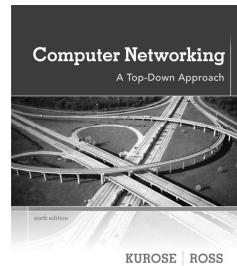


Chapter I Introduction



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

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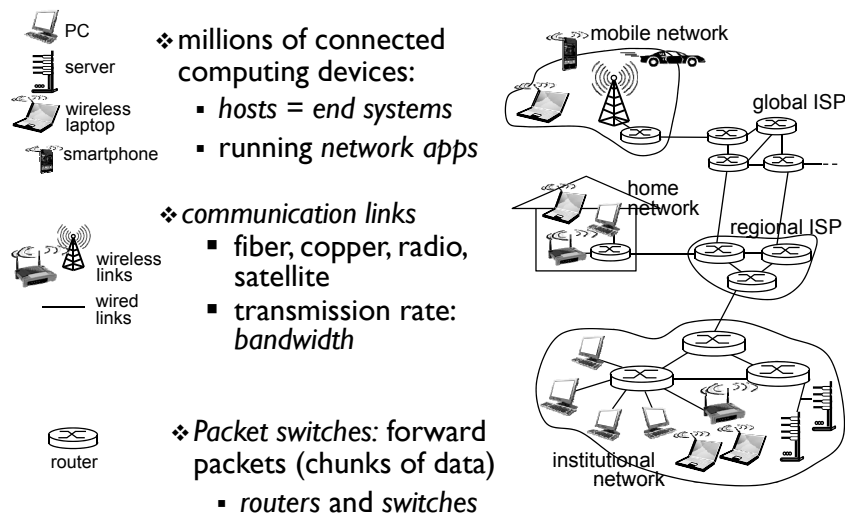
Introduction 1-1

Chapter I: roadmap

- 1.1 what is the Internet?
- 1.2 network edge
 - end systems, access networks, links
- 1.3 network core
 - packet switching, circuit switching, network structure
- 1.4 delay, loss, throughput in networks
- 1.5 protocol layers, service models
- 1.6 networks under attack: security
- 1.7 history

Introduction 1-2

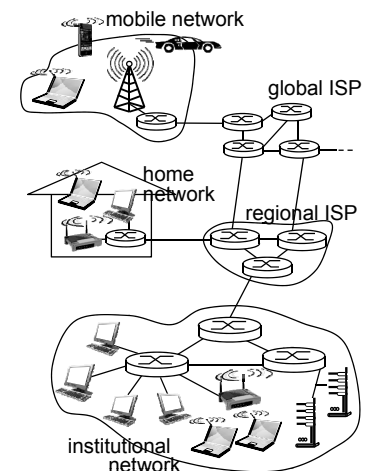
What's the Internet: "nuts and bolts" view



Introduction 1-3

What's the Internet: "nuts and bolts" view

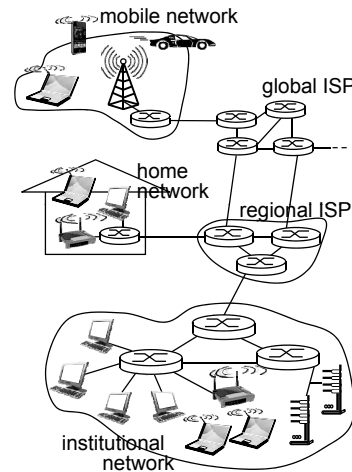
- ❖ Internet: "network of networks"
 - Interconnected ISPs
- ❖ protocols control sending, receiving of msgs
 - e.g., TCP, IP, HTTP, Skype, 802.11
- ❖ Internet standards
 - RFC: Request for comments
 - IETF: Internet Engineering Task Force



Introduction 1-4

What's the Internet: a service view

- ❖ *Infrastructure that provides services to applications:*
 - Web, VoIP, email, games, e-commerce, social nets, ...
- ❖ *provides programming interface to apps*
 - hooks that allow sending and receiving app programs to "connect" to Internet
 - provides service options, analogous to postal service



Introduction 1-5

What's a protocol?

human protocols:

- ❖ "what's the time?"
- ❖ "I have a question"
- ❖ introductions

... specific msgs sent

... specific actions taken when msgs received, or other events

network protocols:

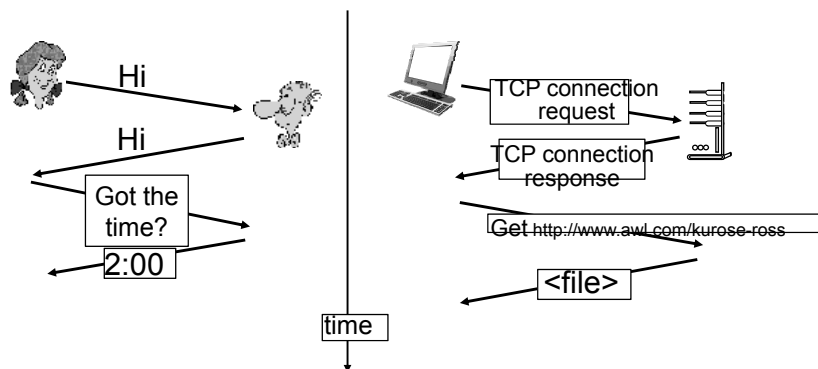
- ❖ machines rather than humans
- ❖ all communication activity in Internet governed by protocols

protocols define format, order of msgs sent and received among network entities, and actions taken on msg transmission, receipt

Introduction 1-6

What's a protocol?

a human protocol and a computer network protocol:



Q: other human protocols?

