Networking Overview

CS 161: Computer Security

Prof. Vern Paxson

TAs: Devdatta Akhawe, Mobin Javed & Matthias Vallentin

http://inst.eecs.berkeley.edu/~cs161/

February 1, 2011

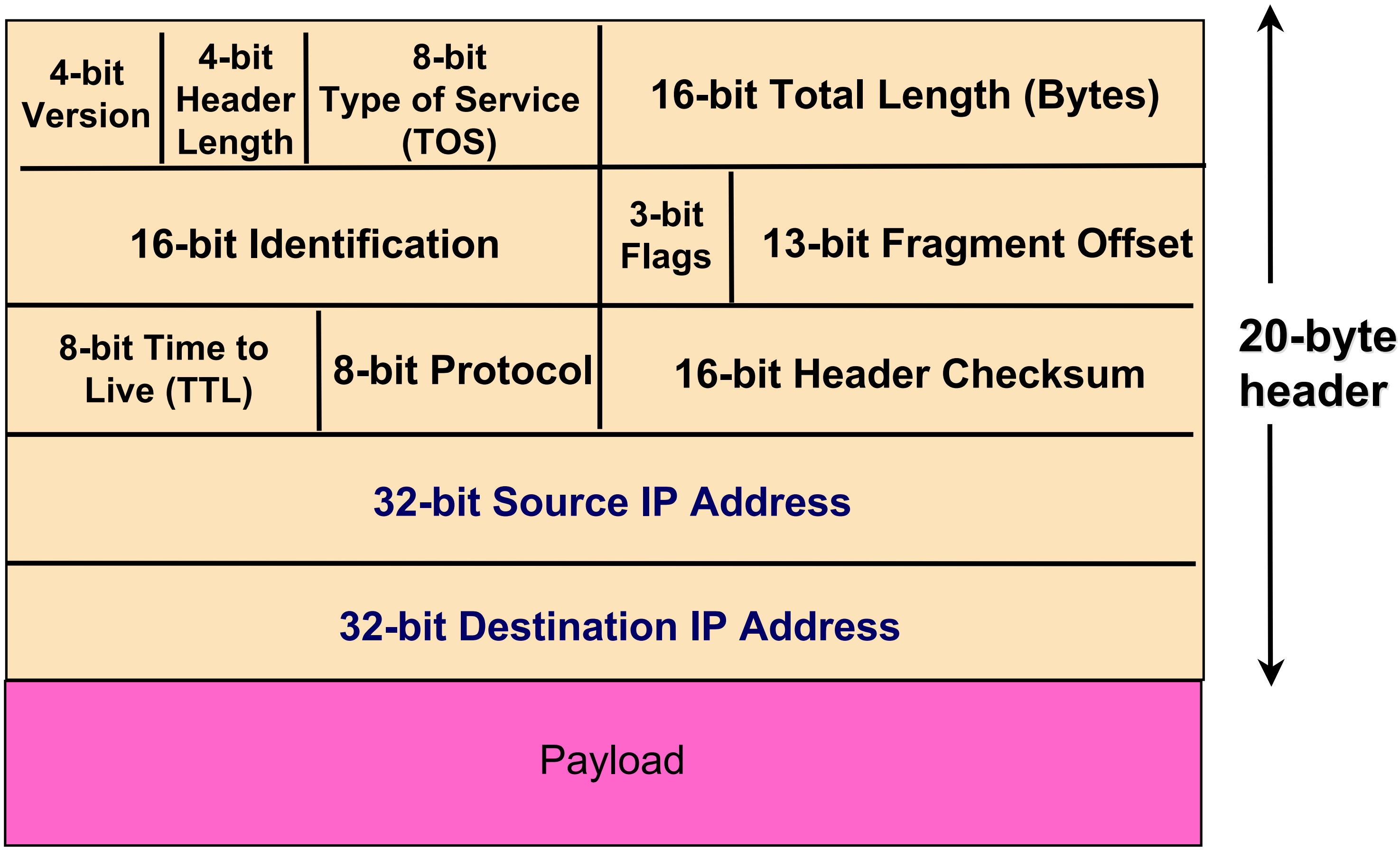
Focus For Today's Lecture

- Sufficient background in networking to then explore security issues in next 3 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: *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*



IP = Internet Protocol

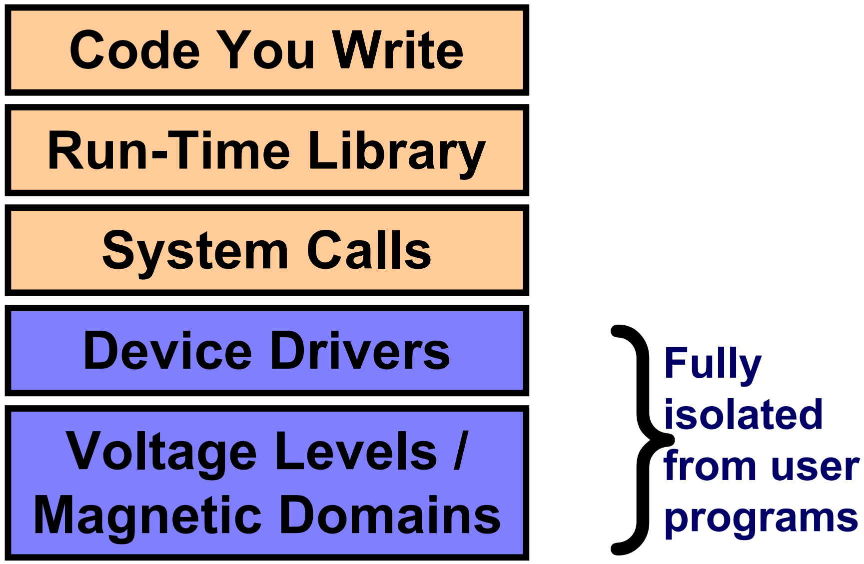
Key Concept #2: *Dumb Network*

- 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

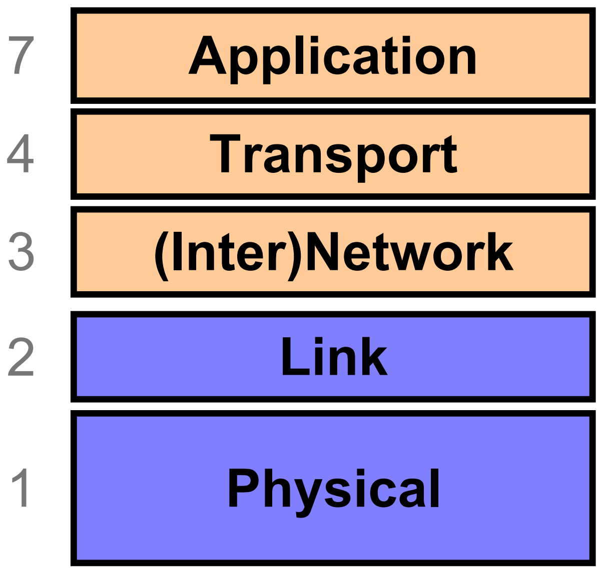
* Today's Internet is full of hacks that violate this

Key Concept #3: *Layering*

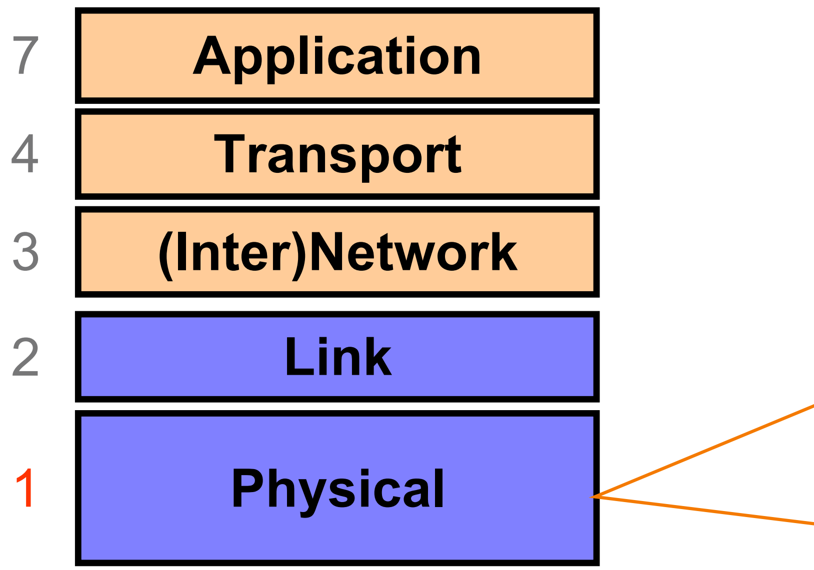
- Internet design is strongly partitioned into layers
  - Each layer relies on services provided by next layer below …
  - … and provides services to layer above it
- Analogy:
  - Consider structure of an application you've written and the "services" each layer relies on / provides



Internet Layering ("Protocol Stack")



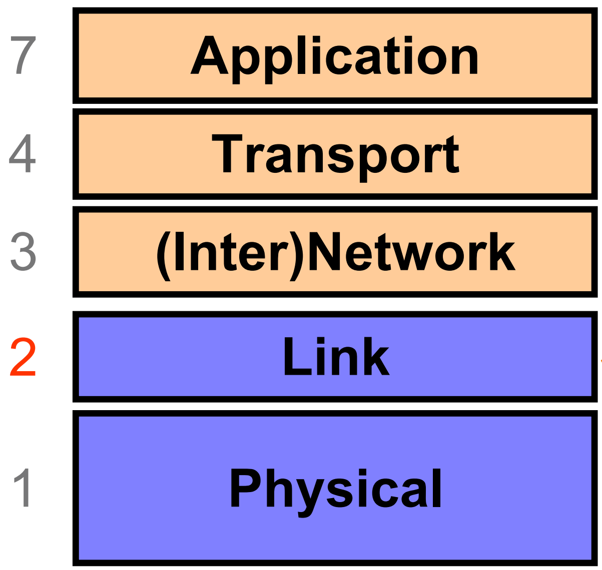
Layer 1: Physical Layer



Encoding bits to send them over a <u>single</u> **physical link**

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

Layer 2: Link Layer

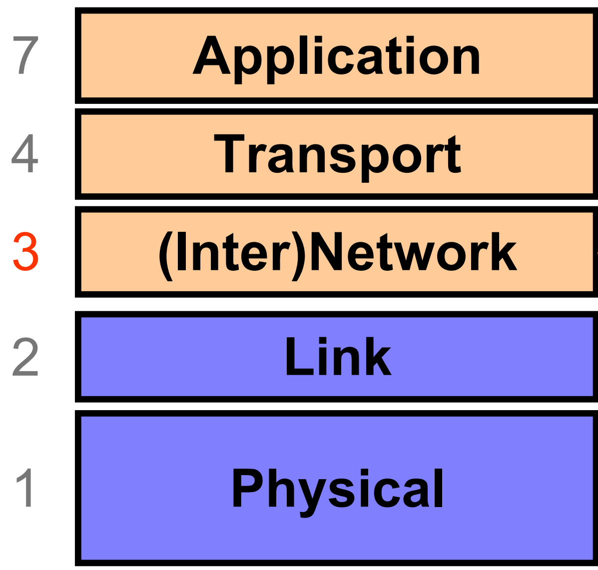


Framing and transmission of a collection of bits into individual messages sent across a single "subnetwork" (one physical technology)

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



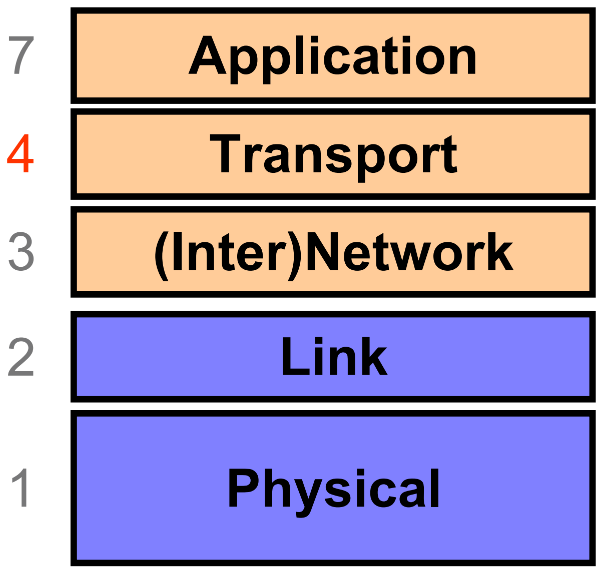
Bridges multiple "subnets" to provide *end-to-end* internet connectivity between nodes

