

# CS250: FOUNDATIONS OF COMPUTER SYSTEMS

## [NETWORKING]

### IP at Work: Fragments Assemble!

Packet's too big?

Fragment, transmit and  
At receiving endpoint coalesce

If something goes awry?

The network shrugs does nothing

If *all* fragments do get through?

Coalesce with needlework so fine  
That the transport can't spot the seams

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## Frequently asked questions from the previous class survey

- Can free-up the space for MAC addresses?
- Do the major port numbers (e.g., SMTP) change between Linux/Windows etc.?
- Can I use fibre instead of Ethernet somewhere?



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## Topics covered in today's lecture

- IPv4
- IPv6



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## INTERNET ARCHITECTURE




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Did you know?  
As of 2026, 20 quadrillion bytes of data are routed every second  
i.e., 20 Petabytes of data per-second

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## Internetwork

- Arbitrary collection of **interconnected** networks
  - ▣ To provide some sort of host-to-host packet delivery service
- Network of networks
  - ▣ Made up of lots of smaller networks

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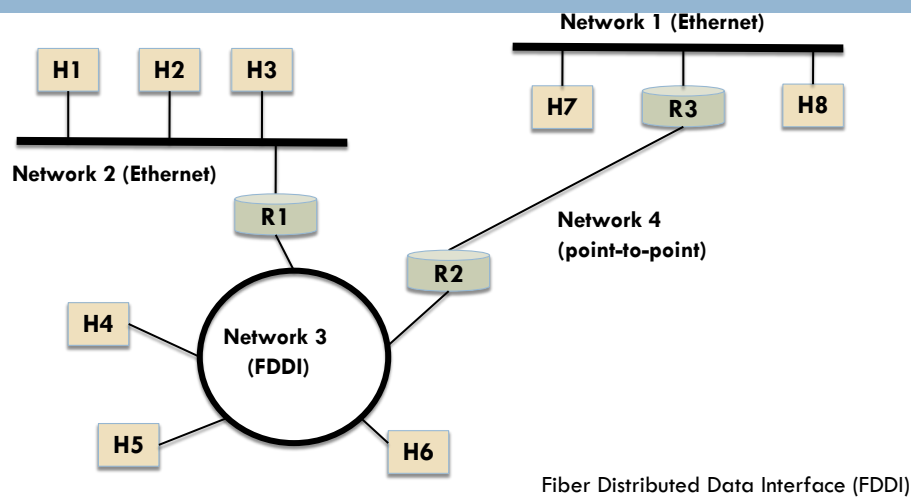
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## A simple internetwork



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## Internet Protocol (IP)

- Key tool to build scalable, **heterogeneous** networks
- Runs on all nodes (hosts and routers)
- Allows nodes and networks to *function as a single logical network*
- Possible to build an internetwork without IP
  - But IP is the only one that has faced **scale** issues



