

# Communications and networking

- **history and background**
  - telephone system
  - local area networks
- **Internet**
  - architecture: what the pieces are and how they fit together
  - names and addresses: what's your name and number?  
Domain Name System, IP addresses
  - routing: how to get from here to there  
traceroute, ping
  - fundamental protocols and layers  
IP, TCP
  - higher level protocols and services:  
HTTP, SSH, SMTP, IMAP, ...; web, email, instant messaging, peer to peer, ...
- **Web**
  - what makes it work: URL, HTTP, HTML, browser

## Early technology:

- runners ("Rejoice, we conquer")
- riders ("Neither snow nor rain nor heat nor gloom of night...")
- signal lights ("1 if by land and 2 if by sea")
- fires, mirrors, flags, drums, voices, pigeons, ...
  
- **Optical telegraph (Chappe, 1792)**
  - faced many of the problems of modern networks
  - protocols: rules by which independent parties exchange info
  - bandwidth limitations: how to send information faster
  - error detection and recovery
  - security and privacy: protecting info from eavesdroppers & imposters

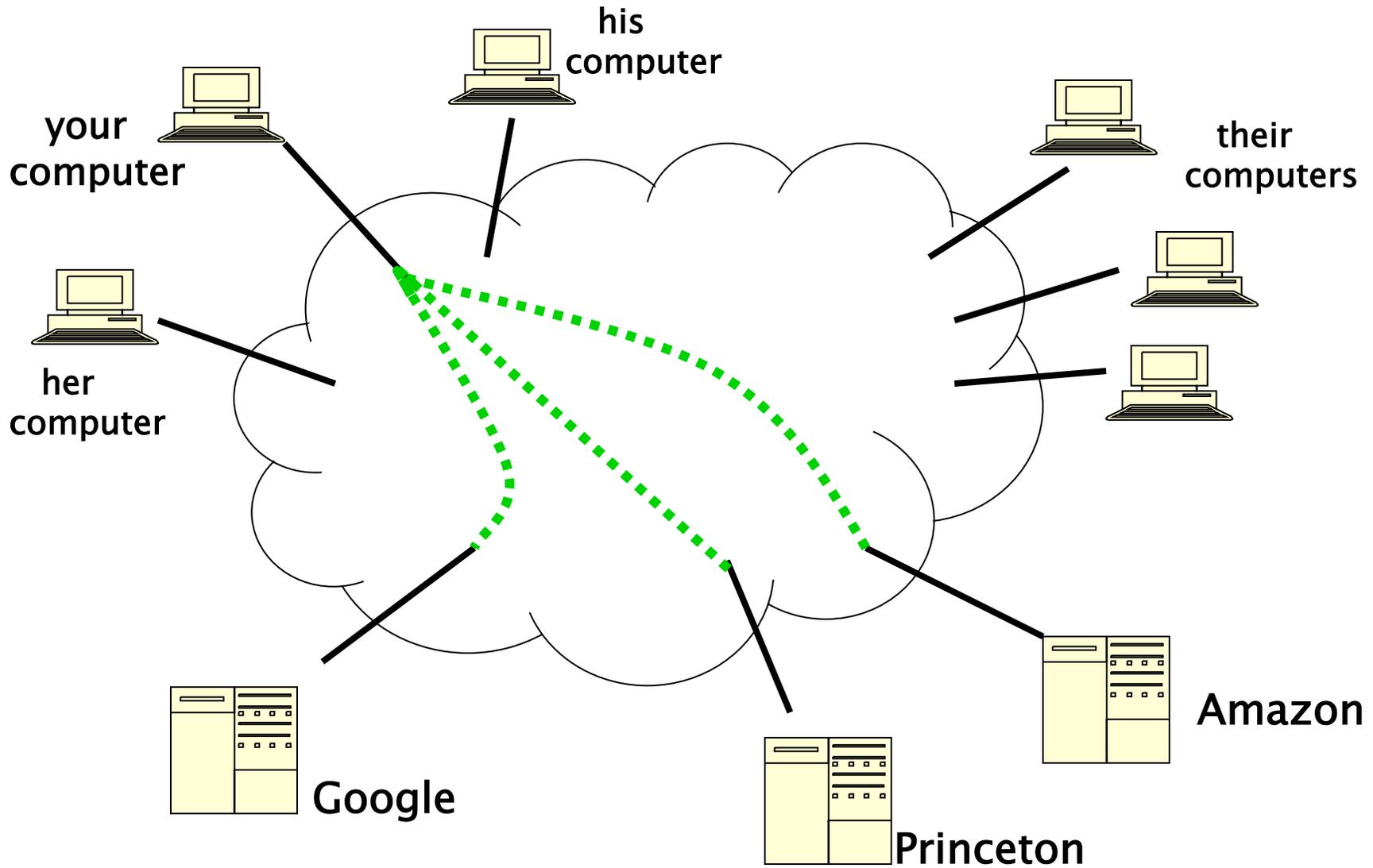
*Gerard Holzmann, The Early History of Data Networks*
  
