



Computer Networks and the Internet

- Overview -

Kyunghan Lee

Networked Computing Lab (NXC Lab)

Department of Electrical and Computer Engineering

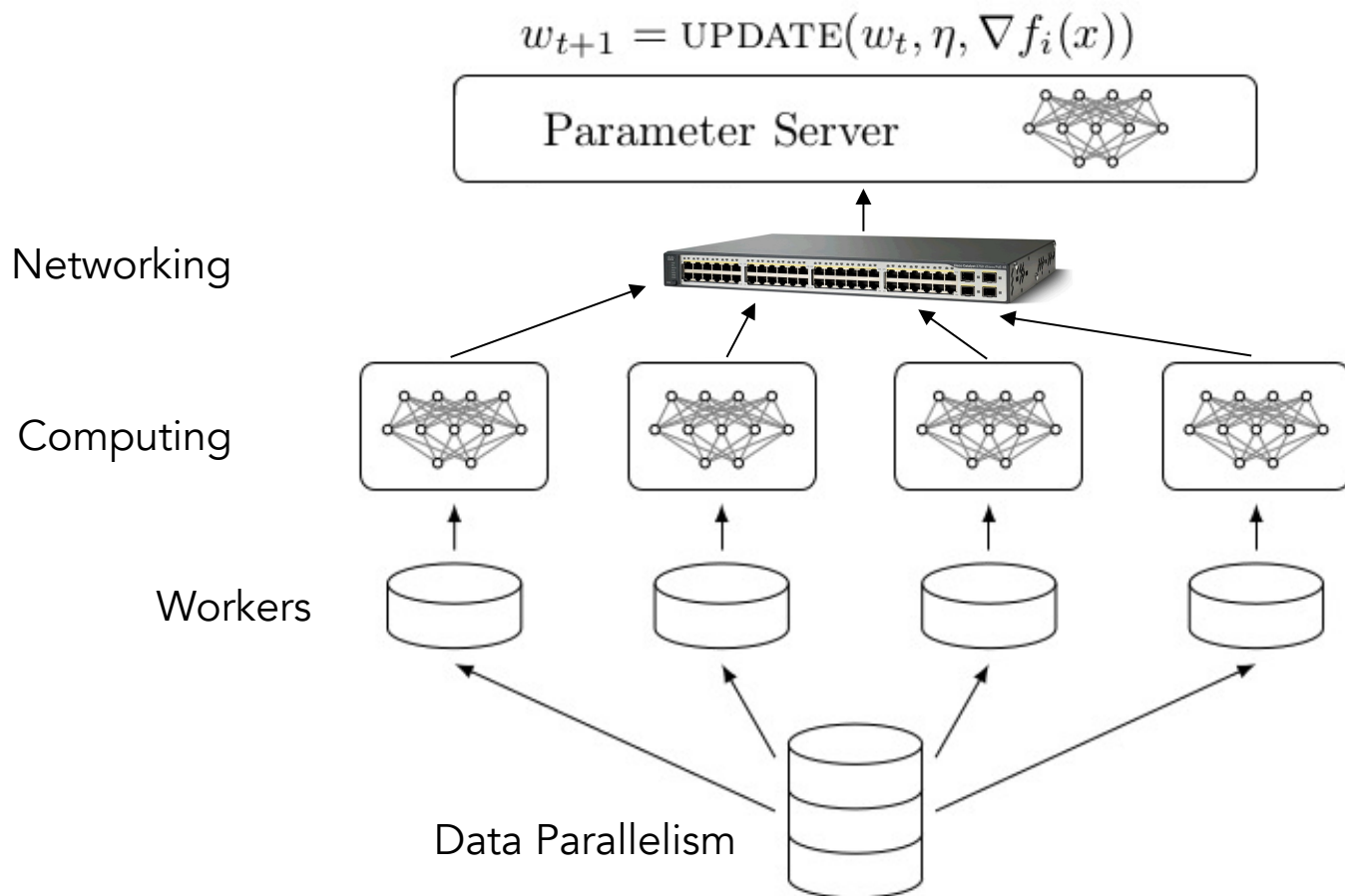
Seoul National University

<https://nxc.snu.ac.kr>

kyunghanlee@snu.ac.kr



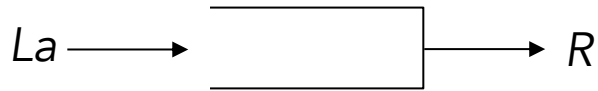
Why Should We Learn Networking?



