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A Whirlwind Introduction to the Internet
Overview

◆ What’s the Internet
◆ Network core
◆ Network edge
◆ Access nets, physical media
◆ Internet Structure & ISPs
◆ Performance: loss, delay
◆ Security
◆ Protocol layers, service models

Introduce the major nouns and verbs of networking!

Some Definitions
The “nuts and bolts” view

◆ Billions of connected computing devices: hosts, **end-systems**
  » PCs, laptops, servers
  » Tablets, phones, e-readers, toasters running “network applications”

◆ Communication links
  » Different media (fiber, copper wire, radio, satellite)
  » Different transmission rates – bits per second (bps)
    ❖ 10^3 (Kbps) to 10^6 (Mbps) to 10^9 (Gbps)

◆ Switches & Routers:
  » Forward “packets” of data through the network
Just What is the Internet?
The “nuts and bolts” view

- Internet: “network of networks”
  - Loosely hierarchical
  - Public Internet versus private intranet

- Protocols:
  - Control sending, receiving of messages
  - e.g., TCP, IP, HTTP, SMTP, ….

- Internet standards
  - RFC: Request for comments
  - IETF: Internet Engineering Task Force
Some Definitions
The “services” view

- Internet: A communication infrastructure enabling distributed applications
  » WWW, email, games, e-commerce, database, voting,…

- Communication services provided:
  » Connectionless:
    ◆ No guarantees
  » Connection-oriented:
    ◆ Guarantees order and completeness

Network Maps

Just how big is the Internet…?
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- Performance: loss, delay
- Security
- Protocol layers, service models
The Structure of the Internet

The physical makeup of the Internet

- **Network core:**
  - Routers
  - Network of networks

- **Network edge:**
  - Applications running on hosts
    - "host" = "end system"

- **In between:** Access networks
  - Physical media: communication links

Network Structure

The network core

- A mesh of interconnected routers

- *The fundamental architectural question: How is data forwarded through the network?*
  - **Circuit switching:** "telephone model"
    - dedicated circuit (path) per call used by all data
  - **Packet switching:** "datagram model"
    - data sent in discrete "chunks" (packets)
    - each packet has a path chosen for it independently
The Network Core
Circuit Switching

- Resources reserved *end-to-end* for the connection (“call”)
  - Resources:
    - Link bandwidth, switch processing capacity, memory buffers, etc.
  - Reservation:
    - Dedicated fraction of available bandwidth, buffers, etc.

- 🌟: Circuit-like (guaranteed) performance
  - Call setup required
  - Call rejection (“busy signal”) possible

Circuit Switching
Allocating fractions of bandwidth — Multiplexing

- Network bandwidth divided into transmission “slots”
  - Slots allocated to calls
  - Slots are unused (“idle”) if not used by owning call
  - No sharing of slots!

- How to divide link bandwidth into slots?
  - Frequency division multiplexing (FDM)
  - Time division multiplexing (TDM)

Transmission Frequency 4 KHz
FDM
Call 1
Call 2
Call 3
Call 4
Link capacity

Time
TDM
Call data
frames/sec × bits/slot = TDM per-call transmission rate
The Network Core
Packet Switching

◆ Each sender divides its messages into "packets" (sequence of bits)
  » Each packet uses full link capacity until transmission completed
  » Senders’ packets share (compete for) network resources
  » Resources allocated & used as needed

◆ But now we have resource contention!
  » Aggregate resource demand can exceed amount available
  » Congestion: packets queue, wait for link availability

◆ Also introduces Store-and-Forward delays:
  » Packets move one hop at a time
    ❖ Routers receive complete packet over incoming link
    ❖ Then transmit over outgoing link

◆ Bandwidth division into slots
◆ Dedicated allocation
◆ Resource reservation

Packet Switching
Statistical multiplexing

◆ Packet-switching versus circuit switching:
  » Restaurant seating analogy
  » Other familiar analogies?
The Network Core
Packet switching v. Circuit switching

- Assume that on a 1 Mbps link:
  - Each user consumes 100Kbps when “active”
  - Each user active 10% of time
- Circuit-switching can support 10 users
- Packet switching can support 35 users
  - With 35 users the probability of more than 10 users active simultaneously is less than 0.0004

Packet Switching vs. Circuit Switching
Is packet switching a “no brainer”?

