

# UCLA CS 118 Winter 2021

Instructor: Giovanni Pau  
TAs:  
Hunter Dellaverson  
Eric Newberry

## Assignment Project Exam Help

1

## Chapter I Introduction

**A note on the use of these Powerpoint slides:**  
We're making these slides freely available to all (faculty, students, readers). They're in PowerPoint form so you can see the animations, and can add, modify, and delete slides. (including the order and slide content) to suit your needs. They obviously represent a lot of work on our part. In return for use, we only ask the following:  

- If you use these slides (e.g., in a class) that you mention their source (after all, we'd like people to use our book)
- If you post any slides on a www site, that you note that they are adapted from (or perhaps identical to) our slides, and note our copyright of this material.

Thanks and enjoy! JFK/KWR  
©All rights reserved. ISBN 978-0-13-413362-0  
J. F. Kurose and K. W. Ross, All Rights Reserved

**Computer Networking: A Top Down Approach**  
7th edition  
Jim Kurose, Keith Ross  
Pearson/Addison Wesley  
April 2016

2

<https://powcoder.com>

### Chapter 1: introduction

**Chapter goal:**

- Get "feel," "big picture," introduction to terminology
  - more depth, detail *later* in course



Introduction: 1-3

3

### Add WeChat powcoder

### The Internet: a "nuts and bolts" view

**Billions of connected computing devices:**

- **hosts** = end systems
- running **network apps** at Internet's "edge"

**Packet switches:** forward packets (chunks of data)

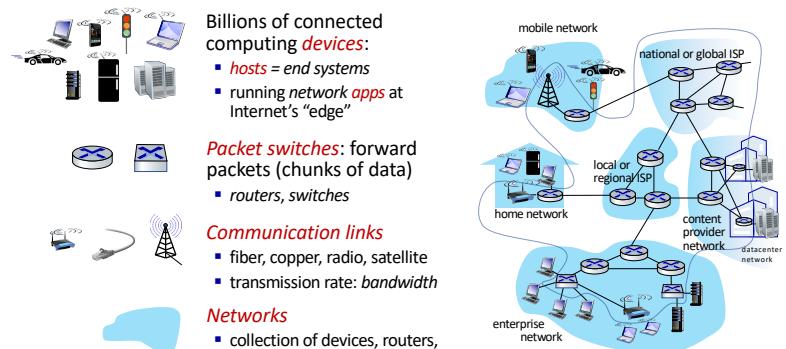
- **routers, switches**

**Communication links**

- fiber, copper, radio, satellite
- transmission rate: **bandwidth**

**Networks**

- collection of devices, routers, links: managed by an organization

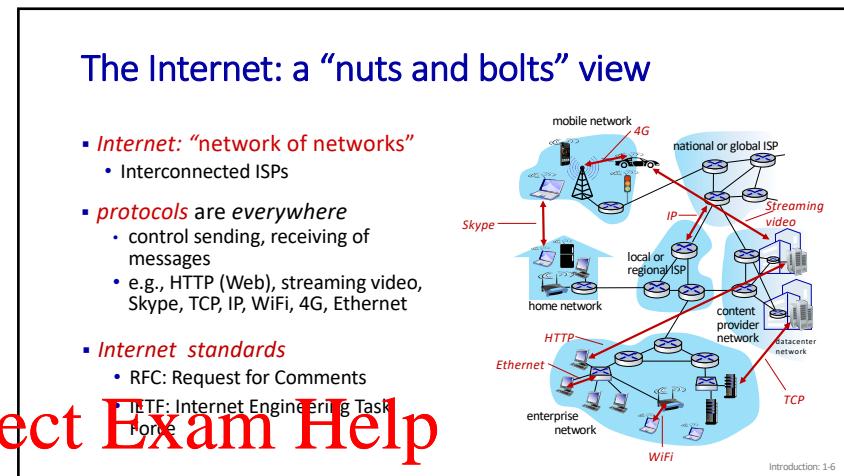


Introduction: 1-4

4

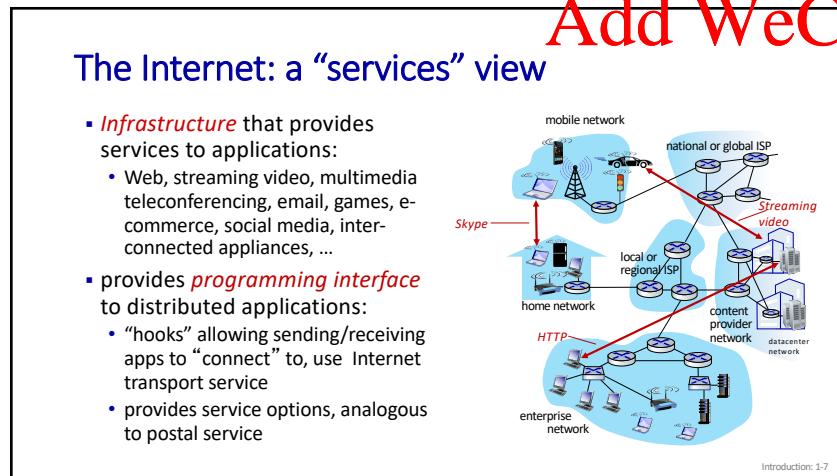


5

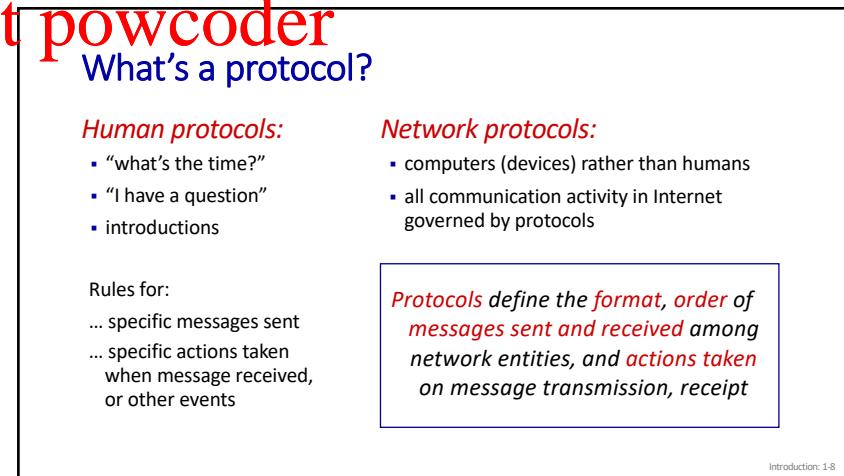


6

<https://powcoder.com>



7



8

**What's a protocol?**

A human protocol and a computer network protocol:

Q: other human protocols?

Assignment Project Exam Help

Introduction: 1-9

9

**Chapter 1: roadmap**

- What is the Internet?
- What is 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

Introduction: 1-10

10

<https://powcoder.com>

**Add WeChat powcoder**

**A closer look at Internet structure**

**Network edge:**

- hosts: clients and servers
- servers often in data centers

Introduction: 1-11

11

**A closer look at Internet structure**

**Network edge:**

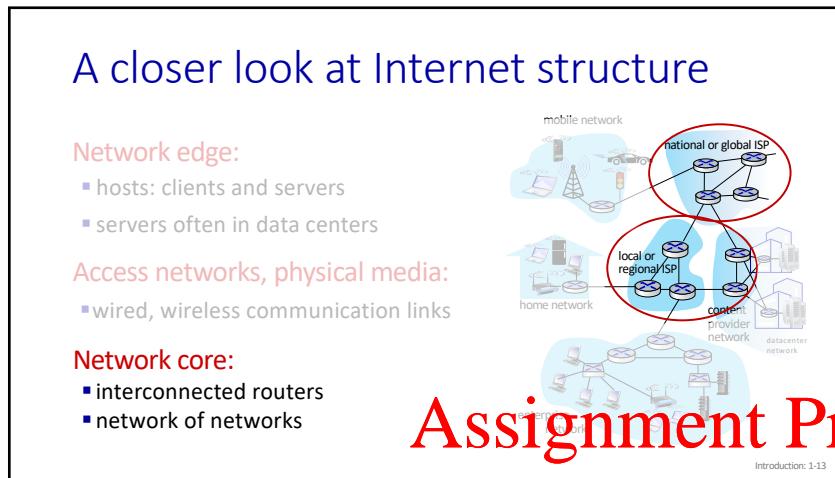
- hosts: clients and servers
- servers often in data centers

