Networking Overview

(as usual, thanks to Dave Wagner and Vern Paxson)

Focus For This Lecture

- Sufficient background in networking to then explore security issues in next few lectures
  - Networking = the Internet
- Complex topic with many facets
  - We will omit concepts/details that aren't very security-relevant
  - We'll mainly look at IP, TCP, DNS and DHCP
- Networking is full of abstractions
  - Goal is for you to develop apt *mental models* / analogies
  - ASK questions when things are unclear
    - (but we may skip if not ultimately relevant for security, or postpone if question itself is directly about security)

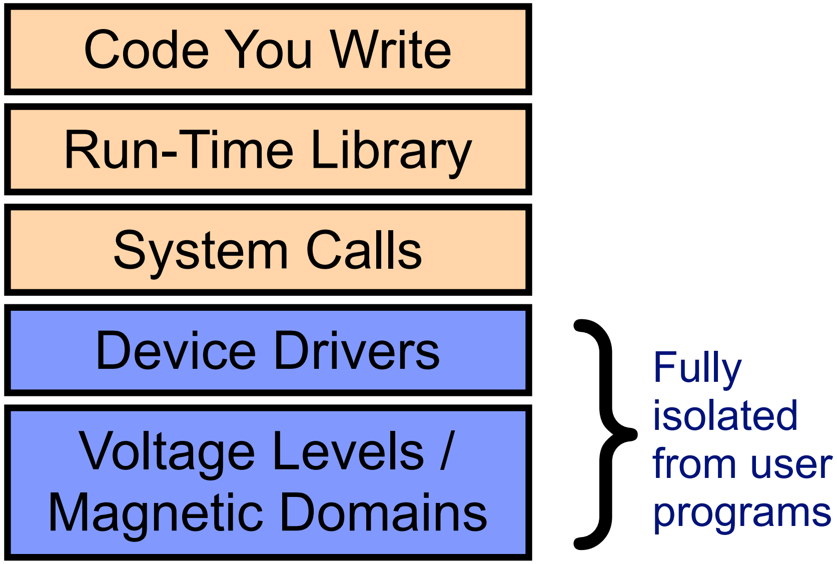
Key Concept #1: *Dumb Network*

- 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"
  - Buys simplicity & robustness at the cost of shifting complexity into end systems

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

Key Concept #2: *Layering*

- Internet design is strongly 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



Code You Write

Run-Time Library

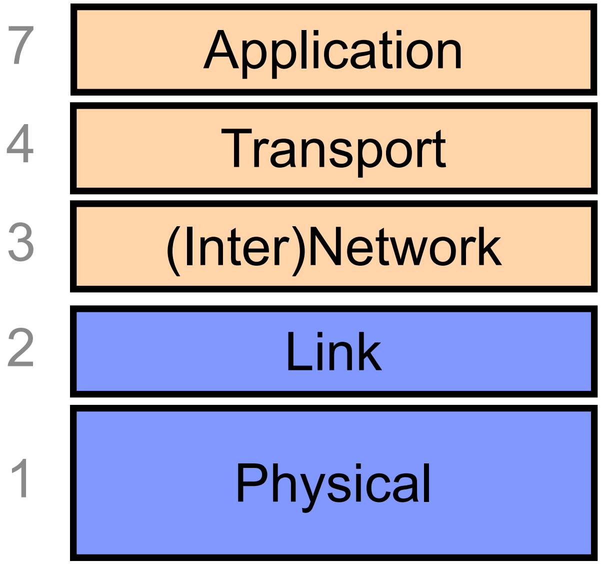
System Calls

Device Drivers

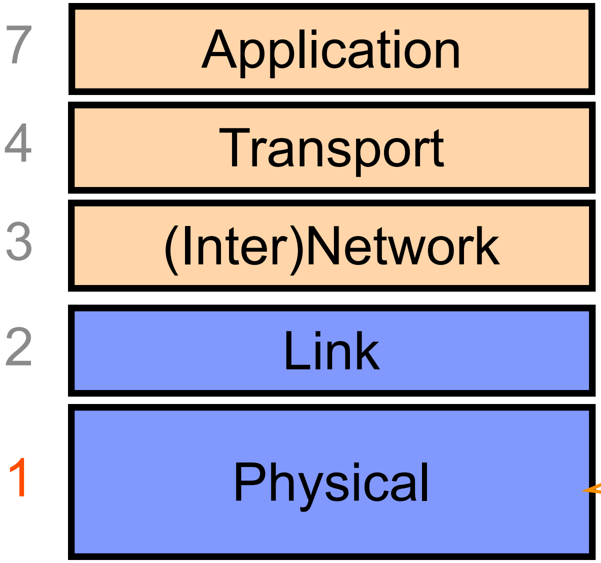
Voltage Levels / Magnetic Domains

Fully isolated from user programs

Internet Layering (“Protocol Stack”)



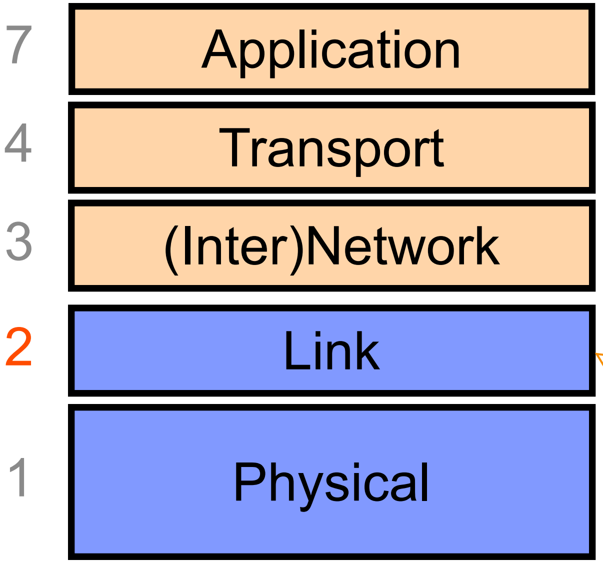
Layer 1: Physical Layer



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)

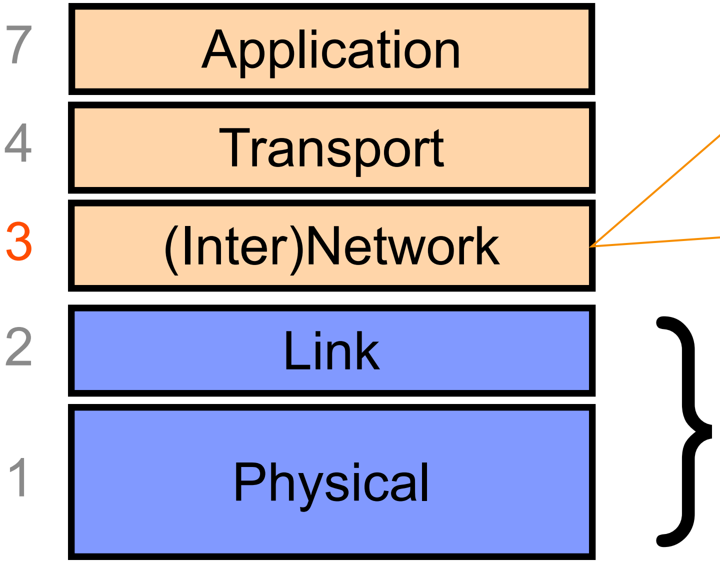
Often technology supports broadcast transmission (every "node" connected to subnet receives)

Layer 3: (Inter)Network Layer

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

- Provides global addressing

Works across different link technologies



7 Application

4 Transport

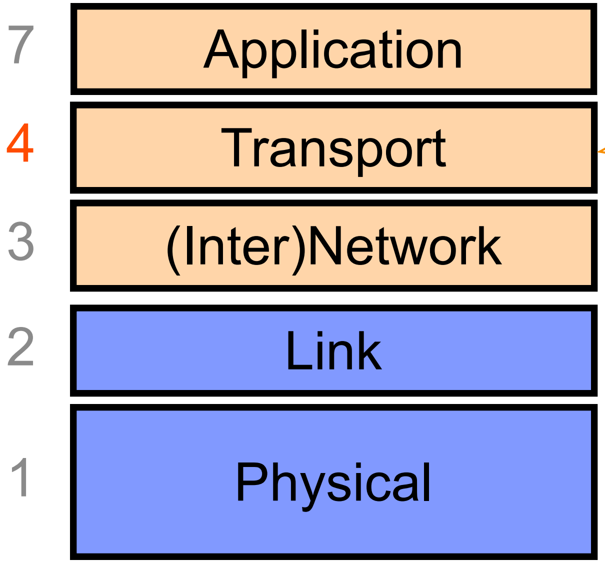
3 (Inter)Network

2 Link

1 Physical

Different for each Internet “hop”

