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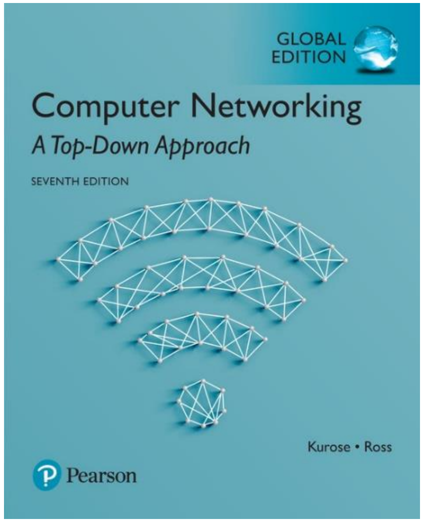
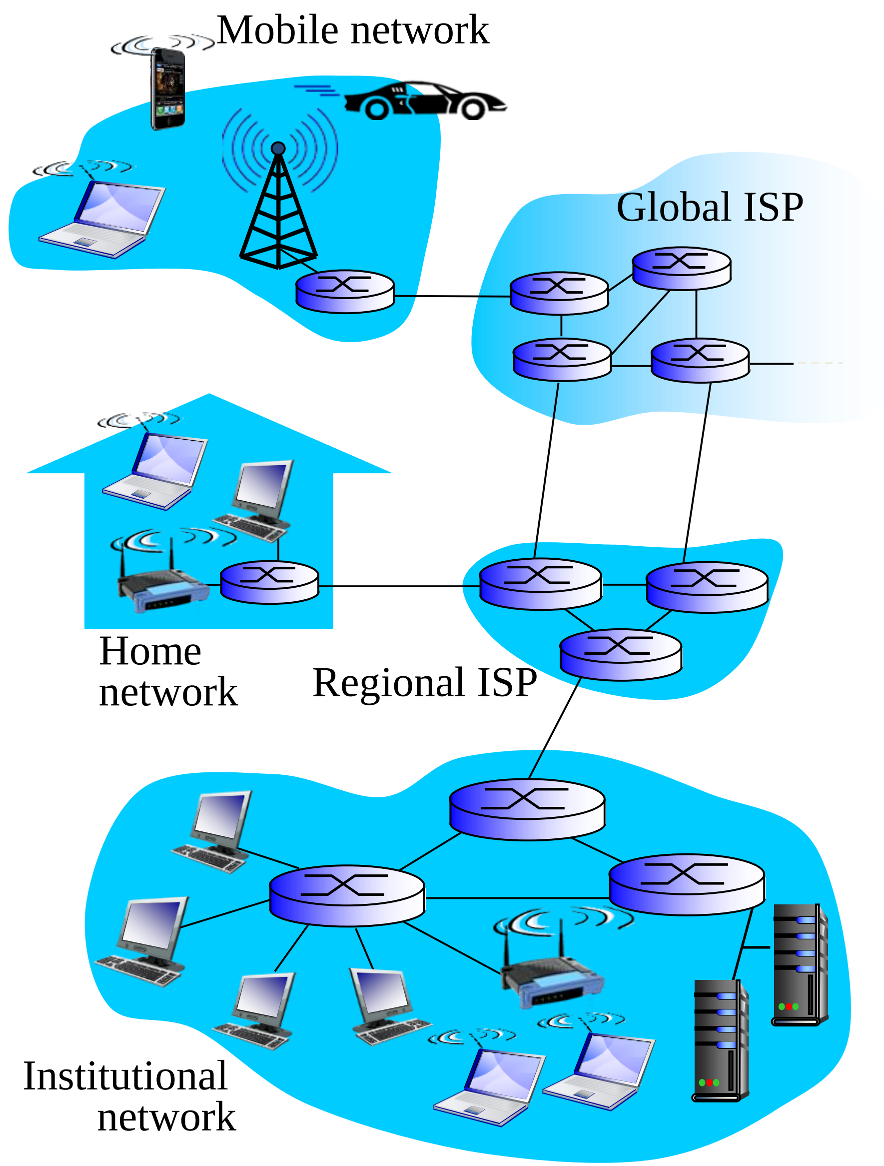


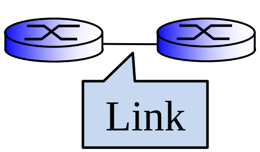
Computer Networking: A Top-down Approach, 7th edition.
Jim Kurose, Keith Ross
Pearson

