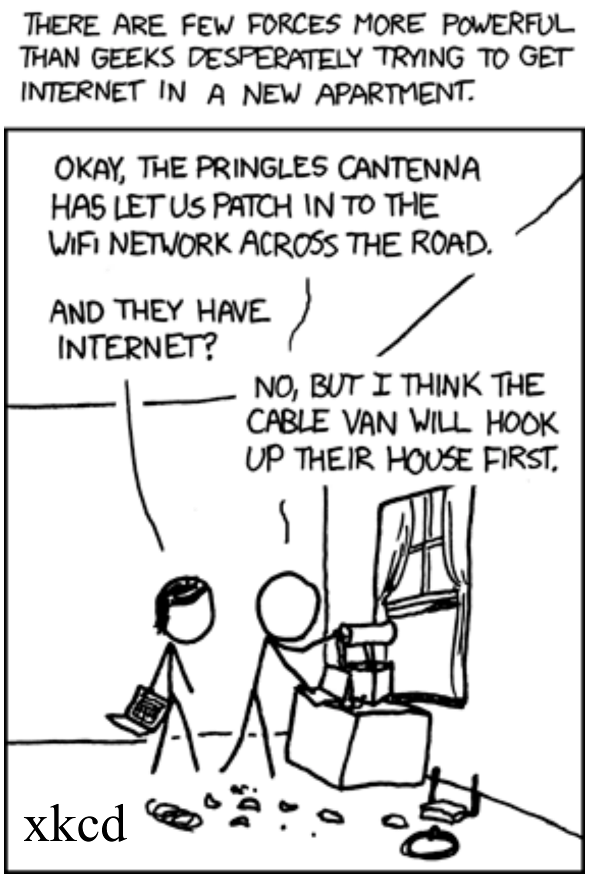
Networking and Internetworking 1

To do ...

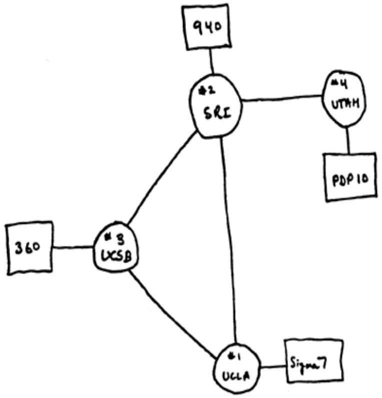
- Networks and distributed systems
- Internet architecture



Internet history – Early days

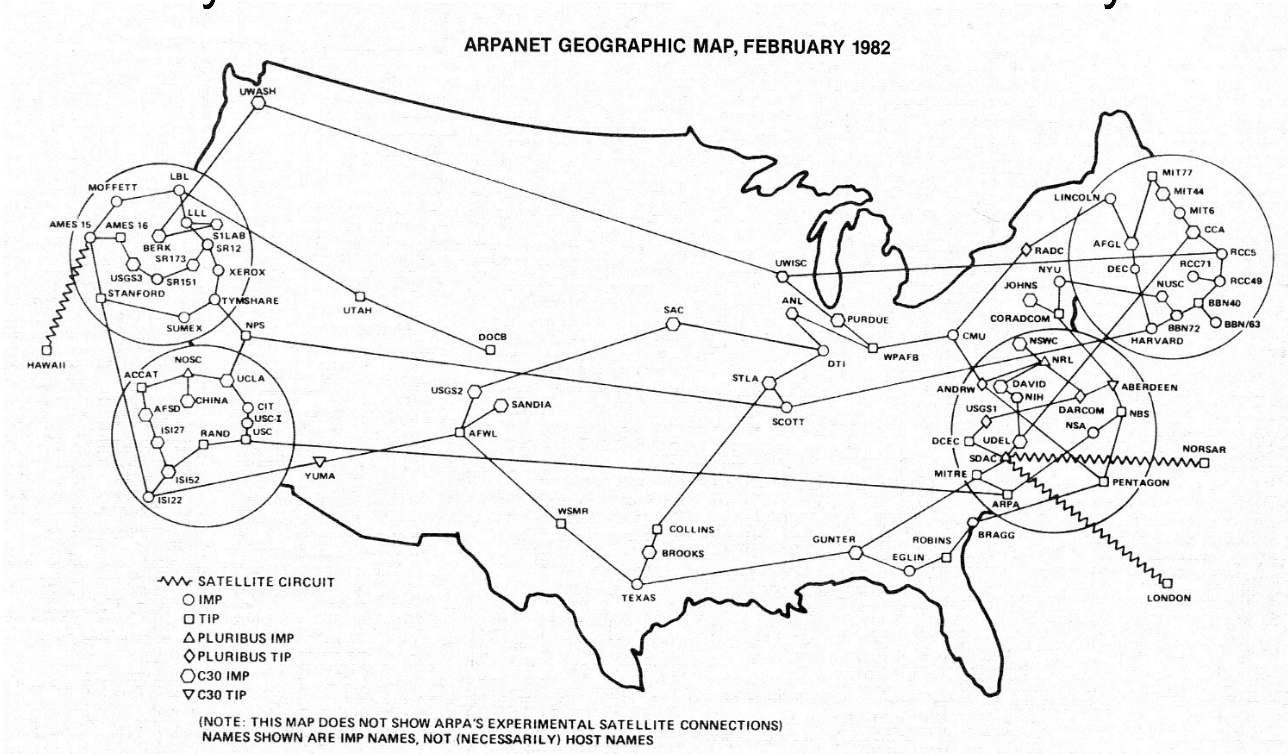
- ~1960 ARPA sponsored research on computer networking to enable remote sharing
  - Electronic computers were scarce resources
  - Renting an IBM System/360 - $5k/month ($35k/month 2016)