- Provides global addressing

Works across different link technologies

Different **for each Internet "hop"**

Layer 4: Transport Layer



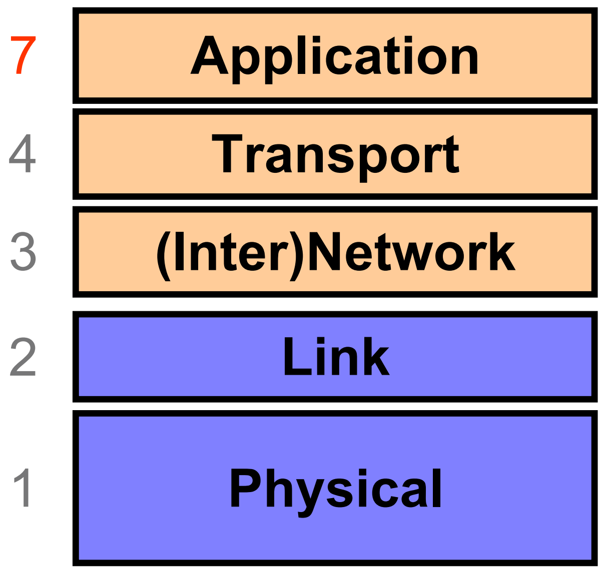
End-to-end communication between processes

Different services provided:

TCP = reliable *byte stream*

UDP = unreliable *datagrams*

Layer 7: Application Layer



Communication of whatever you wish

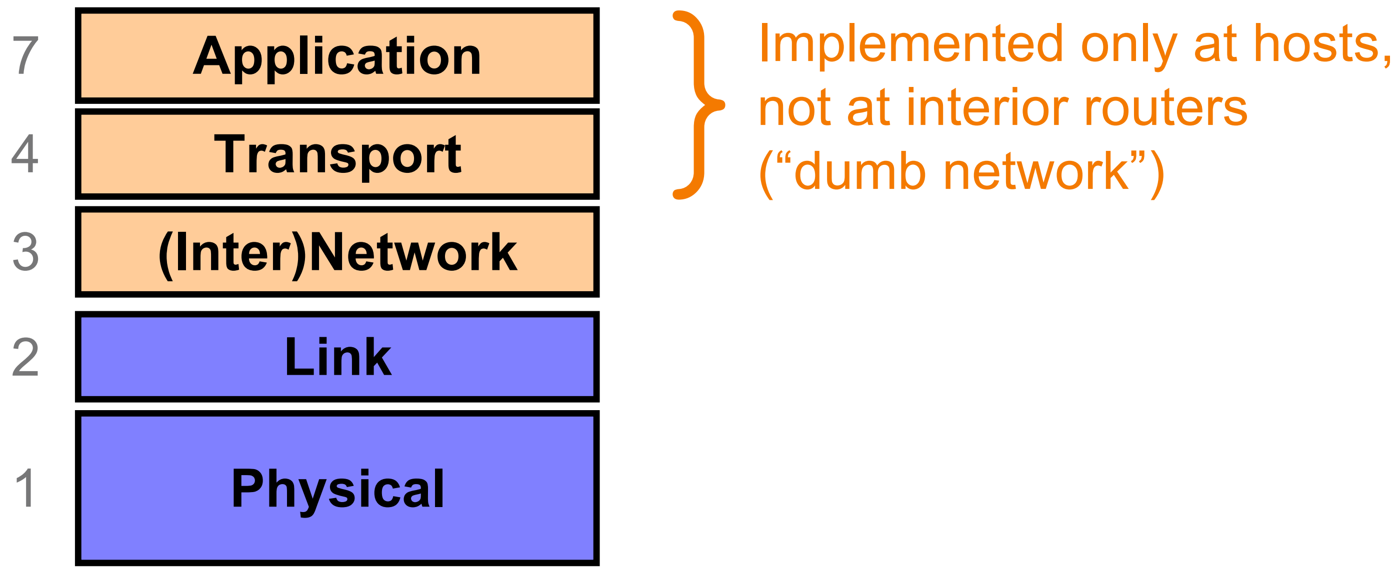
Can use whatever transport(s) is convenient

Freely structured

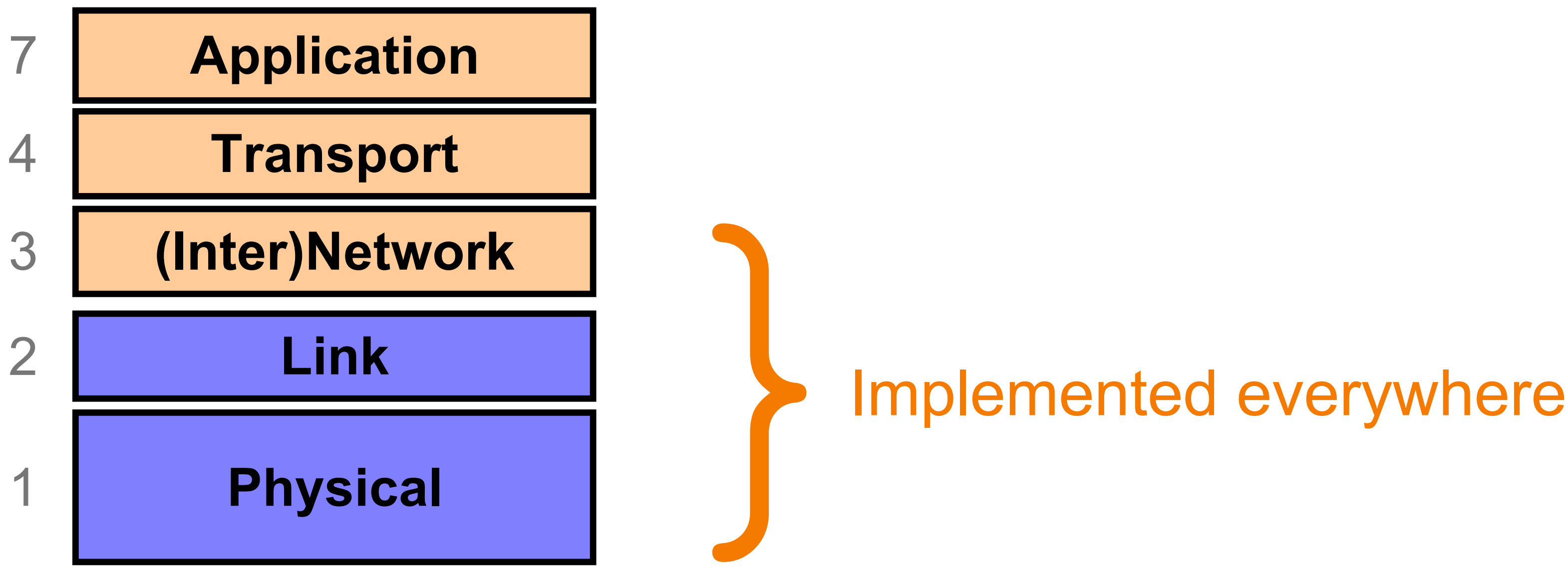
E.g.:

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

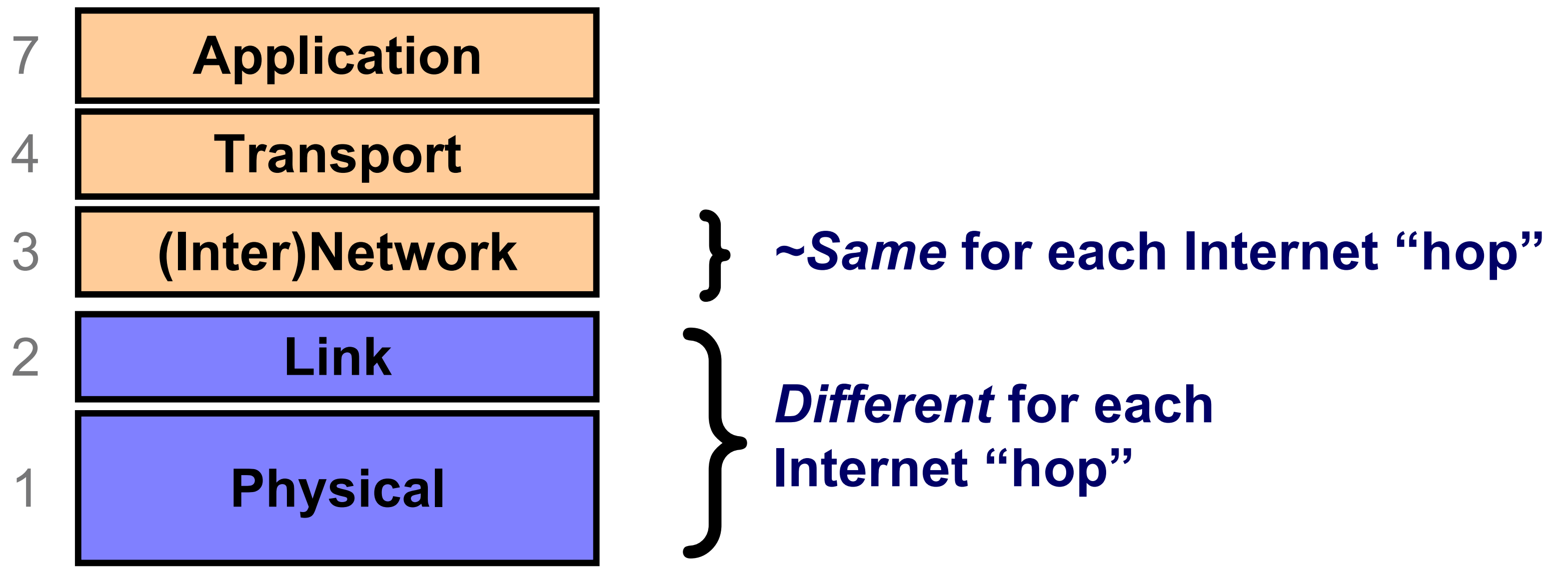
Internet Layering ("Protocol Stack")



Internet Layering ("Protocol Stack")

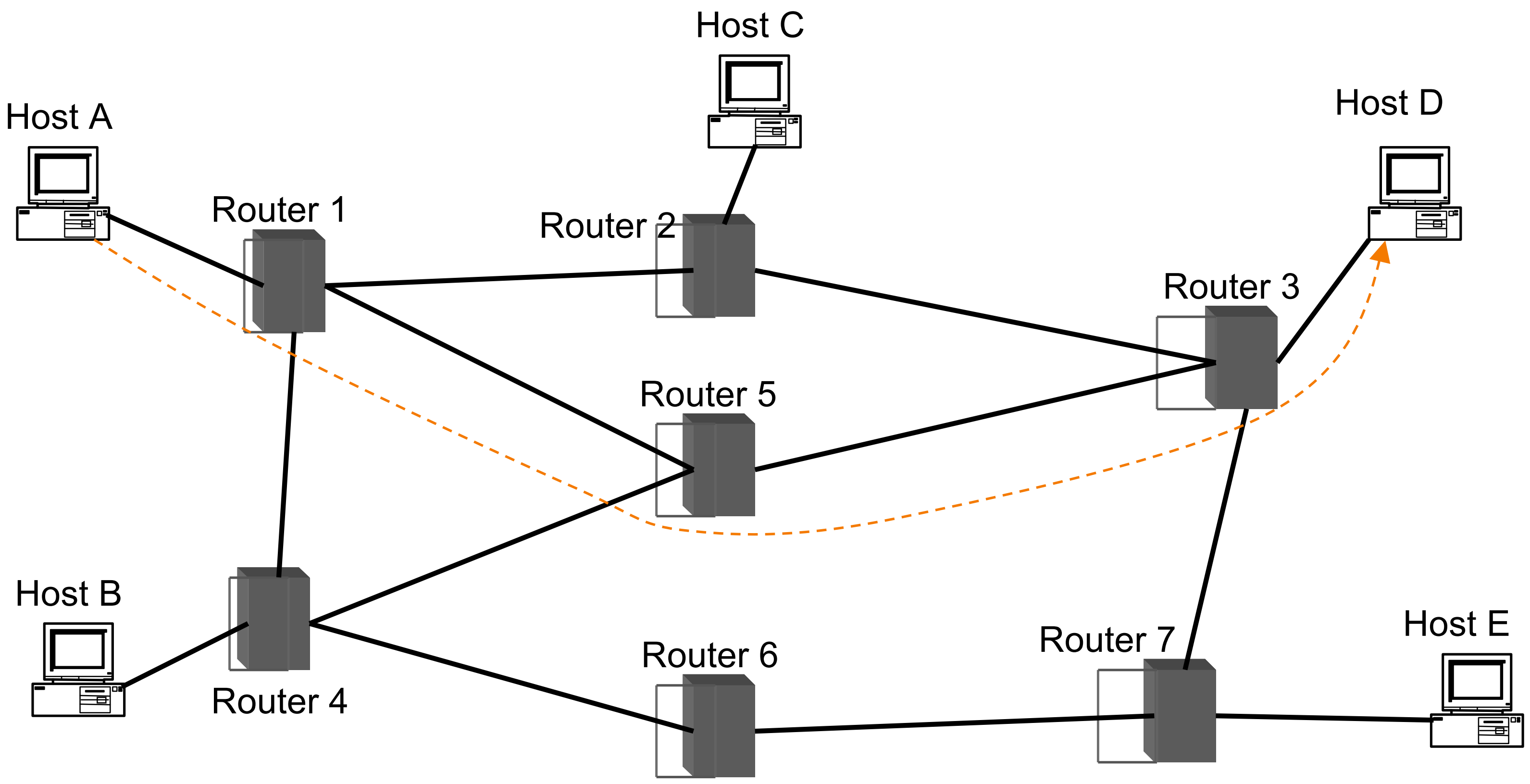


Internet Layering ("Protocol Stack")



