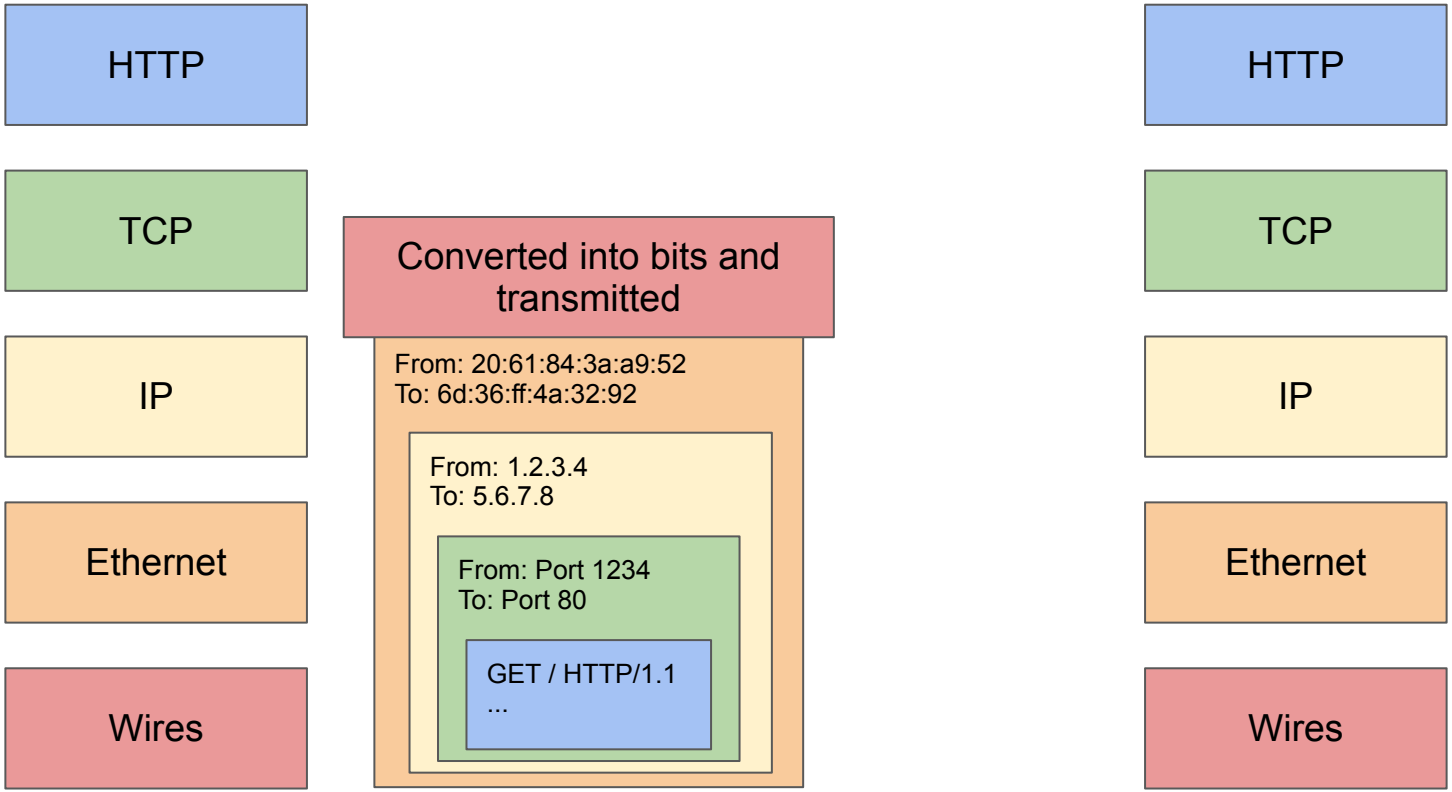

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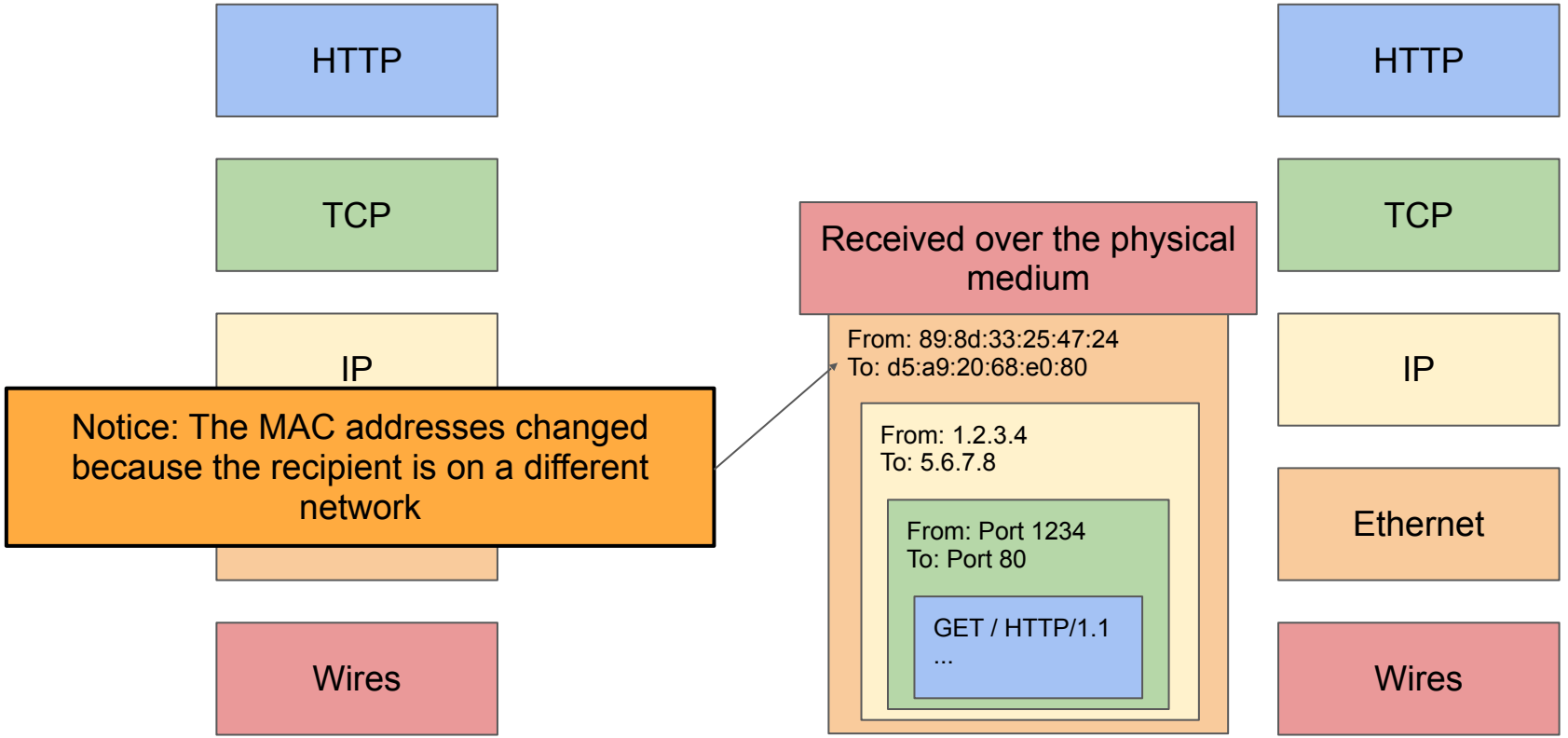

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