Introduction to Networking

- What is a (computer/data) network?
- Statistical multiplexing
  - Packet switching
- OSI Model and Internet Architecture
- Introduction to the Internet
- Readings
  - Chapter 1

What is a Network?

There are many types of networks!

- **Transportation Networks**
  - Transport goods using trucks, ships, airplanes, …
- **Postal Services**
  - Delivering letters, parcels, etc.
- **Broadcast and cable TV networks**
- **Telephone networks**
- **Internet**
- **"Social/Human networks"**
- **…**

Key Features of Networks

- **Providing certain services**
  - transport goods, mail, information or data
- **Shared resources**
  - used by many users, often concurrently
- **Basic building blocks**
  - nodes (active entities): process and transfer goods/data
  - links (passive medium): passive "carrier" of goods/data
- **Typically "multi-hop"**
  - two "end points" cannot directly reach each other
  - need other nodes/entities to relay

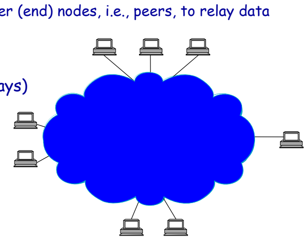
Data/Computer Networks

- **Delivery of information ("data") among computers of all kinds**
  - servers, desktops, laptop, PDAs, cell phones, ……
- **General-Purpose**
  - Not for specific types of data or groups of nodes, or using specific technologies
- **Utilizing a variety of technologies**
  - "physical/link layer" technologies for connecting nodes
    - copper wires, optical links, wireless radio, satellite
  - or even "non-electronic" means: e.g., cars, postal services, humans -- e.g., recent "delay-tolerant networks" efforts for 3rd world countries

How to Build Data/Computer Networks

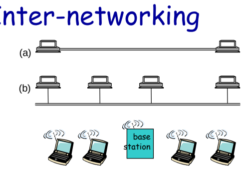
Two possibilities

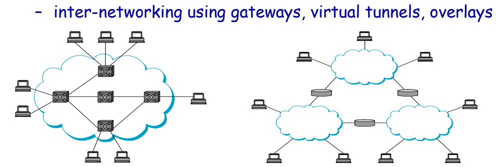
- infrastructure-less (*ad hoc, peer-to-peer*)
  - (end) nodes also help other (end) nodes, i.e., peers, to relay data
- infrastructure-based
  - use special nodes (switches, routers, gateways) to help relay data



Connectivity and Inter-networking

- Point-to-point *vs.*
- broadcast links/ wireless media
- switched networks
- connecting "clouds" (existing physical networks)
  - inter-networking using gateways, virtual tunnels, overlays





Resource Sharing in Switched Networks

Multiplexing Strategies

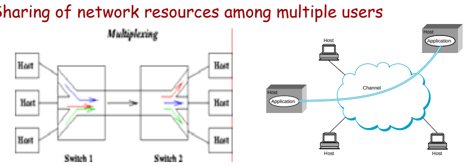
- Circuit Switching
  - set up a dedicated route ("circuit") first
  - carry all bits of a "conversation" on one circuit
    - original telephone network
    - Analogy: railroads and trains
- Packet Switching
  - divide information into small chunks ("packets")
  - each packet delivered independently
  - "store-and-forward" packets
    - Internet

(also Postal Service, but they don't tear your mail into pieces first!)

- Analogy: highways and cars

Common Circuit Switching Methods

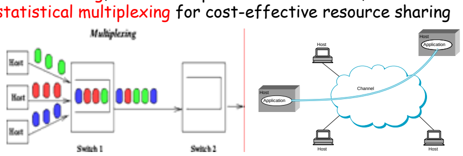
Sharing of network resources among multiple users



- Common multiplexing strategies for circuit switching
  - Time Division Multiplexing Access (TDMA)
  - Frequency Division Multiplexing Access (FDMA)
  - Code Division Multiplexing Access (CDMA)
- What happens if running out of circuits?