Introduction 1-7

Chapter I: roadmap

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A closer look at network structure:

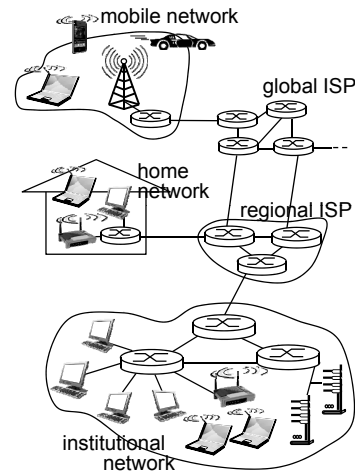
❖ network edge:

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

❖ access networks, physical media: wired, wireless communication links

❖ network core:

- interconnected routers
- network of networks



Introduction 1-9

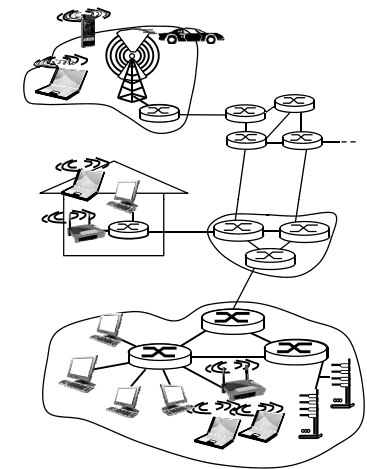
Access networks and physical media

Q: How to connect end systems to edge router?

- ❖ residential access nets
- ❖ institutional access networks (school, company)
- ❖ mobile access networks

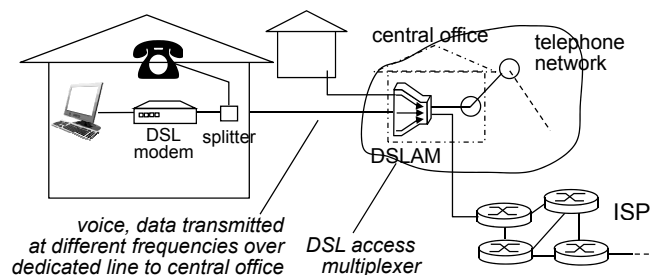
keep in mind:

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



Introduction 1-10

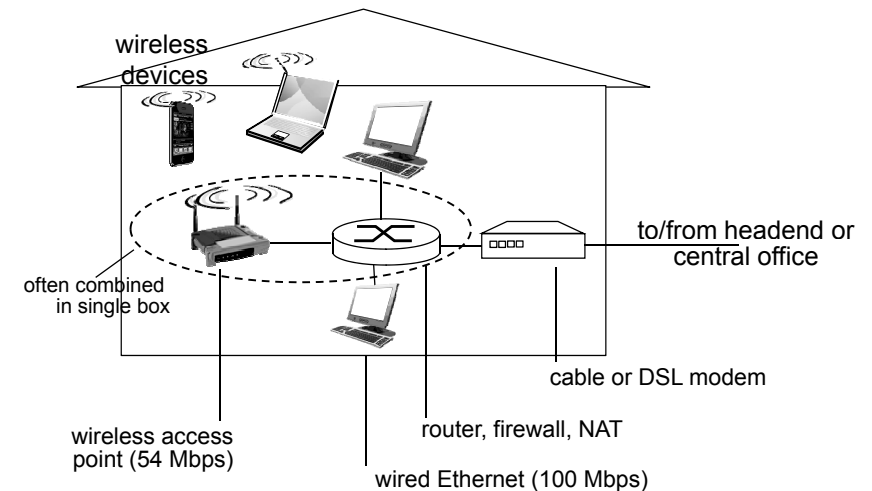
Access net: digital subscriber line (DSL)



- ❖ 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
- ❖ < 2.5 Mbps upstream transmission rate (typically < 1 Mbps)
- ❖ < 24 Mbps downstream transmission rate (typically < 10 Mbps)

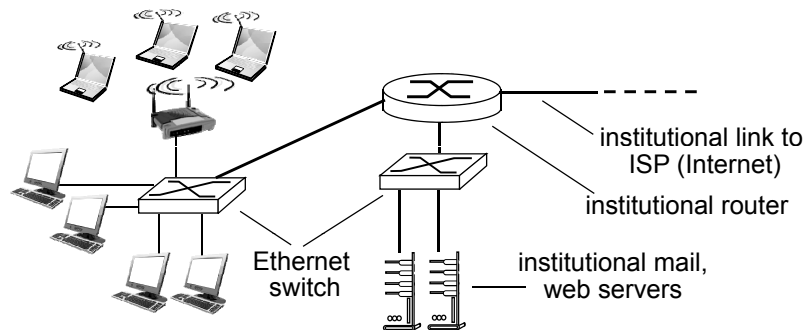
Introduction 1-11

Access net: home network



Introduction 1-12

Enterprise access networks (Ethernet)



