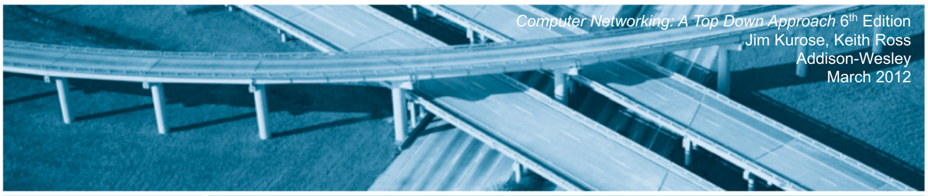


Computer Networking: A Top Down Approach 6th Edition
Jim Kurose, Keith Ross
Addison-Wesley
March 2012

CHAPTER 1

Computer Networks and the Internet

CHAPTER 1

Computer Networks and the Internet

our goal:

- get "feel" and terminology
- more depth, detail *later* in course
- approach:
  - use Internet as example

overview:

- what's the Internet?
- what's a protocol?
- network edge; hosts, access network, physical media
- network core: packet/circuit switching, Internet structure
- performance: loss, delay, throughput
- security
- protocol layers, service models
- history

1-2

CHAPTER 1

Computer Networks and the Internet

Roadmap:

1-3

CHAPTER 1

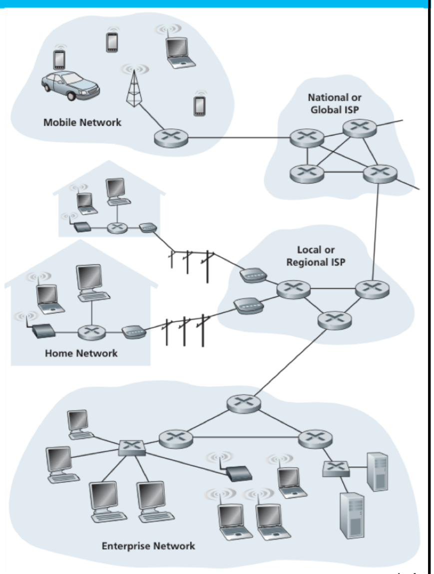
(1.1) What's the Internet?

"Nuts and Bolts" view

- millions of connected computing devices:
  - *hosts* = *end systems*
  - running *network apps*

- *communication links*
  - fiber, copper, radio, satellite
  - transmission rate: ________________

- *Packet switches:* forward packets (chunks of data)
  - ________ and ________

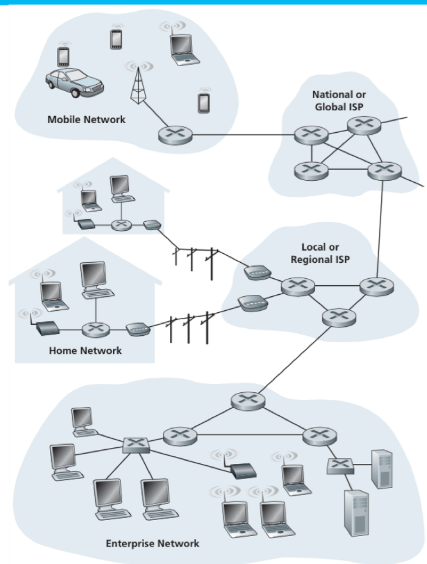


1-4

CHAPTER 1

A Service view

- *Infrastructure that provides services to applications:*
  - Web, VoIP, email, games, e-commerce, social networks, …
- *provides programming interface to apps*
  - hooks that allow sending and receiving application programs to "connect" to Internet
  - provides service options, analogous to postal service
- *Internet: "network of networks"*
  - Interconnected ISPs



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CHAPTER 1

- One of the well known ISP (Internet Service Provider) in Malaysia is TM.
- Malaysia ISPs:

TM, P1 wimax, celcom, DiGi, JARING, REDtone 4G, maxis, U mobile

1-6

CHAPTER 1

Examples:
"Fun" Internet Appliances

Internet refrigerator

IP picture frame
http://www.ceiva.com/

Tweet-a-watt: monitor energy use

Web-enabled toaster + weather forecaster

Slingbox: watch, control cable TV remotely

Internet phones

1-7

CHAPTER 1

What's a Protocol?

Human protocols:

- "What's the time?"
- "I have a question"
- Introductions
  - specific messages sent
  - specific actions taken when messages received, or other events

Network protocols:

- machines rather than humans
- all communication activity in Internet governed by protocols

__________ define format, order of messages sent and received among network entities, and actions taken on message transmission, receipt

Internet communication:
- *protocols* control sending, receiving of messages;
  e.g., TCP, IP, HTTP, Skype, 802.11
- *Internet standards*
  RFC: Request For Comments
  IETF: Internet Engineering Task Force

1-8

CHAPTER 1

What's a Protocol?

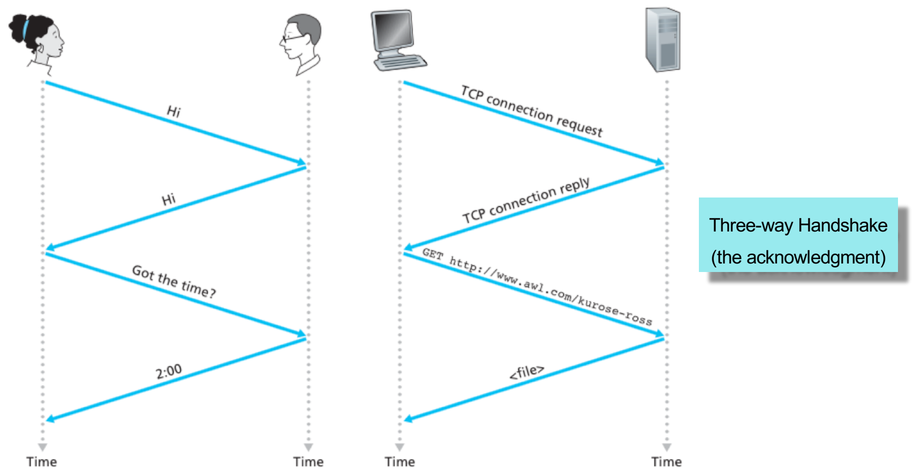


Figure: A human protocol and a computer network protocol

1-9

CHAPTER 1

(1.2) The Network Edge
Network structures

- *network edge:*
  - hosts: _______ and _______
  - servers often in data centers
- *access networks, physical media:*
  - **wired**, **wireless** communication links
- *network core:*
  - interconnected _______
  - network of networks

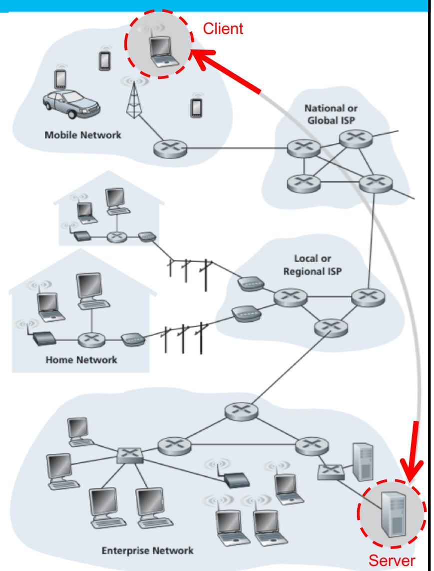


Figure: End-system interaction

1-10

CHAPTER 1

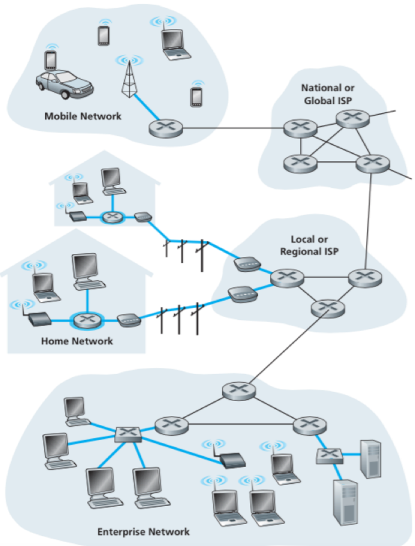
Access networks

Q: How to connect end systems to edge router?

- **residential** access networks
- **institutional** access networks (school, company)
- **mobile** access networks

Keep in mind:

- bandwidth (bits per second) of access network
- shared or dedicated?



Edge Router → first router

1-11

CHAPTER 1

Access networks

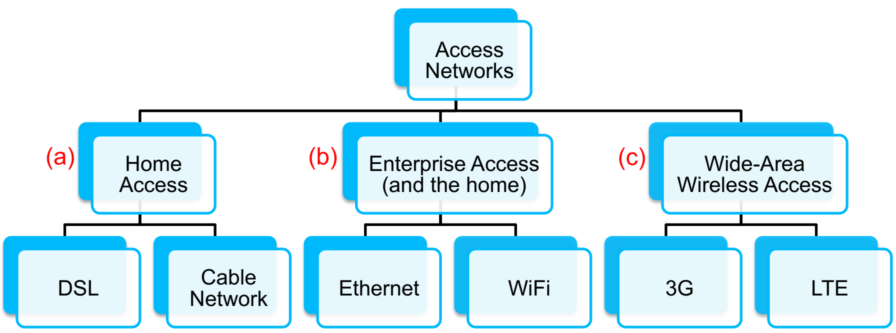


Figure: Several types of of access networks

DSL (Digital Subscriber Line)
3G (Third-Generation)
LTE (Long-Term Evolution)

1-12

CHAPTER 1

(a) Home Access

Digital Subscriber Line (DSL)

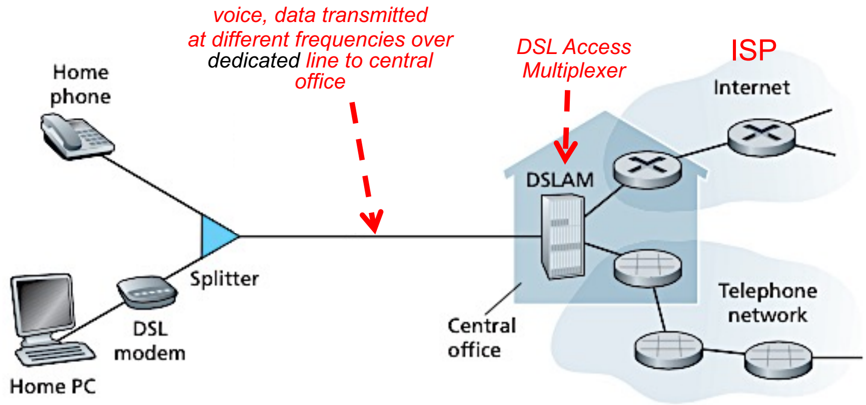


Figure: DSL Internet access

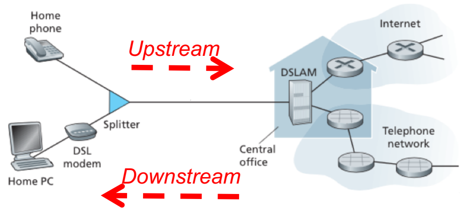
1-13

CHAPTER 1

(a) Home Access

Digital Subscriber Line (DSL)

- use *existing* telephone line to central office DSLAM



____ over DSL phone line goes to Internet

____ over DSL phone line goes to telephone network

- Transmission rates:
  - **Upstream** < 2.5 Mbps (typically < 1 Mbps)
  - **Downstream** < 24 Mbps (typically < 10 Mbps)

The access called ______________ since different upstream and downstream rates.

