EN.601.414/614 Computer Networks

Network Layer and IP

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Fall 2020 (TuTh 1:30-2:45pm on Zoom)

JOHNS HOPKINS UNIVERSITY

https://github.com/xinjin/course-net

Midterm Exam

- **Time: 75 minutes on October 15 (next Thursday)**
- **Location: Take-home**
- **Form: Open-book**
  - Can use slides for reference
  - Can use a calculator
  - Anything else is prohibited

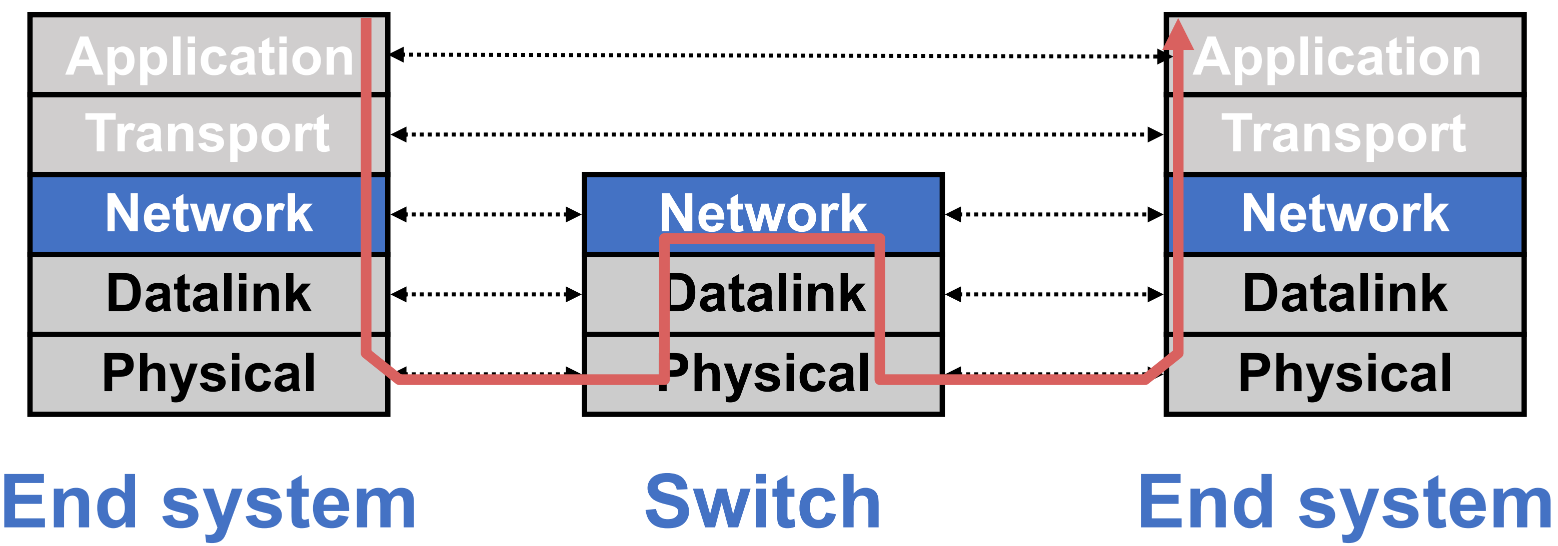
- **Midterm review next Tuesday**

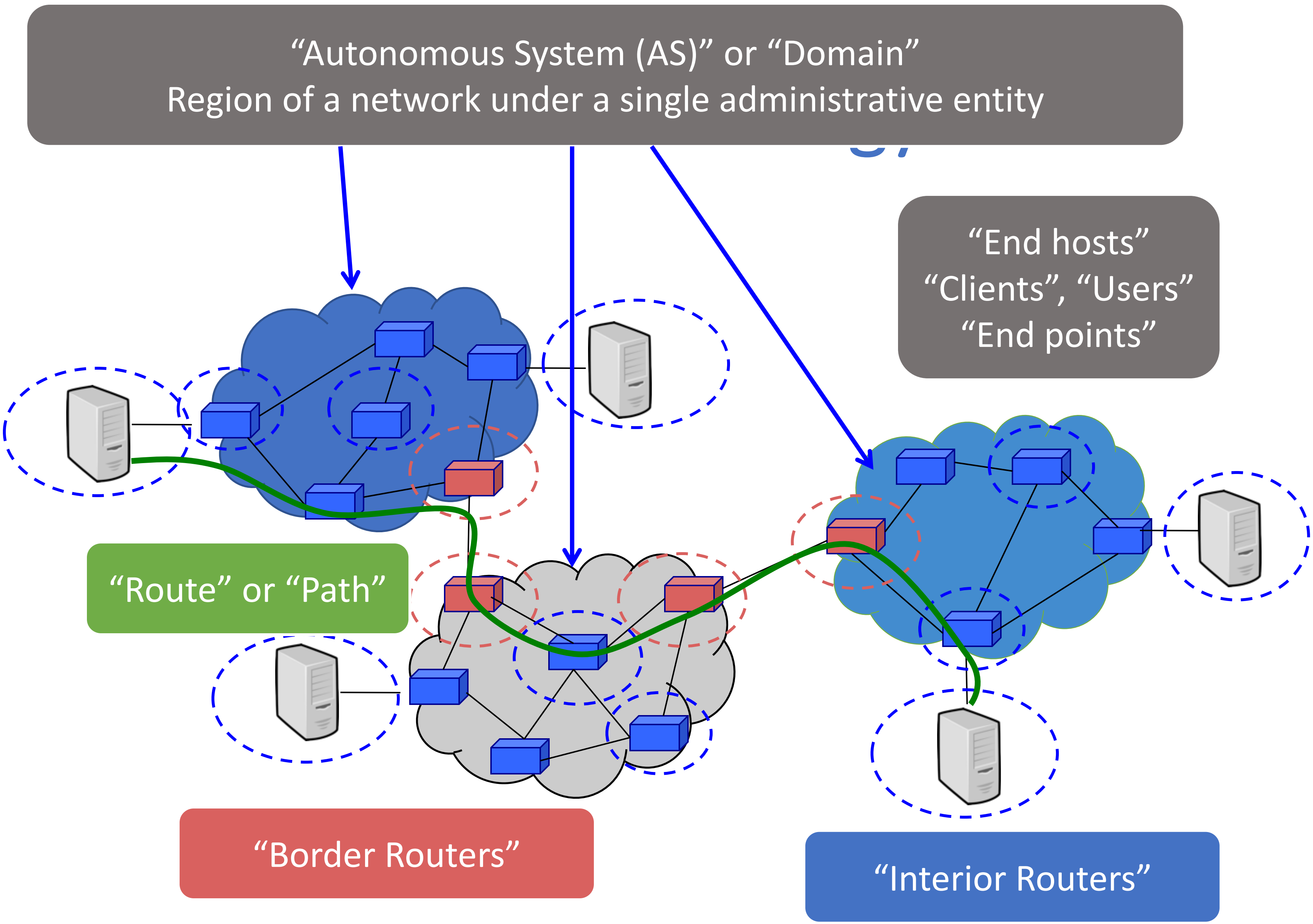
Agenda

- **Network layer basics**
- **The Internet Protocol (IP)**

Network layer

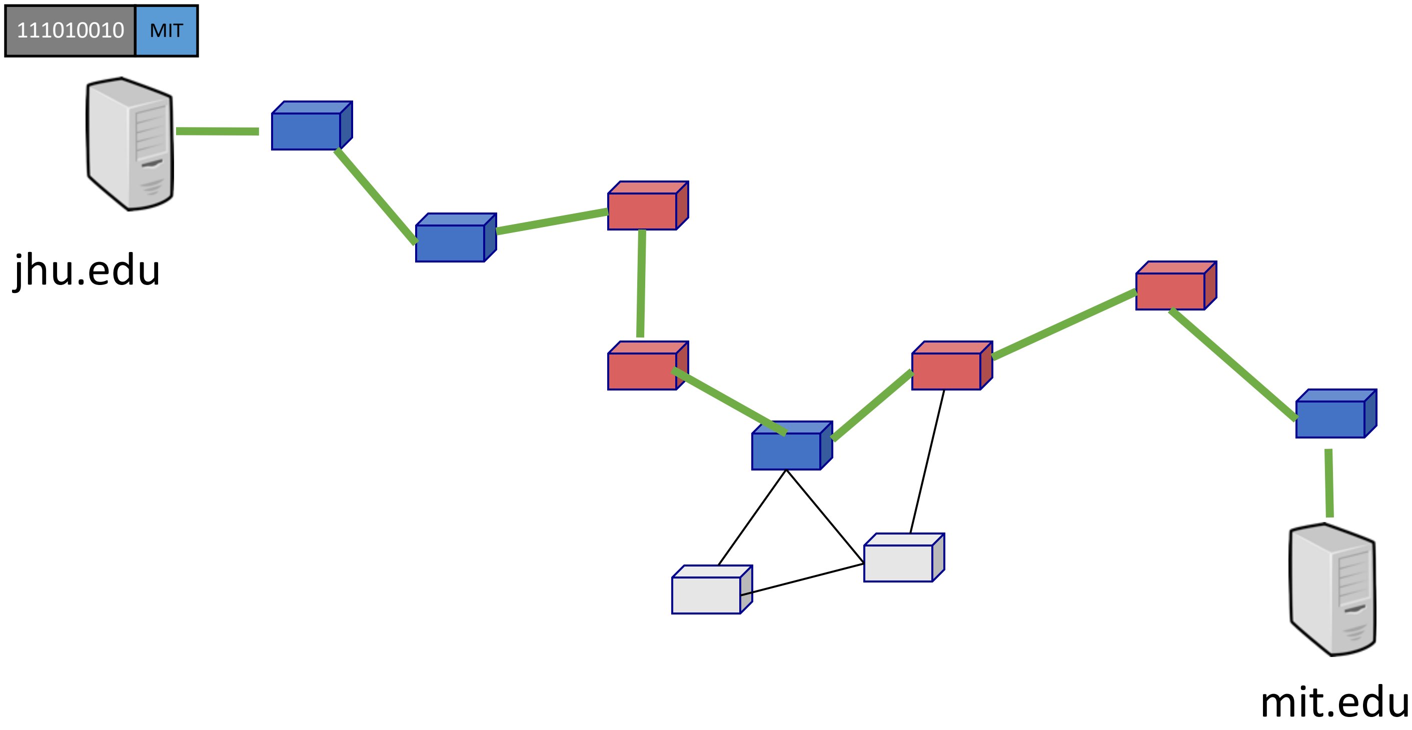
- **Present everywhere**
- **Performs addressing, forwarding, and routing, among other tasks**





