Computer Networks

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Nanjing University

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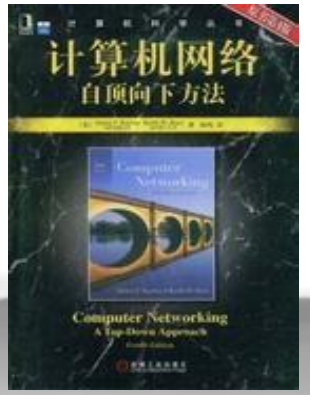
课程安排

- 教学目标：因特网概念和组成，组网原理，协议设计和分析
- 教学内容：课堂+实验
  - 实验课为每双周周五14:00-16:00，地点：乙124
- 课程主页：http://cs.nju.edu.cn/lwz/networks/
- 课程论坛：sys.nju.edu.cn
- 课程考核
  - 平时作业：10%
  - 实验: 30%
  - 期末考试: 60%

参考书籍

- William Stallings. 数据与计算机通信 (8th). 电子工业出版社

- James F. Kurose, Keith W. Ross. 计算机网络—自顶向下方法 (4th). 机械工业出版社



课程大纲

- Chapter 1. Introduction of Networking
- Chapter 2. Direct Link Networks
- Chapter 3. Packet Switching Networks
- Chapter 4. Internetworking
- Chapter 5. End-to-End Protocols
- Chapter 6. Congestion Control and QoS
- Chapter 7. Network Security
- Chapter 8. Internet Applications

Chapter 1. Introduction of Networking

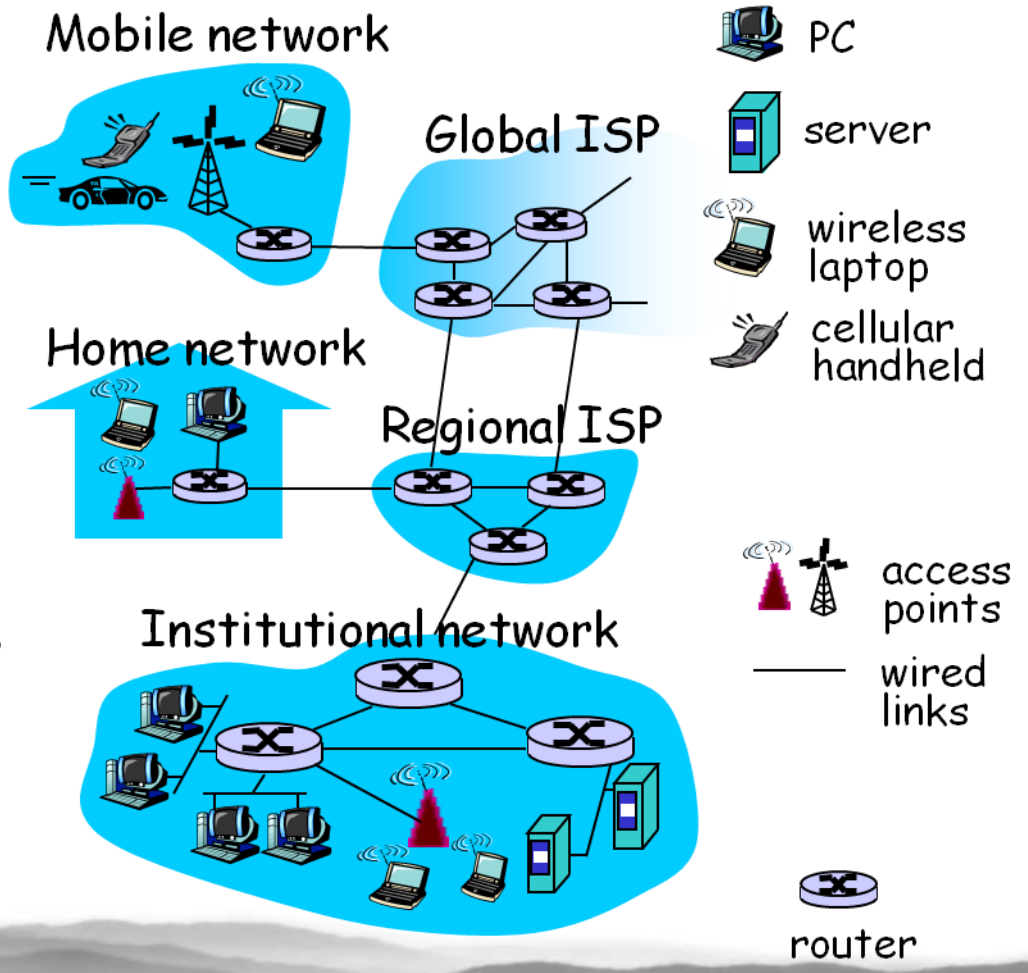
Chapter 1. Introduction of Networking (1)

- Brief Introduction of Internet
- Internet History
- Typical Network Applications
- Protocol Layers and Service Model
- Network Programming
- Network Performance
- Network Security

Brief Introduction of Internet

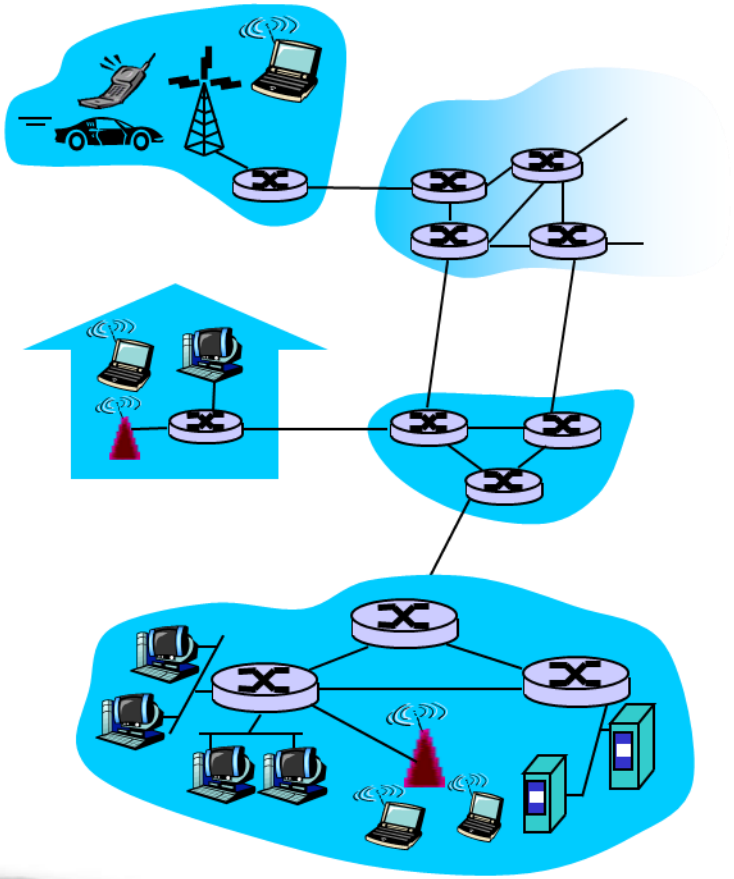
Internet – Component View

- Millions of connected computing devices
  - Hosts = End systems
  - Running network applications
- Communication links
  - Fiber, Copper, Radio, Satellite
  - Building physical networks
- Routers
  - Forward packets (chunks of data) between physical networks



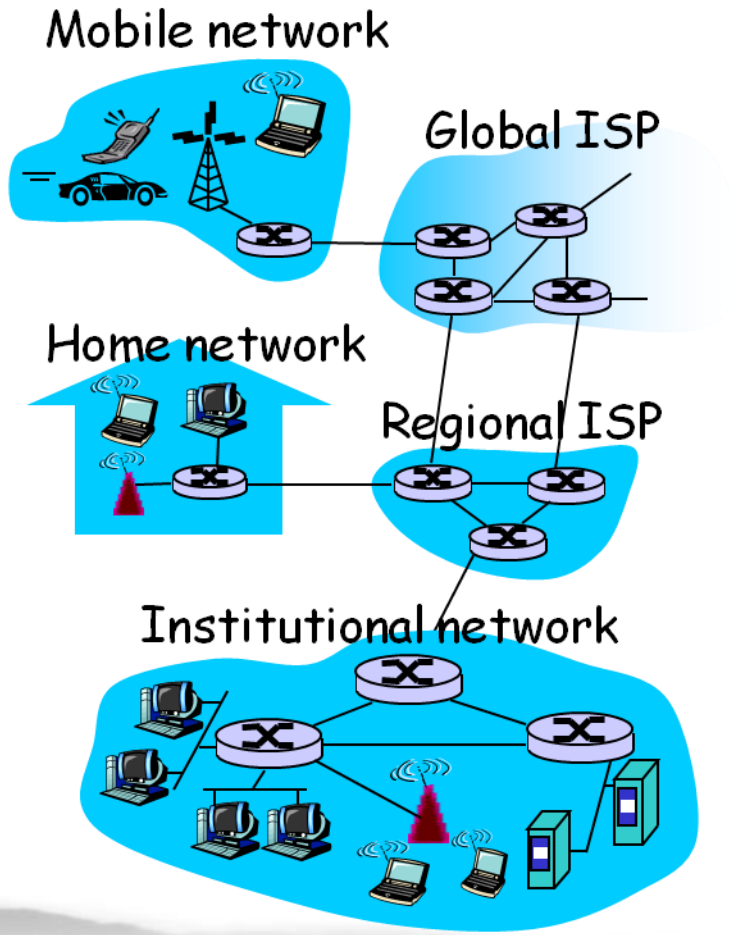
Internet – Service View

- Communication infrastructure
  - Enables distributed applications
  - Web, VoIP, email, online games, e-commerce, file sharing
- Communication services provided
  - Reliable data delivery from source to destination
  - "best effort" (unreliable) data delivery
  - Guaranteed delay and throughput