Packet Switching & Statistical Multiplexing

Packet Switching, used in computer/data networks, relies on statistical multiplexing for cost-effective resource sharing



- Time division, but on demand rather than fixed
- Reschedule link on a per-packet basis
- Packets from different sources interleaved on the link
- Buffer packets that are contending for the link
- Buffer buildup is called congestion

Why Statistically Share Resources

Efficient utilization of the network

- Example scenario
  - Link bandwidth: 1 Mbps
  - Each call requires 100 Kbps when transmitting
  - Each call has data to send only 10% of time
- Circuit switching
  - Each call gets 100 Kbps: supports 10 simultaneous calls
- Packet switching
  - Supports many more calls with small probability of *contention*
    - 35 ongoing calls: *probability that > 10 active is < 0.0017!*

Circuit Switching *vs* Packet Switching

Item	Circuit-switched	Packet-switched
Dedicated "copper" path	Yes	No
Bandwidth available	Fixed	Dynamic
Potentially wasted bandwidth	Yes	No (not really!)
Store-and-forward transmission	No	Yes
Each packet/bit always follows the same route	Yes	Not necessarily
Call setup	Required	Not Needed
When can congestion occur	At setup time	On every packet
Effect of congestion	Call blocking	Queuing delay

Fundamental Issues in Networking

Networking is more than connecting nodes!

- Naming/Addressing
  - How to find name/address of the party (or parties) you would like to communicate with
  - Address: bit- or byte-string that identifies a node
  - Types of addresses
    - Unicast: node-specific
    - Broadcast: all nodes in the network
    - Multicast: some subset of nodes in the network
- Routing/Forwarding:
  - process of determining how to send packets towards the destination based on its address
  - Finding out neighbors, building routing tables

Other Key Issues in Networking

- Detecting whether there is an error!
- Fixing the error if possible
- Deciding how fast to send, meeting user demands, and managing network resources efficiently
- Make sure integrity and authenticity of messages,
- ……

Fundamental Problems in Networking …

What can go wrong?

- Bit-level errors: due to electrical interferences
- Packet-level errors: packet loss due to buffer overflow/congestion
- Out of order delivery: packets may takes different paths
- Link/node failures: cable is cut or system crash
- Others: e.g., malicious attacks

Fundamental Problems in Networking

What can be done?

- Add redundancy to detect and correct erroneous packets
- Acknowledge received packets and retransmit lost packets
- Assign sequence numbers and reorder packets at the receiver
- Sense link/node failures and route around failed links/nodes

Goal: to fill the gap between what applications expect and what underlying technology provides

Key Performance Metrics

- Bandwidth (throughput)
  - data transmitted per time unit
  - link versus end-to-end
- Latency (delay)
  - time to send message from point A to point B
  - one-way versus round-trip time (RTT)
  - components

    Latency = Propagation + Transmit + Queue

    Propagation = Distance / c

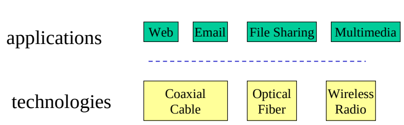
    Transmit = Size / Bandwidth

  Delay Bandwidth Product: # of bits that can be carried in transit
  - RTT usually contains Transmit time plus Queuing delay
- Reliability, availability, …
- Efficiency/overhead of implementation, ……

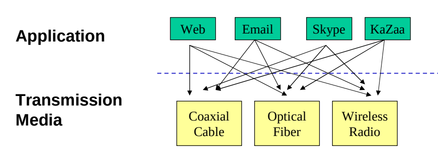
How to Build Data Networks

Bridging the gap between

- what applications expect
  - reliable data transfer
  - response time, latency
  - availability, security ….
- what (physical/link layer) technologies provide
  - various technologies for connecting computers/devices



The Problem



- Do we re-implement every application for every technology?
- Obviously not, but how does the Internet architecture avoid this?