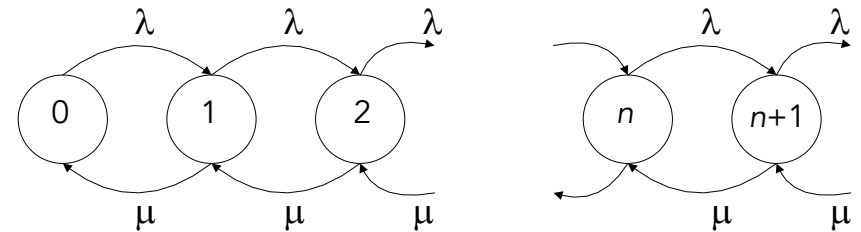
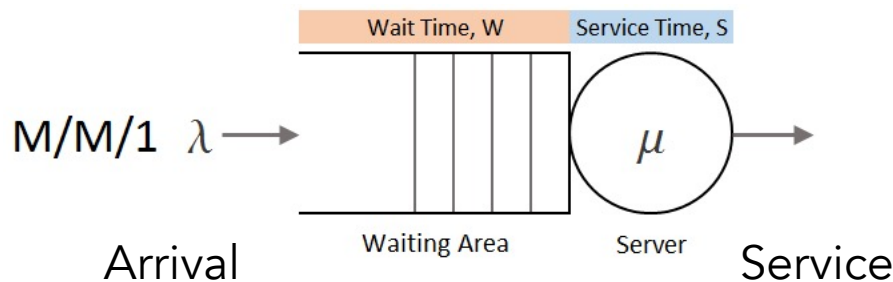
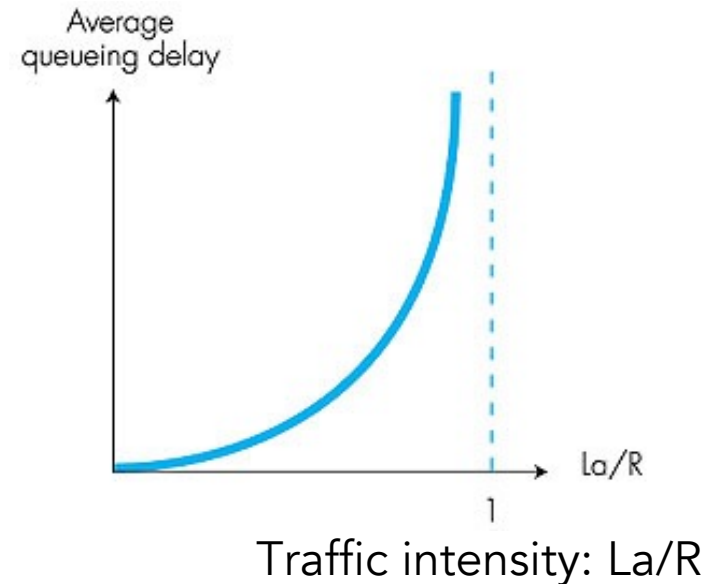
<https://joerihermans.com/ramblings/distributed-deep-learning-part-1-an-introduction/>

Introduction to Data Communication Networks, M2608.001200, 2021 FALL
SEOUL NATIONAL UNIVERSITY

Queueing and Delay (and Throughput)



- R : link bandwidth (bps)
- L : packet length (bits)
- a : average packet arrival rate
- $La/R \sim 0$: avg. queueing delay small
- $La/R < 1$: avg. queueing delay large
- $La/R > 1$: more “work” arriving than can be serviced, average delay infinite!