“Autonomous System (AS)” or “Domain”
Region of a network under a single administrative entity
“End hosts”
“Clients”, “Users”
“End points”
“Route” or “Path”
“Border Routers”
“Interior Routers”

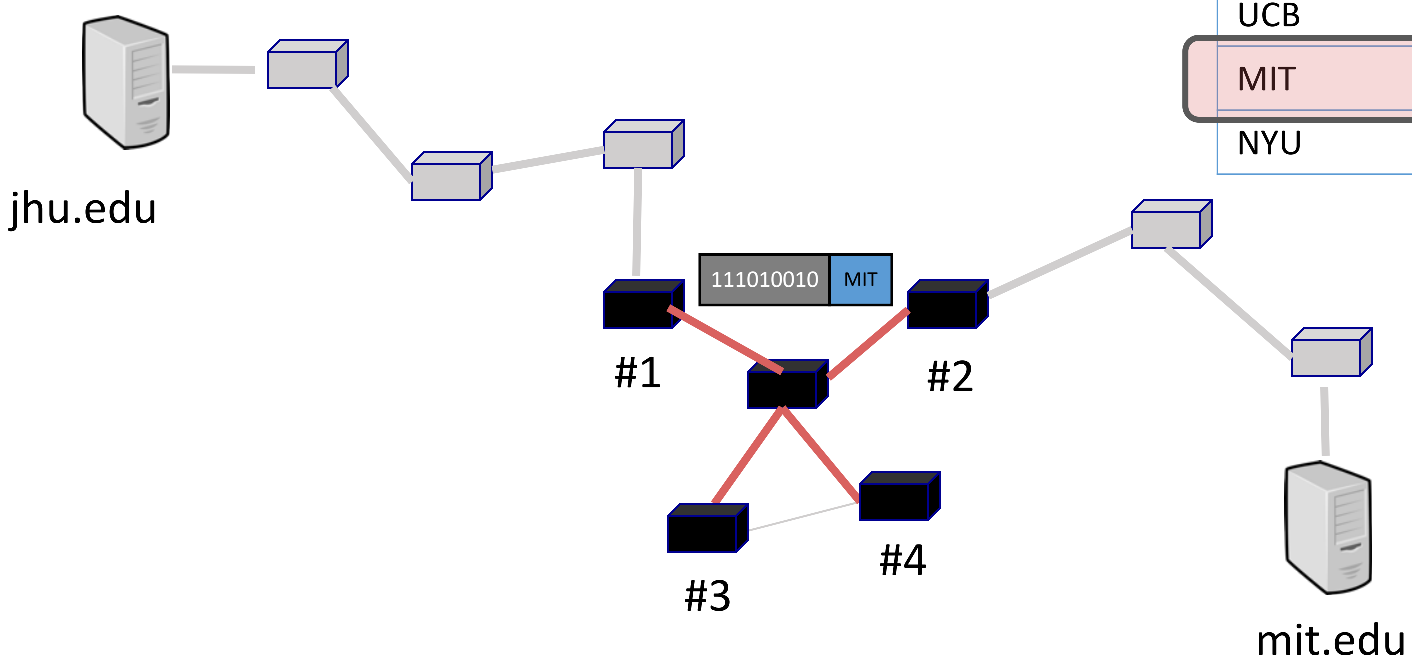
Forwarding



Forwarding

Forwarding Table

Destination	Next Hop
JHU	1
UCB	3
MIT	2
NYU	4



Forwarding

- **Directing a packet to the correct interface so that it progresses to its destination**
  - Local
- **How?**
  - Read address from packet header
  - Search forwarding table

Routing

- **Setting up network-wide *forwarding tables* to enable end-to-end communication**
  - Global
- **How?**
  - Using different routing protocols (after midterm)