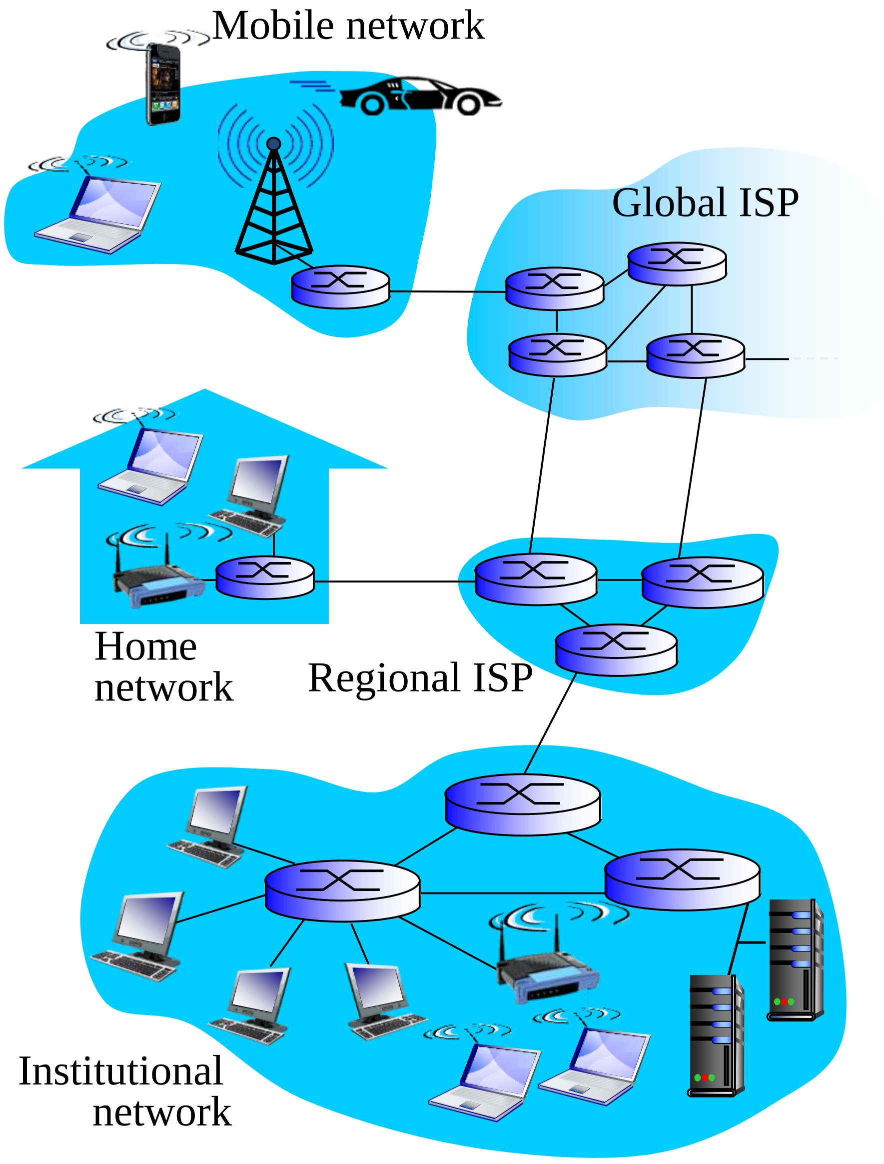


- **Internet Service Provider (ISP)**
  - Provide internet access
  - Examples:
    - Telephone companies
- **Host / End System**
  - Two types
    - Client
      - Computer, smartphone

    - Server / Data centers
      - More powerful machines that store and distribute web pages

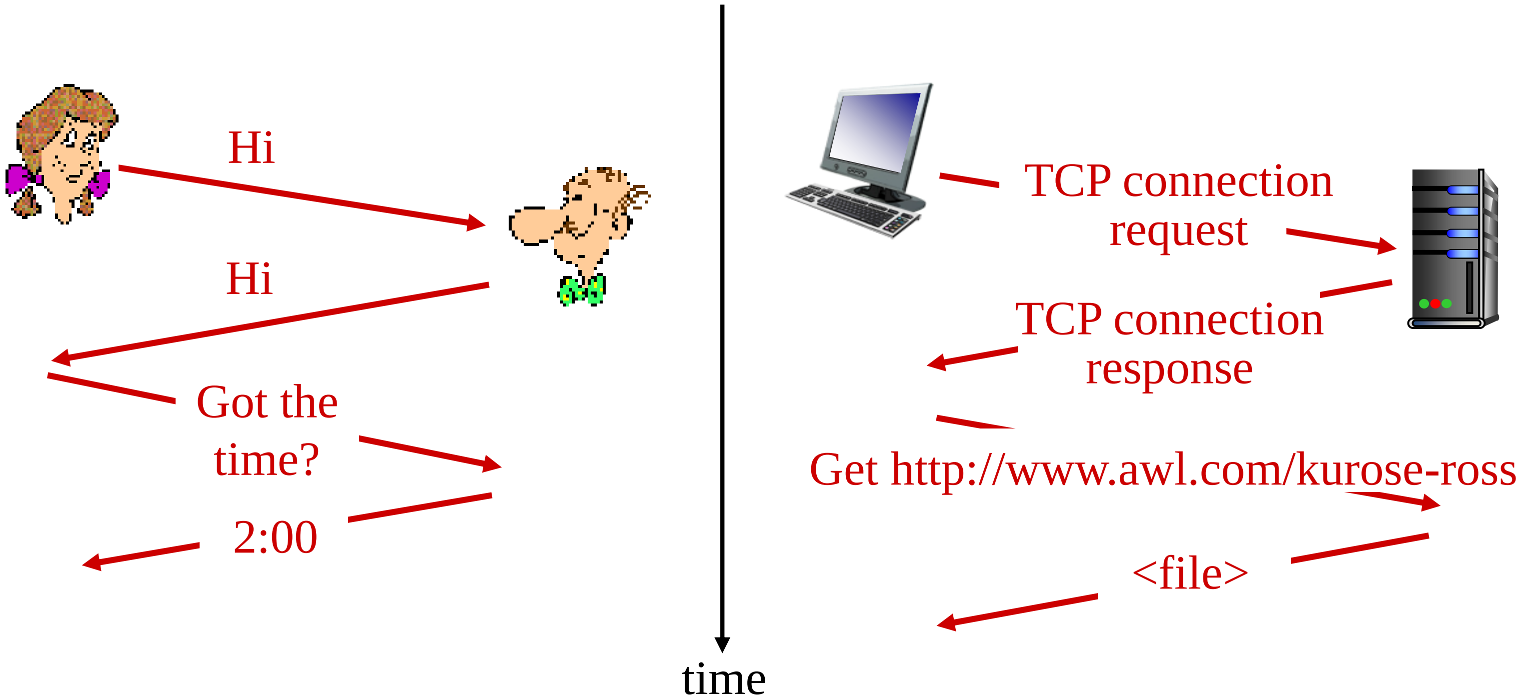
- **Link**
  - Different links transmit at different *transmission rate* (bits per second, bps)
  - Examples:
    - Twisted-pair copper wire, fiber optics