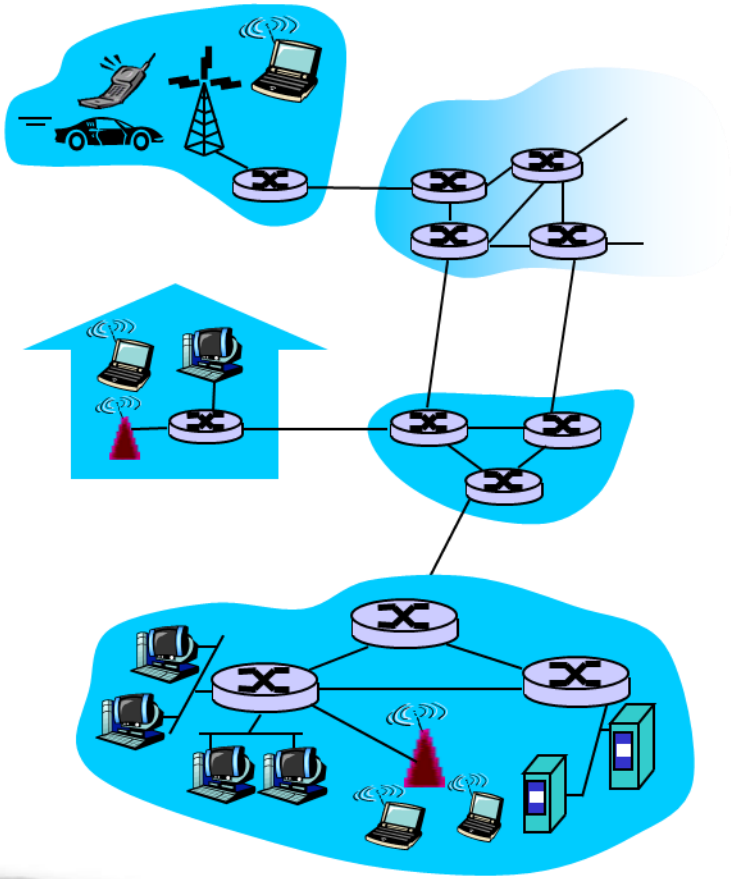
Internet – Protocols

- Network Protocols
  - Control sending, receiving of messages
  - e.g. HTTP, Skype; TCP, IP; PPP, Ethernet
- Internet standards
  - IETF: Internet Engineering Task Force
  - RFC: Request for comments
- Internet: "network of networks"
  - Public Internet versus private Intranet
  - Loosely hierarchical



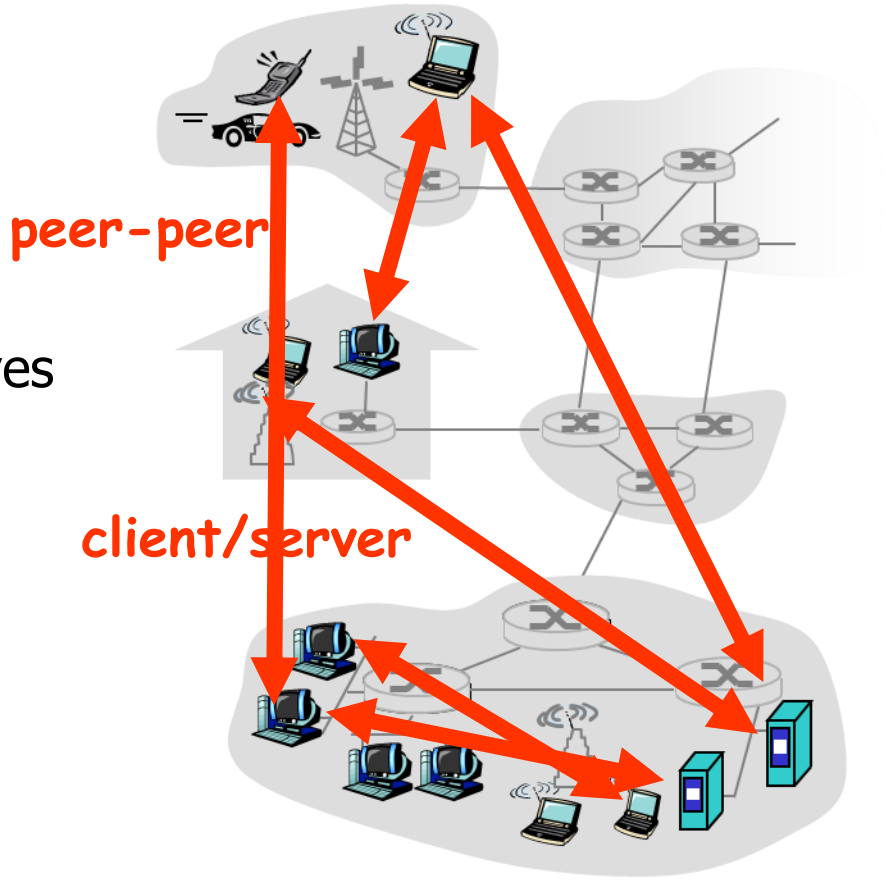
Access Internet

- Network edge
  - Applications and hosts
- Network core
  - Interconnected routers
  - Network of networks
- Access networks
  - Physical media
  - Wired and wireless communication links



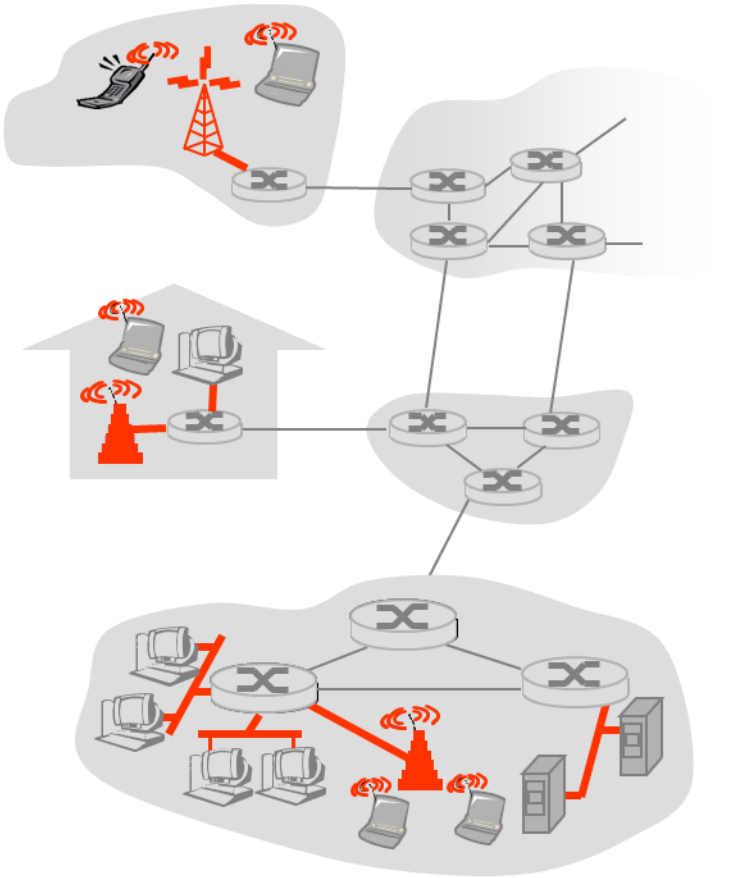
Network Edge

- End systems (hosts)
  - Run application programs
  - e.g. Web, Email
- Client/server model
  - Client host requests, receives service from always-on server
  - e.g. Web browser/server; Email client/server
- Peer-to-peer model
  - Minimal (or no) use of dedicated servers
  - e.g. Skype, BitTorrent



Access Networks

- Connect end systems to edge router
  - Residential (Home) access networks
  - Institutional access networks (school, company)
  - Mobile access networks



- Performance
  - Bandwidth (bits per second) of access network
  - Shared or dedicated

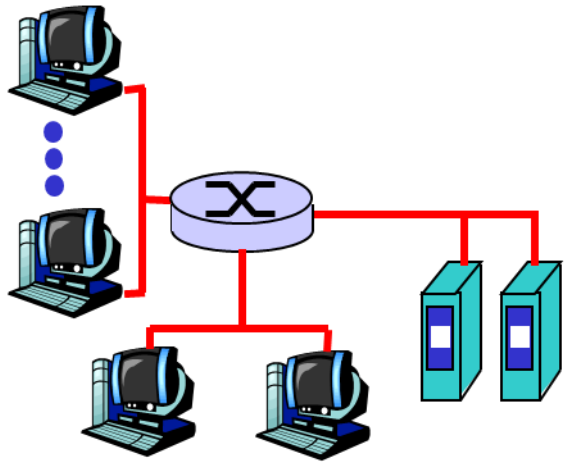
Residential Access

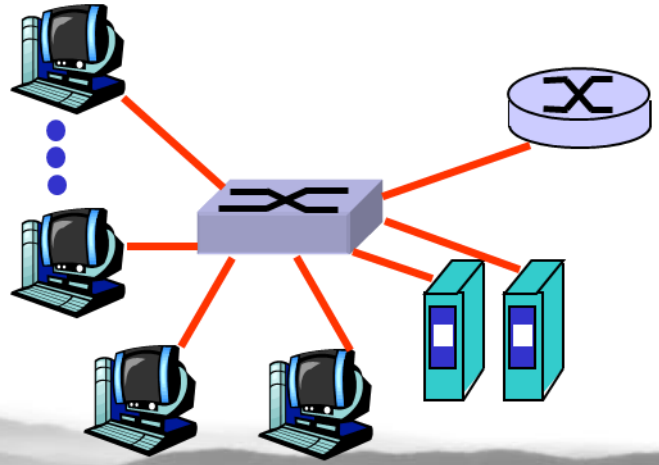
- Dialup via modem
  - Up to 56Kbps direct access to router
- DSL: digital subscriber line
  - Deployment: telephone company
  - Up to 1 Mbps upstream, and 8 Mbps downstream
  - Dedicated physical line to telephone central office
- HFC: hybrid fiber coax
  - Asymmetric: up to 30Mbps downstream, 2 Mbps upstream
  - Homes share access to ISP router
  - Deployment: cable TV companies

Company Access: Local Area Networks

- Company/University local area network (LAN) connects end systems to edge router