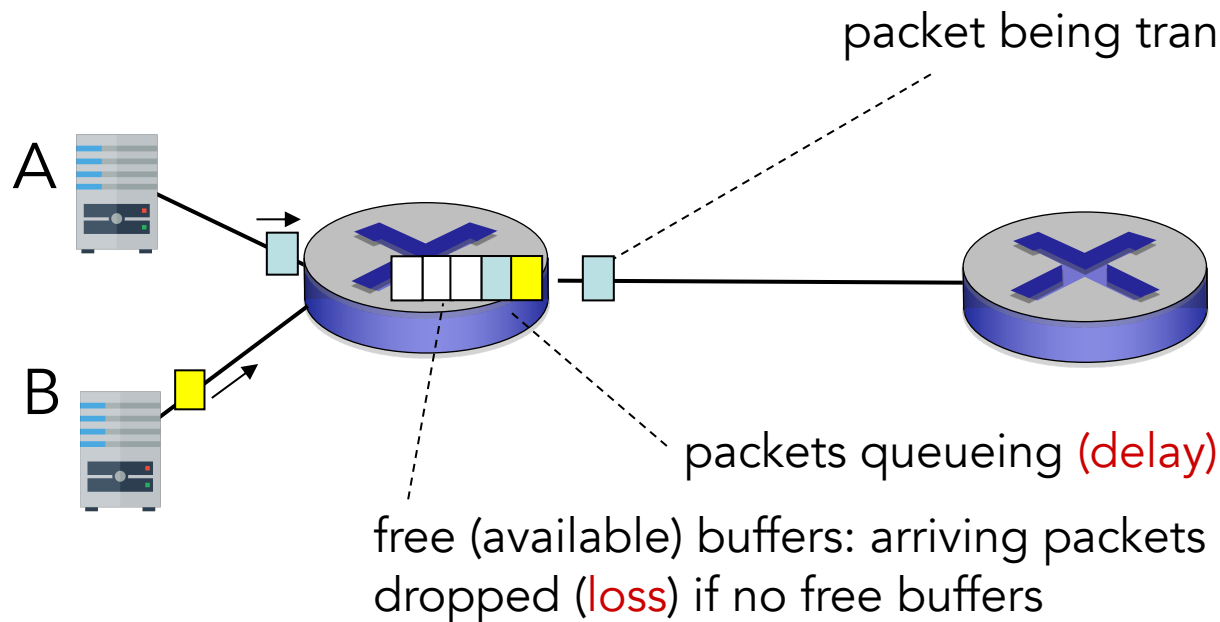


Expected # of packets in the queue: $E(N) = \sum_{n=1}^{\infty} nP_n$

Loss and Delay

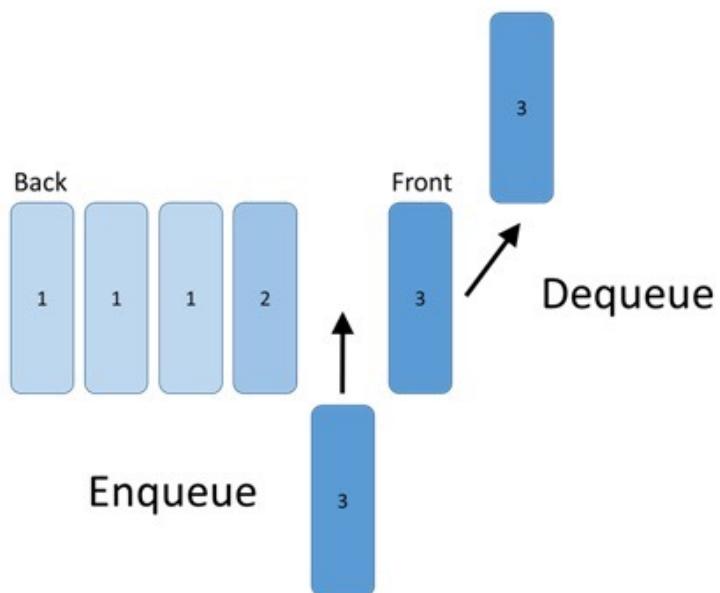
□ Packets *queue* in router buffers

- Packet arrival rate to link (temporarily) exceeds output link capacity
- Packets queue, wait for turn
- Packets are dropped in the tail part (drop-tail queue)

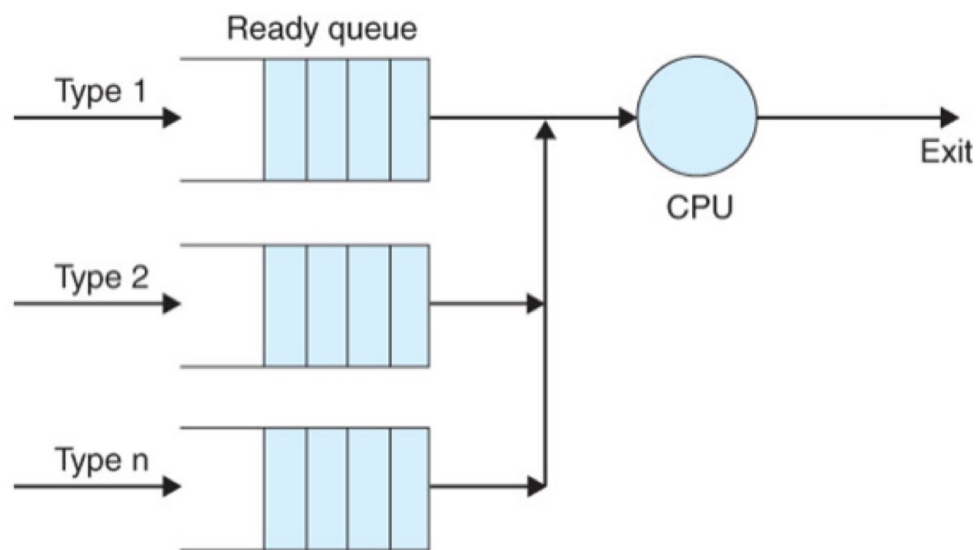


Priority Queue

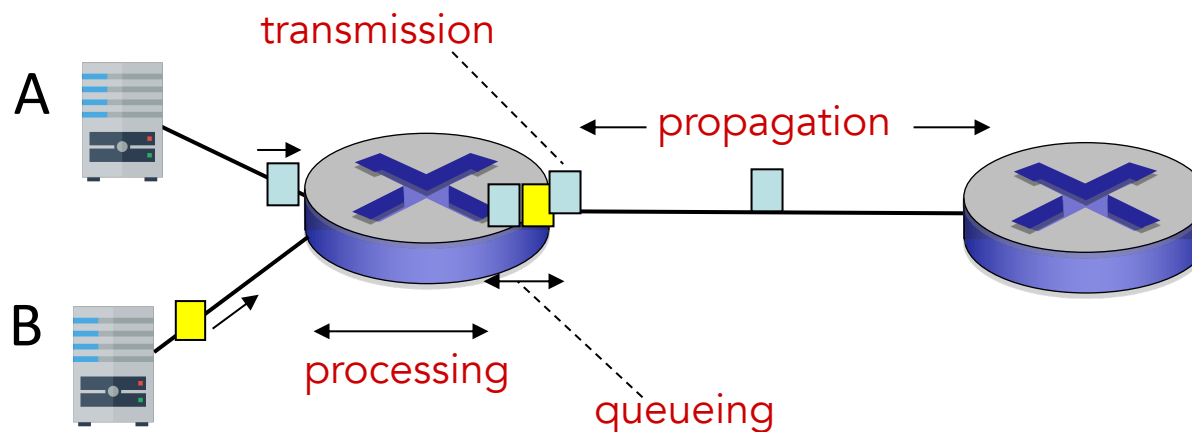
Priority Queue



Multi Queue with Preemption



Queueing and Delay (and Throughput)



$$d_{e2e} = d_{\text{proc}} + d_{\text{queue}} + d_{\text{trans}} + d_{\text{prop}}$$

Nearly deterministic in L2/L3/L4 switches

Variable in L7 switch

2×10^8 m/s

in copper cable & optical fiber

Increases in multi-hop (store-and-forward)

Largely unpredictable

Real Internet Delay

ping www.google.com

```

PING www.google.com (172.217.160.68): 56 data bytes
64 bytes from 172.217.160.68: icmp_seq=0 ttl=44 time=71.642 ms
64 bytes from 172.217.160.68: icmp_seq=1 ttl=44 time=82.027 ms
64 bytes from 172.217.160.68: icmp_seq=2 ttl=44 time=67.633 ms
64 bytes from 172.217.160.68: icmp_seq=3 ttl=44 time=67.492 ms
64 bytes from 172.217.160.68: icmp_seq=4 ttl=44 time=80.396 ms
64 bytes from 172.217.160.68: icmp_seq=5 ttl=44 time=83.657 ms