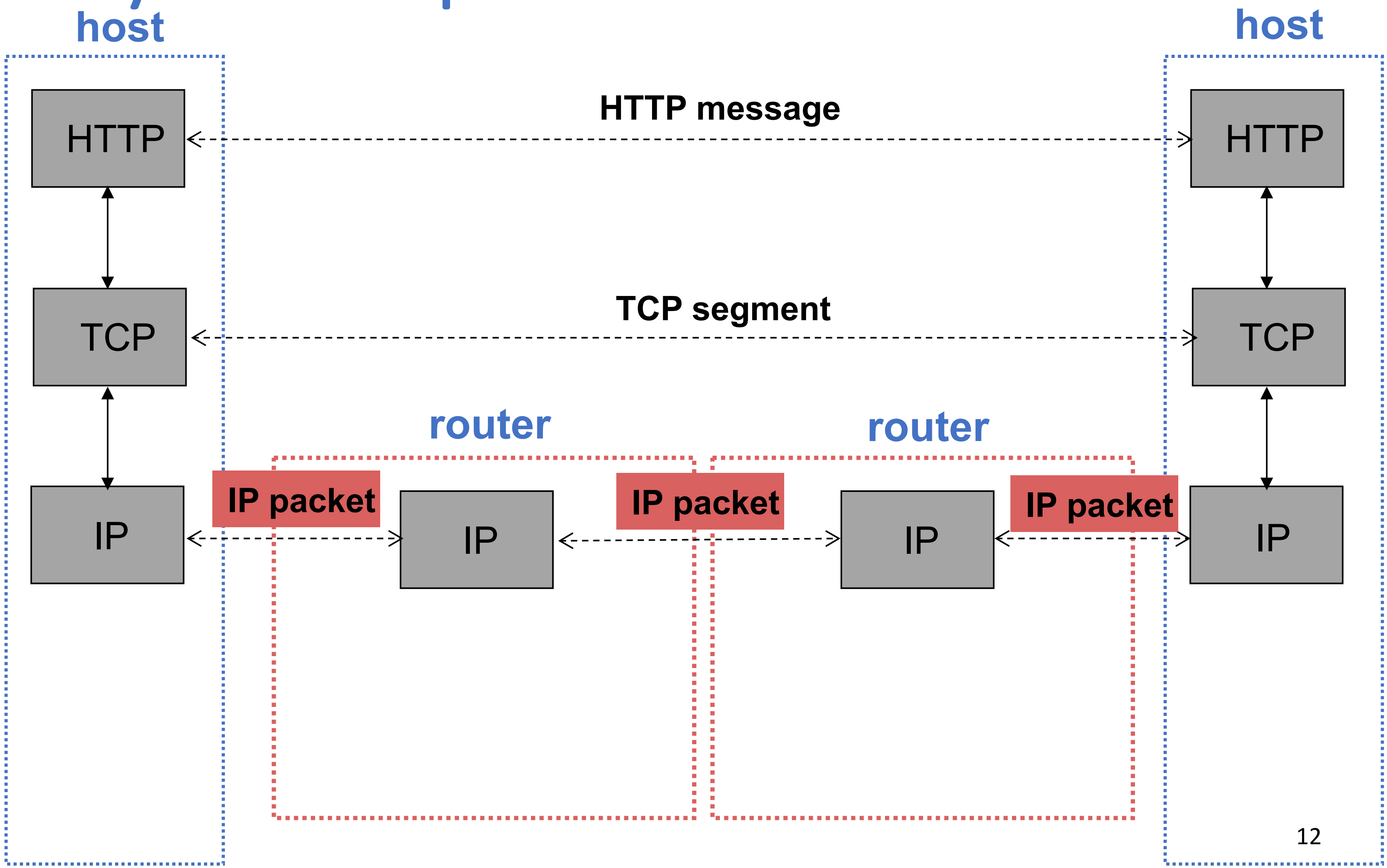
Forwarding vs. routing

- **Forwarding: “data plane”**
  - Directing one data packet
  - Each router using local routing state
- **Routing: “control plane”**
  - Computing the forwarding tables that guide packets
  - Jointly computed by routers using a distributed algorithm

- **Very different timescales!**

The IP layer

Lecture 3:
Layer encapsulation



Recall: IP packet

IP packet

- **IP packet contains a header and payload**
  - Payload is opaque to the network
  - Header is what we care about

Designing the IP header

- **Think of the IP header as an interface**
  - ➢Between the source and destination end-systems
  - ➢Between the source and network (routers)
- **Designing an interface**
  - ➢What task(s) are we trying to accomplish?
  - ➢What information is needed to do it?
- **Header reflects information needed for basic tasks**

What are these tasks? (in network)

- **Parse packet**
- **Carry packet to the destination**
- **Deal with problems along the way**
    - Loops
    - Corruption
    - Packet too large
- **Accommodate evolution**
- **Specify any special handling**

What information do we need?

- **Parse packet**
- **Carry packet to the destination**
- **Deal with problems along the way**
  - Loops
  - Corruption
  - Packet too large
- **Accommodate evolution**
- **Specify any special handling**

What information do we need?

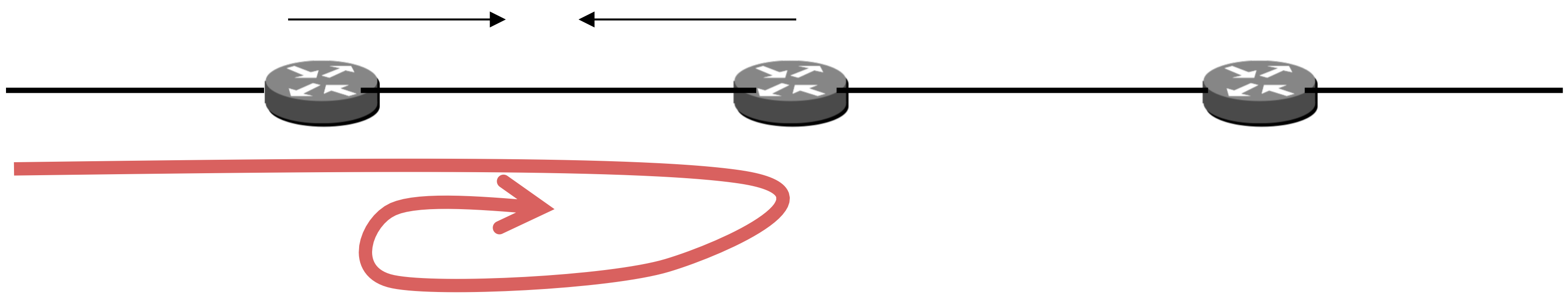
- **Parse packet**
  - IP version number (4 bits), packet length (16 bits)
- **Carry packet to the destination**
  - Destination's IP address (32 bits)
- **Deal with problems along the way**
  - Loops:
  - Corruption:
  - Packet too large:

What information do we need?

- **Parse packet**
  - IP version number (4 bits), packet length (16 bits)
- **Carry packet to the destination**
  - Destination's IP address (32 bits)
- **Deal with problems along the way**
  - Loops: TTL (8 bits)
  - Corruption: checksum (16 bits)
  - Packet too large: fragmentation fields (32 bits)

Preventing loops (TTL)

- **Forwarding loops cause packets to cycle for a long time**
  - ➢Left unchecked would accumulate to consume all capacity



- **Time-to-Live (TTL) Field (8 bits)**
  - ➢Decremented at each hop; packet discarded if 0
    - "Time exceeded" message is sent to the source

Header corruption (Checksum)

- **Checksum (16 bits)**
  - ➢Particular form of checksum over packet header
- **If not correct, router discards packets**
  - ➢So it doesn’t act on bogus information
- **Checksum recalculated at every router**
  - ➢Why?

Fragmentation

- **Every link has a "Maximum Transmission Unit" (MTU)**
  - Largest number of bits it can carry as one unit
- **A router can split a packet into multiple "fragments" if the packet size exceeds the link's MTU**
- **Must reassemble to recover original packet**
- **Will return to fragmentation later today…**

What information do we need?

