Lecture 17: Networking Background

https://cs161.org

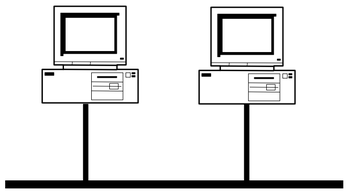
Announcements

- HW2B due tonight
- Project 2 design doc due Friday
- Networking tutorial, Saturday 3/7, 5-7pm, in HP Auditorium (306 Soda)

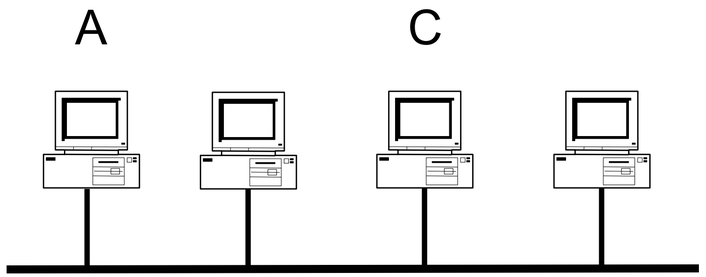
Network Security

- Today: background in networking, so we can explore network security for next 3 weeks
  - Speed running a month of networking in one lecture, so I'll focus on aspects that are security-relevant
  - Please ask questions when things are unclear!

Local-Area Networks



point-to-point

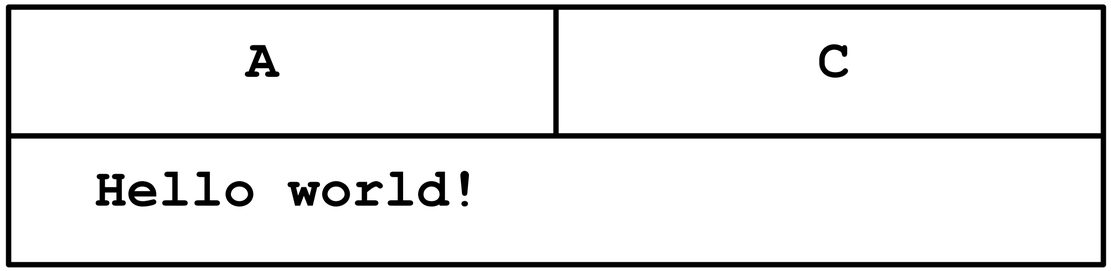


shared

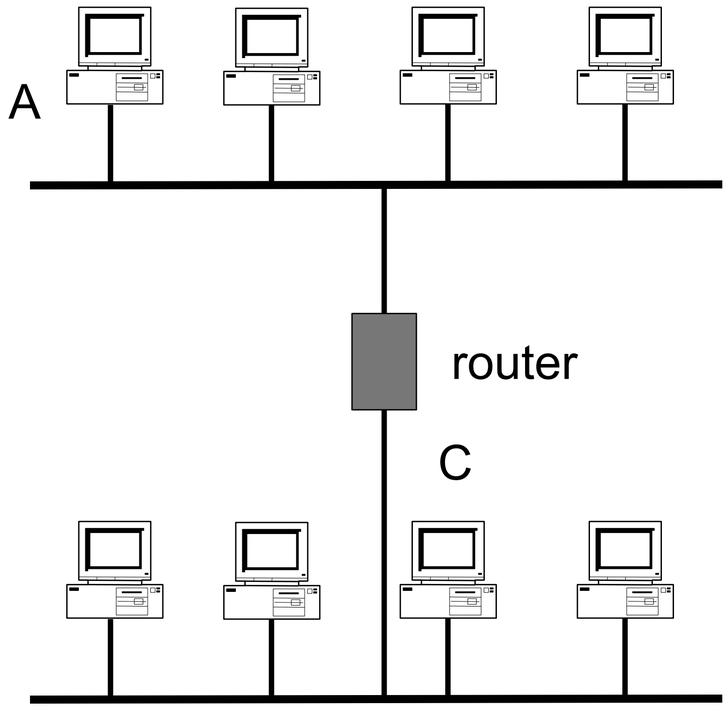
How does computer A send a message to computer C?

Local-Area Networks (LAN): Packets


```
Source: A
Destination: C
Message: Hello world!
```

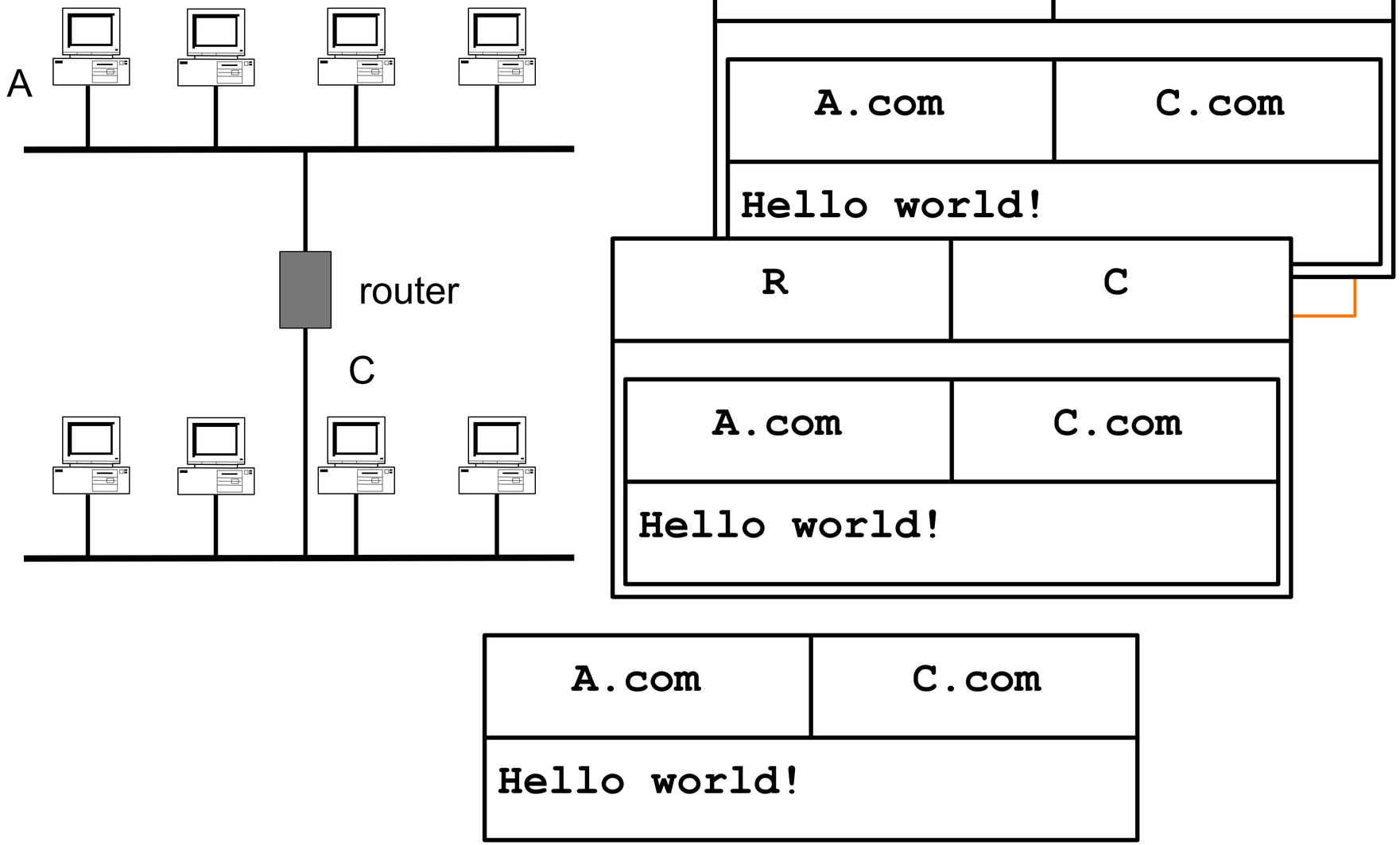


Wide-Area Networks



How do we connect two LANs?

Wide-Area Networks



Protocols

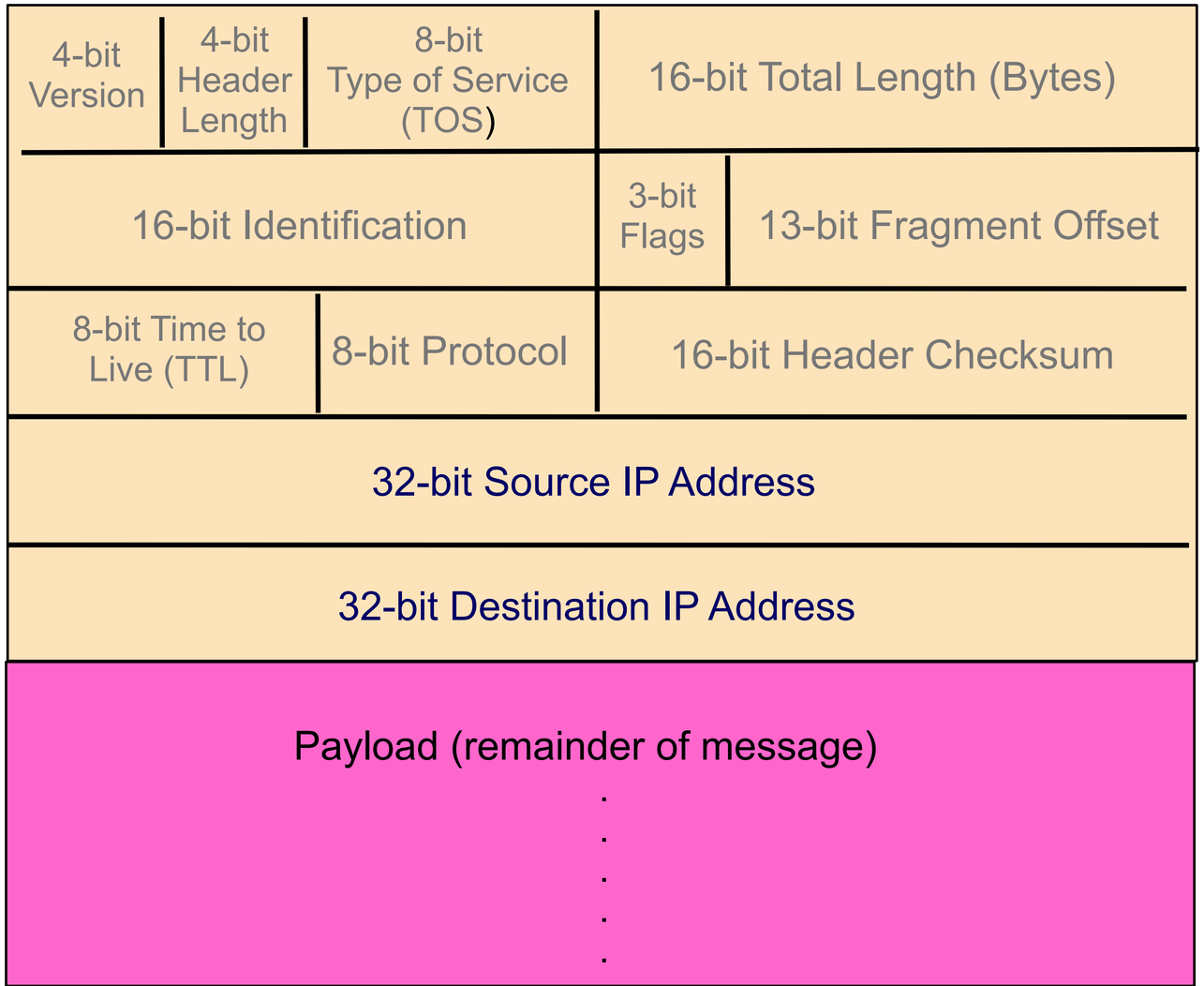
- A protocol is an agreement on how to communicate
- Includes syntax and semantics
  - How a communication is specified & structured
    - Format, order messages are sent and received
  - What a communication means
    - Actions taken when transmitting, receiving, or timer expires
- E.g.: making a comment in lecture?
  1. Raise your hand.
  2. Wait to be called on.
  3. Or: wait for speaker to **pause** and vocalize
  4. If unrecognized (after timeout): vocalize w/ “excuse me”

