CS 348
Computer Networks
Lec 7

Spring 2020 IIT Goa

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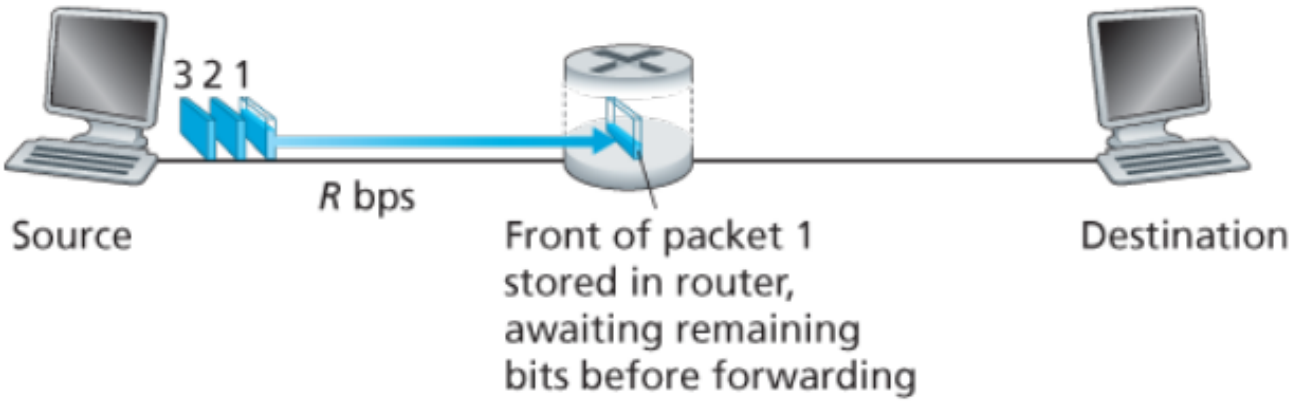
Disclaimer: These slides are adapted from Computer Networking: A Top-down Approach by Kurose & Ross, 7th ed. and lecture slides of cs 168-2020 (http://cs168.io/) by Prof. Sylvia Ratnasamy

Questions

- How do packet-switched networks work?
- How do we understand and analyze the **Performance** of packet-switched networks?
- Why does the Internet use **Packet Switching**? What are the alternatives?