**Access networks, physical media:**

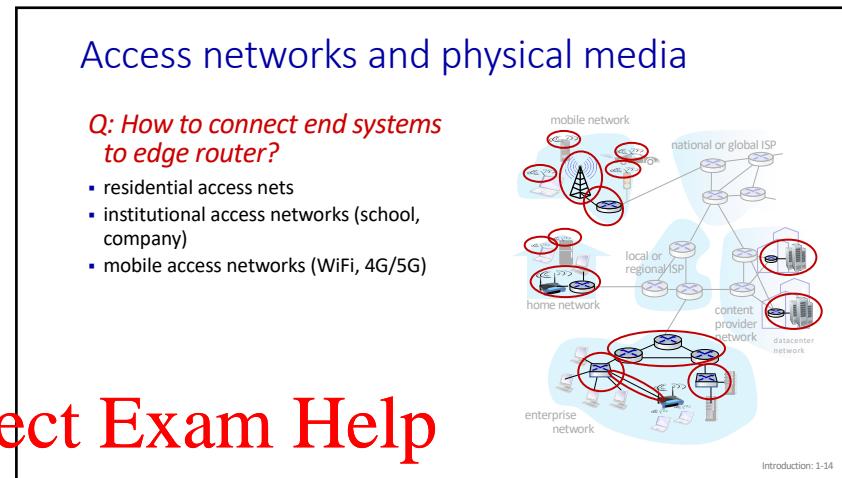
- wired, wireless communication links

Introduction: 1-12

12

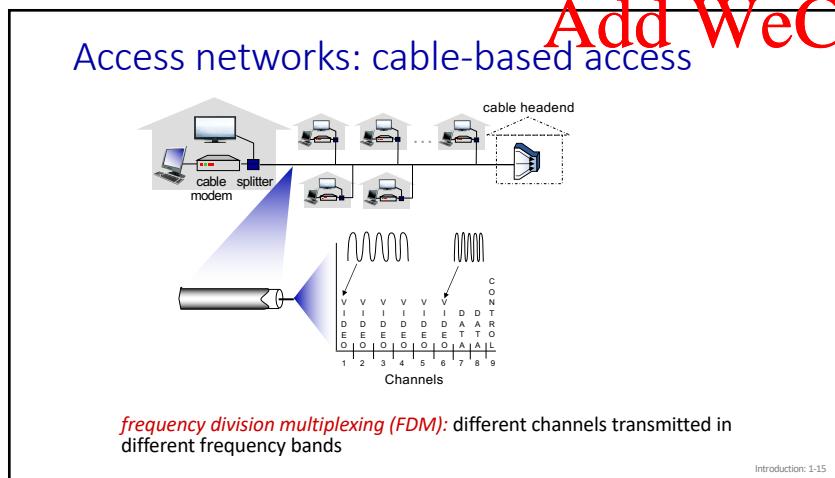


13

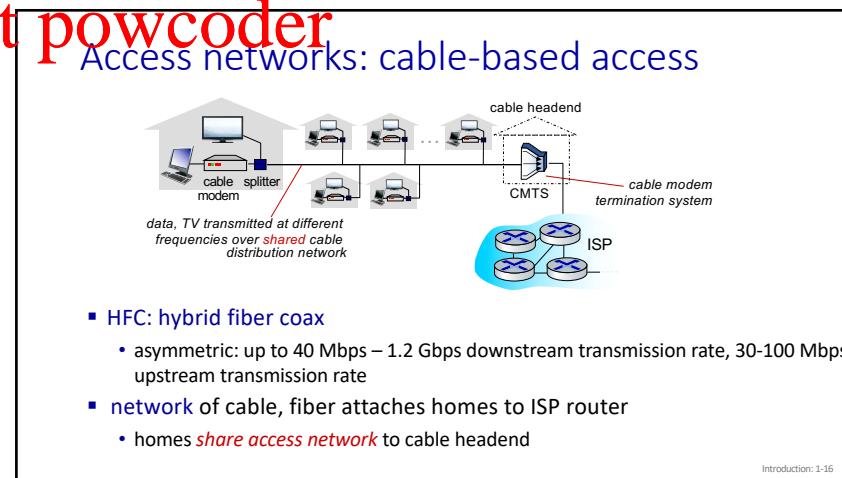


14

Assignment Project Exam Help  
<https://powcoder.com>

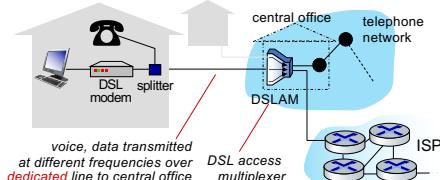


15



16

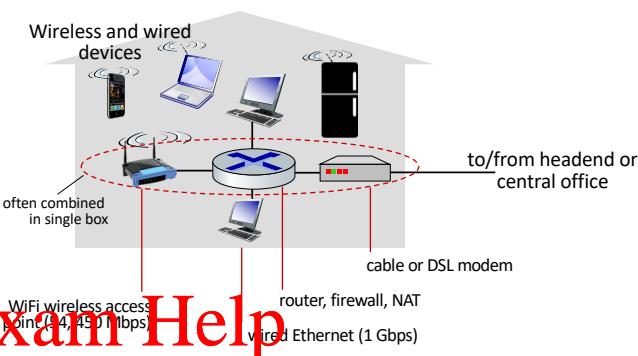
## Access networks: digital subscriber line (DSL)



- use *existing* telephone line to central office DSLAM
  - data over DSL phone line goes to Internet
  - voice over DSL phone line goes to telephone net
- 24-52 Mbps dedicated downstream transmission rate
- 3.5-16 Mbps dedicated upstream transmission rate

Introduction: 1-17

## Access networks: home networks



Introduction: 1-18

17

18

<https://powcoder.com>

## Wireless access networks

Shared *wireless* access network connects end system to router

- via base station aka "access point"

### Wireless local area networks (WLANs)

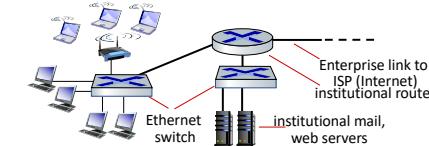
- typically within or around building (~100 ft)
- 802.11b/g/n (WiFi): 11, 54, 450 Mbps transmission rate



Introduction: 1-19

## Add WeChat powcoder

## Access networks: enterprise networks



- companies, universities, etc.
- mix of wired, wireless link technologies, connecting a mix of switches and routers (we'll cover differences shortly)
  - Ethernet: wired access at 100Mbps, 1Gbps, 10Gbps
  - WiFi: wireless access points at 11, 54, 450 Mbps

Introduction: 1-20

19

20

## Access networks: data center networks

- high-bandwidth links (10s to 100s Gbps) connect hundreds to thousands of servers together, and to Internet



Courtesy: Massachusetts Green High Performance Computing Center (nghpcc.org)

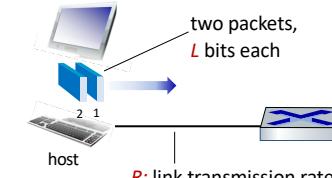
Introduction: 1-21

21

## Host: sends *packets* of data

host sending function:

- takes application message
- breaks into smaller chunks, known as **packets**, of length  $L$  bits
- transmits packet into access network at **transmission rate  $R$** 
  - link transmission rate, aka link **capacity, aka link bandwidth**



Introduction: 1-22

22

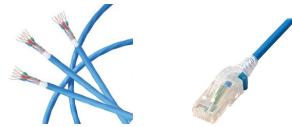
<https://powcoder.com>

## Links: physical media

- bit**: propagates between transmitter/receiver pairs
- physical link**: what lies between transmitter & receiver
- guided media**:
  - signals propagate in solid media: copper, fiber, coax
- unguided media**:
  - signals propagate freely, e.g., radio

### Twisted pair (TP)

- two insulated copper wires
  - Category 5: 100 Mbps, 1 Gbps Ethernet
  - Category 6: 10Gbps Ethernet



Introduction: 1-23

23

Add WeChat **powcoder**

## Links: physical media

Coaxial cable:

- two concentric copper conductors
- bidirectional
- broadband:
  - multiple frequency channels on cable
  - 100's Mbps per channel



Fiber optic cable:

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



Introduction: 1-24

24

## Links: physical media

**Wireless radio**

- signal carried in various “bands” in electromagnetic spectrum
- no physical “wire”
- broadcast, “half-duplex” (sender to receiver)
- propagation environment effects:
  - reflection
  - obstruction by objects
  - Interference/noise