1-14

CHAPTER 1

(a) Home Access

Cable network

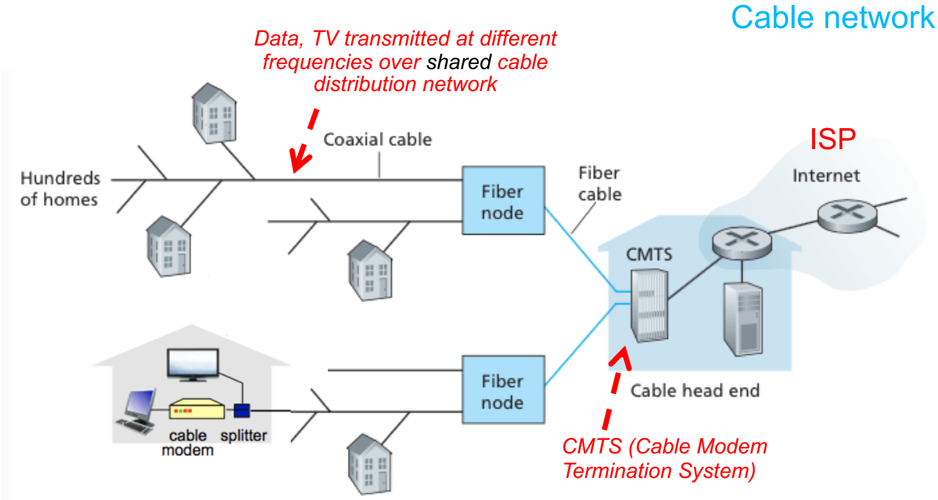


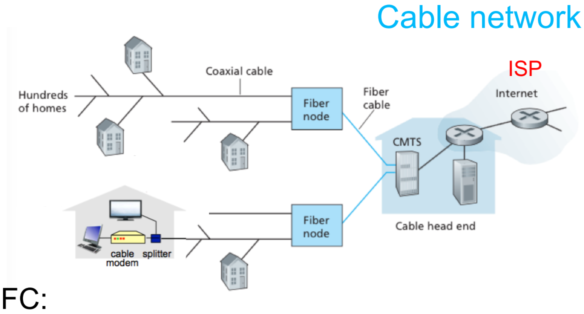
Figure: A Hybrid Fiber-Coaxial (HFC) access network

1-15

CHAPTER 1

(a) Home Access

Cable network



- Transmission rate for HFC:
  - **Upstream** 2 Mbps
  - **Downstream** up to 30Mbps

- network of cable, fiber attaches homes to ISP router
  - homes *share access network* to **cable head end**
  - unlike DSL, which has dedicated access to central office

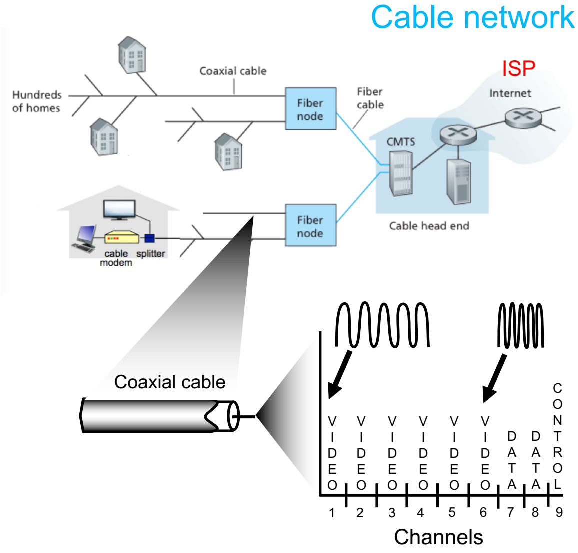
1-16

CHAPTER 1

(a) Home Access

Cable network

- different channels transmitted in different frequency bands
- This is where the ____________ is useful to split between **voice** (phone) and **data** (computer)

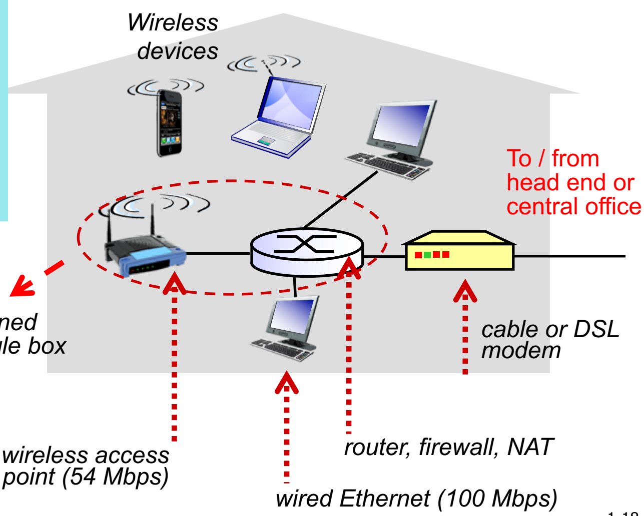


1-17

CHAPTER 1

(b) Enterprise Access (and the home)

- Initially deployed in enterprise (corporate, university).
- Recently become common for home networks.



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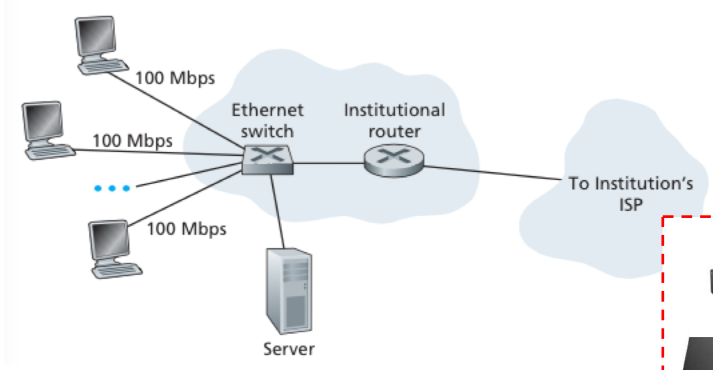
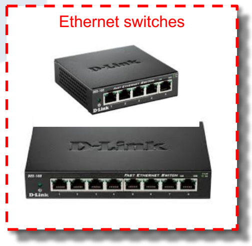
1-18

CHAPTER 1

(b) Enterprise Access (and the home)

Ethernet





- typically used in companies, universities, etc
- Users connected with twister-pair copper wire
- 10 Mbps, 100 Mbps, 1 Gbps, 10 Gbps transmission rates
- today, end systems typically connect into **Ethernet switch**

1-19

CHAPTER 1

(b) Enterprise Access (and the home)

WiFi

- Combined broadband resident access using modem or DSL
- Cheaper wireless LAN technology for home
- A __________ interconnected the base station and the stationary PC with the modem

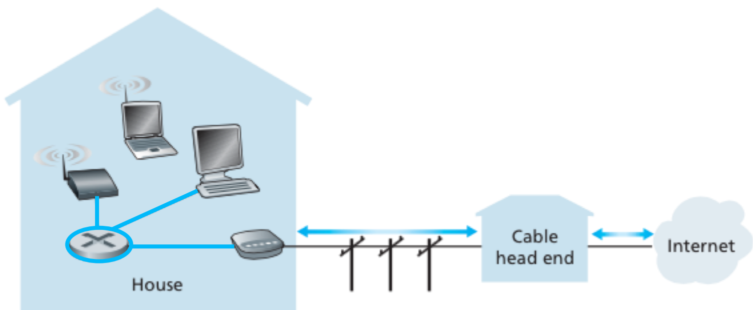


Figure: A typical home access network

1-20

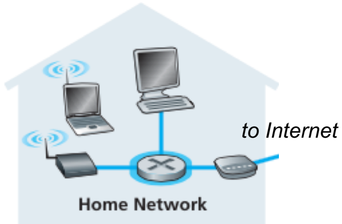
CHAPTER 1

(c) Wide-area Wireless Access

❖ shared *wireless* access network connects end system to router via base station aka "*access point*"

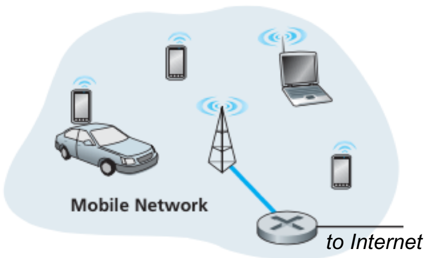
Wireless LANs:

- within building (100 ft)
- 802.11b/g (WiFi): 11, 54 Mbps transmission rate



Wide-area wireless access

- provided by telco (cellular) operator, 10's km
- between 1 and 10 Mbps
- 3G (e.g. 7.2Mbps), 4G: LTE (e.g. 326Mbps)



LTE: Long Term Evolution

1-21

CHAPTER 1

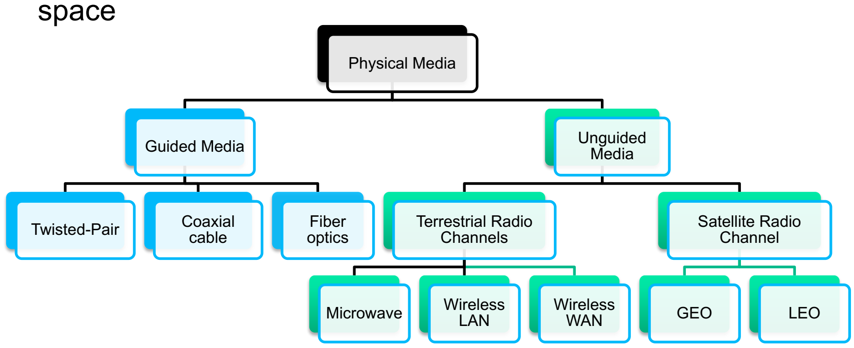
(1.2) The Network Edge
Physical Media

❖ bit: propagates between transmitter / receiver pairs

❖ physical link: what lies between transmitter & receiver

❑ ________________: signals propagate in solid media

❑ ________________: signals propagate in atmosphere & outer space



GEO – Geostationary Orbit
LEO – Low-Earth Orbiting

1-22

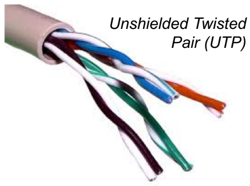
CHAPTER 1

(a) Guided Media

Twisted-Pair Copper Wire

- Least expensive and most commonly used.
- The two insulated copper wires are __________ together to reduce electrical interference from similar pairs close by.
- Numbers of pairs are bundled together in a cable in a protective shield.

- **Unshielded Twisted Pair** (UTP) is commonly used for computer network.



