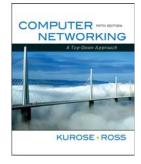
Chapter 1 Computer Networks and the Internet



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Introduction

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 net, physical media
- □ network core: packet/circuit switching, Internet structure
- performance: loss, delay, throughput
- security
- protocol layers, service models
- history

Introduction

Chapter 1: roadmap

- 11 What is the Internet?
- 1.2 Network edge
 - ☐ end systems, access networks, links
- 1.3 Network core
 - circuit switching, packet switching, network structure
- 1.4 Delay, loss and throughput in packet-switched networks
- 1.5 Protocol layers, service models
- 1.6 Networks under attack: security
- 1.7 History

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



laptop

cellular handheld

millions of connected computing devices:



running network apps



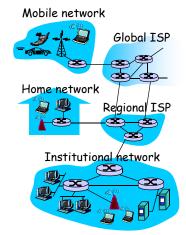


wired

- fiber, copper, radio, satellite
- transmission rate = bandwidth



routers: forward packets (chunks of data)



"Cool" Internet appliances



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



World's smallest web server http://www-ccs.cs.umass.edu/~shri/iPic.html





Internet phones

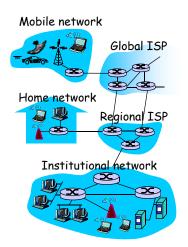
Introduction

Introduction

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

- protocols control sending, receiving of msgs
 - e.g., TCP, IP, HTTP, Skype, Ethernet
- □ Internet: "network of networks"
 - · loosely hierarchical
 - public Internet versus private intranet
- Internet standards
 - * RFC: Request for comments
 - IETF: Internet Engineering Task Force

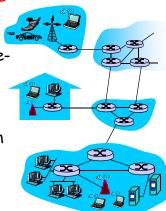
Ex. RFC 791 – IPv4, RFC 1730 IMAP v.4 RFC 2453 RIP v.2



Introduction

What's the Internet: a service view

- Communication infrastructure enables distributed applications:
 - Web, VoIP, email, games, ecommerce, file sharing
- Communication services provided to applications:
 - reliable data delivery from source to destination
 - "best effort" (unreliable) data delivery



What's a protocol?

human protocols:

- □ "what's the time?"
- □ "I have a question"
- introductions
- ... specific messages sent
- ... specific actions taken when msgs received, or other events

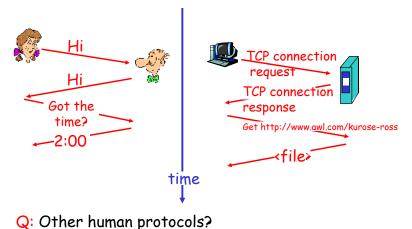
network protocols:

- 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

What's a protocol?

a human protocol and a computer network protocol:



Introduction

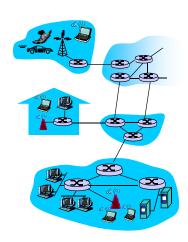
Chapter 1: roadmap

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Introduction

A closer look at network structure:

- Network Edge: applications and hosts
- Access Networks,
 Physical Media:
 wired, wireless
 communication links
- □ Network Core:
 - interconnected routers
 - network of networks



Introduction

The network edge:

□ End systems (hosts):

- run application programs
- · e.g. Web, email
- at "edge of network"

Client/Server model

- client host requests, receives service from always-on server
- e.g. Web browser/server;email client/server

□ Peer-Peer model:

- minimal (or no) use of dedicated servers
- . e.g. Skype, BitTorrent



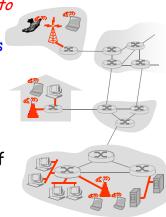
Access networks and physical media

Q: How to connect end systems to edge router?

- ☐ 1. Residential Access networks
- 2. Institutional AccessNetworks (school, company)
- □ 3. Mobile Access Networks

Keep in mind:

- Bandwidth (bits per second) of access network?
- □ Shared or Dedicated?