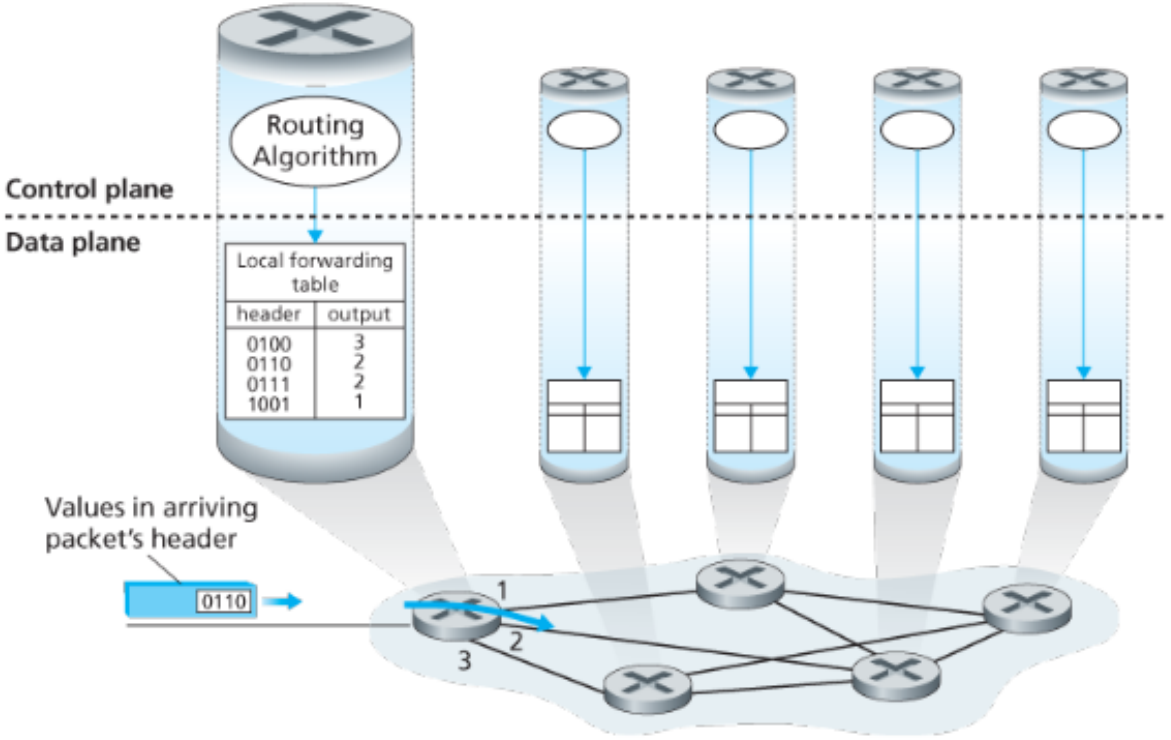
Recap: Store-and-Forward

- A packet switch (Router/Switch) must **receive (buffer) the entire packet** before it can begin to transmit the packet onto the next link.



A Router forwards Packets

based on its destination address
by consulting a forwarding table



Some Terms

- **Latency (same as Delay)**: How much time it takes for something
  - Example: “Transmission Latency for the packet across the link is 10 ms”
- **Bandwidth** : Maximum number of bits that can be sent or received per unit time (bits per second)
  - Example: “The bandwidth of this link is 10 Mbps”
- **Throughput (same as Rate)**: Number of objects/packets/jobs per unit time
  - Example: “The effective throughput between the end-hosts is 10 Kbps”
- **Bottleneck:** The component of a system which is currently limiting the overall performance
  - Example: “The bottleneck link in the system is this copper cable”

“Bandwidth”

- **How CS people use this term:**

  What is the maximum rate at which bits can be sent over this link (units: bits per second)

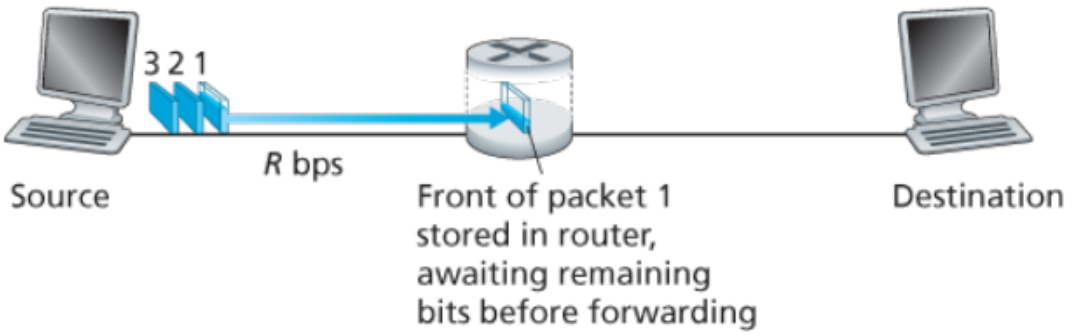
- **How EE people use this term:**

  What is the width of the frequency band that can pass through this medium (unit: Hertz)

Store-and-Forward Packet Switching

- **Transmission Rate** of the link = R bits per second
- **Packet Length** = L bits

  => It will take L/R seconds to transmit the entire packet over **one link**. (Thus **Transmission Delay** over **one link** is **L/R)**
- The Destination will receive the entire packet at time **2L/R**

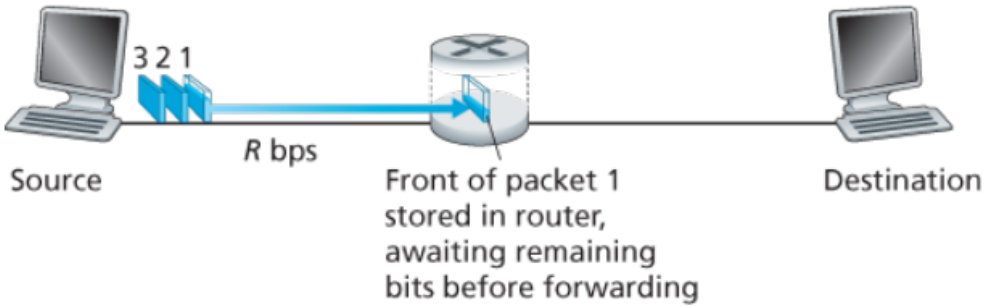


Store-and-Forward Packet Switching

- **Transmission Rate** of the link = R bits per second
- **Packet Length** = L bits