**Radio link types:**

- **Wireless LAN (WiFi)**
  - 10-100's Mbps; 10's of meters
- **wide-area** (e.g., 4G cellular)
  - 10's Mbps over ~10 Km
- **Bluetooth:** cable replacement
  - short distances, limited rates
- **terrestrial microwave**
  - point-to-point; 45 Mbps channels
- **satellite**
  - up to 15 Mbps per channel
  - 120 msec end-to-end delay

Introduction: 1-25

## Chapter 1: roadmap

- What is the Internet?
- What is 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

Introduction: 1-26

25

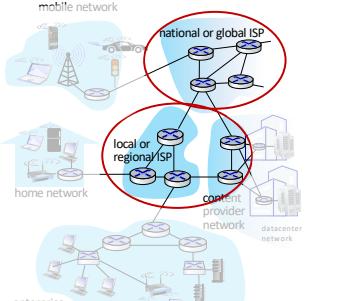
26

# Assignment Project Exam Help

<https://powcoder.com>

## The network core

- mesh of interconnected routers
- **packet-switching:** hosts break application-layer messages into *packets*
- network **forwards** packets from one router to the next, across links on path from **source to destination**



Introduction: 1-27

## Add WeChat powcoder

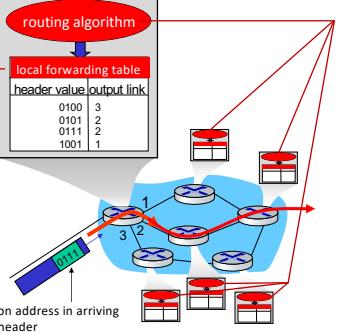
### Two key network-core functions

**Forwarding:**

- aka “switching”
- **local** action: move arriving packets from router’s input link to appropriate router output link

**Routing:**

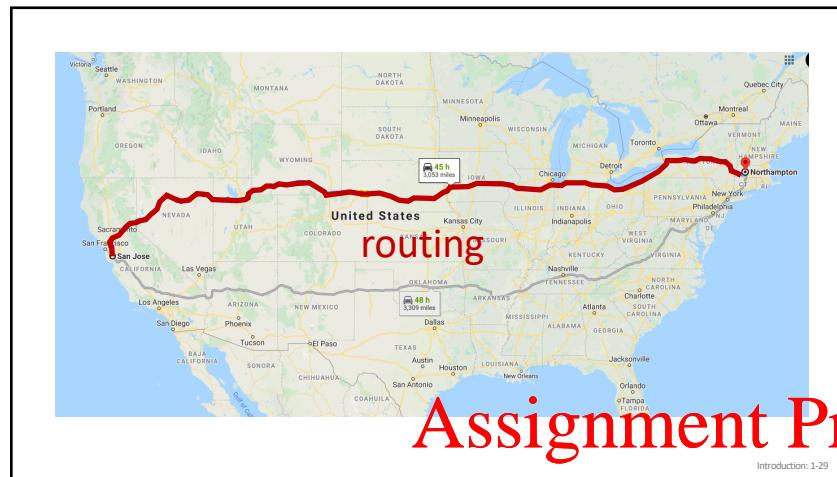
- **global** action: determine source-destination paths taken by packets
- routing algorithms



Introduction: 1-28

27

28

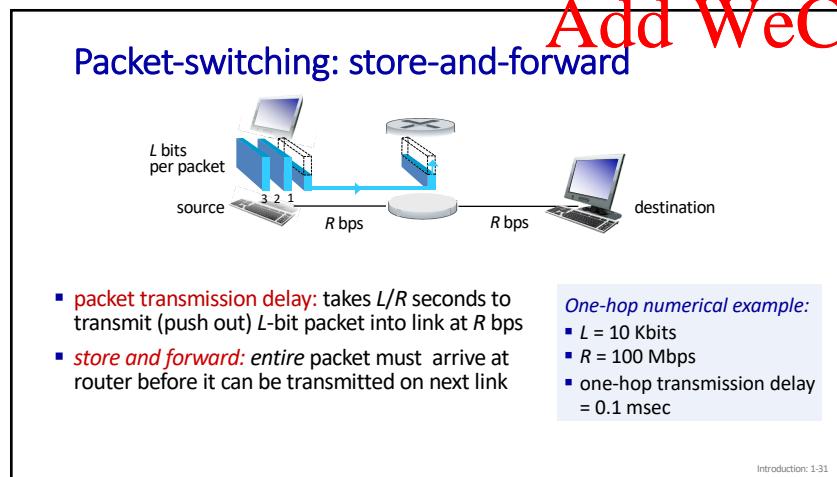


29

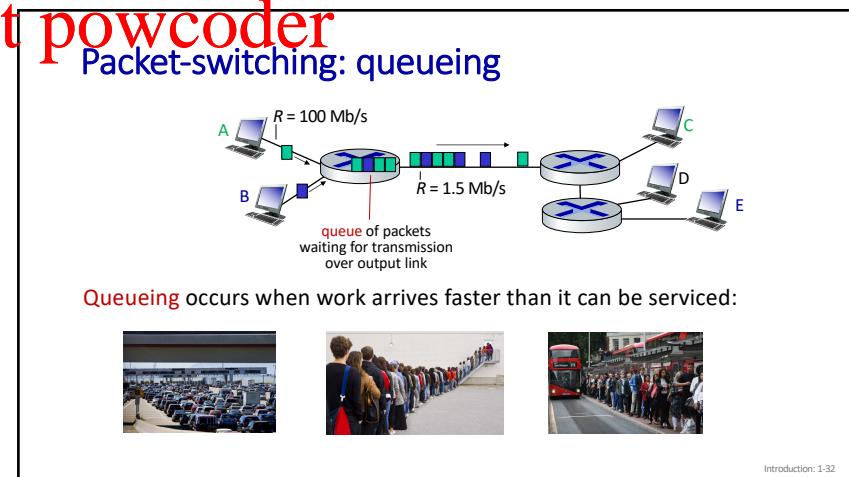


30

<https://powcoder.com>



31



### Packet-switching: queueing

**Packet queuing and loss:** if arrival rate (in bps) to link exceeds transmission rate (bps) of link for some period of time:

- packets will queue, waiting to be transmitted on output link
- packets can be dropped (lost) if memory (buffer) is overfilled

Introduction: 1-33

33

### Alternative to packet switching: circuit switching

end-end resources allocated to, reserved for "call" between source and destination

- in diagram, each link has four circuits.
  - call gets 2<sup>nd</sup> circuit in top link and 1<sup>st</sup> 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

\* Check out the online interactive exercises for more examples: [http://gaia.cs.umass.edu/kurose\\_ross/interactive](http://gaia.cs.umass.edu/kurose_ross/interactive)

Introduction: 1-34

34

Assignment Project Exam Help

<https://powcoder.com>

### Circuit switching: FDM and TDM

**Frequency Division Multiplexing (FDM)**

- optical, electromagnetic frequencies divided into (narrow) frequency bands
- each call allocated its own band, can transmit at max rate of that narrow band

**Time Division Multiplexing (TDM)**

- time divided into slots
- each call allocated periodic slot(s), can transmit at maximum rate of (wider) frequency band (only) during its time slot(s)

Introduction: 1-35

35

### Packet switching versus circuit switching

**example:**

- 1 Gbps link
- each user:
  - 100 Mb/s when "active"
  - active 10% of time

**Q:** how many users can use this network under circuit-switching and packet switching?

- circuit-switching:** 10 users
- packet switching:** with 35 users, probability > 10 active at same time is less than .0004 \*

**Q:** how did we get value 0.0004?

**A:** HW problem (for those with course in probability only)

\* Check out the online interactive exercises for more examples: [http://gaia.cs.umass.edu/kurose\\_ross/interactive](http://gaia.cs.umass.edu/kurose_ross/interactive)

Introduction: 1-36

36

## Packet switching versus circuit switching

Is packet switching a “slam dunk winner”?

- great for “bursty” data – sometimes has data to send, but at other times not
  - resource sharing
  - simpler, no call setup
- **excessive congestion possible:** packet delay and loss due to buffer overflow
  - protocols needed for reliable data transfer, congestion control
- **Q: How to provide circuit-like behavior with packet-switching?**
  - “It’s complicated.” We’ll study various techniques that try to make packet switching as “circuit-like” as possible.