Architectural Principles

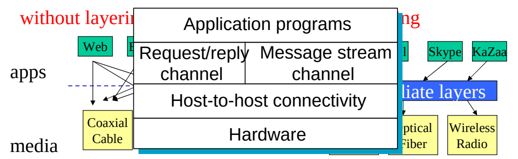
What is (Network) Architecture?

- not the implementation itself
- "design blueprint" on how to "organize" implementations
  - what interfaces are supported
  - where functionality is implemented
- Two (Internet) Architectural Principles
  - Layering
    - how to break network functionality into modules
  - End-to-End Arguments
    - where to implement functionality

Layering

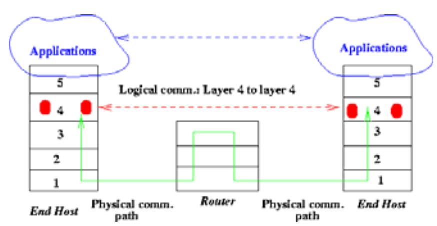
Layering is a particular form of modularization

- system is broken into a vertical hierarchy of logically distinct entities (layers)
- each layer use *abstractions* to hide complexity
- can have alternative abstractions at each layer

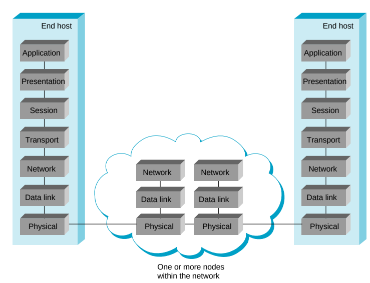


Logical vs. Physical Communications

- Layers interacts with corresponding layer on peer
- Communication goes down to physical network, then to peer, then up to relevant layer



ISO OSI Network Architecture

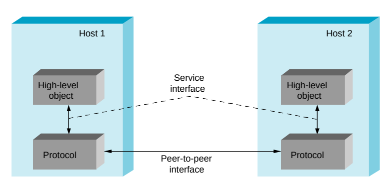


OSI Model Concepts

- Service: what a layer does
- Service interface: how to access the service
  - interface for layer above
- Peer interface (protocol): how peers communicate
  - a set of rules and formats that govern the communication between two network boxes
  - protocol does not govern the implementation on a single machine, but how the layer is implemented between machines

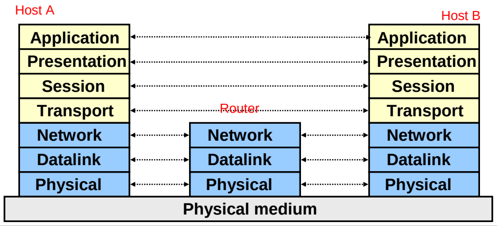
Protocols and Interfaces

- Protocols: specification/implementation of a "service" or "functionality"
- Each protocol object defines two different interfaces
  - *service interface*: operations on this machine
  - *peer-to-peer interface*: messages exchanged with peer



Who Does What?

- Seven layers
  - Lower three layers are implemented everywhere
  - Next four layers are implemented only at hosts



Physical and Data Link layers

- **Physical Layer:** Transmit and receive bits on physical media
  - analog and digital transmission
  - a definition of the 0 and 1 bits
  - bit rate (bandwidth)
- **Data Link Layer:** Provide error-free bit streams across physical media
  - Error detection/correction
  - reliability
  - flow control

Network Layer

Controls the operations of the network

- **Routing**: determining the path from the source of a message to its destination
- **Congestion Control**: handling traffic jams
- **Internetworking** of both homogeneous and heterogeneous networks.