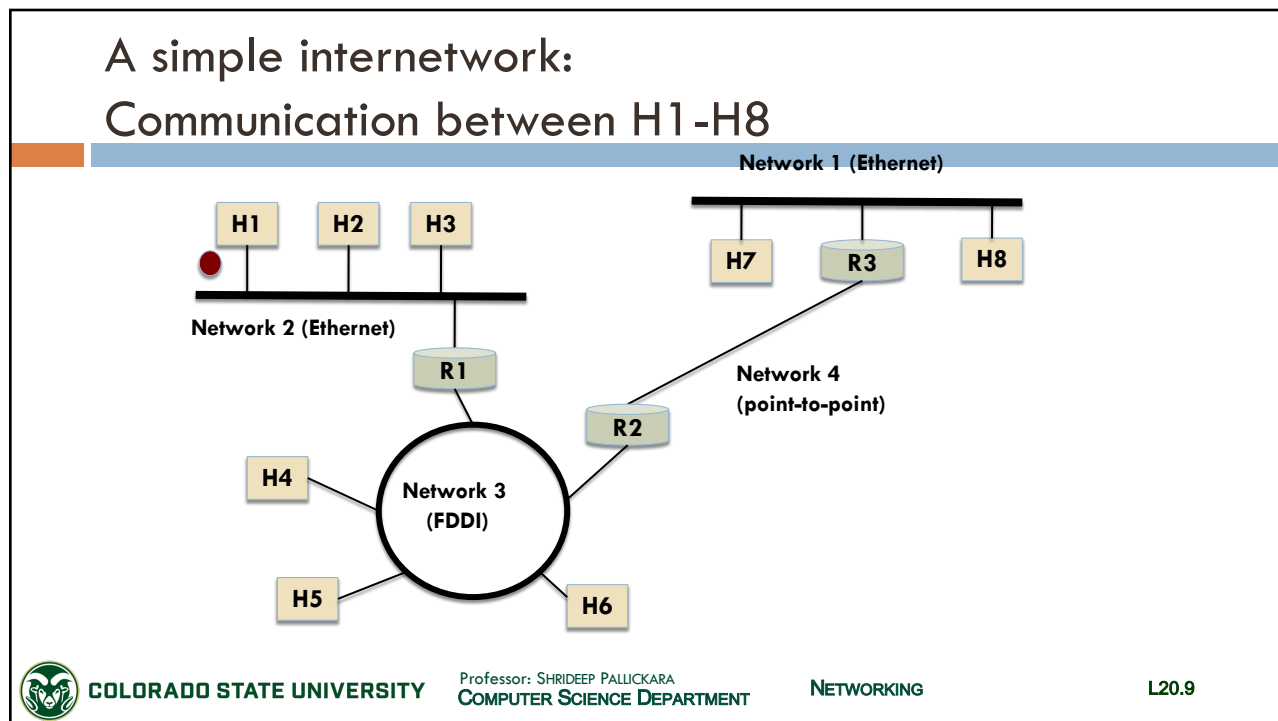
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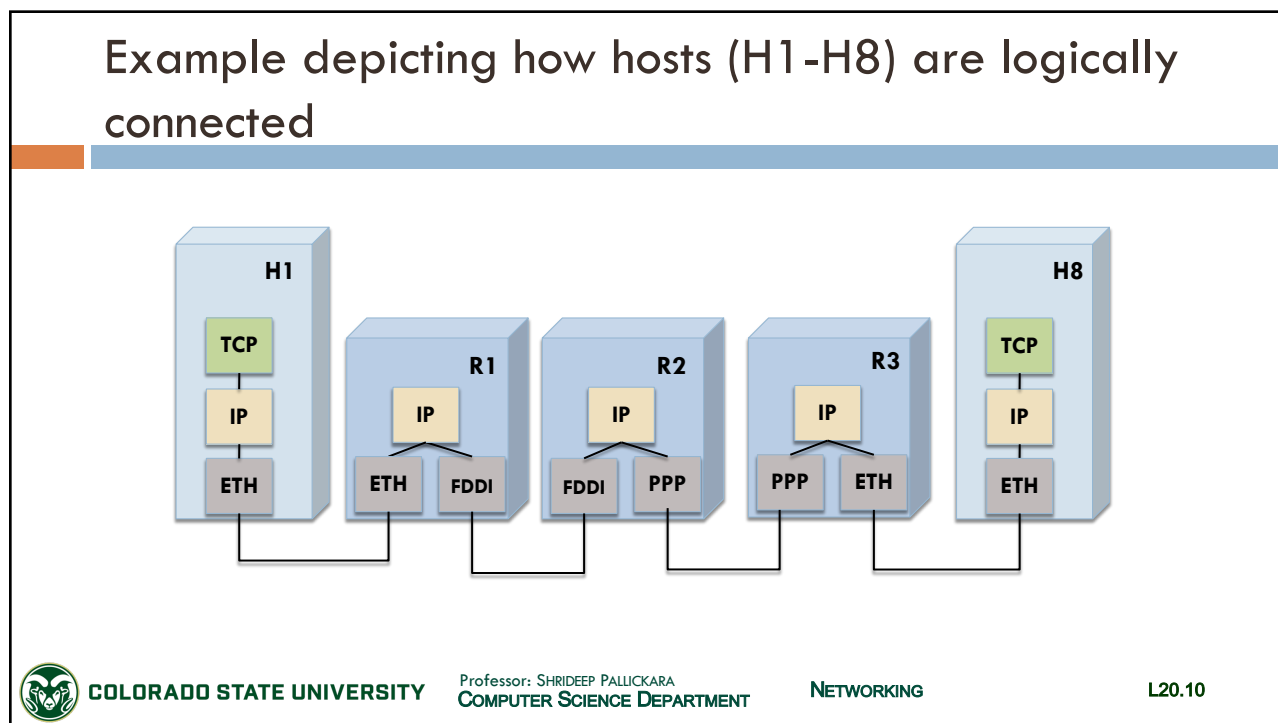
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## The IP service model