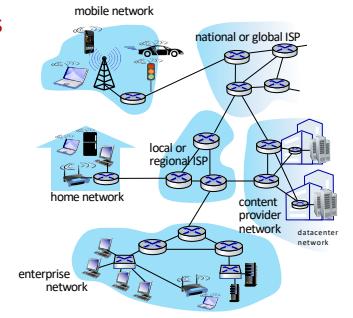
**Q:** human analogies of reserved resources (circuit switching) versus on-demand allocation (packet switching)?

Introduction: 1-37

37

## Internet structure: a “network of networks”

- hosts connect to Internet via **access** Internet Service Providers (ISPs)
- access ISPs in turn must be interconnected
  - so that *any two hosts (anywhere!)* can send packets to each other
- resulting network of networks is very complex
  - evolution driven by **economics, national policies**



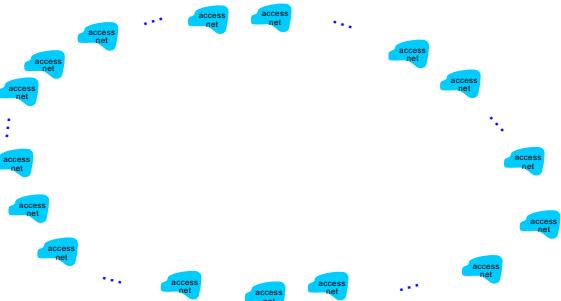
*Let's take a stepwise approach to describe current Internet structure*

38

<https://powcoder.com>

## Internet structure: a “network of networks”

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

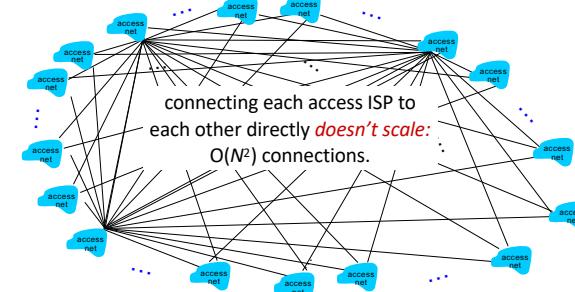


Introduction: 1-39

39

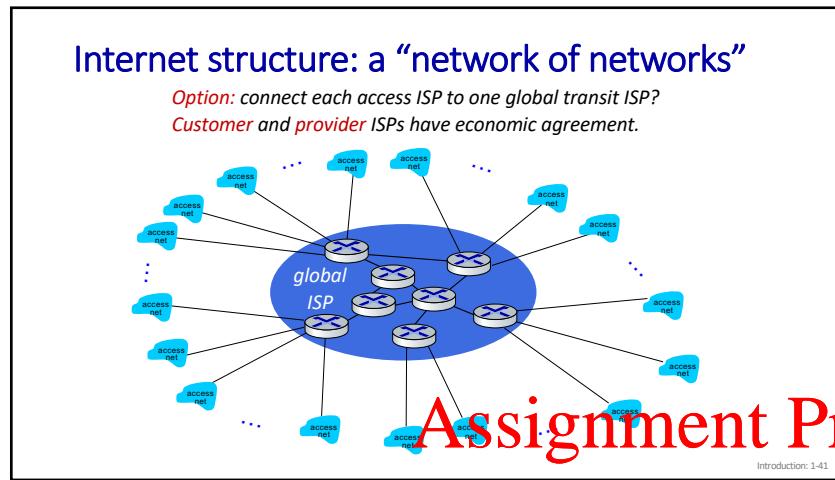
## Internet structure: a “network of networks”