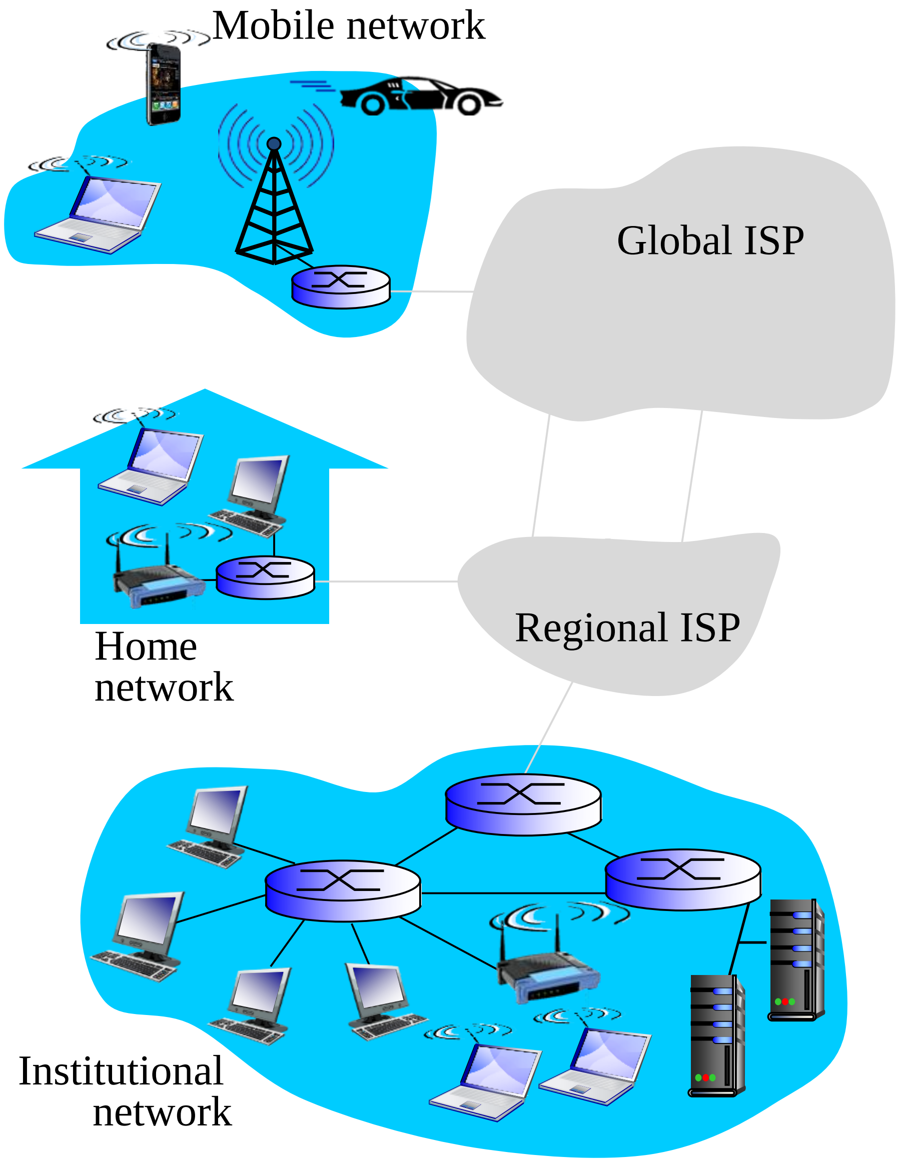
- **Packet**
  - Host divide data into *segments*, add *header* to each segment to generate a *packet*
  - Destination reassemble packets into data
- **Switch**
  - Receive and forward packets towards their destinations
  - Two types
    - Router: Used in core networks
    - Link-layer switch: Used in access networks
- **Route / Path**
  - End-to-end connections from hosts to destinations
    - Comprised of links and switches

1.1 What is a Protocol?



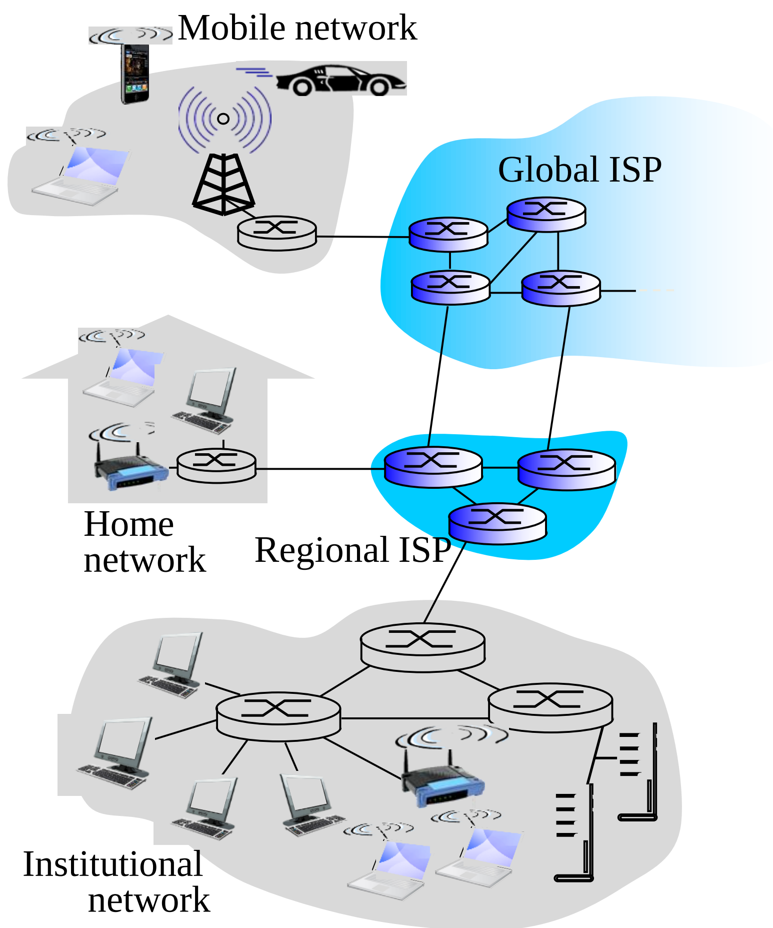
- **Network protocol**
    - Message
        - Format
        - Order
            - Example: TCP connection request → TCP connection response → Get <address> → <file>