- Datagram model of **delivery**
  - ▣ Connectionless
  - ▣ Best effort
  
- **Addressing** scheme
  - ▣ Identifies all hosts in the internetwork



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## Datagram delivery

- Datagram is a type of packet
  - ▣ Sent in a **connectionless** fashion
  
- No need for any **advance** setup mechanisms
  - ▣ That tell network what do when packet arrives
  
- Every datagram contains enough information
  - ▣ To forward packet to correct destination



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## The network makes a best effort to send datagrams across

- Things that could go **wrong** with the packets
  - Lost
  - Corrupted
  - Misdelaivered
  - Out of order and duplicates
- When things go wrong, the network does **nothing**
  - No attempt to recover from the failure



## Keeping routers simple was one of the original design goals of IP

- Important to **run over anything**
- Putting extra functionality into routers to make up for network deficiencies?
  - Not a good idea
- Higher-level protocols/apps that run above IP need to be aware of failure modes

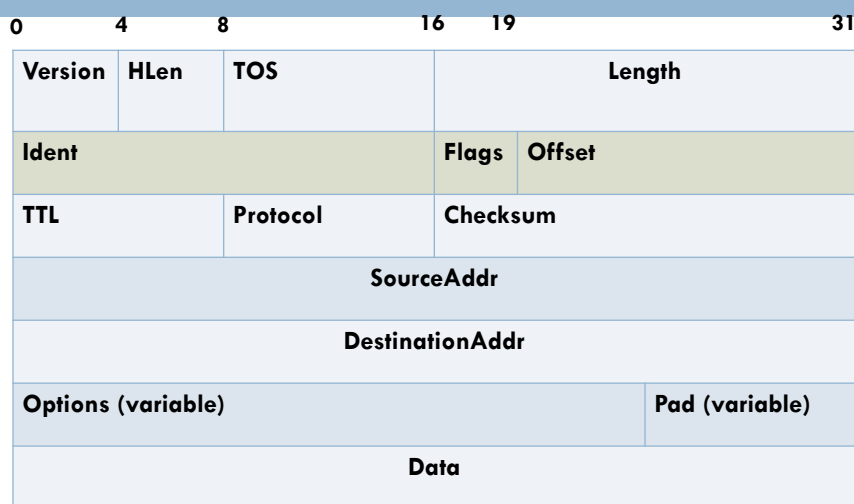


## The IP Packet format consists of a header followed by bytes of data

- Represented as a succession of **32-bit** words
- Packet formats designed to align on 32-bit boundaries
  - Simplifies task of processing in software
- Transmission order
  - **Top word** transmitted first
  - **Leftmost byte** of each word transmitted first



## The IPv4 packet header



## IP Packet format

[1/5]