Transport Layer

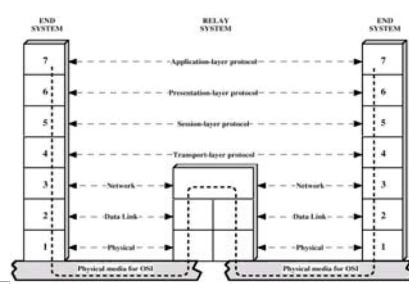
Provides end-to-end (host-to-host) connections

- **Packetization**: cut the messages into smaller chunks (packets)
- An ensuing issue is **ordering**: the receiving end must make sure that the user receives the packets in the right order
- Host-to-host flow control

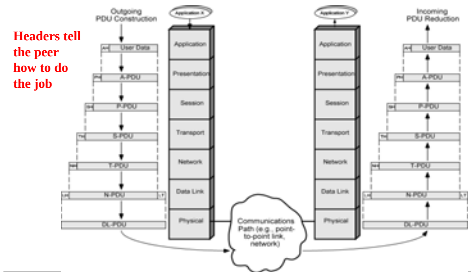
Upper Layers

- **Session Layer**
  - user-to-user connection
  - synchronization, checkpoint, and error recovery
- **Presentation Layer**
  - data representation/compression
  - cryptography and authentication
- **Application Layer**
  - file transfer, email, WWW, and so on

Data Communication based on OSI



Data Encapsulation in OSI

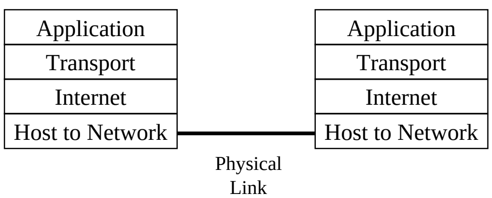


Shortcomings of the OSI Model

Just because someone says it is a model/standard does not mean you have to follow it

- All layers do not have the same size and importance
  - session and presentation layers seldom present
  - data link, network, and transport layers often very full
- Little agreement on where to place various features
  - Encryption, network management
- Large number of layers increases overheads

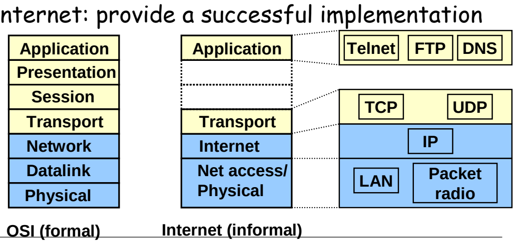
Internet Protocol Suite Reference Model



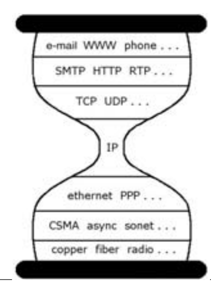
- There are no presentation and session layers in the Internet model.
- The internet layer is the equivalent of the network layer in the OSI model.
- The physical and data link layers in the OSI model are merged to the "Host to Network" layer.

OSI vs. Internet

- OSI: conceptually define services, interfaces, protocols
- Internet: provide a successful implementation



Hourglass

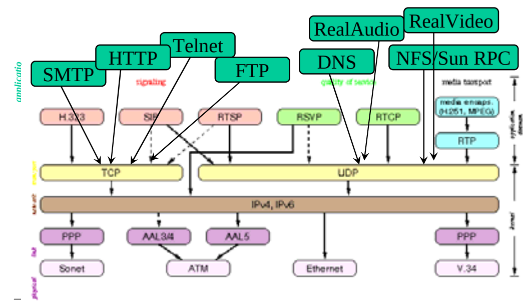


Implications of Hourglass

A single Internet layer module:

- Allows all networks to interoperate
  - all networks technologies that support IP can exchange packets
- Allows all applications to function on all networks
  - all applications that can run on IP can use any network
- Simultaneous developments above and below IP

Internet Protocol "Zoo"