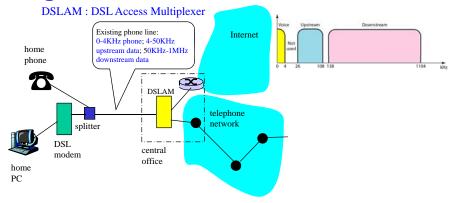
Introduction

Used for voice Used for data Used for data Used for data Used for voice Used for voice Used for voice Used for voice Internet Home dial-up modem (e.g., AOL)

- Uses existing telephony infrastructure
 - * Home is connected to central office
- up to 56Kbps direct access to router (often less)
- * Can't surf and phone at same time: not "always on"

Introduction

Digital Subscriber Line (DSL)



- * Also uses existing telephone infrastruture
- up to 1 Mbps upstream (today typically < 256 kbps)</p>
- up to 8 Mbps downstream (today typically < 1 Mbps)</p>
- * dedicated physical line to telephone central office

Residential access: Cable Modems

- □ Does not use telephone infrastructure
 - * Instead uses Cable TV infrastructure
- □ HFC: hybrid fiber coax
 - Asymmetric: up to 30Mbps downstream,2 Mbps upstream
- Network of cable and fiber attaches homes to ISP router
 - * Homes share access to router
 - unlike DSL, which has dedicated access

Residential access: cable modems

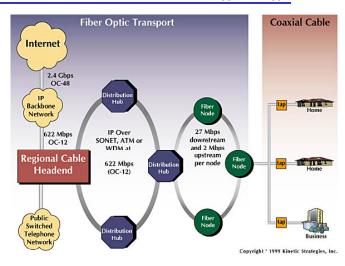
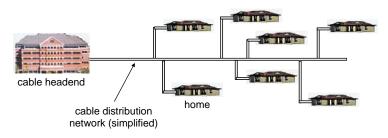


Diagram: http://www.cabledatacomnews.com/cmic/diagram.html

Introduction

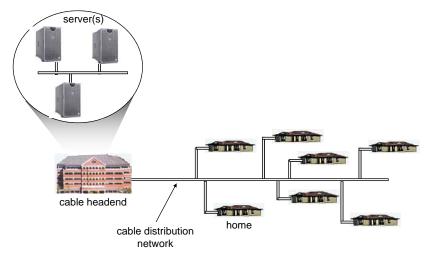
Cable Network Architecture: Overview

Typically 500 to 5,000 homes



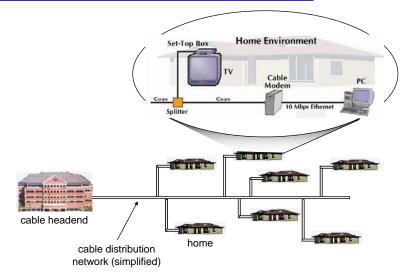
Introduction

Cable Network Architecture: Overview

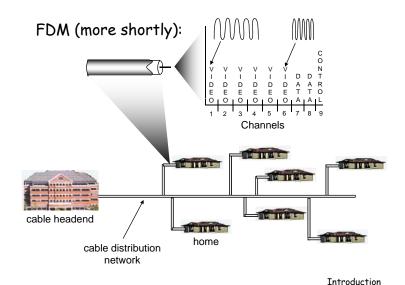


Introduction

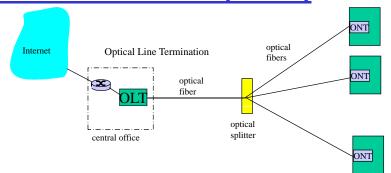
Cable Network Architecture: Overview



Cable Network Architecture: Overview

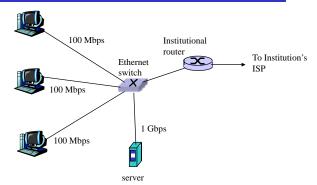


Fiber to the Home (FTTH) Optical Network Unit



- Optical links from central office to the home
- Two competing optical technologies:
 - * Passive Optical network (PON)
 - * Active Optical Network (AON)
- Much higher Internet rates; fiber also carries television and phone services
 Introduction