- ❖ typically used in companies, universities, etc
- ❖ 10 Mbps, 100Mbps, 1Gbps, 10Gbps transmission rates
- ❖ today, end systems typically connect into Ethernet switch

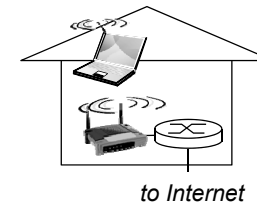
Introduction 1-13

Wireless access networks

- ❖ shared wireless access network connects end system to router
 - via base station aka “access point”

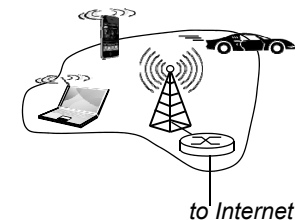
wireless LANs:

- 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, 4G: LTE

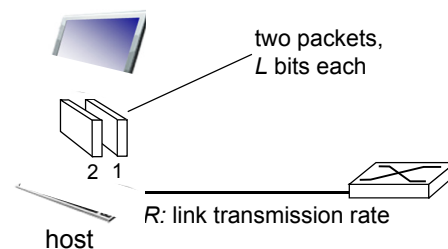


Introduction 1-14

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*



$$\text{packet transmission delay} = \text{time needed to transmit } L\text{-bit packet into link} = \frac{L \text{ (bits)}}{R \text{ (bits/sec)}}$$

1-15

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



Introduction 1-16

Physical media: coax, fiber

coaxial cable:

- ❖ two concentric copper conductors
- ❖ bidirectional
- ❖ broadband:
 - multiple channels on cable
 - HFC



fiber optic cable:

- ❖ glass fiber carrying light pulses, 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



Introduction 1-17

Physical media: radio

- ❖ signal carried in electromagnetic spectrum
- ❖ no physical “wire”
- ❖ bidirectional
- ❖ propagation environment effects:
 - reflection
 - obstruction by objects
 - interference

radio 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 45Mbps channel (or multiple smaller channels)
 - 270 msec end-end delay
 - geosynchronous versus low altitude

Introduction 1-18

Chapter 1: roadmap

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1.2 network edge

- end systems, access networks, links

1.3 network core

- packet switching, circuit switching, network structure

1.4 delay, loss, throughput in networks

1.5 protocol layers, service models

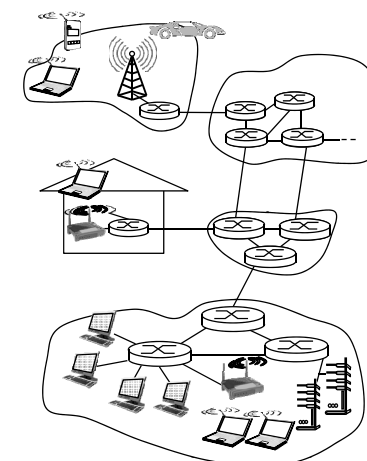
1.6 networks under attack: security

1.7 history

Introduction 1-19

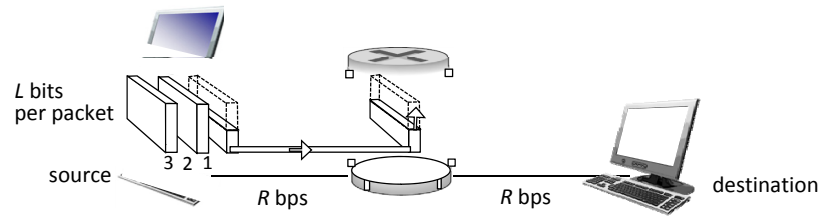
The network core

- ❖ mesh of interconnected routers
- ❖ packet-switching: hosts break application-layer messages into *packets*
 - forward packets from one router to the next, across links on path from source to destination
 - each packet transmitted at full link capacity



Introduction 1-20

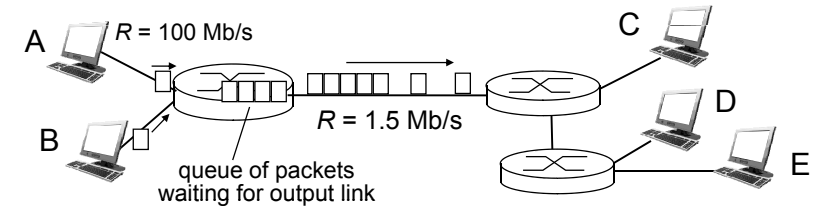
Packet-switching: store-and-forward



- ❖ takes L/R seconds to transmit (push out) L -bit packet into link at R bps
 - ❖ *store and forward*: entire packet must arrive at router before it can be transmitted on next link
 - ❖ end-end delay = $2L/R$ (assuming zero propagation delay)
- one-hop numerical example:
- $L = 7.5$ Mbits
 - $R = 1.5$ Mbps
 - one-hop transmission delay = 5 sec
- } more on delay shortly ...