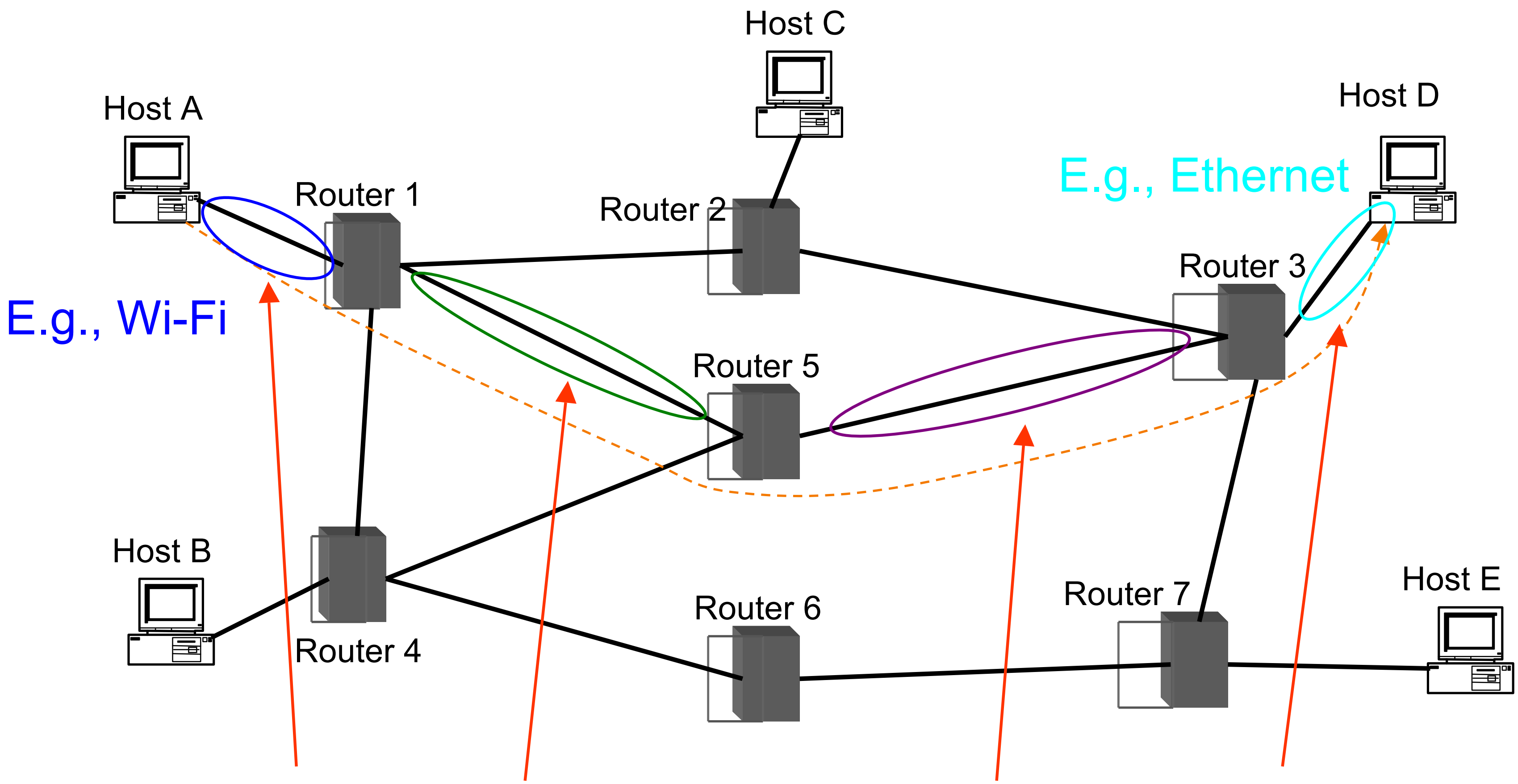
Hop-By-Hop vs. End-to-End Layers

Host A communicates with Host D



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

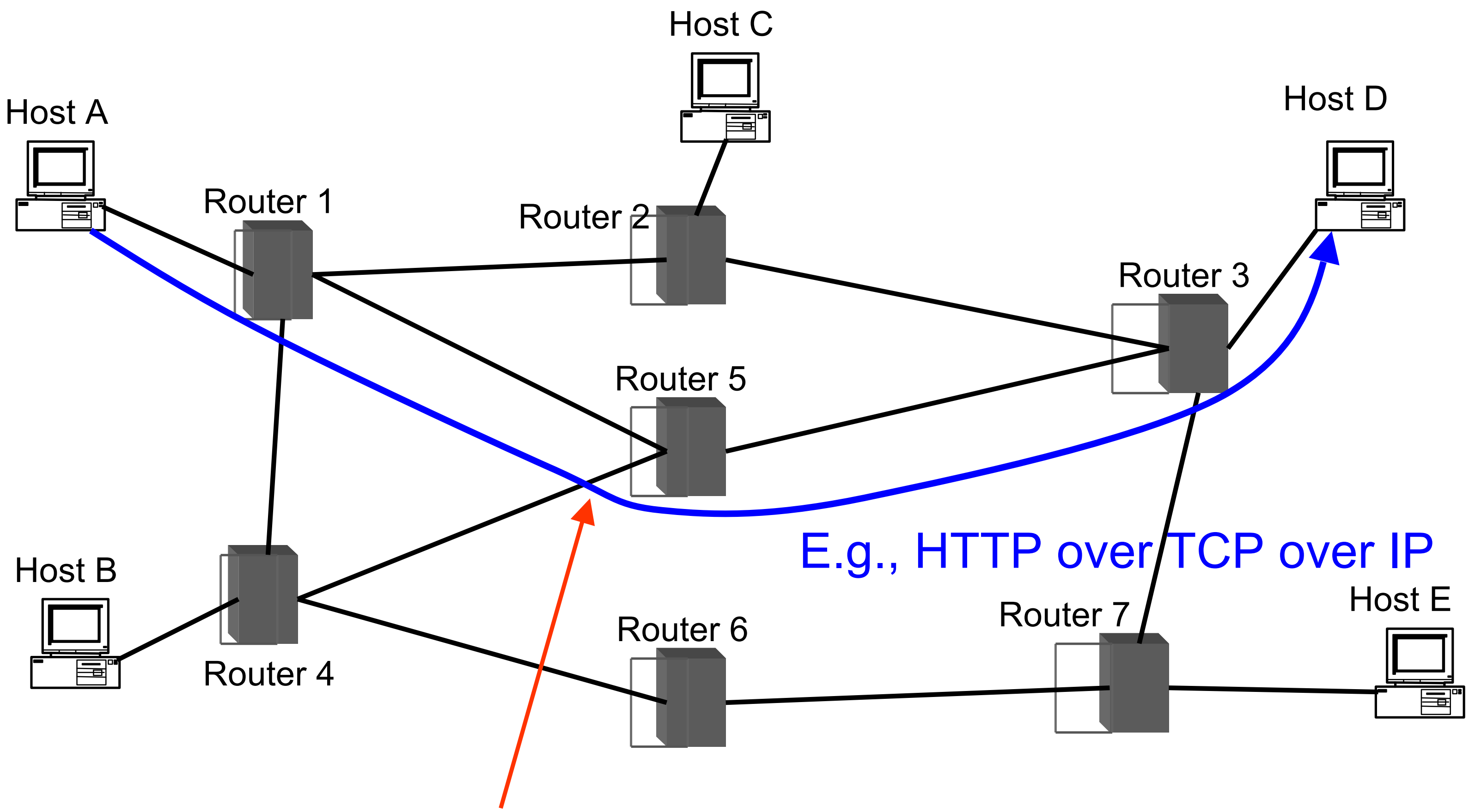
Host A communicates with Host D



Different **Physical & Link Layers (Layers 1 & 2)**

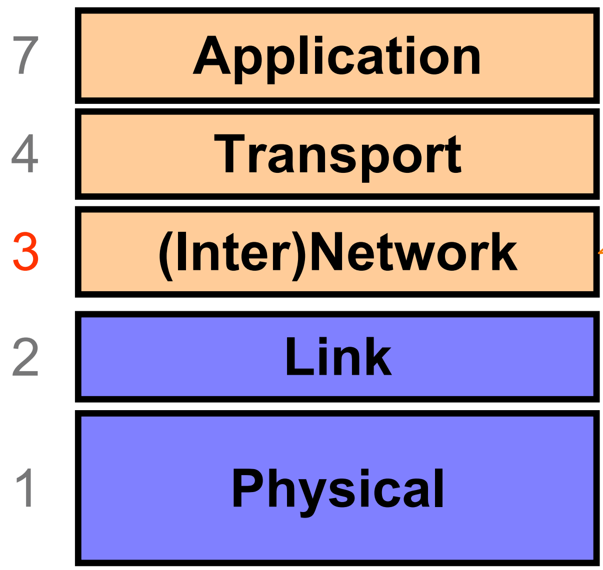
Hop-By-Hop vs. End-to-End Layers

Host A communicates with Host D



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

Layer 3: (Inter)Network Layer

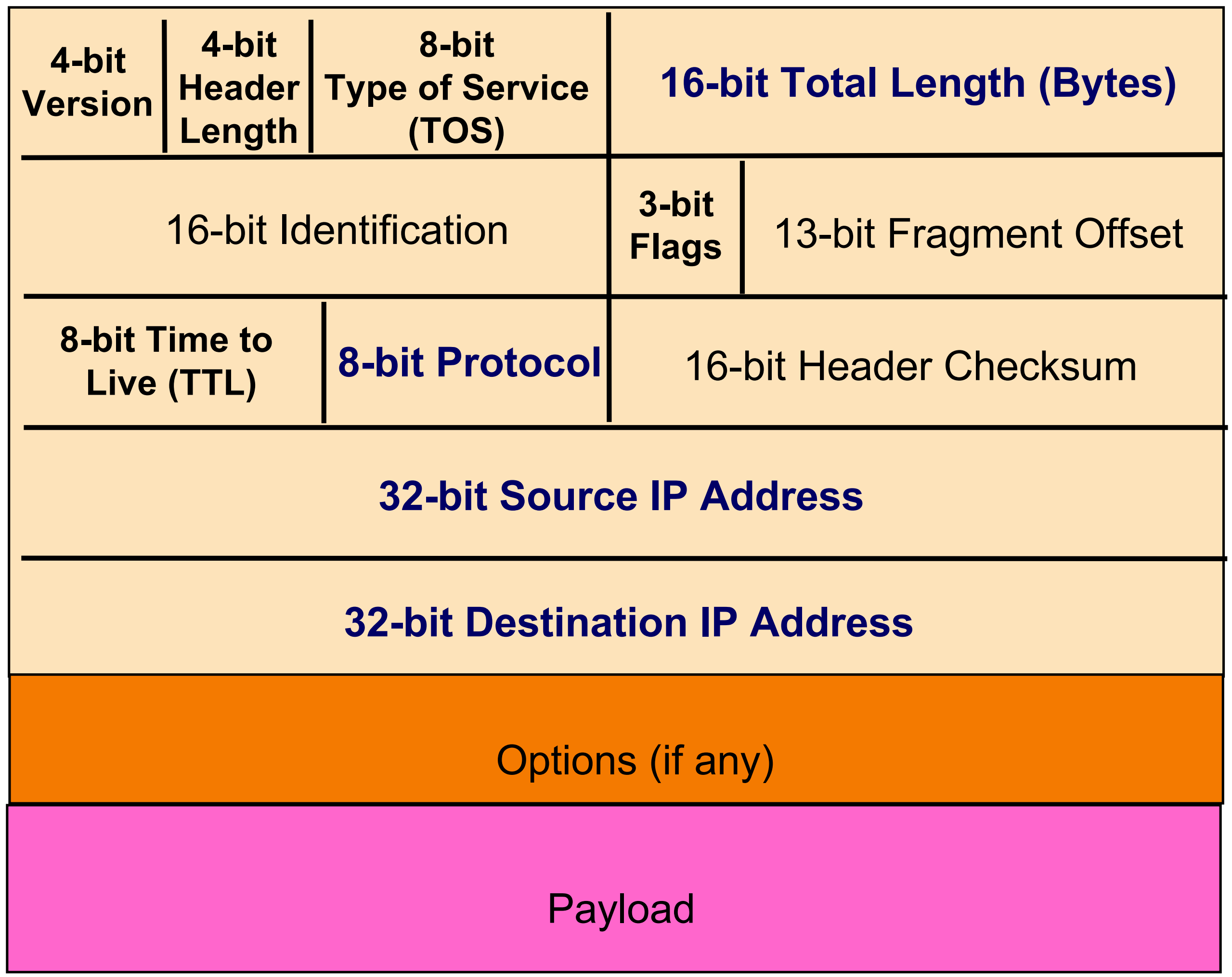


Bridges multiple "subnets" to provide *end-to-end* internet connectivity between nodes

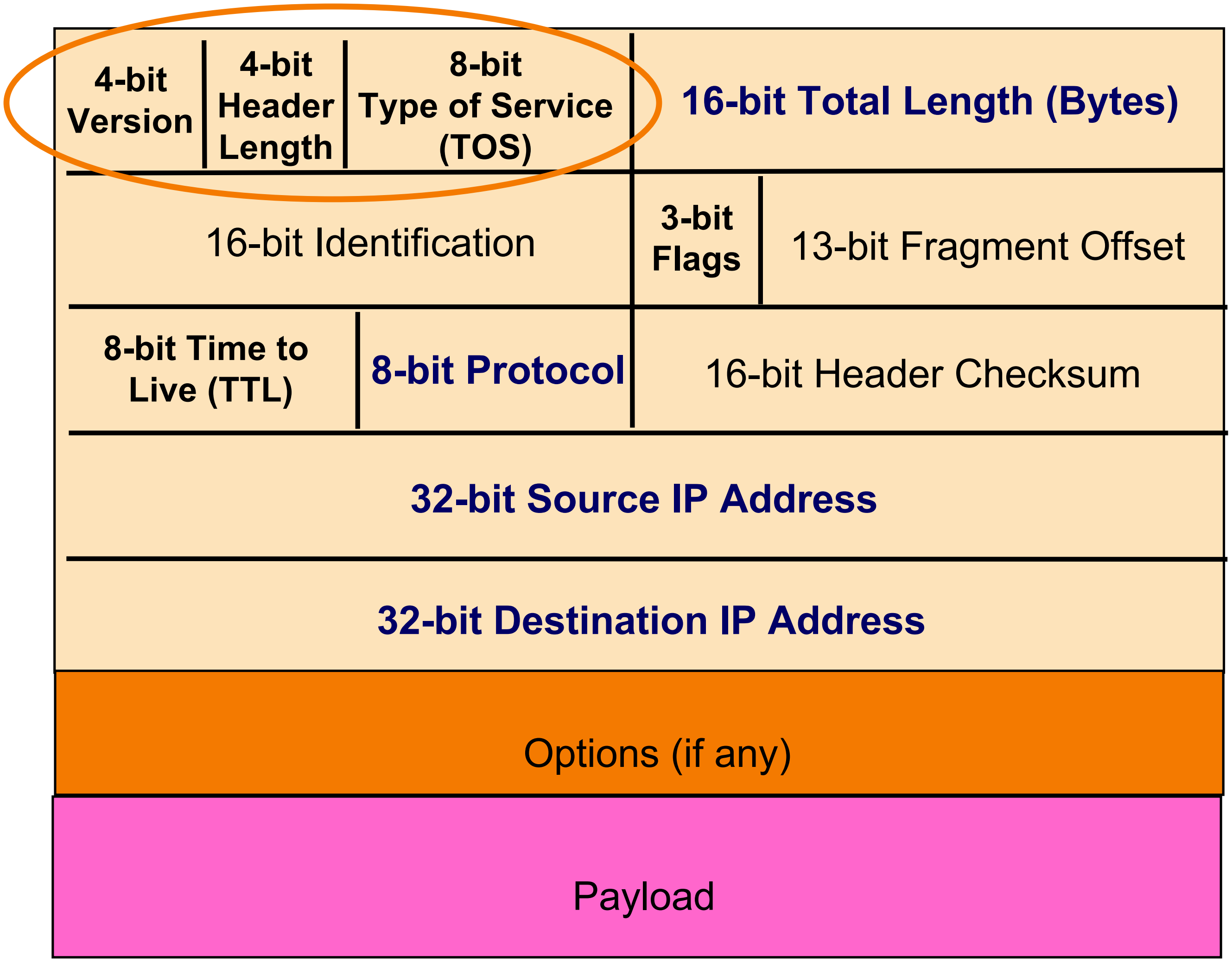
- Provides global addressing