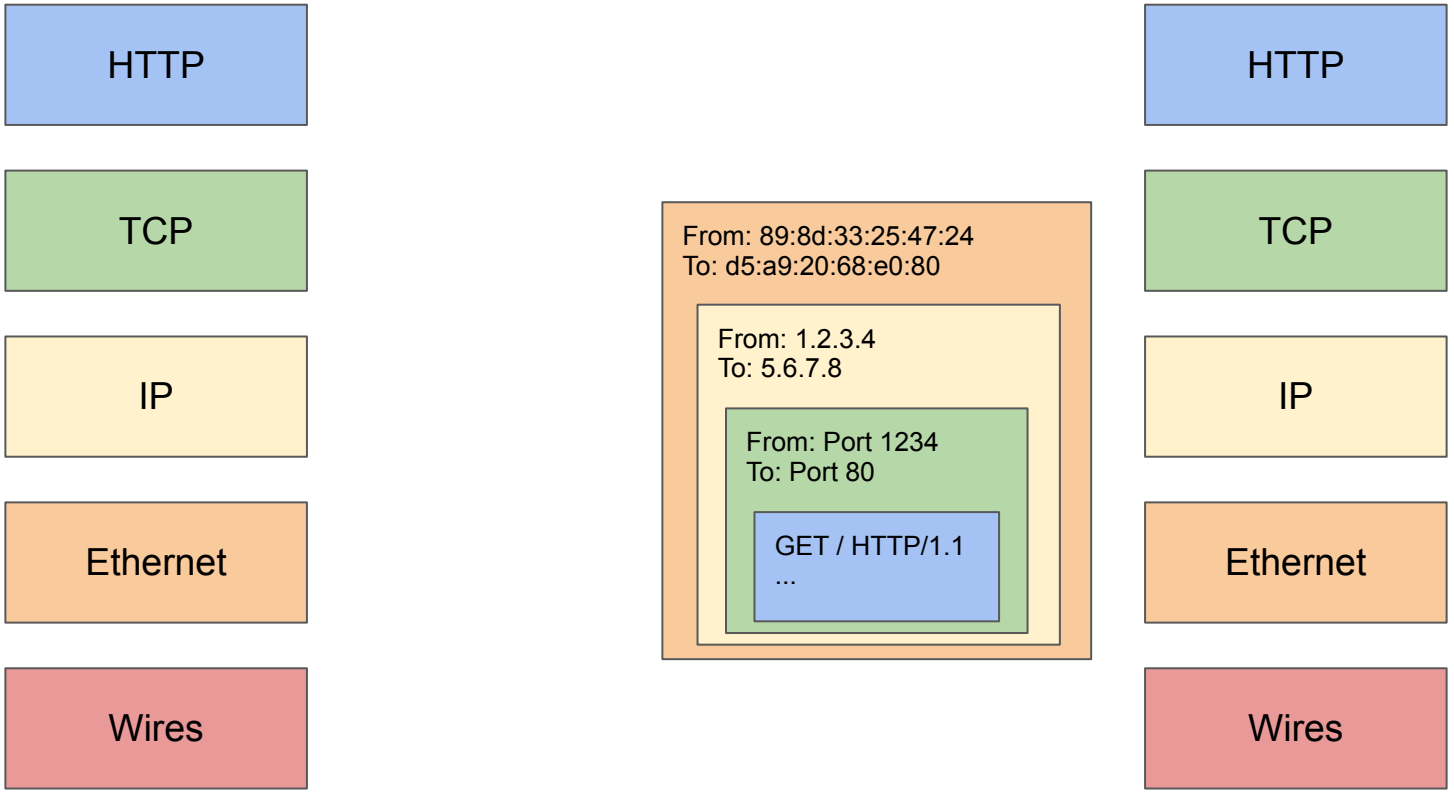

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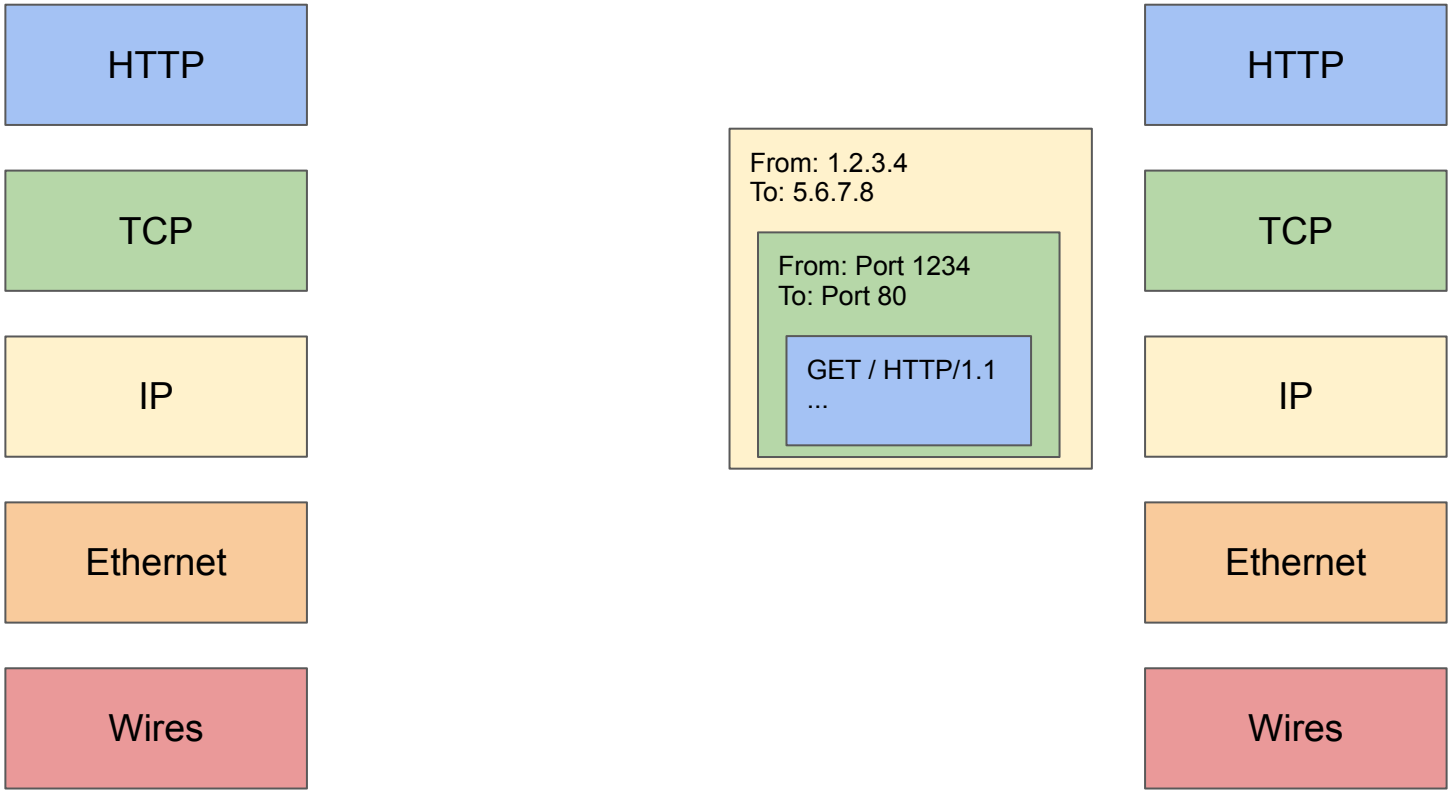