Ethernet Internet access



- □ Typically used in companies, universities, etc
- □ 10 Mbs, 100Mbps, 1Gbps, 10Gbps Ethernet
- Today, end systems typically connect into Ethernet switch

Introduction

Wireless Access Networks

- □ Shared wireless access network connects end system to router "also known as"
 - via base station aka "access point"
- Wireless LANs:
 - 802.11b/g (WiFi): 11 or 54 Mbps
- Wider-area wireless access
 - provided by telco operator
 - ~1Mbps over cellular system (EVDO, HSDPA)
 - next up (?): WiMAX (10's Mbps) over wide area

router base station

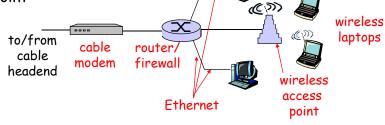
mobile hosts

EVDO: EVolution Data Only HSDPA: High Speed Data Packet Access

Home networks

Typical home network components:

- □ DSL or cable modem
- router/firewall/NAT
- Ethernet
- □ Wireless access point



Introduction

laptops

Physical Media

- ☐ Bit: propagates between transmitter/rcvr pairs
- physical link: what lies between transmitter & receiver
- Guided media:
 - * signals propagate in solid media: copper, fiber, coax
- Unquided media:
 - signals propagate freely, e.g., radio

Twisted Pair (TP)

- two insulated copper wires
 - * Category 3: traditional phone wires, 10 Mbps Ethernet
 - Category 5: 100Mbps Ethernet



Introduction

Physical Media: Coax, Fiber

Coaxial cable:

- □ two concentric copper conductors
- bidirectional
- baseband:
 - * single channel on cable
 - legacy Ethernet
- □ 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 Gps)
- □ low error rate: repeaters spaced far apart; immune to electromagnetic noise



Physical media: Radio

- □ Signal carried in electromagnetic spectrum
- no physical "wire"
- bidirectional
- □ Propagation environment effects:
 - reflection
 - · obstruction by objects
 - interference



- □ Terrestrial Microwave
 - e.g. up to 45 Mbps channels
- □ LAN (e.g., Wifi)
 - 11Mbps, 54 Mbps
- □ Wide-area (e.g., cellular)
 - ❖ 3G cellular: ~ 1 Mbps
- Satellite
 - * Kbps to 45Mbps channel (or multiple smaller channels)
- วงโคจรต่ำของโลก (Low Earth Orbit "LEO") : ไม่เกิน 2,000 กม.
- วงโคจรระยะปานกลาง (Medium Earth Orbit "MEO") Geosynchronous versus Low altitude

- วงโคจรประจำที่ (Geosynchonus Earth Orbit "GEO")

: อยู่สูงจากพื้นโลก 35,786 กม.

: ความสูงตั้งแต่ 5000-15,000 กม.





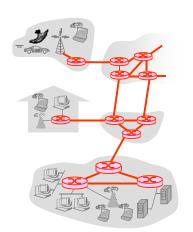
Chapter 1: roadmap

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Introduction

The Network Core

- Mesh of interconnected routers
- the fundamental question: how is data transferred through net?
 - Circuit Switching: dedicated circuit per call: telephone net
 - Packet-Switching: data sent thru net in discrete "chunks"



Introduction

Network Core: Circuit Switching

End-end resources reserved for "call"

- link bandwidth, switch capacity
- dedicated resources: no sharing
- circuit-like (guaranteed) performance
- □ call setup required