Introduction 1-21

Packet Switching: queueing delay, loss



queueing and loss:

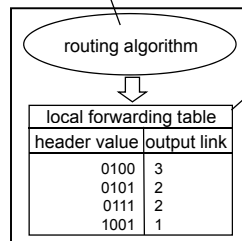
- ❖ If arrival rate (in bits) to link exceeds transmission rate of link for a period of time:
 - packets will queue, wait to be transmitted on link
 - packets can be dropped (lost) if memory (buffer) fills up

Introduction 1-22

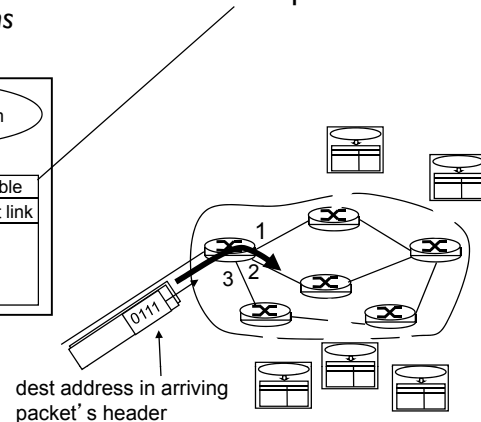
Two key network-core functions

routing: determines source-destination route taken by packets

- *routing algorithms*



forwarding: move packets from router's input to appropriate router output

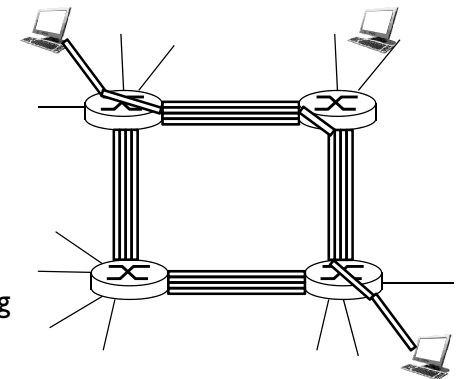


Network Layer 4-23

Alternative core: circuit switching

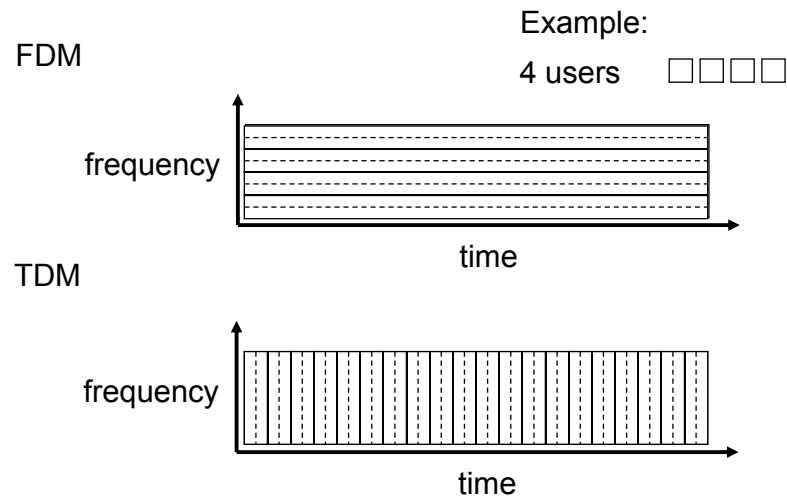
end-end resources allocated to, reserved for "call" between source & dest:

- ❖ In diagram, 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



Introduction 1-24

Circuit switching: FDM versus TDM



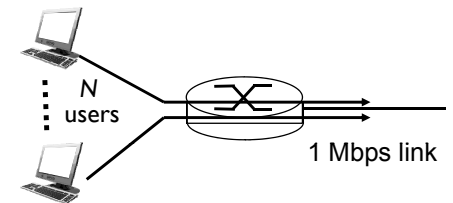
Introduction 1-25

Packet switching versus circuit switching

packet switching allows more users to use network!

example:

- 1 Mb/s link
- each user:
 - 100 kb/s when “active”
 - active 10% of time



❖ *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?

Q: what happens if > 35 users ?

* Check out the online interactive exercises for more examples

Introduction 1-26

Packet switching versus circuit switching

is packet switching a “slam dunk winner?”

- ❖ great for bursty data
 - resource sharing
 - simpler, no call setup
- ❖ 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 apps
 - still an unsolved problem (chapter 7)