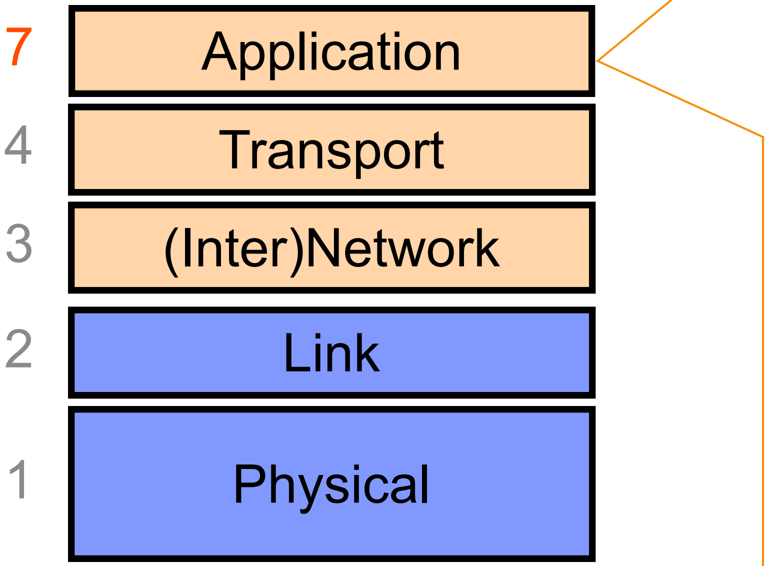
Layer 4: Transport Layer



End-to-end communication between processes

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

Layer 7: Application Layer



Communication of whatever you wish

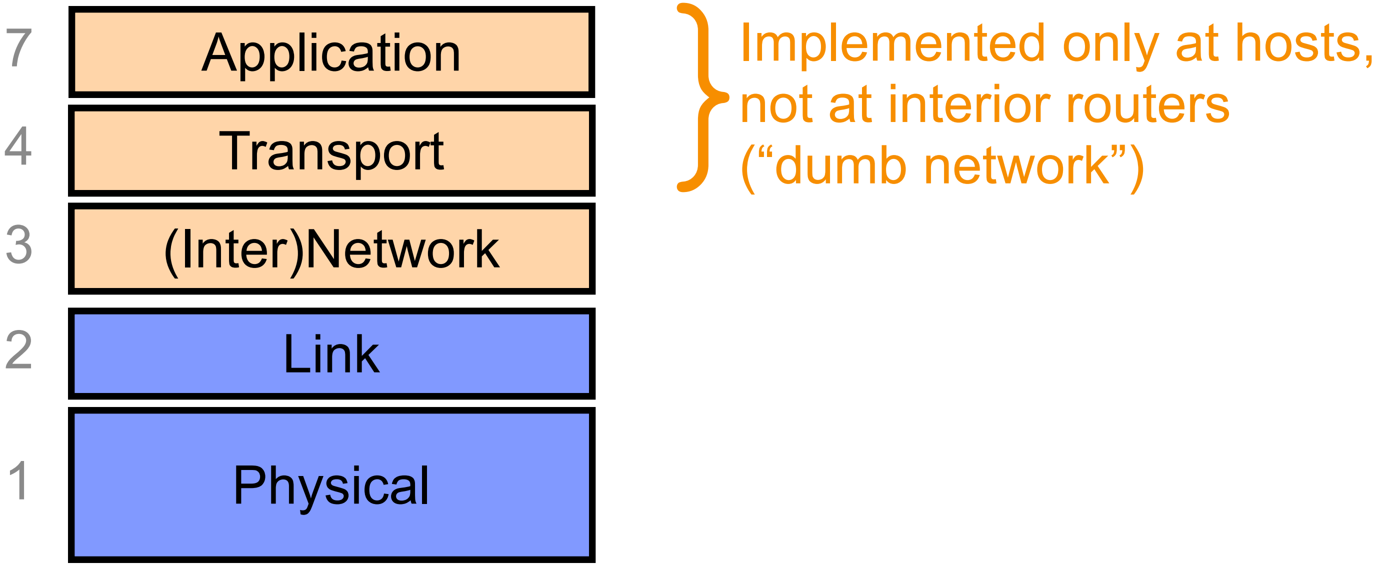
Can use whatever transport(s) is convenient

Freely structured

E.g.:

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

Internet Layering ("Protocol Stack")



7 Application

4 Transport

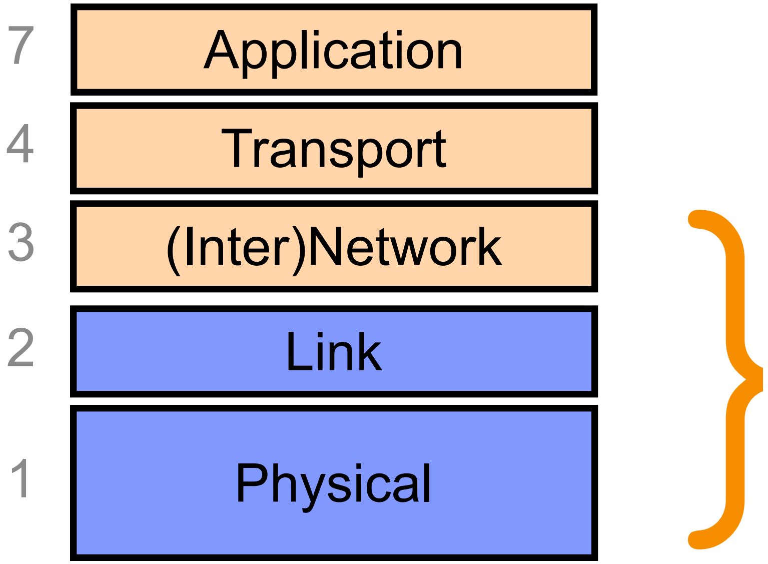
3 (Inter)Network

2 Link

1 Physical

Implemented only at hosts, not at interior routers ("dumb network")

Internet Layering ("Protocol Stack")