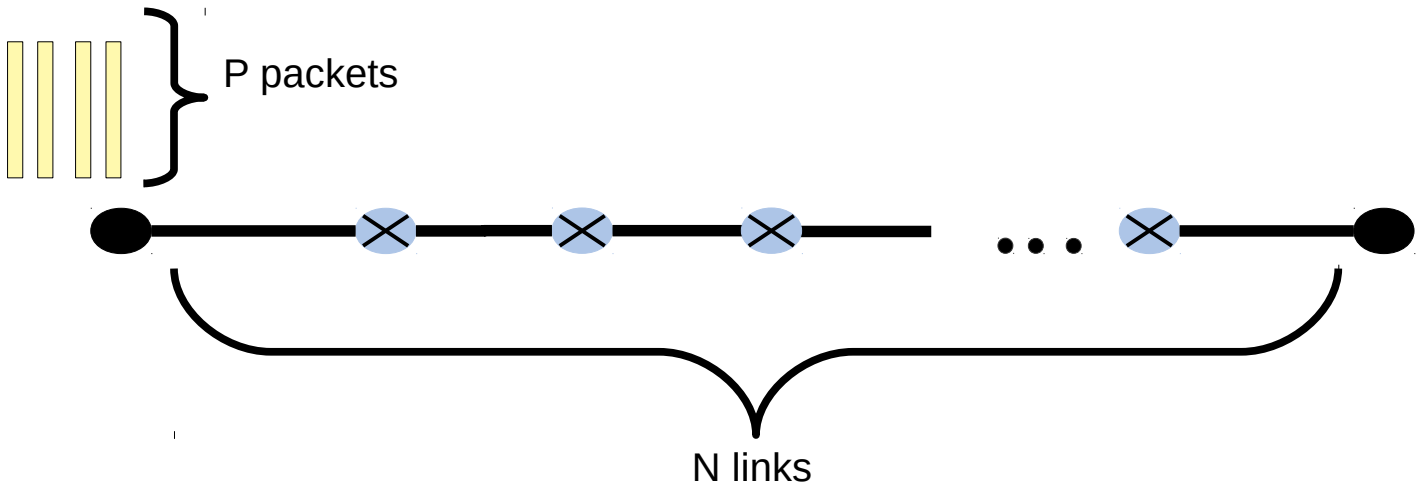
Need to send 3 packets of the same length.

After how much time will the Destination receive all 3 packets?



Store-and-Forward Packet Switching

- Consider a path consisting of **N** links and **N-1** routers. We need to send **P** packets. After how much time will the destination receive all packets?



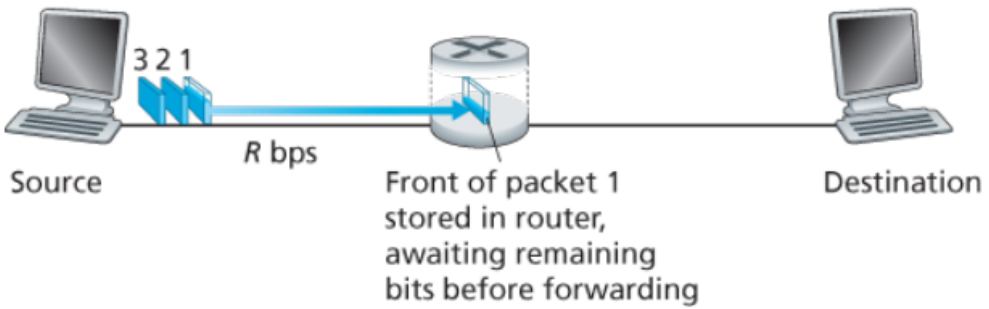
Store-and-Forward Packet Switching

- **Transmission Rate** of the link = R bits per second

  Need to send 3 packets.

  Lengths of the packtes: **L, 2L, L**

  After how much time will the Destination receive all 3 packets?