1-23

CHAPTER 1

(a) Guided Media

Twisted-Pair Copper Wire

- Example of UTP types:

Type	Data Rate	Usage
Cat 1	Up to 1 Mbps	Telephone Line
Cat 2	Up to 4 Mbps	Token Ring
Cat 3	Up to 10 Mbps	Token Ring & 10 Base – T
Cat 4	Up to 16 Mbps	Token Ring
Cat 5	Up to 100 Mbps	Ethernet – 16 for Token Ring
Cat 5e	Up to 1000 Mbps	Ethernet
Cat 6	Up to 1000 Mbps	Ethernet

http://1.bp.blogspot.com/-u_CH-X--loc/UEGipUdTzkI/AAAAAAAAAH0/DjOMGPWah-4/s1600/utp+types.jpg

- The data rates depend on the ____________ of the wire and ____________ between transmitter & receiver
- Cat 6a: data rates 10Gbps, distance up to 100 km

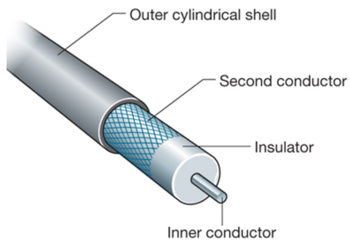
1-24

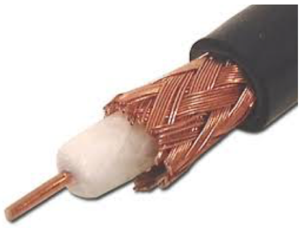
CHAPTER 1

(a) Guided Media

Coaxial Cable

- two concentric copper conductors to achieve high data transmission rates
- Common as cable TV systems (10Mbps)
- Bidirectional
- Broadband:
  - Multiple channels on cable
  - HFC (Hybrid Fiber Coax)





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BNC Connectors

1-25

CHAPTER 1

(a) Guided Media

Fiber Optics Cable

- glass fiber carrying _______________, each pulse a bit
- high-speed operation:
  - high-speed point-to-point transmission (e.g., 10's-100's Gbps transmission rate)
- low error rate:
  - repeaters spaced far apart
  - immune to electromagnetic noise

1-26

CHAPTER 1

(b) Unguided Media

Radio Channels

- signal carried in electromagnetic spectrum
- no physical "wire"
- Bidirectional

- propagation environment effects:
  - **reflection**
  - **obstruction by objects**
  - ______________

Link types:

- terrestrial microwave
  - e.g. up to 45 Mbps channels
- LAN (e.g., WiFi)
  - 11 Mbps, 54 Mbps
- wide-area (e.g., cellular)
  - 3G cellular: ~ few Mbps
- satellite
  - Kbps to 45 Mbps channel (or multiple smaller channels)
  - 270 msec end-end delay
  - geosynchronous vs low altitude

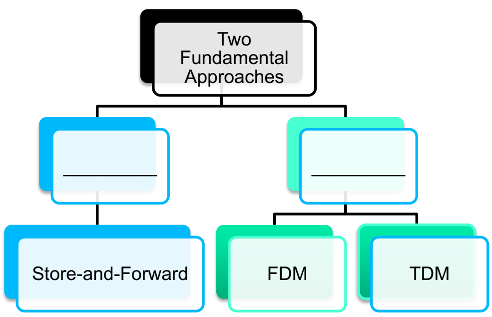
1-27

CHAPTER 1

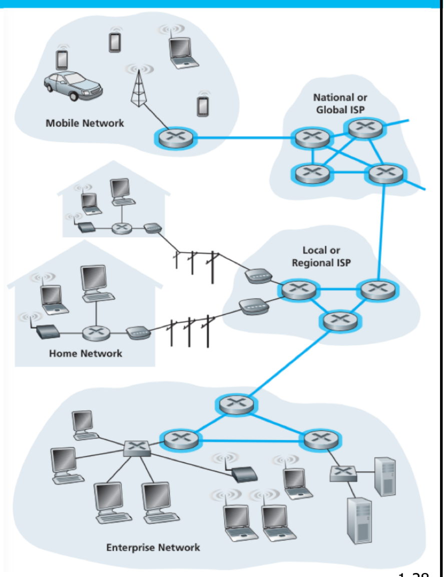
(1.3) The Network Core

Introduction

- mesh of ***packet switches*** (routers & link layer switches) and ***links*** that interconnects the Internet's end system



FDM (Frequency-Division Multiplexing)
TDM (Time-Division Multiplexing)



1-28

CHAPTER 1

(a) Packet Switching

- the hosts / source <u>break</u> application-layer messages (long massages) into ____________ (smaller chunks of data)
- <u>forward</u> packets from one router to the next, across ***links*** on path from source to destination
- each packet transmitted at <u>full link capacity</u> (rates of the link)

- If a packet of *L bits* is sending over a link with transmission rate *R bits/sec*, the time to transmit the packet (transmission delay) in seconds:

$$d_{trans} = \frac{L}{R}$$

1-29

CHAPTER 1

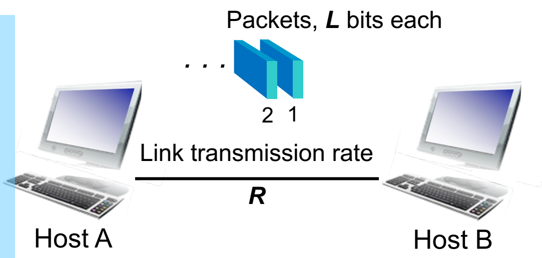
(a) Packet Switching

<u>Example 1.1</u>:

Consider two hosts, Hosts A and B, connected by a single link of rate 10 Mbps. Host A is to send a packet of size 30 Mbits to Host B.

(a) Determine the transmission time of the packet, d_{trans} in terms of L and R.

(b) Calculate the d_{trans}



<u>Solution 1.1(a):</u>
Transmission time

<u>Solution 1.1(b):</u>

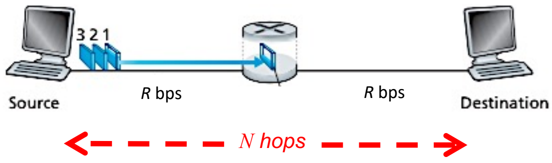
1-30

CHAPTER 1

(a) Packet Switching

Store-and-Forward

- entire packet must arrive at router before it can be transmitted on next link



- takes L / R seconds to transmit (push out) L-bits packet into link at R bps

- **End-End Delay**:
  (assuming zero propagation delay)

$$d_{end-to-end} = N\frac{L}{R}$$

Two-hop numerical example:

- L = 7.5 Mbits
- R = 1.5 Mbps
- N = 2 hops

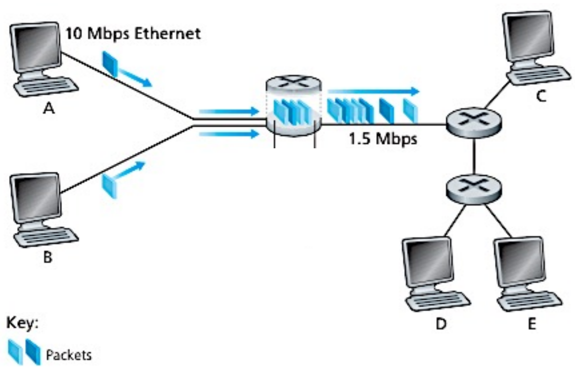
1-31

CHAPTER 1

(a) Packet Switching

(Queuing Delays and Packet Loss)

- If arrival rate (in bits) to link *exceeds* transmission rate of link for a period of time:
  - packets will _______, wait to be transmitted on link
  - packets can be ***dropped*** (lost) if memory (buffer) fills up

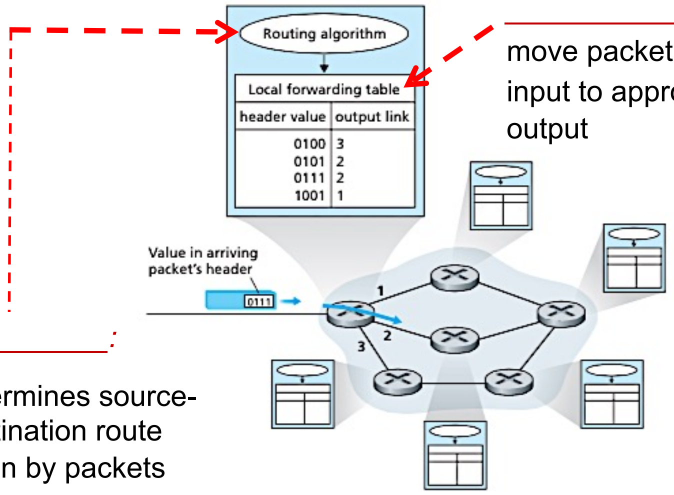


1-32

CHAPTER 1

(a) Packet Switching

(Two Key Network-core Functions)



________:

move packets from router's input to appropriate router output

________:

determines source-destination route taken by packets

4-33

CHAPTER 1

(b) Circuit Switching

- end-end resources allocated to, reserved for "call" between source & destination:
- In figure, each link has four circuits.
  - ***call*** gets 2nd circuit in top link and 1st circuit in right link.
- dedicated resources: no sharing
  - circuit-like (guaranteed) performance
- circuit segment idle if not used by call *(no sharing)*
- Commonly used in traditional telephone networks

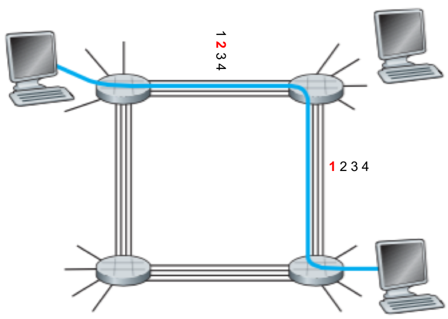


Figure: A simple circuit-switched network consisting of 4 switches and 4 links

1-34

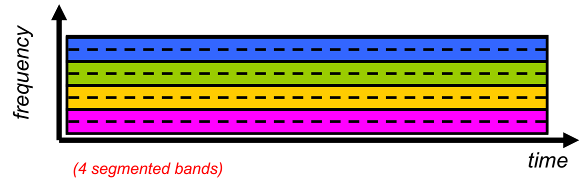
CHAPTER 1

(b) Circuit Switching

Example: 4 users

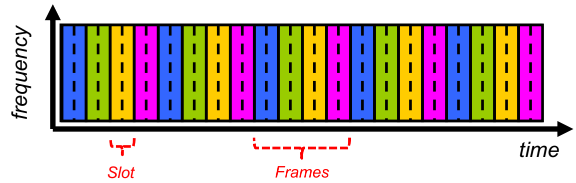
FDM versus TDM

FDM (Frequency-Division Multiplexing)



Users will access media (e.g. cable) based on different ***frequency*** (Hz) allocation

TDM (Time-Division Multiplexing)



Users will access media (e.g. cable) based on different ***time slot*** (second) allocation

1-35

CHAPTER 1

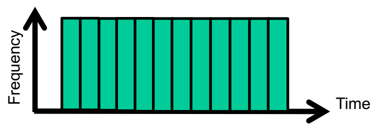
(b) Circuit Switching

Example 1.2:

Consider two hosts, Hosts A and B, connected by a circuit-switched network. Suppose all links use TDM with 12 slots and have a bit rate of 1.536 Mbps. Host A is to send a file of 640000 bits to Host B.

Calculate the time needed to send the file.

Solution 1.2:



Transmission rate for each circuit:

Transmission time:

1-36

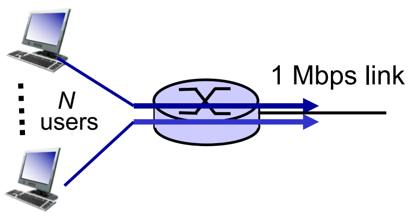
CHAPTER 1

Packet Switching vs Circuit Switching

	Packet Switching	Circuit Switching
Offer better sharing of transmission capacity	Yes	No
Simplicity (call setup)	Yes	No
More efficient (#users)	Yes	No
Less cost to implement	Yes	No
Great for bursty data	Yes	No

Example:

- 1 Mbps link
- Each user:
  - 100 Kbps when "active"
  - active 10% of time



1-37

CHAPTER 1

Case 1: Packet switching allows more users to use network!

VS

Circuit Switching

- 100 Kbps must be reserved for each user at all time
- Maximum users can be supported simultaneously by circuit switching with TDM ? :

$$= \frac{1Mbps}{100Kbps} = \frac{1000Kbps}{100Kbps} = 10 \text{ users}$$

Packet Switching

- Probability of active users is 0.1 (10%)
- with 35 users, probability > 10 active at same time is less than 0.0004 *

Q: how did we get value 0.0004?

Q: what happens if > 35 users ?

1-38

CHAPTER 1

Case 2: Packet switching is more efficient!