7 Application

4 Transport

3 (Inter)Network

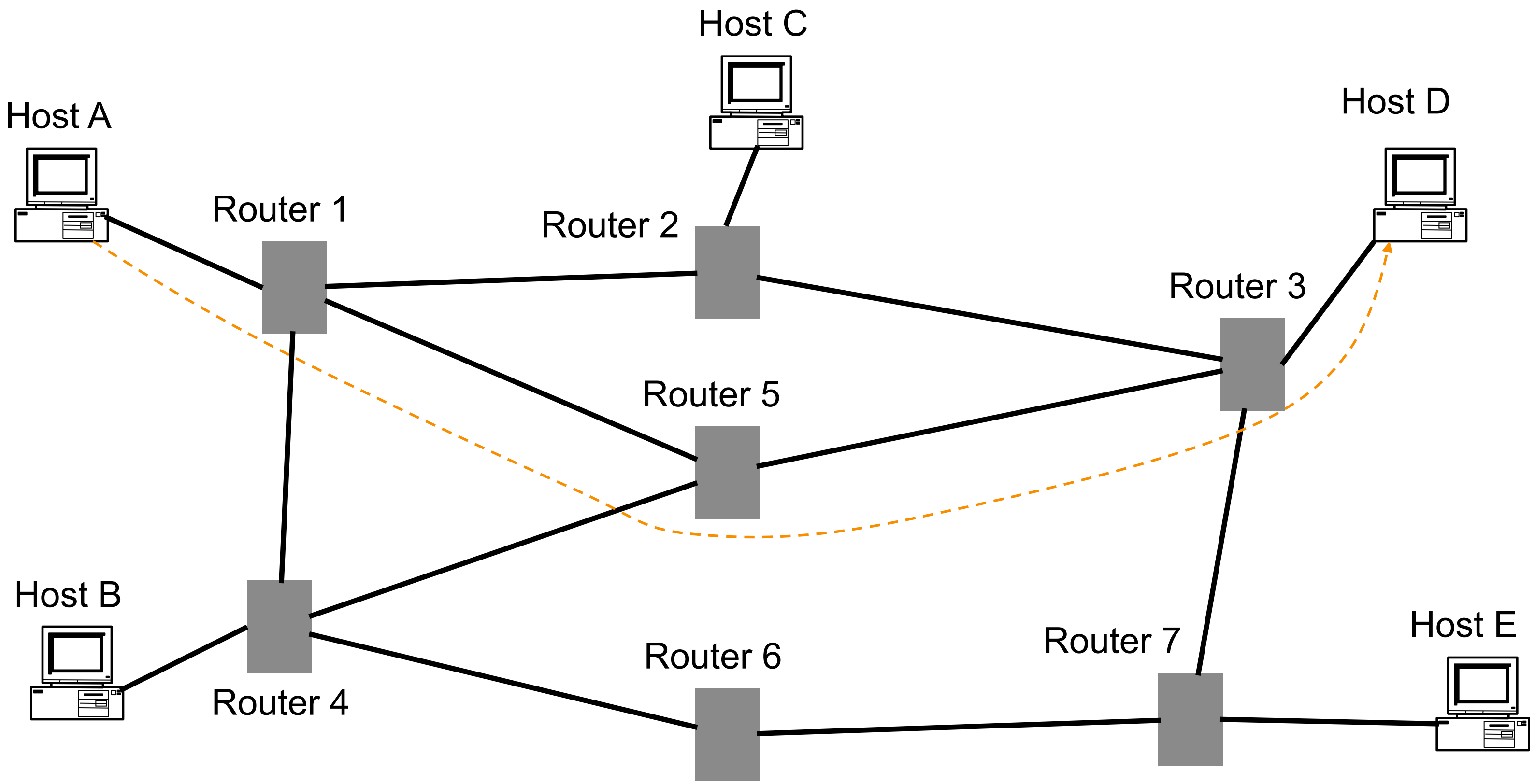
2 Link

1 Physical

Implemented everywhere

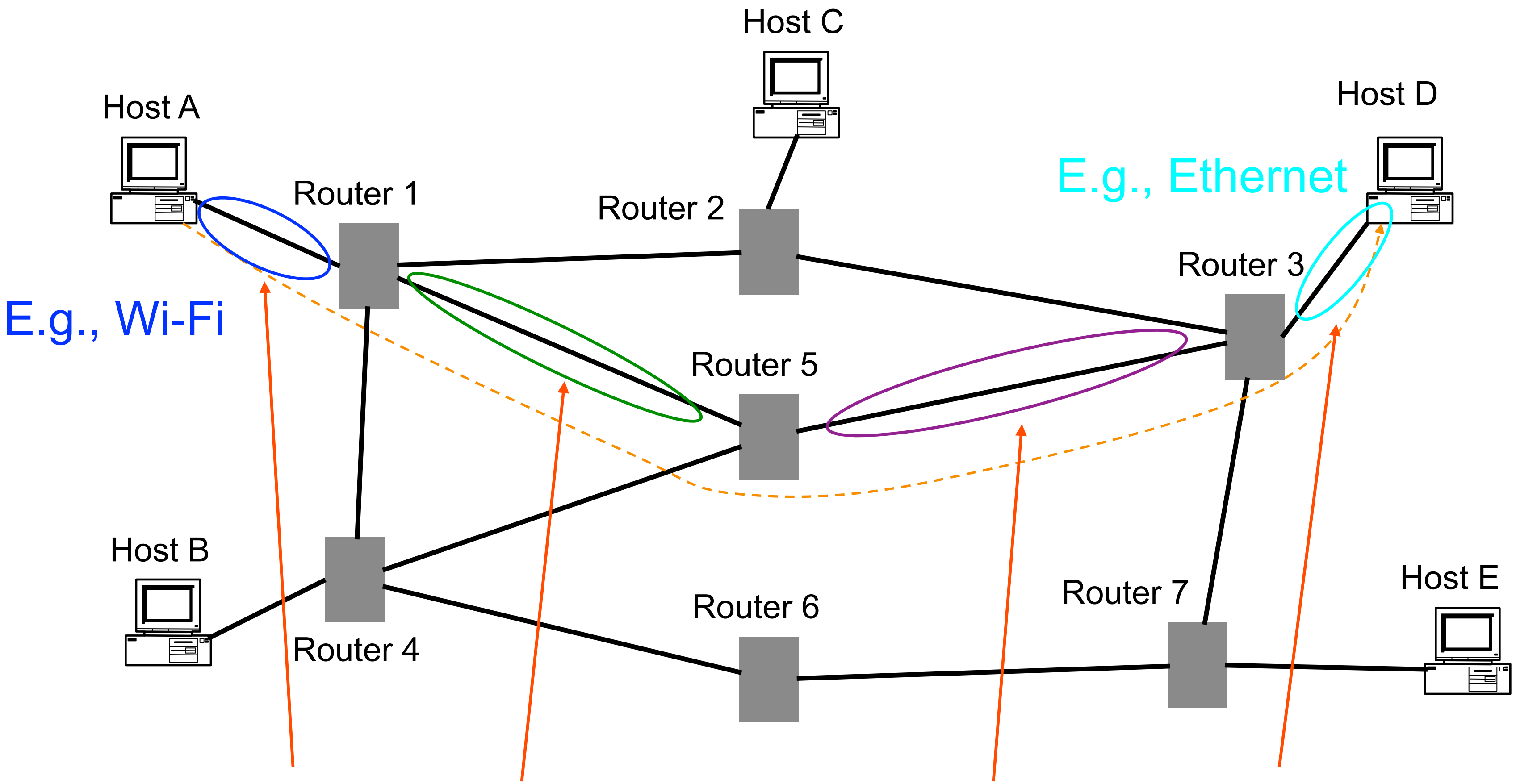
Hop-By-Hop vs. End-to-End Layers

Host A communicates with Host D



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

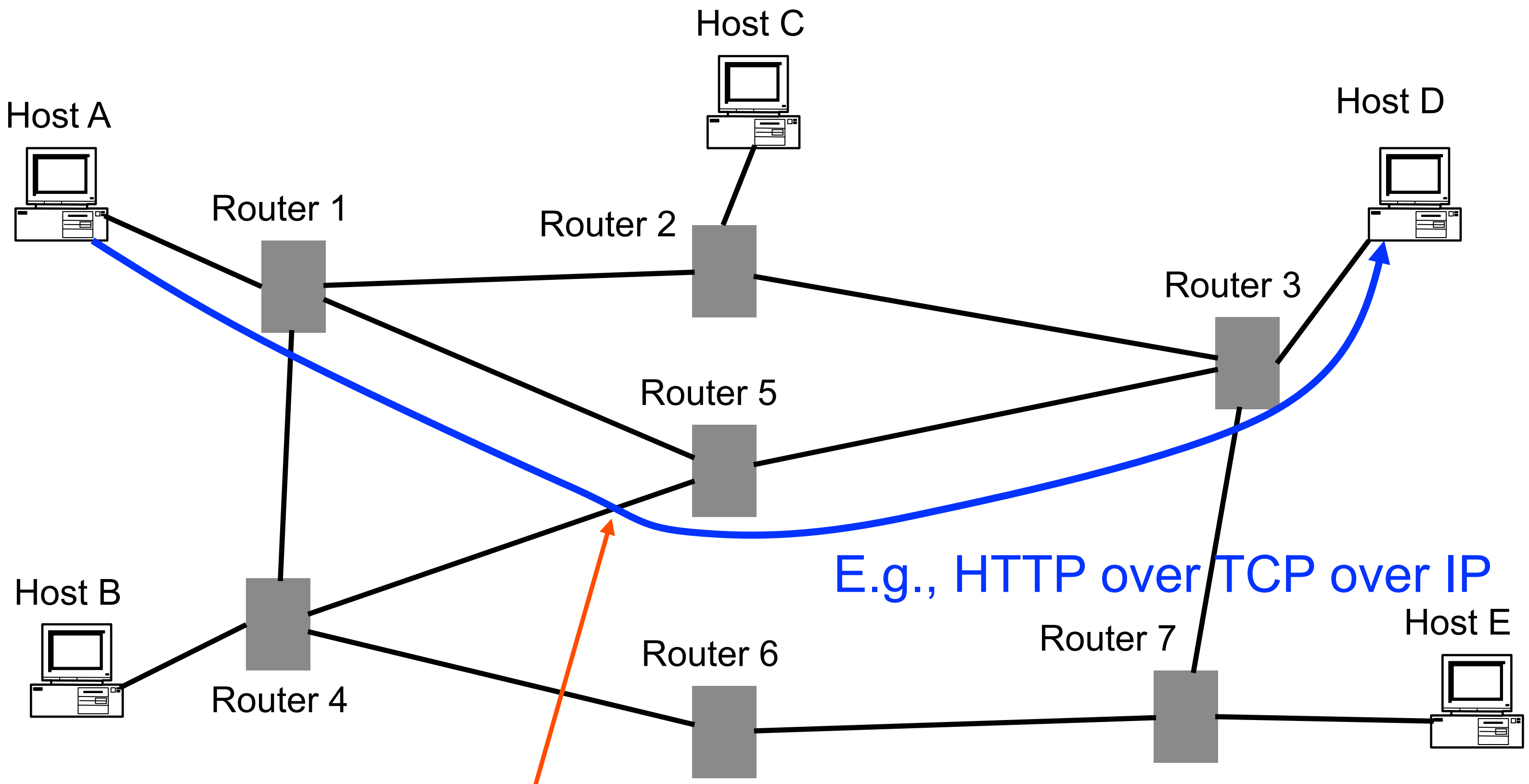
Host A communicates with Host D



Different Physical & Link Layers (Layers 1 & 2)