- ☺:
  - Great for bursty data ☺
    - Resource sharing
  - No call setup
  - Light-weight fault recovery

- Excessive congestion: packet delay and loss ☹
  - Protocols needed for reliable data transfer, congestion control

- How to provide circuit-like behavior?
  - Bandwidth guarantees needed for audio/video applications?
  - Still an unsolved problem (go to grad school!)
Packet Switching (Store and Forward)
Why switch packets instead of entire messages?

◆ “Message switching” example
  » Transmit a 7.5 Mb message over a network with 1.5 Mbps links
  » What is the total elapsed transmission time?

Packet Switching (Store and Forward)
Why switch packets instead of entire messages?

◆ Packet-switching: store and forward behavior
  » 1,500 bit packets, 1 packet forwarded every 1 ms

Animation
Packet Switching

Forwarding

- Forwarding:
  - The process of moving packets among routers from source to destination

- Datagram network:
  - Each packet carries a destination address
  - Destination address used to look up next hop
  - Route (next hop) may change at any time

- Virtual circuit (path) network:
  - Packets carry a "tag" (virtual circuit ID) that determines the next hop
  - Path determined at call setup time & remains fixed throughout call
  - Routers maintain per-call path state

Forwarding in Packet Switched Networks

Virtual circuit forwarding

- A (static) route is computed before any data is sent
- Packets contain a VC identifier
  - Identifier replaced at every hop
- Routers maintain per-connection state
  - And perform set-up/tear-down operations

(Why not choose a single VC identifier for the entire path and avoid replacing it at each hop?)
Forwarding in Packet Switched Networks

Datagram forwarding

- Packets contain complete destination address
  » Address specifies both a network and a host
- Each router examines the destination address
  » And forwards packet to the next router closest to the destination network
    ✓ Routers maintain a table of "next hops" to all destination networks
- Routers maintain no per-connection state

The Structure of the Internet

The physical makeup of the Internet

- Network core:
  » Routers
  » Network of networks
- Network edge:
  » Applications and hosts
- In between: Access networks
  » Physical media: communication links
Network Structure

The network edge

- End systems (hosts)
  - Live at the "edge of network"
  - Run applications

- Interaction paradigms:
  - Client/server model
    - Client requests, receives service from server
    - WWW browser/server, email client/server
  - Peer-to-peer model:
    - Host interactions symmetric
      - File sharing (BitTorrent, Limewire, Kazaa, eMule,...)
  - What about?
    - Remote login?
    - Newsgroups?
    - Telephony?

Transport Services @ The Network Edge

Connection-oriented service

- Connection-oriented service on the Internet:
  - TCP - Transmission Control Protocol [RFC 793]
- Goal: Transfer data between end systems
  - Handshaking: setup data transfer ahead of time
    - "Hello, hello-back" human protocol
  - Set up "state" in two communicating hosts
  - Transmit data

TCP service model

- reliable, in-order, byte-stream
  - Losses detected and recovered from
- Flow control:
  - Sender won’t overwhelm receiver
- Congestion control:
  - Senders “slow down sending rate” when network congested

Each of the above services can be defined only in the context of a “connection”!
Transport Services @ The Network Edge
Connectionless service

- Connectionless service on the Internet:
  - UDP - User Datagram Protocol [RFC 768]
    - Unreliable data transfer
    - No flow control
    - No congestion control

- Goal: Transfer data between end systems
  - Same as before!

- Applications using TCP:
  - HTTP (WWW),
  - FTP (file transfer),
  - Telnet (remote login),
  - SMTP (email)

- Applications using UDP:
  - DNS (name to address mapping),
  - Streaming media (some),
  - Teleconferencing,
  - Internet telephony (VoIP)

Network Taxonomy

- The Internet
  - Is a Datagram network
  - Provides two types of services to applications:
    - Connectionless (UDP)
    - Connection-oriented (TCP)
The Structure of the Internet
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Network Structure
Access networks and physical media

- How to connect end-systems to the Internet (edge router)?
  - Residential access nets
  - Institutional/enterprise access networks
  - Mobile access networks