```

traceroute www.google.com

```

traceroute to www.google.com (172.217.160.68), 64 hops max, 52 byte packets
 1  router.asus.com (192.168.2.1)  2.360 ms  1.030 ms  1.131 ms
 2  router.asus.com (192.168.1.1)  1.624 ms  4.172 ms  1.429 ms
 3  * * *
 4  10.240.88.237 (10.240.88.237)  4.098 ms  3.047 ms *
 5  10.204.92.105 (10.204.92.105)  2.368 ms  4.382 ms  3.328 ms
 6  1.213.64.165 (1.213.64.165)  2.583 ms
    1.208.64.161 (1.208.64.161)  2.580 ms
    1.213.64.165 (1.213.64.165)  2.552 ms
 7  1.214.58.177 (1.214.58.177)  9.980 ms
    1.209.58.181 (1.209.58.181)  9.874 ms
    1.214.58.205 (1.214.58.205)  9.172 ms
 8  1.208.104.61 (1.208.104.61)  10.285 ms
    1.213.104.61 (1.213.104.61)  9.528 ms  10.819 ms
 9  1.208.148.141 (1.208.148.141)  12.972 ms  10.580 ms  8.417 ms
10  203.233.117.81 (203.233.117.81)  10.343 ms
    203.248.208.229 (203.248.208.229)  18.325 ms
    210.120.117.113 (210.120.117.113)  9.409 ms

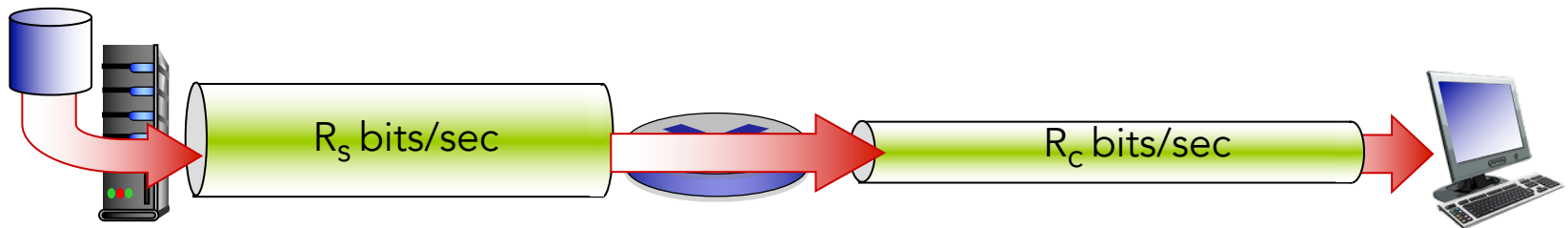
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Hop-by-hop ping