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

Host A communicates with Host D



E.g., HTTP over TCP over IP

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

Key Concept #3: *Protocols*

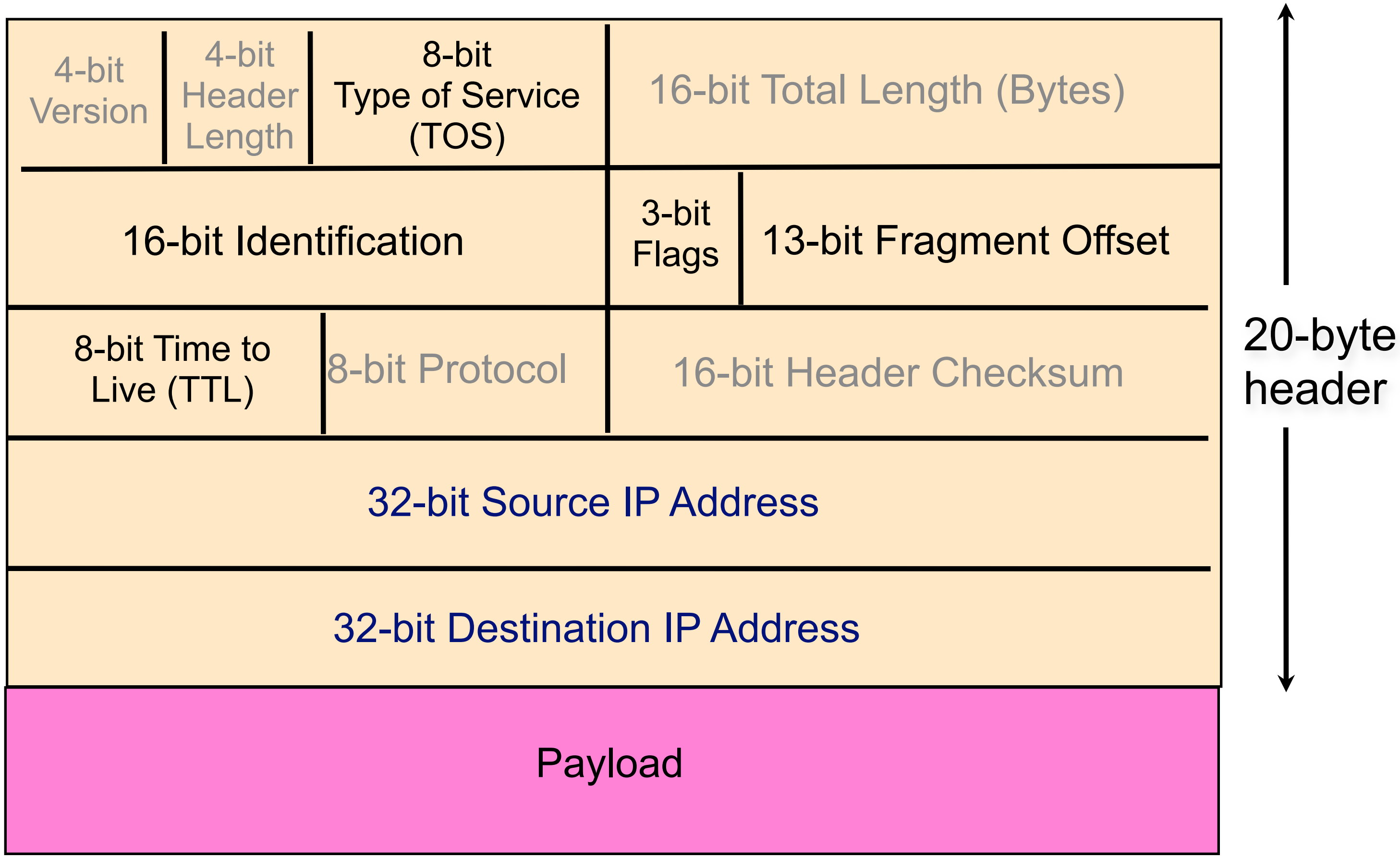
- A protocol is an agreement on how to communicate

- 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.: asking a question 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”

Example: IP Packet *Header*

(Network layer / layer 3)

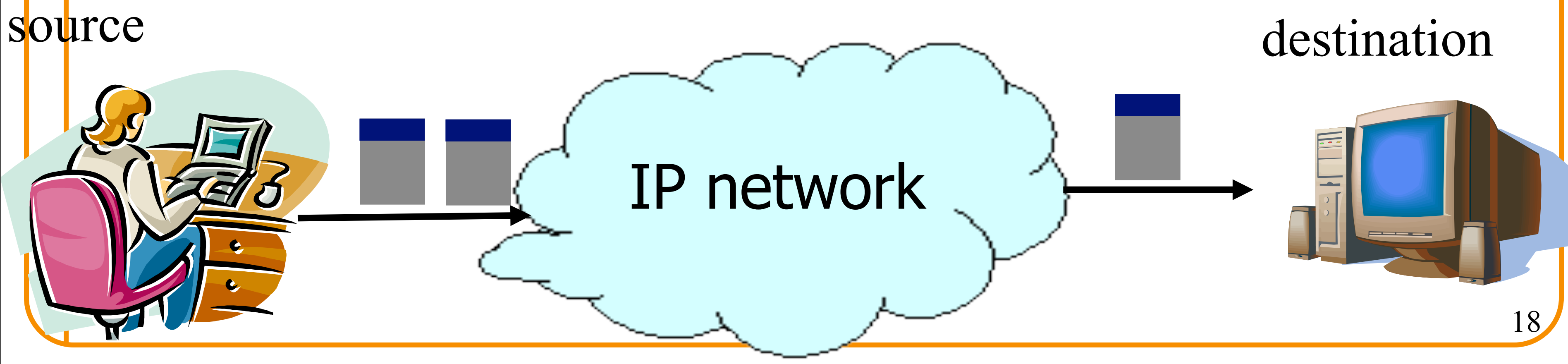


<table>
<tr><td>4-bit Version</td><td>4-bit Header Length</td><td>8-bit Type of Service (TOS)</td><td colspan="2">16-bit Total Length (Bytes)</td></tr>
<tr><td colspan="3">16-bit Identification</td><td>3-bit Flags</td><td>13-bit Fragment Offset</td></tr>
<tr><td colspan="2">8-bit Time to Live (TTL)</td><td>8-bit Protocol</td><td colspan="2">16-bit Header Checksum</td></tr>
<tr><td colspan="5">32-bit Source IP Address</td></tr>
<tr><td colspan="5">32-bit Destination IP Address</td></tr>
<tr><td colspan="5">Payload</td></tr>
</table>

IP = Internet Protocol

IP: “*Best Effort* ” Packet Delivery

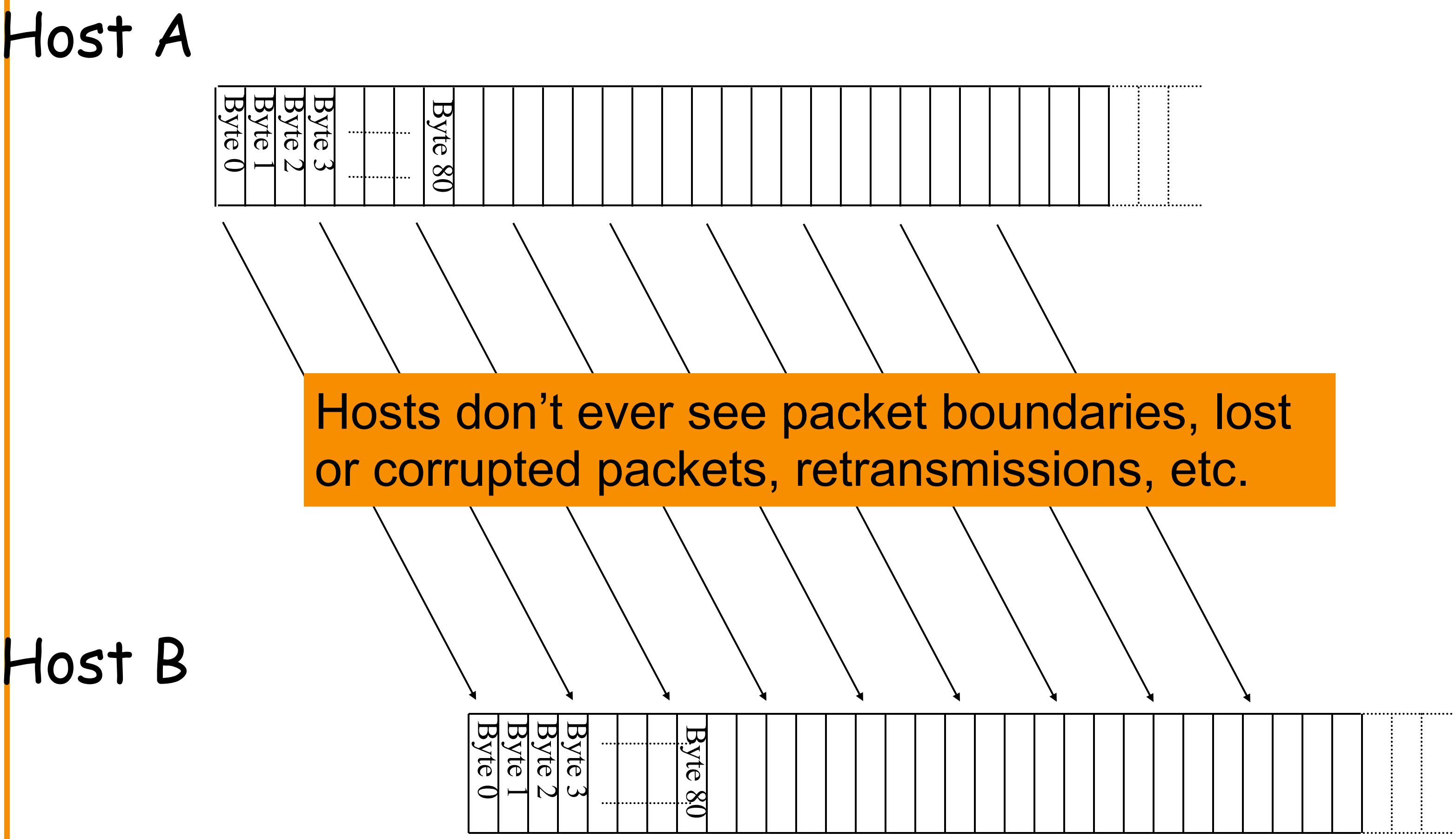
- Routers inspect destination address, locate “next hop” in forwarding table
  - Address = ~unique identifier/locator for the receiving host
  - (decrements TTL “Time To Live” field, drops packet if = 0)
- Only provides a “I’ll give it a try” delivery service:
  - Packets may be lost
  - Packets may 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
- #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

TCP "Stream of Bytes" Service



Hosts don't ever see packet boundaries, lost or corrupted packets, retransmissions, etc.