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

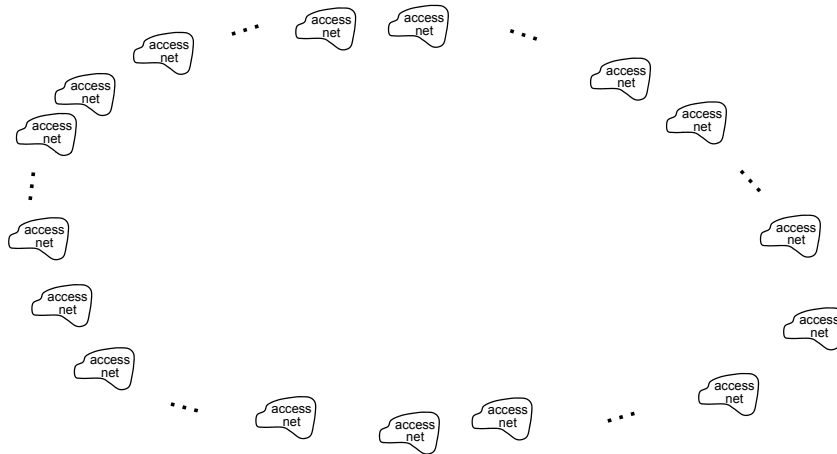
Introduction 1-27

Internet structure: 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

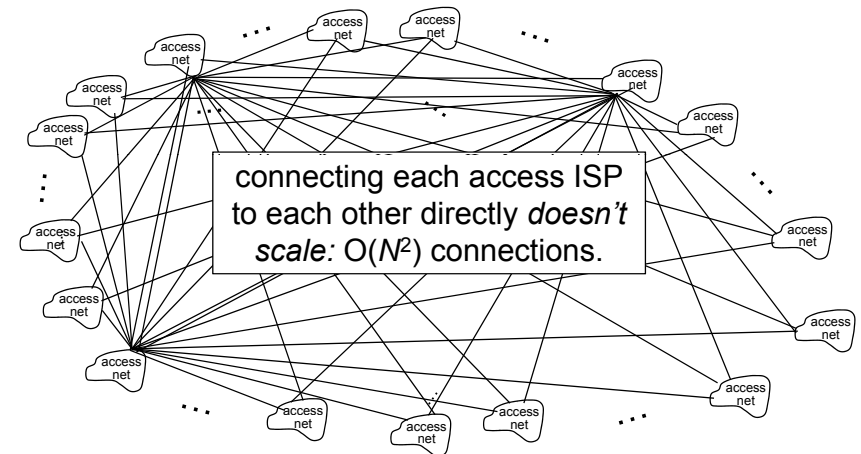
Internet structure: network of networks

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



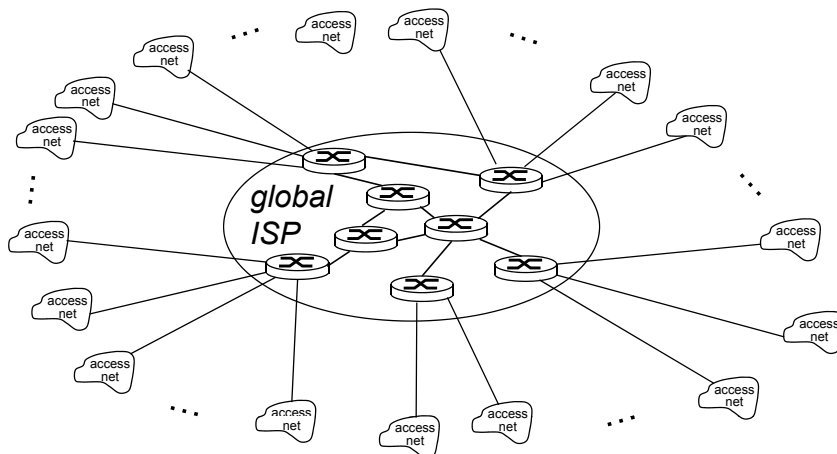
Internet structure: network of networks

Option: connect each access ISP to every other access ISP?



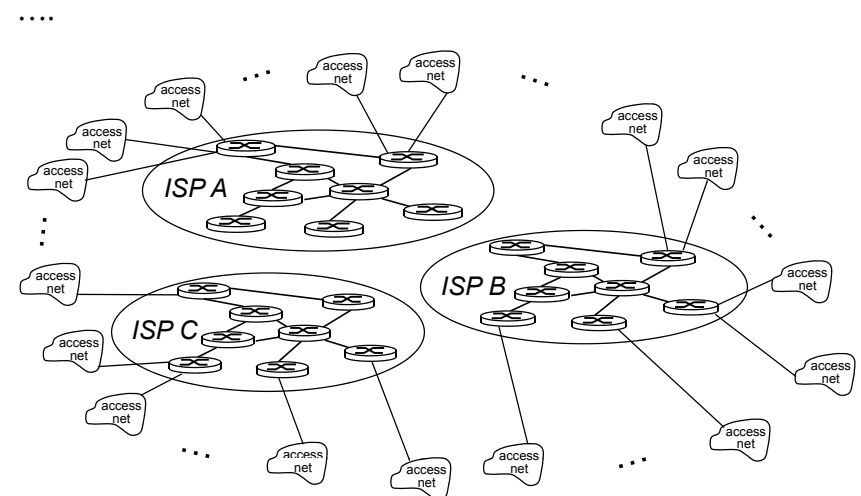
Internet structure: network of networks

Option: connect each access ISP to a global transit ISP? Customer and provider ISPs have economic agreement.