- **Telegraph (Morse, 1850's)**
  - similar issues (and a new technology that killed the old one)

*Tom Standage, The Victorian Internet*

# Telephone system (Alexander Graham Bell, 1876)

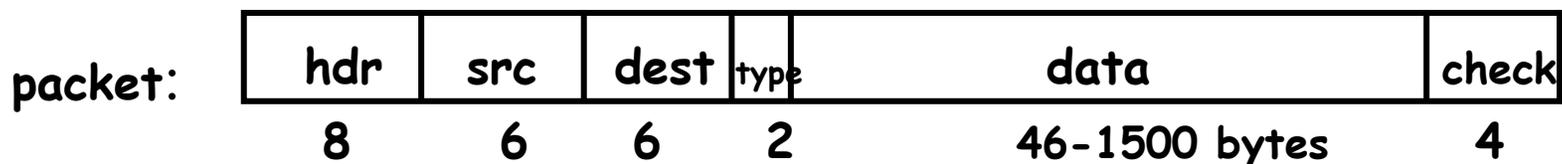
- **organizing principles, all based on voice traffic:**
  - voice calls need only a narrow bandwidth channel
  - a call uses a dedicated circuit, with long setup and hold times
  - telephone number is a unique identifier
  - fixed routing for a specific call
  - parallel signaling network; data separated from control
  - simple user interface: all intelligence inside network
  - guarantees on quality of service; high reliability
- **running out of some resources (area codes, 800/888/877/866, ...)**
- **traffic model changing rapidly (cell phones, data, ...)**
- **technology changing rapidly (wireless, Internet, ...)**
- **worldwide evolution from highly regulated and/or government-operated to deregulated / private**
  - highly competitive
  - incumbent carriers threatened by Internet

# The Internet



# Local Area Networks; Ethernet

- a LAN connects computers ("hosts") in a small geographical area
- **Ethernet is the most widely used LAN technology**
  - developed by Bob Metcalfe & David Boggs at Xerox PARC, 1973
  - each host has a unique 48-bit identification number
  - data sent from one host to another in "packets" of 100-1500 bytes including source and destination address and error checking bitstypical data rate 10-1000 Mbits/sec; limits on cable length

