Part I: Introduction

Chapter goal:
- get context, overview, “feel” of networking
- more depth, detail later in course
- approach:
  - descriptive
  - use Internet as example

Overview:
- what’s the Internet
- what’s a protocol?
- network edge
- network core
- access net, physical media
- performance: loss, delay
- protocol layers, service models
- backbones, NAPs, ISPs
- history
- ATM network
What’s the Internet: “nuts and bolts” view

- millions of connected computing devices: hosts, end-systems
  - pc’s workstations, servers
  - PDA’s phones, toasters
  - running network apps
- communication links
  - fiber, copper, radio, satellite
- routers: forward packets (chunks) of data thru network
What's the Internet: “nuts and bolts” view

- **protocols**: control sending, receiving of msgs
  - e.g., TCP, IP, HTTP, FTP, PPP

- **Internet**: “network of networks”
  - loosely hierarchical
  - public Internet versus private intranet

- **Internet standards**
  - RFC: Request for comments
  - IETF: Internet Engineering Task Force
What’s the Internet: a service view

- communication infrastructure enables distributed applications:
  - WWW, email, games, e-commerce, database, voting,
  - more?

- communication services provided:
  - connectionless
  - connection-oriented

- cyberspace [Gibson]:
  “a consensual hallucination experienced daily by billions of operators, in every nation, ...."
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
What’s a protocol?

A human protocol and a computer network protocol:

Q: Other human protocol?
A closer look at network structure:

- **network edge:** applications and hosts

- **network core:**
  - routers
  - network of networks

- **access networks, physical media:** communication links
The network edge:

- **end systems (hosts):**
  - run application programs
  - e.g., WWW, email
  - at “edge of network”

- **client/server model**
  - client host requests, receives service from server
  - e.g., WWW client (browser)/server; email client/server

- **peer-peer model:**
  - host interaction symmetric
  - e.g.: teleconferencing
**Network edge: connection-oriented service**

**Goal:** data transfer between end sys.
- *handshaking:* setup (prepare for) data transfer ahead of time
  - Hello, hello back human protocol
  - *set up “state”* in two communicating hosts
- *TCP - Transmission Control Protocol*
  - Internet’s connection-oriented service

**TCP service** [RFC 793]
- *reliable, in-order byte-stream data transfer*
  - loss: acknowledgements and retransmissions
- *flow control:*
  - sender won’t overwhelm receiver
- *congestion control:*
  - senders “slow down sending rate” when network congested
Network edge: connectionless service

**Goal:** data transfer between end systems
- same as before!

- **UDP - User Datagram Protocol [RFC 768]:**
  - Internet's connectionless service
  - unreliable data transfer
  - no flow control
  - no congestion control

**App's using TCP:**
- HTTP (WWW), FTP (file transfer), Telnet (remote login), SMTP (email)

**App's using UDP:**
- streaming media, teleconferencing, Internet telephony
Why VIA - Hardware structure
A Case for Data and Control Flow between Host and NIC
The Network Core

- mesh of interconnected routers
- *the* fundamental question: how is data transferred through the net?
  - circuit switching: dedicated circuit per call: telephone net
  - packet-switching: data sent thru net in discrete “chunks”
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
Internet Architecture

- NAP
  - National network
    - ISP
    - Company
    - University
  - Regional network
  - On-line services
    - Access via modem
- International lines
- LANs
NAPs, NSPs, ISPs

- NSP: National Service Provider (Tier 1 Backbones)
  - Example: Internet MCI, Sprint Link, UUNET
- NAP: National Access Point

![Diagram of NAPs, NSPs, and ISPs in the United States](image-url)
NAP and Private Peering
Internet Network

Leveraging Sprint’s SONET-based, gigabit switch Internet backbone
Network Core: Circuit Switching

network resources (e.g., bandwidth) divided into “pieces”
- pieces allocated to calls
- resource piece *idle* if not used by owning call (no sharing)
- dividing link bandwidth into “pieces”
  - frequency division
  - time division
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,

Bandwidth division into “pieces”
Dedicated allocation
Resource reservation

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
    - transmit over link
    - wait turn at next link
Network Core: Packet Switching

Packet-switching versus circuit switching: human restaurant analogy
- other human analogies?
Network Core: Packet Switching

Packet-switching: store and forward behavior
Packet switching versus circuit switching

Packet switching allows more users to use network!

- 1 Mbit link
- each user:
  - 100Kbps when “active”
  - active 10% of time
- circuit-switching:
  - 10 users
- packet switching:
  - with 35 users, probability > 10 active less that .004
Packet switching versus circuit switching

Is packet switching a “slam dunk winner?”