- 1969 – First four ARPANET nodes connected
  - Key decision: use packet switching



Internet history – Early days

- From 1975 to 1980s
  - Successful ARPANET ~ 100 nodes
  - ARPA research on packet switching over radio and satellite
  - New LANs connected via gateways
  - TCP/IP conversion in 1983
  - Autonomous Systems and backbone AS for scalability

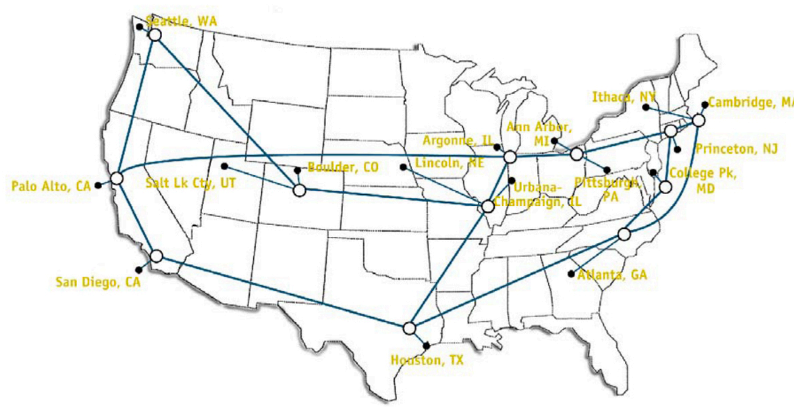


A bit of history – NSF takes over

- Late 1980s NSF takes over
  - Works on expanding the backbone
  - Encourages development of regional networks
  - Three tiers: backbone, regional, enterprise