1.2 Access Networks: Overview



- **Access Networks**
  - Connect hosts to edge router
    - Edge router is the first router in the global or regional ISPs
  - Example
    - Fiber to the Home (FTTH)

1.3 The Network Core



- Two Types
  - **Packet switching**
  - **Circuit switching**

	Packet switching	**Circuit switching**
Require-ment on end-to-end resource reservation	No. A source host wants to communicate with a destination host • It use resources (e.g., bandwidth) along a path from source host to destination host in an on demand manner.	Yes. A source host wants to communicate with a destination host • It must *reserve resources* along a path (called **circuit** or **dedicated end-to-end connection**) from source host to destination host. • The resource must be reserved for the *entire duration of the communication session*.
Example	Internet	Telephone networks

1.3 The Network Core: Packet Switching

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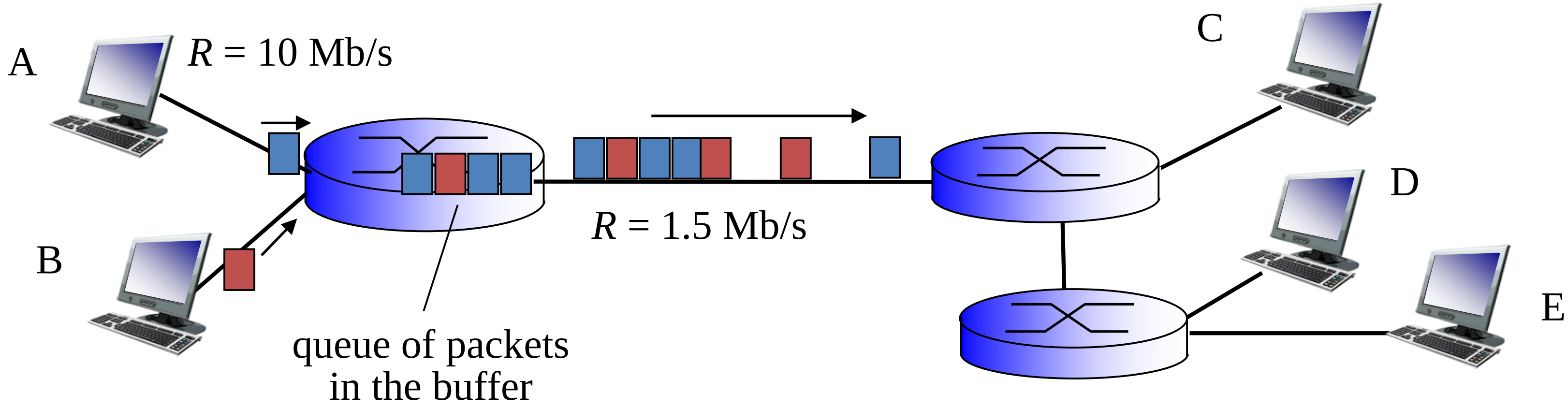
- Main concept
  - **Store-and-Forward Transmission**
    - Packet switch must receive (store) all bits of a packet, then only it can transmit (forward) the first bit of the packet

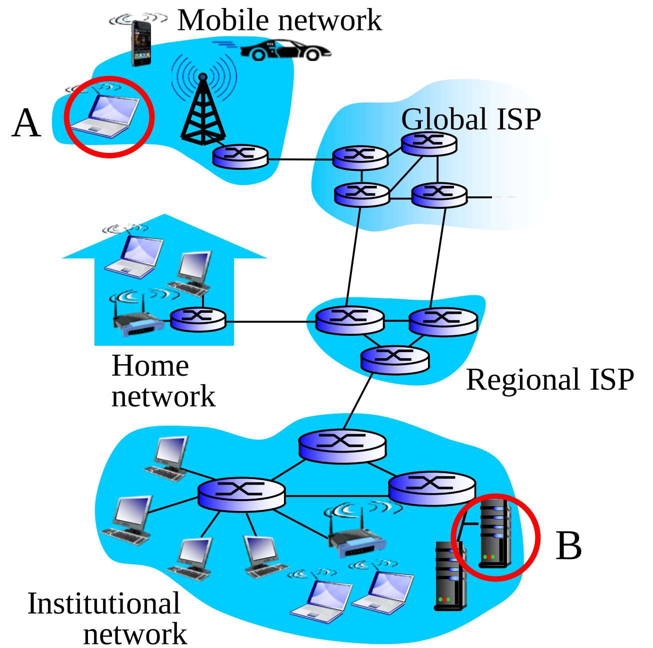
- Network performance
  - **Queuing delay**
  - **Packet loss**

- Suppose Host A and B are sending packets to Host E. Hosts A and B first send their packets along 10 Mbps links to the first router. The router then directs these packets to the 1.5 Mbps link. If, during a short interval of time, the arrival rate of packets to the router exceeds 1.5 Mbps, congestion will occur at the router as the queue becomes full. This increases *queuing delay* and *packet loss*.



1.3 The Network Core: Packet Switching

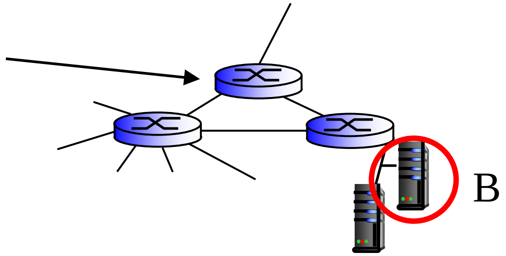
- **Routing protocol**
  - Each router determine the shortest path to each destination and use the shortest path to configure its forwarding table



Routing protocol:
Which is the shortest path from point A to point B?