Benefits/Drawbacks of Layering

- Benefits of layering
  - Encapsulation/informing hiding
    - Functionality inside a layer is self-contained;
    - one layer does not need to know how other layers are implemented
  - Modularity
    - can be replaced without impacting other layers
    - Lower layers can be re-used by higher layer
  - Consequences:
    - Applications do not need to do anything in lower layers;
    - information about network hidden from higher layers (applications in particular)
- Drawbacks?
  - Obviously, too rigid, may lead to inefficient implementation

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

PC
server
wireless laptop
cellular handheld

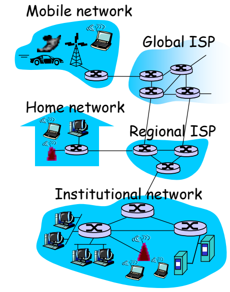
- millions of connected computing devices: *hosts = end systems*
  - running *network apps*

access points
wired links

- *communication links*
  - fiber, copper, radio, satellite
  - transmission rate = *bandwidth*

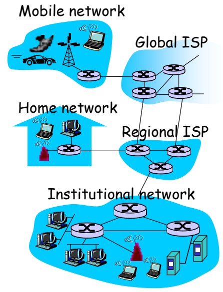
router

- *routers:* forward packets (chunks of data)



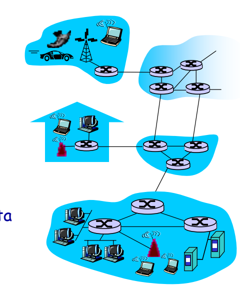
What's the Internet: "nuts and bolts" view

- *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



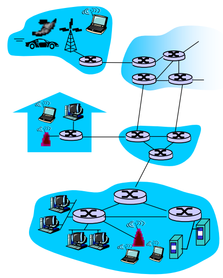
What's the Internet: a service view

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



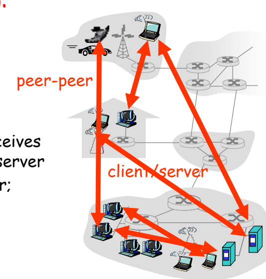
A closer look at network structure:

- network edge: applications and hosts
- access networks, physical media: wired, wireless communication links
- network core:
  - interconnected routers
  - network of networks



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



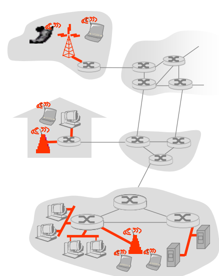
Access networks and physical media

Q: How to connect end systems to edge router?

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

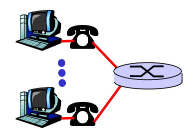
Keep in mind:

- 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 (often less)
  - Can't surf and phone at same time: can't be "always on"



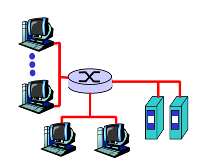
- DSL: digital subscriber line
  - deployment: telephone company (typically)
  - up to 1 Mbps upstream (today typically < 256 kbps)
  - up to 8 Mbps downstream (today typically < 1 Mbps)
  - dedicated physical line to telephone central office

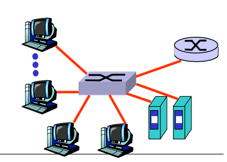
Residential access: cable modems

- 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
- deployment: available via cable TV companies

Company access: local area networks

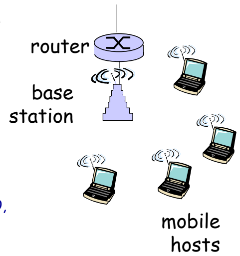
- company/univ local area network (LAN) connects end system to edge router
- Ethernet:
  - 10 Mbs, 100Mbps, 1Gbps, 10Gbps Ethernet
  - modern configuration: end systems connect into *Ethernet switch*