Network is Dumb

- Original Internet design: interior nodes ("routers") have no knowledge* of ongoing connections going through them
- Not how you picture the telephone system works
  - Which internally tracks all of the active voice calls
- Instead: the postal system!
  - Each Internet message ("packet") self-contained
  - Interior routers look at destination address to forward
  - If you want smarts, build it "*end-to-end*", not "hop-by-hop"
  - Buys simplicity & robustness at the cost of shifting complexity into end systems

* Today's Internet is full of hacks that violate this

Self-Contained IP Packet Format

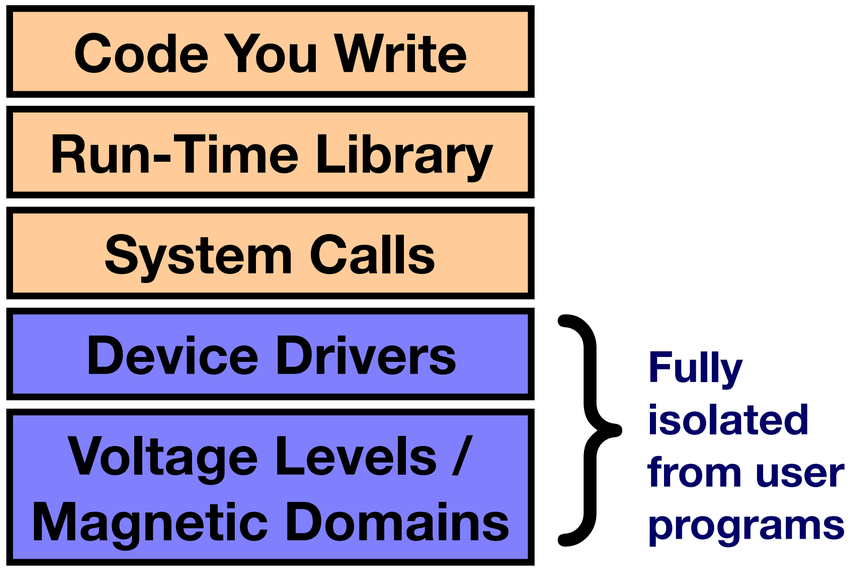


IP = Internet *Protocol*

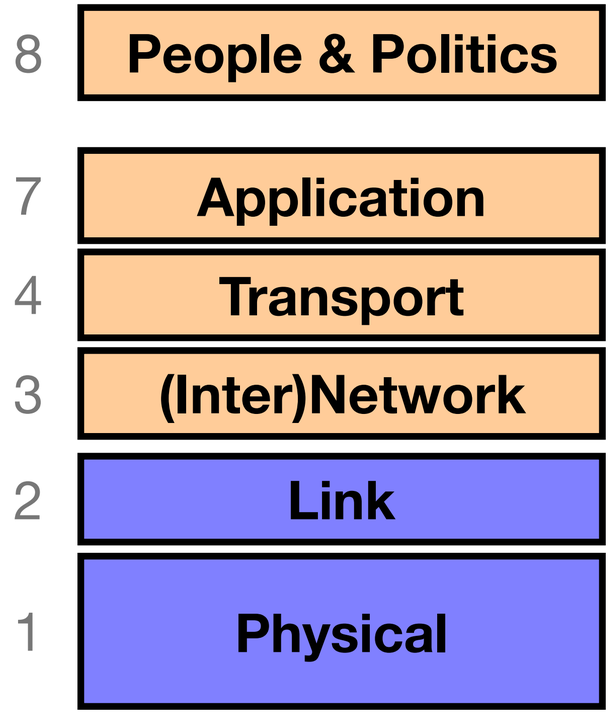
***Header* is like a letter envelope: contains all info needed for delivery**

Layering

- Internet design is partitioned into layers
  - Each layer relies on services provided by next layer below …
  - … and provides services to layer above it
- Analogy:
  - Consider structure of an application you've written and the "services" each layer relies on / provides



Internet Layering ("Protocol Stack"/"**OSI Model**")



Note on a point of potential confusion: these diagrams are always drawn with lower layers **below** higher layers …

But diagrams showing the layouts of packets are often the *opposite*, with the lower layers at the **top** since their headers precede those for higher layers

(And nobody remembers what layers 5 and 6 are for ("Session" and "Presentation) for the trivia buffs because they aren't really used)

(also, layer 8 is a "joke", but really is important)

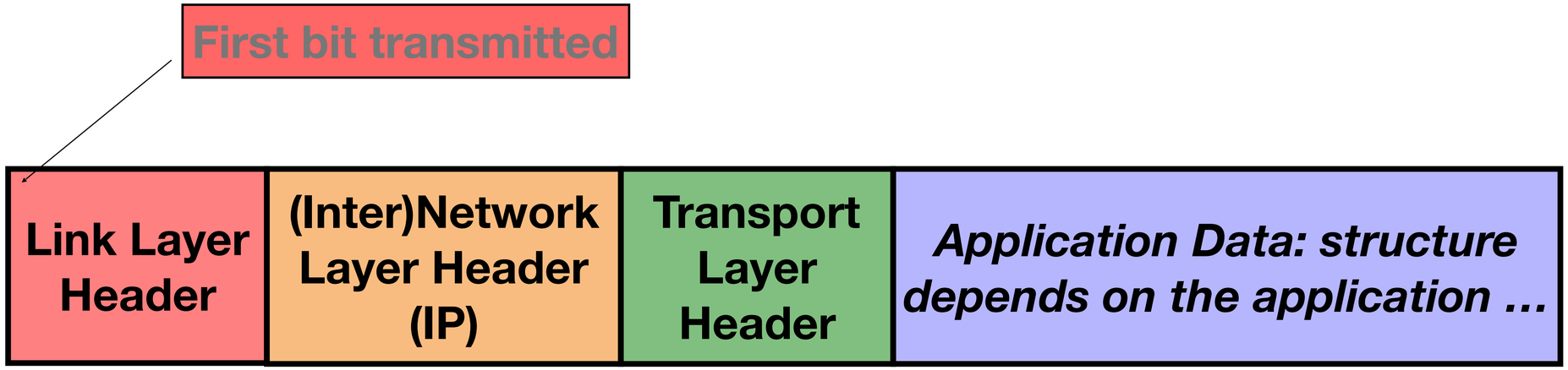
Packets and The Network

- Modern networks break communications up into packets
  - For our purposes, packets contain a variable amount of data up to a maximum specified by the particular network
- The sending computer breaks up the message and the receiving computer puts it back together
  - So the software doesn't actually see the packets per-se
  - Network itself is ***packet switched***: sending each packet on towards its next destination