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

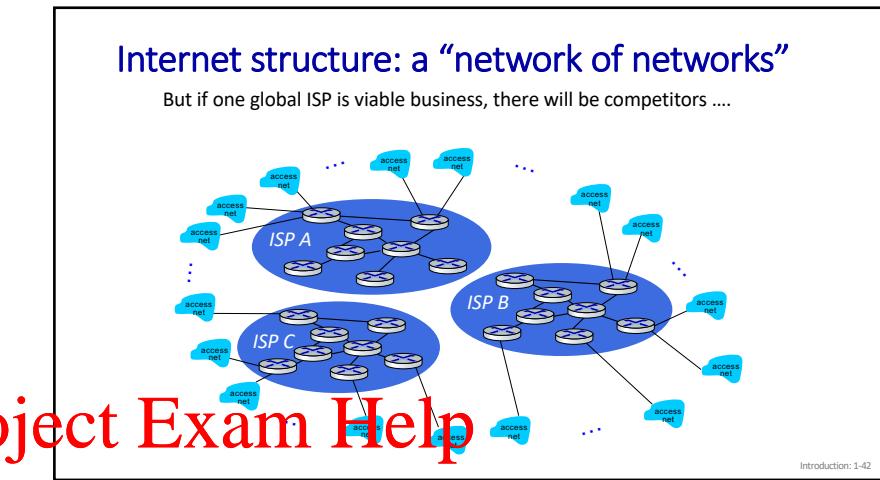


Introduction: 1-40

40

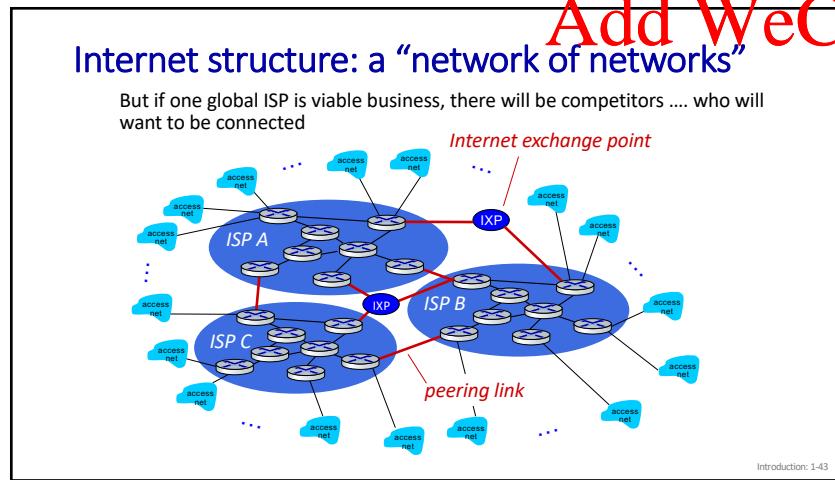


41

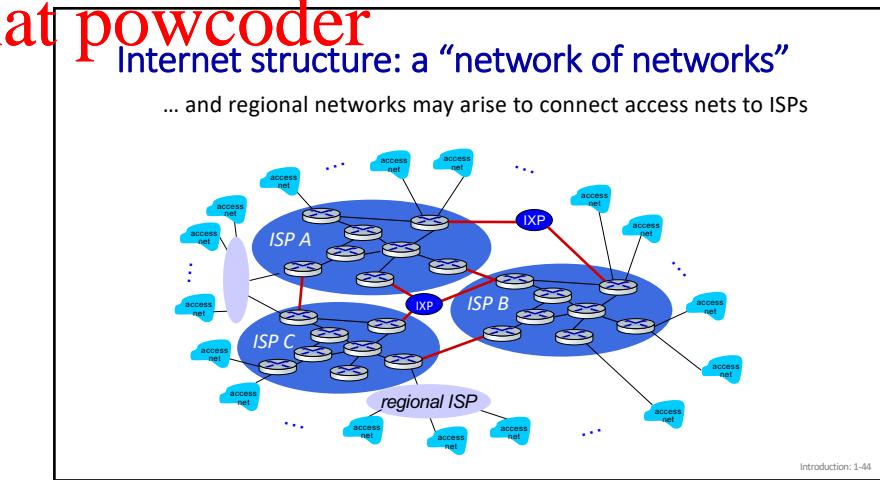


42

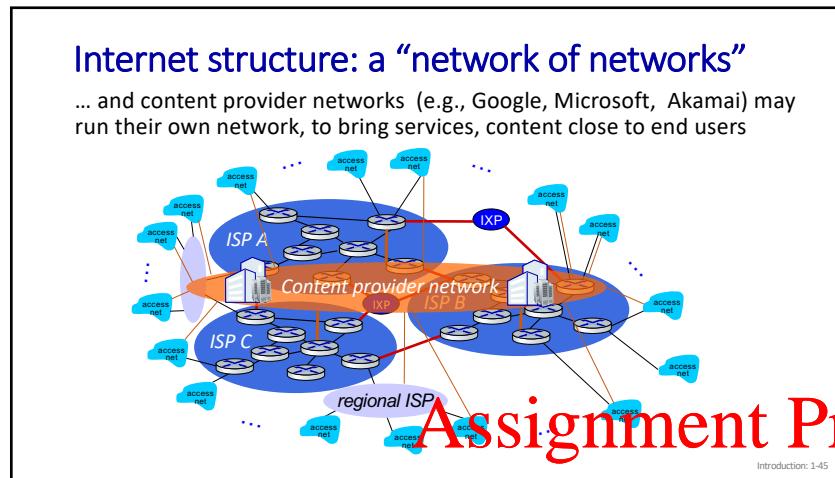
<https://powcoder.com>



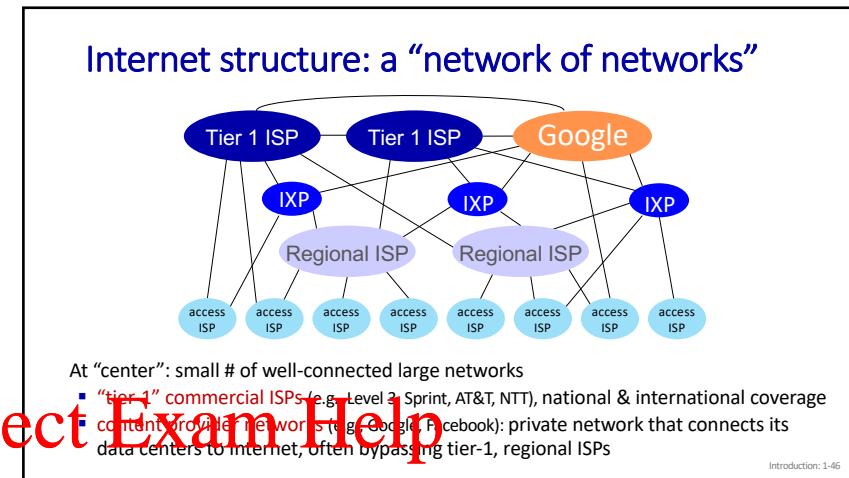
43



44

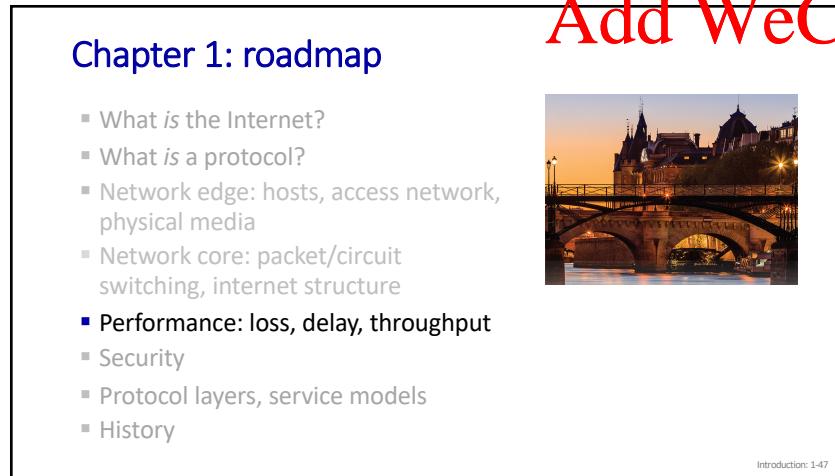


45

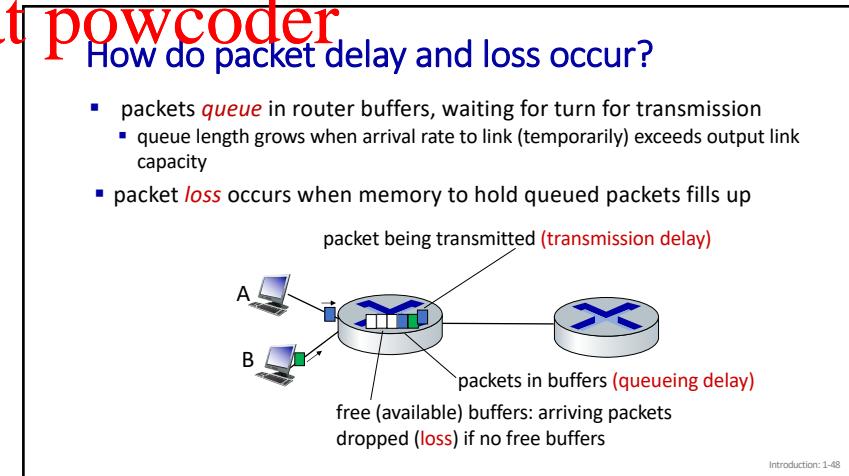


46

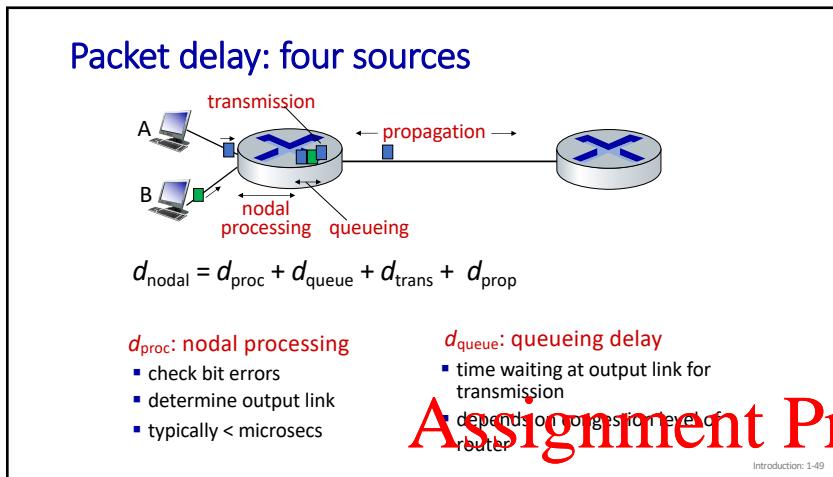
<https://powcoder.com>



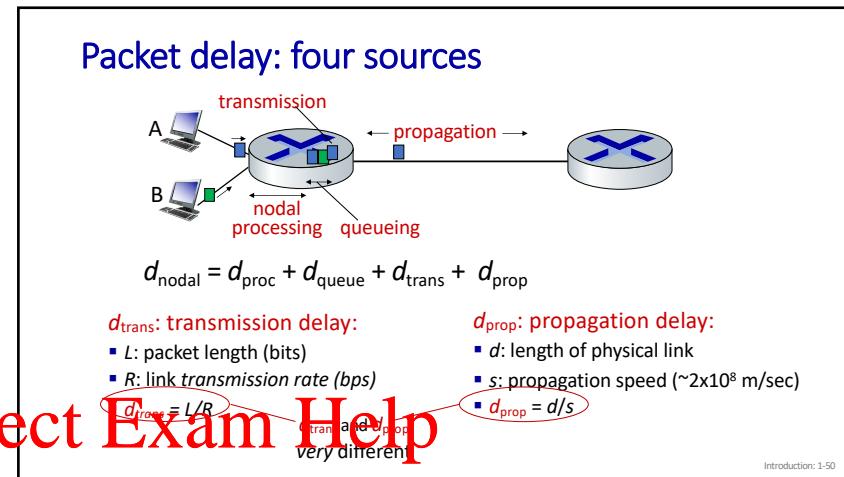
47



48

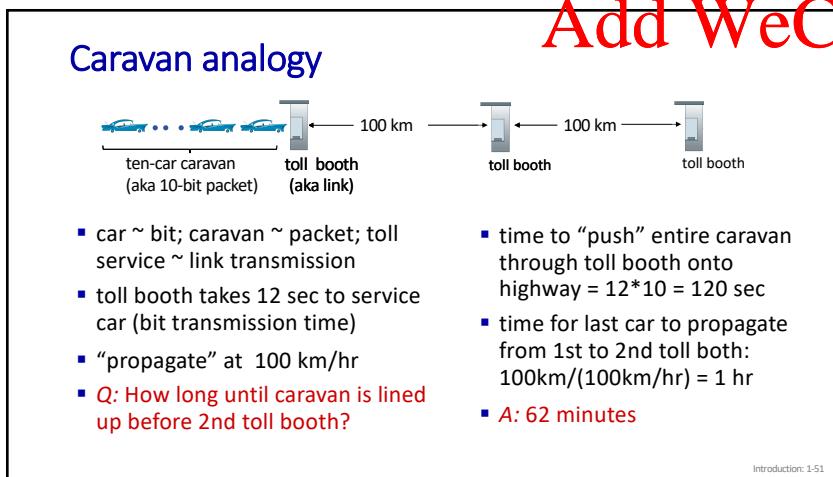


49

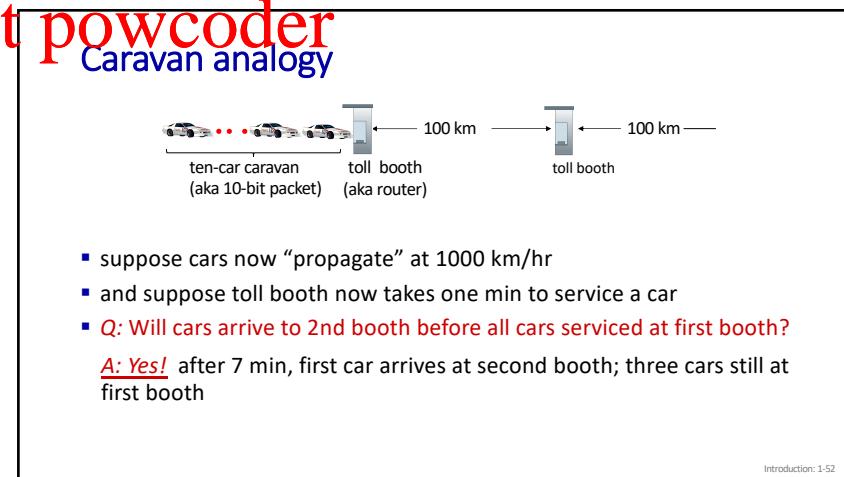


50

<https://powcoder.com>



51



52

## Packet queueing delay (revisited)

- $a$ : average packet arrival rate
- $L$ : packet length (bits)
- $R$ : link bandwidth (bit transmission rate)

$$\frac{L \cdot a}{R} : \frac{\text{arrival rate of bits}}{\text{service rate of bits}} \quad \text{"traffic intensity"}$$

$\frac{L \cdot a}{R} : \frac{\text{arrival rate of bits}}{\text{service rate of bits}} \quad \text{"traffic intensity"}$

- $La/R \sim 0$ : avg. queueing delay small
- $La/R \rightarrow 1$ : avg. queueing delay large
- $La/R > 1$ : more "work" arriving is more than can be serviced - average delay infinite!

average queueing delay

traffic intensity =  $La/R$

$La/R \sim 0$

$La/R \rightarrow 1$

Introduction: 1-53

53

## "Real" Internet delays and routes

- what do "real" Internet delay & 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 (with time-to-live field value of  $i$ )
  - router  $i$  will return packets to sender
  - sender measures time interval between transmission and reply

Introduction: 1-54

54

Assignment Project Exam Help

<https://powcoder.com>

## Real Internet delays and routes

**traceroute:** gaia.cs.umass.edu to www.eurecom.fr

```

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.gant.net (62.40.96.129) 109 ms 102 ms 104 ms
10 de.fr1.fr.gant.net (62.40.96.50) 113 ms 121 ms 114 ms
11 renater-gw.fr1.fr.gant.net (62.40.103.54) 112 ms 114 ms 116 ms
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 *** * means no response (probe lost, router not replying)
18 ***
19 fantasia.eurecom.fr (193.55.113.142) 132 ms 128 ms 136 ms
  
```

\* Do some traceroutes from exotic countries at [www.traceroute.org](http://www.traceroute.org)

Introduction: 1-55

55

## 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

buffer (waiting area)

packet being transmitted

packet arriving to full buffer is lost

A

B

\* Check out the Java applet for an interactive animation (on publisher's website) of queuing and loss

Introduction: 1-56

56

## Throughput

- **throughput:** rate (bits/time unit) at which bits are being sent from sender to receiver
  - **instantaneous:** rate at given point in time
  - **average:** rate over longer period of time

server sends bits (fluid) into pipe

pipe that can carry fluid at rate ( $R_s$  bits/sec)

pipe that can carry fluid at rate ( $R_c$  bits/sec)

Introduction: 1-57

57