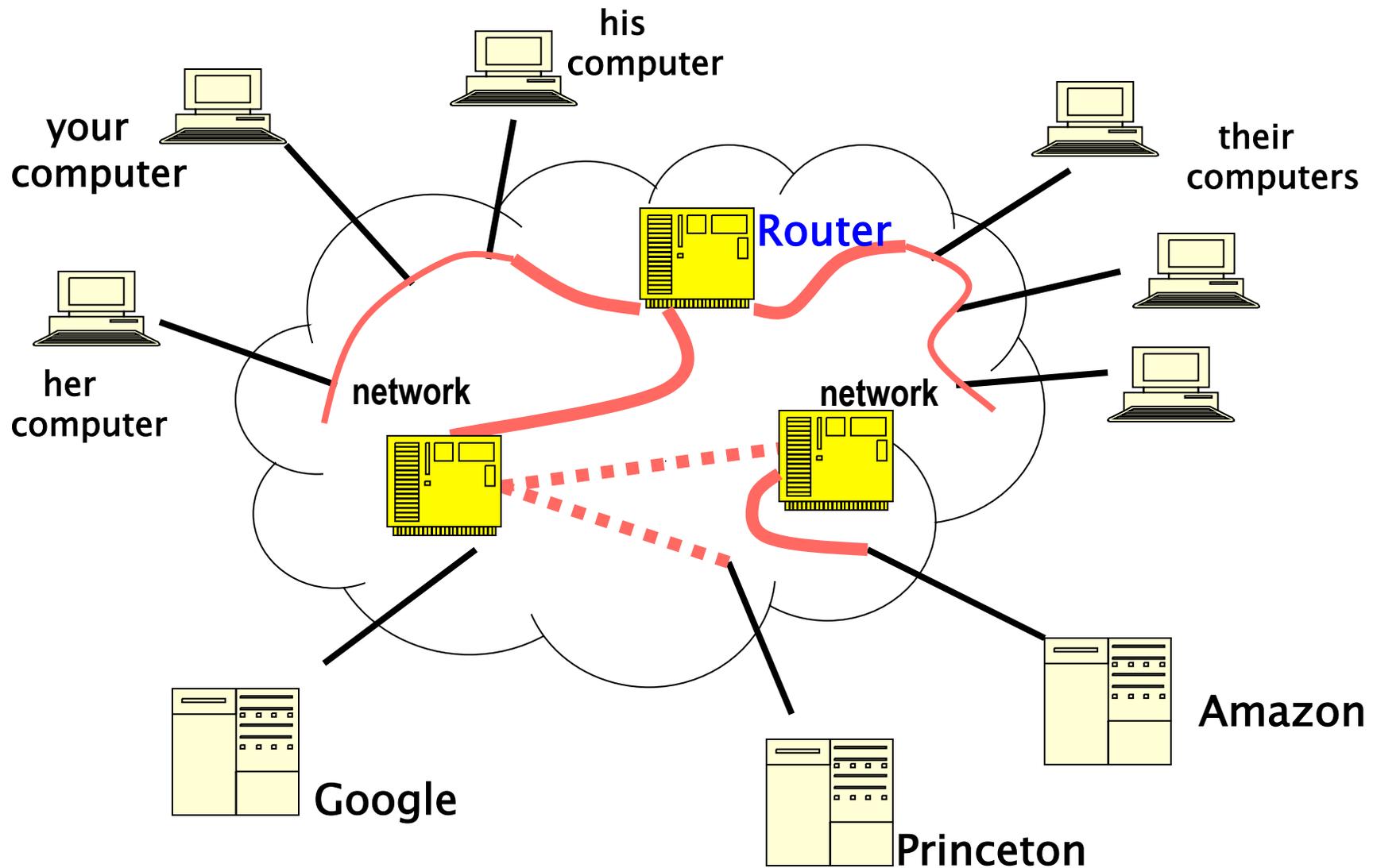


- **"broadcast" technology: data sent to all connected hosts**
  - sender broadcasts, but if it detects someone else sending, stops, waits a random interval, tries again
- **wireless Ethernet uses radio to carry signals**
  - logical behavior is exactly like a wired Ethernet

# Connecting networks (wide area networks / WAN)

- **how do we connect LANs to each other?**
  - LANs may have different properties
  - may be far away
- **names & addresses now needed to find other networks and hosts**
- **routing needed to find a path if multiple networks are involved**
  - can't have each network connected directly to all others
- **need to agree on format of information and how it is exchanged**
  - especially if networks are different kinds that use
    - different format for packets
    - different physical and electrical properties
    - different names and addresses themselves
- **how do we handle errors, delays, overload, etc.?**
- **how does it scale as the number of networks gets really big?**

# Gateways and Routers



# The Internet

- **a huge number of independent networks that are connected**
  - NOT a giant computer or a single network
  - each network may serve many host computers
- **nearby computers are connected by a local area network**
  - most often Ethernet
- **information travels through networks in small "packets"**
  - each packet independent of all others
    - like individual envelopes through the mail
  - all packets have the same format
  - standard protocols for format of info and behavior
- **networks connected by specialized gateway computers (routers)**
  - route packets of information from one network to the next
  - gateways continuously exchange routing information
- **each packet passes through multiple gateways**
  - gateway passes packet to gateway that is closer to ultimate destination
  - gateways usually operated by different companies

# Internet History

- 1961: packet switching concept (Leonard Kleinrock, MIT, UCLA)
  - 1960's: ARPANET, funding from DARPA (Dept of Defense)
  - 1969: first Internet communication
  - 1972: first network email
  - 1973: basic protocols: TCP/IP (Bob Kahn \*64, Vint Cerf)
  - 1980's: National Science Foundation funding, NSFNet (Al Gore)
  - 1980's: Internet Engineering Task Force for technical decisions
  - 1990's: commercialization, Web, dot-com boom
  - 2000: dot-com bust
  - 2010: universal availability
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- for lots more, <http://www.isoc.org/internet/history/>