Throughput and Bottleneck

- *Throughput*: rate (bits/time unit) at which bits transferred between sender/receiver
 - *instantaneous*: rate at given point in time
 - *average*: rate over longer period of time
- $R_s > R_c$ What is average end-to-end throughput?

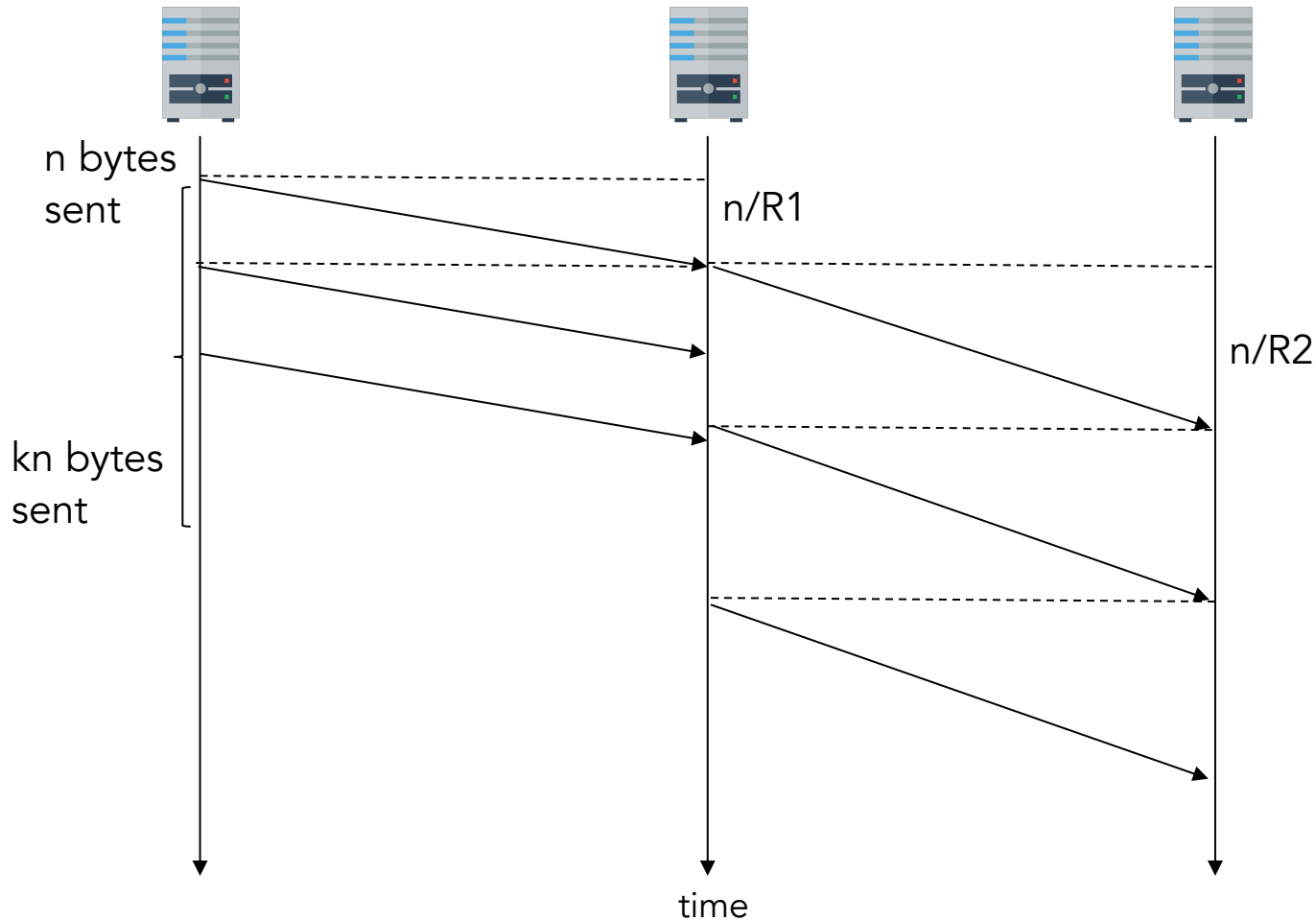


□ *Bottleneck link*

- link on e2e path that constrains e2e throughput

Throughput (Illustrated)

What would happen here?

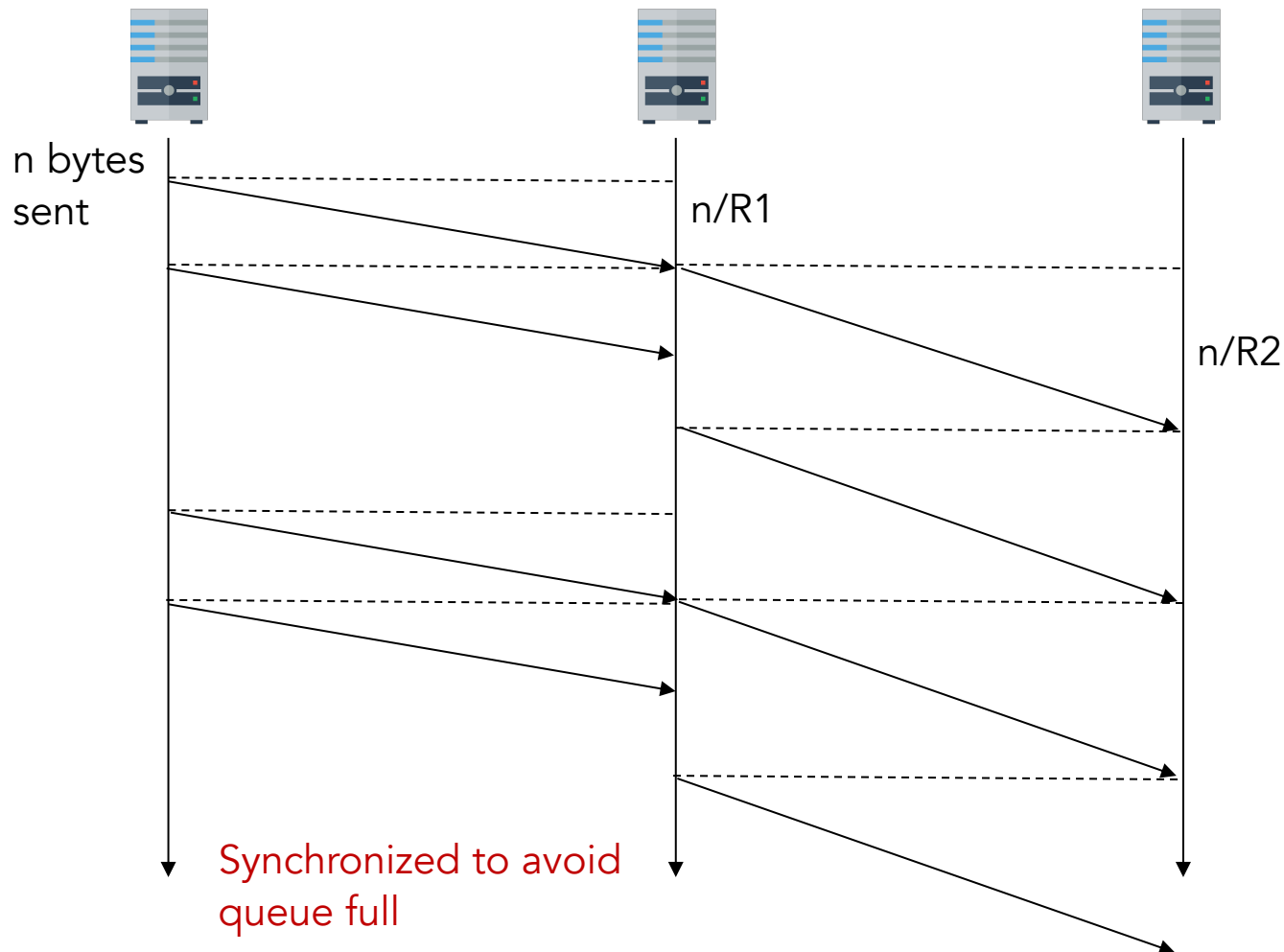


When $R1 > R2$

$$\begin{aligned} \text{Throughput} &= n / (n/R1 + n/R2) \\ &= R1R2 / (R1 + R2) \\ &?? \end{aligned}$$

$$\begin{aligned} \text{Throughput} &= kn / (n/R1 + kn/R2) \\ &= kR1R2 / (kR1 + R2) \\ &?? \end{aligned}$$

Throughput (Illustrated again)

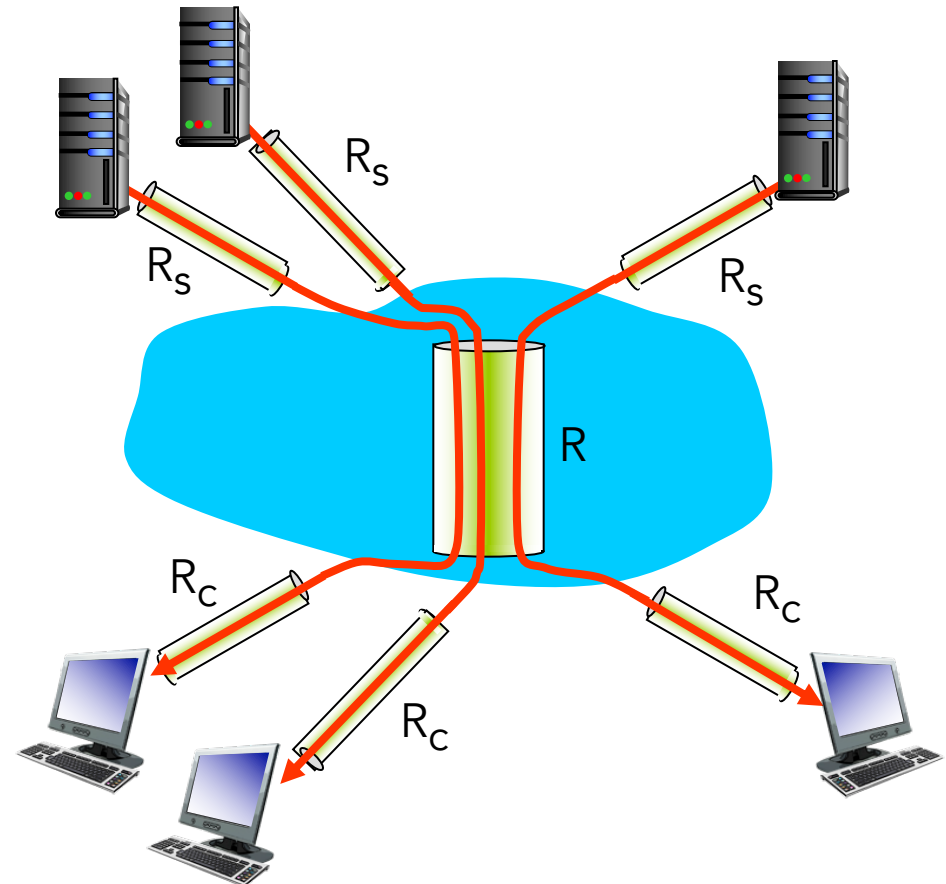


$$\begin{aligned} \text{Throughput} &= kn / (n/R1 + kn/R2) \\ &= kR1R2 / (kR1 + R2) \\ &?? \end{aligned}$$

What if $R1 < R2$?

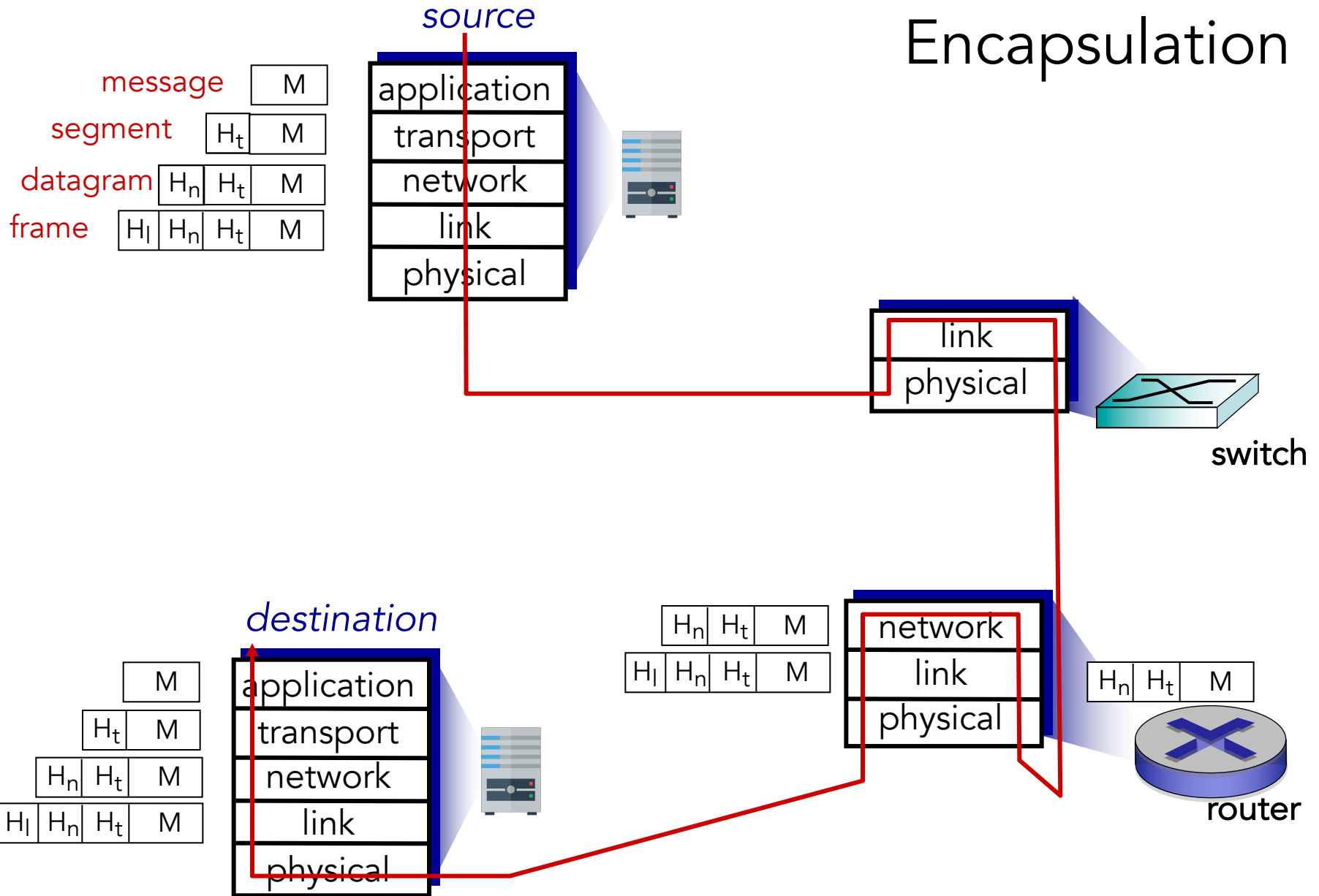
Throughput and Bottleneck

- Per-connection end-end throughput:
 $\min(R_c, R_s, R/10)$
- In practice: R_c or R_s is often bottleneck