- **Version**
  - Makes it easy to **redefine** packet format later on
- **HLen**
  - Specifies length of header **in 32-bit words**
  - When there are no options (most of the time)
    - Header is **5 words** or 20 bytes
- **TOS (type of service)**
  - Allow packets to be treated differently
    - Based on application needs



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## IP Packet format

[2/5]

- **Length**
  - Length of the datagram **in bytes**
  - Maximum size of IP datagram is  **$2^{16}$**  bytes
- SECOND WORD OF IP PACKET
  - {Ident, Flags, Offset}
  - Information about **fragmentation**



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## IP Packet format

[3/5]

- **TTL** (time to live)
  - Hop-count not timer (as originally intended)
- **Protocol** field
  - **Demultiplexing** key
    - Identifies higher-level protocol
    - TCP (6), UDP (17)
- **Checksum**
  - Consider IP header as a sequence of 16-bit words
  - Doing a bitwise AND of a number with its 1's complement results in 0 ( $x \& \sim x$ )



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## IP Packet format

[4/5]

- **SourceAddr**
  - Decide if packet should be accepted
  - Also used for replies
- **DestinationAddr**
  - Full address of destination
  - Forwarding decisions are made at each router
- Presence or absence of options
  - Can be checked **based on size of Hlen**
    - without "options" the header is 20 bytes



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## IP Packet format

[5/5]

### TOS field {Type of Service}

- Meant to specify **how** the datagram should be **handled** as it traversed the internet
  - Preference for low delay
  - Preference for high throughput
  - Preference for high reliability
- In practice TOS was not widely implemented



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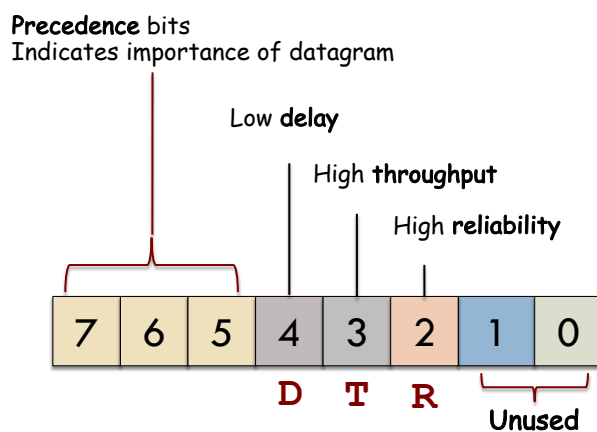
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## The 8 bits allocated to TOS can be divided into 5 parts



7: Most Significant Bit  
0: Least Significant Bit



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## Providing host-to-host service model over heterogeneous collection of networks

- Each network technology has its own idea of how large a packet can be
  - Ethernet v2: 1500 bytes
  - FDDI: 4352 bytes



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## Every network type has a Maximum Transmission Unit (MTU)

- Largest IP datagram that it can carry in its frame
- Smaller than the largest packet-size of network
  - IP datagram needs to fit in payload of **link-layer frame**