- **Parse packet**
  - IP version number (4 bits), packet length (16 bits)
- **Carry packet to the destination**
  - Destination's IP address (32 bits)
- **Deal with problems along the way**
  - TTL (8 bits), checksum (16 bits), fragmentation (32 bits)
- **Accommodate evolution**
  - Version number (4 bits) (+ fields for special handling)
- **Specify any special handling**

Special handling

- **“Type of Service” (8 bits)**
  - ➢Allow packets to be treated differently based on needs
    - e.g., indicate priority, congestion notification
  - ➢Has been redefined several times
  - ➢Now called “Differentiated Services Code Point (DSCP)”

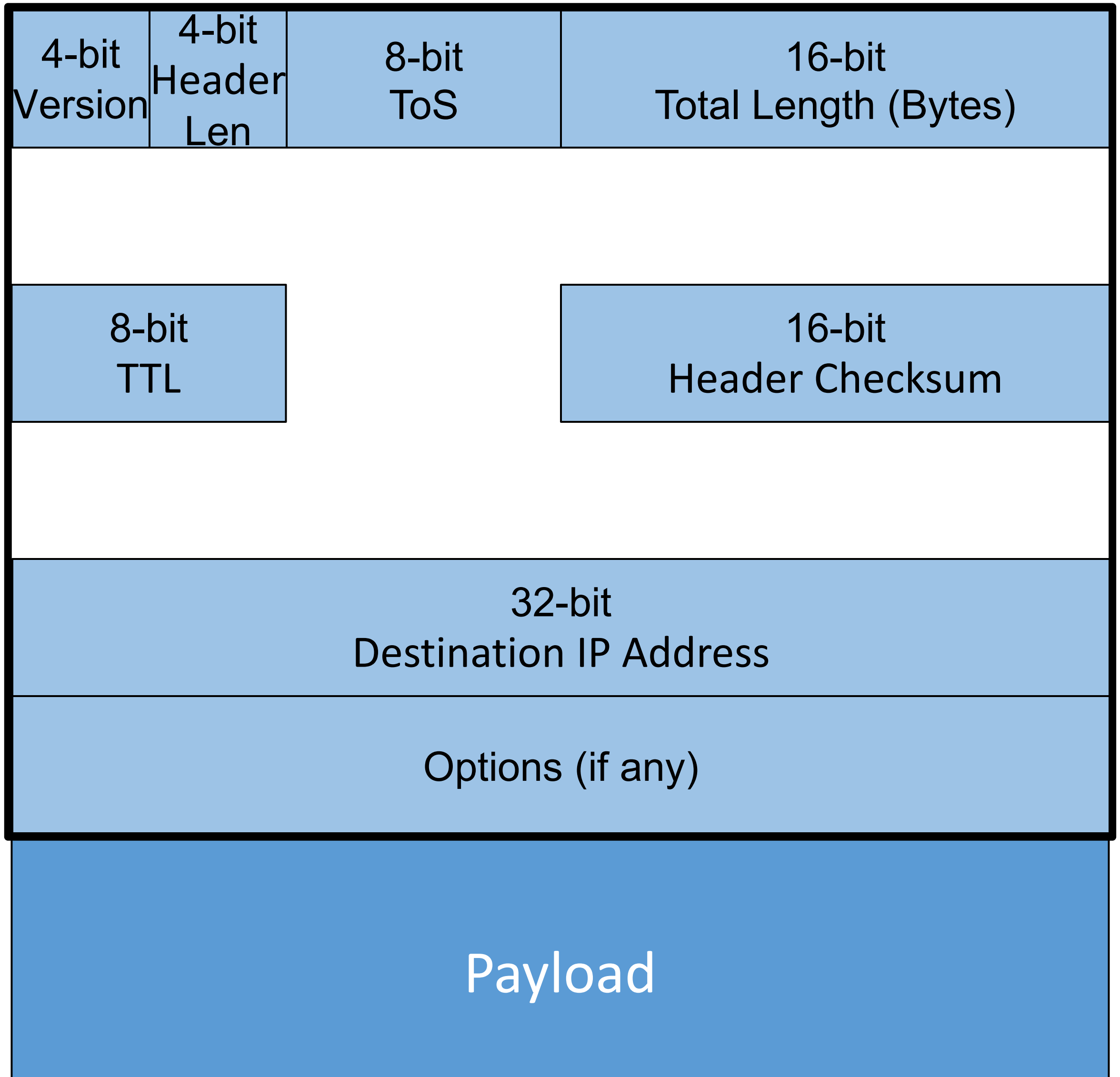
Options

- **Optional directives to the network**
  - Not used very often
  - 16 bits of metadata + option-specific data
- **Examples of options**
  - Record Route
  - Strict Source Route
  - Loose Source Route
  - Timestamp

What information do we need?

- **Parse packet**
  - IP version number (4 bits), packet length (16 bits)
- **Carry packet to the destination**
  - Destination’s IP address (32 bits)
- **Deal with problems along the way**
  - TTL (8 bits), checksum (16 bits), frag. (32 bits)
- **Accommodate evolution**
  - Version number (4 bits) (+ fields for special handling)
- **Specify any special handling**
  - ToS (8 bits), Options (variable length)