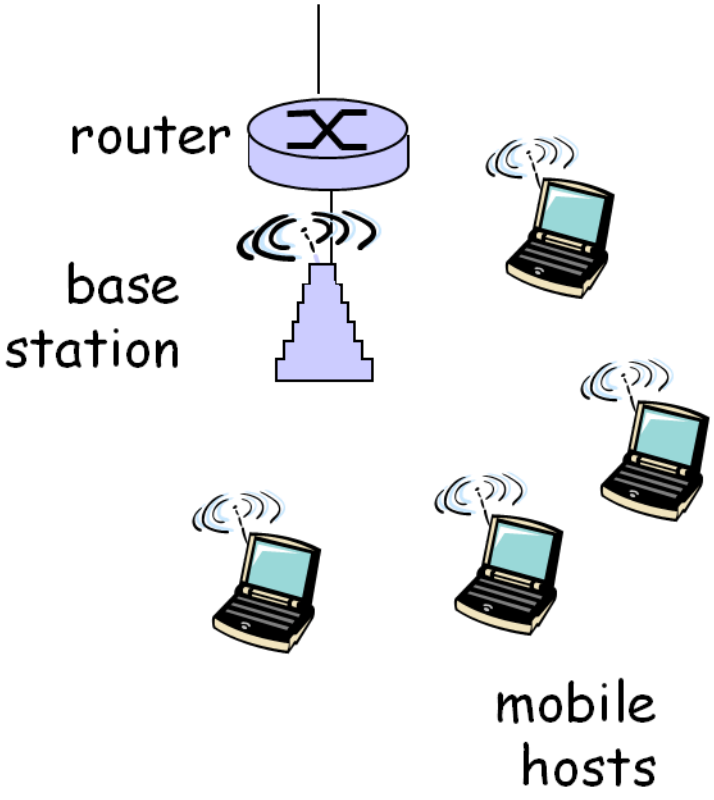
- Ethernet:
  - 10 Mbs, 100Mbps, 1Gbps, 10Gbps Ethernet
  - Modern configuration: end systems connect into backbone of Ethernet switches





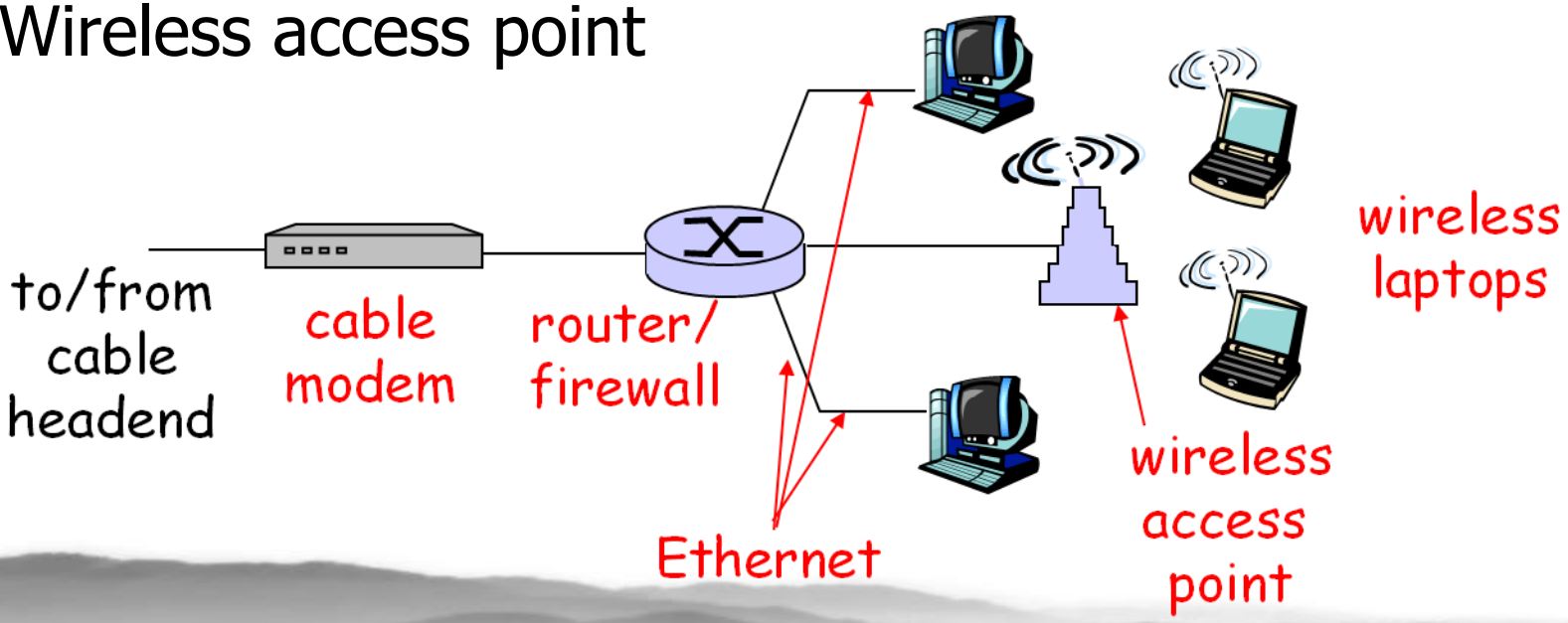
Wireless Access Networks

- Shared wireless media connects end system to router
  - via base station, or "access point"
- Wireless LANs:
  - 802.11b/g (WiFi): 11 or 54 Mbps
- Wider-area wireless access
  - Provided by telecommunication operator
  - ~1Mbps over cellular system
  - Next up (?): WiMAX (10's Mbps) over wide area



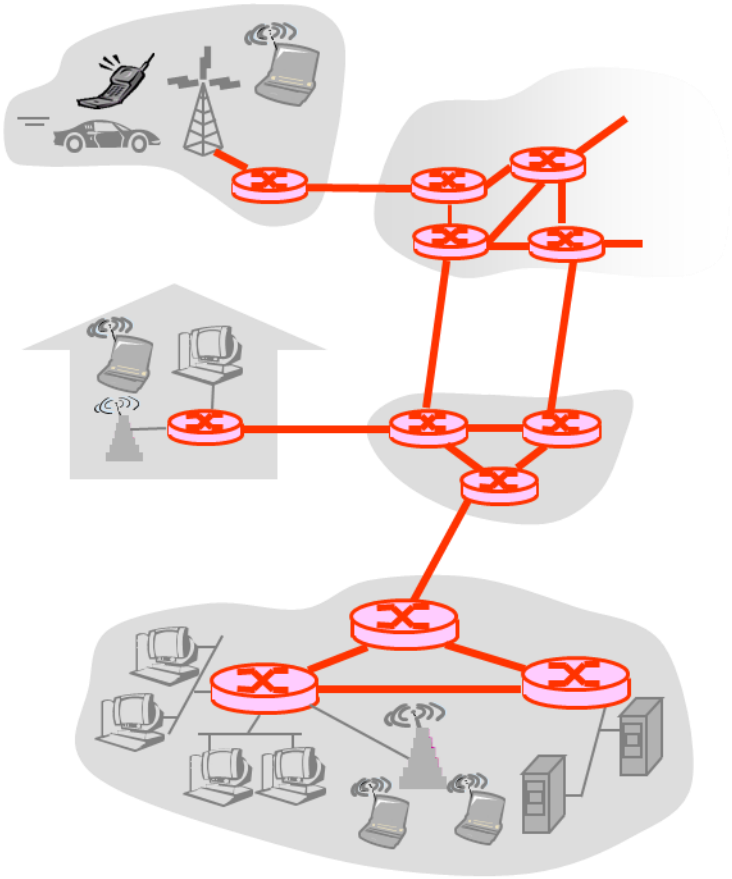
Example: A Modern Family

- A home network components:
  - DSL or cable modem
  - Router/Firewall/NAT
  - Ethernet switch
  - Wireless access point



The Network Core

- Mesh of interconnected routers
- Fundamental question
  - How is data transferred through the net?
- Circuit switching
  - Dedicated circuit per call, e.g. telephone net
- Packet-switching
  - Data sent through net in discrete chunks

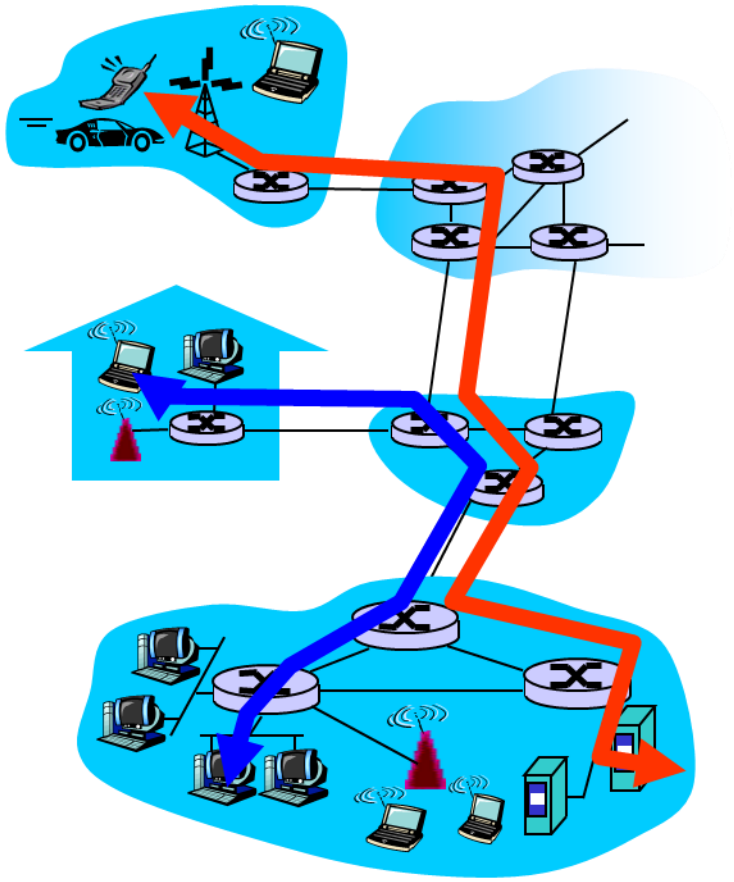


Circuit Switching

End-to-end resources reserved for "call"