Works across different link technologies

IP Packet Structure



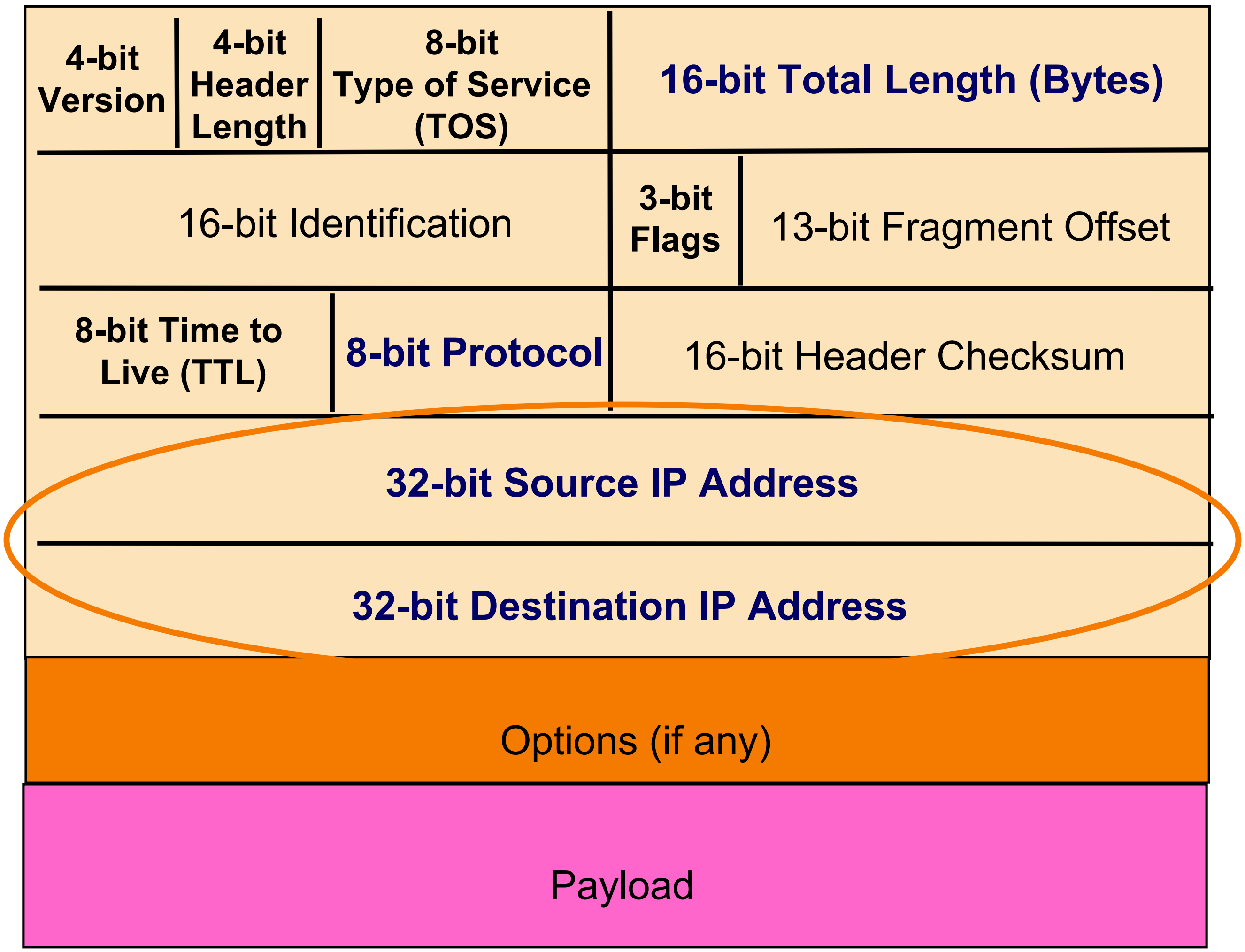
IP Packet Structure



IP Packet Header Fields

- Version number (4 bits)
  - Indicates the version of the IP protocol
  - Necessary to know what other fields to expect
  - Typically "4" (for IPv4), and sometimes "6" (for IPv6)
- Header length (4 bits)
  - Number of 32-bit words in the header
  - Typically "5" (for a 20-byte IPv4 header)
  - Can be more when IP options are used
- Type-of-Service (8 bits)
  - Allow packets to be treated differently based on needs
  - E.g., low delay for audio, high bandwidth for bulk transfer

IP Packet Structure

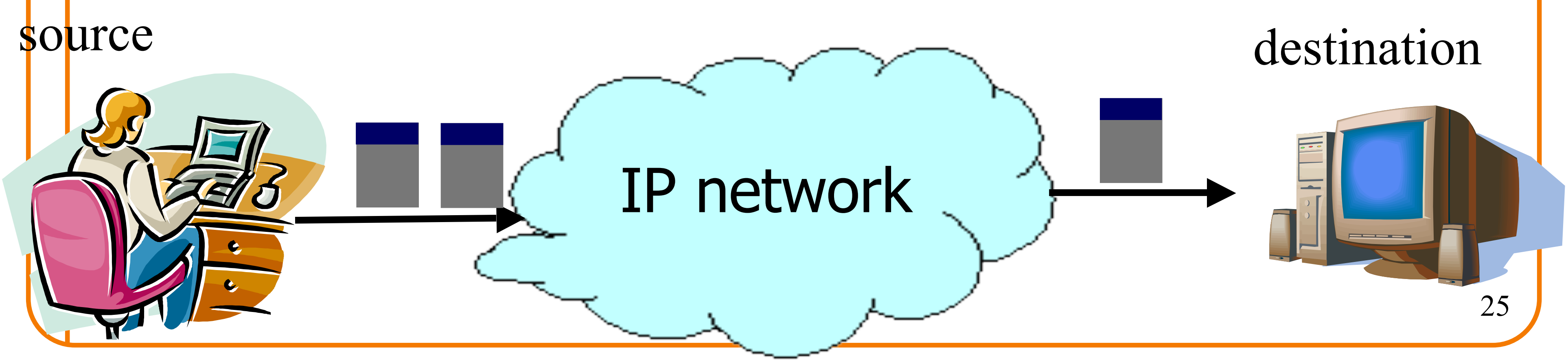


IP Packet Header (Continued)