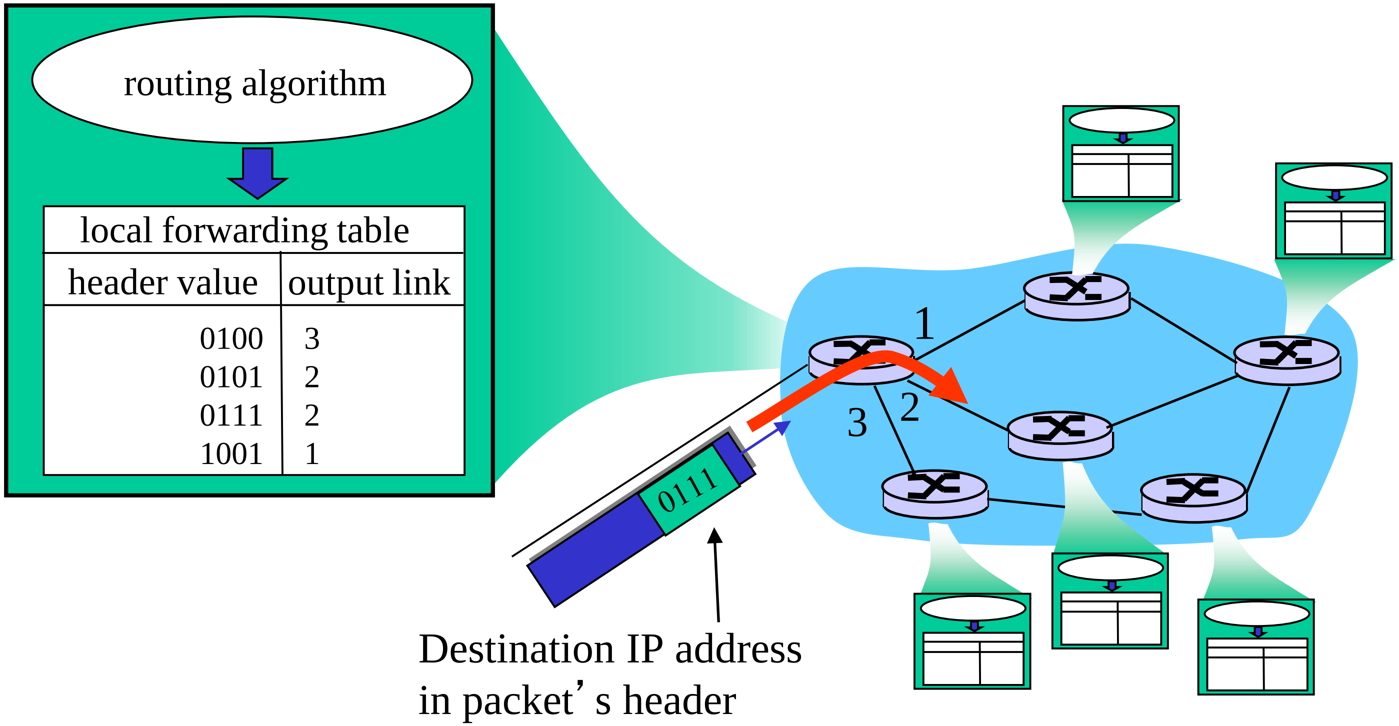
- **Forwarding table**
  - Each host has IP address. Each router use forwarding table to map a destination IP address to one of its outgoing link.

Forwarding table:
Which is the outgoing link to point B?

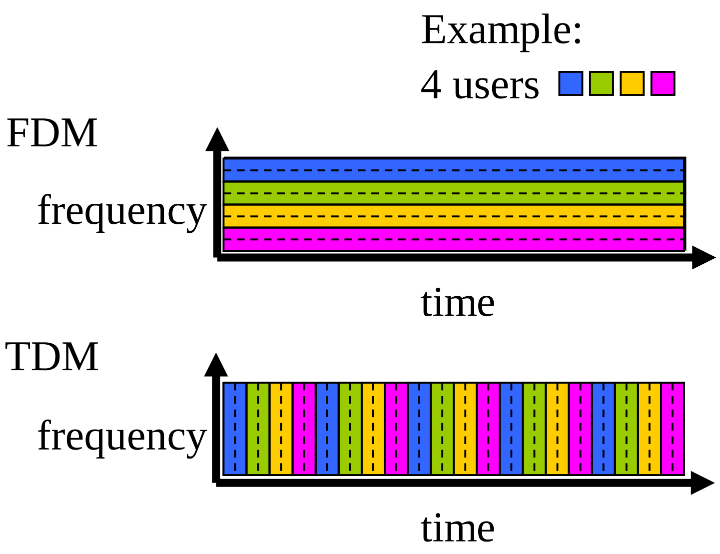


1.3 The Network Core: Packet Switching

- Routing protocol and forwarding table



1.3 The Network Core: Circuit Switching



- Two types
  - **Frequency-Division Multiplexing (FDM)**
    - A link dedicate a frequency band to each connection
      - The width of the frequency band indicate bandwidth
      - Example: 4 kHz
  - **Time-Division Multiplexing (TDM)**
    - A link dedicate one time slot in every frame to each connection
      - Note:
        - Time is divided into fixed duration frames
        - Each frame is divided into a fixed number of time slots

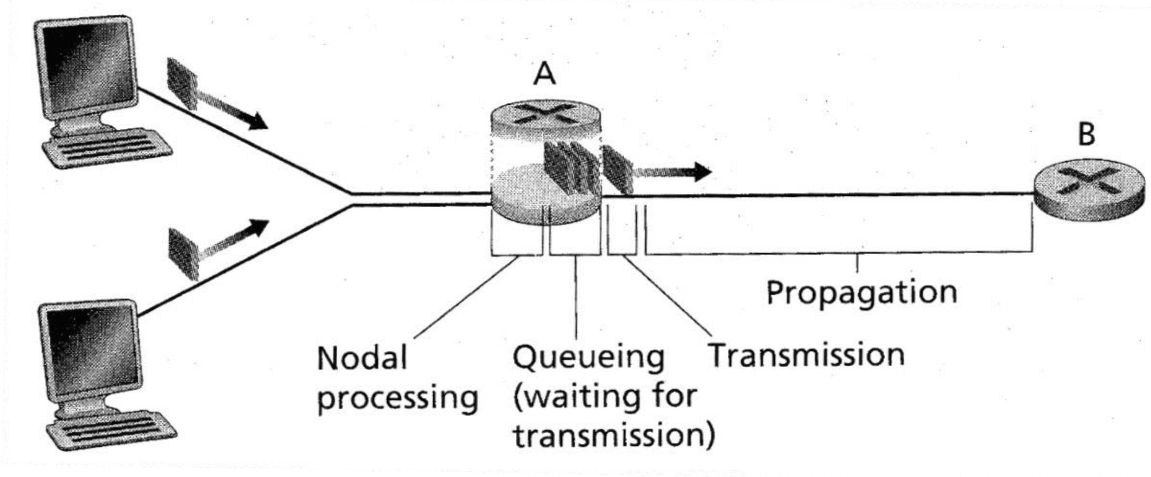
1.3 The Network Core Performance: Packet Switching vs. Circuit Switching