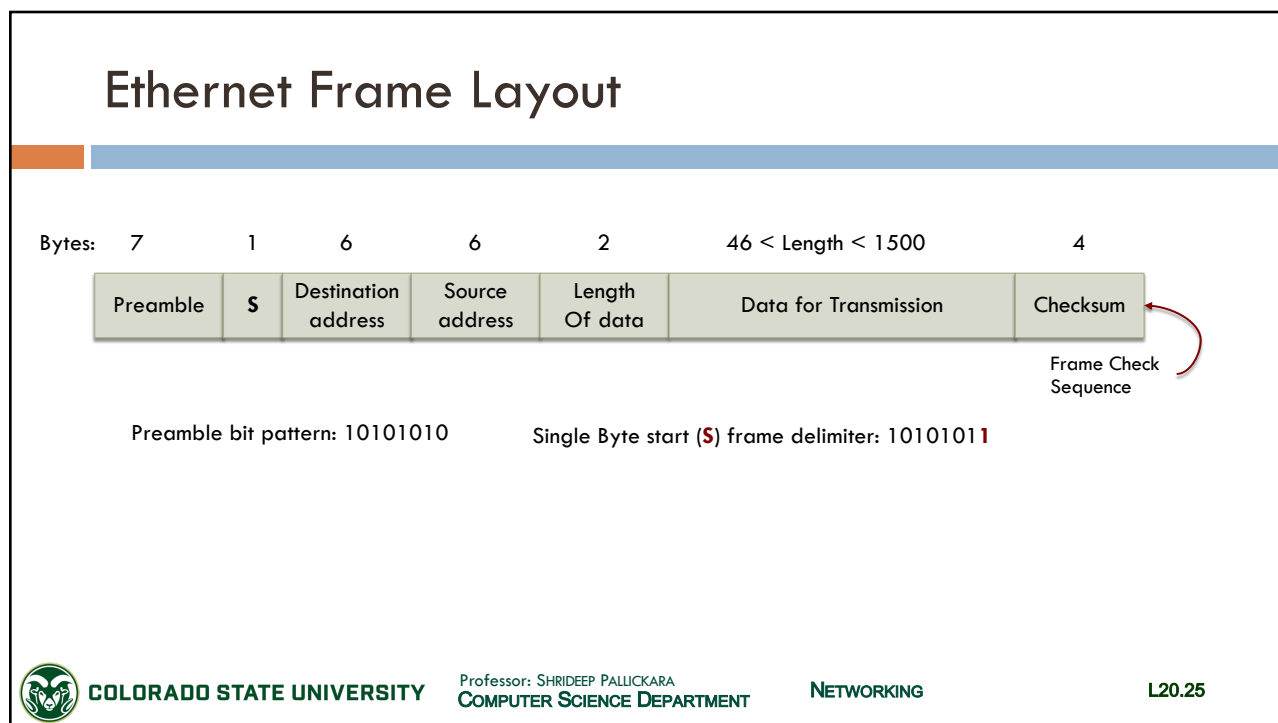
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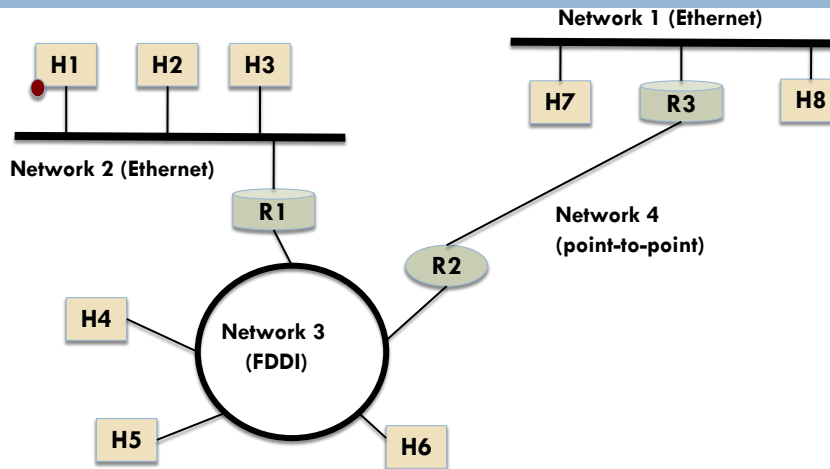
## Fragmentation is necessary when datagram path includes network with smaller MTU

- All fragments carry same identifier in **Ident** field
  - To enable fragment reassembly
  - Chosen by the source host
- If all fragments do not arrive at receiving host?
  - ① Receiver **gives up** reassembly [reassembly timeout: 15 seconds RFC0791]
  - ② **Discards** fragments that did arrive
- IP **does not attempt** to recover from missing fragments

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## A simple internetwork: Sending IP datagrams from H1 to H8