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

IP: "*Best Effort* " Packet Delivery

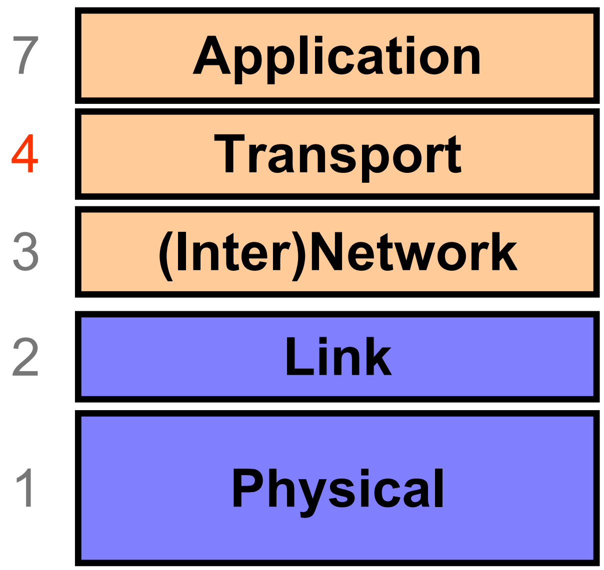
- Routers inspect destination address, locate "next hop" in forwarding table
  - Address = ~unique identifier/locator for the receiving host
- Only provides a "*I'll give it a try*" delivery service:
  - Packets may be lost
  - Packets may be corrupted
  - Packets may be delivered out of order



“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

Layer 4: Transport Layer



End-to-end communication between processes

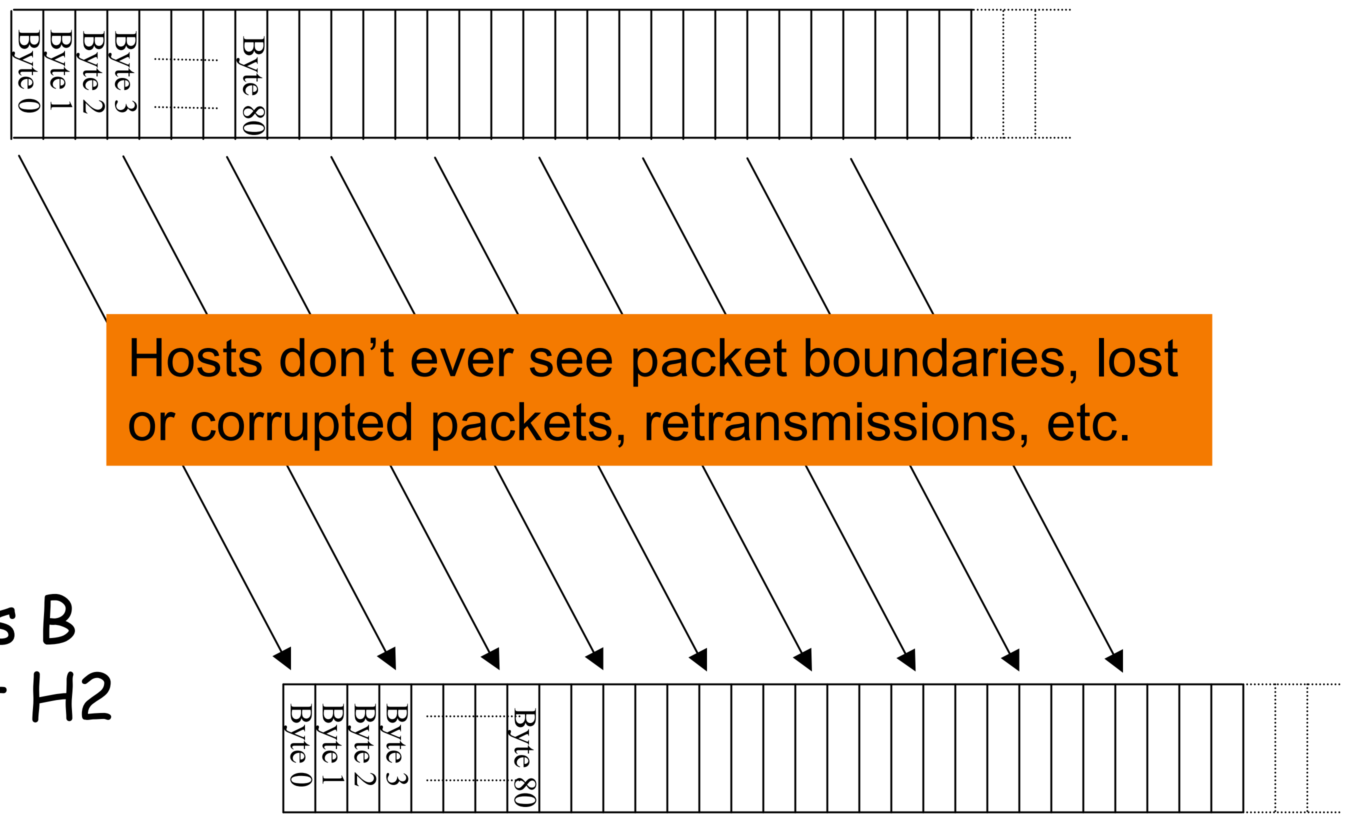
Different services provided:
- TCP = reliable *byte stream*
- UDP = unreliable *datagrams*

"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 "Bytestream" Service

Process A on host H1



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

Process B on host H2

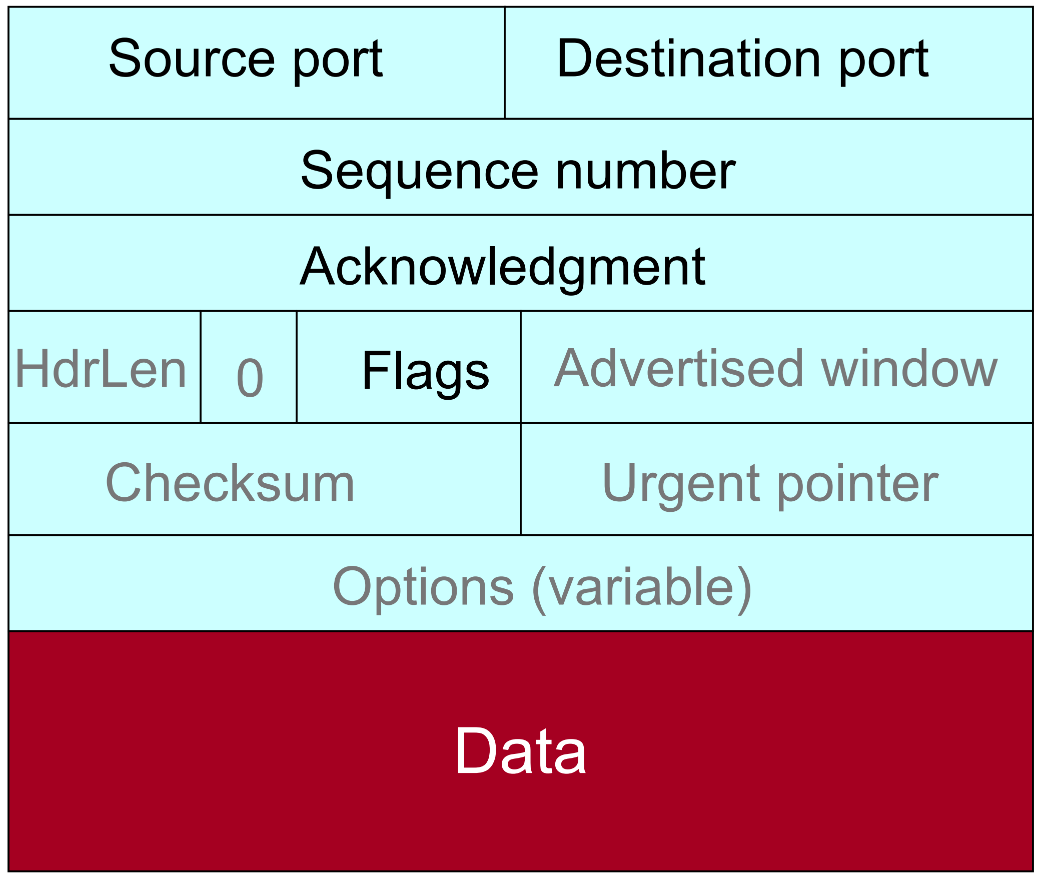
"Best Effort" is Lame! What to do?

- 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)
- TCP service:
  - Connection oriented (explicit set-up / tear-down)
    - End hosts (processes) can have multiple concurrent long-lived dialog
  - Reliable, in-order, byte-stream delivery
    - Robust detection & retransmission of lost data
  - Congestion control
    - Dynamic adaptation to network path's capacity

5 Minute Break

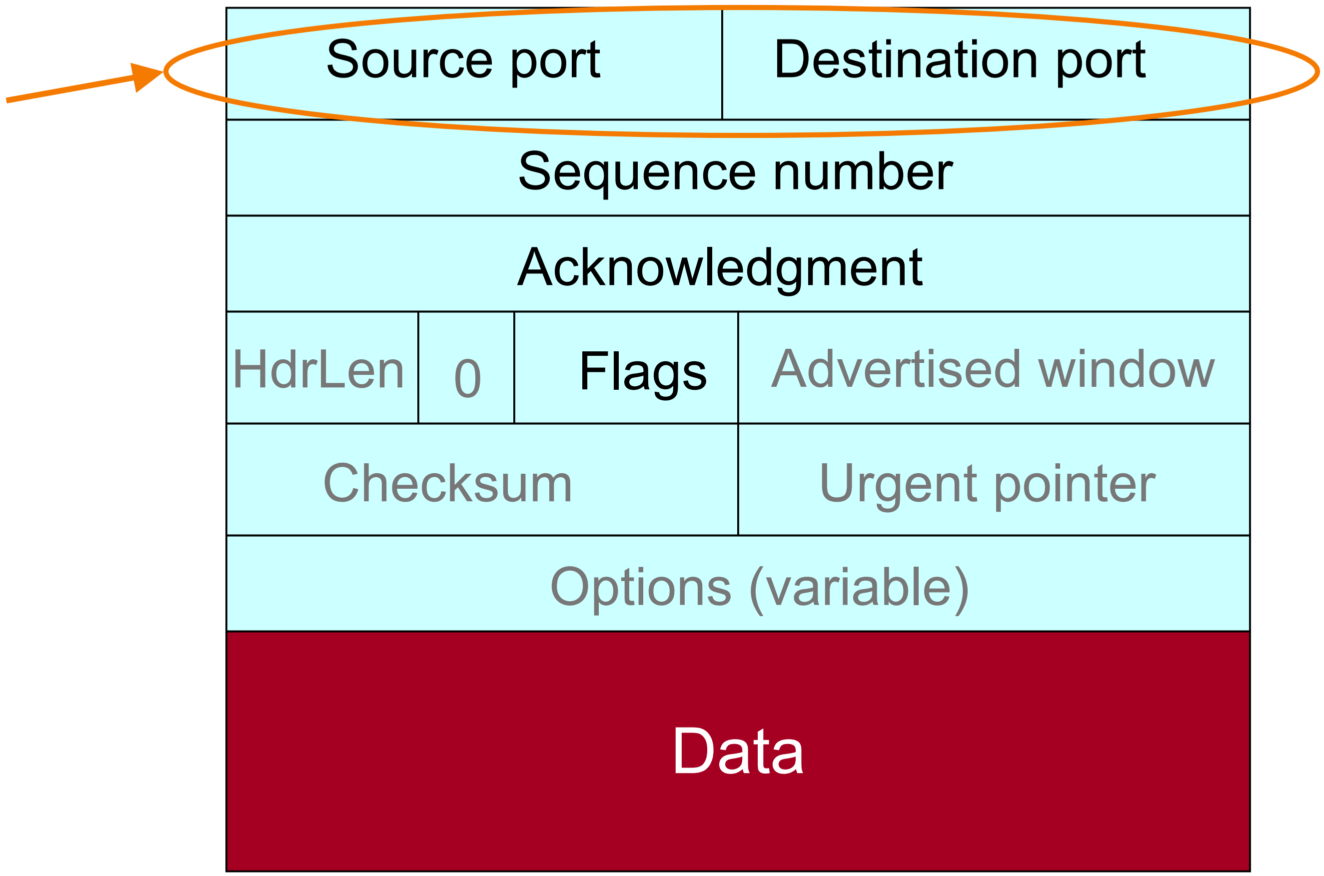
Questions Before We Proceed?