NSFNET

NSFNET T3 Network 1992



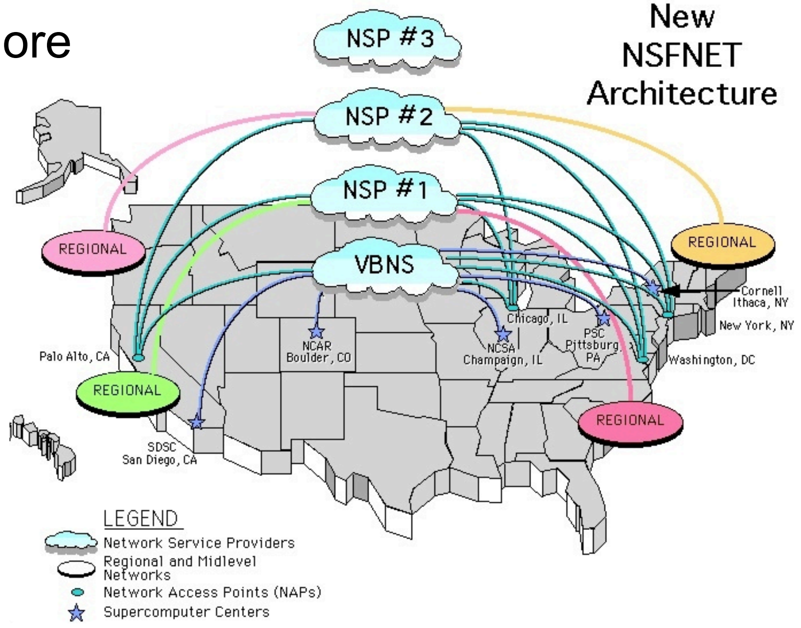
- Enterprises were building TCP/IP networks and wanted to connect
  - But NSF charter prohibited them from using NSFNET
  - 1987 first commercial ISP, many follow shortly

@THE WORLD

A Public Information Utility

A bit of history – Commercial operation

- By 1990 service providers where interconnected
  - Congress lets NSFNET interconnect with commercial networks
  - By 1995, NSFNET was retired
    - No single default backbone anymore
    - Many backbones interconnected trough Network Access Points