	Packet switching	**Circuit switching**

Performance Efficiency	Higher
	• No reservation
	    • More sharing of link capacity
		Lower
		• Require reservation
		    • Reserved resources may not be fully utilized
		    • Reserved resources may not be sufficient
		        • Underutilized reserved resources cannot be used for other packets

Packets need to wait at queue?	Yes • There is variable and unpredictable delay • Not suitable for real-time service	No • Reserved resource provides guaranteed constant rate
Complexity	Lower	Higher • Reservation requires end-to-end signaling protocol
Cost Efficiency	Higher • No reservation • Less cost involve	Lower
Popularity	More popular	Less popular

1.4 Overview of Delay in Packet-Switched Networks



Node delay = Processing delay + Queuing delay + Transmission delay + Propagation delay

$$d_{node} = d_{proc} + d_{queue} + d_{trans} + d_{prop}$$

Processing delay

- Read packet header
- Determine the outgoing link
- Check bit errors
- Value: μs

Queuing delay

- Wait to be transmitted
- Value: ms

Transmission delay

- Push all bits of a packet into the link
- $d_{trans} = \frac{L}{R}$
- Value: ms

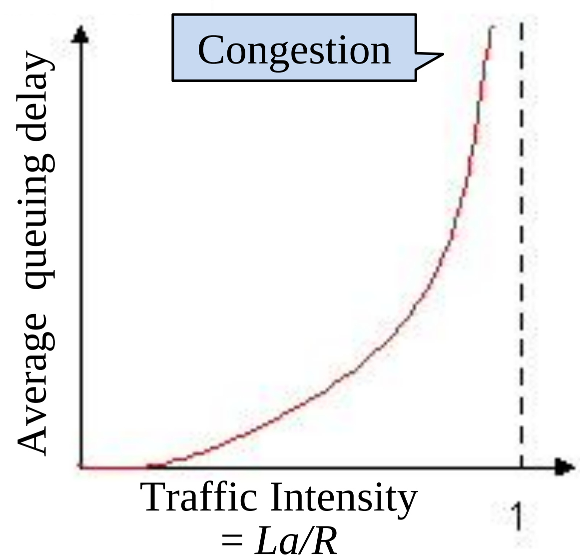
Propagation delay

- Travel from one router to another across a link
- Speed depends on
  - Propagation speed of physical media, s
  - Distance between the routers, d
- $d_{prop} = \frac{d}{s}$
- s : 3×10^8 meters/sec

1.4 Queuing Delay and End-to-end Delay

Traffic Intensity

- Ratio of bits arrival rate (bits/second) to transmission rate
- Traffic intensity $= \frac{La}{R}$
  - L = packet length (bits)
  - a = Packet arrival rate (packets/second)
  - R = Transmission rate (bits/second)
- Assumption:
  - Queue size is infinite, so there is no packet loss