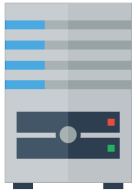
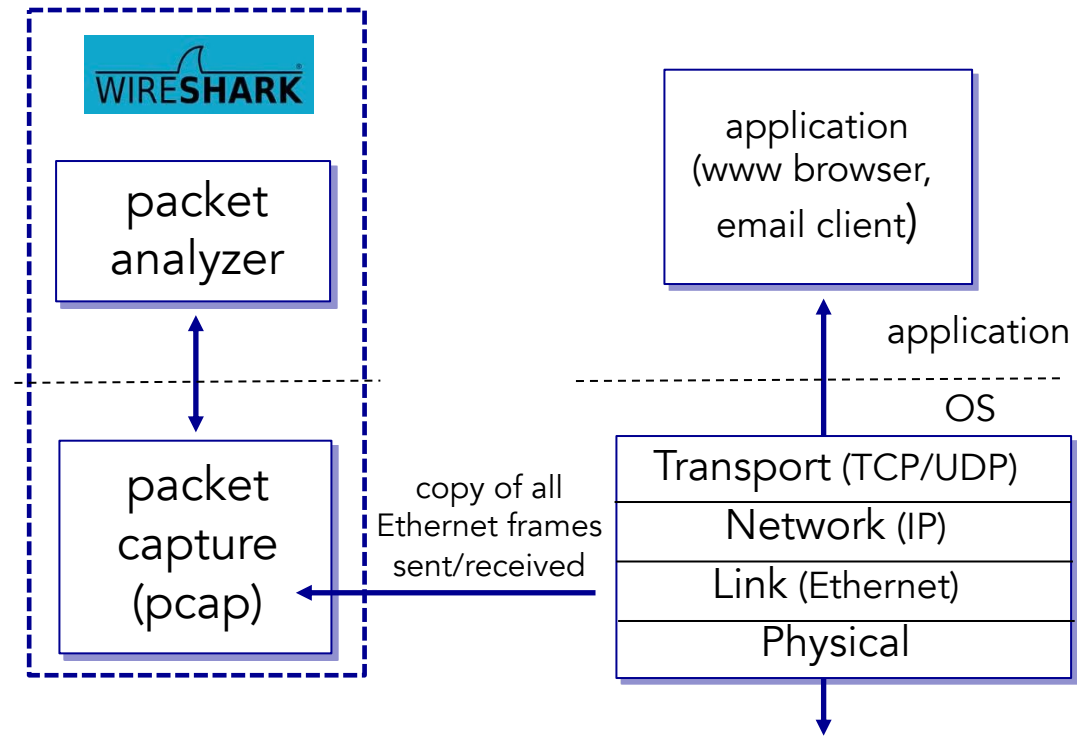


10 connections (fairly) share backbone
bottleneck link R bits/sec

Encapsulation



Packet Capturing



Internet History

(1962-1972: Early Packet-Switching Principles)

- 1961: Kleinrock - queueing theory shows effectiveness of packet-switching



- 1964: Baran - packet-switching in military nets
- 1967: ARPAnet conceived by Advanced Research Projects Agency
- 1969: first ARPAnet node operational (with 4 nodes)

- 1972:

- ARPAnet public demo
- NCP (Network Control Protocol) first host-host protocol
- first e-mail program
- ARPAnet has 15 nodes



The ARPANET in December 1969



Internet History

(1972-1980: Internetworking, new and proprietary nets)

- 1970: ALOHAnet satellite network in Hawaii
- 1974: Cerf and Kahn - architecture for interconnecting networks
- 1976: Ethernet at Xerox PARC
- late70s: proprietary architectures: DECnet, SNA, XNA
- late 70s: switching fixed length packets (ATM precursor)
- 1979: ARPAnet has 200 nodes