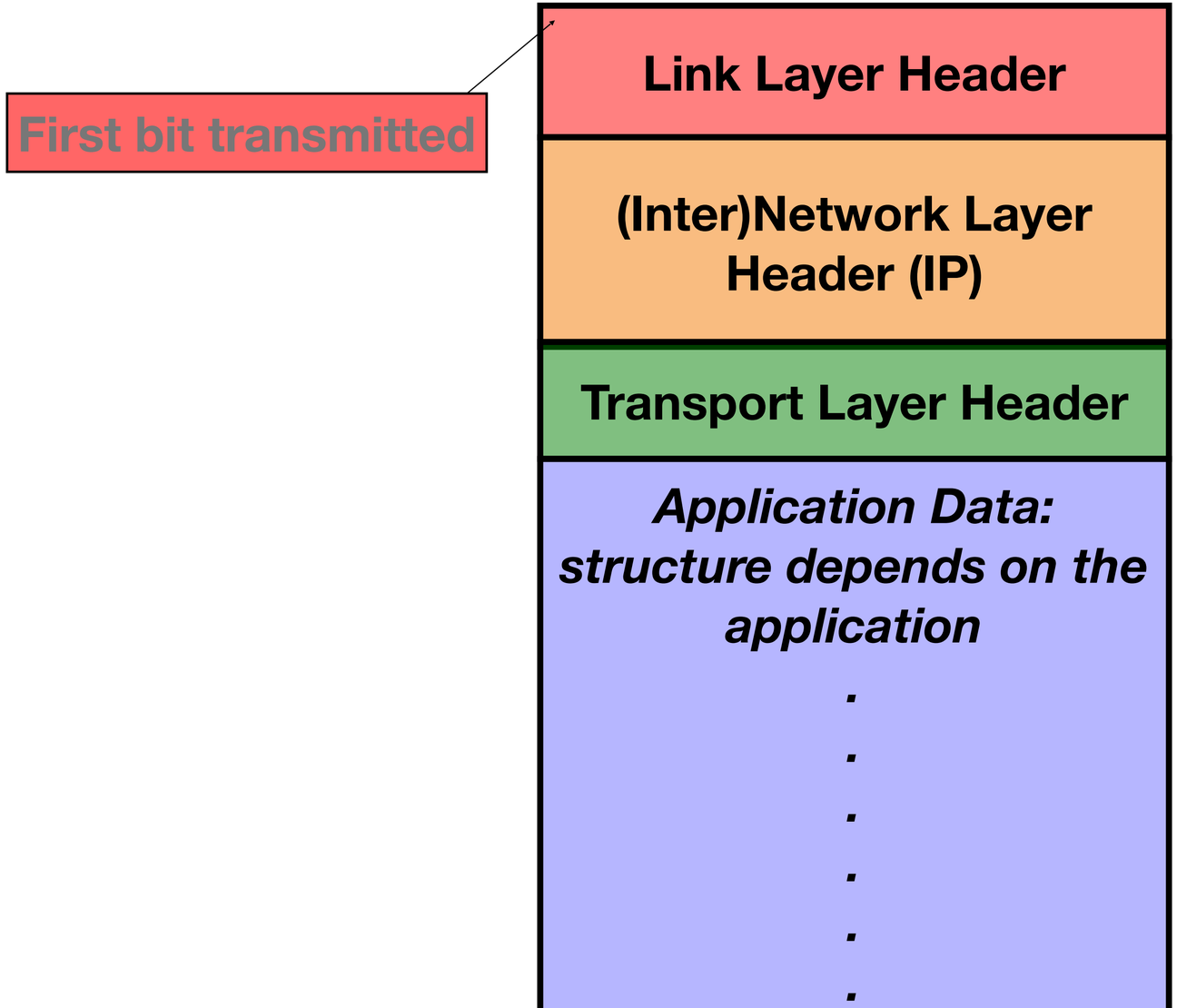
Reliability

- Packets are received ***correctly*** or not at all, if ***random*** errors occur
  - Packets have a checksum
  - No guarantees if adversary modifies packets (no cryptographic MACs)
- Packets may be ***unreliable*** and “dropped”
  - It’s up to higher-level protocols to make the connection reliable

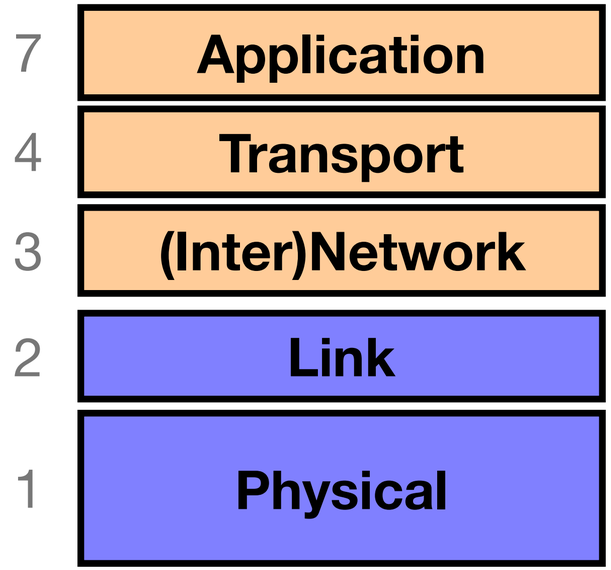
Horizontal View of a Single Packet



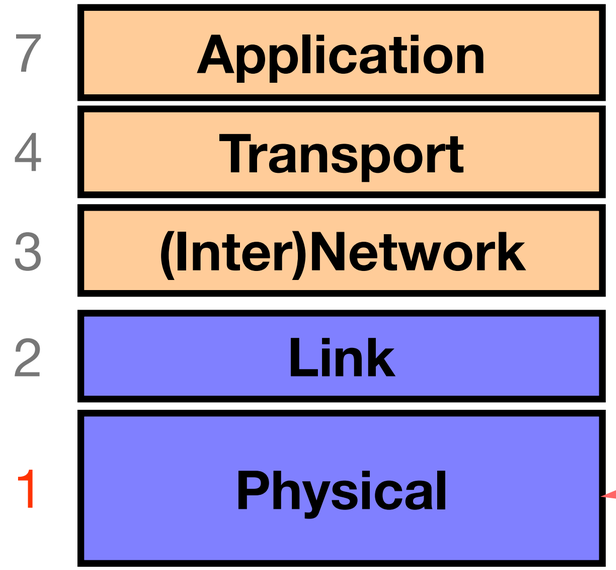
Vertical View of a Single Packet



Internet Layering (“Protocol Stack”)



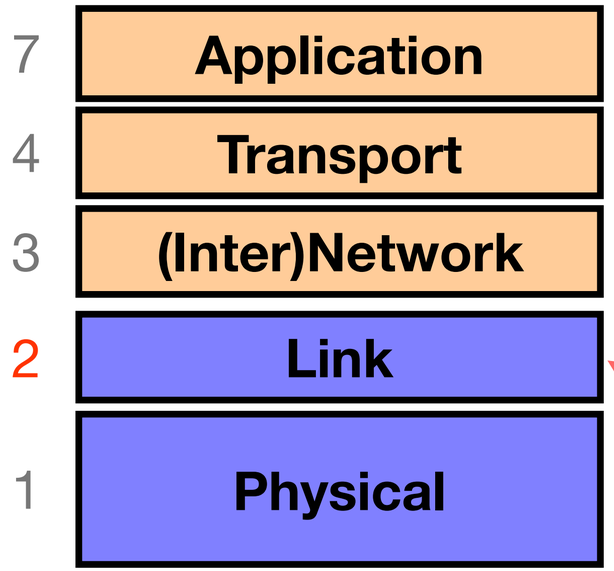
Layer 1: Physical Layer



Encoding bits to send them over a single **physical link**

e.g. patterns of
voltage levels /
photon intensities /
RF modulation

Layer 2: Link Layer

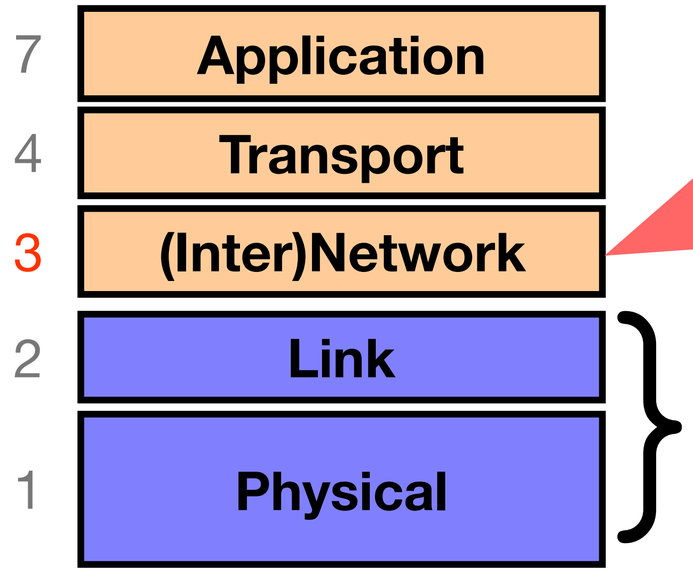


Framing and transmission of a collection of bits into individual messages sent across a single "subnetwork" (one physical technology)

Might involve multiple *physical links* (e.g., modern Ethernet)

Often technology supports broadcast transmission (**every** "node" connected to subnet receives)

Layer 3: (Inter)Network Layer *(IP)*



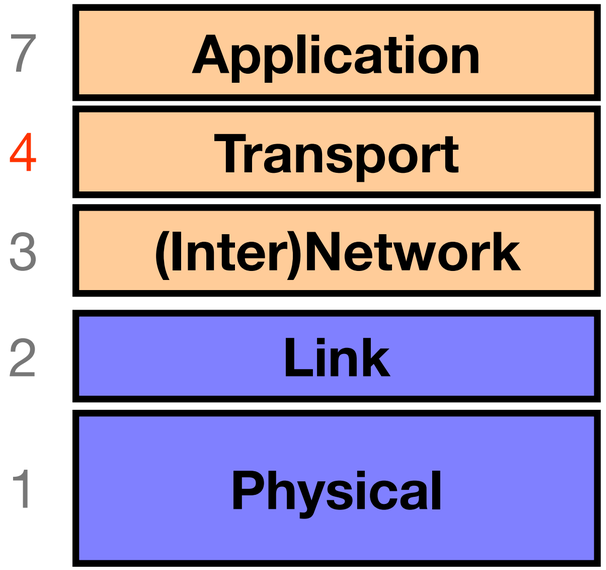
Bridges multiple "subnets" to provide *end-to-end* internet connectivity between nodes

- Provides global addressing

Works across different link technologies

***Different* for each Internet "hop"**

Layer 4: Transport Layer

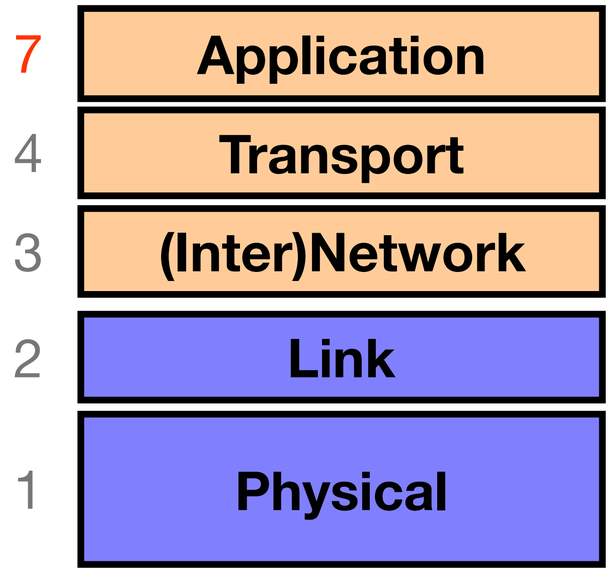


End-to-end communication between processes

Different services provided:
- TCP = reliable *byte stream*
- UDP = unreliable *datagrams*

(Datagram = single packet message)