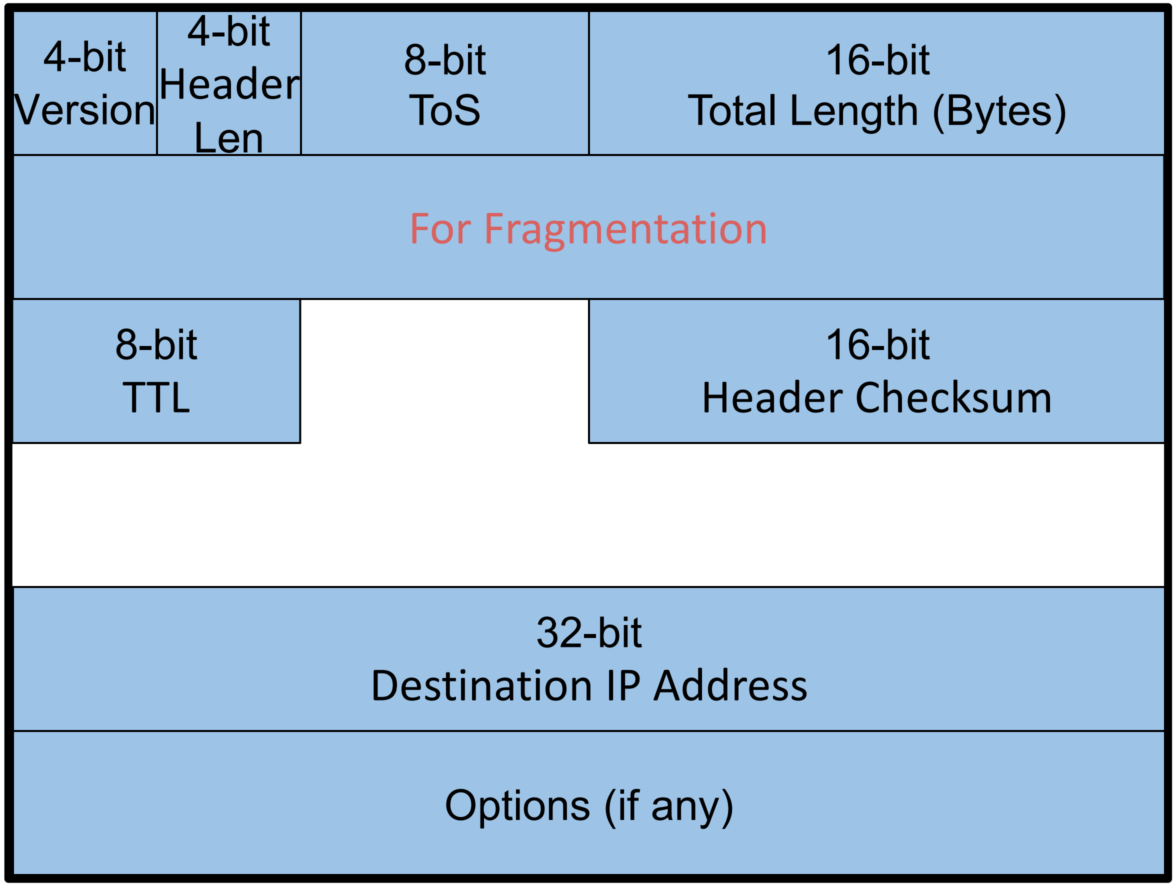
IP packet structure



Parse packet

- **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

IP packet structure

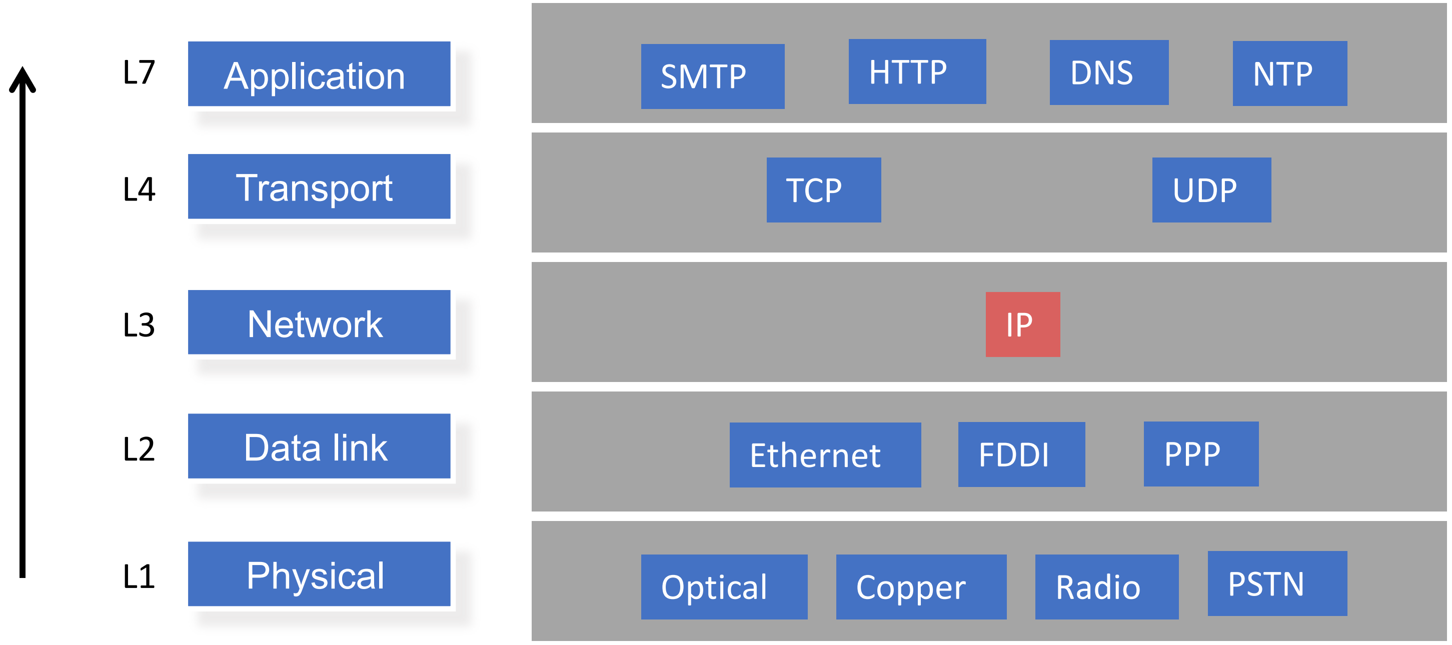


Tasks at the destination end-system

- **Tell destination what to do with the received packet**
- **Get responses to the packet back to the source**

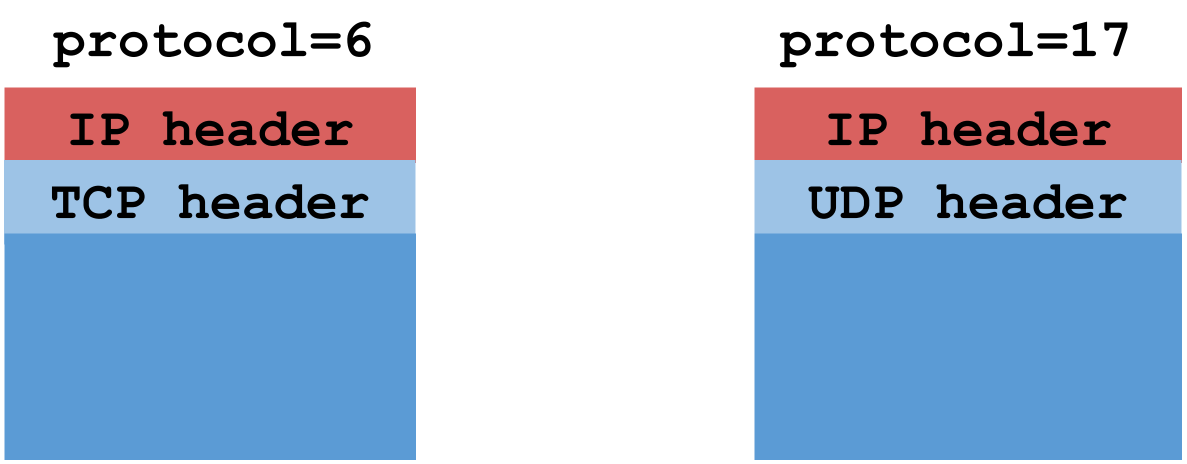
Telling end-host how to handle packet

- **Protocol (8 bits)**
  - ➢Identifies the higher-level protocol
  - ➢Important for de-multiplexing at receiving host



Telling end-host how to handle packet

- **Protocol (8 bits)**
  - ➢ Identifies the higher-level protocol
  - ➢ Important for de-multiplexing at receiving host
- **Most common examples**
  - ➢ E.g., "6" for the Transmission Control Protocol (TCP)
  - ➢ E.g., "17" for the User Datagram Protocol (UDP)



Tasks at the destination end-system

- **Tell destination what to do with the received packet**
  - Transport layer protocol (8 bits)
- **Get responses to the packet back to the source**
  - Source IP address (32 bits)

IP packet structure

<table>
<tr><td>4-bit
Version</td><td>4-bit
Header
Len</td><td>8-bit
ToS</td><td colspan="2">16-bit
Total Length (Bytes)</td></tr>
<tr><td colspan="5">For Fragmentation</td></tr>
<tr><td colspan="2">8-bit
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">Options (if any)</td></tr>
</table>

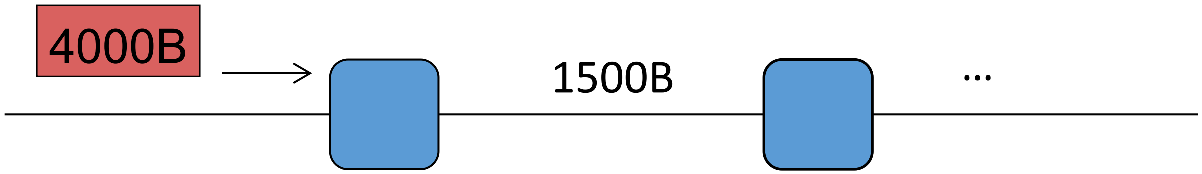
Dealing with fragmentation

A closer look at fragmentation

- **Every link has a "Maximum Transmission Unit" (MTU)**
  - ➢Largest number of bits it can carry as one unit
- **A router can split a packet into multiple "fragments" if the packet size exceeds the link's MTU**
- **Must reassemble to recover original packet**