- Link bandwidth, switch capacity
- Dedicated resources: no sharing

- Circuit-like (guaranteed) performance
- Call setup/teardown required



Packet Switching

Each end-to-end data stream divided into packets

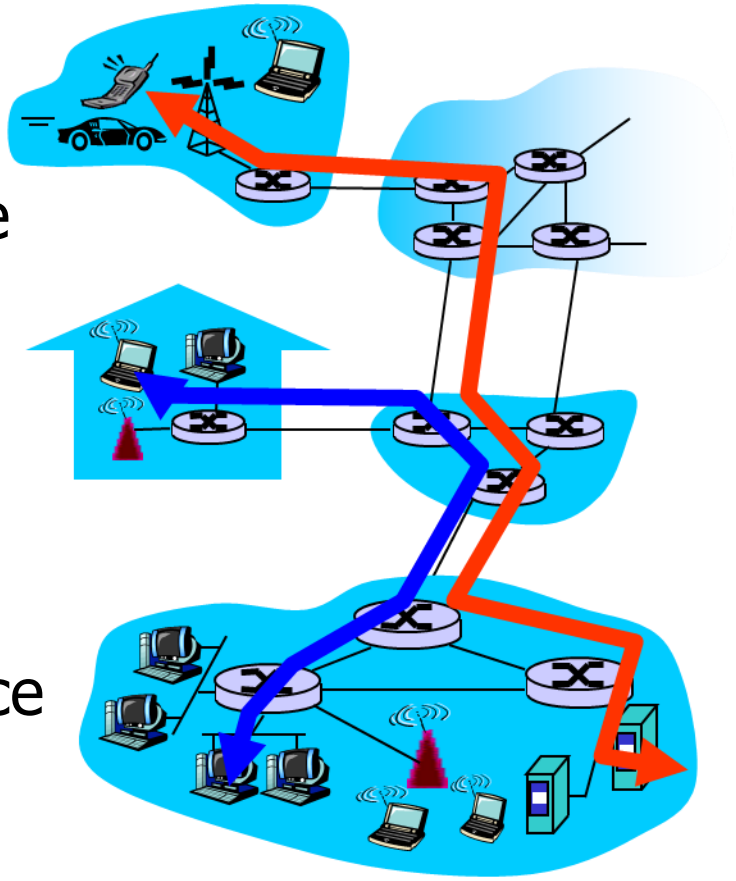
- Application A, B packets share network resources

- Store and forward: packets move one hop at a time, stored (queued) at switches
- Each packet uses full link bandwidth

- Resource contention: aggregate (burst-up) resource demand can exceed amount available
- Congestion: packets queue and wait for link use

Virtual Circuit

- Circuit Switching + Packet Switching
  - Routes or main cross roads are fixed
  - Resources shared, congestion control needed
  - Resources can be preserved, leading to different performance
  - Connection setup/teardown needed



Comparison

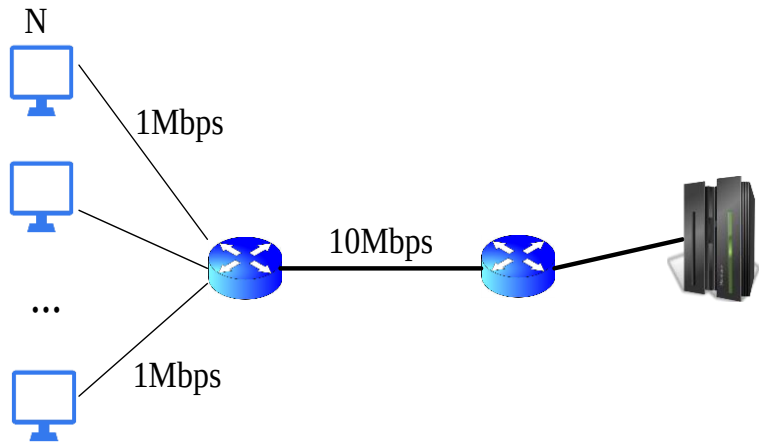
	电路交换	数据报分组交换	虚电路分组交换
传输通路	专用	非专用	非专用
连续性	连续传输	分组传输	分组传输
带宽	固定	动态使用	动态使用
路由	固定	动态	固定
时延	实时（只有呼叫建立时延）	分组传输时延	分组传输时延+呼叫建立时延
扩展性	差（接入用户有上限）	好（用户数量可动态扩充）	较好（用户数量动态，由拥塞控制来保证服务质量）

Example: Statistical Multiplexing

- Statistical Multiplexing (统计多路复用): Link bandwidth shared on demand （按需共享）

Example:
- **N users share one link (10Mbps)**
- **Each user requires 1Mbps**
- **Each user: active 10%, idle 90%.**

How many users are supported?



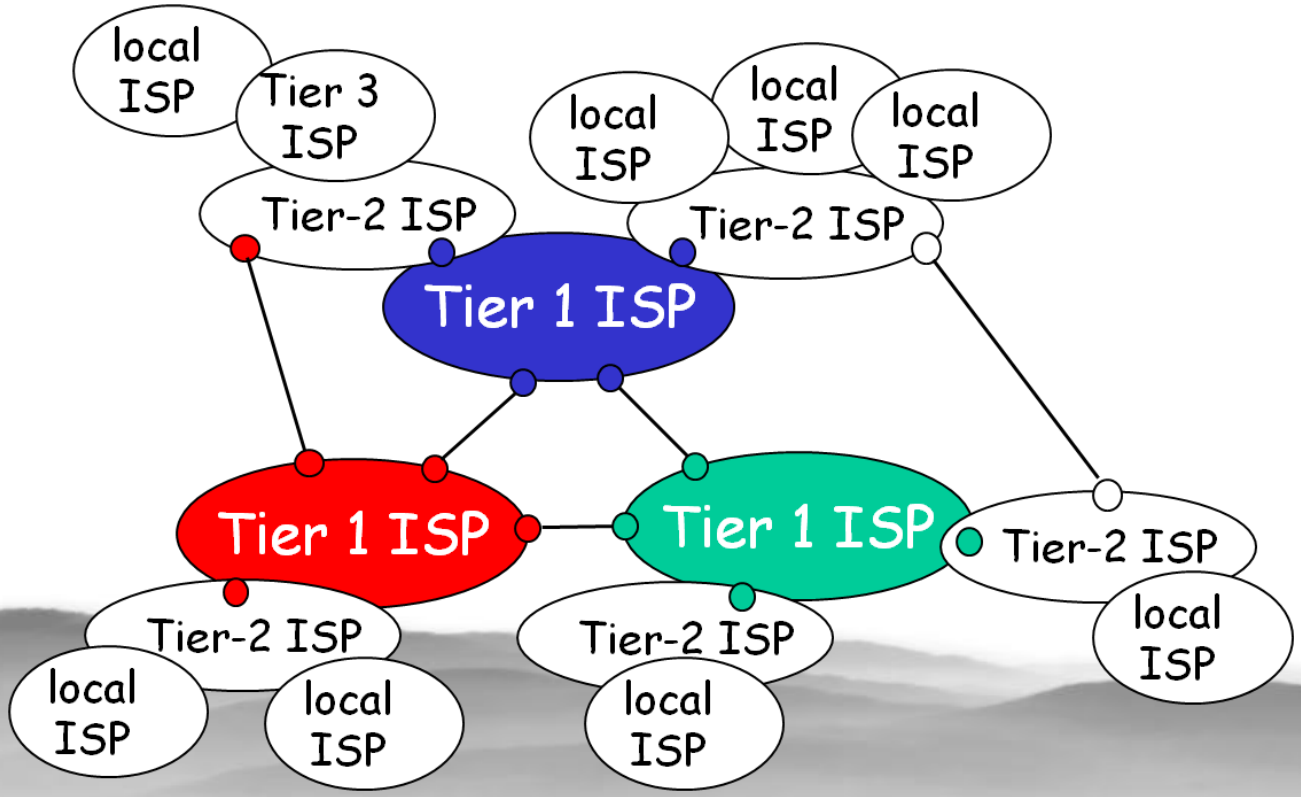
Circuit Switching:
N=10Mbps/1Mbps=10 users

Statistical Multiplexing:
Assume N=35,
Prob{active user>10}<=0.0004,
So for N=35, with probability 0.9996 a user have bandwidth larger than 1Mbps.

Internet Structure – Network of Networks

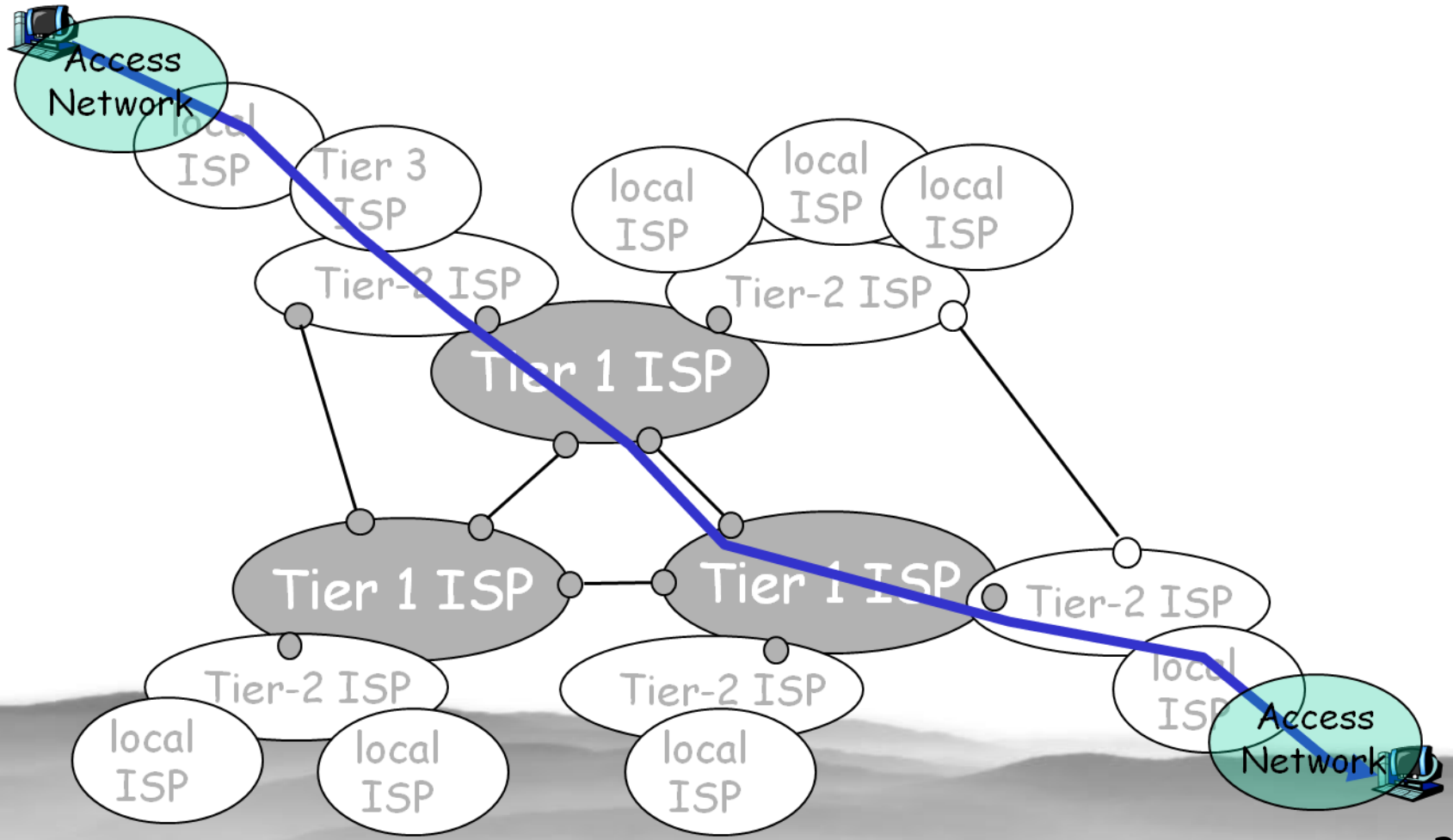
Roughly hierarchical

- At center: "tier-1" (National) ISPs
- "Tier-2" ISPs: smaller (often regional) ISPs
- "Tier-3" ISPs and local/edge ISPs, connect access networks