Circuit Switching VS **Packet Switching**

Circuit Switching

- Suppose one active user of 10 generates 1000 packets with 1000-bit each on TDM.
- The active user can only use a time slot per frame.
- Time to transmit:

$$= \frac{1000\text{-bit} \times 1000 \text{ packets}}{100 \text{ Kbps}}$$

$$= \frac{1000000}{100000} = 10s$$

Packet Switching

- An active user can continuously send its packet at the full link rate of 1 Mbps
- Since no other users active, time to transmit:

1-39

CHAPTER 1

Is packet switching a "slam dunk winner?"

- Excessive congestion possible: packet delay and loss
  - protocols needed for reliable data transfer, congestion control

- Q: How to provide circuit-like behavior?
  - bandwidth guarantees needed for audio / video applications
  - still an unsolved problem !

1-40

CHAPTER 1 A Network of Networks

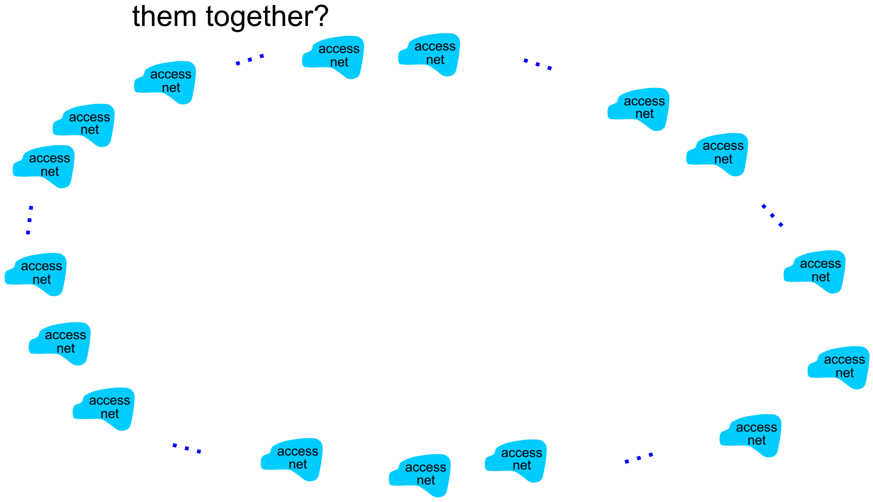
- End systems connect to Internet via access ISPs (Internet Service Providers)
  - Residential, company and university ISPs
- Access ISPs in turn must be interconnected.
  - So that any two hosts can send packets to each other
- Resulting network of networks is very complex
  - Evolution was driven by economics and national policies

(Let's take a stepwise approach to describe current Internet structure)

1-41

CHAPTER 1 A Network of Networks

Question: given millions of access ISPs, how to connect them together?



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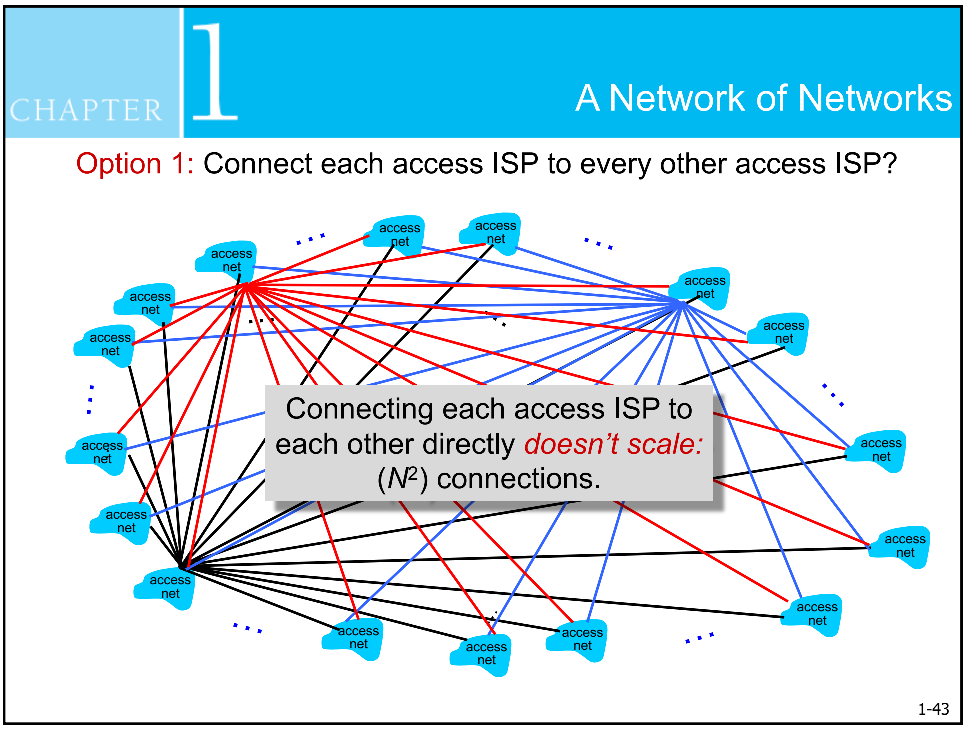
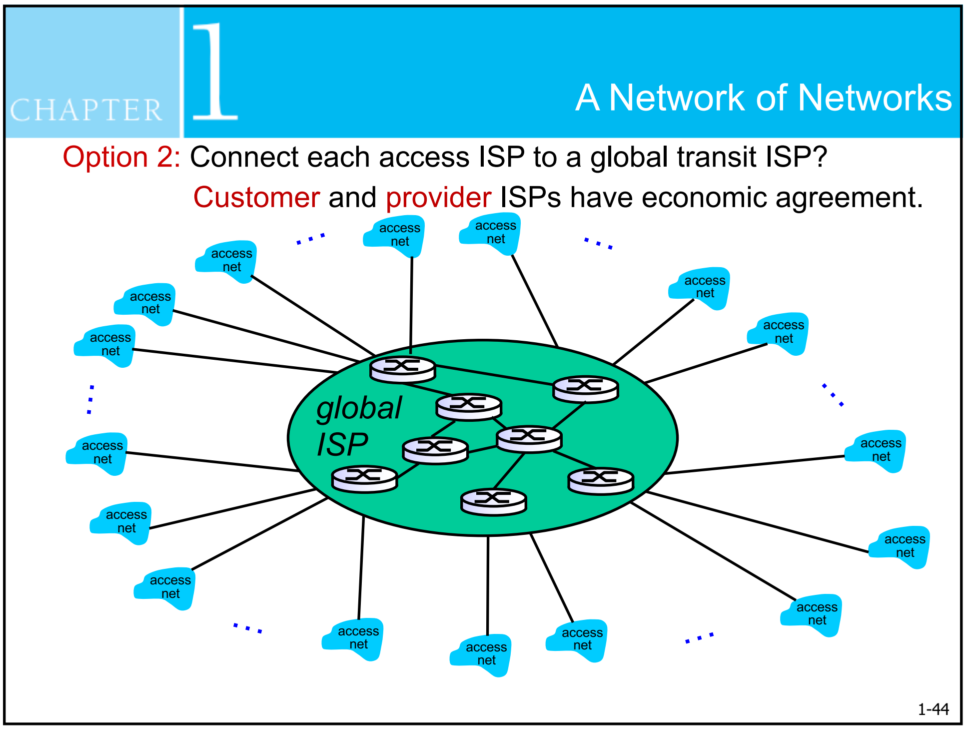
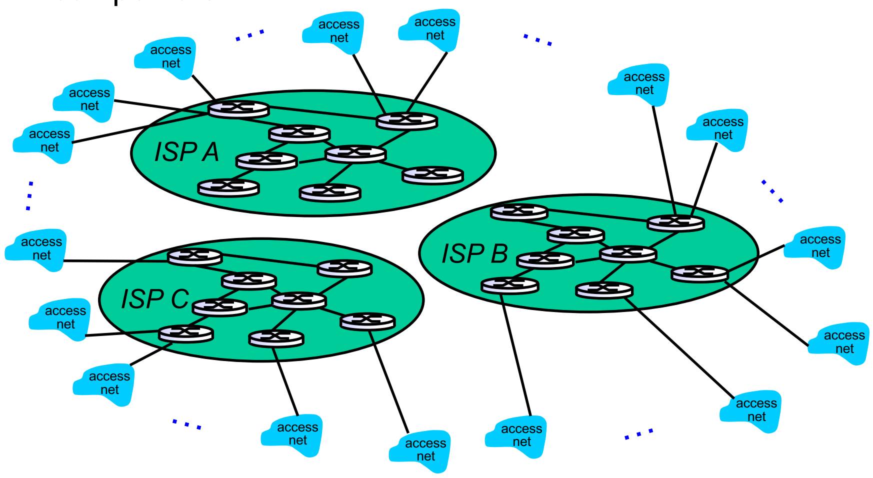

CHAPTER 1
A Network of Networks
Option 1: Connect each access ISP to every other access ISP?
access net
Connecting each access ISP to each other directly doesn't scale: (N^2) connections.
1-43


CHAPTER 1
A Network of Networks
Option 2: Connect each access ISP to a global transit ISP?
Customer and provider ISPs have economic agreement.
access net
global ISP
1-44

CHAPTER 1

A Network of Networks

But if one global ISP is viable business, there will be competitors ….

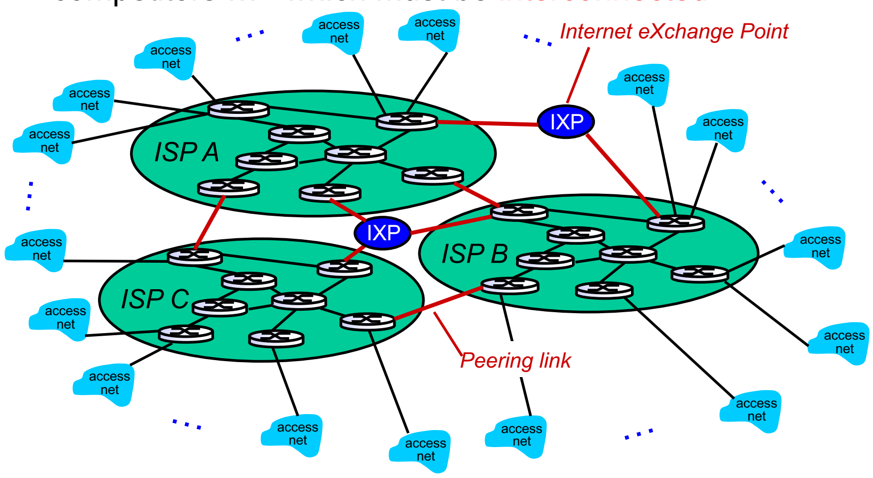


1-45

CHAPTER 1

A Network of Networks

But if one global ISP is viable business, there will be competitors …. which must be interconnected