Wireless access networks

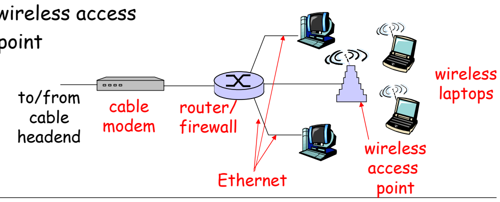
- shared *wireless* access network connects end system to router
  - via base station aka "access point"
- wireless LANs:
  - 802.11b/g (WiFi): 11 or 54 Mbps
  - 802.11a
- wider-area wireless access
  - provided by telco operator
  - ~1Mbps over cellular system (EVDO, HSDPA)
  - WiMAX (10's Mbps) over wide area



Home networks

Typical home network components:

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



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

<u>Twisted Pair (TP)</u>

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

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

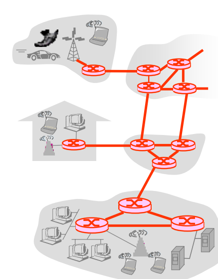
- signal carried in electromagnetic spectrum
- no physical "wire"
- bidirectional
- propagation environment effects:
  - reflection
  - obstruction by objects
  - interference

Radio link types:

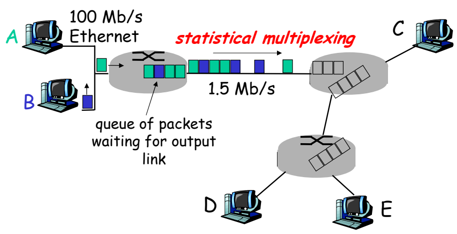
- terrestrial microwave
  - e.g. up to 45 Mbps channels
- LAN (e.g., Wifi)
  - 11Mbps, 54 Mbps
- wide-area (e.g., cellular)
  - 3G cellular: ~ 1 Mbps
- satellite
  - Kbps to 45Mbps channel (or multiple smaller channels)
  - 270 msec end-end delay
  - geosynchronous versus low altitude

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"



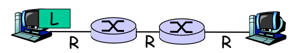
Packet Switching: Statistical Multiplexing



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

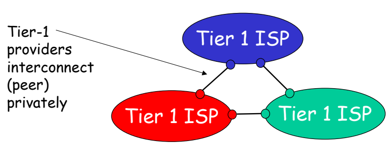


- takes L/R seconds to transmit (push out) packet of L bits on to link at R bps
- *store and forward:* entire packet must arrive at router before it can be transmitted on next link
- delay = 3L/R (assuming zero propagation delay)

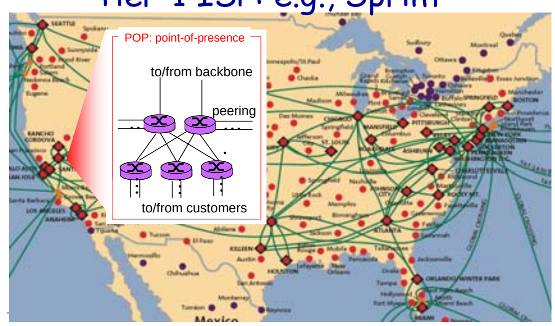
Example:
- L = 7.5 Mbits
- R = 1.5 Mbps
- transmission delay = 15 sec

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

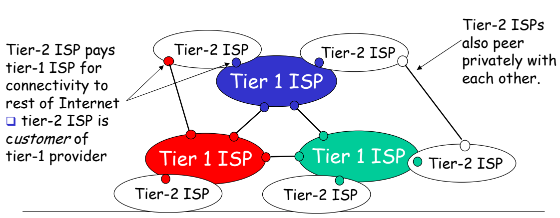


Tier-1 ISP: e.g., Sprint



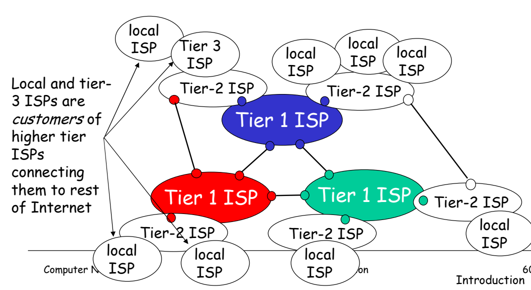
Internet structure: network of networks

- "Tier-2" ISPs: smaller (often regional) ISPs
  - Connect to one or more tier-1 ISPs, possibly other tier-2 ISPs