Layer 7: Application Layer



Communication of whatever you wish

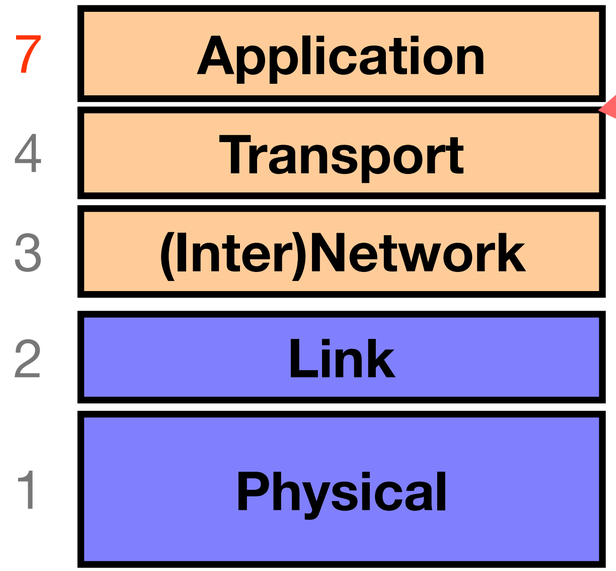
Can use whatever transport(s) is convenient

Freely structured

E.g.:

Skype, SMTP (email), HTTP (Web), Halo, BitTorrent

4.5: Some Crypto…

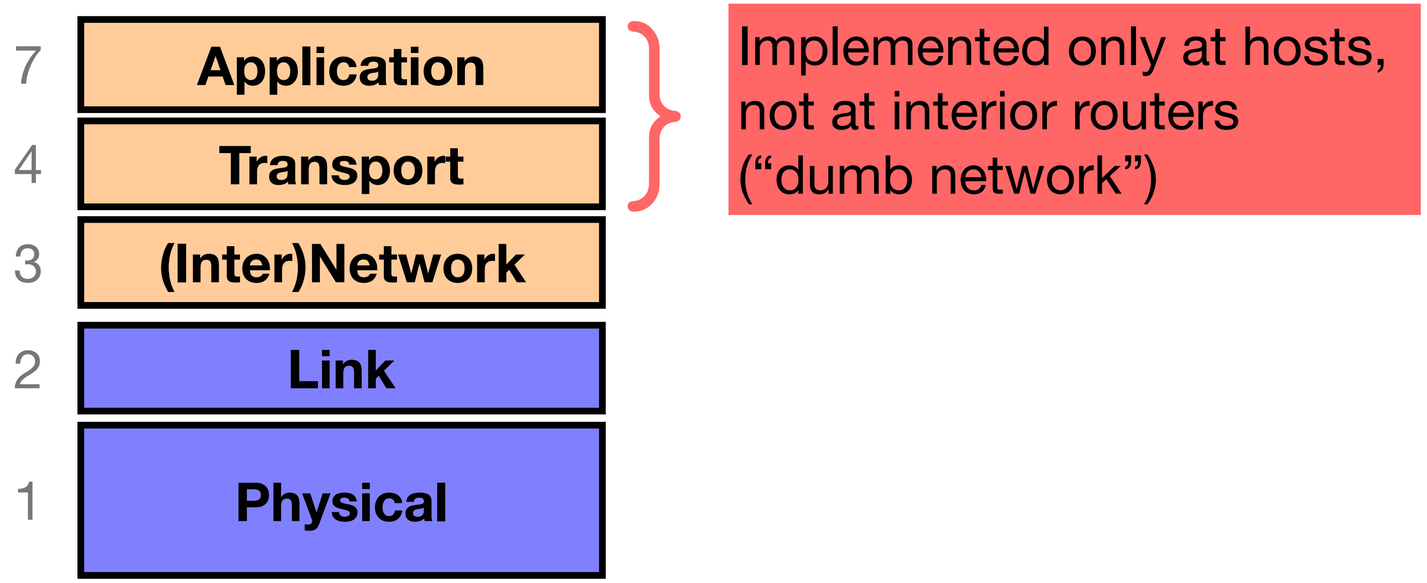


TLS cryptography
(aka the ’s’ in HTTPS)

Often basically used as a “layer 4.5” transport layer to encrypt otherwise unencrypted network connections

Other times crypto may be at the application layer (e.g. ssh

Internet Layering (“Protocol Stack”)



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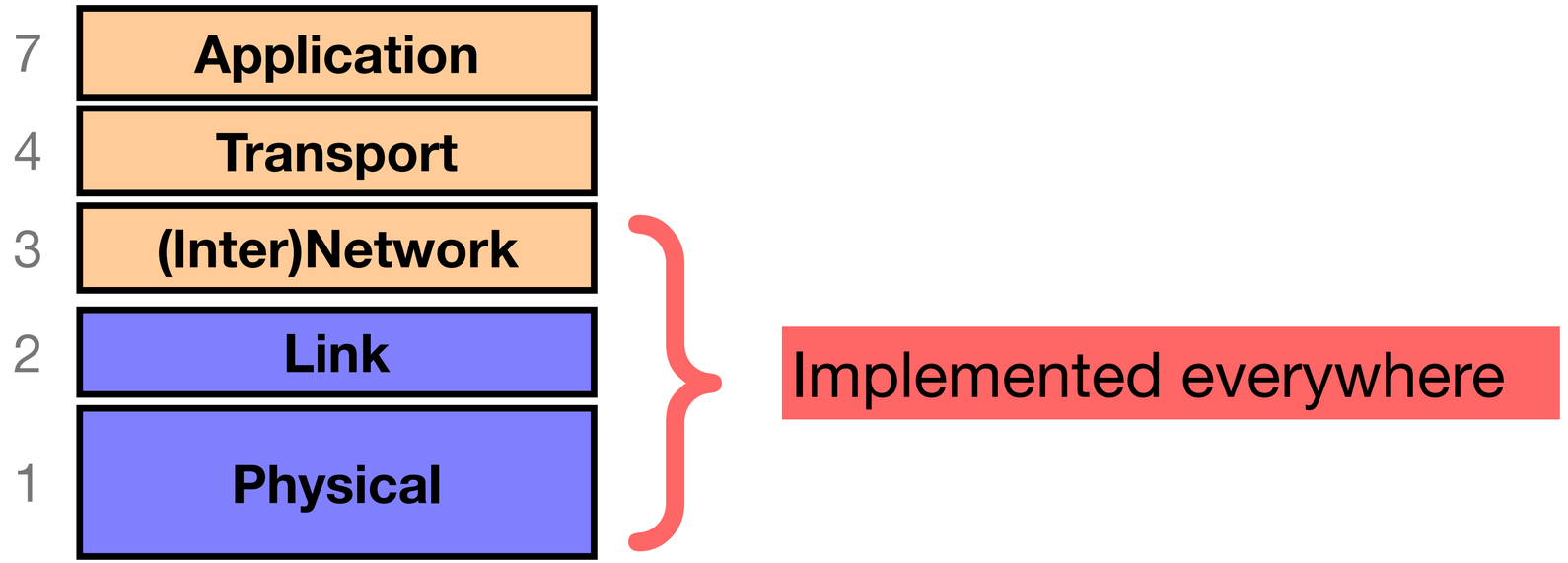
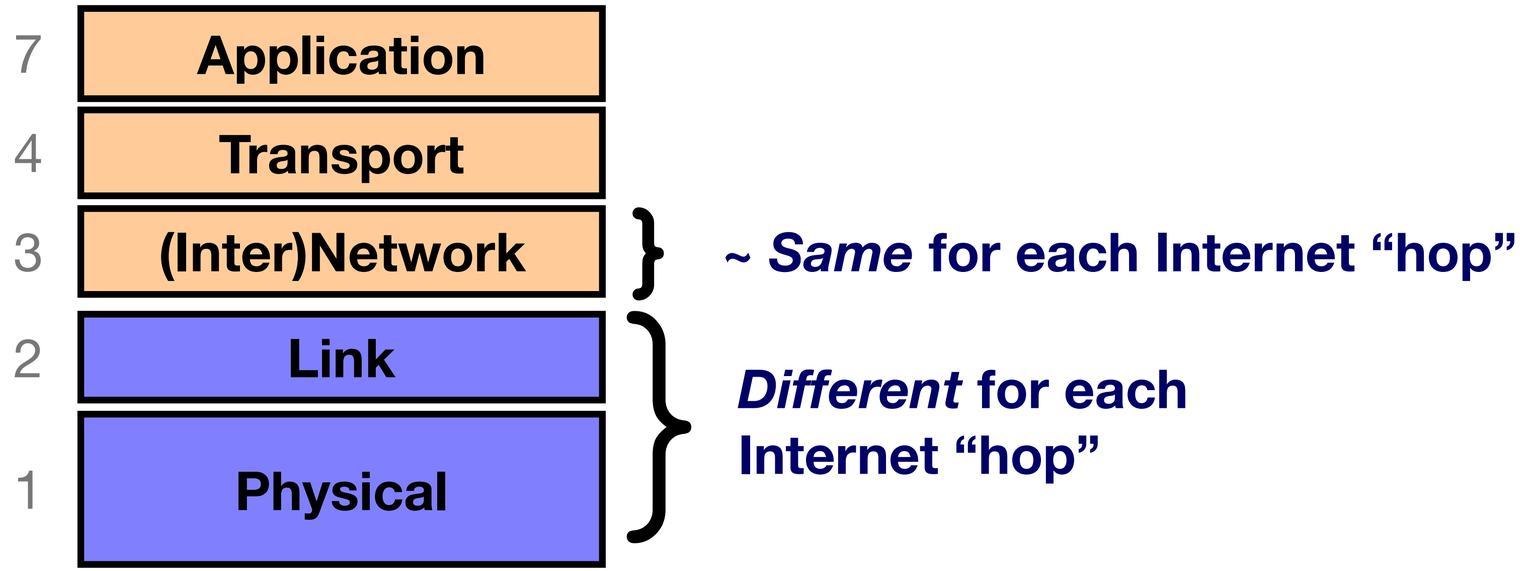
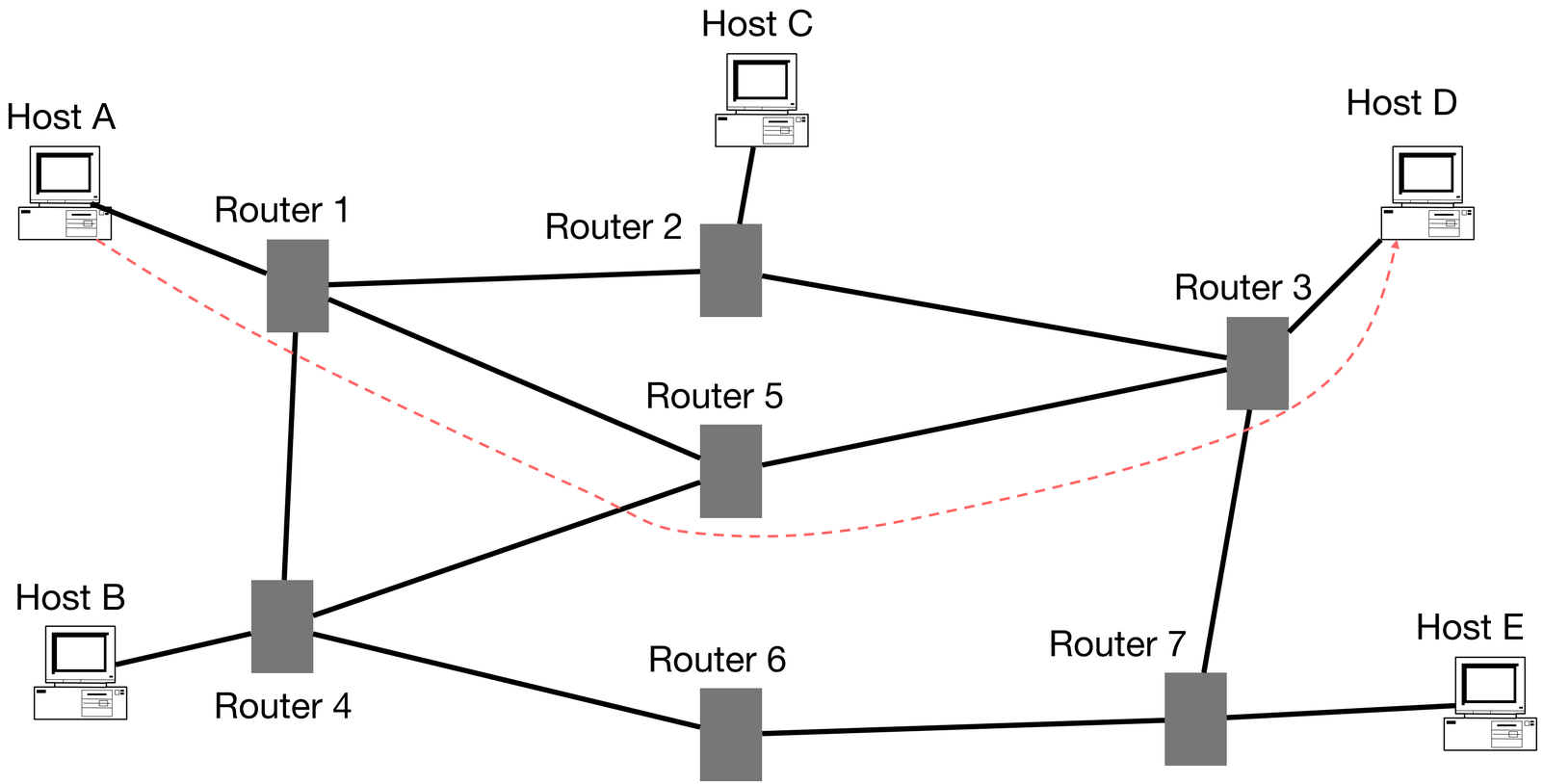