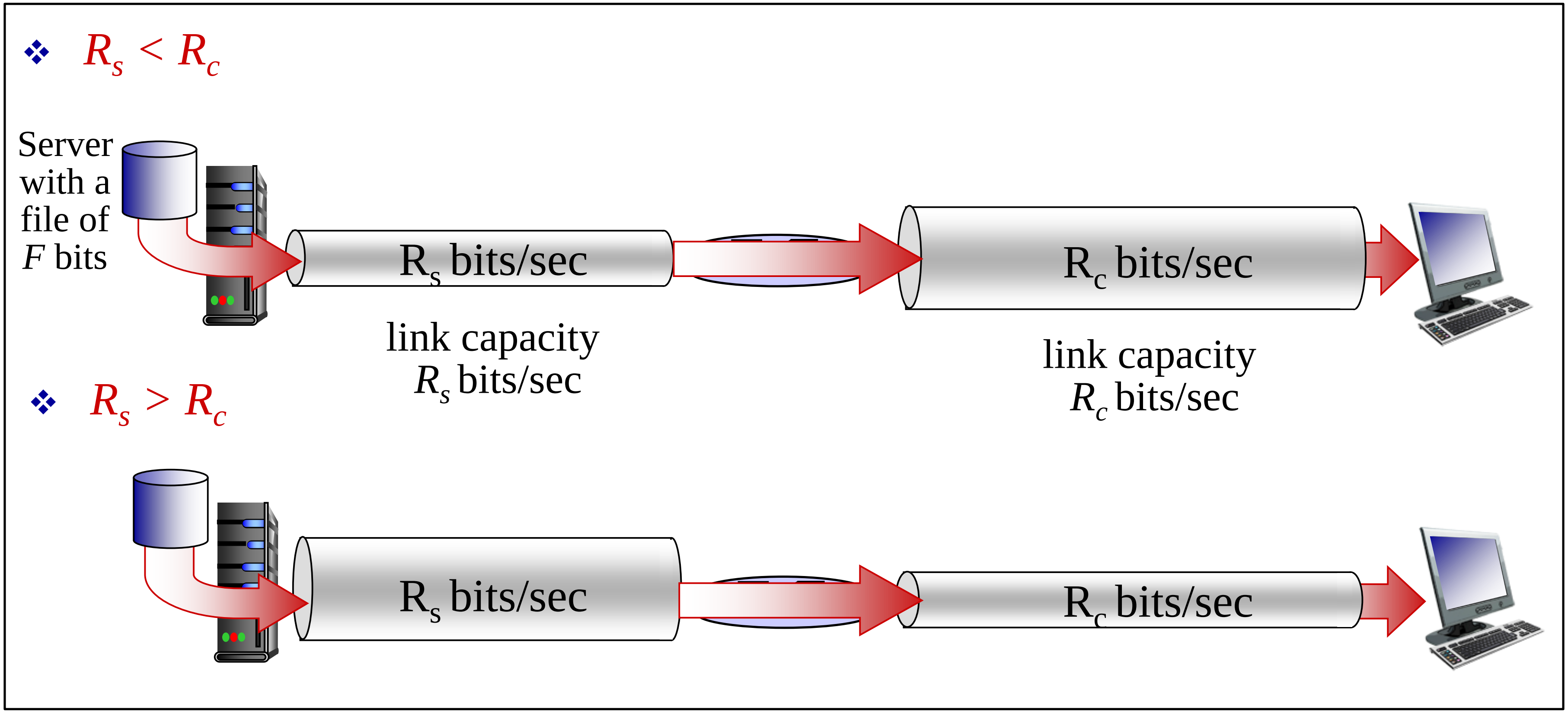
La/R ~ 0

La/R -> 1

- When *La/R* ~ 0, queue size decreases, and so queuing delay approaches zero
- When *La/R* -> 1, queue size increases without bound, and so queuing delay approaches infinity
- Queuing delay increases exponentially
  - Small increment in traffic intensity provide larger increment in queuing delay

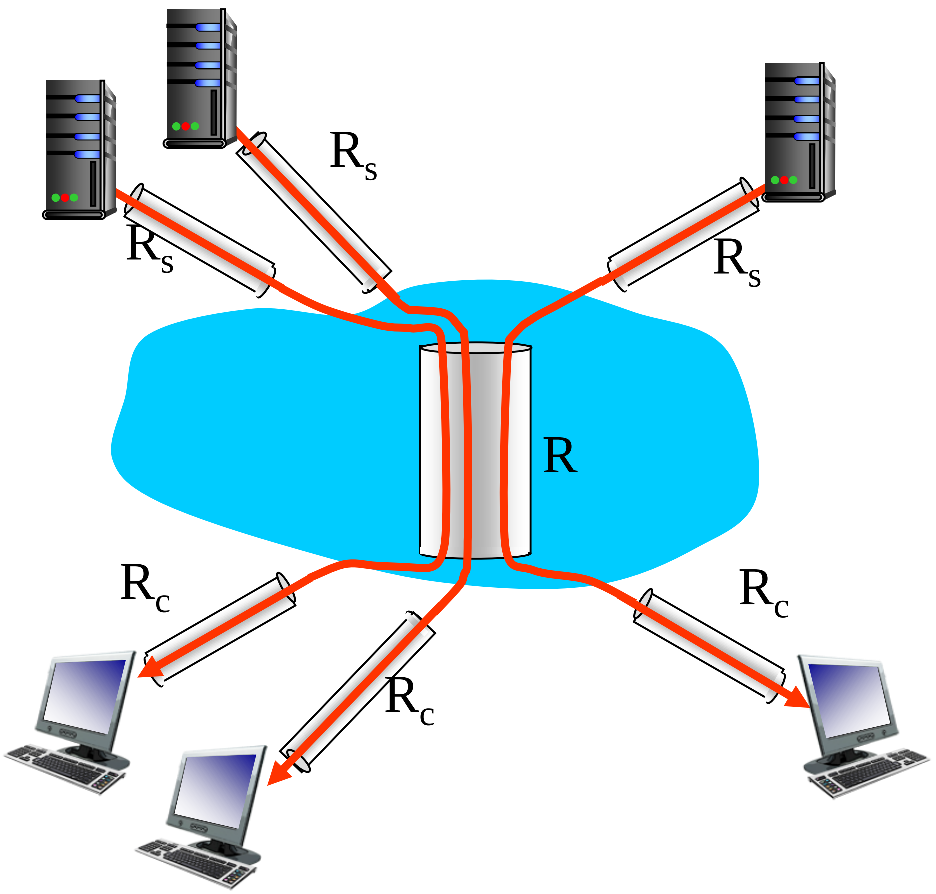
- **Packet Loss**
  - Packet arrive at a full queue will cause packet drop
    - Lost packet may be retransmitted
- **Throughput**
  - Rate (bits/seconds) at which bits are transferred between source host and destination host
  - Two types
    - **Instantaneous throughput**
      - Rate at a given point in time
    - **Average throughput**
      - Rate over a longer period of time

- **Bottleneck link**
  - Link on end-to-end path that constraints end-to-end throughput
  - What is the bottleneck bandwidth in each of the following scenarios?
    - min{ R_C , R_S }
  - What is the end-to-end delay in each of the following scenarios?



Answer: F / min{ R_C , R_S }

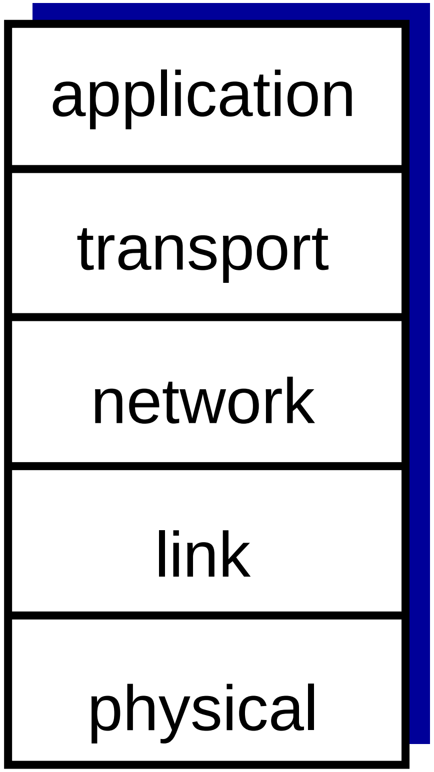
- **Internet**
  - What is the end-to-end delay in the following scenario?