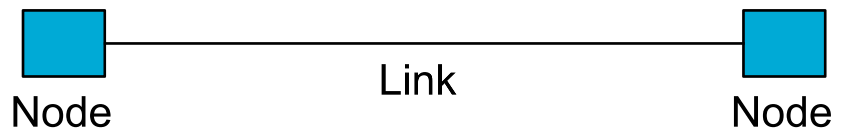


- ~1995 Web
  - Easier to use Internet
  - Million of non-academic users

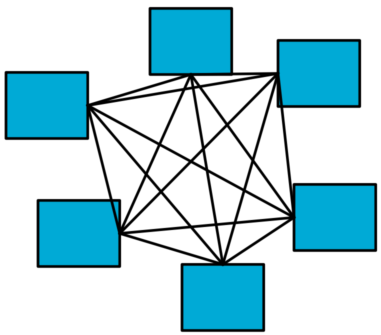
- …

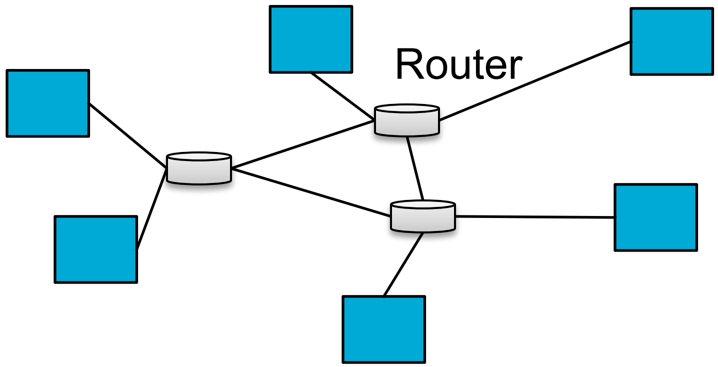
Internet building blocks

- Basic blocks



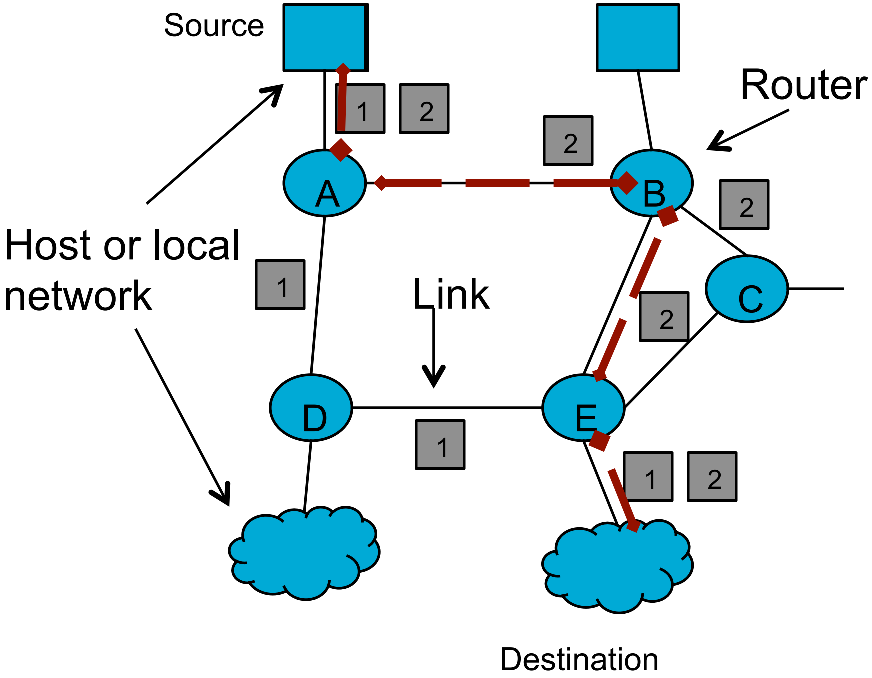
- More hosts?
  - Wires for everyone or routers
  - Routers act as switches routing mgs between nodes





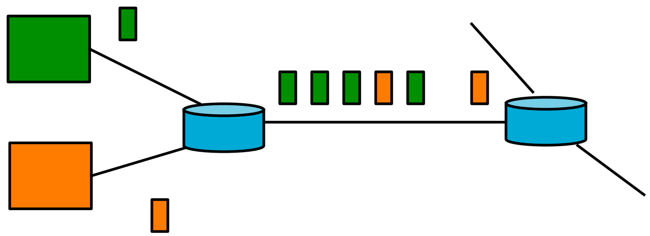
Packet switching for communication

- Packet over circuit switching
  - Information sent as self-contained packets, with an address
  - Each routed independently to destination
  - Store and forward
  - Simpler than circuit-switched (in plain old telephone service)



Packet switching for communication

- Statistically multiplexing
  - Switches arbitrate between inputs
  - Send from any input that's ready (keep busy)



- If network is overloaded
  - Short burst: buffer
  - After that
    - Packet drop
    - Sender adjust rate until load matches resources – congestion control

Networking protocols

- IPC is based on send/receive messages
- Message/packet transmission
  - Message: logical unit of information
  - Data transmission is in packets: transmission unit
  - Restricted length: sufficient buffer storage, reduce hogging

- For communication to work, parties must agree on several things
  - How does the receiver knows it got the last bit of a msg?
  - How longs are integers?
  - …