Internet Layering ("Protocol Stack")



Hop-By-Hop vs. End-to-End Layers

Host A communicates with Host D



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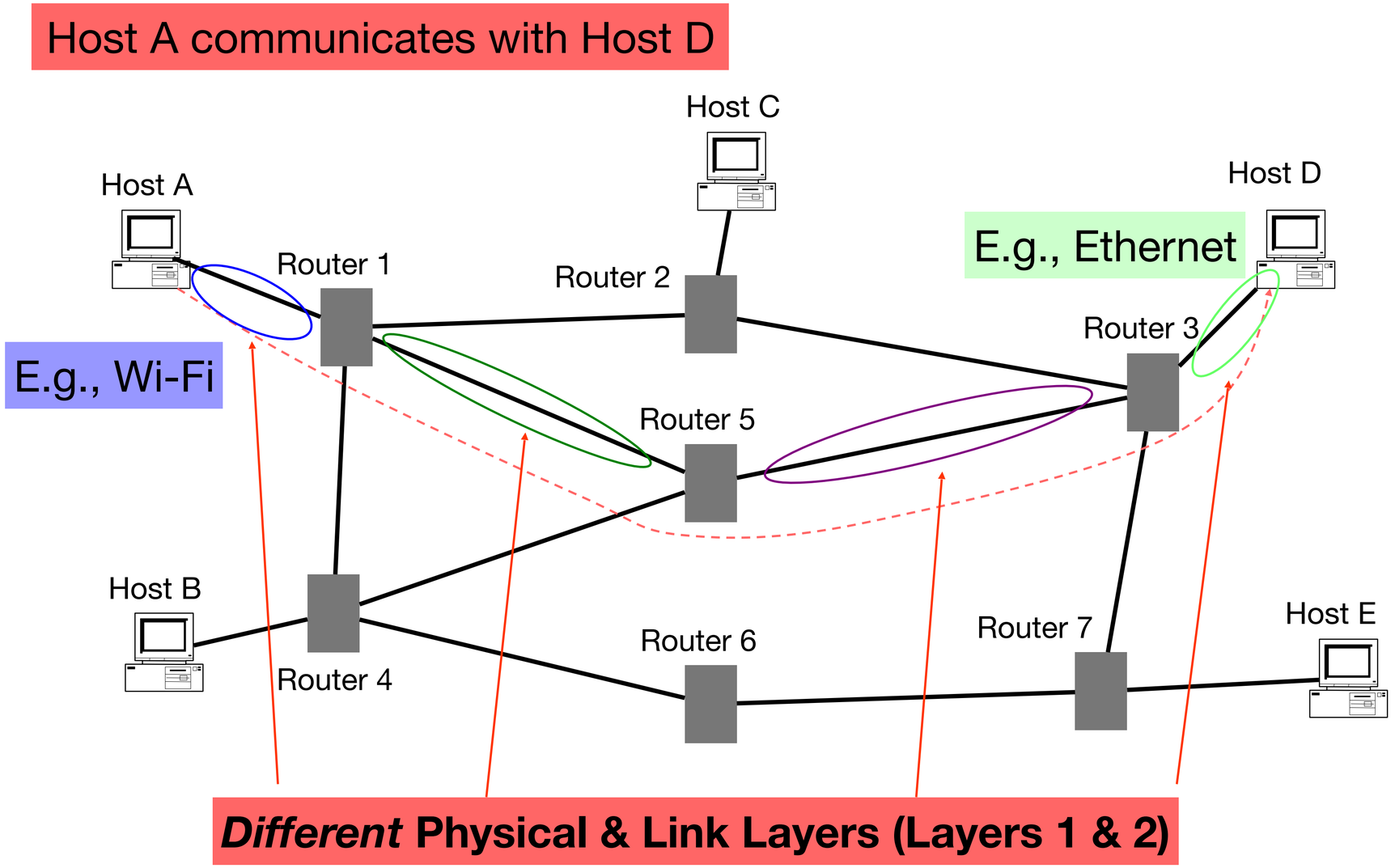

Hop-By-Hop vs. End-to-End Layers

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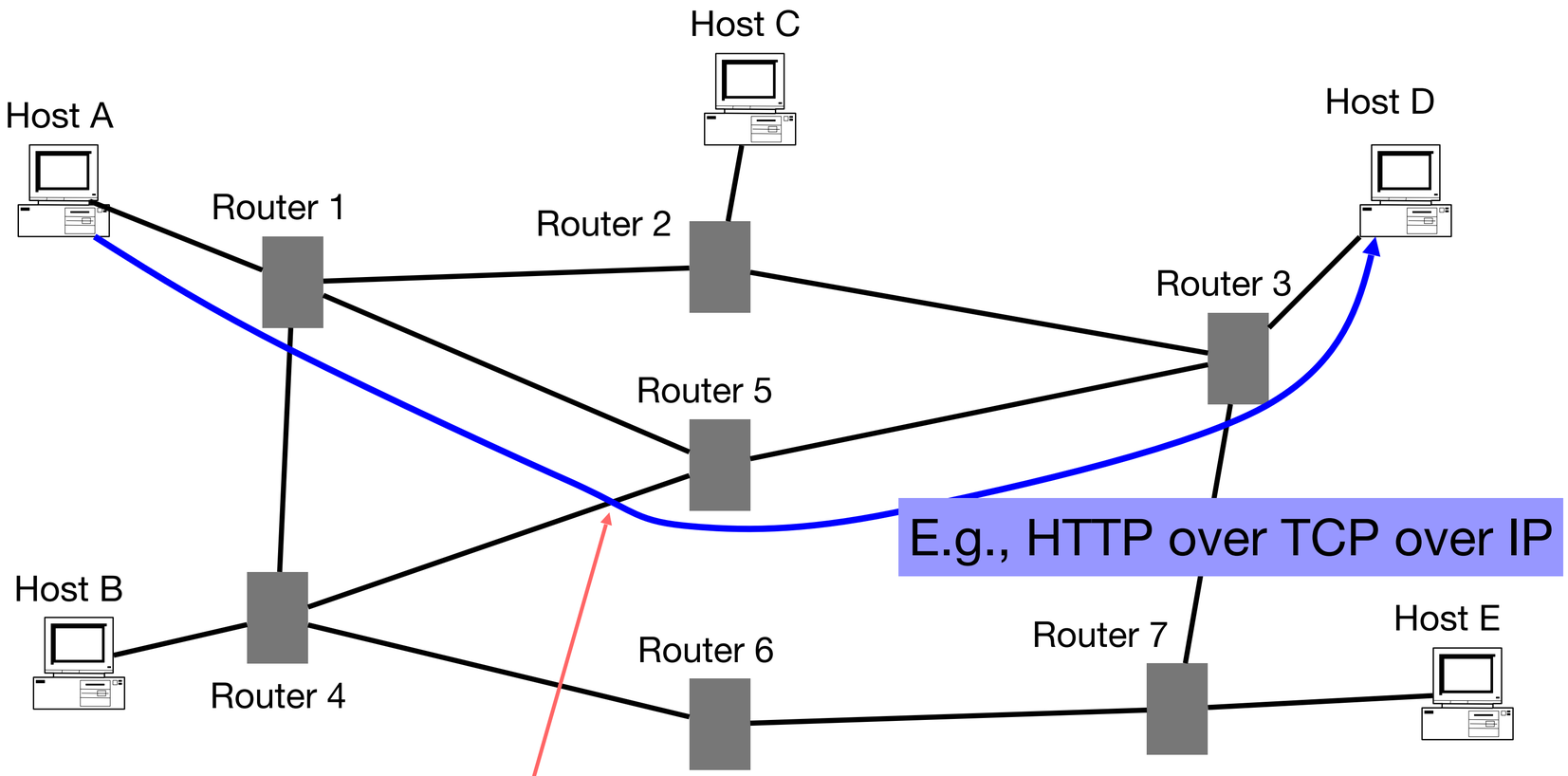
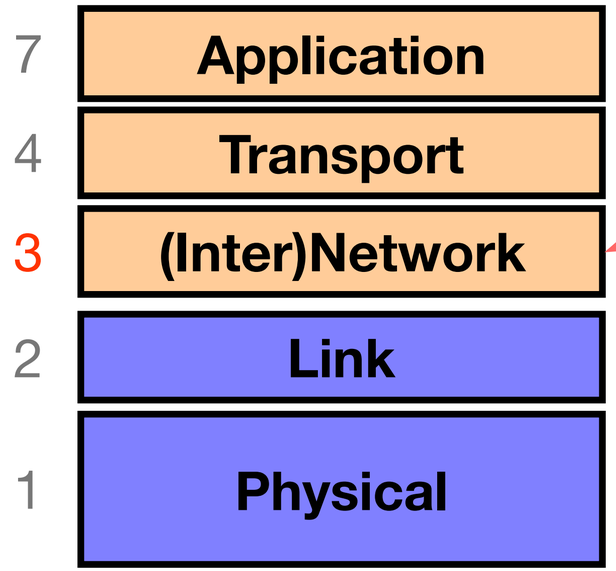