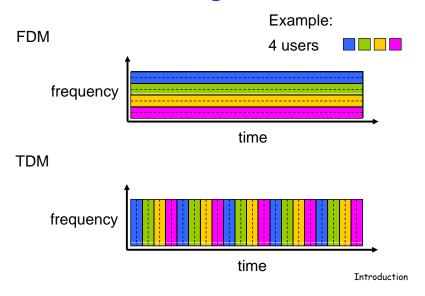


Network Core: Circuit Switching

Network Resources (e.g., bandwidth) divided into "pieces"

- pieces allocated to calls
- if not used by owning call (no sharing)
- dividing link bandwidth into "pieces"
 - Frequency division
 - Time division

Circuit Switching: FDM and TDM



Numerical example

- How long does it take to send a file of 640,000 bits from host A to host B over a circuit-switched network?
 - All links are 1.536 Mbps
 - * Each link uses TDM with 24 slots/sec
 - * 500 msec to establish end-to-end circuit

Let's work it out!

Introduction

Network Core: Packet Switching

each end-end data stream divided into *packets*

- □ user A, B packets *share* network resources
- each packet uses full link bandwidth
- □ resources used as needed

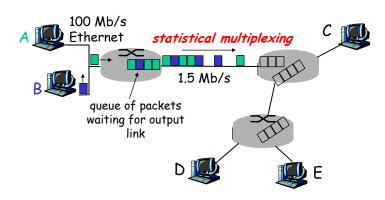


Resource Contention:

- Aggregate resource demand can exceed amount available
- Congestion: packets queue, wait for link use
- Store and Forward: packets move one hop at a time
 - Node receives complete packet before forwarding

Introduction

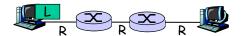
Packet Switching: Statistical Multiplexing



Sequence of A & B packets does not have fixed pattern, bandwidth shared on demand → statistical multiplexing.

TDM: each host gets same slot in revolving TDM frame.

Packet-switching: Store-and-Forward



- □ takes L/R seconds to transmit (push out) packet of L bits on to link at R bps
- Store and Forward: entire packet must arrive at router before it can be transmitted on next link
- delay = 3L/R (assuming zero propagation delay)

Example:

- □ L = 7.5 Mbits
- □ R = 1.5 Mbps
- □ transmission delay = 15 sec

more on delay shortly ...

Introduction

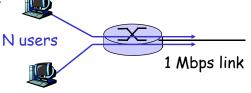
Packet Switching versus Circuit Switching

Packet switching allows more users to use network!

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



- 10 users
- □ Packet Switching:
 - with 35 users, probability > 10 active at same time is less than 0.0004



Q: how did we get value 0.0004?

Introduction

Packet Switching versus Circuit Switching

Is packet switching a "slam dunk winner?"

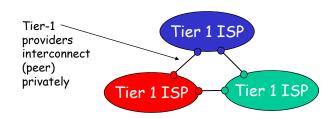
- ☐ Great for bursty data
 - * resource sharing
 - * simpler, no call setup
- Excessive Congestion: packet delay and loss
 - protocols needed for reliable data transfer, congestion control
- Q: How to provide circuit-like behavior?
 - bandwidth guarantees needed for audio/video applications
 - still an unsolved problem (chapter 7)

real-time streaming protocol (RTSP)

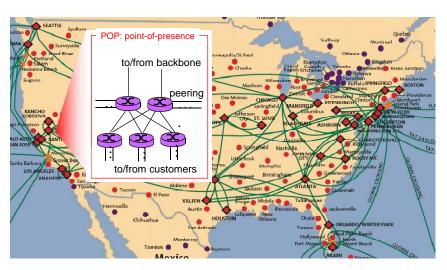
Introduction

Internet structure: network of networks

- roughly hierarchical
- □ at center: "tier-1" ISPs (e.g., Verizon, Sprint, AT&T, Cable and Wireless), national/international coverage
 - treat each other as equals