Cerf and Kahn's internetworking principles:

- minimalism, autonomy - no internal changes required to interconnect networks
- best effort service model
- stateless routers
- decentralized control

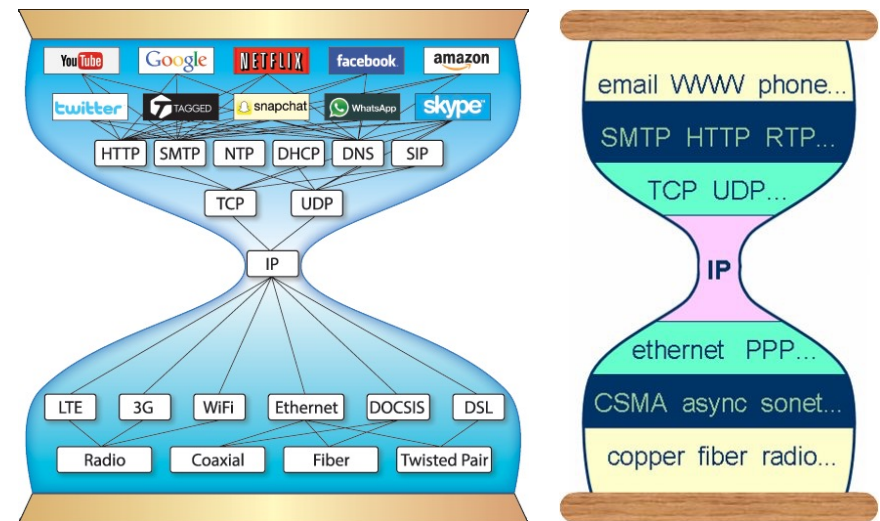
define today's Internet architecture



Internet History

(1980-1990: new protocols, a proliferation of networks)

- 1983: deployment of TCP/IP
 - 1982: smtp e-mail protocol defined
 - 1983: DNS defined for name-to-IP-address translation
 - 1985: FTP protocol defined
 - 1988: TCP congestion control
- new national networks: CSnet, BITnet, NSFnet, Minitel
 - 100,000 hosts connected to confederation of networks



Drawing from Johann Schleier-Smith



Internet History

(1990s, 2000s: commercialization, the Web, new apps)

- Early 1990s: ARPAnet decommissioned
- 1991: NSF lifts restrictions on commercial use of NSFnet (decommissioned, 1995)
- Early 1990s : Web
 - hypertext [Bush 1945, Nelson 1960s]
 - 1990: HTML, HTTP by Berners-Lee
 - 1994: Mosaic, later Netscape
 - late 1990s: commercialization of the Web