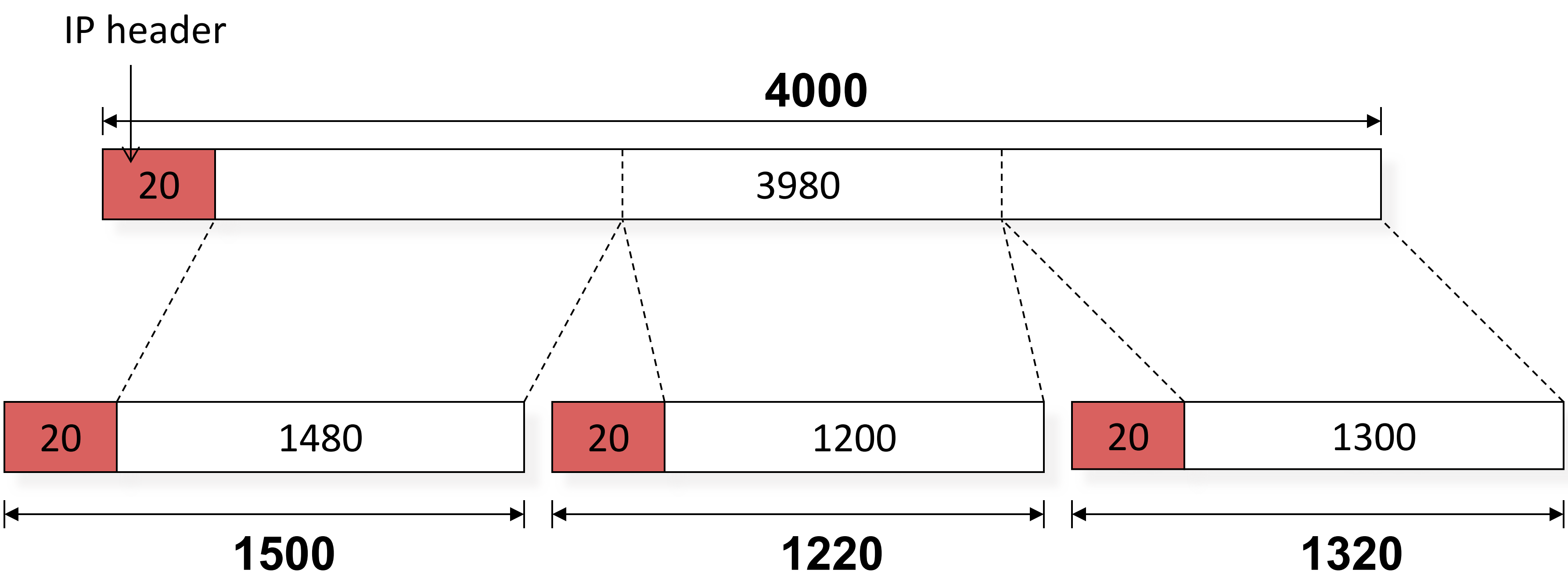
Example of fragmentation

- **A 4000 byte packet crosses a link w/ MTU=1500B**

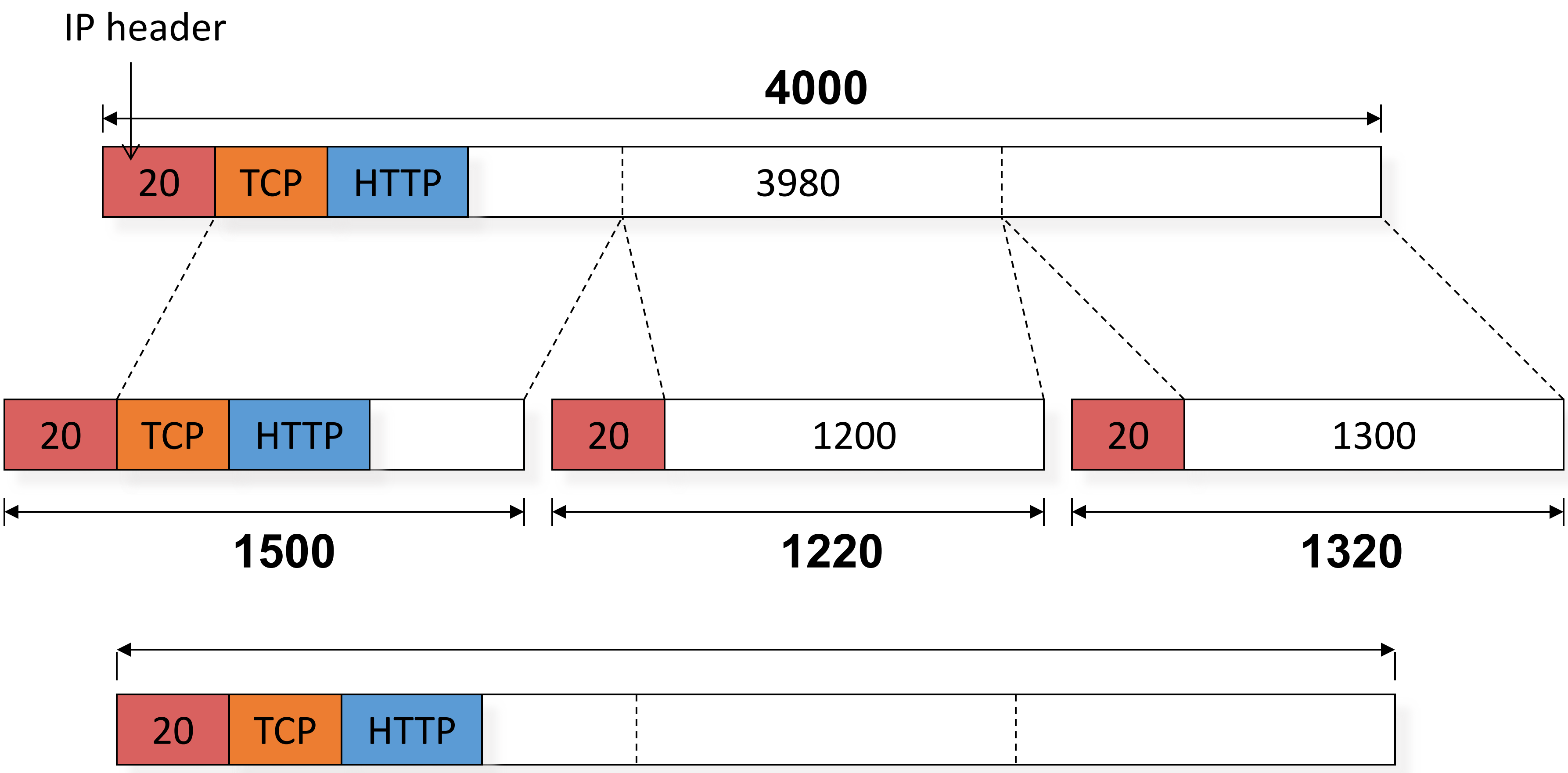


Example of fragmentation

- **A 4000 byte packet crosses a link w/ MTU=1500B**



Why reassemble?



Must reassemble before sending the packet to the higher layers!

A few considerations

- **Where to reassemble?**
- **Fragments can get lost**
- **Fragments can follow different paths**
- **Fragments can get fragmented again**

Where should reassembly occur?

- **Classic case of E2E principle**
- **At next-hop router imposes burden on network**
  - Complicated reassembly algorithm
  - Must hold onto fragments/state
- **Any other router may not work**
  - Fragments may take different paths
- **Little benefit, large cost for network reassembly**
- **Hence, reassembly is done at the destination**

Reassembly: What fields?

- **Need a way to identify fragments of the packet**
  - Introduce an identifier
- **Fragments can get lost**
  - Need some form of sequence number or offset
- **Sequence numbers / offset**
  - How do I know when I have them all? (need max seq# / flag)
  - What if a fragment gets re-fragmented?