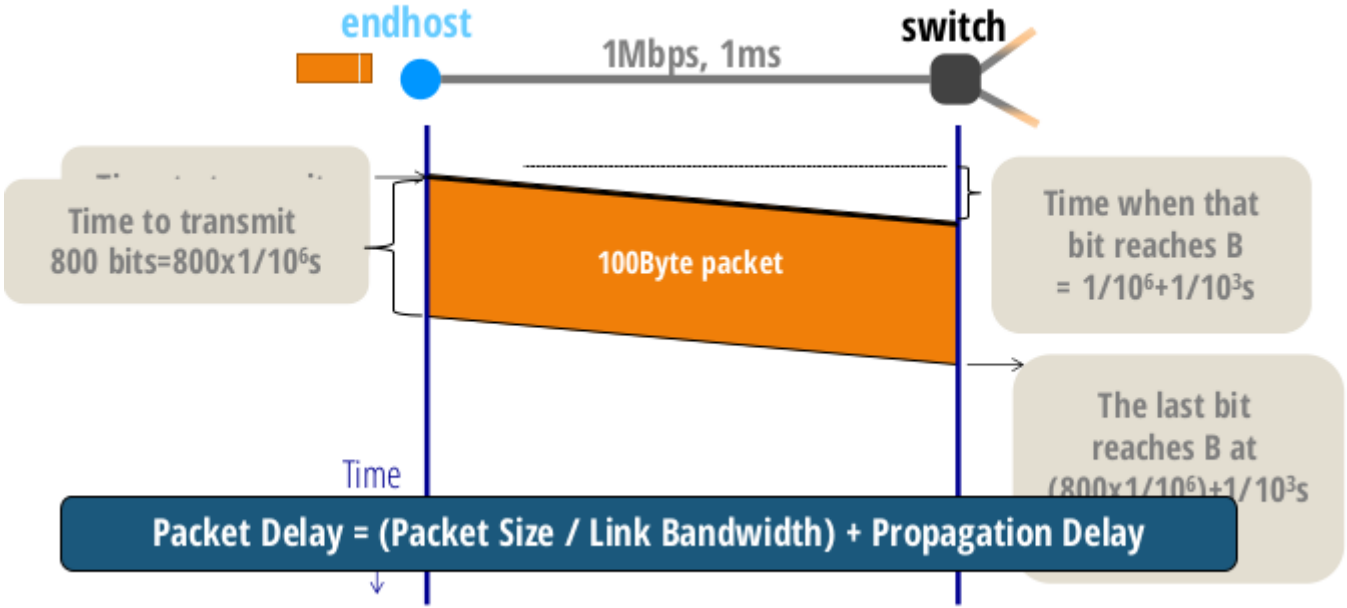


Store-and-Forward Packet Switching

- **So far we've considered only Transmission Delay.**
- **What about Propagation delay? :**
  - Time it takes for a bit to travel along a link. Proportional to the **length** of the link.
- Example:
  - Speed of a signal in a copper cable: approx 2*10^8 m/s
  - Speed of a signal in optical cables: approx 3 *10^8 m/s (speed of light)
  - **Propagation delay** in a **100m** copper cable = **distance/speed**= 0.5 us

Transmission and Propagation Delays

- **Transmission Rate** of the link (R) = 1Mbps
- Packet Length (L)=100 Bytes = 800 bits
- Propagation Delay = 1ms



Transmission and Propagation Delays

- **Transmission Delay:** Depends on the Transmission Rate (bandwidth) of the link and the size of the packet
  - Transmission Rate: R bits per second, Packet size: L bits

    => **Transmission delay = L/R**
- **Propagation Delay**: Depends on the Length of the wire/link/cable and propagation speed of the signal on that medium

    => **Propagation delay = (length of the wire)/(propagation speed)**

Transmission and Propagation Delays

- **Which Link is better?**
- **Link 1:** Bandwidth =10Mbps, Propagation delay = 10ms
- **Link 2:** Bandwidth =1Mbps, Propagation delay = 1ms

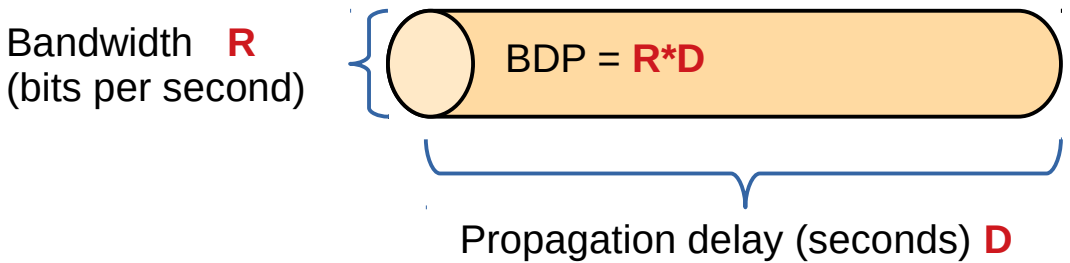
- Packet delay for a **10 B packet**:
  - Link1: about 10ms
  - Link2: about 1ms
- Packet delay for a **10,000 B packet**:
  - Link 1: about 18ms
  - Link 2: about 81 ms

Round-Trip Time (RTT)