Internet – Network of Networks

- A packet may pass through many networks



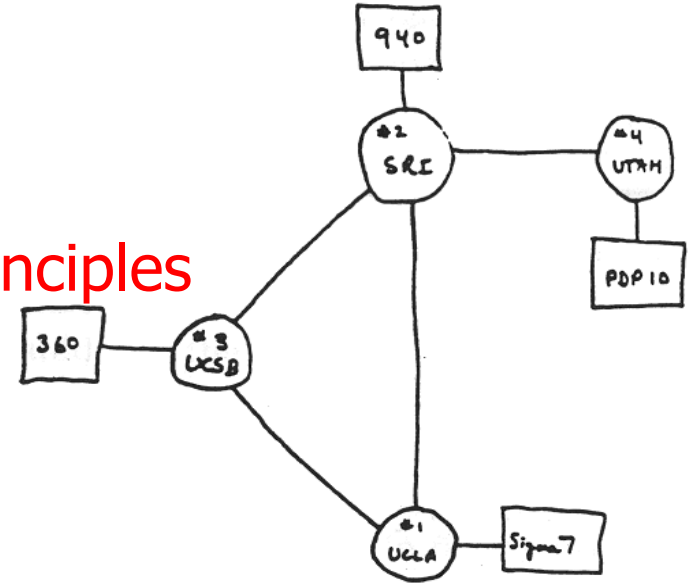
Internet History

Internet History (1)

1961-1972: Early packet-switching principles

60年代：诞生-分组交换网络

- 1961: Kleinrock – queuing theory shows effectiveness of packet-switching
- 1964: Baran – packet-switching in military nets
- 1967: ARPAnet conceived by Advanced Research Projects Agency
- 1969: first ARPAnet node operational, Kleinrock



THE ARPA NETWORK

- 1972:
  - ARPAnet demonstrated publicly
  - NCP (Network Control Protocol) first host-host protocol [RFC001]
  - First email program
  - ARPAnet has 15 nodes

Internet History (2)

1972-1980: Internetworking, new and proprietary nets

70年代：成型
单一、封闭网络 -〉开放互联网络

- 1970: ALOHAnet satellite network in Hawaii, Norman Abramson （无线分组网络）
- 1973: Metcalfe's PhD thesis proposes Ethernet（以太网）, at Xerox PARC in 1976（局域网诞生）
- 1974: Cerf and Kahn – architecture for interconnecting networks（Internet构架）
- Late70's:
  - Proprietary architectures: DECnet, SNA, XNA
  - 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

Internet History (3)

1980-1990: new protocols, a proliferation of networks

80年代：持续发展
- 新协议： **NCP-〉TCP/IP**
- **DNS**：实现域名解析
- 应用：**Email，Ftp**

- 1983: deployment of TCP/IP
- 1982: SMTP email 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

Internet History (4)

1990's, 2000's: commercialization, the Web, new apps

90年代：因特网爆炸
- 万维网出现：**www （http，HTML，Web Server，Browser）**
- 商用化，逐渐普及
- 新型应用：**Email，Web，IM （instant messaging），MP3**文件共享

- Early 1990's: ARPAnet decommissioned
- 1991: NSF lifts restrictions on commercial use of NSFnet (decommissioned in 1995)
- Early 1990's: Web
  - Hypertext [Bush 1945, Nelson 1960's]
  - HTML, HTTP: Berners-Lee
- 1994: Mosaic, later Netscape Browser

Late 1990's: commercialization of the Web

Late 1990's ~ 2000's:

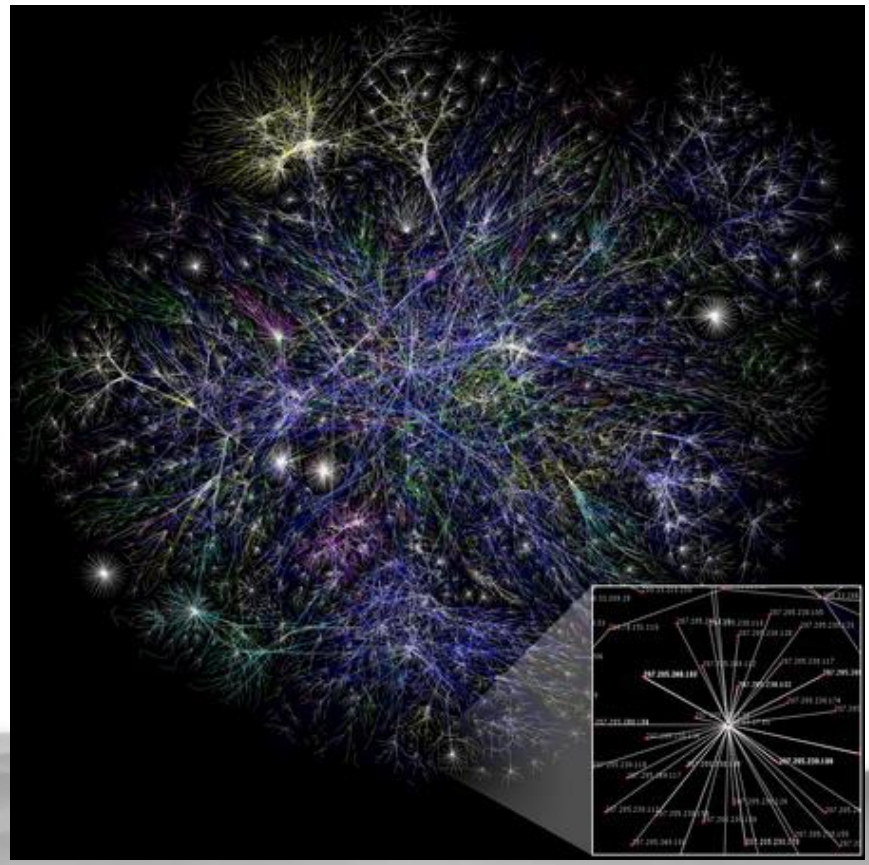
- More killer apps: instant messaging, peer2peer file sharing (e.g. Napster)
- Network security to forefront
- Est. 50 million host, 100 million+ users
- Backbone links running at Gbps

Internet History (5)

2000年以后，新型应用涌现
- 多媒体
- **P2P**网络
- 社交网络（**Facebook**，**Twitter**，人人，微博，微信，...）

2007

- ~500 million hosts
- Voice, Video over IP
- P2P applications: BitTorrent (file sharing), Skype (VoIP), PPLive (video)
- More applications: YouTube, online gaming
- Wireless and mobility



Typical Network Applications

Typical Network Applications

- Client-Server Applications
  - Electronic Mail
  - FTP
  - Web and HTTP
  - Social Networks
- Peer-to-Peer Applications
  - Skype
  - BitTorrent