Same Network / Transport / Application Layers (3/4/7)
(Routers **ignore** Transport & Application layers)

Layer 3: (Inter)Network Layer *(IP)*

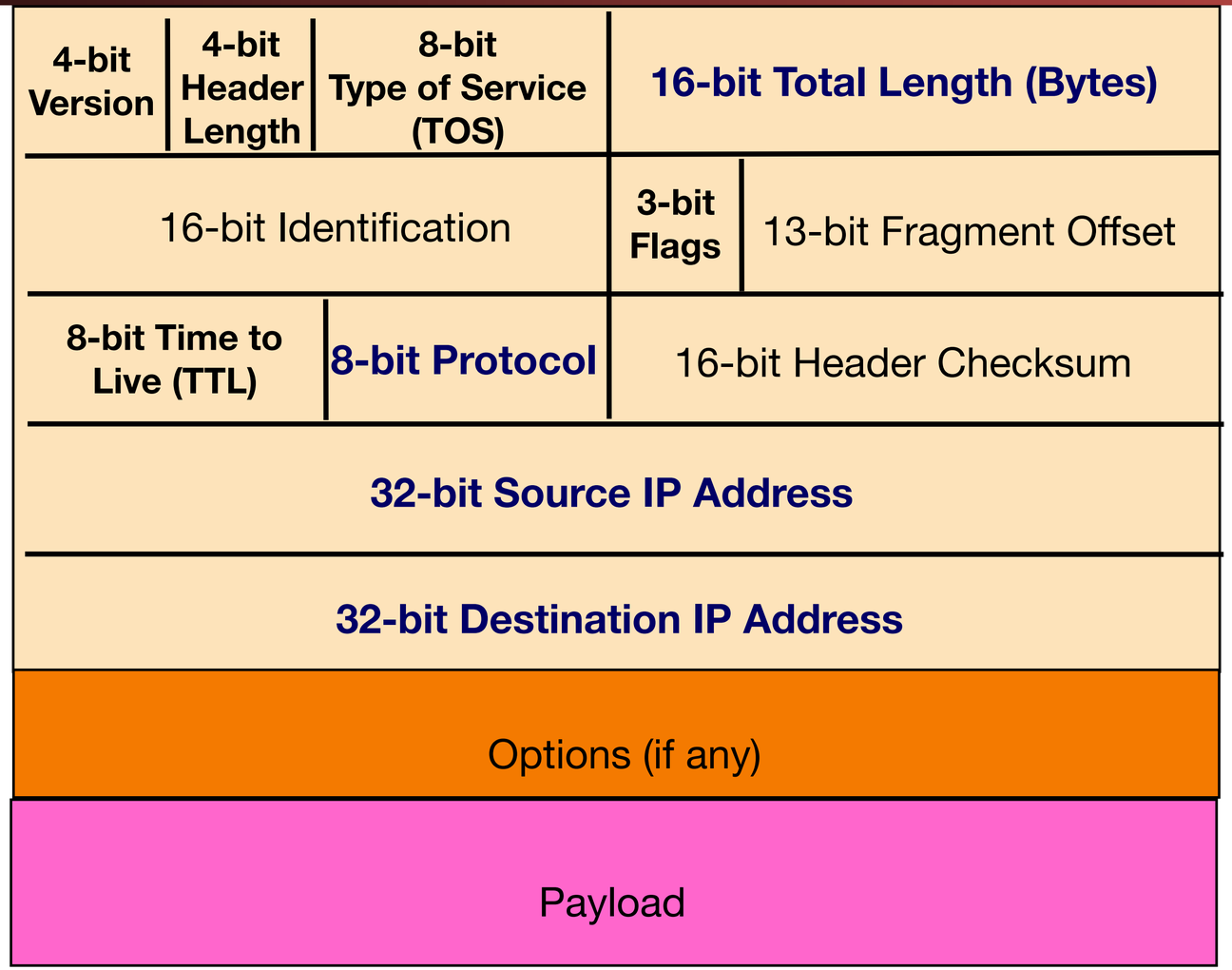


Bridges multiple “subnets” to provide *end-to-end* internet connectivity between nodes

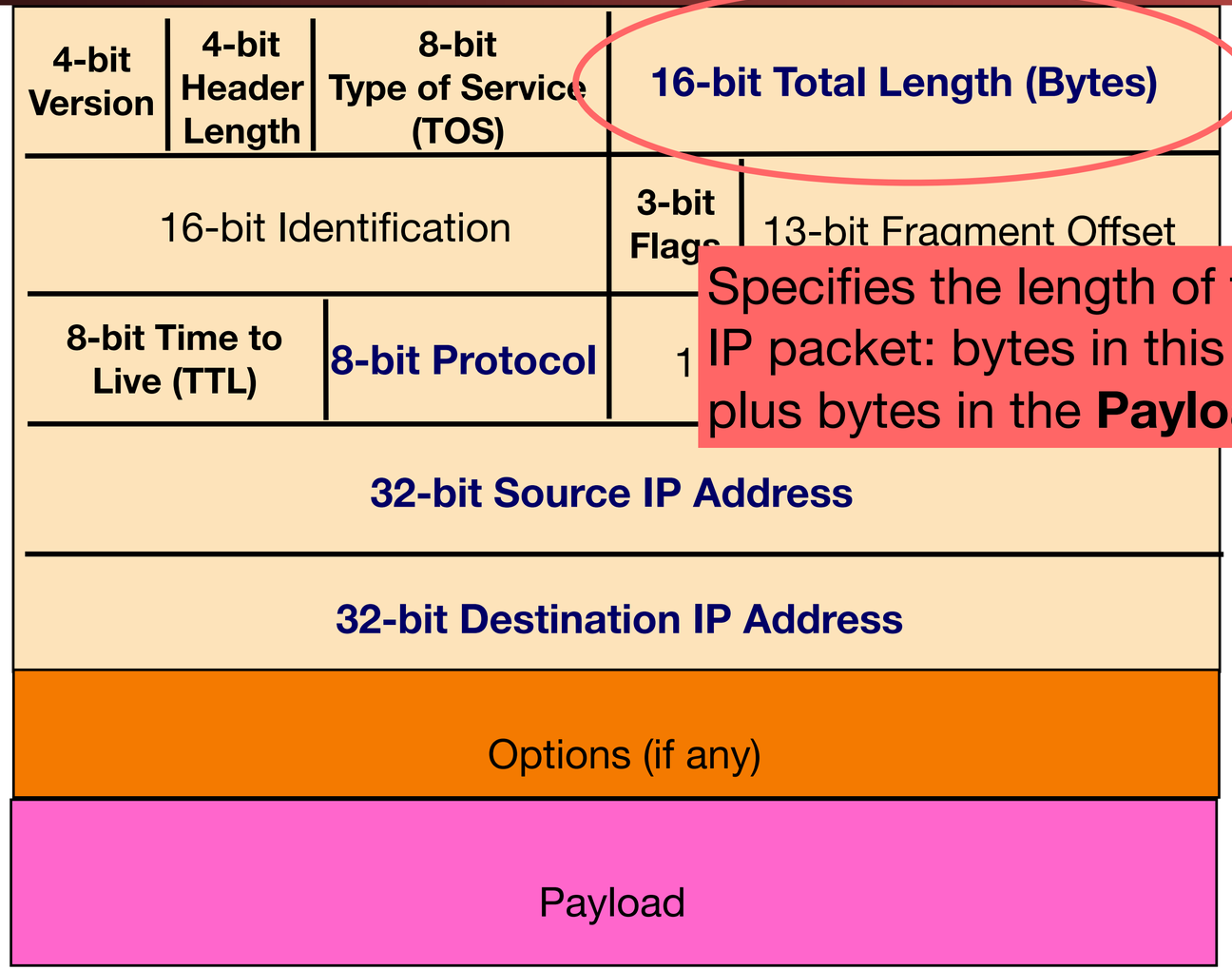
- Provides global addressing

Works across different link technologies

IPv4 Packet Structure (IP version 6 is different)