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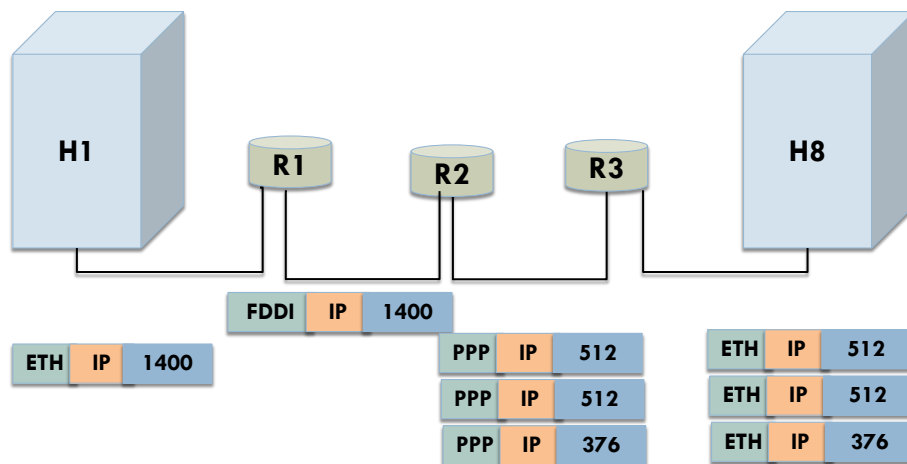
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## IP datagrams traversing a sequence of physical networks



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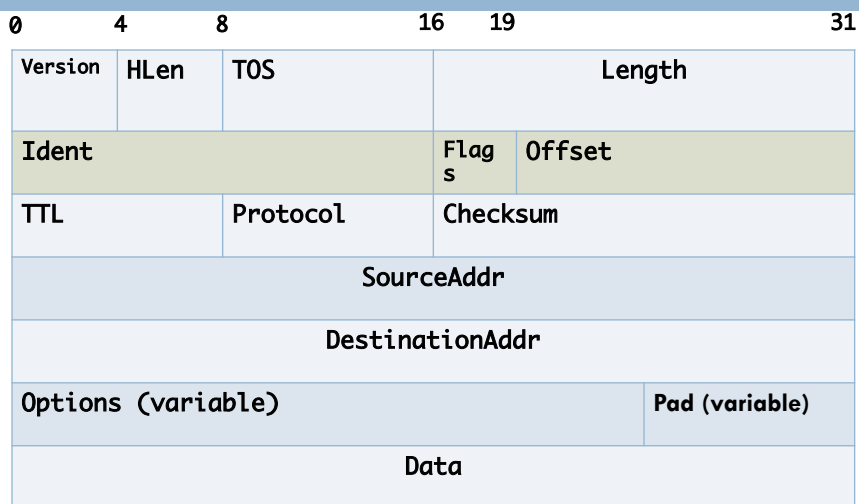
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## IPv4 Packet header



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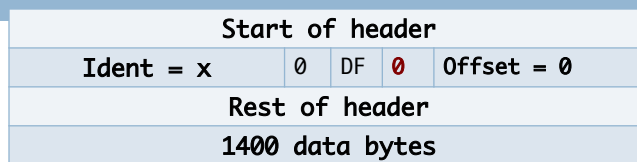
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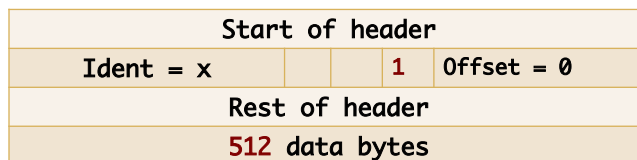
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## Header fields used in IP fragmentation: Fragmentation occurs at 8-byte boundaries



**Unfragmented packet**



**Fragmented packet**



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## Header fields used in IP fragmentation: Fragmentation occurs at **8-byte boundaries**

Start of header			
Ident = x		1	Offset = 64
Rest of header			
512 data bytes			

**Fragmented packet**

Start of header			
Ident = x		0	Offset = 128
Rest of header			
376 data bytes			

**Fragmented packet**



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Time is never time at all  
 You can never ever leave  
 Without leaving a piece of youth

And our lives are forever changed  
 We will never be the same  
 The more you change, the less you feel

...