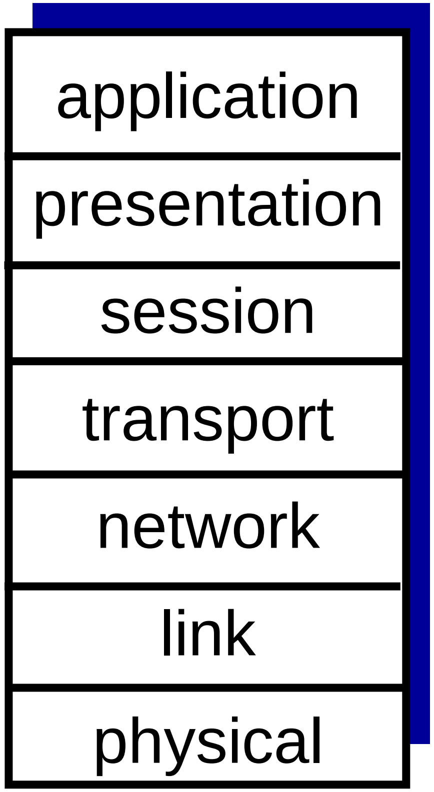
Answer: For a particular connection, the end-to-end delay is *F* / min{ R_C , R_S }. This is because, in internet, $R \gg R_s$ and $R \gg R_c$, and so the bottleneck link occur at access network

1.5 Protocol Layers and Their Service Models

- Protocol stack
  - Two types
    - **Internet Protocol Stack**
    - **ISO Open Systems Interconnection (OSI) Reference Model**
- Each layer
  - Perform certain actions
  - Use services of the layer directly below it
- Layering
  - Divide a complex system into layers
  - Advantage
    - Can maintain and update each layer without affecting the entire system
  - Disadvantage
    - Similar functions in more than one layer
      - E.g.: error recovery in *link layer* and *network layer*



Internet Protocol Stack



ISO Open Systems Interconnection (OSI) Reference Model

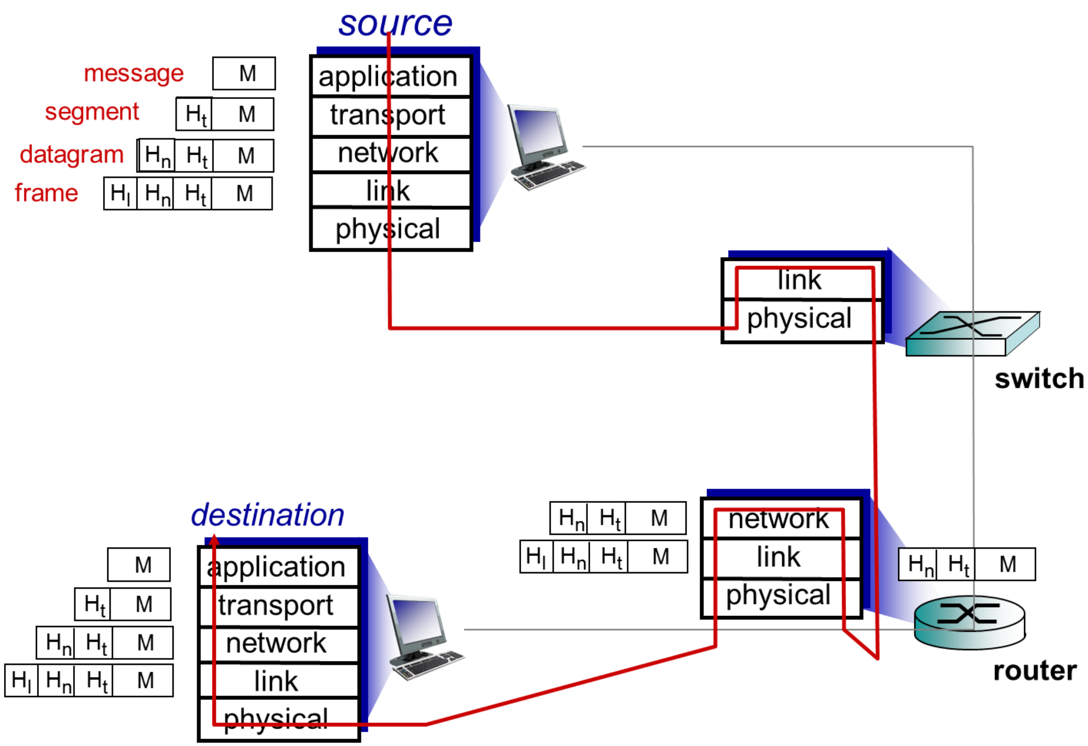
1.5 Layered Architecture

Layer	Packet is called	Functions
Application Layer	Message	•Support network applications •Provide Domain Name System (DNS) •Translate address (e.g., www.ietf.org to 32-bit address) •Examples: HTTP, email
Transport Layer	Segment	•Break a long message into shorter segment •Reduce source host transmission rate during congestion •Examples: transmission control protocol (TCP), user datagram protocol (UDP)
Network Layer	Datagram	•Determine routes between source host and destination host •Example: IP Protocol
Link Layer (Ethernet, WiFi)	Frame	•Transmit frame from a transmitting host to a receiving host over one link •Example: Ethernet, WiFi
Physical Layer	Bit	•Transmit bits on physical media (e.g., wireless, fiber optic)

Question

1. Which is more popular: internet protocol stack or OSI reference model?
2. Which layer performs tasks carried out by the presentation and session layers in the absence of those layers in the internet protocol stack?

1.5 Encapsulation



- Packet switch
  - Link-layer switch
    - Used in access networks
    - Consist layer 1 and 2
  - Router
    - Used in core networks
    - Consist layer 1, 2 and 3

Question: Why?

- Encapsulation
  - At each layer, a packet consist
    - Header
    - Payload (a packet from the upper layer)
- E.g:
  - Segment = Message + Header of Transport Layer
  - Datagram = Segment + Header of Network Layer
  - Frame = Datagram + Header of Link Layer