- **RTT (also known as ping time) :** the time from the start of the transmission from the sender until a response packet is received back.
- **Affected by:**
  - Packet transmission time, propagation delay and processing time at the destination

RTT = 2* transmission delay + 2*propagation delay + processing delay

Bandwidth Delay Product (BDP)



BDP (unit: bits) = Bandwidth (bits per second) X Propagation delay (seconds)

How many bits can be “in flight” on the link at any given time

In some cases, BDP may be defined as **BDP= R * RTT** (Round Trip Time)

- Ref: https://en.wikipedia.org/wiki/Bandwidth-delay_product

Other sources of Delay

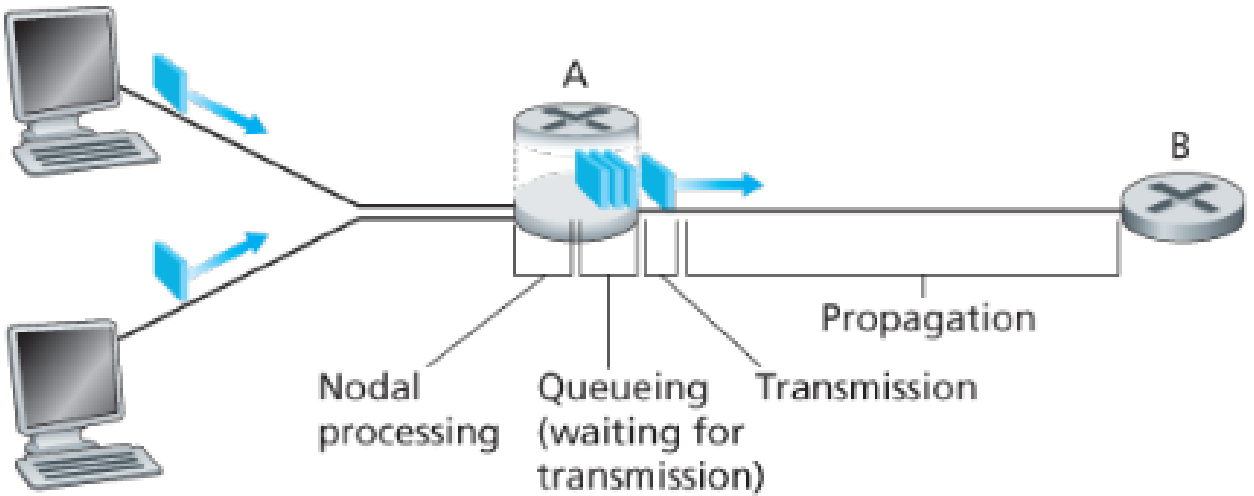


Figure 1.16 The nodal delay at router A

Sources of Delay

- Nodal Processing delay
- Queueing delay
- Transmission delay
- Propagation delay

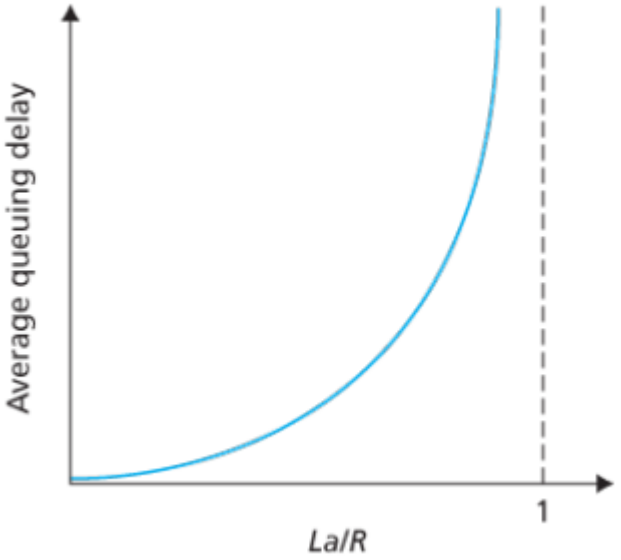
Total delay at a node is the sum of all above.