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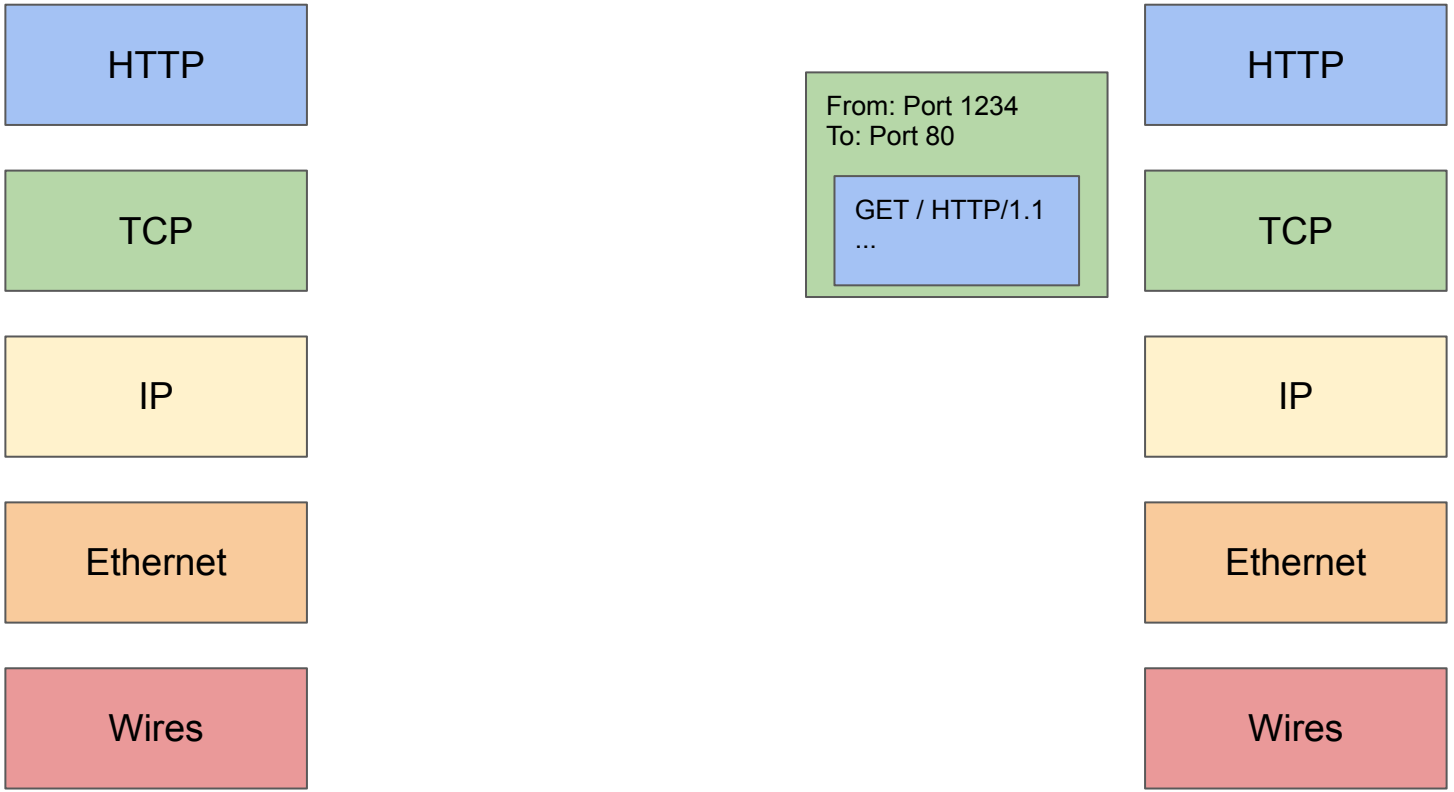

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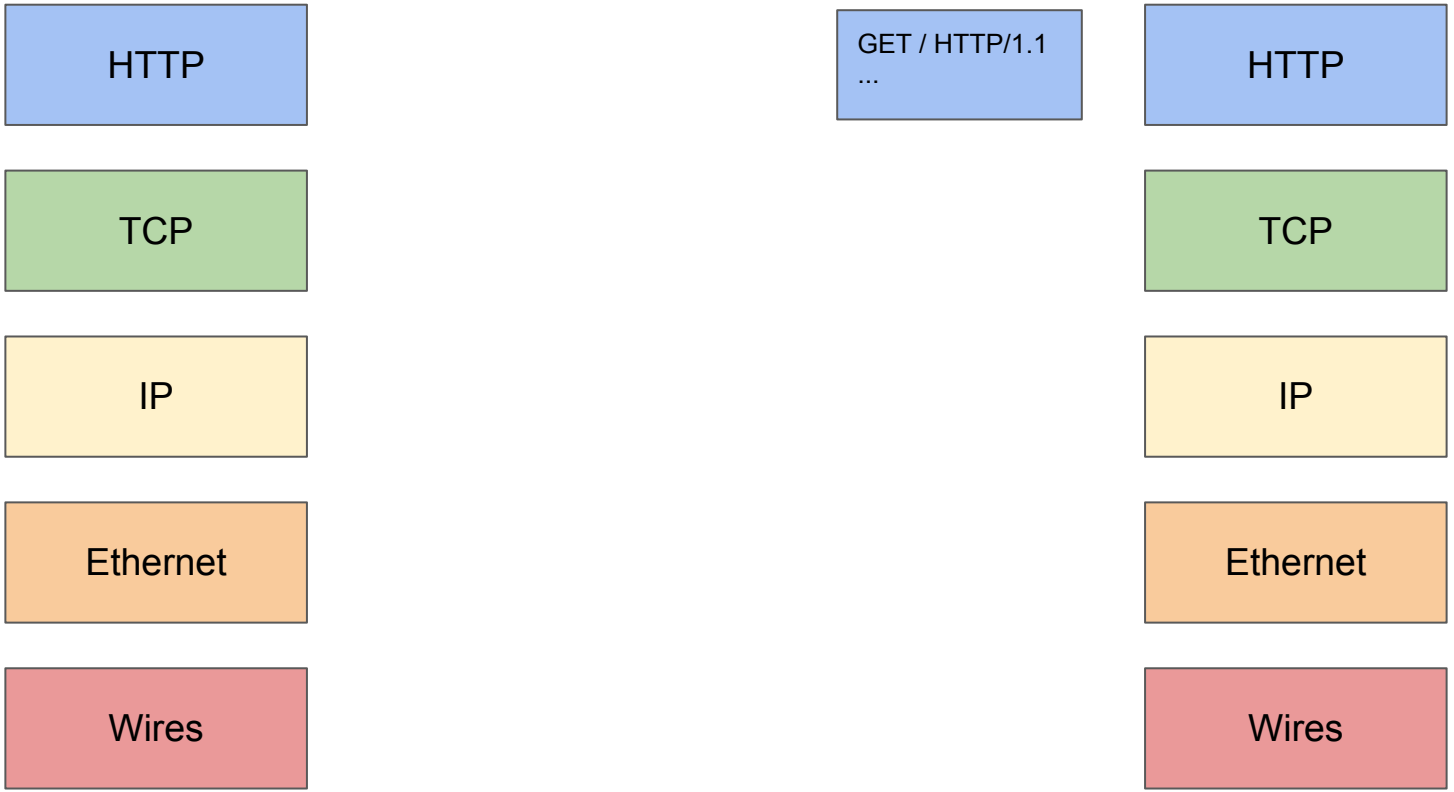