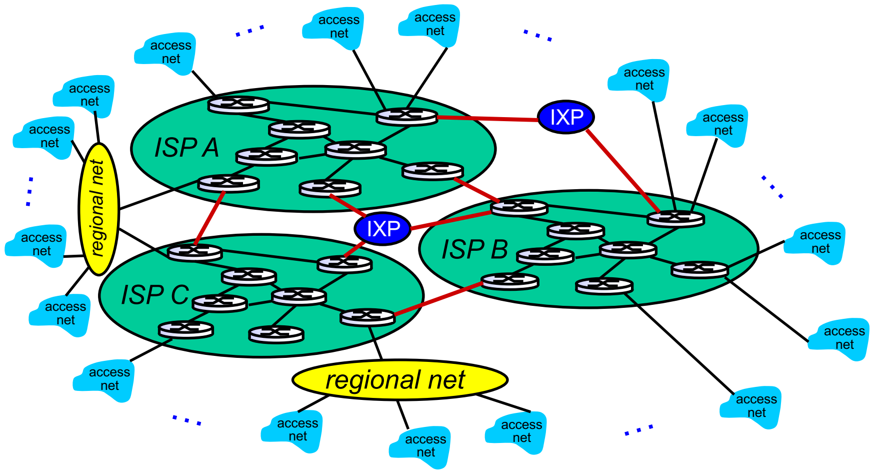


1-46

CHAPTER 1

A Network of Networks

… and regional networks may arise to connect access networks to ISPs

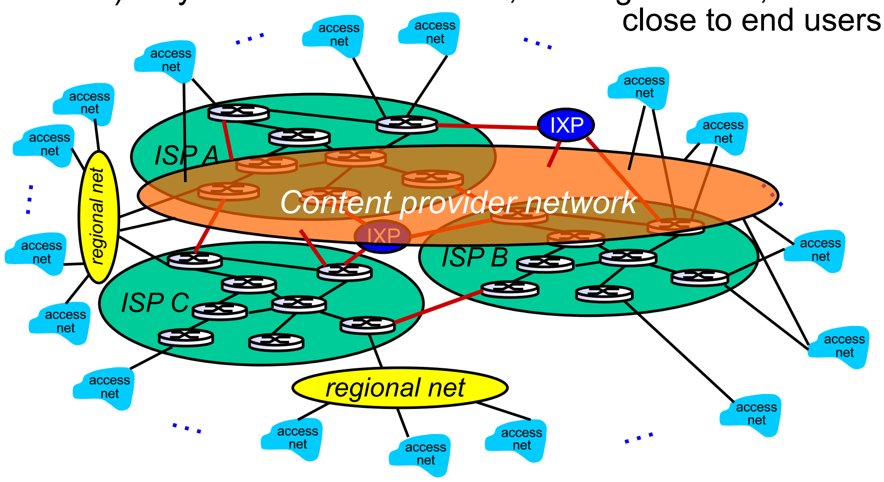


1-47

CHAPTER 1

A Network of Networks

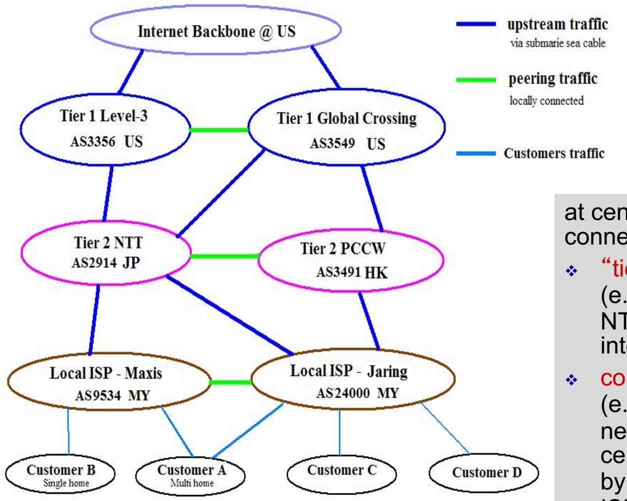
… and content provider networks (e.g., Google, Microsoft, Akamai) may run their own network, to bring services, content close to end users



1-48

CHAPTER 1

A Network of Networks



at center: small # of well-connected large networks

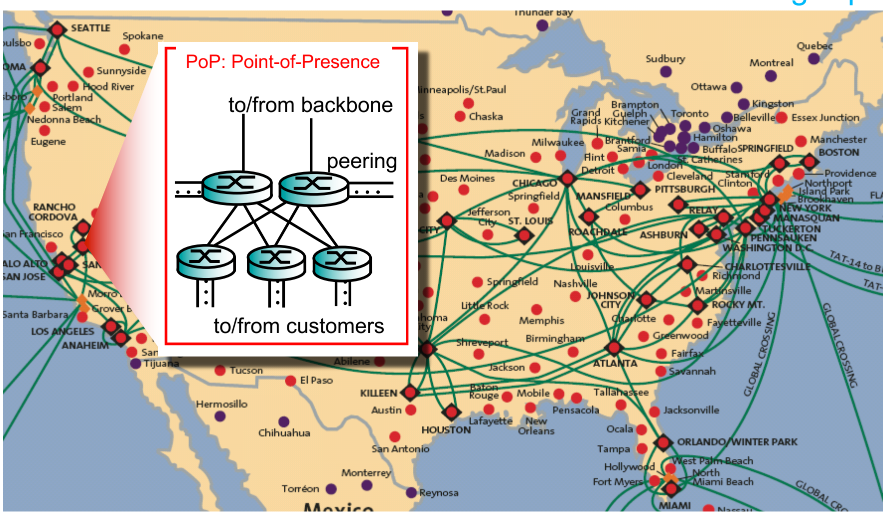
- "tier-1" commercial ISPs (e.g., Level 3, Sprint, AT&T, NTT), national & international coverage
- content provider network (e.g, Google): private network that connects it data centers to Internet, often bypassing tier-1, regional ISPs

1-49

CHAPTER 1

A Network of Networks

Tier-1 ISP: e.g. Sprint



1-50

Test Yourself — Section 1.1

1) .... are the connected computing devices that running network applications.
2) .... define format, order of messages sent/received, and actions taken one message transmission.
3) The acknowledgement in computer network protocol is known as ....
4) List 2 (TWO) hosts in network edge structures:
   ....
5) What is the access network type for the Ethernet?
   ....
6) What is the function of splitter used in DSL modem?
   ....
7) What is the asymmetric access? ....

1-51

Test Yourself — Section 1.2

1) Signal that propagate in atmosphere referred to
   ....
2) Why the UTP cable need to twist its two insulated copper wires? ....
3) Give an affect of propagation environment in radio channels.
   ....
4) *Store-and-forward* is an approach used in ....
5) What is the transmission delay, d_{trans}? ....
6) What is the different between *routing* and *forwarding*?
   .
7) Give an example of the content provider network.
   ....

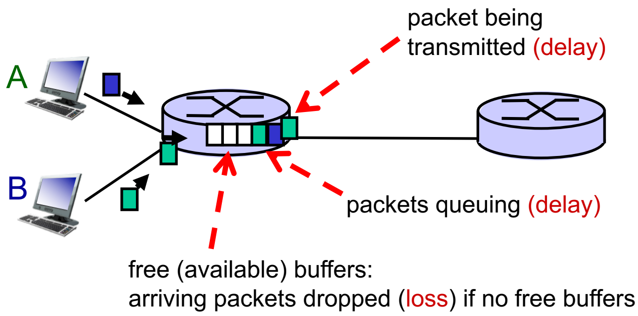
1-52

CHAPTER 1 (1.4) Delay, Loss, & Throughput in Networks

Q: How do loss and delay packet occur?

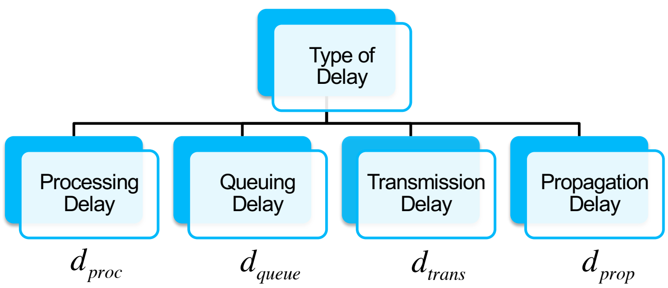
Packets *queue* in router buffers :

- packet arrival rate to link (temporarily) ________ output link capacity
- packets queue, wait for turn



1-53

CHAPTER 1 Overview of Delay



Total nodal delay:

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

1-54

CHAPTER 1

Overview of Delay

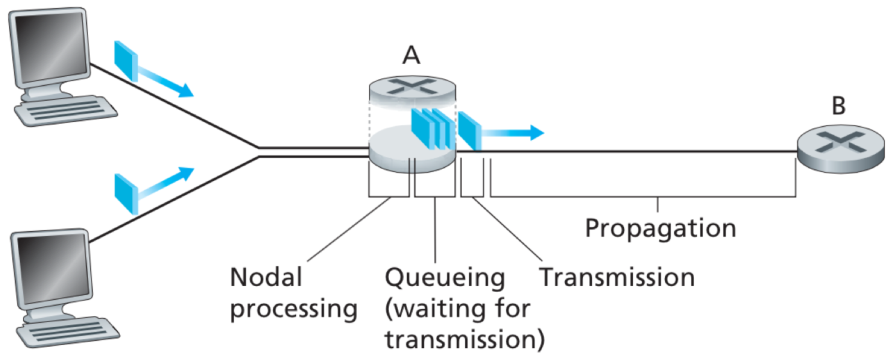


Figure: The nodal delay at router A

1-55

CHAPTER 1

Overview of Delay

d_{proc}: processing delay check bit errors

- determine output link
- typically < *msec*

d_{queue}: queuing delay

- time waiting at output link for transmission
- depends on congestion level of router

d_{trans}: transmission delay

- L : packet length (*bits*)
- R : link *bandwidth (bps)*

$$d_{trans} = \frac{L}{R}$$

d_{prop}: propagation delay

- d : length of physical link
- s : propagation speed in medium ($\sim 2 \times 10^8$ m/sec)

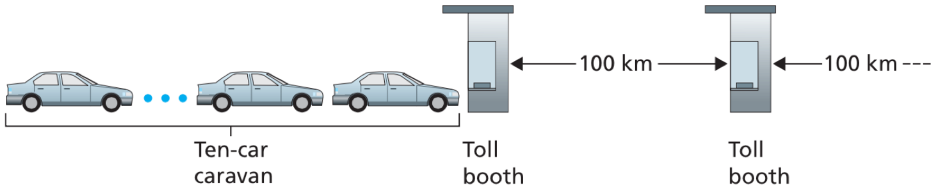
$$d_{prop} = \frac{d}{s}$$

1-56

CHAPTER 1

Overview of Delay

Comparing d_{trans} and d_{prop}



Example 1.3a: Caravan analogy

- Cars "propagate" at 100 kmh
- toll booth takes 12 sec to service a car (transmission time)
- *Car ~ bit*; *caravan ~ packet*
- Q: How long until caravan is lined up before 2nd toll booth?

1-57

CHAPTER 1

Overview of Delay

Comparing d_{trans} and d_{prop}

Solution 1.3a:

- time to "push" entire caravan through toll booth onto highway : $= 12 \text{ sec} \times 10 \text{ cars}$ $= 120 \text{ sec} = 2 \text{ min}$ — Analogous to the transmission delay, d_{trans}
- time for a car to propagate from 1st to 2nd toll both : $= \dfrac{100 \text{ km}}{100 \text{ kmh}}$ $= 1 \text{ h} = 60 \text{ min}$ — Analogous to the propagation delay, d_{prop}
- Time taken to 2nd toll both :

1-58

CHAPTER 1

Overview of Delay

Comparing d_{trans} and d_{prop}

Example 1.3b: Caravan analogy 2

- Suppose cars now "propagate" at 1000 kmh
- And suppose toll booth now take 1 min to service a car
- Q: Will cars arrive to 2nd toll booth before all cars serviced at 1st toll booth?

- *A: Yes!* after 7 min, 1st car arrives at 2nd toll booth; three cars still at 1st booth.