- Great for bursty data
  - resource sharing
  - 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 apps
  - still an unsolved problem (chapter 6)
Packet-switched networks: routing

- **Goal**: move packets among routers from source to destination
  - we’ll study several path selection algorithms (chapter 4)
- **datagram network**:
  - *destination address* determines next hop
  - routes may change during session
  - analogy: driving, asking directions
- **virtual circuit network**:
  - each packet carries tag (virtual circuit ID), tag determines next hop
  - fixed path determined at *call setup time*, remains fixed thru call
  - routers maintain per-call state
Access networks and physical media

Q: How to connection 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?
Residential access: point to point access

- **Dialup via modem**
  - up to 56Kbps direct access to router (conceptually)

- **ISDN**: integrated services digital network: 128Kbps all-digital connect to router

- **ADSL**: asymmetric digital subscriber line
  - up to 1 Mbps home-to-router
  - up to 8 Mbps router-to-home
  - ADSL deployment: *UPDATE THIS*
Residential access: cable modems

- **HFC: hybrid fiber coax**
  - asymmetric: up to 10Mbps upstream, 1 Mbps downstream

- network of cable and fiber attaches homes to ISP router
  - shared access to router among home
  - issues: congestion, dimensioning

- deployment: available via cable companies, e.g., MediaOne
Institutional access: local area networks

- company/univ local area network (LAN) connects end system to edge router

- Ethernet:
  - shared or dedicated cable connects end system and router
  - 10 Mbs, 100Mbps, Gigabit Ethernet

- deployment: institutions, home LANs soon

- LANs: chapter 5
Wireless access networks

- **shared wireless access network** connects end system to router
- **wireless LANs:**
  - radio spectrum replaces wire
  - e.g., Lucent Wavelan 10 Mbps
- **wider-area wireless access**
  - CDPD: wireless access to ISP router via cellular network
Physical Media

- **physical link:** transmitted data bit propagates across link

- **guided media:**
  - signals propagate in solid media: copper, fiber

- **unguided media:**
  - signals propagate freely e.g., radio

**Twisted Pair (TP)**

- two insulated copper wires
  - Category 3: traditional phone wires, 10 Mbps ethernet
  - Category 5 TP: 100Mbps ethernet
Physical Media: coax, fiber

Coaxial cable:
- wire (signal carrier) within a wire (shield)
  - baseband: single channel on cable
  - broadband: multiple channel on cable
- bidirectional
- common use in 10Mbs Ethernet

Fiber optic cable:
- glass fiber carrying light pulses
- high-speed operation:
  - 100Mbps Ethernet
  - high-speed point-to-point transmission (e.g., 5 Gps)
- low error rate
Physical media: radio

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

Radio link types:

- microwave
  - e.g. up to 45 Mbps channels
- LAN (e.g., waveLAN)
  - 2Mbps, 11Mbps
- wide-area (e.g., cellular)
  - e.g. CDPD, 10’s Kbps
- satellite
  - up to 50Mbps channel (or multiple smaller channels)
  - 270 Msec end-end delay
  - geosynchronous versus LEOS
Delay in packet-switched networks

- packets experience delay on end-to-end path
- four sources of delay at each hop
  - nodal processing:
    - check bit errors
    - determine output link
  - queueing
    - time waiting at output link for transmission
    - depends on congestion level of router
Transmission delay:
- $R =$ link bandwidth (bps)
- $L =$ packet length (bits)
- time to send bits into link = $L/R$

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

Note: $s$ and $R$ are very different quantities!
Queueing delay (revisited)

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

\[
\text{traffic intensity } = \frac{a \cdot L}{R}
\]

- $\frac{a \cdot L}{R} \sim 0$: average queueing delay small
- $\frac{a \cdot L}{R} \rightarrow 1$: delays become large
- $\frac{a \cdot L}{R} > 1$: more “work” arriving than can be serviced, average delay infinite!
Overview of Architectures

Hybrid Fiber/Coax
- Cable modems

Satellite
- DBS
- Teledesic

Fiber-to-the-??
- FTTH/B/C/Node
- xDSL

Wireless
- PCS
- MMDS/LMDS
ADSL Deployed on Existing Copper Twisted Pairs

Central Office

12 Kft. of Existing Twisted Pair

6 Mbps

640 Kbps

Existing Voice Service

ADSL Lineframe

Deme-MUX

OC-3Term.

ATM Video Switch/Encoder

ADSL

Head End

Fast Tone MHEC Encoder

Feeder

Circuit Switch

Class 5 Circuit Switch
FTTCurb/Node (VDSL)

VDSL Max ~1km from ONU to Home

FTTC .2km from ONU to Home

Central Office

Host Digital Terminal

OLUs

Laser TX & RX

PON Splitter

Fiber Cable

ONU

POTS

BroadBand

Copper Drops
Satellite General Architecture

PSTN

PSTN