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    - Robust detection & retransmission of lost data
  - Congestion control
    - Dynamic adaptation to network path’s capacity
    - (Also adaptation to receiver’s ability to absorb data)

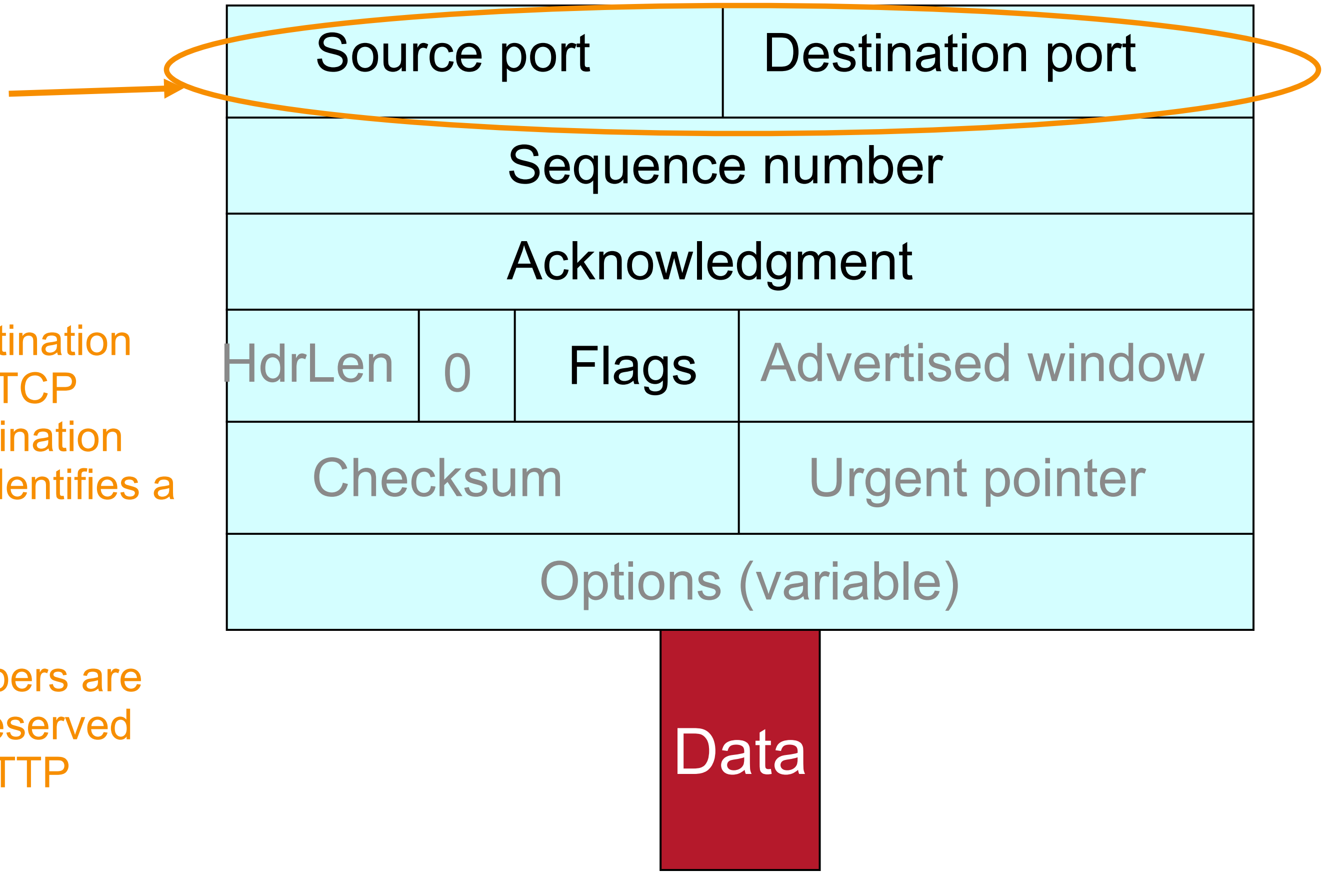
TCP Header

<table>
<tr><td colspan="3">Source port</td><td>Destination port</td></tr>
<tr><td colspan="4">Sequence number</td></tr>
<tr><td colspan="4">Acknowledgment</td></tr>
<tr><td>HdrLen</td><td>0</td><td>Flags</td><td>Advertised window</td></tr>
<tr><td colspan="3">Checksum</td><td>Urgent pointer</td></tr>
<tr><td colspan="4">Options (variable)</td></tr>
</table>

Data

TCP Header

Ports are associated with OS processes



Source port | Destination port

Sequence number

Acknowledgment

HdrLen | 0 | Flags | Advertised window

Checksum | Urgent pointer

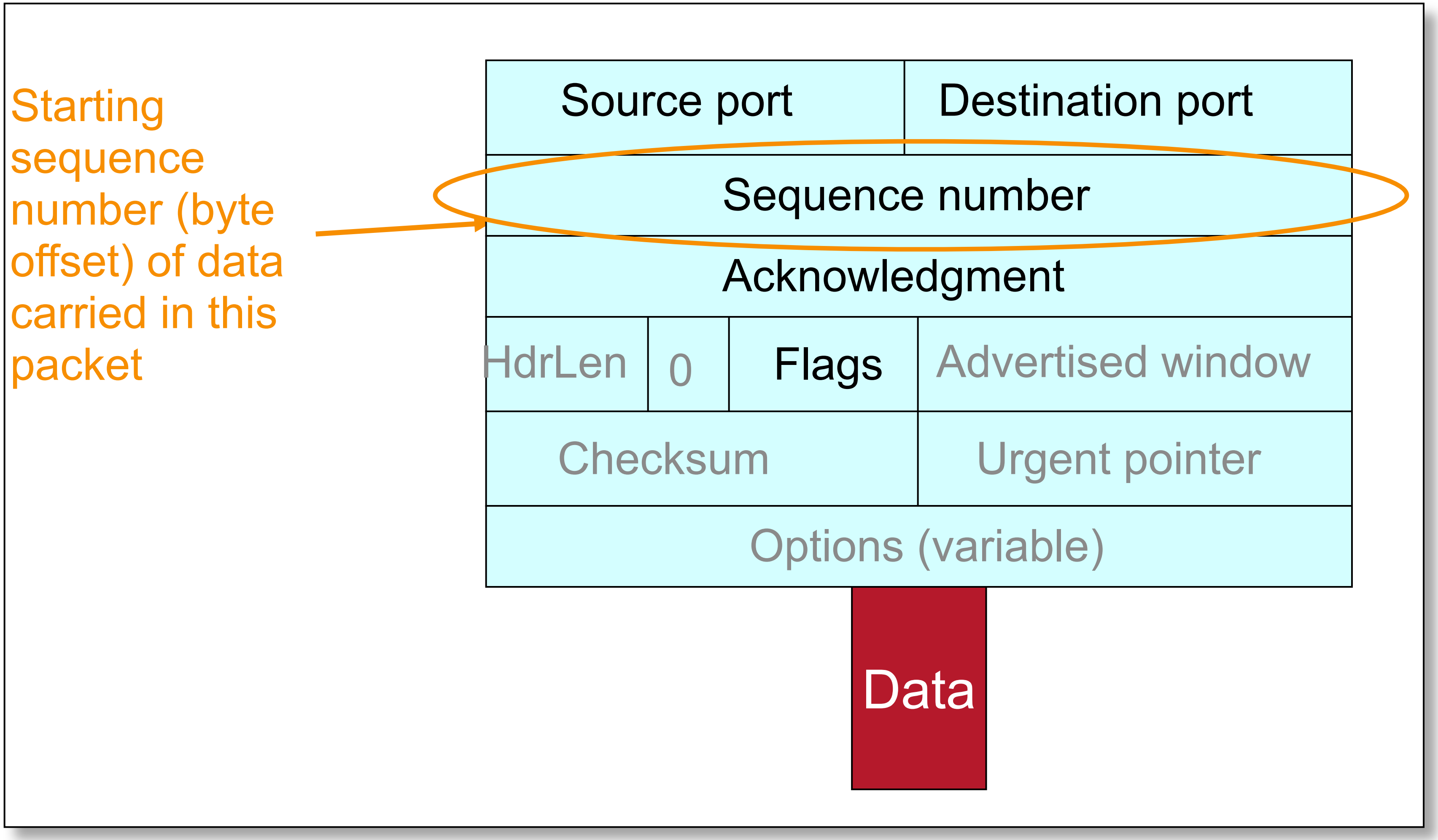
Options (variable)

Data

IP source & destination addresses plus TCP source and destination ports uniquely identifies a TCP connection