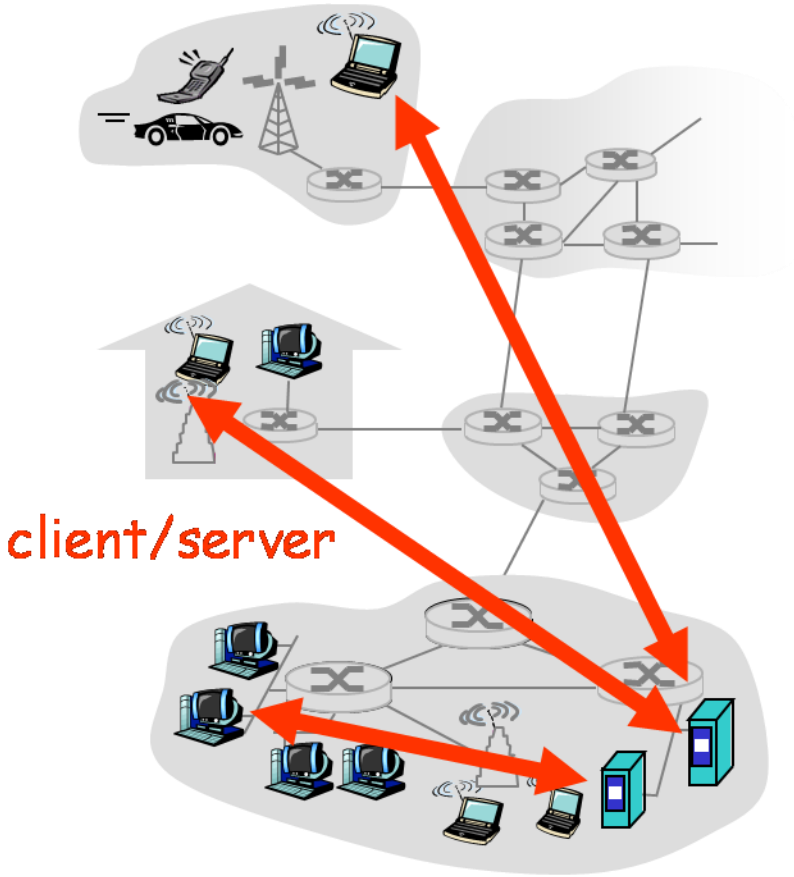
Client-Server Architecture

Server

- Always-on host
- Permanent IP address
- Server farms for scaling

Clients

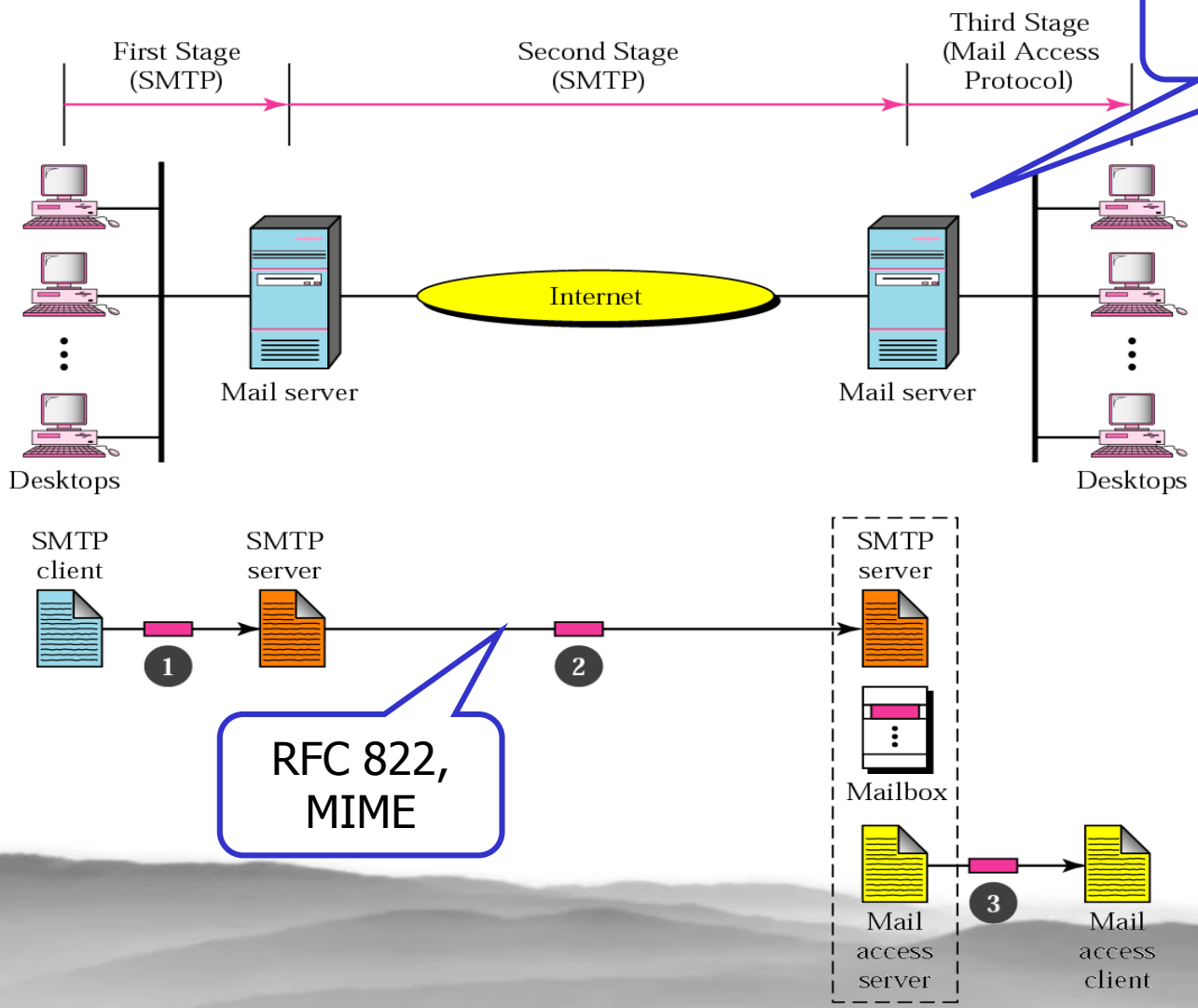
- Communicate with server
- May be intermittently connected
- May have dynamic IP addresses
- Do not communicate directly with each other



Electronic Mail

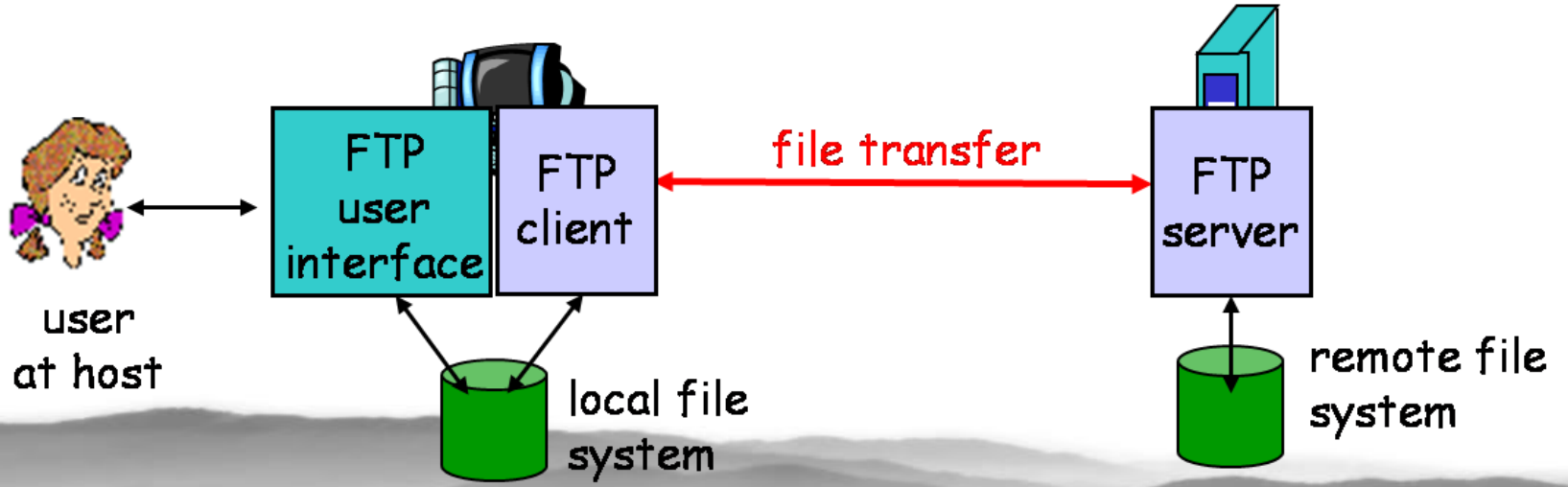
- SMTP: Simple Mail Transfer Protocol
  - Delivery of simple text mail
- MIME: Multi-purpose Internet Mail Extension
  - Express of other types of data, e.g. voice, images, video clips
- POP: Post Office Protocol
  - Mail retrieval from server, including authorization and download
- IMAP: Internet Mail Access Protocol
  - Manipulation of stored mails on server

Illustration of A Mail System



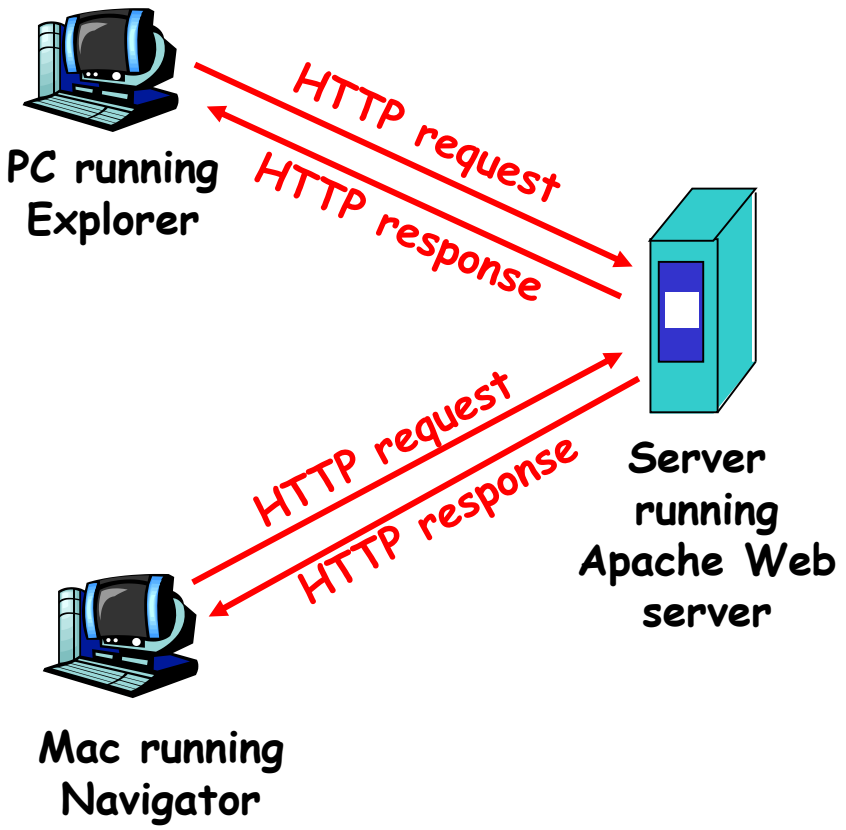
FTP

- Transfer file to/from remote host
- Control connection
  - Login/logout, file transfer command/reply
- Data connection
  - Transferring file contents
  - Client side initiates file transfer