- Differences/Issues:
  - Transmission speed (bits per second) of access network?
  - Shared or dedicated?
**Access Networks**

**Example: Digital subscriber line (DSL)**

- Uses the existing telephone line to connect to the “central office” DSLAM
  - Data sent over DSL phone line goes to Internet
  - Voice sent over DSL phone line goes to telephone net
- Lots of flavors of DSL but common data rates are:
  - A max of 2.5 Mbps upstream (typically < 1 Mbps)
  - ~24 Mbps downstream (possibly up to 50 Mbps)

**Access Networks**

**Example: Cable networks**

- Cable relies on *frequency division* multiplexing (FDM)
  - Different communication “channels” are transmitted in different frequency bands
Access Networks

Example: Cable networks

◆ HFC: hybrid fiber coax
  » Asymmetric: 10-300 Mbps downstream transmission rate, 2-10 Mbps upstream transmission rate

◆ Network of coax/fiber attaches homes to ISP router
  » Homes share the access network to the cable headend (unlike DSL, which has dedicated access to central office)

Access Networks

Example: Your home network!

◆ YOUR home network today is likely more complex than the entire UNC network was 25 years ago!
  » And has a higher capacity!
### Access Networks

#### Example: Enterprise access

- Ethernet (mostly wired) is the dominant medium
  - Scalable (& symmetric): 10 Mbps, 100 Mbps, 1,000 Mbps (1 Gbps), 10,000 Mbps (10 Gbps)
  - End-systems typically physically connect to an Ethernet switch

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- Ethernet switch
- Institutional link to ISP (Internet)
- Institutional router
- Institutional mail, web servers

#### Example: Wireless access networks

**wireless LANs:**
- Access point per room (100 ft.)
- 802.11 b/g/n (WiFi): 11, 54, 450 Mbps transmission rate

**wide-area wireless access**
- Provided by telco (cellular) operator, 10s km range
- Between 1 and 10 Mbps
- 3G, 4G: LTE

- End-systems connect to router via a radio base station (an “access point”)
  - Inherently a shared transmission medium
Physical Transmission Media
Transmitting the bits and bytes

◆ Transmission is the propagation of an electromagnetic wave (or optical pulse) through a physical medium

◆ Media types
  » Guided media — signals propagate in solid media (copper, fiber)
  » Unguided media — signals propagate freely (radio, infrared)

Twisted pair (UTP)
Coaxial cable

Physical Transmission Media
Twisted pair copper wiring

◆ What do you use?
  » Twisted Pair (UTP) — Two insulated copper wires

◆ Category 3 UTP:
  » Traditional phone wires, 10 Mbps Ethernet

◆ Category 5/5e UTP:
  » 100Mbps Ethernet
  » Gigabit possible
  » Distance limited (100 m)

◆ Category 6/6a UTP:
  » 10Gbps Ethernet
  » Distance limited (37-55 m)
Physical Transmission Media
Coaxial and fiber optic cable

- Coaxial cable
  - Wire (signal carrier) within a wire (shield)
    - Baseband: single channel on cable
    - Broadband: multiple channels on cable
  - Bi-directional transmission
  - Largely used for cable TV

- Fiber optic cable
  - Glass fiber carrying light pulses
  - Higher-speed operation:
    - 100-1,000 Mbps Ethernet
    - High-speed point-to-point transmission (e.g., 10 Gbps)
  - Low signal attenuation – long distances
  - Low error rate

Physical Transmission Media
Radio frequency (“RF”)

- Signal carried in electromagnetic spectrum
  - No physical “wire”
- Bi-directional
- Physical environment effects propagation
  - Reflection/obstruction by objects
  - Interference

- Radio link types:
  - Microwave
    - Up to 45 Mbps channels
  - LAN (e.g., 802.11)
    - 2 Mbps, 11, 56 Mbps
  - Wide-area (e.g., cellular)
    - CDPD, 10’s Kbps
    - 3G, 100’s Kbps
    - 4G, 100’s Kbps - 1.5 Mbps
    - LTE, 10-20 Mbps
  - Satellite
    - Up to 50 Mbps channel (or multiple smaller channels)
    - 270 msec end-end delay
    - Geosynchronous versus LEOS