Solution 1.3b:

- time to "push" entire caravan through toll booth onto highway :

$$= 1 \text{ min } \times 10 \text{ cars}$$
$$= 10 \text{ min}$$

- time for a car to propagate from 1st to 2nd toll both :

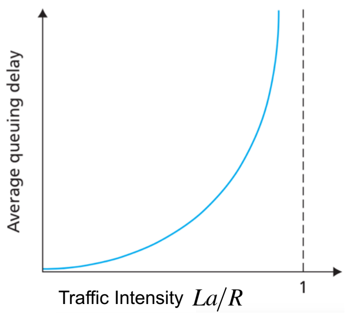
$$= \frac{100 \text{ km}}{1000 \text{ kmh}}$$
$$= 0.1 \text{ h } = 6 \text{ min}$$

1-59

CHAPTER 1

Queuing Delay and Packet Loss

Queuing Delay



R : link bandwidth (bps)
L : packet length (bits)
a : average packet arrival rate

- La/R ~ 0 : avg. queuing delay **small**
- La/R -> 1: avg. queuing delay **large**
- La/R > 1: more "work" arriving than can be serviced, average delay **infinite**!

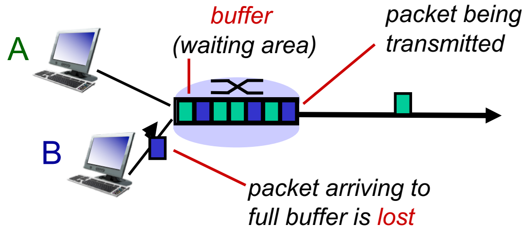
1-60

CHAPTER 1

Queuing Delay and Packet Loss

Packet Loss

- **queue** (aka *buffer*) preceding link in buffer has finite capacity
- packet arriving to full queue dropped (aka *lost*)
- lost packet may be retransmitted by previous node, by source end system, or not at all



* Check out the Java applet on queuing and loss

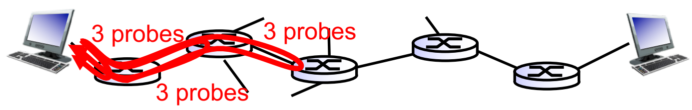
1-61

CHAPTER 1

End-to-End Delay

Internet Delays and Routes

- What do "real" Internet delay and loss look like?
- Traceroute program: provides delay measurement from source to router along end-end Internet path towards destination. For all *i:*
  - sends three packets that will reach router *i* on path towards destination
  - router *i* will return packets to sender
  - sender times interval between transmission and reply.



1-62

CHAPTER 1 End-to-End Delay

Internet Delays and Routes

Traceroute: `gaia.cs.umass.edu to www.eurecom.fr`

3 delay measurements from gaia.cs.umass.edu to cs-gw.cs.umass.edu

```
1   cs-gw (128.119.240.254)  1 ms  1 ms  2 ms
2   border1-rt-fa5-1-0.gw.umass.edu (128.119.3.145)  1 ms  1 ms  2 ms
3   cht-vbns.gw.umass.edu (128.119.3.130)  6 ms 5 ms 5 ms
4   jn1-at1-0-0-19.wor.vbns.net (204.147.132.129)  16 ms 11 ms 13 ms
5   jn1-so7-0-0-0.wae.vbns.net (204.147.136.136)  21 ms 18 ms 18 ms
6   abilene-vbns.abilene.ucaid.edu (198.32.11.9)  22 ms  18 ms  22 ms
7   nycm-wash.abilene.ucaid.edu (198.32.8.46)  22 ms  22 ms  22 ms
8   62.40.103.253 (62.40.103.253)  104 ms 109 ms 106 ms
9   de2-1.de1.de.geant.net (62.40.96.129)  109 ms 102 ms 1
10  de.fr1.fr.geant.net (62.40.96.50)  113 ms 121 ms 114
11  renater-gw.fr1.fr.geant.net (62.40.103.54)  112 ms  1
12  nio-n2.cssi.renater.fr (193.51.206.13)  111 ms  114 ms  116 ms
13  nice.cssi.renater.fr (195.220.98.102)  123 ms  125 ms  124 ms
14  r3t2-nice.cssi.renater.fr (195.220.98.110)  126 ms  126 ms  124 ms
15  eurecom-valbonne.r3t2.ft.net (193.48.50.54)  135 ms  128 ms  133 ms
16  194.214.211.25 (194.214.211.25)  126 ms  128 ms  126 ms
17  * * *
18  * * *
19  fantasia.eurecom.fr (193.55.113.142)  132 ms  128 ms  136 ms
```

trans-oceanic link

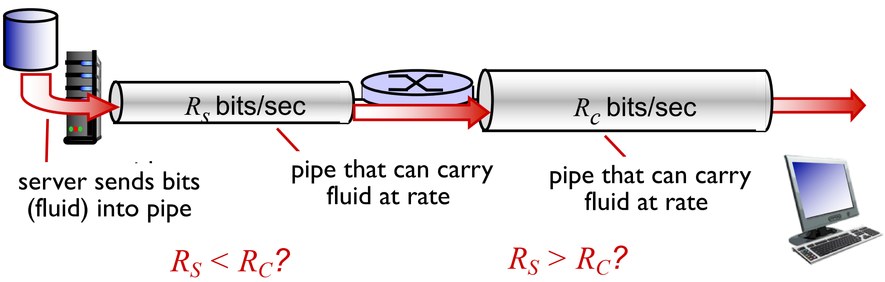
* means no response (probe lost, router not replying)

* Do some traceroutes at www.traceroute.org

1-63

CHAPTER 1 Throughput in Computer Network

- *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



$R_S < R_C$? $R_S > R_C$?

Bottleneck link

link on end-end path that constrains end-end throughput

1-64

CHAPTER 1

Throughput in Computer Network

Internet Scenario 1

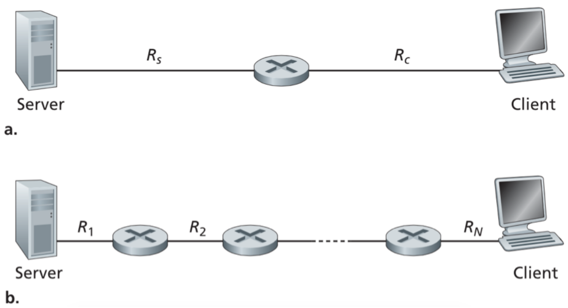


Figure: Throughput for a file transfer from server

- connection end-end throughput:

$$\min\{R_S, R_C\}$$

$$\min\{R_1, R_2, \dots, R_N\}$$

- in practice: R_S or R_C is often ______

Example: from figure (a)

- Suppose R_S = 3*Mbps*, R_C = 2*Mbps*
- The bottleneck provides the download with 2*Mbps* of throughput

1-65

CHAPTER 1

Throughput in Computer Network

Internet Scenario 2

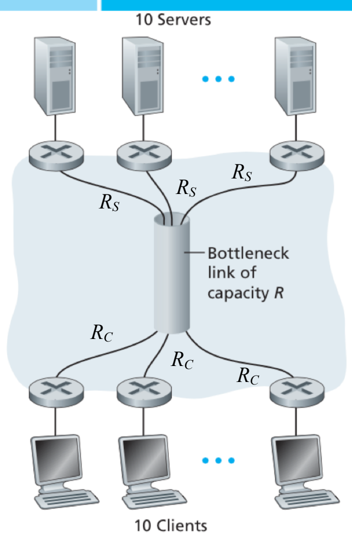


Figure: End-to-end throughput of 10 clients downloading with 10 servers

- per-connection end-end throughput:

$$\min\left\{R_S, R_C, \frac{R}{10}\right\}$$

Example:

- Suppose R_S = 2*Mbps*, R_C = 1*Mbps*, *R* = 5*Mbps*
- The bottleneck provides each download with 500*kbps* of throughput

1-66

CHAPTER 1

Exercises 1

Suppose Host A wants to send a large file to Host B. The path from Host A to Host B has 3-links, of rate R_1 = 150*kbps*, R_2 = 2*Mbps*, and R_3 = 1*Mbps*.

a) Assuming no other traffic in the network, what is the throughput for the file transfer? [2 marks]

b) Suppose the file is 4 million bytes. Roughly, how long will it take to transfer the file to Host B? [5 marks]

1-67

CHAPTER 1

Exercises 1

Solution:

1-68

CHAPTER 1

Exercises 2

Host A wants to send a 30-*Mbit* MP3 file to Host B. All the links in the path between source and destination have a transmission rate of 10*Mbps*. Assume that the propagation speed is 2×10^8 *meters/sec*, and the distance between source and destination is 10*km*. Initially suppose there is only one link between the source and the destination. Also suppose that the entire MP3 file is sent as one packet (Ignore processing delay and queuing delay). Show your workings.

a) Calculate the transmission delay?

b) What will be the end-to-end delay?

c) How many bits will the source have transmitted when the first bit of the MP3 file arrives at the destination?

1-69

CHAPTER 1

Exercises 2

Solution:

1-70

CHAPTER 1

(1.5) Protocol Layers & Service Models

Layered Architecture

Networks are complex, with many "pieces":

- hosts
- routers
- links of various media
- applications
- protocols
- hardware, software

Question:

Is there any hope of *organizing* structure of network?

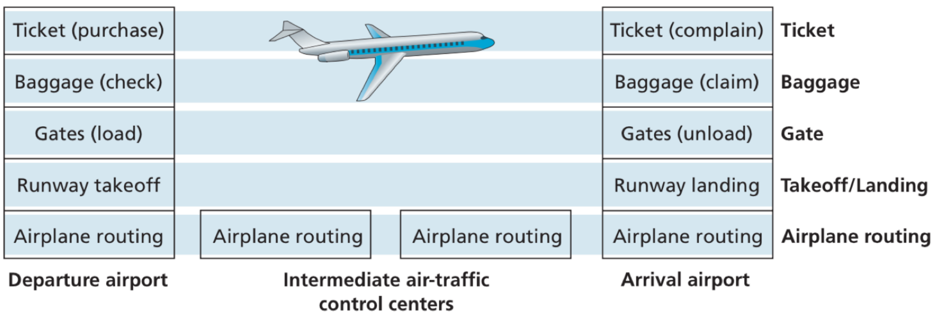
…. or at least our discussion of networks?

1-71

CHAPTER 1

Layered Architecture

Analogy: Airline Functionality



- a series of steps
- *layers:* each layer implements a service
  - via its own internal-layer actions
  - relying on services provided by layer below

1-72

CHAPTER 1

Layered Architecture

Why Layering?

Dealing with complex systems:

- explicit structure allows <u>identification</u>, <u>relationship</u> of complex system's pieces
  - layered *reference model* for discussion
- modularization eases <u>maintenance</u>, <u>updating</u> of system
  - change of implementation of layer's service transparent to rest of system
  - e.g., change in gate procedure doesn't affect rest of system
- *Q:* layering considered harmful?

1-73

CHAPTER 1

Layered Architecture

OSI Reference Model

***O**pen **S**ystem **I**nterconnection (OSI)* model defines a **generic** networking framework to implement protocols in seven (7) layers

	Data unit	Layer	Function
Host layers	*Data / Message*	**7. Application**	Network process to **application**
		6. Presentation	Allow applications **to interpret meaning of data**, e.g. data representation, encryption and decryption, convert machine dependent data to machine independent data
		5. Session	Interhost **communication**, managing sessions between applications, synchronization, data recovery
	Segments	**4. Transport**	Reliable **delivery** of packets between points on a network.
Media layers	*Packet / Datagram*	**3. Network**	**Addressing**, **routing** and (not necessarily reliable) delivery of datagrams between points on a network.
	Bit / Frame	**2. Data link**	A reliable direct point-to-point **data connection**.
	Bit	**1. Physical**	A (not necessarily reliable) direct point-to-point data connection.