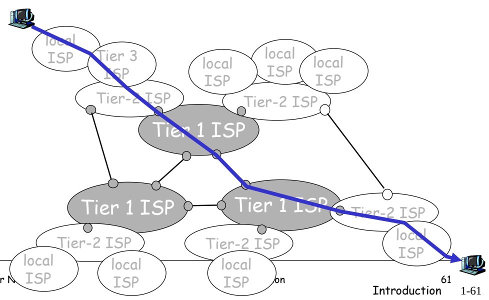
Internet structure: network of networks

- "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!



Summary

- Computer networks use packet switching
- Fundamental issues in networking
  - Addressing/Naming and Routing/Forwarding
  - Error/Flow/Congestion control
- Layered architecture and protocols
- Internet is based on TCP/IP protocol suite
  - Networks of networks!
  - Shared, distributed and complex system in global scale
  - No centralized authority

Readings for Next Week

- Review Chapter 1
- Read Chapter 9: sections 9.1 -9.3; 9.4.2-3
  - Review how web/email and other applications work
  - Learn how p2p and CDN work
  - Understand what Domain Name System does for us
- Read Chapter 7 if interested/needed

Who Runs the Internet

"nobody" really!

- standards: *Internet Engineering Task Force (IETF)*
- names/numbers: *The Internet Corporation for Assigned Names and Numbers (ICANN)*
- operational coordination: IEPG(Internet Engineering Planning Group)
- networks: ISPs (Internet Service Providers), NAPs (Network Access Points), ……
- fibers: telephone companies (mostly)
- content: companies, universities, governments, individuals, …;

Internet "Governing" Bodies

- Internet Society (ISOC): membership organization
  - raise funds for IAB, IETF& IESG, elect IAB
- Internet Engineering Task Force (IETF):
  - **a body of several thousands or more volunteers**
  - organized in working groups (WGs)
  - meet three times a year + email
- Internet Architecture Board
  - architectural oversight, elected by ISOC
- Steering Group (IESG): approves standards,
  - Internet standards, subset of RFC
- *RFC: "Request For Comments"*, since 1969
  - most are *not* standards, *also*
    - **experimental, informational and historic(al)**

Internet Standardization Process

- All standards of the Internet are published as RFC
- But not all RFCs are Internet Standards
- A typical (but not only) way of standardization is:
  - Internet Drafts
  - RFC
  - Proposed Standard
  - Draft Standard (requires 2 working implementation)
  - Internet Standard (declared by IAB)

- David Clark, MIT 1992: *"We reject: kings, presidents, and voting. We believe in: rough consensus and running code."*

Internet Names and Addresses

- Internet Assigned Number Authority (IANA):
  - keep track of numbers, delegates Internet address assignment
  - designates authority for each top-level domain
- InterNIC, gTLD-MOU, CORE:
  - hand out names
  - provide "root DNS service"
- RIPE, ARIN, APNIC:
  - hand out blocks of addresses

Many responsibilities (e.g., those of IANA) are now taken over by the *Internet Corporation for Assigned Names and Numbers (ICANN)*

Origin of Internet?