## Throughput

$R_s < R_c$  What is average end-end throughput?

$R_s > R_c$  What is average end-end throughput?

bottleneck link

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

Introduction: 1-58

58

Assignment Project Exam Help  
<https://powcoder.com>

## Throughput: network scenario

per-connection end-end throughput:  $\min(R_c, R_s, R/10)$

in practice:  $R_c$  or  $R_s$  is often bottleneck

\* Check out the online interactive exercises for more examples: [http://gala.cs.umass.edu/kurose\\_ross/](http://gala.cs.umass.edu/kurose_ross/)

Introduction: 1-59

59

## Add WeChat powcoder

### Chapter 1: roadmap

- What is the Internet?
- What is 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

Introduction: 1-60

60

## Network security

- 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!
- We now need to think about:
  - how bad guys can attack computer networks
  - how we can defend networks against attacks
  - how to design architectures that are immune to attacks

Introduction: 1-61

61

## Network security

- 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!
- We now need to think about:
  - how bad guys can attack computer networks
  - how we can defend networks against attacks
  - how to design architectures that are immune to attacks

Introduction: 1-62

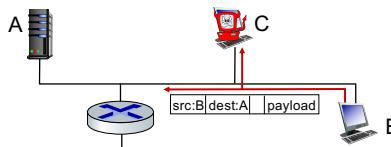
62

# Assignment Project Exam Help

## Bad guys: packet interception

### *packet “sniffing”:*

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



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

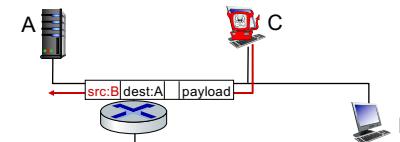
Introduction: 1-63

63

## Add WeChat powcoder

## Bad guys: take identity

### *IP spoofing*: injection of packet with false source address



Introduction: 1-64

64

## Bad guys: denial of service

**Denial of Service (DoS):** attackers make resources (server, bandwidth) unavailable to legitimate traffic by overwhelming resource with bogus traffic

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


Introduction: 1-65

65

## Lines of defense:

- **authentication:** proving you are who you say you are
  - cellular networks provides hardware identity via SIM card; no such hardware assist in traditional Internet
- **confidentiality:** via encryption
- **integrity checks:** digital signatures prevent/detect tampering
- **access restrictions:** password-protected VPNs
- **firewalls:** specialized “middleboxes” in access and core networks:
  - off-by-default: filter incoming packets to restrict senders, receivers, applications
  - detecting/reacting to DoS attacks

... lots more on security (throughout, Chapter 8)
Introduction: 1-66

66

**Assignment Project Exam Help**

## Chapter 1: roadmap

- What is the Internet?
- What is 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


Introduction: 1-67

67

**Add WeChat powcoder**

## Protocol “layers” and reference models

Networks are complex, with many “pieces”:

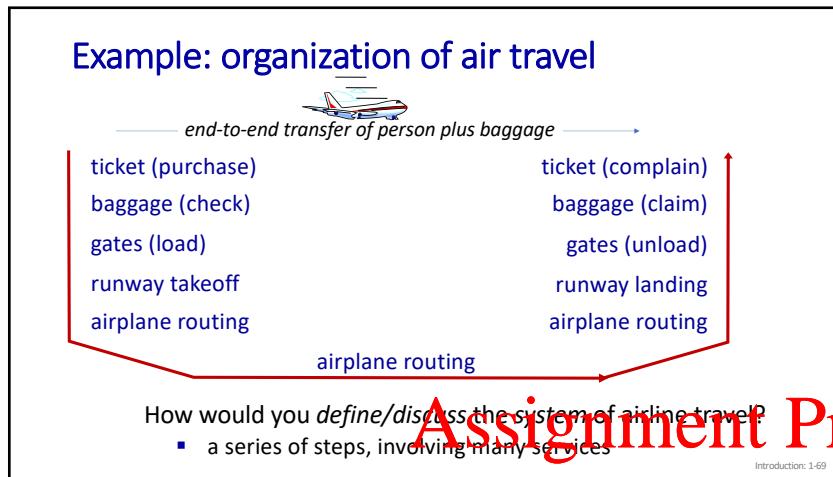
- hosts
- routers
- links of various media
- applications
- protocols
- hardware, software