And you know you're never sure  
 But you're sure you could be right  
 If you held yourself up to the light

And the embers never fade  
 In your city by the lake  
 The place where you were born  
*Tonight, Tonight; William Corgan; The Smashing Pumpkins*

## IPV6 (AND COMPARING WITH IPV4)

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## IPv6 Packet Header: Some more details [1/2]

- **Version:** 4 bits [0110]
- Traffic Class: 6+2 bits
  - Differentiated Services (priority, type of service) for QoS [Quality of Service]
  - Anything that ends in 2 “1” bits is intended for experimental or local use
- Flow Label (20 bits)
  - If it is non-zero: Serves as a hint to routers and switches with multiple outbound paths that these **packets should stay on the same path**, so that they will not be reordered
- Payload length (**16 bits**): Size of payload *including* extension headers



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## IPv6 Packet Header: Some more details [2/2]

- Next Header (8 bits)
  - Specifies the type of the next header
- Hop Limit (8 bits)
  - Replaces the time-to-live field of IPv4
- Destination and Source Addresses (**128-bits** or 16 bytes each)
  - The mass of earth is  $2^{92}$  grams
- Note: The IPv6 packet **header has no checksum**
  - Transport or application layer protocols are assumed to provide sufficient error detection



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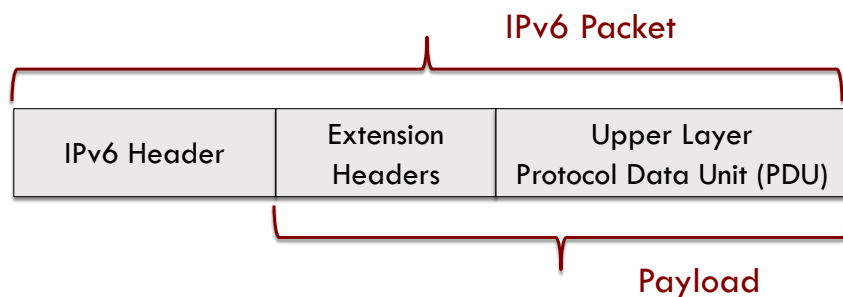
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## Structure of the IPv6 Packet



PDU typically contains an upper layer protocol header and its payload.  
For e.g.: a TCP segment, UDP Datagram, or an ICMPv6 message



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## Extension Header

[1/2]

- If the Next Header field is non-zero
  - ▣ It defines an extension header
- Current extension header types
  - ▣ Information for routers, route definition, fragment handling, authentication, encryption, etc.
- Each extension header has a specific size and defined format



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## Extension Header

[2/2]

- If an extension header is present?
  - **Follows** the basic header and **precedes** the payload AND
  - Includes a Next Header
- Every extension header starts off with the Next Header



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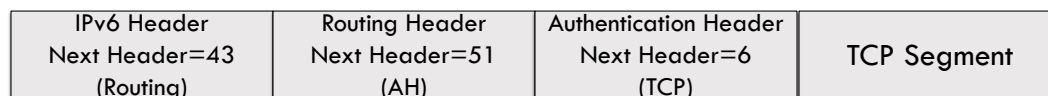
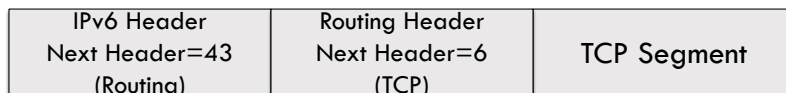
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## IPv6 Extension Headers: The chain of pointers using the Next Header field

Each extension header must fall on a 64-bit (8-byte) boundary. Use Padding to get there if less than that.