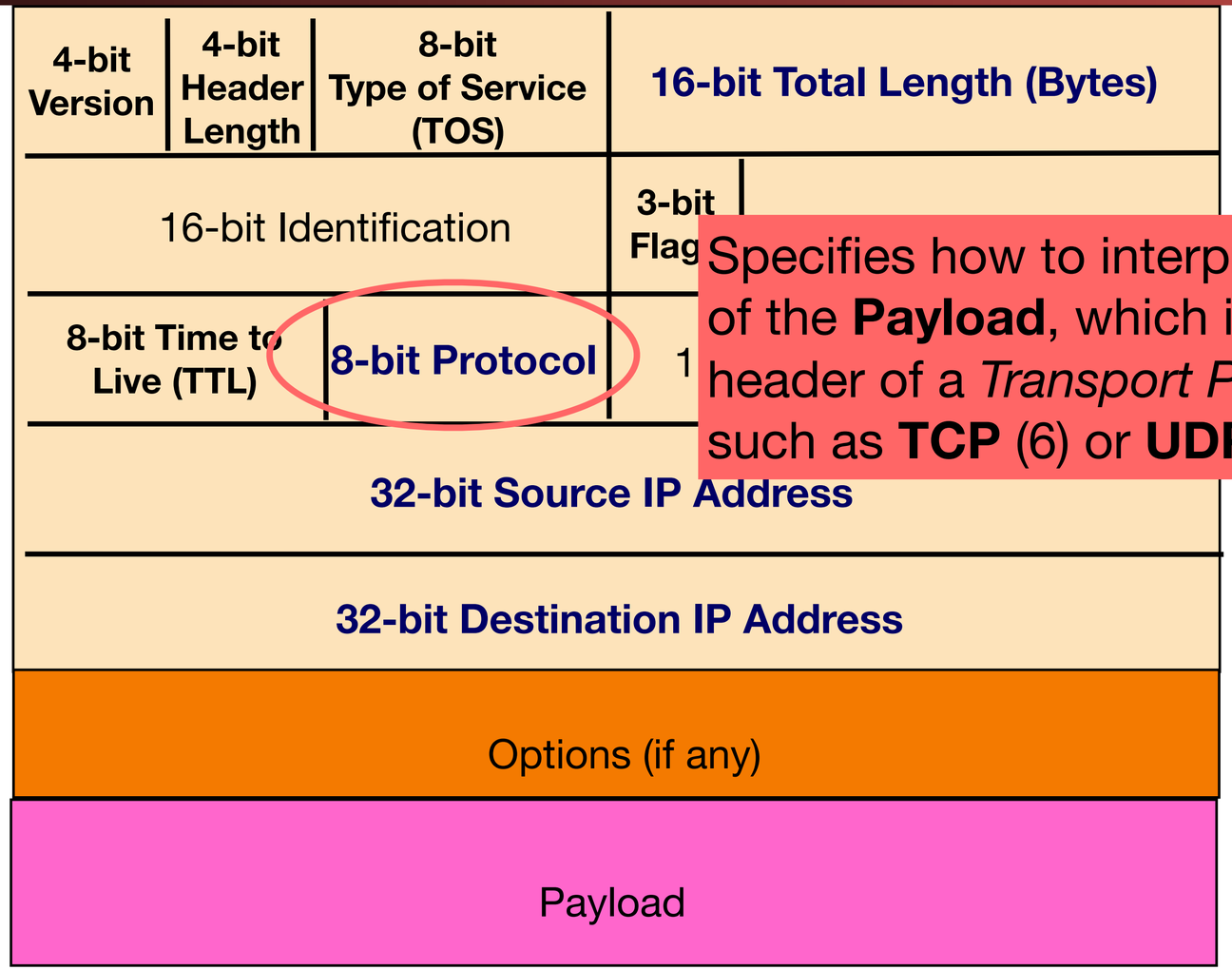


IP Packet Structure



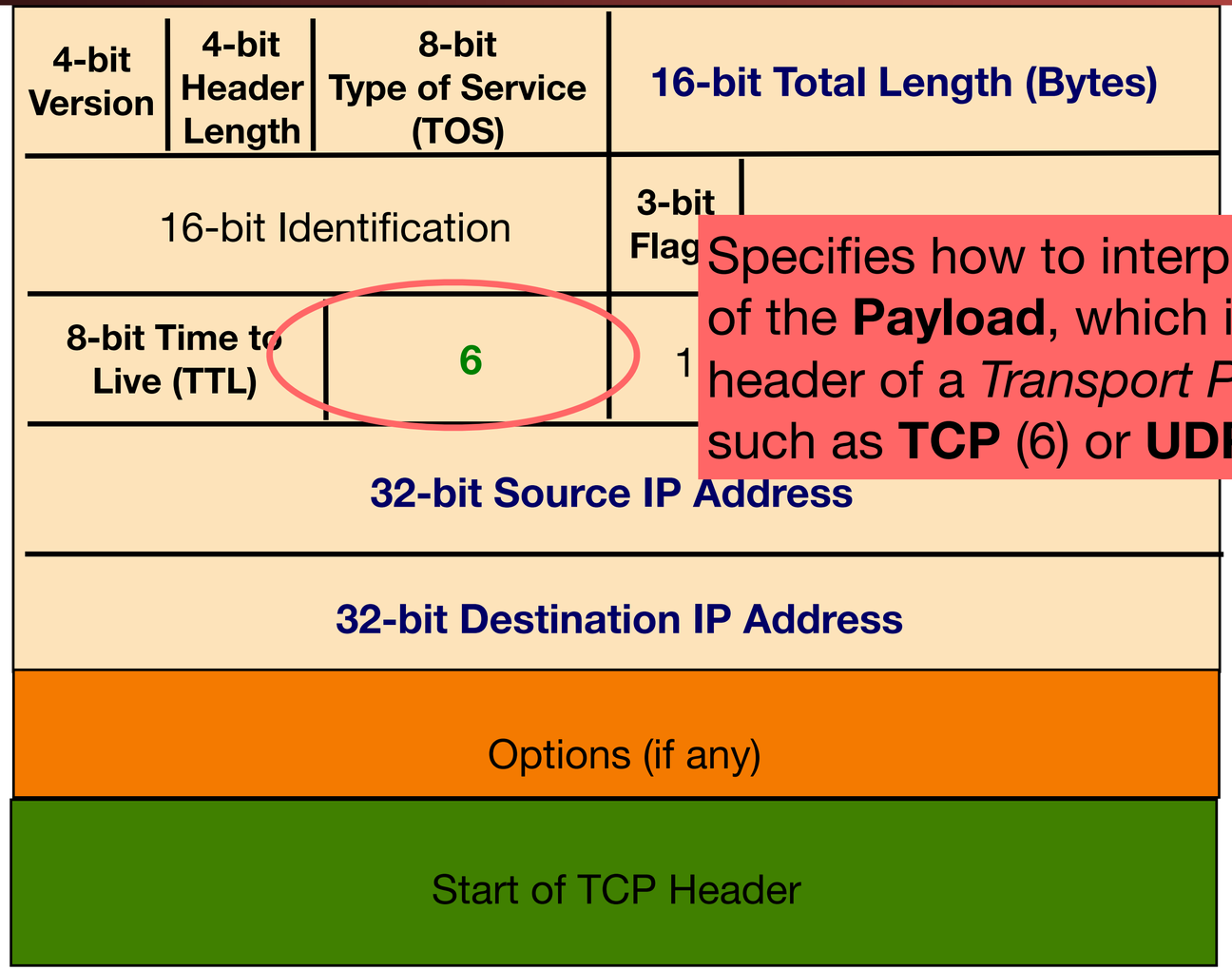
Specifies the length of the entire IP packet: bytes in this header plus bytes in the **Payload**

IP Packet Structure



Specifies how to interpret the start of the **Payload**, which is the header of a *Transport Protocol* such as **TCP** (6) or **UDP** (17)