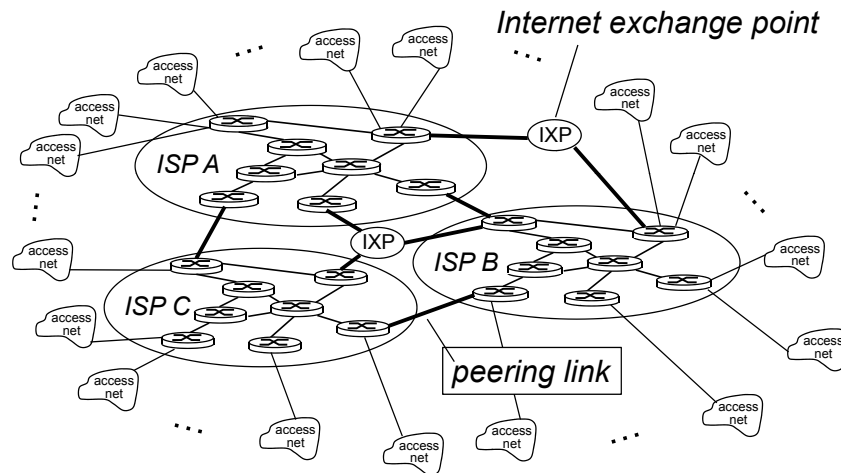
Internet structure: network of networks

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



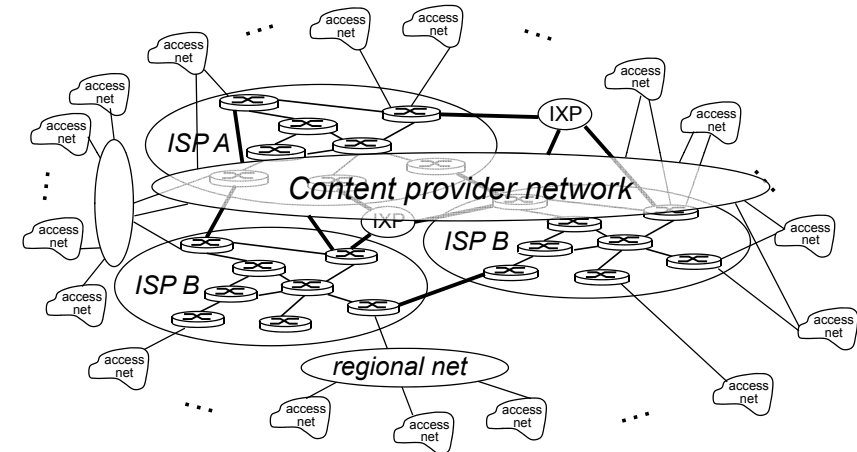
Internet structure: network of networks

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

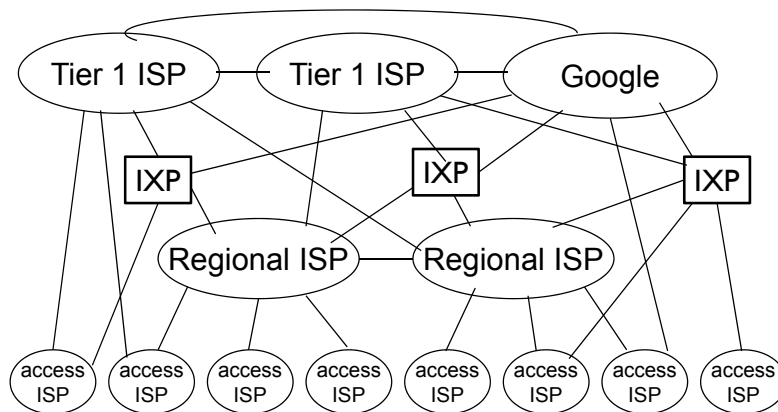


Internet structure: network of networks

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



Internet structure: 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 its data centers to Internet, often bypassing tier-1, regional ISPs

Introduction 1-35

Chapter I: roadmap

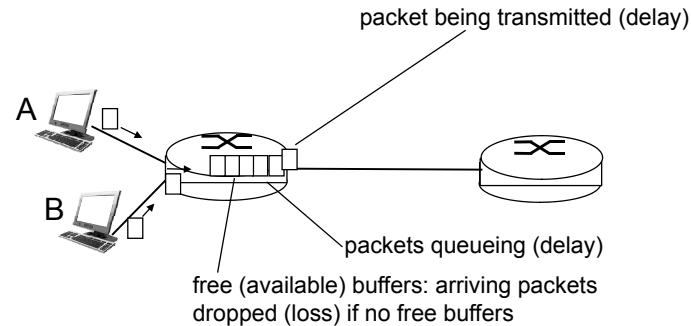
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How do loss and delay occur?

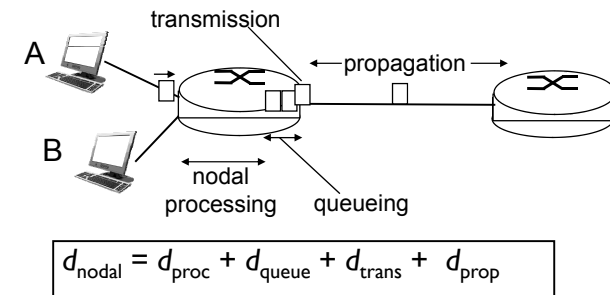
packets *queue* in router buffers

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



Introduction 1-37

Four sources of packet delay



d_{proc} : nodal processing

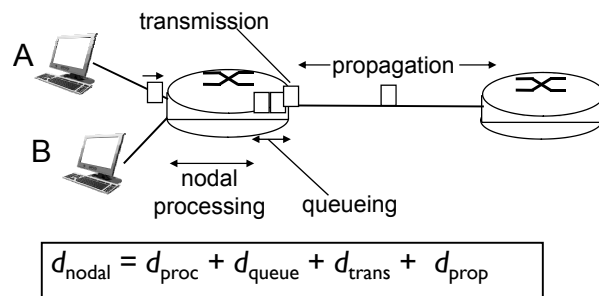
- check bit errors
- determine output link
- typically < msec

d_{queue} : queueing delay

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

Introduction 1-38

Four sources of packet delay



d_{trans} : transmission delay:

- L : packet length (bits)
- R : link bandwidth (bps)
- $d_{\text{trans}} = L/R$

d_{prop} : propagation delay:

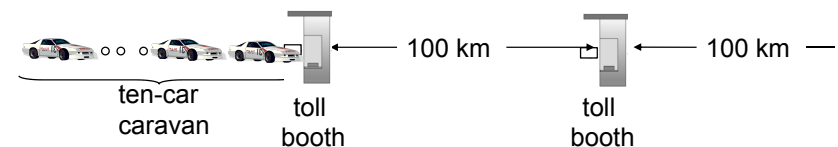
- d : length of physical link
- s : propagation speed in medium ($\sim 2 \times 10^8$ m/sec)
- $d_{\text{prop}} = d/s$

d_{trans} and d_{prop}
very different

* Check out the Java applet for an interactive animation on trans vs. prop delay

Introduction 1-39

Caravan analogy

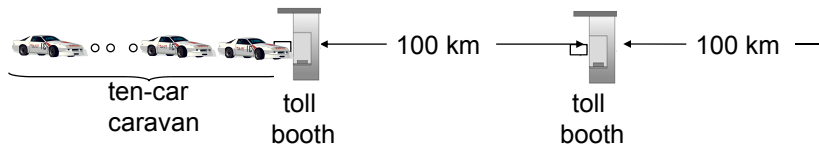


- ❖ cars "propagate" at 100 km/hr
- ❖ toll booth takes 12 sec to service car (bit transmission time)
- ❖ car ~ bit; caravan ~ packet
- ❖ Q : How long until caravan is lined up before 2nd toll booth?

- time to "push" entire caravan through toll booth onto highway = $12 \times 10 = 120$ sec
- time for last car to propagate from 1st to 2nd toll booth: $100 \text{ km} / (100 \text{ km/hr}) = 1$ hr
- A: 62 minutes

Introduction 1-40

Caravan analogy (more)

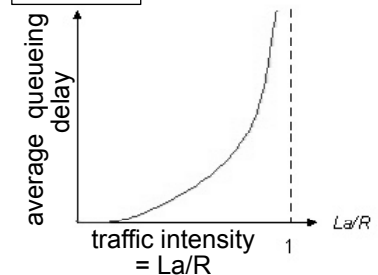


- ❖ suppose cars now “propagate” at 1000 km/hr
- ❖ and suppose toll booth now takes one min to service a car
- ❖ Q: Will cars arrive to 2nd booth before all cars serviced at first booth?
 - A: Yes! after 7 min, 1st car arrives at second booth; three cars still at 1st booth.

Introduction 1-41

Queueing delay (revisited)

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



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

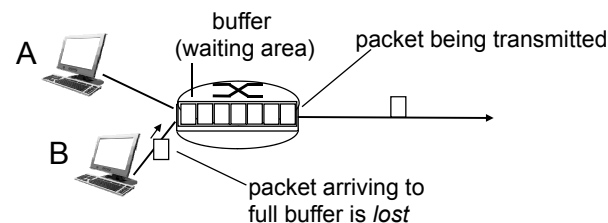


* Check out the Java applet for an interactive animation on queueing and loss

Introduction 1-42

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

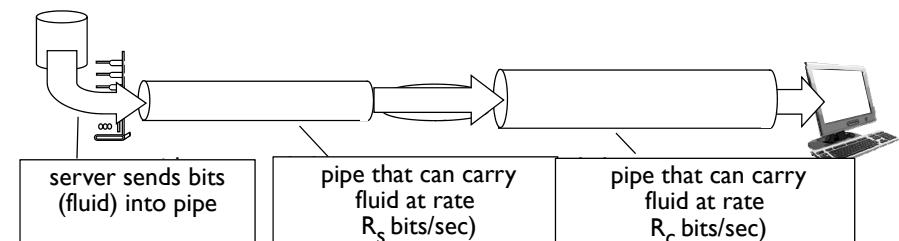


* Check out the Java applet for an interactive animation on queueing and loss

Introduction 1-43

Throughput

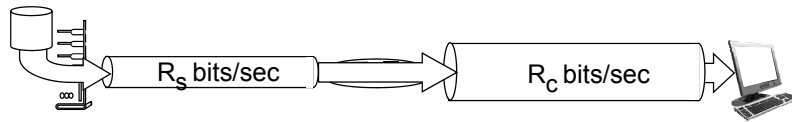
- ❖ *throughput*: rate (bits/time unit) at which bits transferred between sender/receiver
 - *instantaneous*: rate at given point in time
 - *average*: rate over longer period of time