Fragmentation Header: 44



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# UDP SIMPLE DEMULTIPLEXER

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## User Datagram Protocol

- **Simplest** possible transport protocol
  - ▣ Extends host-to-host into process-to-process communications
- No additional functionality to best-effort service provided by underlying network
- Adds **demultiplexing**
  - ▣ Allows applications on a host to **share** the service



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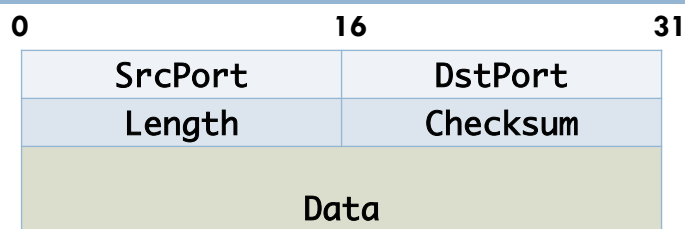
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## UDP identification of processes

- Processes *indirectly* identify each other
  - Abstract locator called **port**
- Source sends a message to a port
  - Destination receives messages from a port
- Process is identified by a **port on a particular host**



## Format of a UDP header



## A port is just an abstraction

- Typically implemented as a **message queue**
- When message arrives?
  - Protocol appends message to end of the queue
- **UDP**
  - If the queue is full, message is discarded
  - No flow-control mechanism



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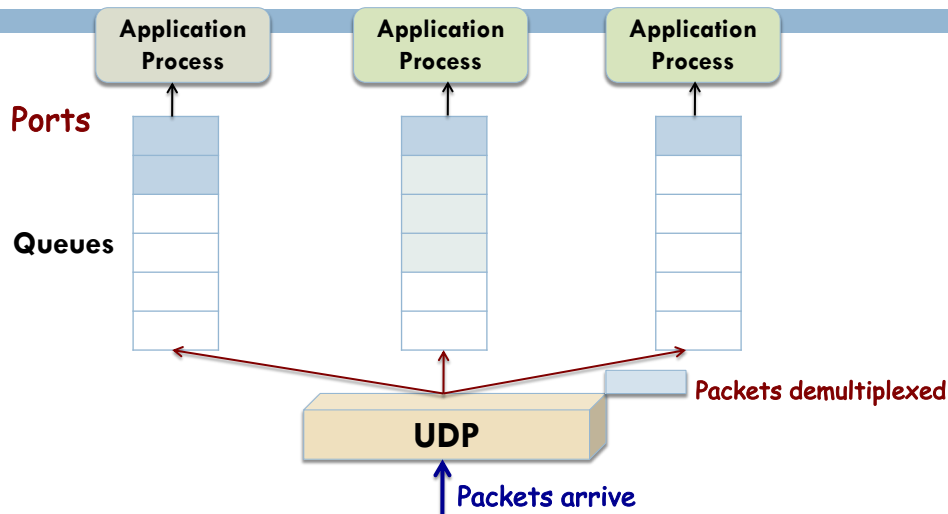
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## UDP message queue: The port abstraction



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## Some work that UDP does do besides demultiplexing: Checksumming

- UDP header
  - Message body
  - **Pseudoheader**: From the IP header
    - ▣ Protocol number
    - ▣ Source IP address
    - ▣ Destination IP address
  - UDP length
    - ▣ Used twice
- } Verify if message is delivered  
between the correct endpoints



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## The contents of this slide-set are based on the following references

- *Computer Networks: A Systems Approach*. Larry Peterson and Bruce Davie. 4th edition. Morgan Kaufmann. ISBN: 978-0-12-370548-8. [Chapter 1, 2]
- Matthew Justice. *How Computers Really Work: A Hands-On Guide to the Inner Workings of the Machine*. ISBN-10/ISBN-13 : 1718500661/ 978-1718500662. No Starch Press. 2020. [Chapter 11]



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