PDU (Protocol Data Unit)

1-74

CHAPTER 1

Layered Architecture

An Analogy of OSI model: Source Host

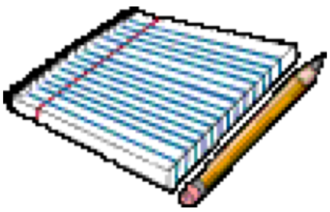
APPLICATION:
After riding your new bicycle a few times in Tokyo, you decide that you want to give it to a friend who studies in UTM, JB.

1-75

CHAPTER 1

Layered Architecture

An Analogy of OSI model: Source Host



PRESENTATION:
Make sure you have the proper directions to disassemble and reassemble the bicycle.

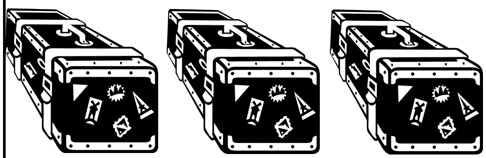
SESSION:
Call your friend and make sure you have his correct address.

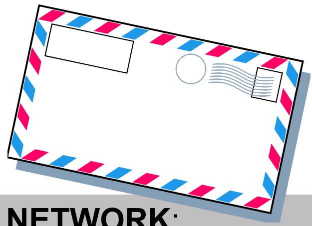
1-76

CHAPTER 1

Layered Architecture

An Analogy of OSI model: Source Host





NETWORK:
Put your friend's complete mailing address (and yours) on each box. Since the packages are too big for your mailbox (and since you don’t have enough stamps) you determine to go to the post office.

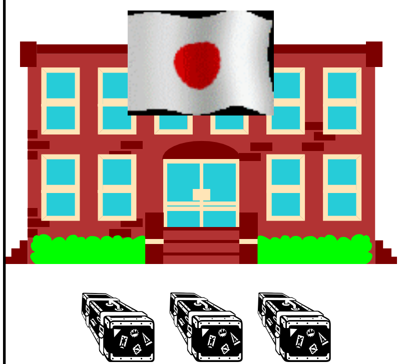
TRANSPORT:
Disassemble the bicycle and put different pieces in different boxes. The boxes are labeled “1 of 3”, “2 of 3”, and “3 of 3”.

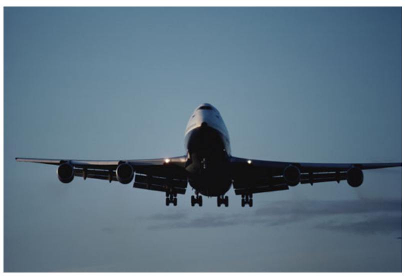
1-77

CHAPTER 1

Layered Architecture

An Analogy of OSI model: Source Host





Data LINK:
Tokyo post office takes possession of the boxes.

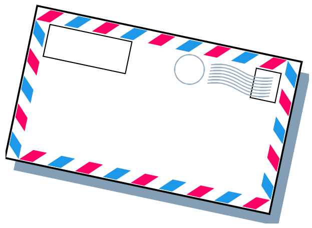
PHYSICAL: Media
The boxes are flown from Tokyo to JB.

1-78

CHAPTER 1 Layered Architecture

An Analogy of OSI model: Destination

Data LINK:
UTM post office receives your boxes.

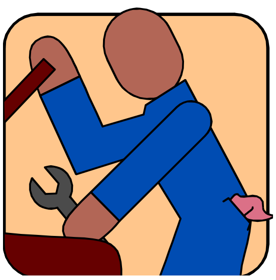


NETWORK:
Upon examining the destination address, UTM post office determines that your boxes should be delivered to the written home address.

1-79

CHAPTER 1 Layered Architecture

An Analogy of OSI model: Destination



TRANSPORT:
Your friend calls you and tells you he got all 3 boxes and he is having another friend named FARIS reassemble the bicycle.

SESSION:
Your friend hangs up because he is done talking to you.

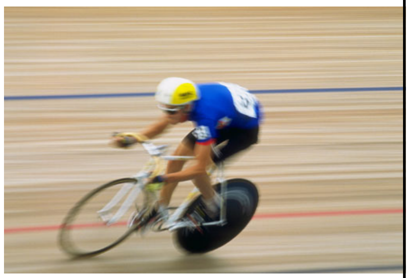
1-80

CHAPTER 1

Layered Architecture

An Analogy of OSI model: Destination

PRESENTATION:
FARIS is finished and "presents" the bicycle to your friend. Another way to say it is that your friend is finally getting his "present".



APPLICATION:
Your friend enjoys riding his new bicycle in UTM.

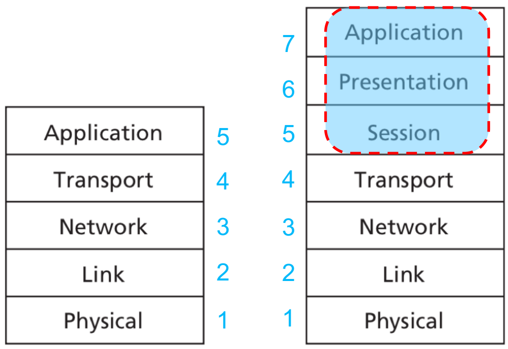
1-81

CHAPTER 1

Layered Architecture

Internet Protocol Stack (TCP/IP Model)

- TCP/IP was developed by Advanced Research Projects Agency (ARPA) to build a nationwide packet data network in 1960s.
- It was first used in UNIX-based computers in universities and government installations.
- Today, it is the main protocol used in all Internet operations.



a. Five-layer Internet protocol stack

b. Seven-layer ISO OSI reference model

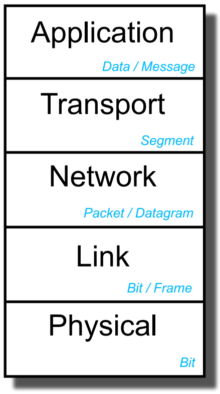
2-82

CHAPTER 1

Layered Architecture

Internet Protocol Stack (TCP/IP Model)

- __________: supporting network applications
  - FTP, SMTP, HTTP
- ___________: process-process data transfer
  - TCP, UDP
- *Network:* routing of datagrams from source to destination
  - IP, routing protocols
- *Link:* data transfer between neighboring network elements
  - Ethernet, 802.111 (WiFi), PPP
- *Physical:* bits "on the wire"



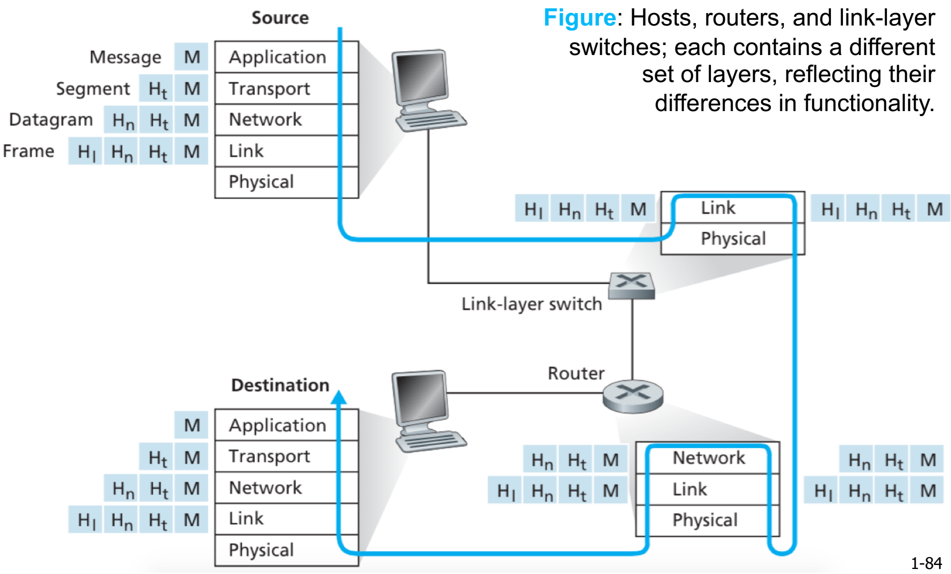
FTP (File Transfer Protocol)
SMTP (Simple Mail Transfer Protocol)
HTTP (HyperText Transfer Protocol)
PPP (Point-to-Point Protocol)

1-83

CHAPTER 1

Encapsulation

Figure: Hosts, routers, and link-layer switches; each contains a different set of layers, reflecting their differences in functionality.



1-84

CHAPTER 1

(1.6) Network Under Attack

Network Security

- field of network security:
  - how bad guys can **attack** computer networks?
  - how we can **defend** networks against attacks?
  - how to **design** architectures that are **immune** to attacks?
- Internet not originally designed with (much) security in mind
  - *original vision:*

    "a group of mutually trusting users attached to a transparent network" ☺
  - Internet protocol designers playing "catch-up"
  - security considerations in all layers!

1-85

CHAPTER 1

Network Security

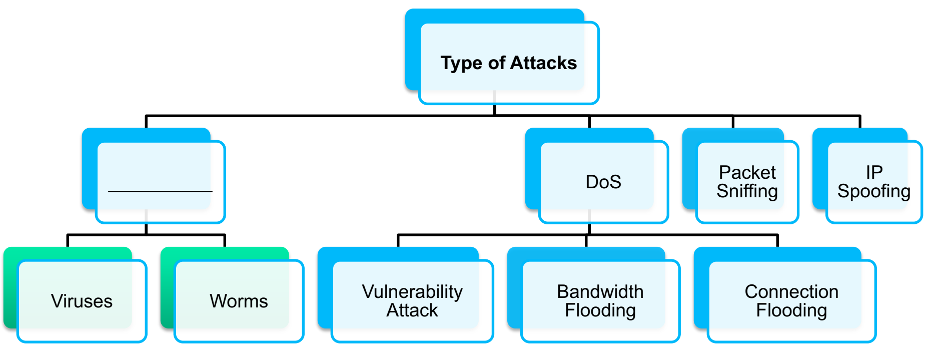


Figure: The way of bad guys can attack computer networks

DoS (Denial-of-Service)

1-86

CHAPTER 1 Network Security

Malware

- Bad guys can put **malware** into hosts via Internet
- Malware can get in host from:

________ : self-replicating infection by receiving /executing object (e.g., e-mail attachment)	_______ : self-replicating infection by passively receiving object that gets itself executed

- spyware malware can *record keystrokes*, *web sites visited*, *upload info to collection site*
- infected host can be enrolled in botnet, used for spam distribution or DoS (*Denial-of-Service*) attacks

1-87

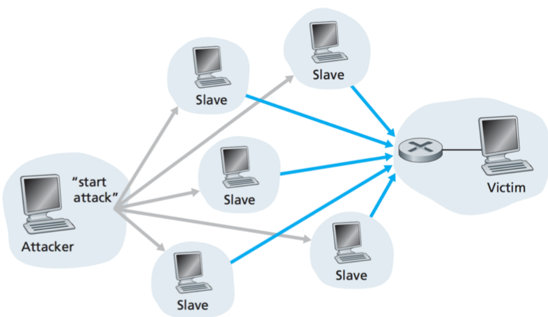
CHAPTER 1 Network Security

Denial-of-Service (DoS)

- Bad guys can attack server, network infrastructure
- *DoS:* attackers make resources (server, bandwidth) unavailable to legitimate traffic by overwhelming resource with bogus traffic

Steps:

1. select target
2. break into hosts around the network (see botnet)
3. send packets to target from compromised hosts

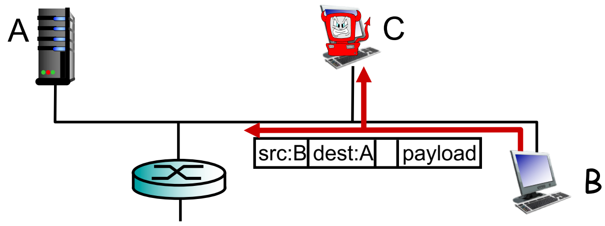


CHAPTER 1

Network Security

Packet Sniffing

- Bad guys can sniff packets
  - broadcast media (shared ethernet, wireless)
  - promiscuous network interface reads/records all packets (e.g., including passwords!) passing by.