**Question:** is there any hope of organizing structure of network?

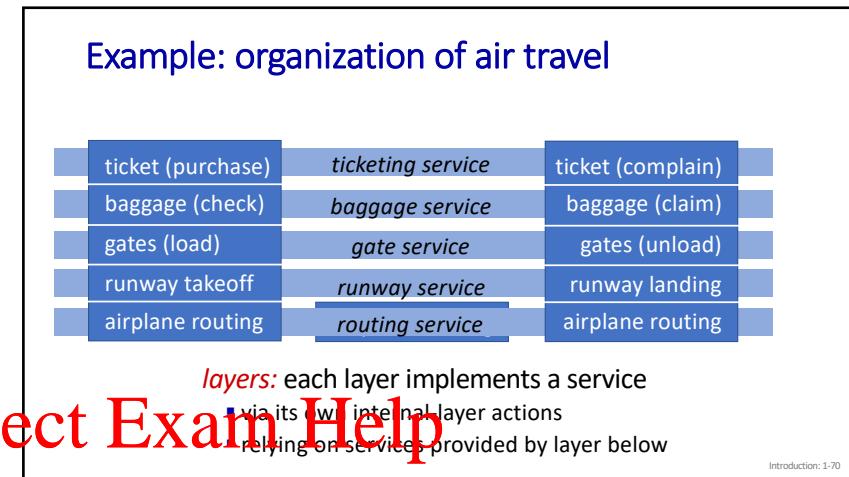
- and/or our discussion of networks?