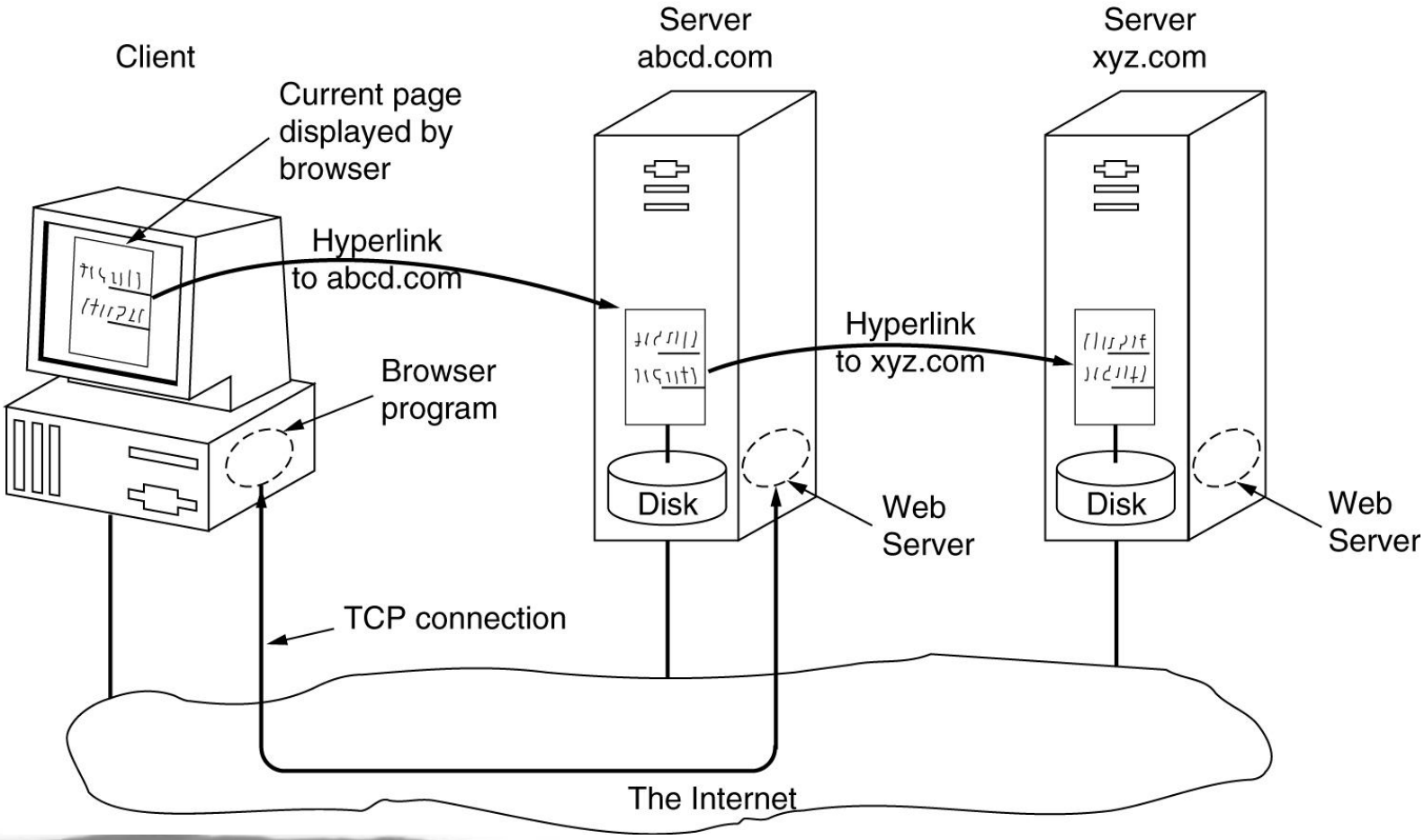


Web and HTTP

- Clients use browser to send URL(URI)s via HTTP to servers requesting a Web page
- Web pages constructed using HTML (or other markup language), inter-connected by URL
- Servers (or caches) respond with requested Web page
- Client's browser displays Web page returned by server

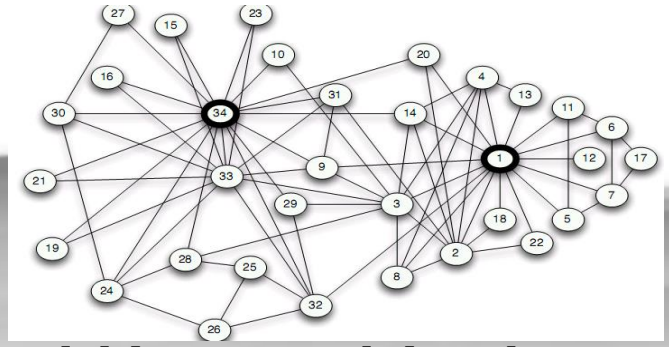


WWW Architecture

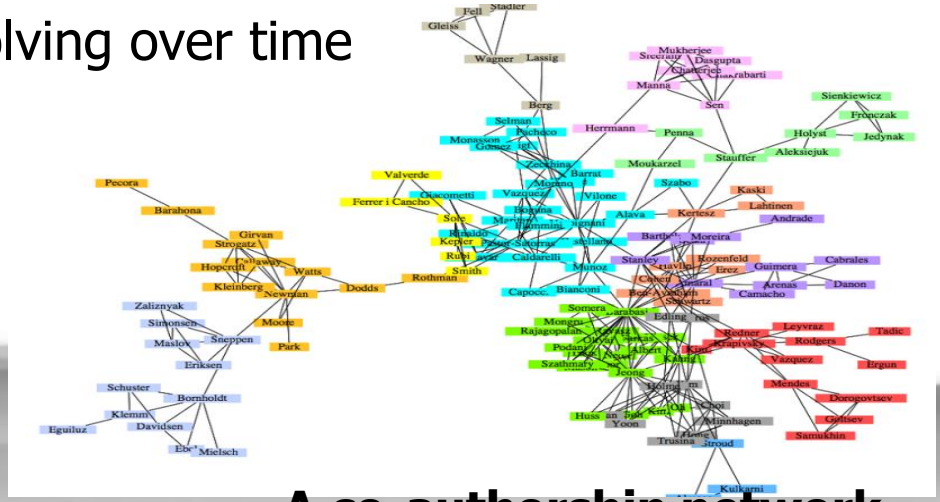


Social Networks

- Social Network
  - A network made up by a set of individuals interconnecting with each other basing on social relationships (such as friendships, partnerships, etc.)
- Characteristics
  - Virtual: it is not physically exists
  - Complex: it consists of a large scale number of nodes
  - Grouping: it forms communities due to different interests
  - Dynamic: it's structure is evolving over time



A friendship network in a karate

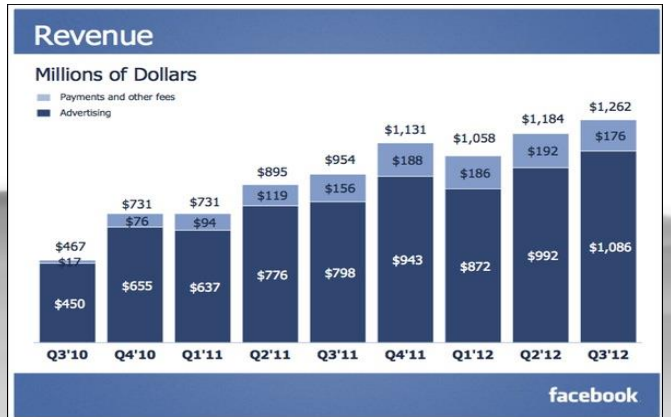


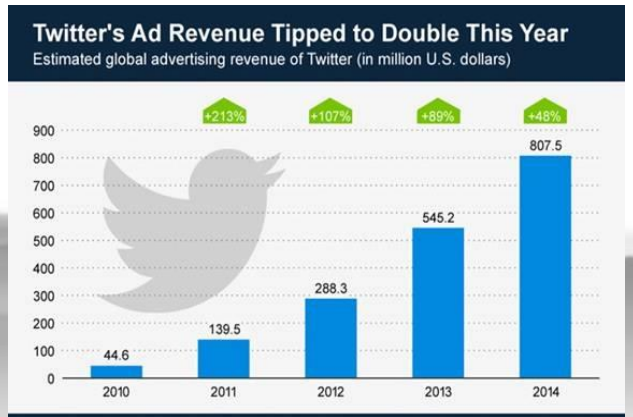
A co-authorship network

Social Network Applications

- Online Social Networks: Facebook, Twitter, etc.

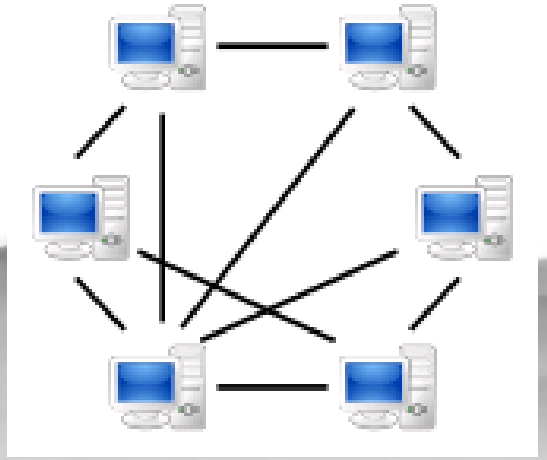
- Population of online social networks grows rapidly
  - Facebook: 1.28 billion (active March 2014, Wikipedia)
  - Twitter: 200 million (active February 2013, Wikipedia)
  - Renren: 160 million (Feb 2011, Wikipedia)