WIRESHARK Wireshark software used for end-of-chapter labs is a (free) packet-sniffer

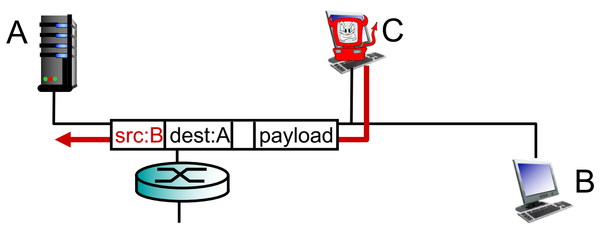
1-89

CHAPTER 1

Network Security

Internet Protocol (IP) Spoofing

- Bad guys can use masquerade as someone you trust by faking addresses
- *IP spoofing:* send packet with false source address



1-90

(1.7) History of Computer Network & the Internet

CHAPTER 1

Internet History

1961-1972: Early packet-switching principles

- 1961: Kleinrock - queuing 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
- 1972:
  - ARPAnet public demo
  - NCP (Network Control Protocol) first host-host protocol
  - first e-mail program
  - ARPAnet has 15 nodes

1-91

CHAPTER 1

Internet History

1972-1980: Internetworking, new and proprietary networks

- 1970: ALOHAnet satellite network in Hawaii
- 1974: Cerf and Kahn - architecture for interconnecting networks
- 1976: Ethernet at Xerox PARC
- late70's: proprietary architectures: DECnet, SNA, XNA
- late 70's: 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

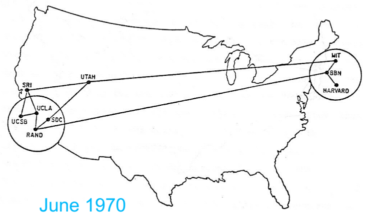
define today's Internet architecture

1-92

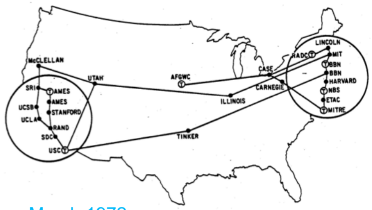
CHAPTER 1

Internet History

September 1969



June 1970



March 1972

July 1977

http://internetprojemiz.weebly.com

1-93

CHAPTER 1

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

DNS (Domain Name Server)
SMTP (Simple Mail Transfer Protocol)
FTP (File Transfer Protocol)

1-94

CHAPTER 1

Internet History

1990, 2000's: commercialization, the Web, new apps

- early 1990's: ARPAnet decommissioned
- 1991: NSF lifts restrictions on commercial use of NSFnet (decommissioned, 1995)
- early 1990s: Web
  - hypertext [Bush 1945, Nelson 1960's]
  - HTML, HTTP: Berners-Lee
  - 1994: Mosaic, later Netscape
  - late 1990's: commercialization of the Web

late 1990's – 2000's:

- more killer apps: instant messaging, P2P file sharing
- network security to forefront
- est. 50 million host, 100 million+ users
- backbone links running at Gbps

1-95

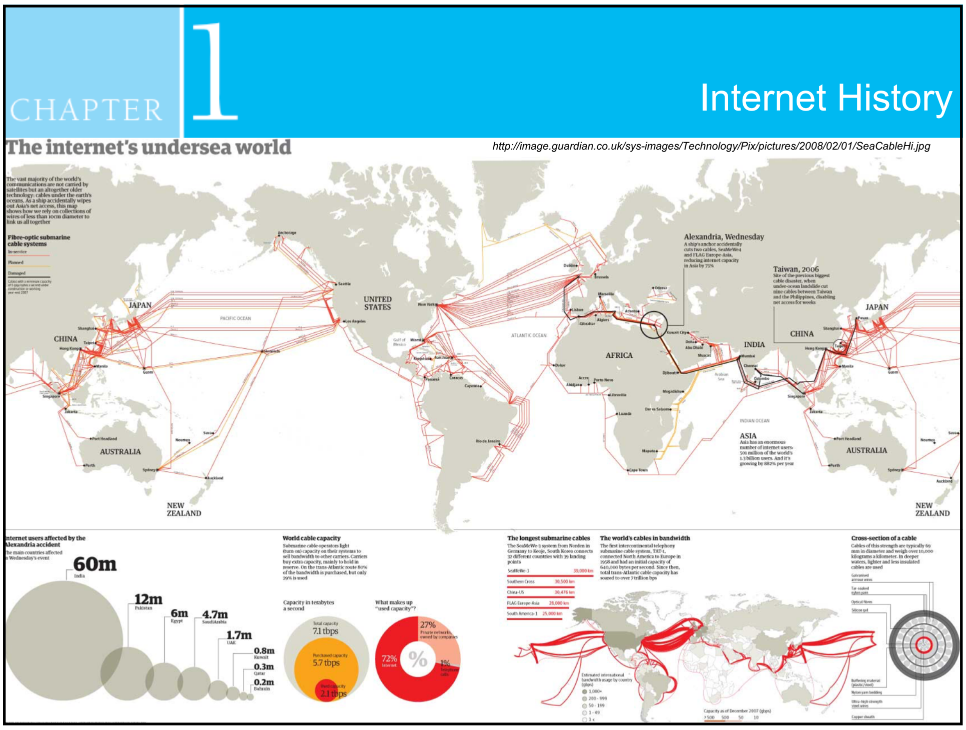
CHAPTER 1

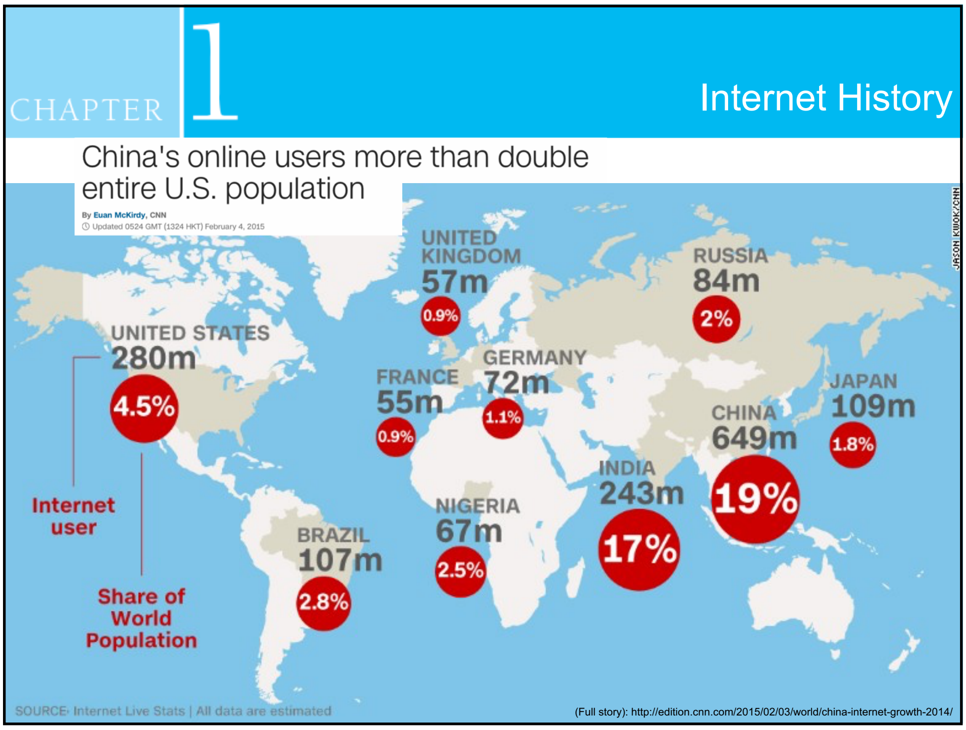
Internet History

2005 - Present

- ~750 million hosts
  - Smartphones and tablets
- Aggressive deployment of broadband access
- Increasing ubiquity of high-speed wireless access
- Emergence of online social networks:
  - Facebook: soon one billion users
- Service providers (Google, Microsoft) create their own networks
  - Bypass Internet, providing "instantaneous" access to search, e-mail, etc.
- E-commerce, universities, enterprises running their services in "cloud" (eg, Amazon EC2)

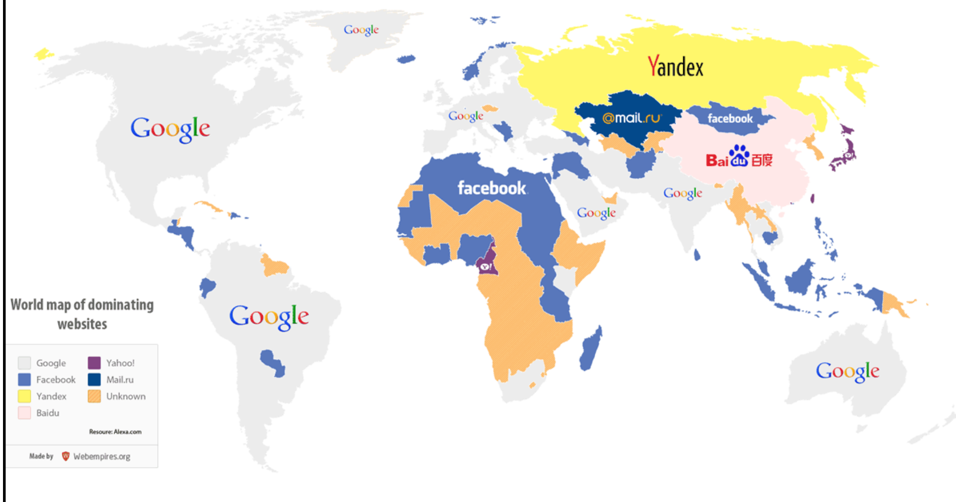
1-96


CHAPTER
1
Internet History
The internet's undersea world
http://image.guardian.co.uk/sys-images/Technology/Pix/pictures/2008/02/01/SeaCableHi.jpg
JAPAN
CHINA
UNITED STATES
AFRICA
INDIA
CHINA
JAPAN
AUSTRALIA
NEW ZEALAND
ASIA
AUSTRALIA
NEW ZEALAND
60m
12m
6m
4.7m
1.7m
0.8m
0.3m
0.2m


CHAPTER
1
Internet History
China's online users more than double
entire U.S. population
By Euan McKirdy, CNN
Updated 0524 GMT (1324 HKT) February 4, 2015
UNITED KINGDOM
57m
0.9%
RUSSIA
84m
2%
UNITED STATES
280m
4.5%
FRANCE
55m
0.9%
GERMANY
72m
1.1%
JAPAN
109m
1.8%
CHINA
649m
19%
INDIA
243m
17%
NIGERIA
67m
2.5%
BRAZIL
107m
2.8%
Internet user
Share of World Population
SOURCE: Internet Live Stats | All data are estimated
(Full story): http://edition.cnn.com/2015/02/03/world/china-internet-growth-2014/

CHAPTER 1

Internet History



https://img.labnol.org/di/popular_websites.png

1-99

CHAPTER 1

Summary

covered a "ton" of material!

- Internet overview
- what's a protocol?
- network edge, core, access network
  - packet-switching versus circuit-switching
  - Internet structure
- performance: loss, delay, throughput
- layering, service models
- security
- history

you now have:

- context, overview, "feel" of networking
- more depth, detail *to follow!*

1-100