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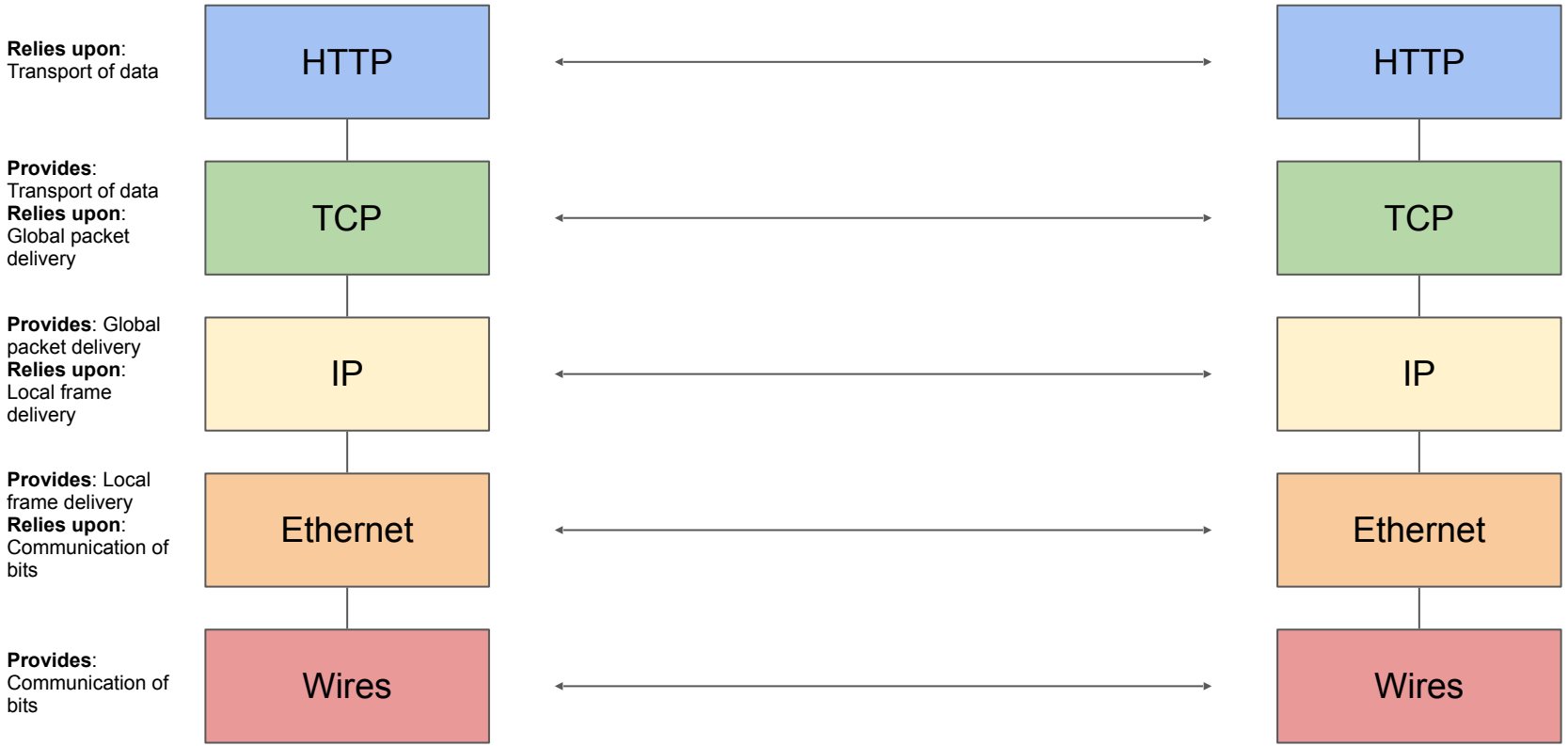

Intro to Networking: Summary

- Internet: A global network of computers
  - Protocols: Agreed-upon systems of communication

- OSI model: A layered model of protocols
  - Layer 1: Communication of bits
  - Layer 2: Local frame delivery
    - Ethernet: The most common Layer 2 protocol
    - MAC addresses: 6-byte addressing system used by Ethernet
  - Layer 3: Global packet delivery
    - IP: The universal Layer 3 protocol
    - IP addresses: 4-byte (or 16-byte) addressing system used by IP
  - Layer 4: Transport of data (more on this next time)
  - Layer 7: Applications and services (the web)