Tier-1 ISP: e.g., Sprint

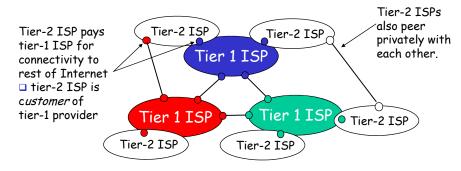


Introduction

Internet structure: network of networks

□ "Tier-2" ISPs: smaller (often regional) ISPs

Connect to one or more tier-1 ISPs, possibly other tier-2 ISPs

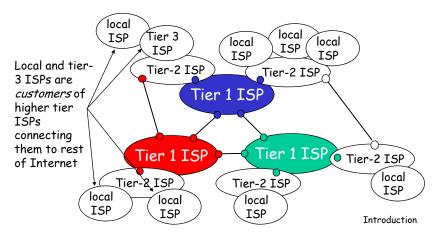


Introduction

Internet structure: network of networks

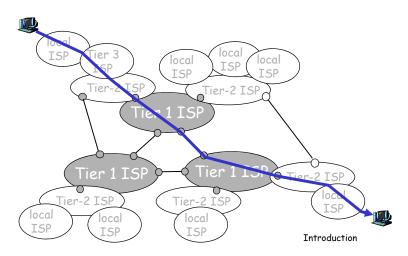
□ "Tier-3" ISPs and local ISPs

last hop ("access") network (closest to end systems)



Internet structure: network of networks

a packet passes through many networks!



Chapter 1: roadmap

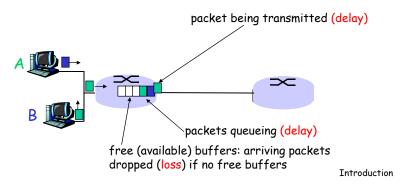
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Introduction

How do loss and delay occur?

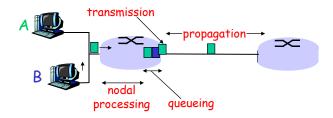
Packets Queue in Router Buffers

- packet arrival rate to link exceeds output link capacity
- □ packets queue, wait for turn



Four sources of Packet Delay

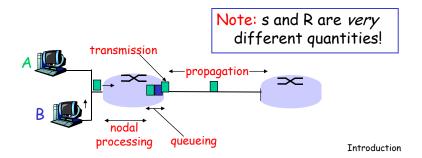
- 1. Nodal Processing:
 - check bit errors
 - determine output link
- 2. Queueing
 - time waiting at output link for transmission
 - depends on congestion level of router



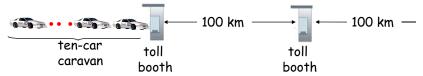
Introduction

Delay in packet-switched networks

- 3. Transmission delay:
- □ R=link bandwidth (bps)
- □ L=packet length (bits)
- □ time to send bits into link = L/R
- 4. Propagation delay:
- □ d = length of physical link
- □ s = propagation speed in medium (~2x108 m/sec)
- □ propagation delay = d/s



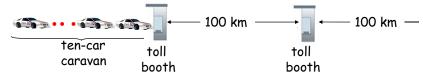
Caravan analogy



- □ cars "propagate" at 100 km/hr
- toll booth takes 12 sec to service car (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*10 = 120 sec
- □ Time for last car to propagate from 1st to 2nd toll both: 100km/(100km/hr)= 1 hr
- □ A: 62 minutes

Introduction

Caravan analogy (more)



- □ Cars now "propagate" at 1000 km/hr
- □ Toll booth now takes 1 min to service a car
- Q: Will cars arrive to 2nd booth before all cars serviced at 1st booth?
- Yes! After 7 min, 1st car at 2nd booth and 3 cars still at 1st booth.
- □ 1st bit of packet can arrive at 2nd router before packet is fully transmitted at 1st router!