Some port numbers are “well known” / reserved e.g. port 80 = HTTP

TCP Header



Starting sequence number (byte offset) of data carried in this packet

Source port | Destination port

Sequence number

Acknowledgment

HdrLen | 0 | Flags | Advertised window

Checksum | Urgent pointer

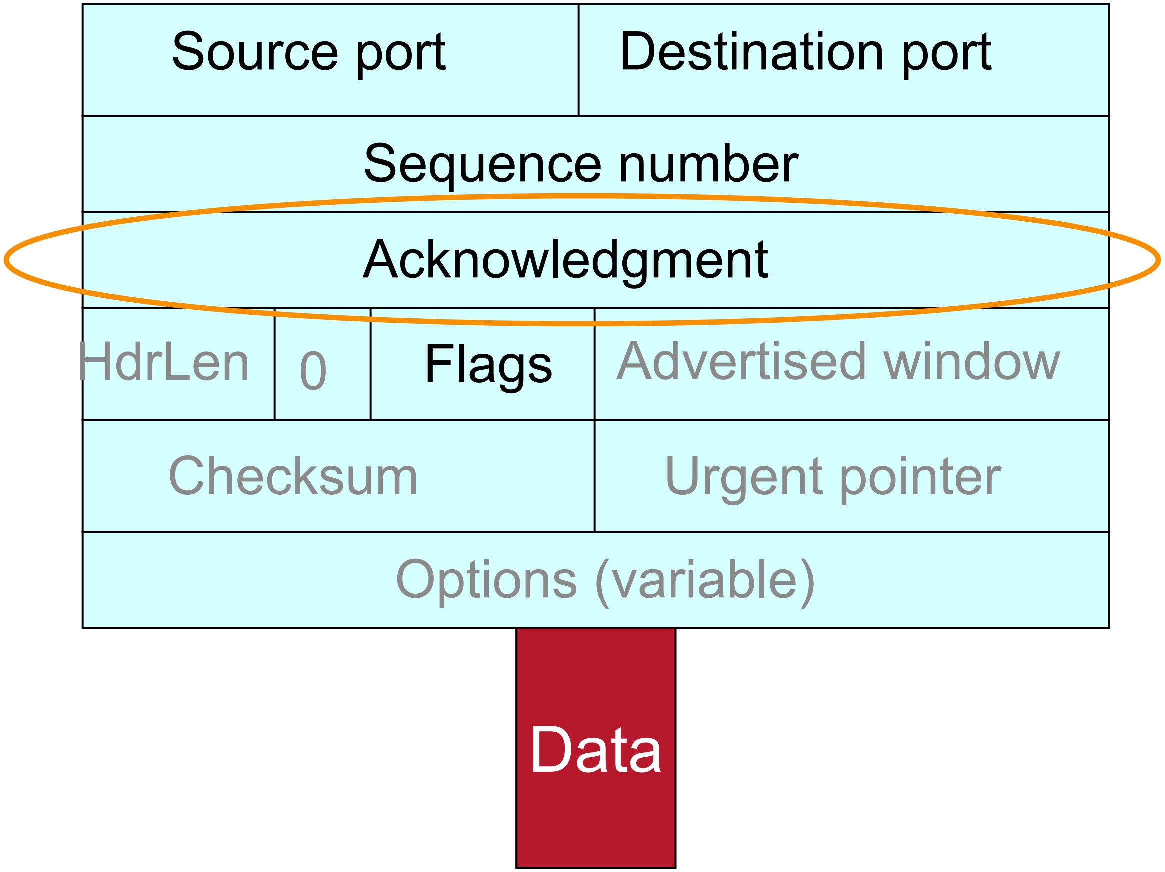
Options (variable)

Data

TCP Header

Acknowledgment gives seq # just beyond highest seq. received in order.

If sender sends N in-order bytes starting at seq S then ack for it will be S+N.



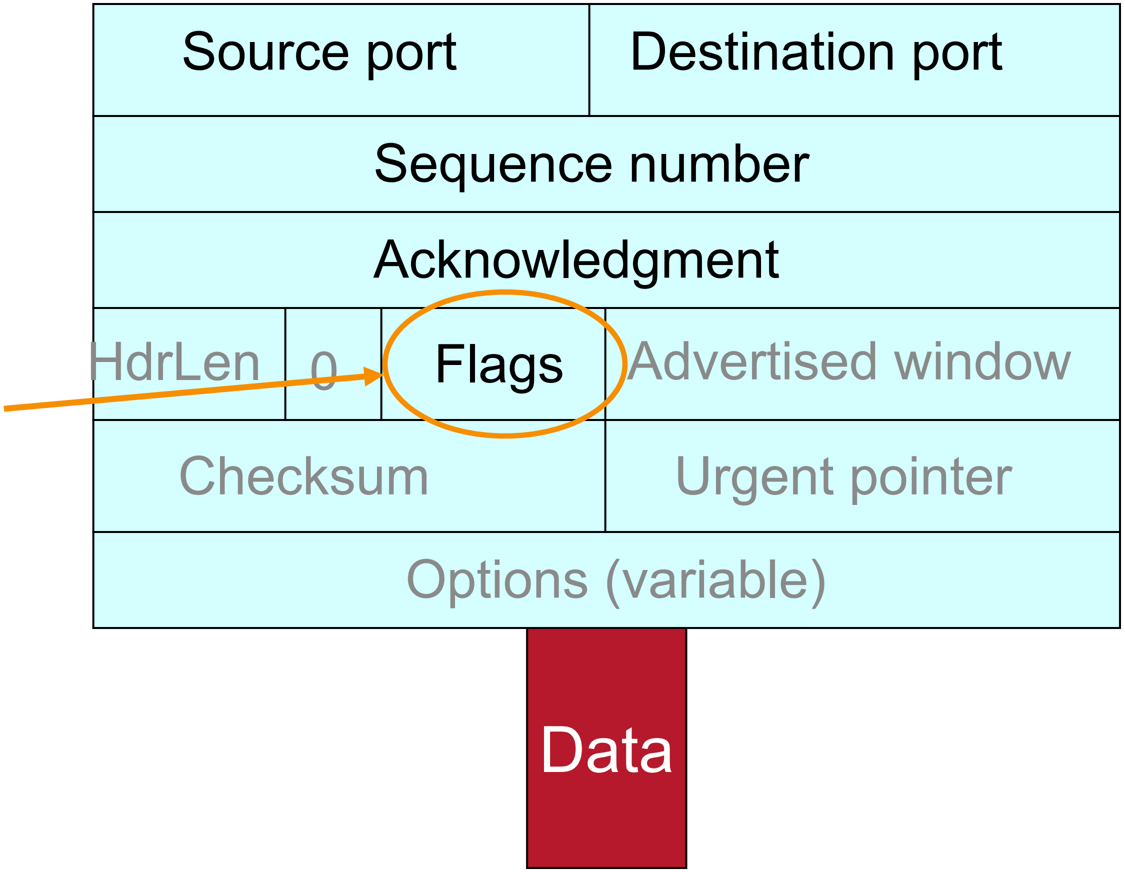
Source port
Destination port
Sequence number
Acknowledgment
HdrLen
0
Flags
Advertised window
Checksum
Urgent pointer
Options (variable)
Data

TCP Header

Uses include:

acknowledging data ("ACK")

setting up ("SYN") and closing connections ("FIN" and "RST")



Source port | Destination port

Sequence number

Acknowledgment

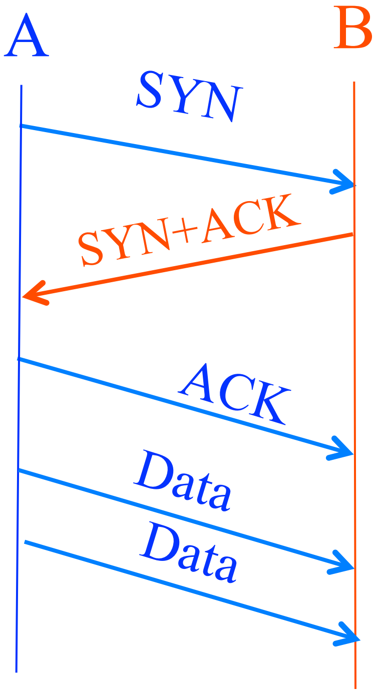
HdrLen | 0 | Flags | Advertised window

Checksum | Urgent pointer

Options (variable)