Queueing Delays and Packet Loss

- **If** the rate of arrival of packets is >= the rate at which they're leaving, the queue size will grow indefinitely!
- However, Routers have finite buffers. What happens when the buffer is full?
  - Incoming packets are simply discarded (**packet loss**)

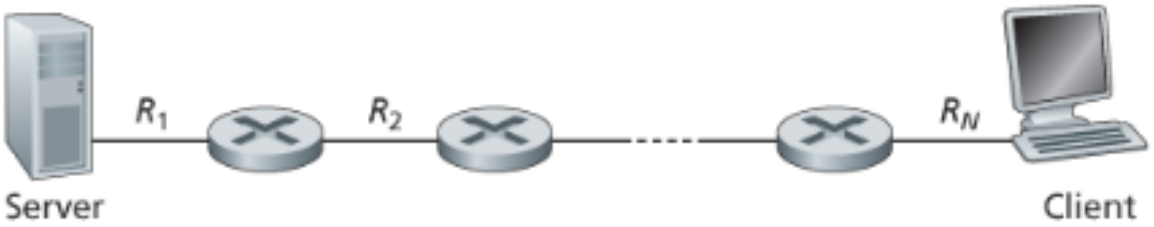
Queueing Delays and Packet Loss

- Let:
  - **a**: data arrival rate (bits per second)
  - **L/R**: Transmission rate at the output link (bits per second)



- **Traffic Intensity= arrival rate/service rate = La/R**

Throughput



What is the effective throughput between the Client and the Server?

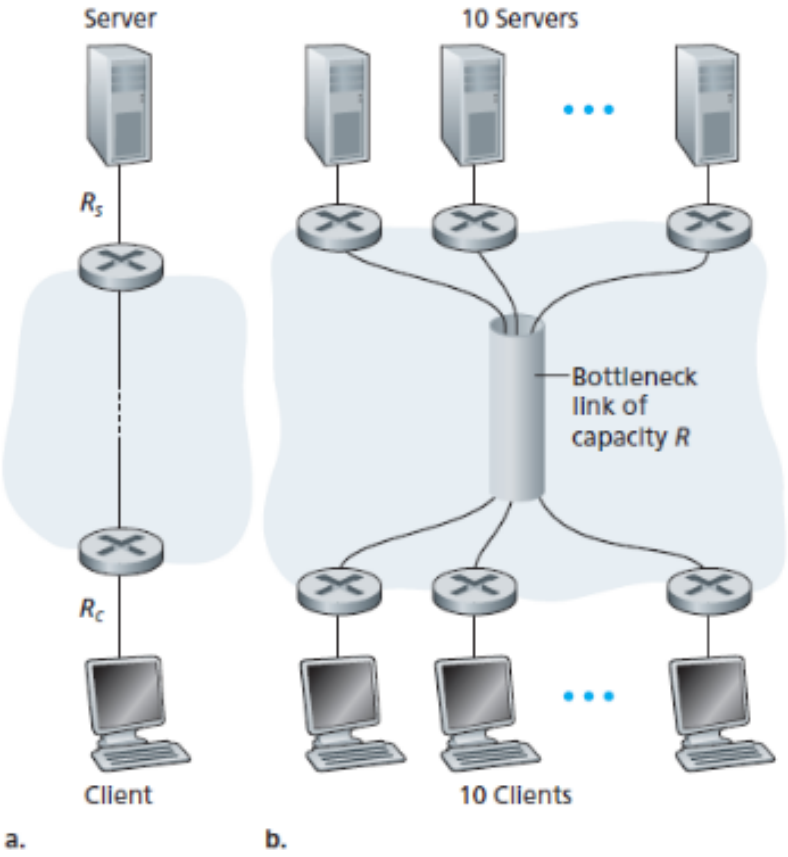
- Approximately: min{R1, R2, ..RN}
- The effective throughput is determined by the **Botteneck** link
- Typically, access networks are the bottleneck

Throughput: an Example

Suppose
Rs=2 Mbps,
Rc=1 Mbps,
R=5 Mbps,

the common link divides its transmission rate equally among the 10 downloads.

What is the End-to-end throughput for each download ?



Summary

- How packet switched networks operate:
  - Store-and-forward
  - Routing and Forwarding

- Some Performance Measures: Latency, Throughput, Bandwidth
- Sources of delays: Transmission, Propagation, Queueing, Processing
- How to analyze and approximate common performance measures of a network

Questions (Next Up)

- **Why does the Internet use Packet-switching ? How does it compare with circuit switching?**
- What is it’s history?

Questions (Going forward)

- How are forwarding tables populated? How/when do routers update the forwarding tables when some link goes down?
- What happens if there are Malicious routers?
- What exactly is contained inside the header in IP datagrams or TCP segements?
- How does TCP provide reliable transmission over an unreliable channel?
- How does TCP perform congestion control?
- What are some Application-layer protocols? How do they work?

Reference

- Kurose and Ross, Sections 1.3 and 1.4
- https://en.wikipedia.org/wiki/Transmission_time