TCP Header


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

TCP Header

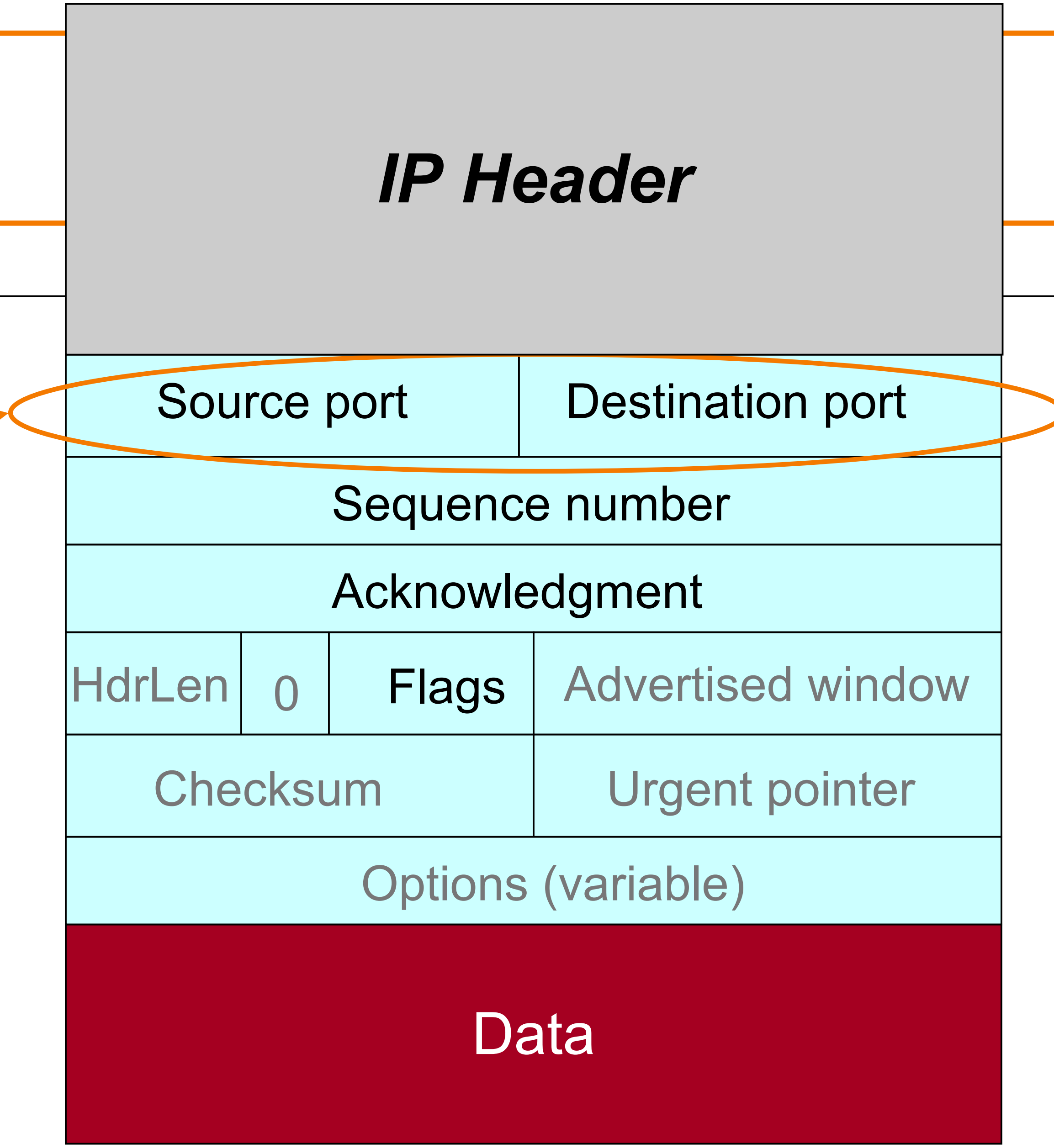
Ports are associated with OS processes



TCP Header

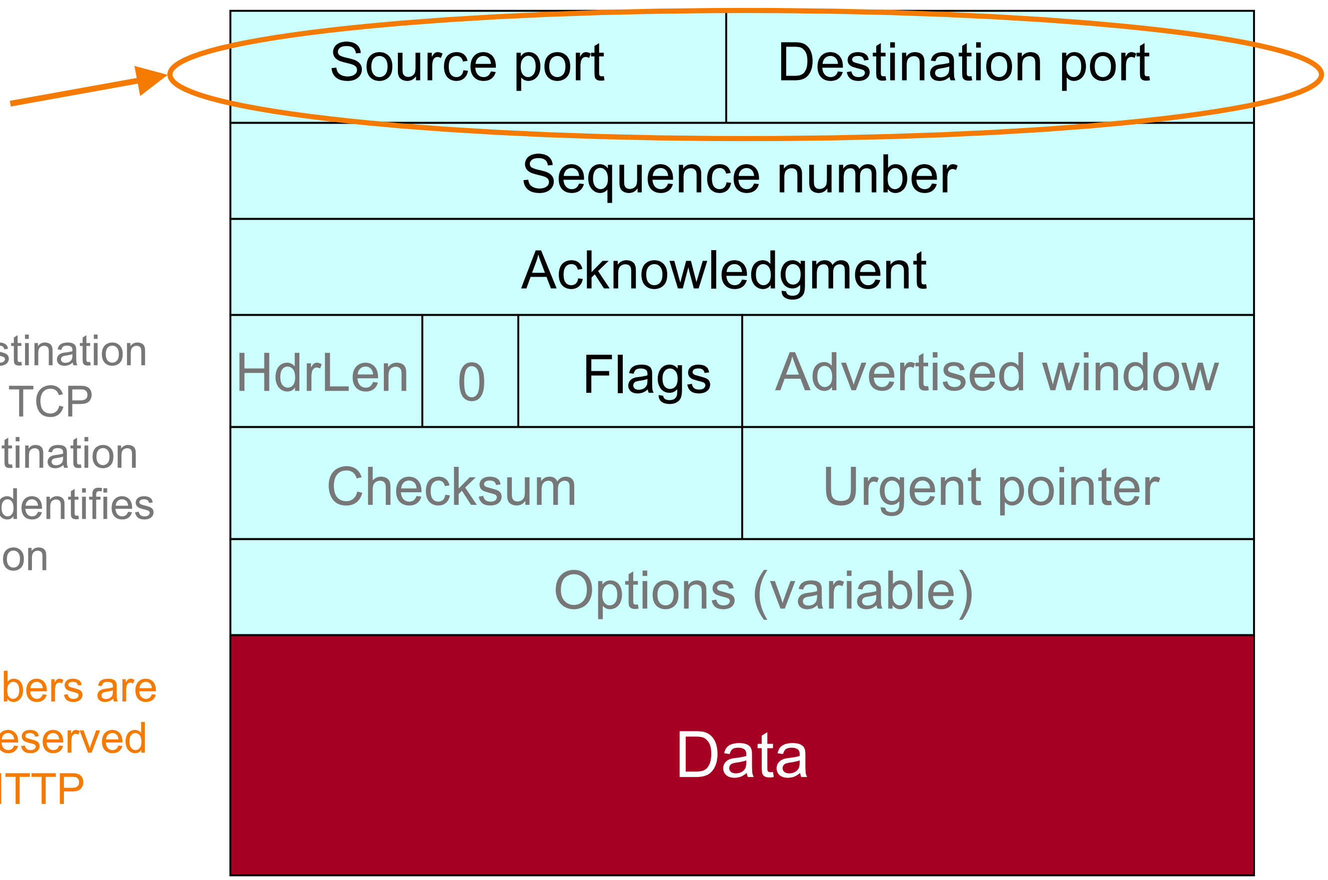
Ports are associated with OS processes

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



TCP Header

Ports are associated with OS processes

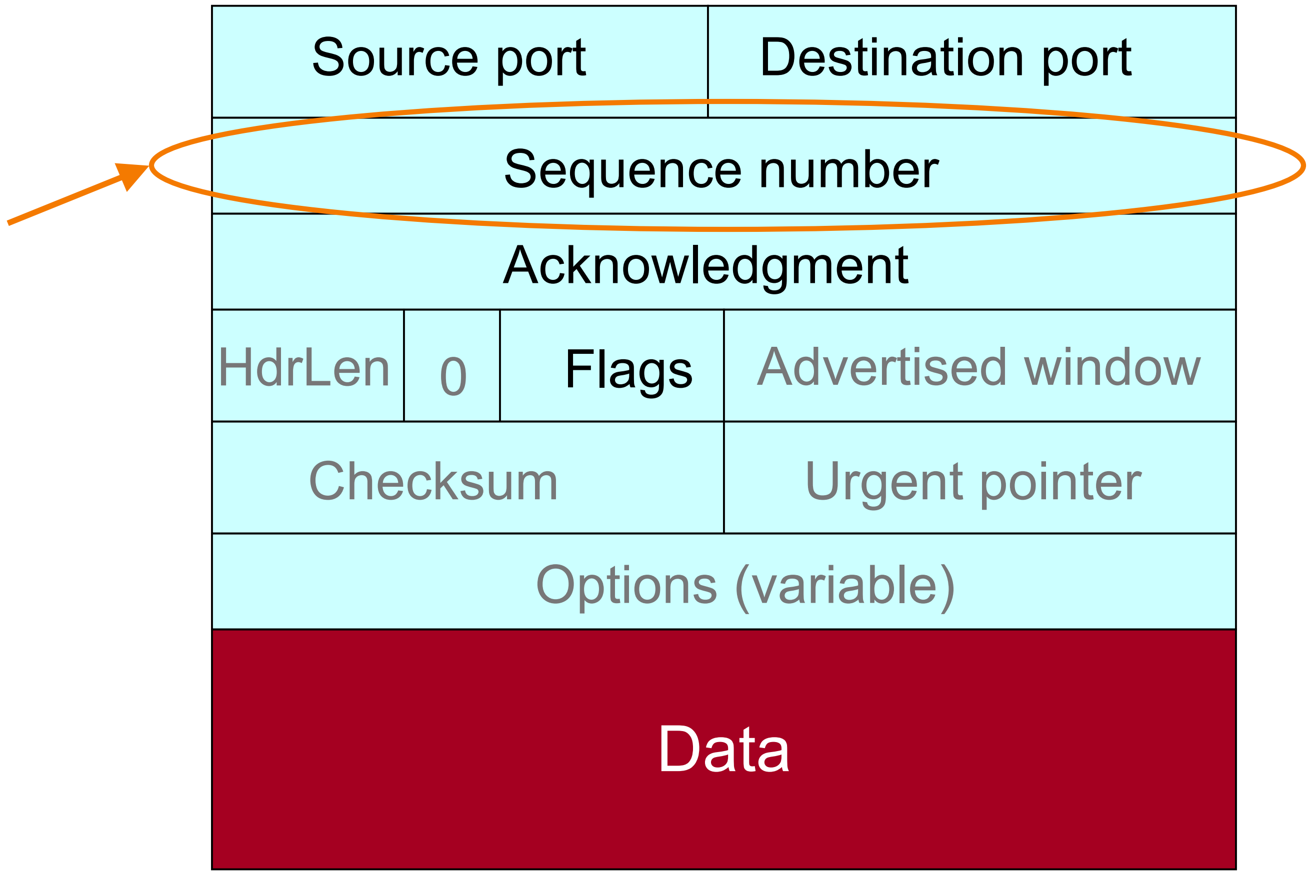


IP source & destination addresses plus TCP source and destination ports uniquely identifies a TCP connection