Started by U.S. research/military organizations:

- Three Major Actors:
  - **DARPA**: Defense Advanced Research Projects Agency
    - funds technology with military goals
  - **DoD**: U.S. Department of Defense
    - early adaptor of Internet technology for production use
  - **NSF**: National Science Foundation
    - funds university

A Brief History of Internet

The Dark Age before the Internet: before 1960

- 1830: telegraph
- 1876: circuit-switching (telephone)
- TV (1940?) , and later cable TV (1970s)

The Dawn of the Internet: 1960s

- early 1960's: concept of packet switching *(Leonard Kleinrock, Paul Baran et al)*
- 1965: MIT's Lincoln Laboratory commissions Thomas Marill to study computer networking
- 1968: ARPAnet contract awarded to Bolt Beranek and Newman (BBN)
  - Robert Taylor (DARPA program manager)
  - BoB Kahn (originally MIT) and the team at BBN built the first router (aka IMP)

A Brief History of Internet …

- 1969: ARPAnet has 4 nodes (UCLA, SRI, UCSB, U. Utah)
  - UCLA team: Len Kleinrock, Vincent Cerf, Jon Postel, et al

Early Days of the Internet: 1970s

- multiple access networks (i.e., LANs): ALOHA, Ethernet(10Mb/s)
- companies: DECnet (1975), IBM SNA (1974)
- 1971: 15 nodes and 23 hosts: UCLA, SRI, UCSB, U. Utah, BBN, MIT, RAND, SDC, Harvard, Lincoln Lab, Stanford, UIUC, CWRU, CMU, NASA/Ames
- 1972: First public demonstration at ICCC
- 1973: TCP/IP design
- 1973: first satellite link from California to Hawwii

A Brief History of Internet …

- 1973:first international connections to ARPAnet: *England and Norway*
- 1978: TCP split into TCP and IP
- 1979: ARPAnet: approx. 100 nodes

The Internet Coming of Age: 1980s

- proliferation of local area networks: Ethernet and token rings
- late 1980s: fiber optical networks; FDDI at 100 Mbps

- 1980's: DARPA funded Berkeley Unix, with TCP/IP
- 1981: Minitel deployed in France
- 1981: BITNET/CSNet created
- 1982: Eunet created (European Unix Network)
- Jan 1, 1983: *flag day*, NCP -> TCP

A Brief History of Internet …

- 1983: split ARAPNET (research), MILNET
- 1983: Internet Activities Board (IAB) formed
- 1984: Domain Name Service replaces hosts.txt file
- 1986: Internet Engineering/Research Task Force created
- 1986: NSFNET created (56kbps backbone)
- 1987: UUNET founded
- Nov 2, 1988: Internet worm, affecting ~6000 hosts
- 1988: Internet Relay Chat (IRC) developed by Jarkko Oikarinen
- 1988: Internet Assigned Numbers Authority (IANA) established
- 1989: Internet passes 100,000 nodes
- 1989: NSFNET backbone upgraded to T1 (1.544 Mpbs)
- 1989: ***Berners-Lee invented WWW at CERN***

A Brief History of Internet …

The Boom Time of the Internet: 1990s

- high-speed networks: ATM (150 Mbps or higher), Fast Ethernet (100Mbps) and Gigabit Ethernet
- new applications: gopher, and of course *WWW*!
- wireless local area networks
- commercialization
- National Information Infrastructure (NII) (Al Gore, "father" of what?)

- 1990: Original ARPANET disbanded
- 1991: *Gopher released by Paul Lindner & Mark P. McCahill, U.of Minnesota*
- *1991: WWW released by Tim Berners-Lee, CERN*
- 1991: NSFNET backbone upgrade to T3 (44.736 Mbps)
- Jan 1992: Internet Society (ISOC) chartered

A Brief History of Internet …

- March 1992: first MBONE audio multicast
  - MBONE: multicast backbone, "overlayed" on top of Internet
- Nov 1992: first MBONE video multicast
- 1992: numbers of Internet hosts break 1 million
  - The term "*surfing the Internet*" is coined by Jean Armour Polly
- *1993: Mosaic takes the Internet by storm*
- 1993: InterNIC (Internet information center) created by NSF
  - US White House, UN come on-line
- 1994: ARPANET/Internet celebrates 25th anniversary
- 1994: NSFNET traffic passes 10 trillion bytes/month
- Apr 30 1995: NSFNET backbone disbanded
  - traffic now routed through interconnected network providers