# Basic mechanisms

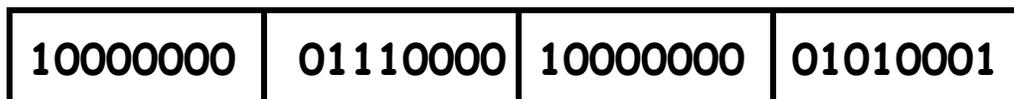
- **names** for computers
  - princeton.edu, finance.yahoo.com, www.whitehouse.gov, kernighan.net, ...
- **addresses** for identifying networks and computers
  - each has a unique number like 128.112.128.81 (IP address)
  - central authority assigns numbers to networks
  - each host computer has unique address (32 bit integer in IPv4),  
assigned locally according to what network it's on
- **Domain Name System** to convert names to addresses
- **routing** for finding paths from network to network
- **protocols** (rules) for packaging and transporting information
  - IP, or "Internet Protocol": a uniform transport mechanism  
at IP level, all information is in a common format
  - below IP, different hardware uses different protocols
  - above IP, higher-level protocols for handling web pages, mail, login ...

# Internet (IP) addresses

- each network and each connected computer has an IP address
- IP address: a unique 32-bit number in IPv4 (IPv6 is 128 bits)
  - 1st part is network id, assigned centrally in blocks  
(Internet Assigned Numbers Authority -> Internet Service Provider -> you)
  - 2nd part is host id within that network  
assigned locally, often dynamically



- written in "dotted decimal" notation: each byte in decimal
  - e.g., 128.112.128.81 = www.princeton.edu



# Domain names

- **a hierarchical naming scheme**
  - central authority (ICANN) manages top level of names
- **top level domains include .com, .edu, .gov, .xx for country XX**
  - and newer domains like .biz, .info, .name, .xxx, ...
- **each domain delegates responsibilities to levels below**
  - for administration and translation into addresses
- **each level is responsible for names within it**
  - princeton.edu handles all of princeton
  - delegates cs.princeton.edu to a CS machine
  - CS department manages names within, e.g., tux.cs.princeton.edu
- **names impose logical structure, not physical or geographical**

# ICANN

- **Internet Corporation for Assigned Names and Numbers**
  - non-profit corporation, established 1998 by Dept of Commerce
  - technical coordination of the Internet
  - [www.icann.org](http://www.icann.org)
- **"coordinates the assignment of the following identifiers that must be globally unique for the Internet to function:**
  - Internet domain names
  - IP address numbers
  - protocol parameter and port numbers
- **"coordinates the stable operation of the Internet's root server system"**

# Domain name system (DNS)

- **DNS converts names to IP addresses and vice versa**
  - www.princeton.edu == 128.112.132.86
  - carnegiehall.org == 63.131.135.198
  - kernighan.com == 72.9.232.170
- **hierarchical searching for addresses**
  - central authority controls top level domain names (.com, etc.)
  - delegates responsibilities for searching to levels below
  - each level responsible for names and addresses within it
    - princeton.edu handles address lookup for all of princeton
    - delegates cs.princeton.edu to a CS machine
- **top level domains handled by 13 root servers**
- **lookup for a name asks a local name server first**
  - if not known locally, asks a server higher up, ..., to root server
  - recently-used names are cached to speed up access
- **names impose logical structure, not physical or geographical**

# Routing

- **networks are connected by gateways or routers**
- **routing rules direct packets from gateway to gateway**
  - trying to get closer to ultimate destination
- **routers exchange information frequently about routes**
- **bottom-up view:**
  - gateways move packets from one network to another based on network id
  - if destination on the same network, use physical address
  - otherwise send to a gateway, which passes it to another network
- **top-down view:**
  - networks connected only through gateways
  - core has a small set of gateways that exchange complete routing info about which nets it knows about and number of hops to reach them
  - autonomous system: group of networks under single authority
  - passes reachability info to core for use by other autonomous systems
  - interior gateway protocols exchange routing info within a single AS
- **traceroute: how do you get from here to there?**