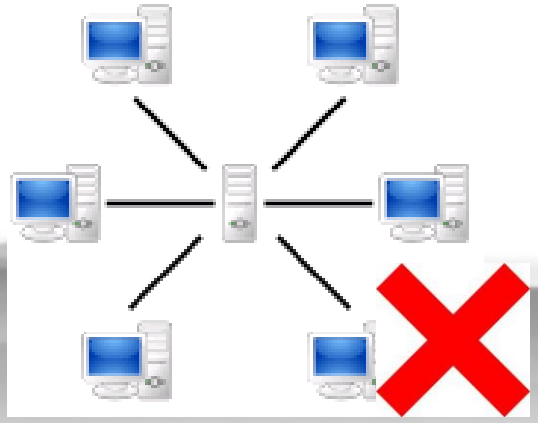




Peer-to-Peer Architecture

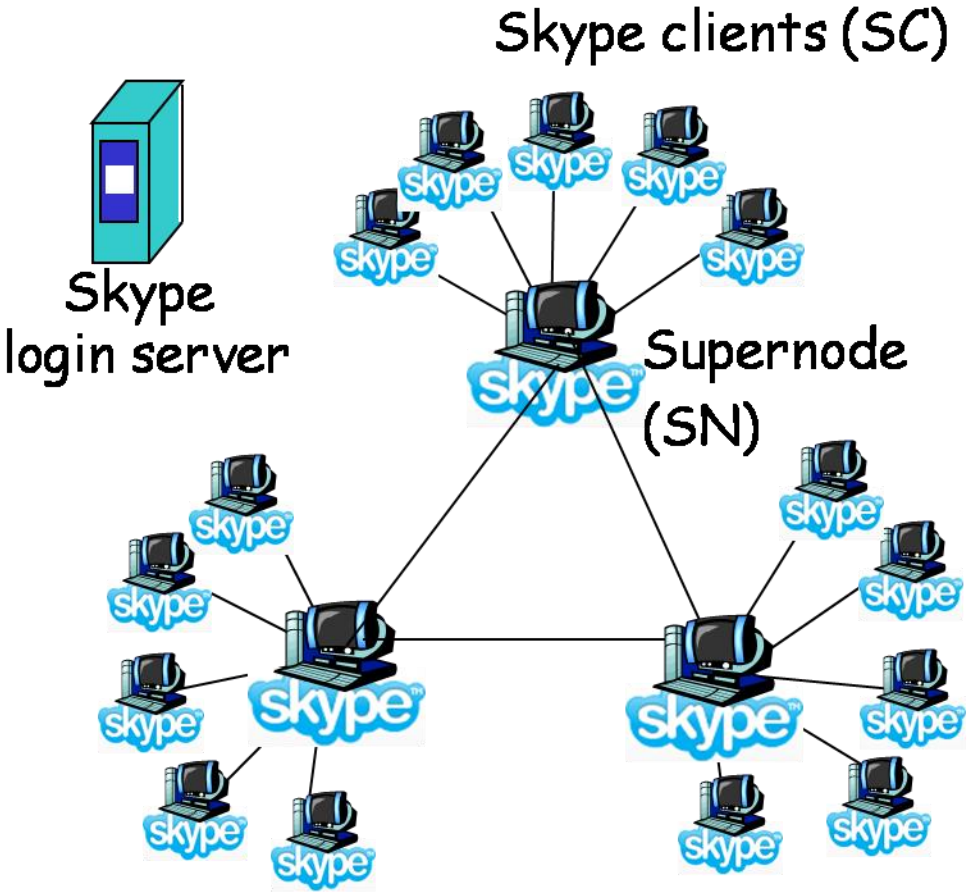
- Peer-to-peer (abbreviated to P2P) refers to a computer network in which each computer in the network can act as a client or server for the other computers in the network, allowing shared access to files and peripherals without the need for a central server [Wiki]





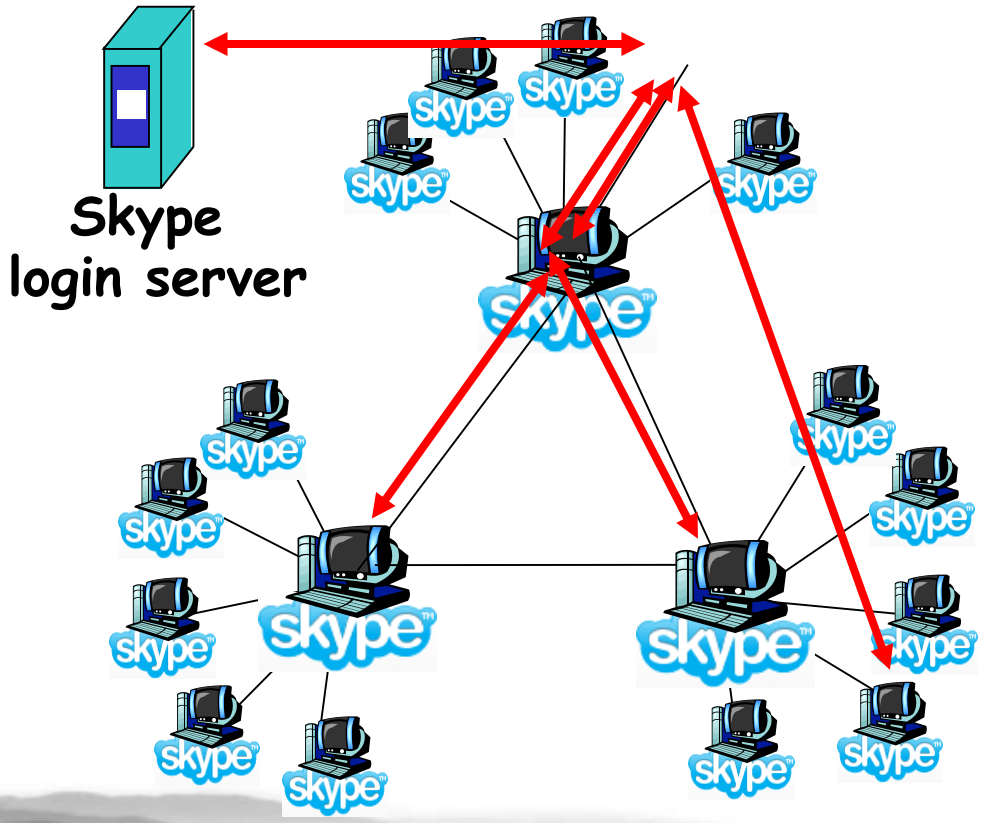
Skype

- P2P Voice-Over-IP (VoIP) application
  - pc-to-pc, pc-to-phone, phone-to-pc
- Proprietary application-layer protocol



Skype: Making a Call

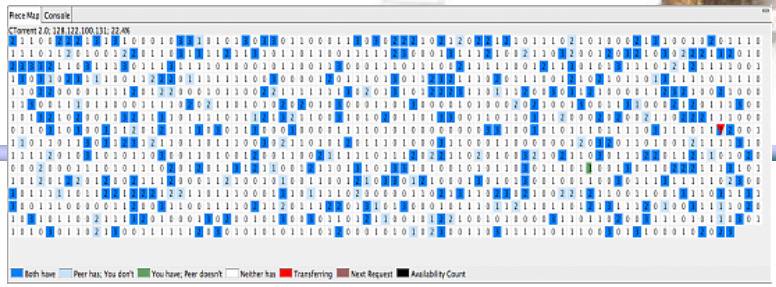
- User starts Skype
- SC registers with SN
- SC logs in (authenticate)
- Call: SC contacts SN with callee ID
- SN contacts other SNs to find address of callee
- SC directly contacts callee, over TCP



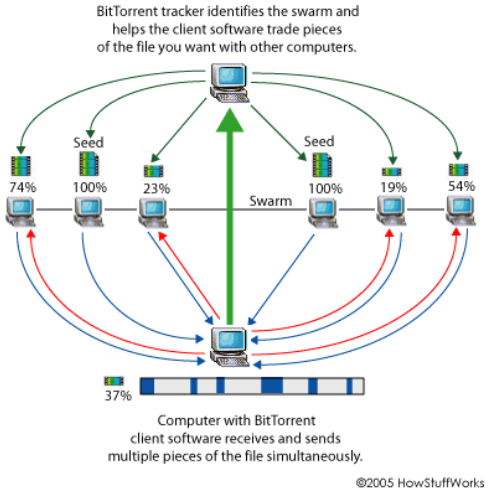
BitTorrent

- A new popular approach to sharing large files
  - It accounts for 30-50% of all Internet traffic
- Originally used for distributing legal content
  - Linux distributions, software updates
  - Official movies
  - Games, …
- Goal:
  - Quickly and reliably replicate one file to a large number of clients
- Call it "P2P content distribution"

Basic Idea



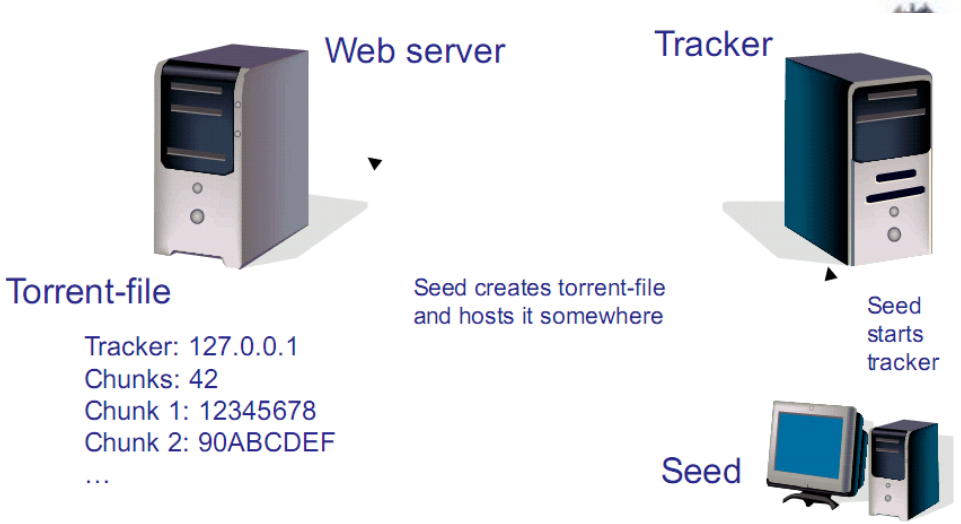
- Chucking:
  - Files split into smaller pieces or chunks
  - Chunks can be downloaded in parallel
  - Downloading order does not matter
- Swarming
  - Clients join a crowd of peers uploading and downloading the same content
  - Nodes request chucks from neighbors and download content in parallel
- Use the web server to publish content
- Use a central unit to locate resource



Basic Components

- Web server: for content publication
- Tracker: a special central server for running the content distribution system
  - Tracking active peers
  - Mapping from file name to peers
- Peer
  - Seed: a peer with a complete copy of the file
  - Leecher: peer still downloading the file
- ".torrent" file: metadata and description of the file
  - The number of chunks
  - The tracker's IP

Operation



- Sharing a file:
  - (1) Seed generates a ".torrent" file from the file
  - (2) Upload the ".torrent" file to some public web server or sending it to friends by email
- Searching a file:
  - No dedicate search component
  - User can search ".torrent" file from web server
- Downloading a file:
  - (1) Download the ".torrent" file
  - (2) Connect to the tracker to locate the file
  - (3) Choose some fast peers to download chunks in parallel

Summary

- Internet基本概念
  - 什么是Internet
    - 组成、服务、协议
  - 网络边缘
  - 网络接入
    - 家庭、公司、无线
  - 网络核心
    - 电路交换、分组交换、虚电路
- Internet历史
- Internet应用
  - C/S构架
  - P2P构架

Homework

- Read Chapter 1 and Chapter 2 of the textbook