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

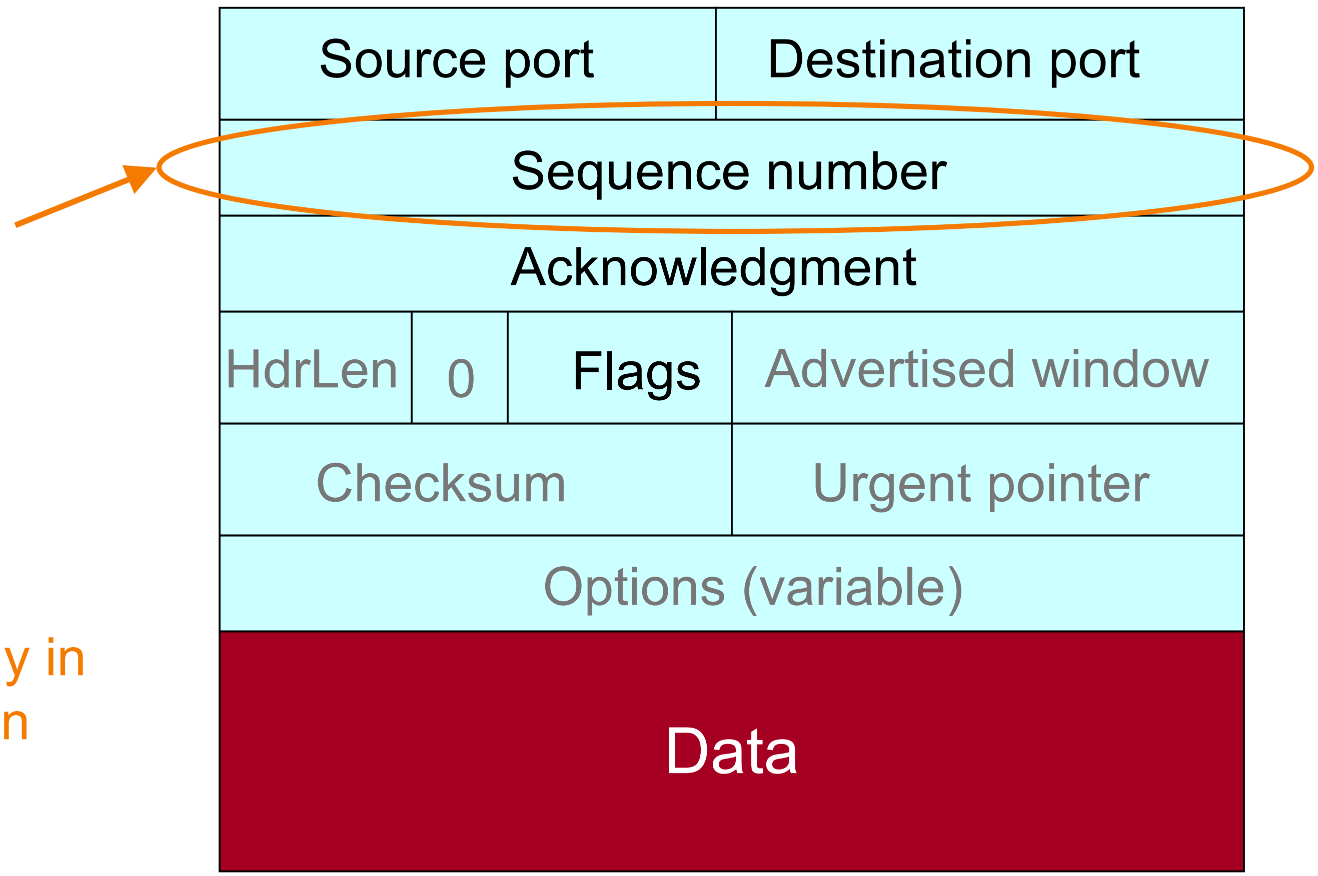
TCP Header

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



TCP Header

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

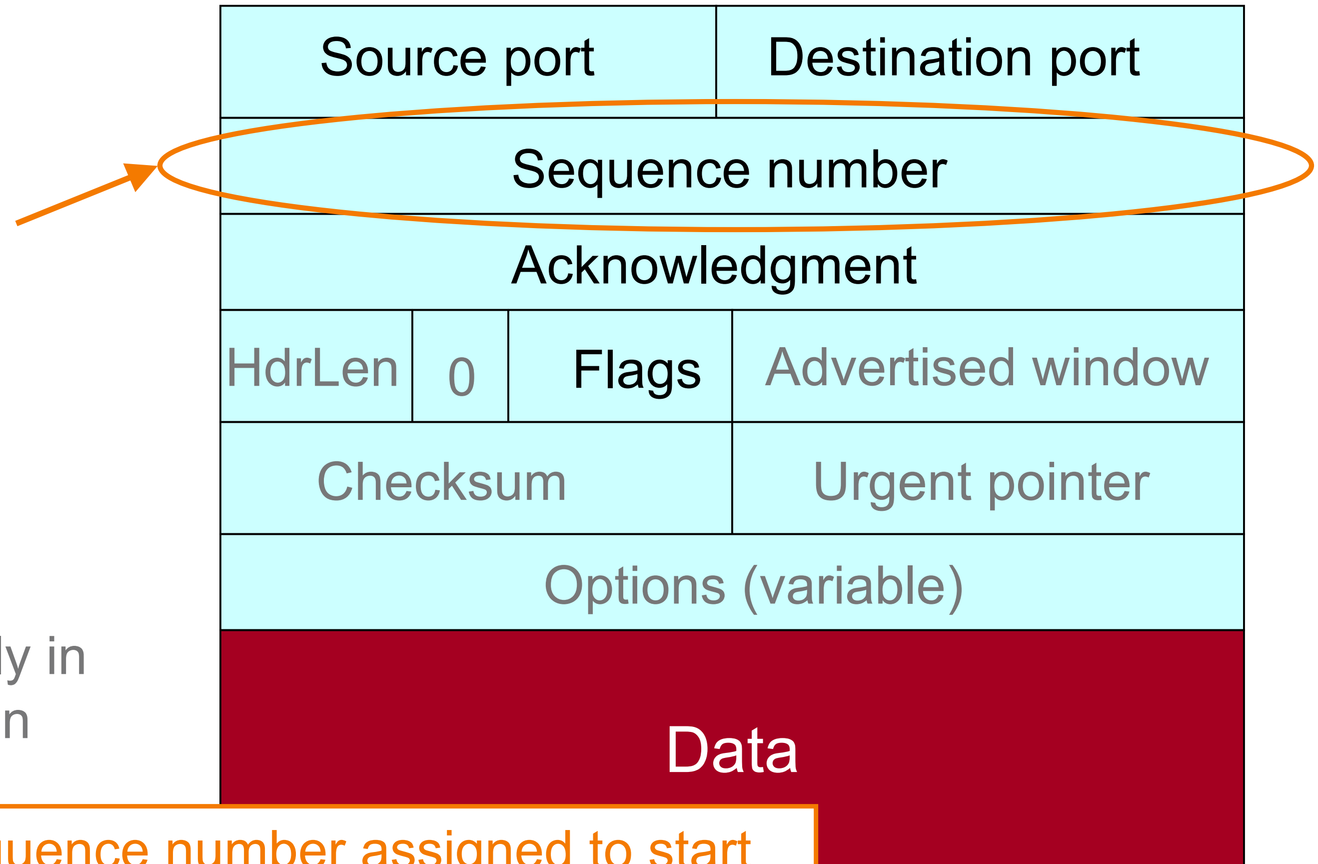


Byte stream numbered independently in each direction

TCP Header

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

Byte stream numbered independently in each direction

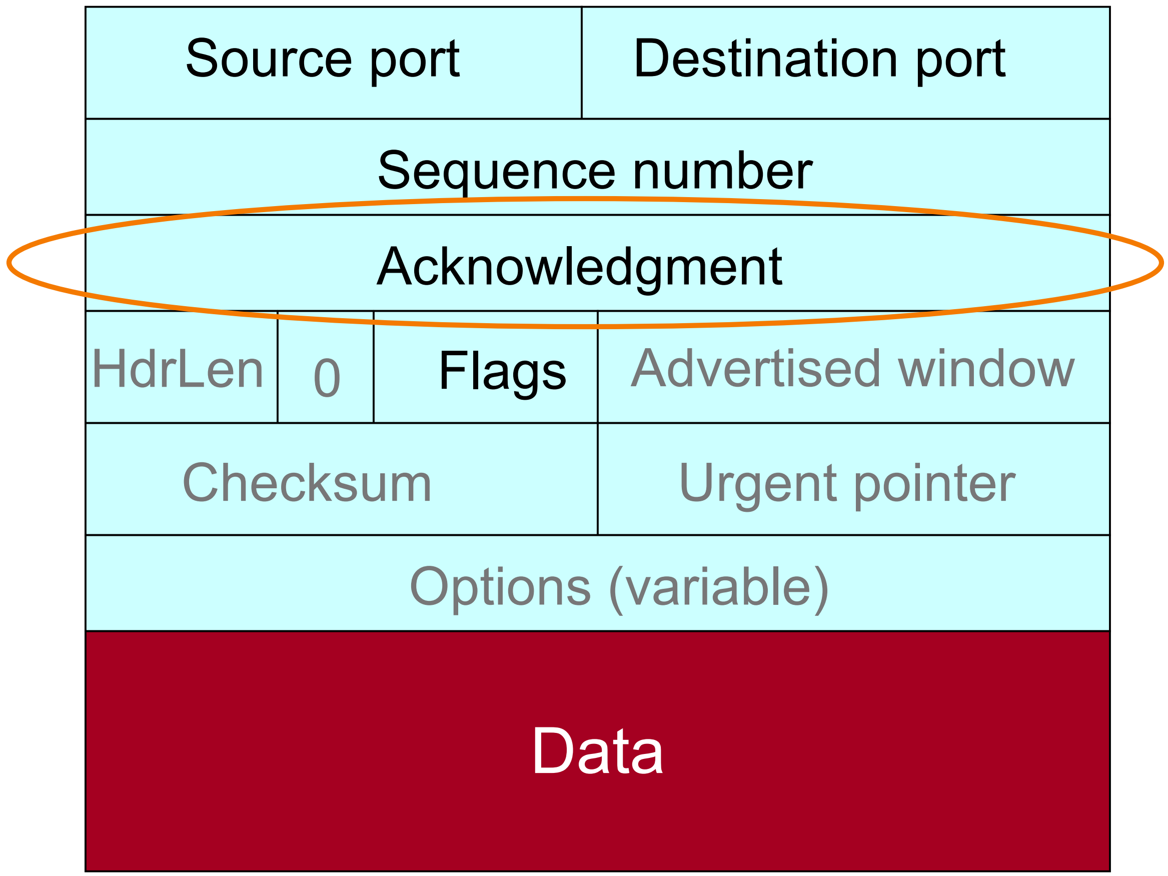


Sequence number assigned to start of byte stream is picked when connection begins; **doesn't** start at 0

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**.

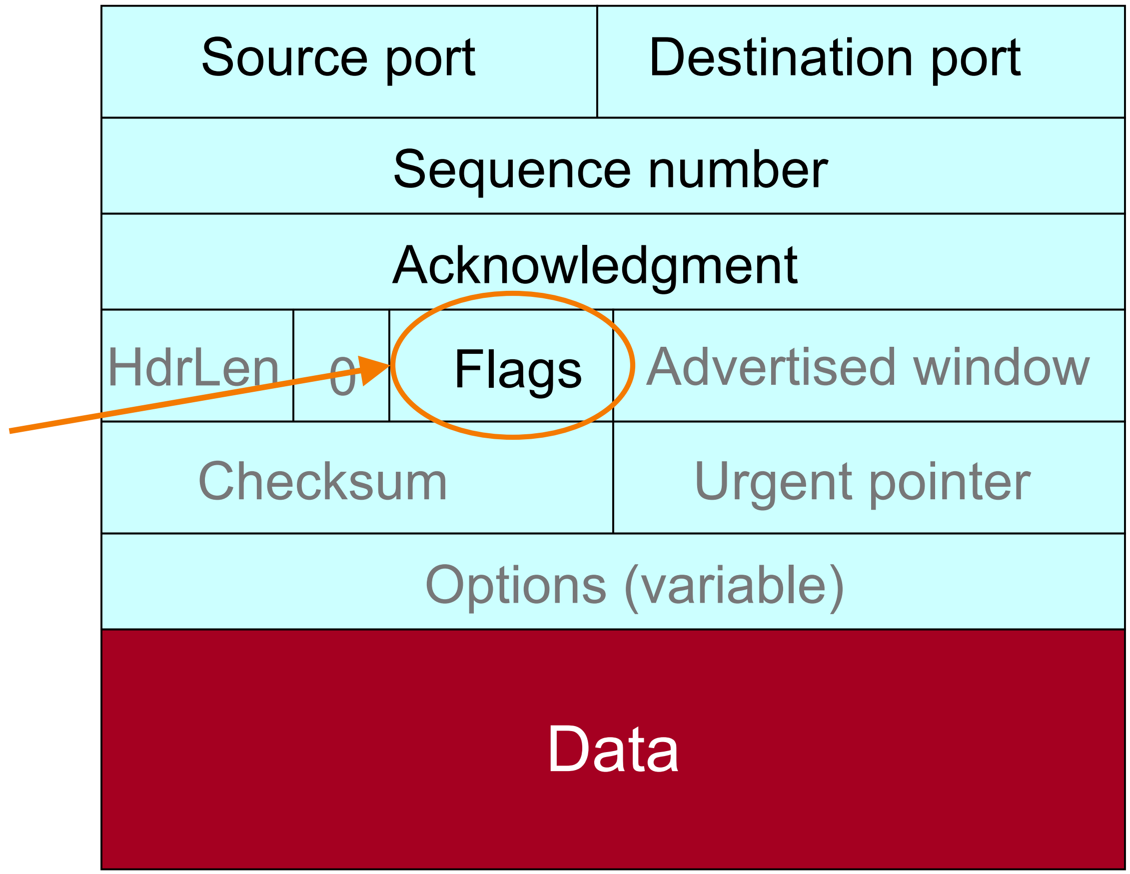


TCP Header

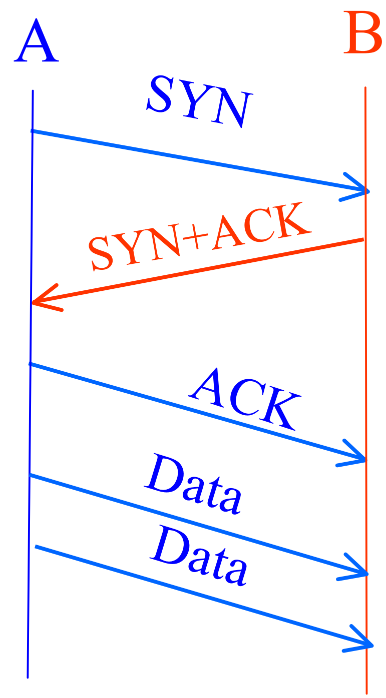
Uses include:

acknowledging data ("**ACK**")