IP Packet Structure



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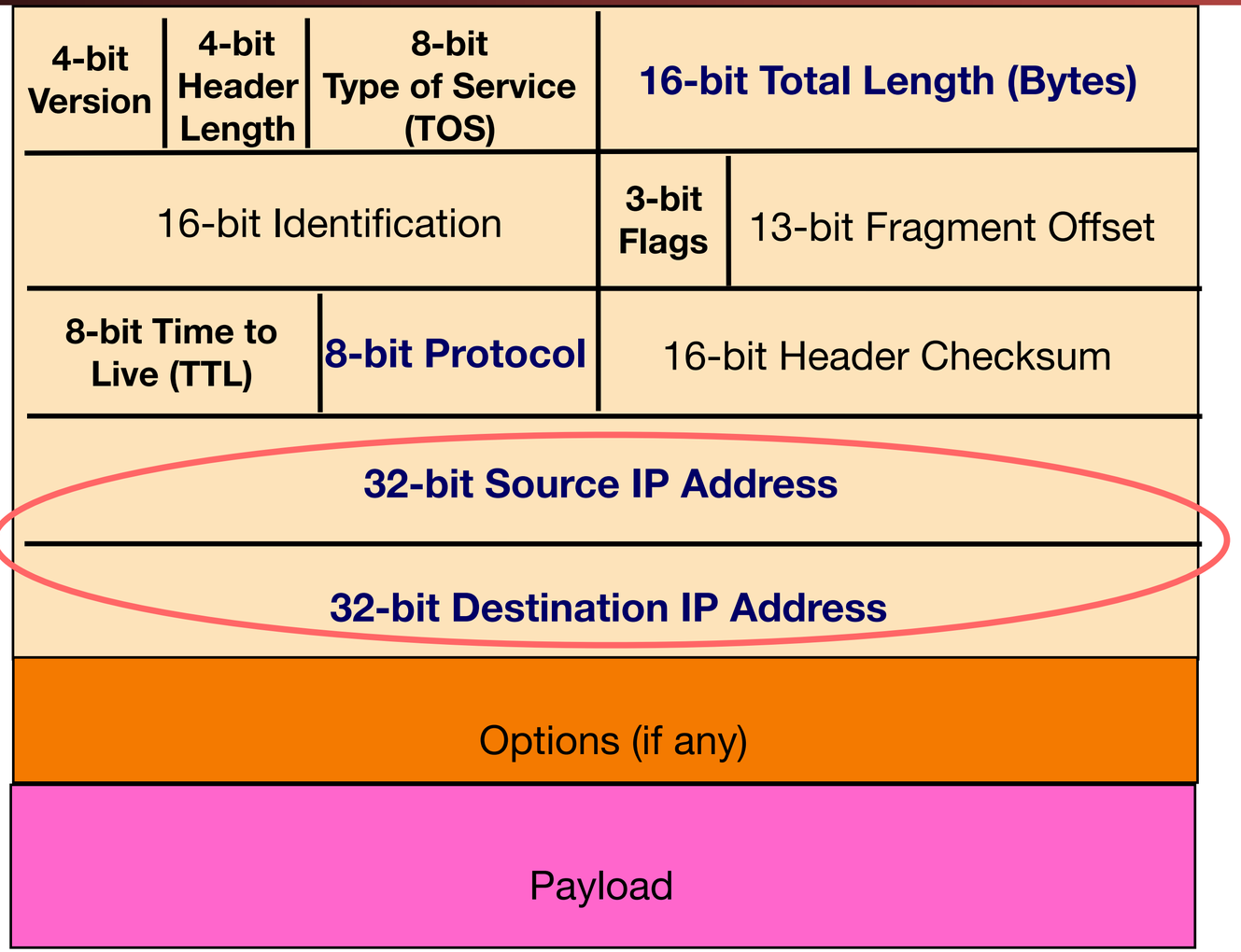
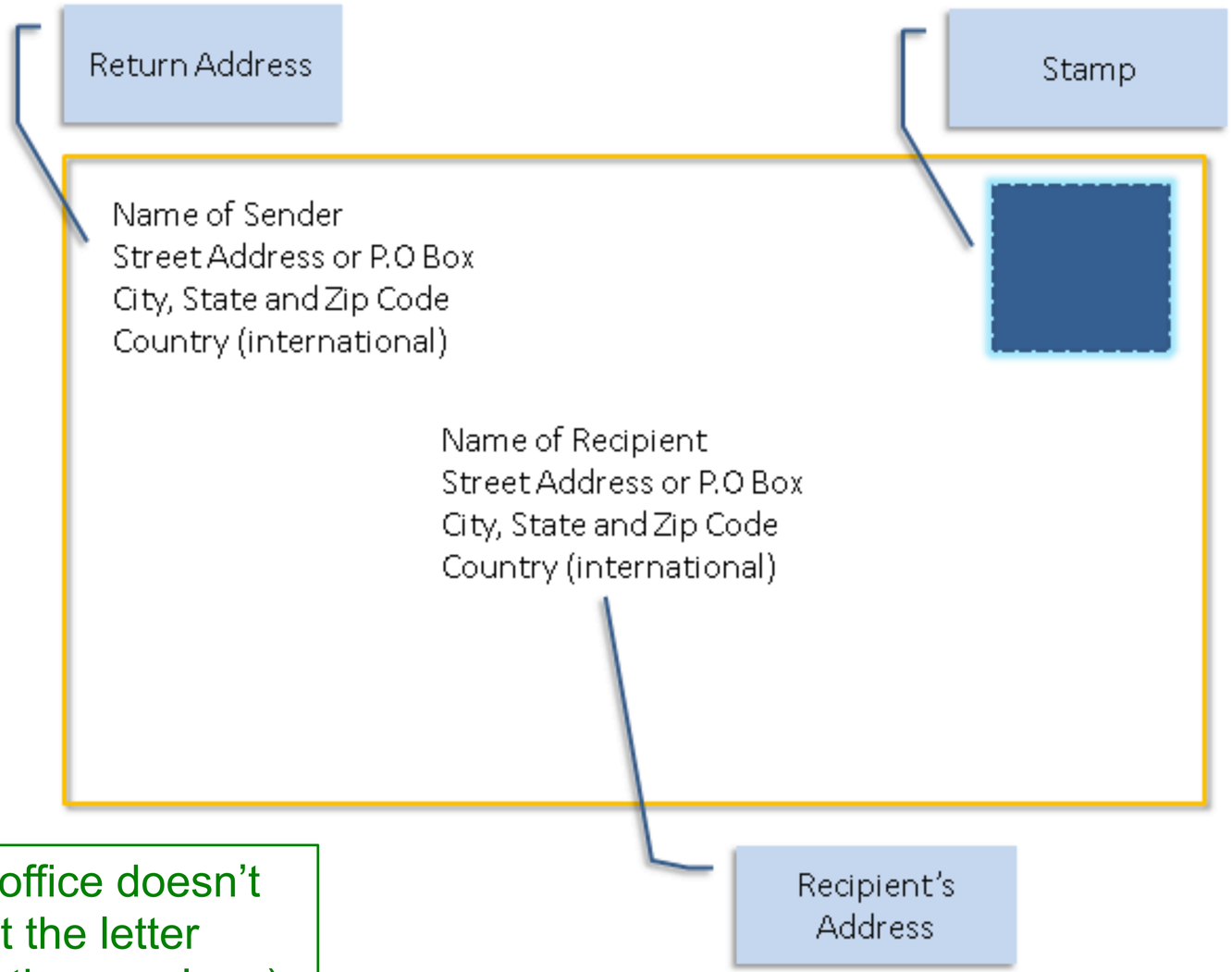


IP Packet Header - IP addresses

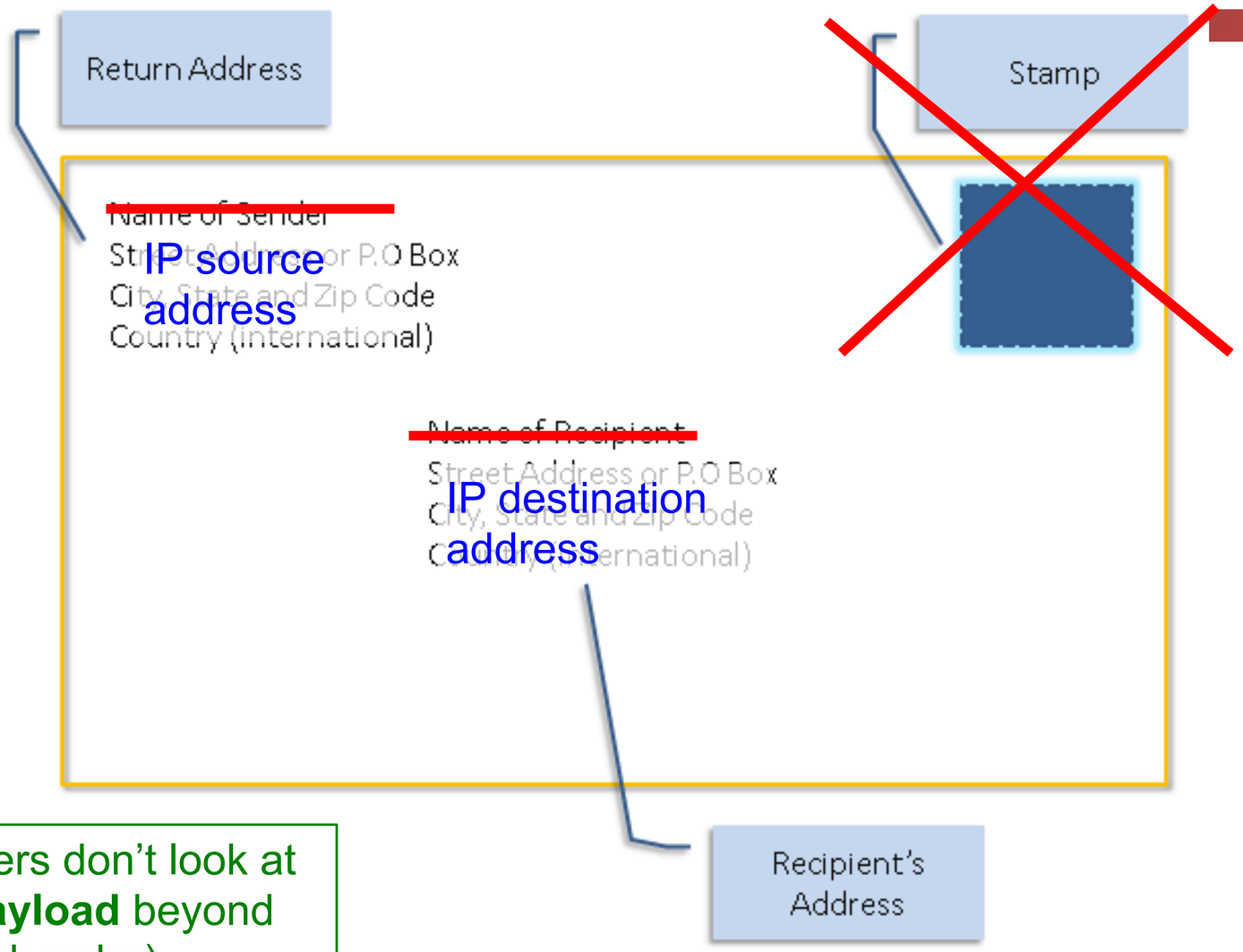
- Source address (32 bits)
  - Unique identifier/locator for the sending host
  - Recipient can decide whether to accept packet
  - Enables recipient to send reply back to source
- Destination address (32 bits)
  - Unique identifier/locator for the receiving host
  - Allows each node to make forwarding decisions

Postal Envelopes:



(Post office doesn't look at the letter inside the envelope)

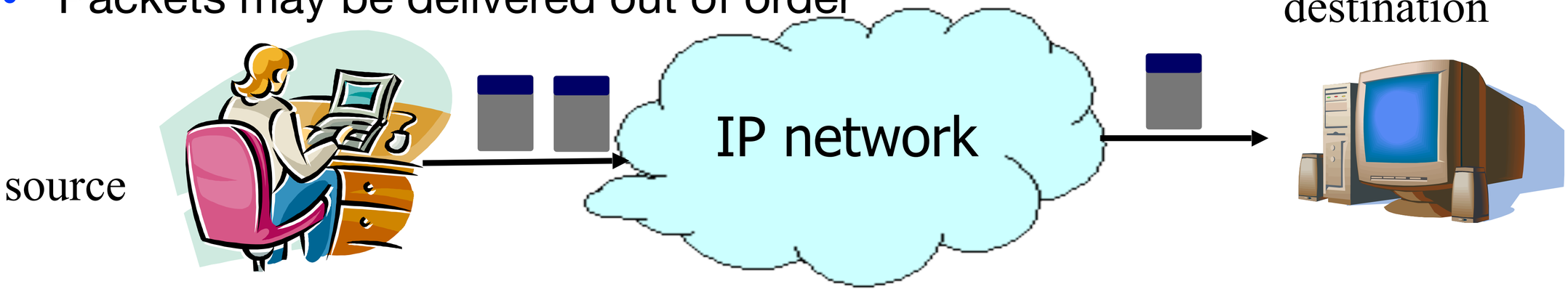
Analogy of IP to Postal Envelopes:



(Routers don't look at the **payload** beyond the IP header)

IP: "*Best Effort*" Packet Delivery

- Routers inspect destination address, locate "next hop" in forwarding table
  - Address = ~unique identifier/locator for the receiving host
- Only provides a "*I'll give it a try*" delivery service:
  - Packets may be lost
  - Packets may be corrupted
  - Packets may be delivered out of order



“Best Effort” is Lame! What to do?

- It’s the job of our Transport (layer 4) protocols to build services our apps need out of IP’s modest layer-3 service

“Best Effort” is Lame! What to do?

- #1 workhorse: TCP (Transmission Control Protocol)
- Service provided by TCP:
  - Connection oriented (explicit set-up / tear-down)
    - End hosts (processes) can have multiple concurrent long-lived communication
  - **Reliable**, in-order, *byte-stream* delivery
    - Robust detection & retransmission of lost data