IPv4's fragmentation fields

- **Identifier: which fragments belong together**
- **Flags:**
  - Reserved: ignore
  - DF: don't fragment
    - May trigger error message back to sender
  - MF: more fragments coming
- **Offset: portion of original payload this fragment contains**
  - In 8-byte units

IP packet structure

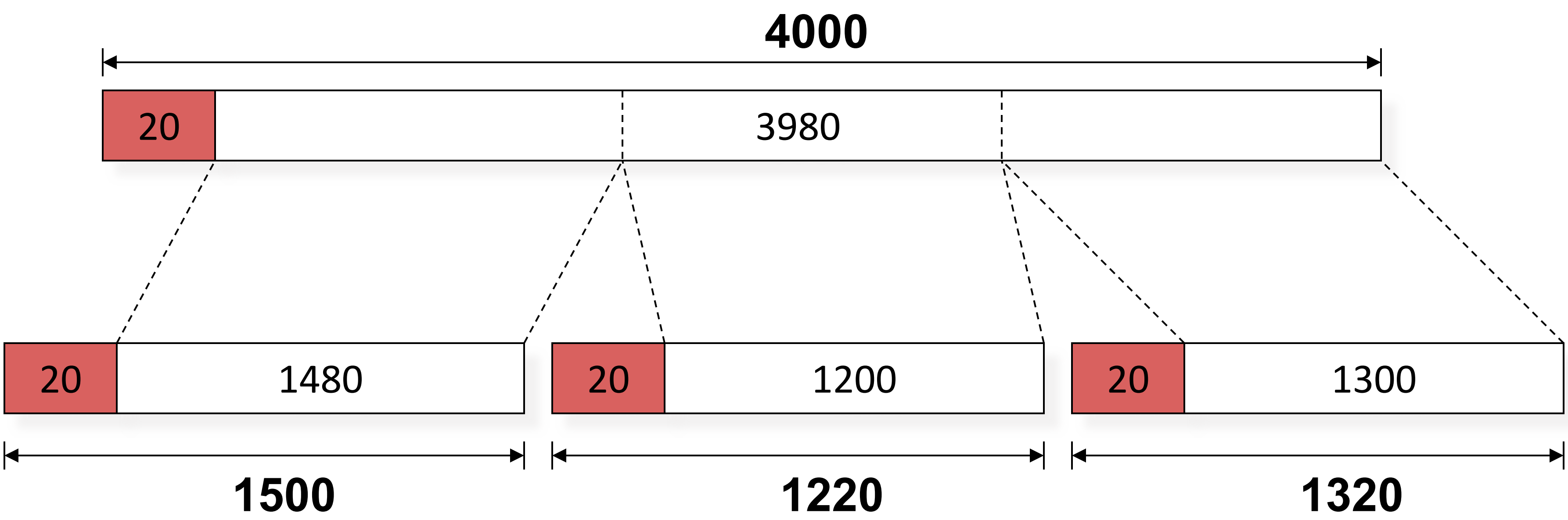
<table>
<tr><td>4-bit
Version</td><td>4-bit
Header
Len</td><td>8-bit
ToS</td><td>16-bit
Total Length (Bytes)</td></tr>
<tr><td colspan="4">For Fragmentation</td></tr>
<tr><td colspan="2">8-bit
TTL</td><td>8-bit
Protocol</td><td>16-bit
Header Checksum</td></tr>
<tr><td colspan="4">32-bit
Source IP Address</td></tr>
<tr><td colspan="4">32-bit
Destination IP Address</td></tr>
<tr><td colspan="4">Options (if any)</td></tr>
</table>

Why this works

- **Fragment without MF set (last fragment)**
  - Tells host which are the last bits in original payload
- **All other fragments fill in holes**
- **Can tell when holes are filled, regardless of order**
  - Use offset field
- **Q: why use a byte-offset for fragments rather than numbering each fragment?**
  - Allows further fragmentation of fragments

Example of fragmentation (contd.)

- **Packet split into 3 pieces**
- **Example:**



Example of fragmentation, contd.

- **4000 byte packet from host 1.2.3.4 to 5.6.7.8 traverses a link with MTU 1,500 bytes**

Version 4	Header Len 5	ToS 0	Total Length (Bytes) 4000	
Identification 56273			R/D/M 0/0/0	Fragment Offset 0
TTL 127		Protocol 6	Header Checksum 44019	
Source IP Address 1.2.3.4				
Destination IP Address 5.6.7.8				

(3980 more bytes of payload here)

Example of fragmentation, contd.

- **Datagram split into 3 pieces. Possible first piece:**

<table>
<tr><td>Version
4</td><td>Header Len
5</td><td>ToS
0</td><td colspan="2">Total Length (Bytes)
1500</td></tr>
<tr><td colspan="3">Identification
56273</td><td>R/D/M
0/0/1</td><td>Fragment Offset
0</td></tr>
<tr><td colspan="2">TTL
127</td><td>Protocol
6</td><td colspan="2">Header Checksum
xxx</td></tr>
<tr><td colspan="5">Source IP Address
1.2.3.4</td></tr>
<tr><td colspan="5">Destination IP Address
5.6.7.8</td></tr>
</table>

Example of fragmentation, contd.

- **Possible second piece: Frag#1 covered 1480bytes**

Version 4	Header Len 5	ToS 0	Total Length (Bytes) 1220
Identification 56273		R/D/M 0/0/1	Fragment Offset 185 (185 * 8 = 1480)
TTL 127	Protocol 6	Header Checksum yyy	
Source IP Address 1.2.3.4			
Destination IP Address 5.6.7.8			

Example of fragmentation, contd.

- **Possible third piece: 1480+1200 = 2680**

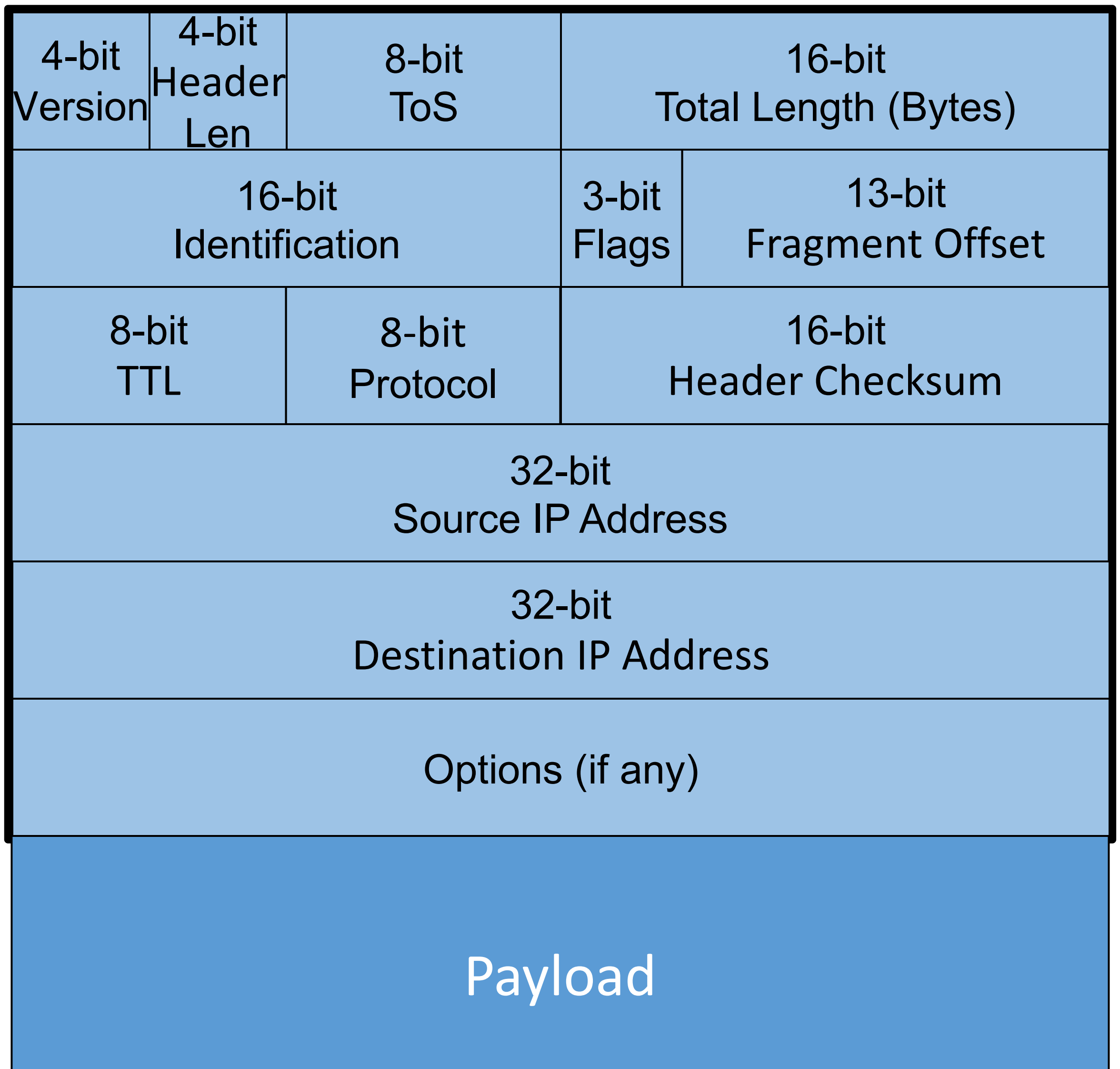
<table>
<tr><td>Version
4</td><td>Header Len
5</td><td colspan="2">ToS
0</td><td colspan="4">Total Length (Bytes)
1320</td></tr>
<tr><td colspan="4">Identification
56273</td><td>R/D/M
0/0/0</td><td colspan="3">Fragment Offset
335 (335 * 8 = 2680)</td></tr>
<tr><td colspan="2">TTL
127</td><td colspan="2">Protocol
6</td><td colspan="4">Header Checksum
zzz</td></tr>
<tr><td colspan="8">Source IP Address
1.2.3.4</td></tr>
<tr><td colspan="8">Destination IP Address
5.6.7.8</td></tr>
</table>