Data

Establishing a TCP Connection

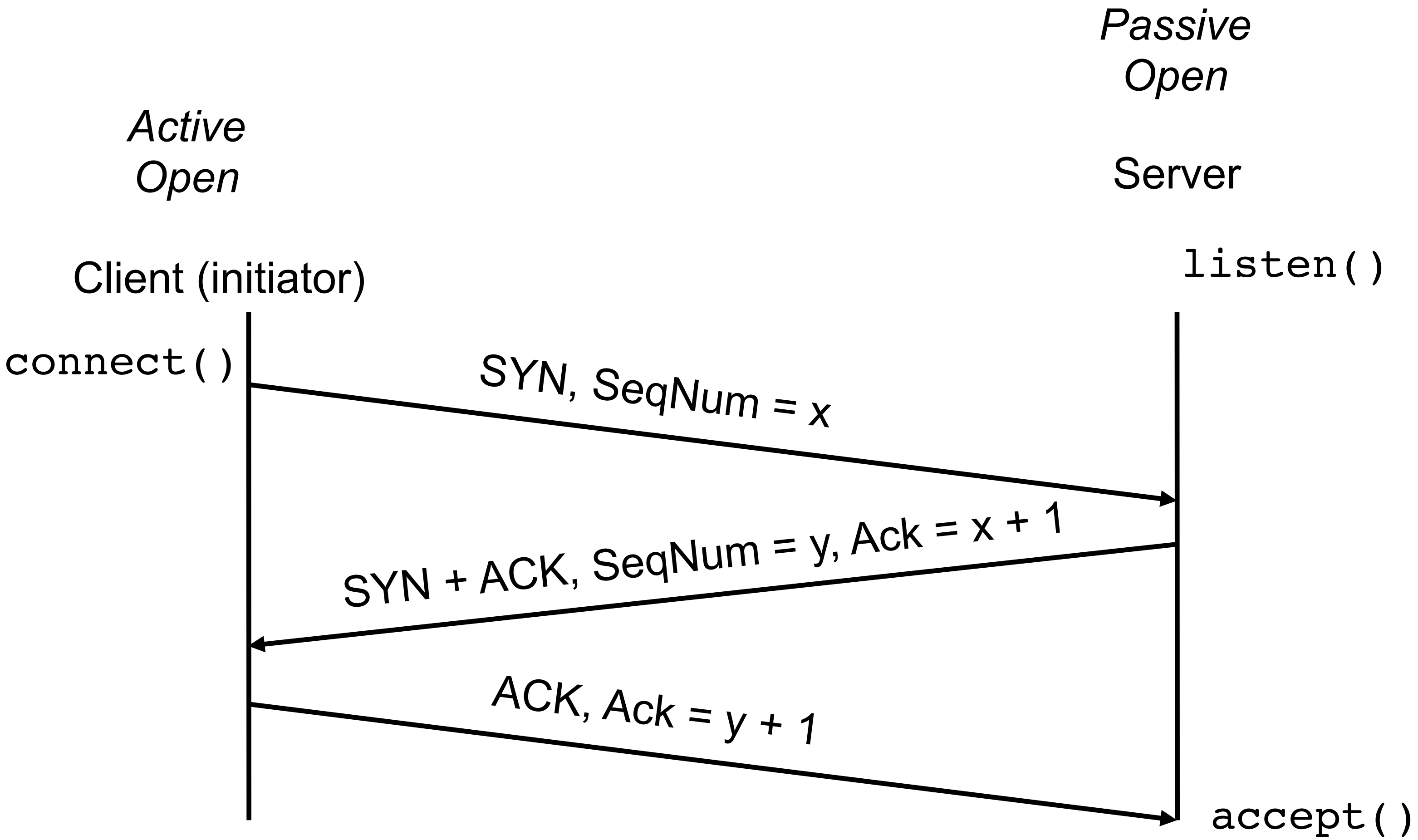


Each host tells its *Initial Sequence Number* (ISN) to the other host.

(Spec says to pick based on local clock)

- Three-way handshake to establish connection
  - Host A sends a **SYN** (open; "synchronize sequence numbers") to host B
  - Host B returns a SYN acknowledgment (**SYN+ACK**)
  - Host A sends an **ACK** to acknowledge the SYN+ACK

Timing Diagram: 3-Way Handshaking



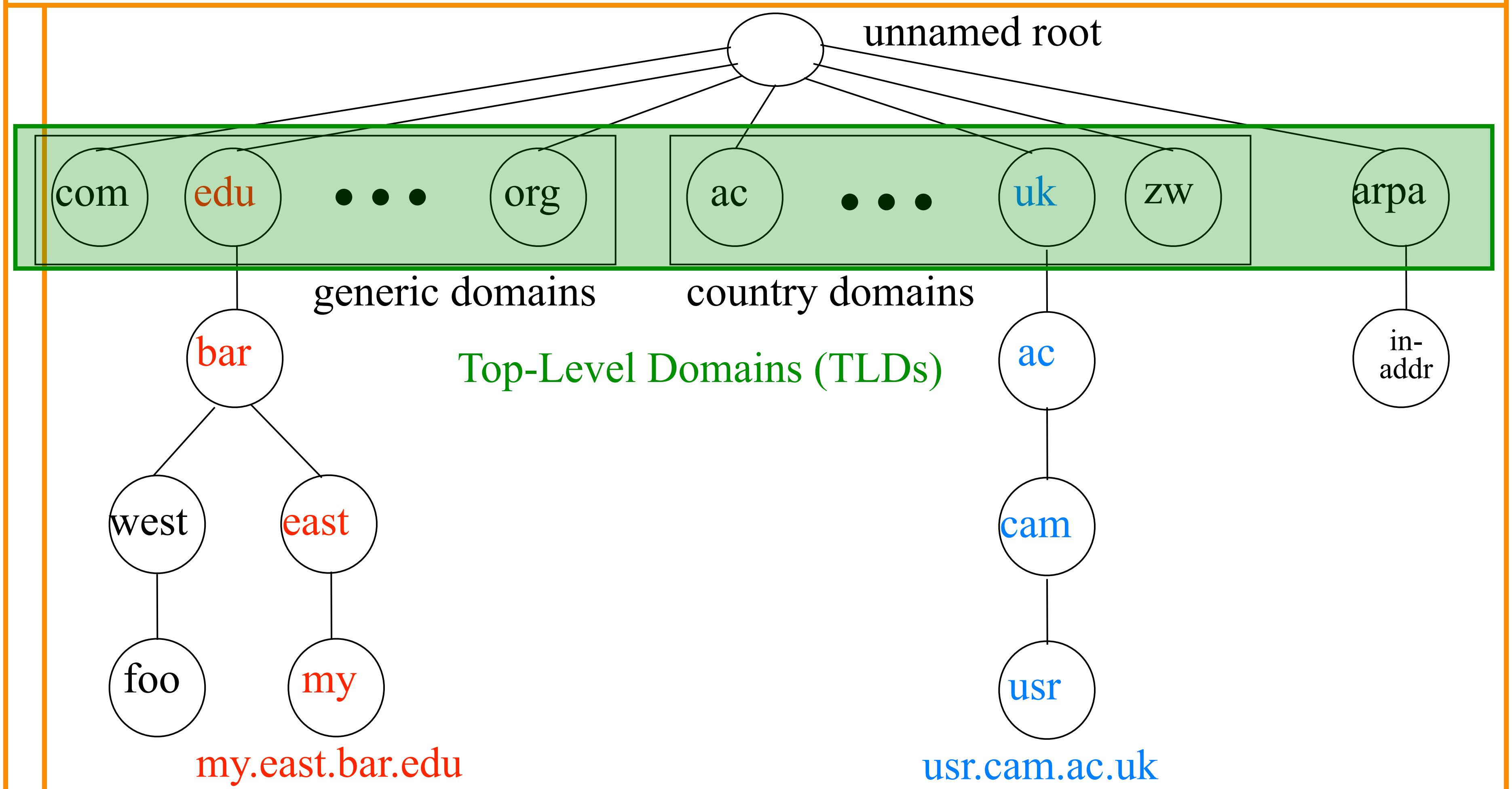
Host Names vs. IP addresses

- Host names
  - Examples: `www.cnn.com` and `bbc.co.uk`
  - Mnemonic name appreciated by humans
  - Variable length, full alphabet of characters
  - Provide little (if any) information about location
- IP addresses
  - Examples: `64.236.16.20` and `212.58.224.131`
  - Numerical address appreciated by routers
  - Fixed length, binary number
  - Hierarchical, related to host location

Mapping Names to Addresses

- Domain Name System (DNS)
  - Hierarchical name space divided into zones
  - Zones distributed over collection of DNS servers
  - (Also separately maps addresses to names)
- Hierarchy of DNS servers
  - Root (hardwired into other servers)
  - Top-level domain (TLD) servers
  - "Authoritative" DNS servers (e.g. for *berkeley.edu*)

Distributed Hierarchical Database



Mapping Names to Addresses

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  - Hierarchical name space divided into zones
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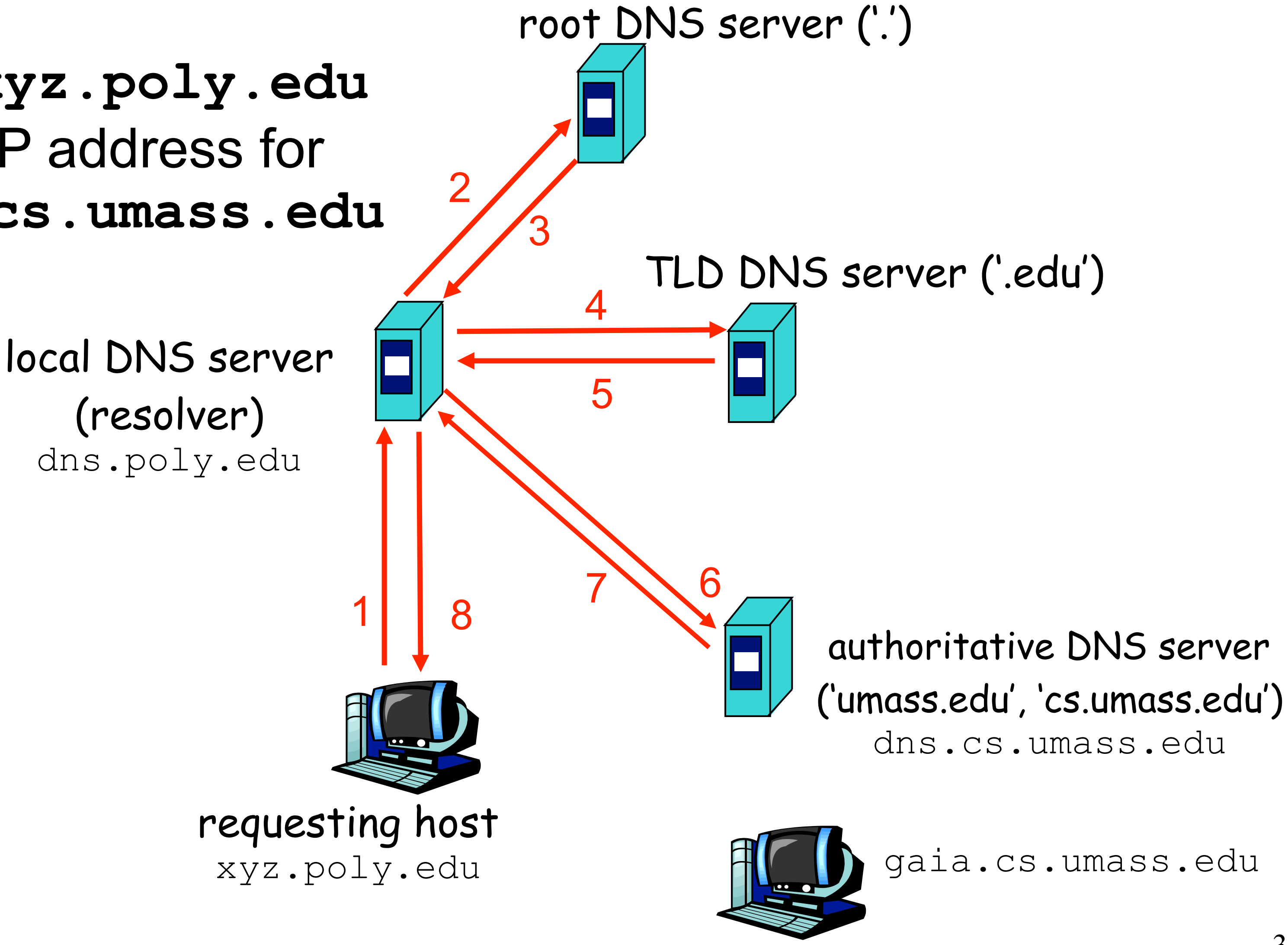
- Hierarchy of DNS servers
  - Root (hardwired into other servers)
  - Top-level domain (TLD) servers
  - "Authoritative" DNS servers (e.g. for *berkeley.edu*)
- Performing the translations
  - Each computer configured to contact a *resolver*