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



Establishing a TCP Connection

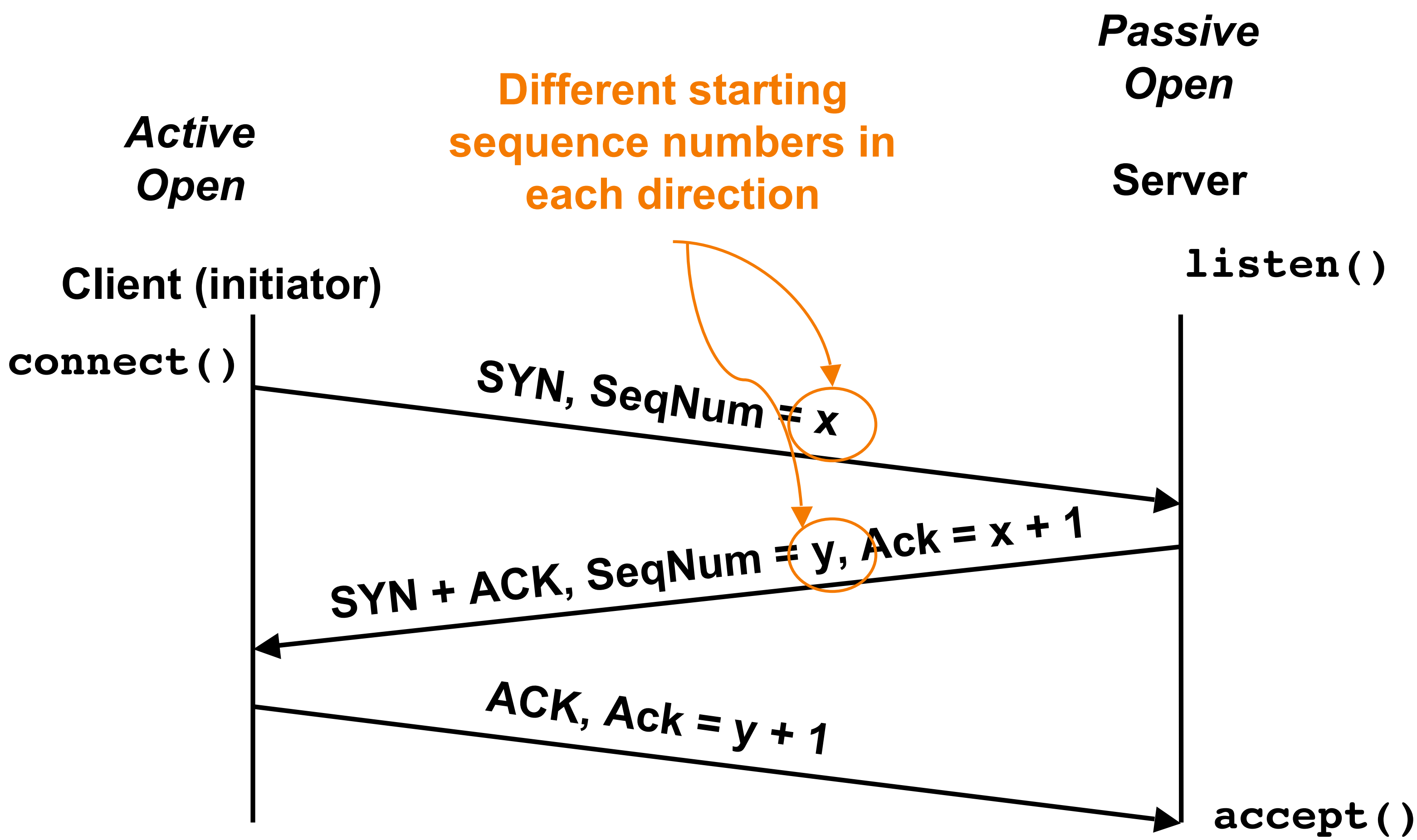


Each host tells its *Initial Sequence Number* (ISN) to the other host.

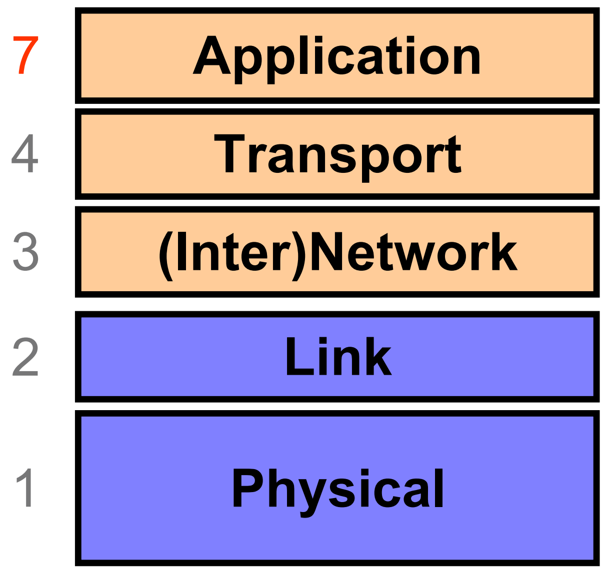
(Spec says to pick based on local clock)

- 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



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

Sample Email (SMTP) interaction

```
S: 220 hamburger.edu
C: HELO crepes.fr
S: 250  Hello crepes.fr, pleased to meet you
C: MAIL FROM: <alice@crepes.fr>
S: 250 alice@crepes.fr... Sender ok
C: RCPT TO: <bob@hamburger.edu>
S: 250 bob@hamburger.edu ... Recipient ok
C: DATA
S: 354 Enter mail, end with "." on a line by itself
C: From: alice@crepes.fr
C: To: hamburger-list@burger-king.com
C: Subject: Do you like ketchup?
C:
C: How about pickles?
C: .
S: 250 Message accepted for delivery
C: QUIT
S: 221 hamburger.edu closing connection
```

Email header

Email body

Lone period marks end of message

Web (HTTP) Request

Method — Resource — HTTP version — Headers

```
GET /index.html HTTP/1.1
Accept: image/gif, image/x-bitmap, image/jpeg, */*
Accept-Language: en
Connection: Keep-Alive
User-Agent: Mozilla/1.22 (compatible; MSIE 2.0; Windows 95)
Host: www.example.com
Referer: http://www.google.com?q=dingbats

```

Blank line

Data (if POST; none for GET)

GET: download data. POST: upload data.

Web (HTTP) Response

HTTP version

Status code

Reason phrase

Headers

Data

```
HTTP/1.0 200 OK
Date: Sun, 19 Apr 2009 02:20:42 GMT
Server: Microsoft-Internet-Information-Server/5.0
Connection: keep-alive
Content-Type: text/html
Last-Modified: Sat, 18 Apr 2009 17:39:05 GMT
Set-Cookie: session=44eb; path=/servlets
Content-Length: 2543

<HTML> Some data... blah, blah, blah </HTML>
```

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

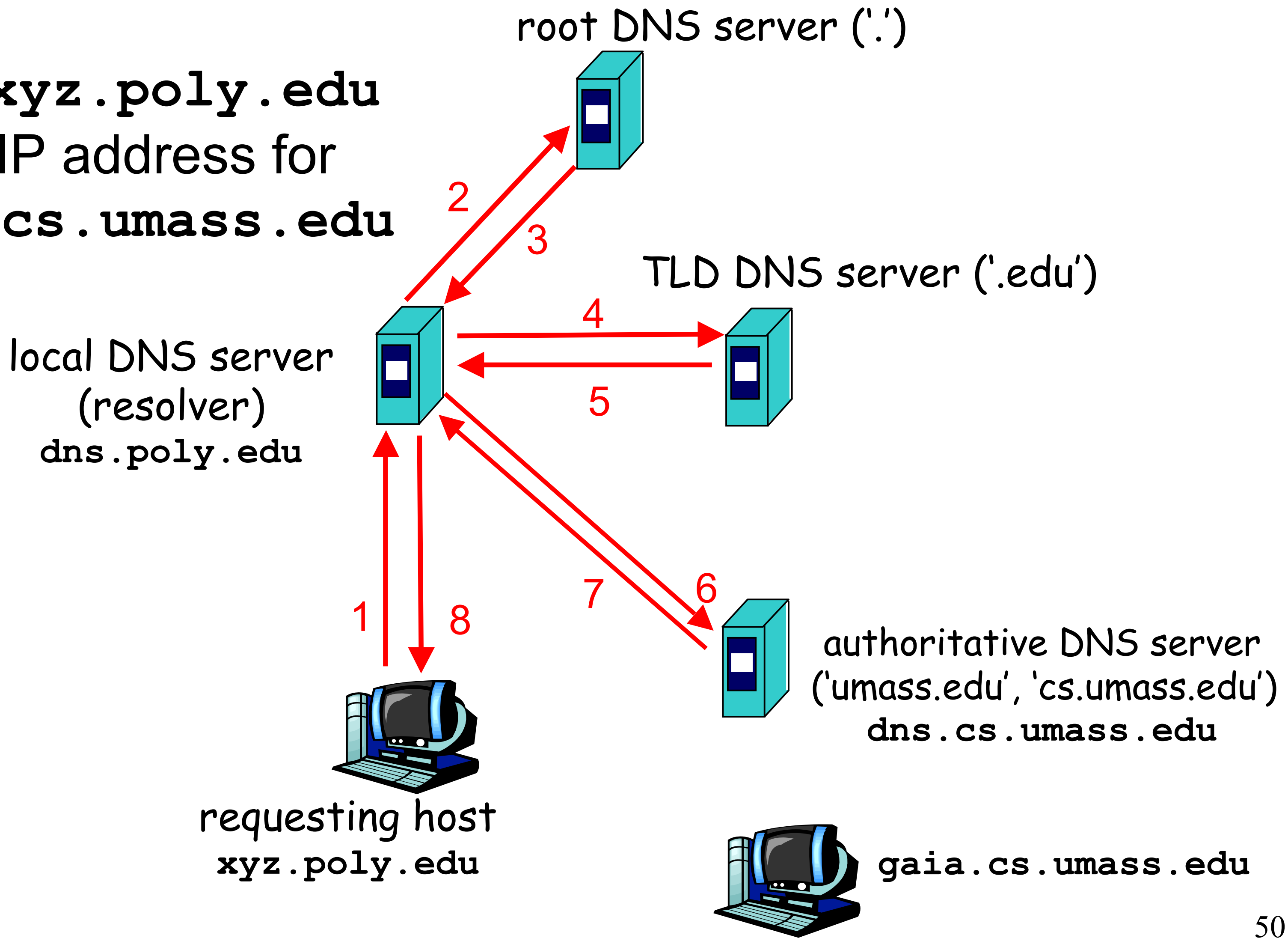
- Domain Name System (DNS)
  - Hierarchical name space divided into zones
  - Zones distributed over collection of DNS servers
  - (Also separately maps addresses to names)
- Hierarchy of DNS servers
  - Root (hardwired into other servers)
  - Top-level domain (TLD) servers
  - "Authoritative" DNS servers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

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*)
- 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)	