Introduction

Nodal delay

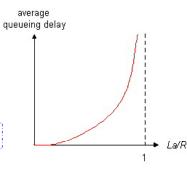
$$d_{\text{nodal}} = d_{\text{proc}} + d_{\text{queue}} + d_{\text{trans}} + d_{\text{prop}}$$

- \Box d_{proc} = processing delay
 - typically a few microsecs or less
- \Box d_{queue} = queuing delay
 - depends on congestion
- \Box d_{trans} = transmission delay
 - = L/R, significant for low-speed links
- \Box d_{prop} = propagation delay
 - · a few microsecs to hundreds of msecs

Queueing delay (revisited)

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



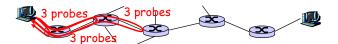


- □ La/R ~ 0: average queueing delay small
- □ La/R -> 1: delays become large
- □ La/R > 1: more "work" arriving than can be serviced, average delay infinite!

Introduction

"Real" Internet delays and routes

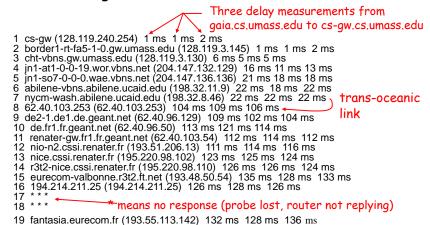
- □ What do "real" Internet delay & loss look like?
- ☐ <u>Traceroute program:</u> provides delay measurement from source to router along end-end Internet path towards destination. For all *i*:
 - sends three packets that will reach router / on path towards destination
 - * router / will return packets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



Introduction

"Real" Internet delays and routes

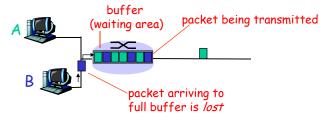
traceroute: gaia.cs.umass.edu to www.eurecom.fr



Introduction

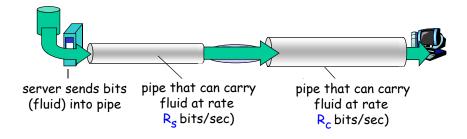
Packet loss

- 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



Throughput

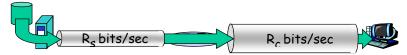
- □ throughput: rate (bits/time unit) at which bits transferred between sender/receiver
 - * instantaneous: rate at given point in time
 - * average: rate over longer period of time



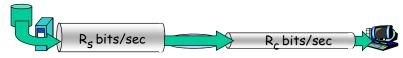
Introduction

Throughput (more)

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



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



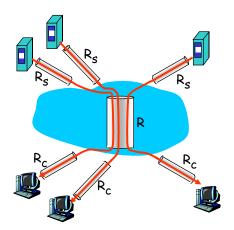
- bottleneck link

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

Introduction

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

Introduction

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Protocol "Layers"

Networks are complex!

- □ 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?

Organization of air travel

ticket (purchase)

baggage (check)

gates (load)

runway takeoff

airplane routing

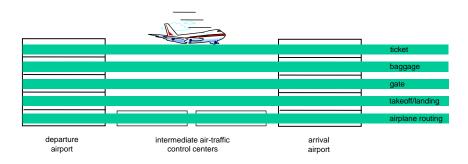
airplane routing

airplane routing

a series of steps

Introduction

Layering of airline functionality



Layers: each layer implements a service

- via its own internal-layer actions
- * relying on services provided by layer below

Introduction

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?

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
 - PPP, Ethernet
- physical: bits "on the wire"

application

network

link

physical

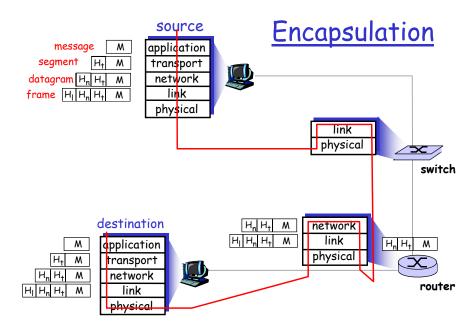
Introduction

ISO/OSI reference model

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



Introduction



Introduction

Chapter 1: roadmap

- 1.1 What is the Internet?
- 1.2 Network edge
 - end systems, access networks, links
- 1.3 Network core
 - circuit switching, packet switching, network structure
- 1.4 Delay, loss and throughput in packet-switched networks
- 1.5 Protocol layers, service models
- 1.6 Networks under attack: security
- 1.7 History

Network Security

- □ The field of network security is about:
 - * 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!