Introduction: 1-68

68

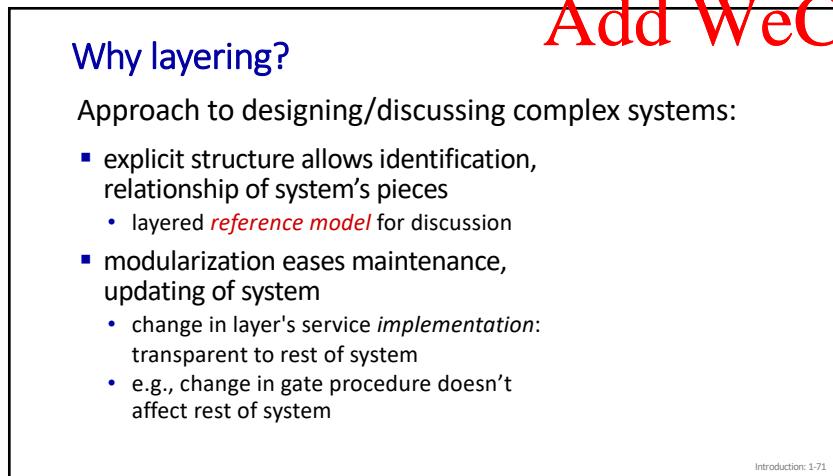


69

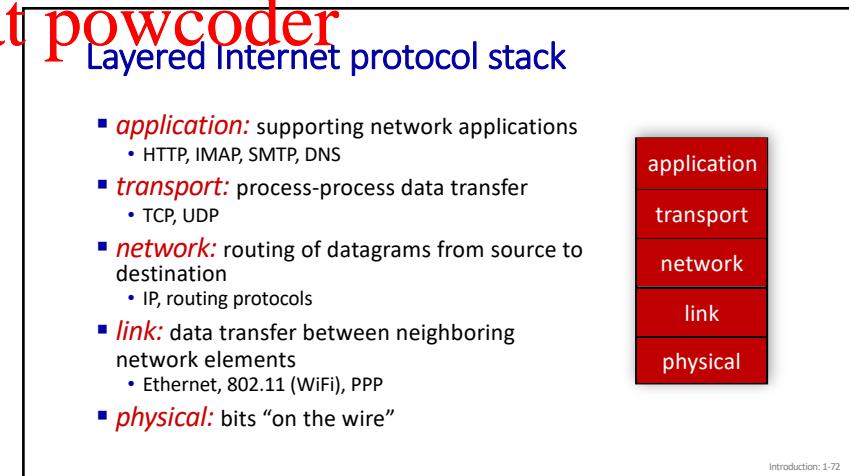


70

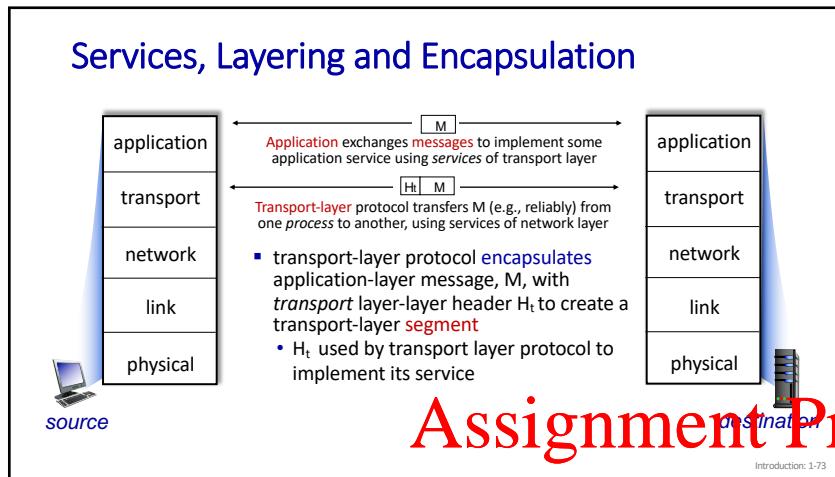
# Assignment Project Exam Help



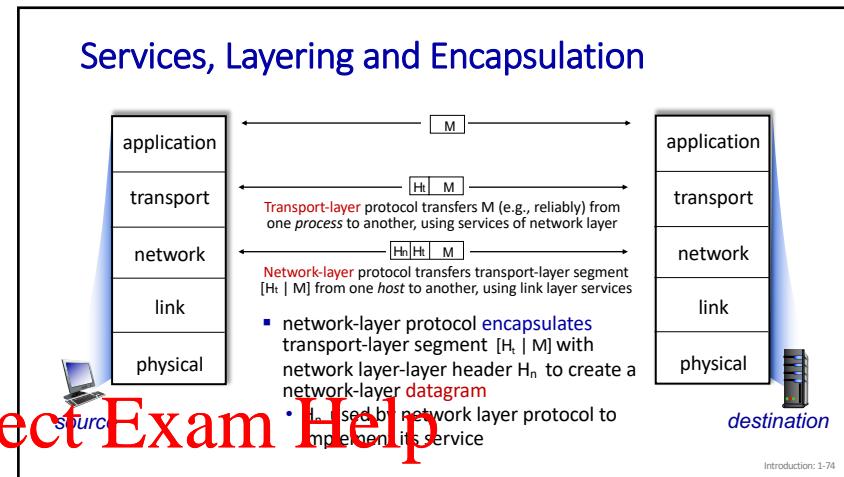
71



72

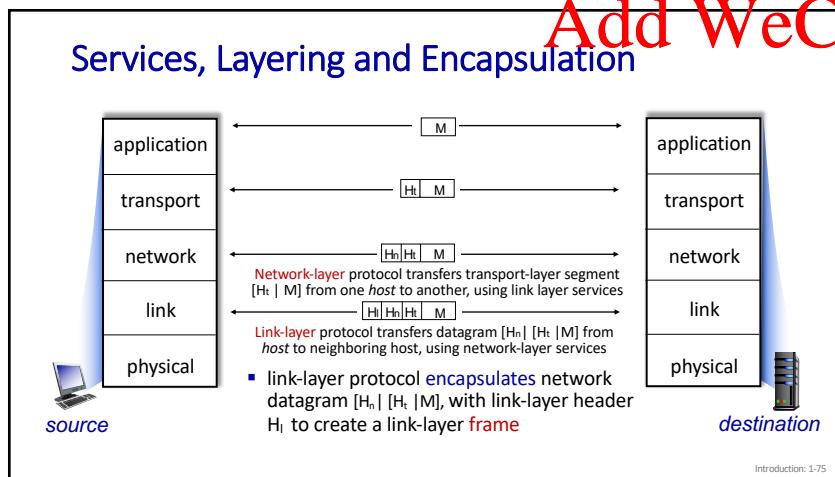


73

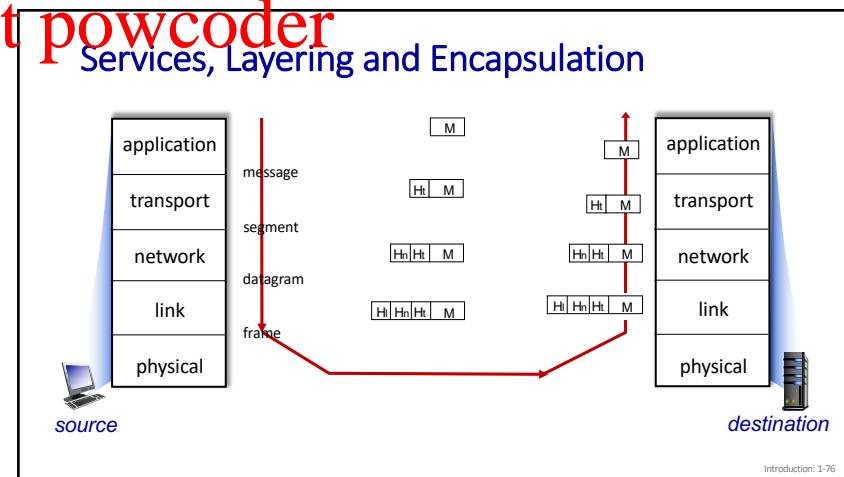


74

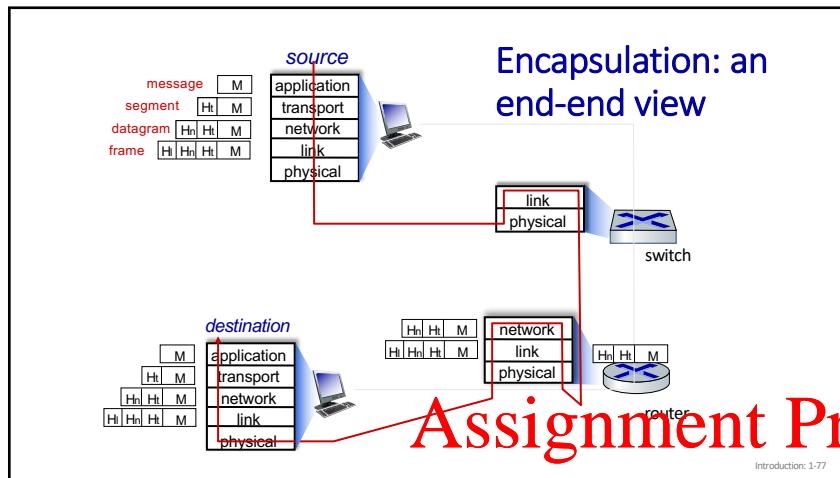
Assignment Project Exam Help  
<https://powcoder.com>



75



76



77

## Chapter 1: roadmap

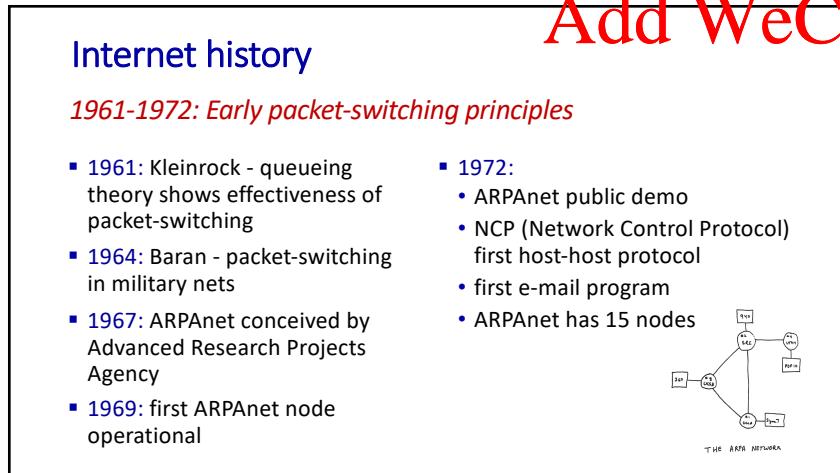
- What is the Internet?
- What is a protocol?
- Network edge: hosts, access network, physical media
- Network core: packet/circuit switching, internet structure
- Performance: loss, delay, throughput
- Security
- Protocol layers, service models
- History



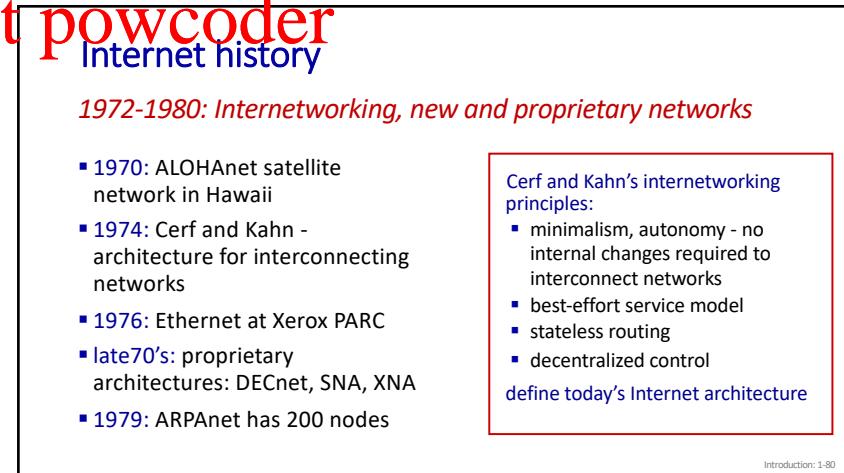
Introduction: 1-78

78

<https://powcoder.com>



79

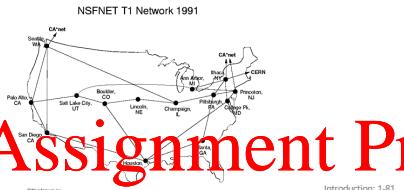


80

## 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



Introduction: 1-81

## Internet history

*1990, 2000s: commercialization, the Web, new applications*

- early 1990s: 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 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

Introduction: 1-82

81

82

Assignment Project Exam Help

## Internet history

*2005-present: scale, SDN, mobility, cloud*

- aggressive deployment of broadband home access (10-100's Mbps)
- 2008: software-defined networking (SDN)
- increasing ubiquity of high-speed wireless access: 4G/5G, WiFi
- service providers (Google, FB, Microsoft) create their own networks
  - bypass commercial Internet to connect "close" to end user, providing "instantaneous" access to social media, search, video content, ...
- enterprises run their services in "cloud" (e.g., Amazon Web Services, Microsoft Azure)
- rise of smartphones: more mobile than fixed devices on Internet (2017)
- ~18B devices attached to Internet (2017)

Introduction: 1-83

## Add WeChat powcoder

*Chapter 1: summary*

*We've covered a "ton" of material!*

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

*You now have:*

- context, overview, vocabulary, "feel" of networking
- more depth, detail, and fun to follow!

Introduction: 1-84

83

84

Additional Chapter 1 slides

## Assignment Project Exam Help

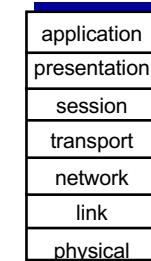
Introduction: 1-85

85

### ISO/OSI reference model

Two layers not found in Internet protocol stack!

- ***presentation***: allow applications to interpret meaning of data, e.g., encryption, compression, machine-specific conventions
- ***session***: synchronization, checkpointing, recovery of data exchange
- Internet stack “missing” these layers!
  - these services, *if needed*, must be implemented in application
  - *needed?*



The seven layer OSI/ISO reference model

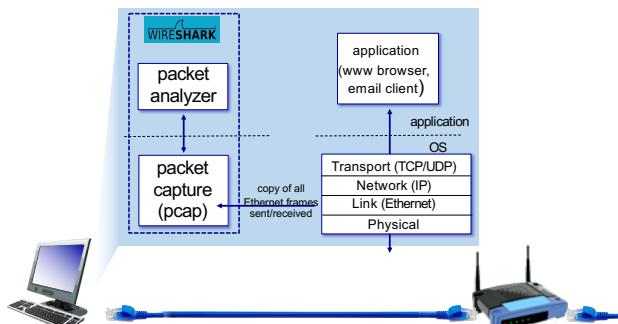
Introduction: 1-86

86

<https://powcoder.com>

Wireshark

Add WeChat powcoder



87