Example

Host at **xyz.poly.edu** wants IP address for **gaia.cs.umass.edu**



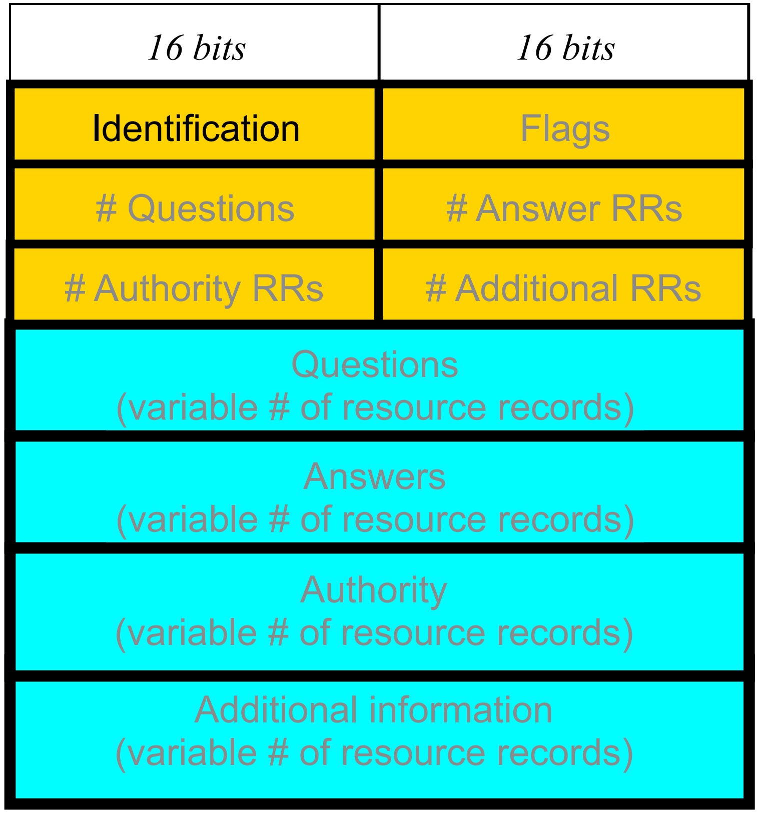
DNS Protocol

DNS protocol: *query* and *reply* messages, both with same *message format*

(Mainly uses UDP transport rather than TCP)

Message header:

- Identification: 16 bit # for query, reply to query uses same #
- Replies can include “Authority” (name server responsible for answer) and “Additional” (info client is likely to look up soon anyway)
- Replies have a Time To Live (in seconds) for caching



16 bits	16 bits
Identification	Flags
# Questions	# Answer RRs
# Authority RRs	# Additional RRs

Questions
(variable # of resource records)

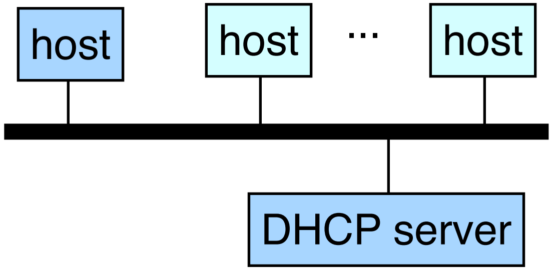
Answers
(variable # of resource records)

Authority
(variable # of resource records)

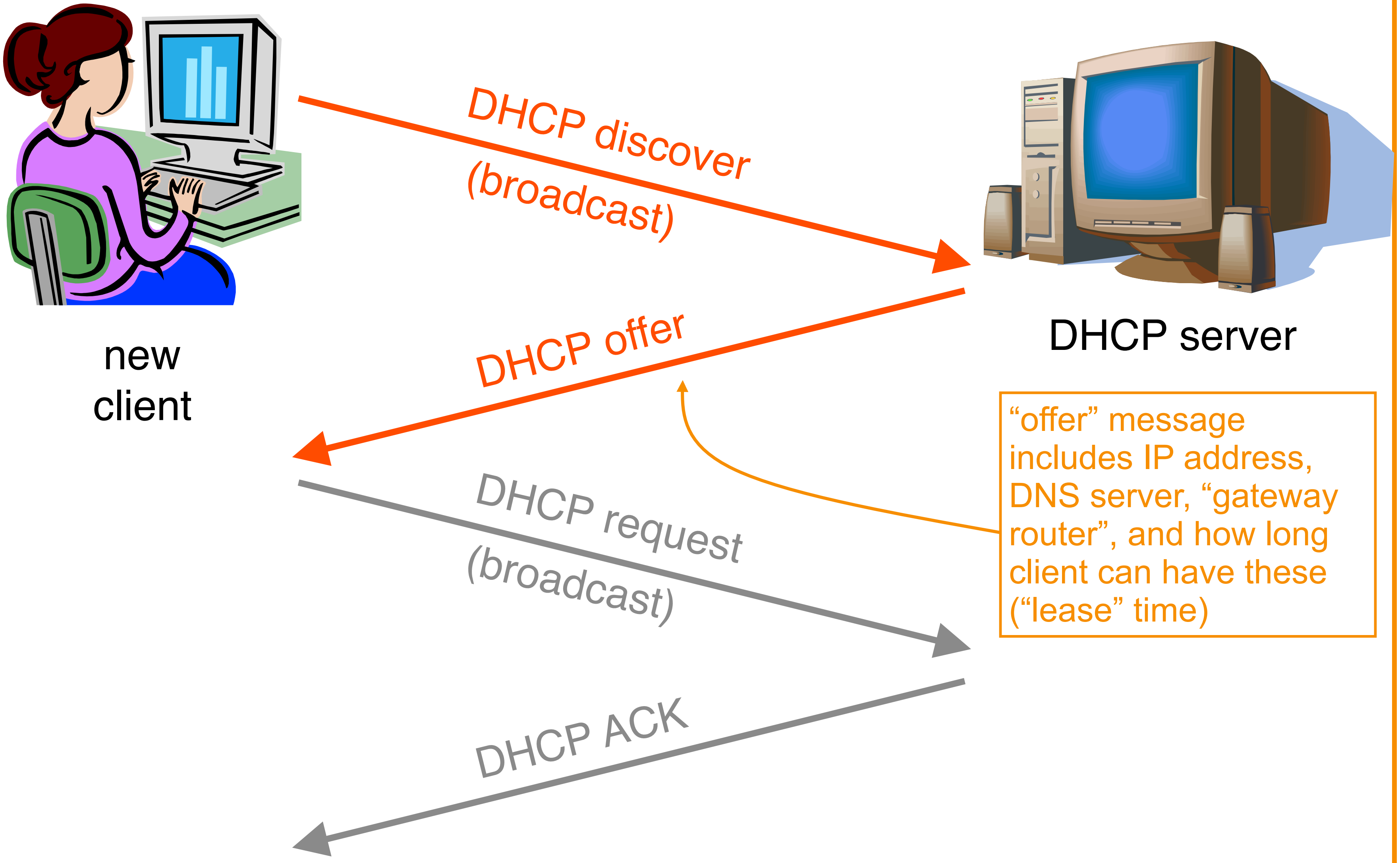
Additional information
(variable # of resource records)

Bootstrapping Problem

- New host doesn’t have an IP address yet
  - So, host doesn’t know what source address to use
- Host doesn’t know *who to ask* for an IP address
  - So, host doesn’t know what destination address to use
- Solution: shout to “**discover**” server that can help
  - Broadcast a server-discovery message (layer 2)
  - Server(s) sends a reply offering an address



Dynamic Host Configuration Protocol



new client

DHCP server

DHCP discover (broadcast)

DHCP offer

DHCP request (broadcast)

DHCP ACK

“offer” message includes IP address, DNS server, “gateway router”, and how long client can have these (“lease” time)

Questions?