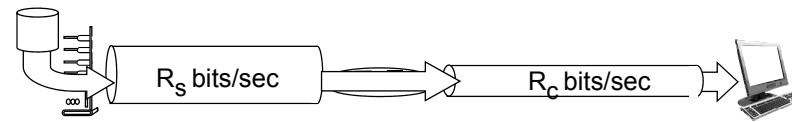
Introduction 1-44

Throughput (more)

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



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



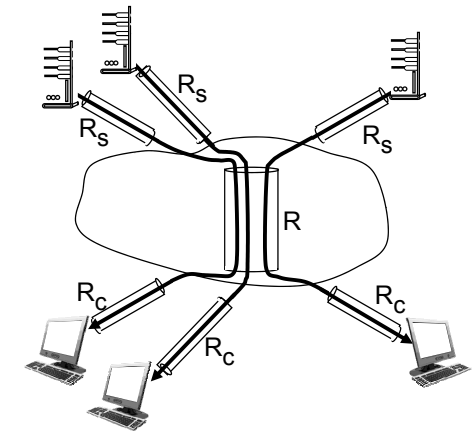
bottleneck link

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

Introduction 1-45

Throughput: Internet scenario

- ❖ 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

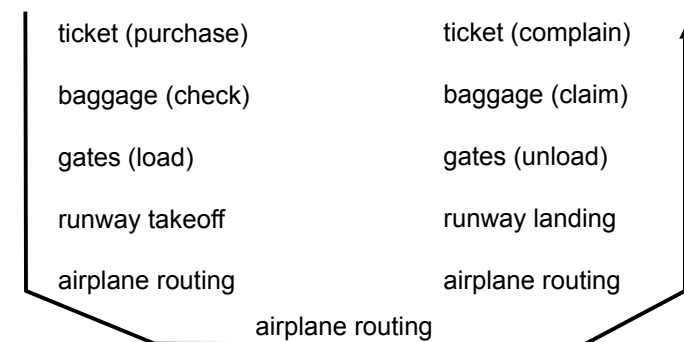
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Chapter I: roadmap

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- I.7 history

Introduction 1-47

Organization of air travel



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

Introduction 1-48

Why layering?

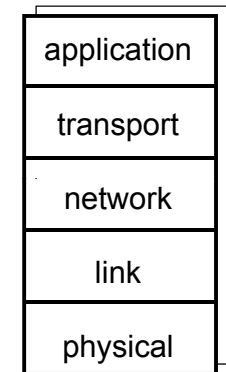
dealing with complex systems:

- ❖ explicit structure allows identification, relationship of complex system's pieces
 - layered *reference model* for discussion
- ❖ modularization eases maintenance, updating 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
- ❖ layering considered harmful?

Introduction 1-49

Internet protocol stack

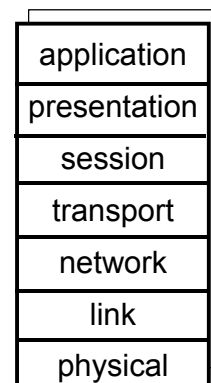
- ❖ *application*: supporting network applications
 - FTP, SMTP, HTTP
- ❖ *transport*: process-process data transfer
 - TCP, UDP
- ❖ *network*: routing of datagrams from source to destination
 - IP, routing protocols
- ❖ *link*: data transfer between neighboring network elements
 - Ethernet, 802.111 (WiFi), PPP
- ❖ *physical*: bits "on the wire"



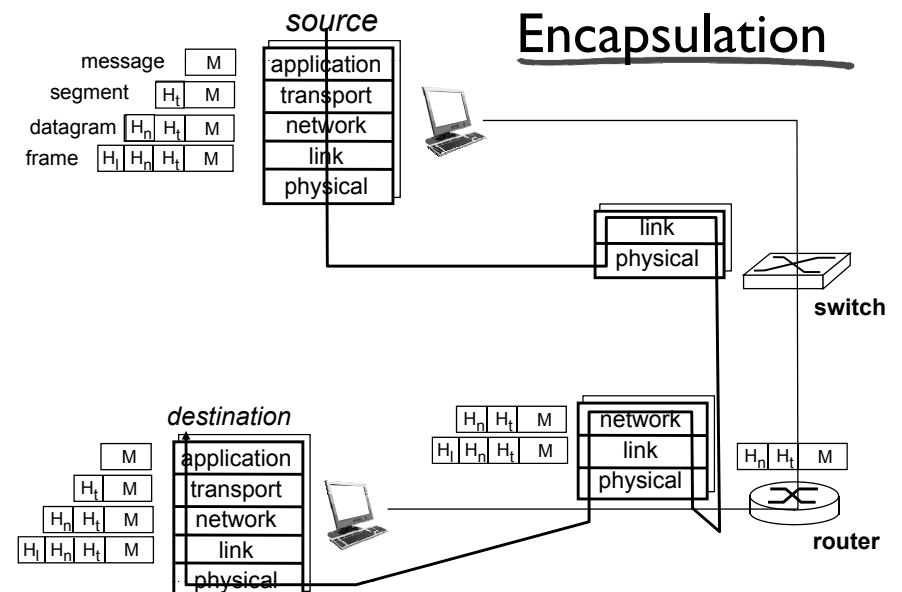
Introduction 1-50

ISO/OSI reference model

- ❖ *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?



Introduction 1-51



Introduction 1-52