A quick look into IPv6

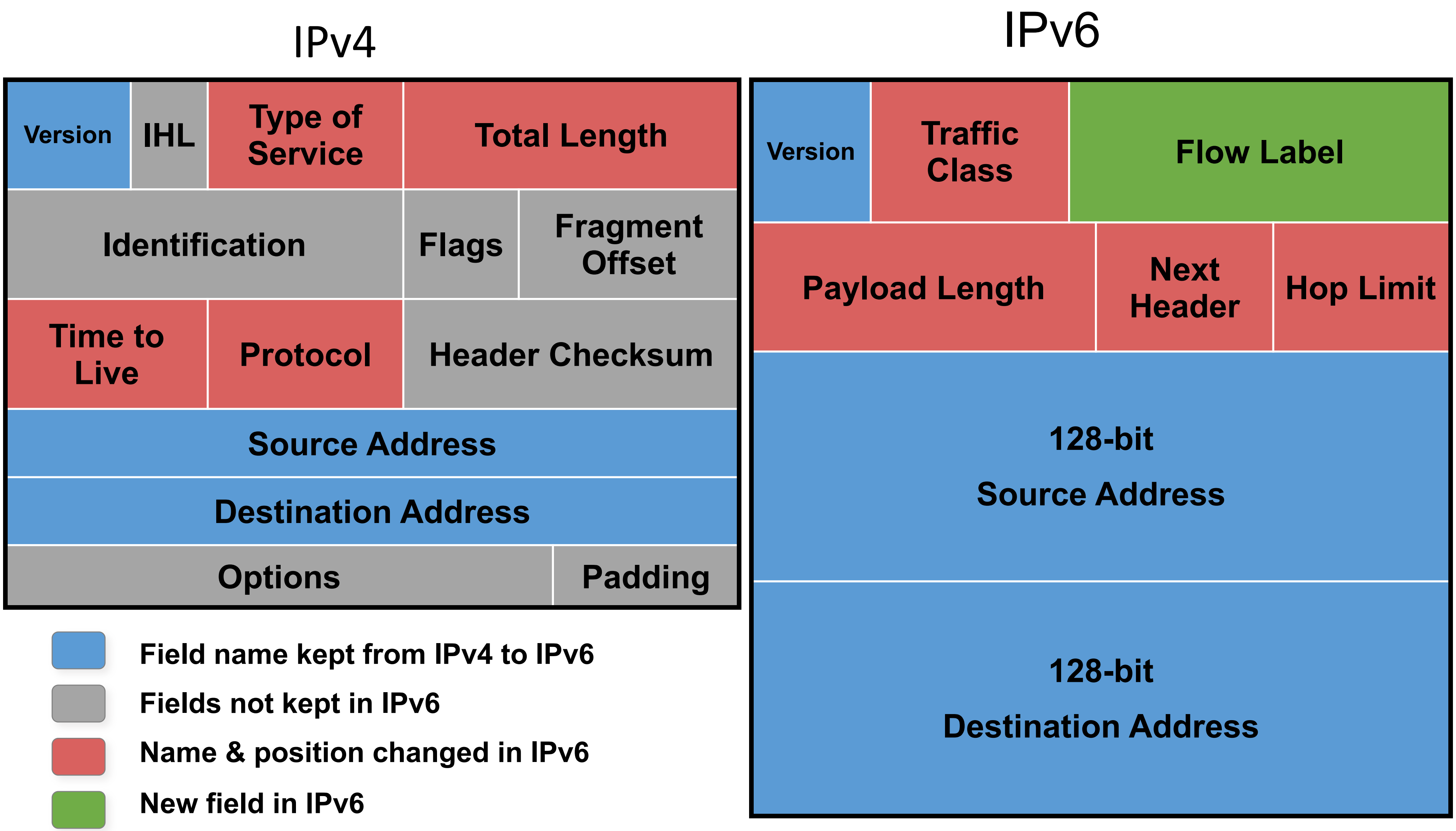
IPv6

- **Motivated (prematurely) by address exhaustion**
  - Addresses four times as big (128-bit)
- **Focused on simplifying IP**
  - Got rid of all fields that were not absolutely necessary
- **Result is an elegant, if unambitious, protocol**

What “clean up” would you do?



IPv4 and IPv6 header comparison



Group Discussion

- **Topic: IPv4 vs. IPv6**
  - ➢ Discuss why IPv6 makes the following changes.
    - Eliminate fragmentation
    - Eliminate checksum
    - New options mechanism
    - Eliminate header length

- **Discuss in groups, and each group chooses a leader to summarize the discussion**
  - ➢ In your group discussion, please do not dominate the discussion, and give everyone a chance to speak
  - ➢ Turn on your video if you can

Summary of changes

- **Eliminated fragmentation (why?)**
- **Eliminated checksum (why?)**
- **New options mechanism (why?)**
- **Eliminated header length (why?)**
- **Expanded addresses**
- **Added Flow Label**

Philosophy of changes

- **Don’t deal with problems: leave to ends**
  - Eliminated fragmentation and checksum
  - Why retain TTL?
- **Simplify handling:**
  - New options mechanism (uses next header)
  - Eliminated header length
    - Why couldn’t IPv4 do this?
- **Provide general flow label for packet**
  - Not tied to semantics
  - Provides great flexibility

Summary

- **Network layer can be divided into data plane and control plane**
  - ➢Data plane deals with “how?”
  - ➢Control plane deals with “what?”
- **IP is simple yet nuanced**
- **Next class: IP routers**

Thanks!
Q&A