- Late 1990s – 2000s:
 - more killer apps: instant messaging, P2P file sharing
 - network security to forefront
 - est. 50 million host, 100 million+ users
 - backbone links running at Gbps



Internet History (2005-present)

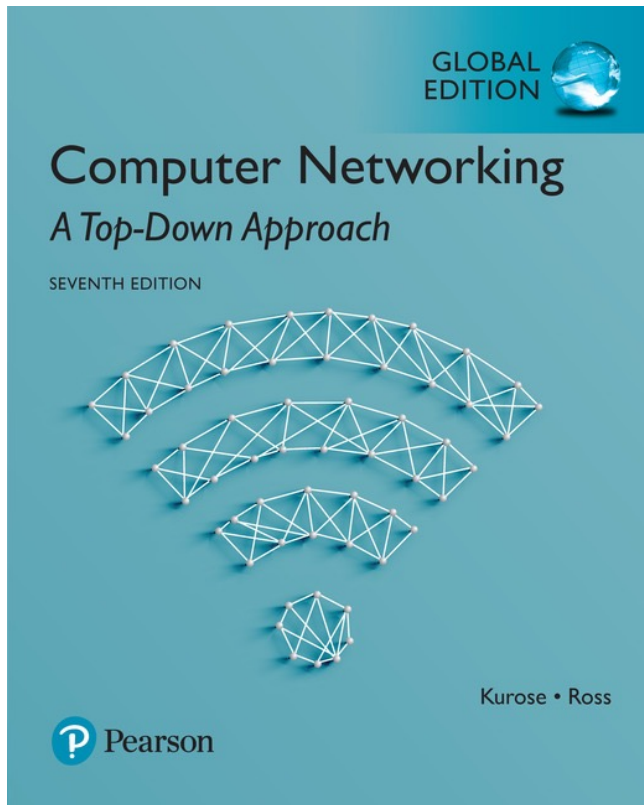
- ~5B devices attached to Internet (2016)
 - smartphones and tablets
- Aggressive deployment of broadband access
- Increasing ubiquity of high-speed wireless access
- Emergence of online social networks:
 - Facebook: ~ one billion users
- Service providers (Google, Microsoft) create their own networks
 - bypass Internet, providing “instantaneous” access to search, video content, email, etc.
- e-commerce, universities, enterprises running their services in “cloud” (e.g., Amazon EC2)



Reading Assignment #2 – Chapter 2

Quiz #1: 9/30 (covering chapters 1 and 2, 4-5 questions, 40 mins, Lecture will follow)

Sample question: What are the advantages and the disadvantages of packet-switched networks over circuit-switched networks?



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