Bad guys can put malware into hosts via Internet

- □ Malware can get in host from a virus, worm, or trojan horse.
- □ Spyware malware can record keystrokes, web sites visited, upload info to collection site.
- □ Infected host can be enrolled in a botnet, used for spam and Distributed Denial of Service (DDoS) attacks.
- Malware is often self-replicating: from an infected host, seeks entry into other hosts

Introduction

Bad guys can put malware into hosts via Internet

□ Trojan horse

- Hidden part of some otherwise useful software
- Today often on a Web page (Active-X, plugin)

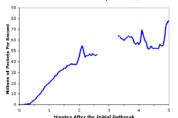
Virus

- infection by receiving object (e.g., e-mail attachment), actively executing
- self-replicating: propagate itself to other hosts, users

■ Worm:

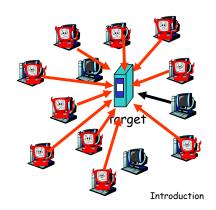
- infection by passively receiving object that gets itself executed
- self- replicating: propagates to other hosts, users

Sapphire Worm: aggregate scans/sec in first 5 minutes of outbreak (CAIDA, UWisc data)



Bad guys can attack servers and network infrastructure

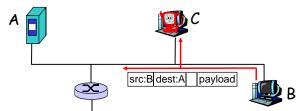
- □ Denial of service (DoS): attackers make resources (server, bandwidth) unavailable to legitimate traffic by overwhelming resource with bogus traffic
- 1. select target
- break into hosts around the network (see botnet)
- send packets toward target from compromised hosts



The bad guys can sniff packets

Packet sniffing:

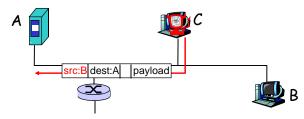
- broadcast media (shared Ethernet, wireless)
- promiscuous network interface reads/records all packets (e.g., including passwords!) passing by



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

The bad guys can use false source addresses

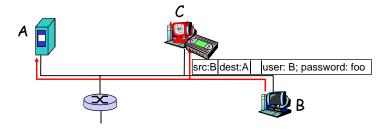
☐ *IP spoofing:* send packet with false source address



Introduction

The bad guys can record and playback

- □ record-and-playback: sniff sensitive info (e.g., password), and use later
 - password holder is that user from system point of view



Introduction

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Internet History

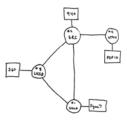


Leonard Kleinrock

1961-1972: Early packet-switching principles

- □ 1961: Kleinrock queueing theory shows effectiveness of packetswitching
- □ 1964: Baran packetswitching in military nets
- 1967: ARPAnet conceived by Advanced Research Projects Agency
- 1969: first ARPAnet node operational

- **1**9/2
 - * ARPAnet public demonstration
 - NCP (Network Control Protocol) first host-host protocol
 - * first e-mail program
 - ARPAnet has 15 nodes



THE ARPA NETWORK

Introduction

Internet History

1972-1980: Internetworking, new and proprietary nets

- 1970: ALOHAnet satellite network in Hawaii
- 1974: Cerf and Kahn architecture for interconnecting networks
- □ 1976: Ethernet at Xerox
- ate70'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

Introduction

Internet History

1980-1990: new protocols, a proliferation of networks

- \square 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

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

Internet History

2007:

- □ ~500 million hosts
- □ Voice, Video over IP
- P2P applications: BitTorrent (file sharing) Skype (VoIP), PPLive (video)
- more applications: YouTube, gaming
- wireless, mobility