Networking protocols

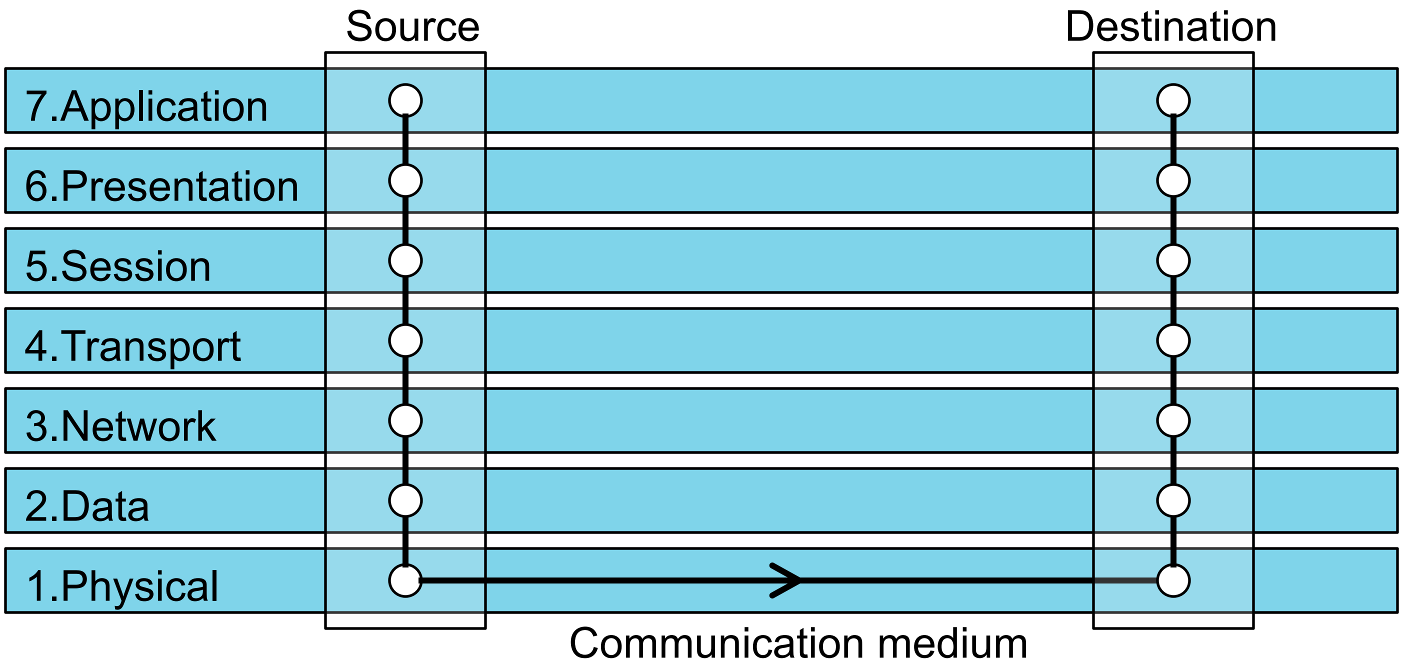
- Protocols – agreed-upon rules and formats
  - Sequence of messages to exchange, their formats
  - Implemented by pair of software modules on each end
  - Typically arranged in layers – protocol suite or stack
    - Layering and modularity to handle complexity
- Up and down the stack
  - As a message is pass down, each layer adds a header (sometimes a trailer)
  - On the receiver side the message is push upward with each layer stripping off and examining their own headers

Ethernet header	IP header	TCP header	HTTP header	Application data (webpage)

An example on the Web

Protocol stacks

- OSI and Internet
- Open Systems Interconnection model – ISO OSI
  - Not used in practice but good for understanding



Lower-level protocols

- Lower-level protocols, together implementing the basic functions of a computer network
  - Physical – deals with (standardizing) mechanical and electrical details
    - Just send bits, how long as there are no errors, all is fine …
  - Data link – groups bits into frames and ensure they are correctly received
    - Frames include checksums to check correctness
  - Network – describes how packet are routed from source to destination
    - Most used network protocol – Internet Protocol (IP)
- For many distributed systems, the lowest-level interface is that of the network layer

Transport and higher layers

- Transport protocols
  - Transfer messages between clients, including breaking them into packets, controlling flow, etc.

- According to the OSI, three high-level layers
  - Session – provides dialog control and synchronization
    - Control to keep track of who is currently talking
    - To insert checkpoints in long transfers
  - Presentation – resolves differences in formats among sites
    - Concern with meaning of transferred data to make resolving differences easier
  - Application – to meet the specs of a set of standard apps
    - Originally intended to support a collection of standard network applications; now the container for all

Routing

- A packet placed in the network must be forward to its destination as specified in its packet's header
- A graph theory problem – find the lowest-cost path between two nodes
- Routers decide outgoing interface for each packet
  - Decision is called routing
  - Placing it in the appropriate outgoing interface – forwarding
  - Set of links used – packet's path
- For routing, routers must keep information on the configuration and state of the network
  - Update state of links (added, removed, failed router, …)

Routing example – RIP

- Routing Information Protocol
- Highly popular, distributed with BSD Unix
- Based on distance vector algorithm (Bellman-Ford)
- Router's routing table
  - A record for each destination
  - Fields: outgoing link, cost (e.g. hop count)
  - A link that is down has an ∞ cost
- Routers send table summary periodically (30s) or when an update from other routers changes its tab
  - If received table shows new or better route, update local one
  - Distance vector router talks only to its neighbors, but tells them everything it has learned

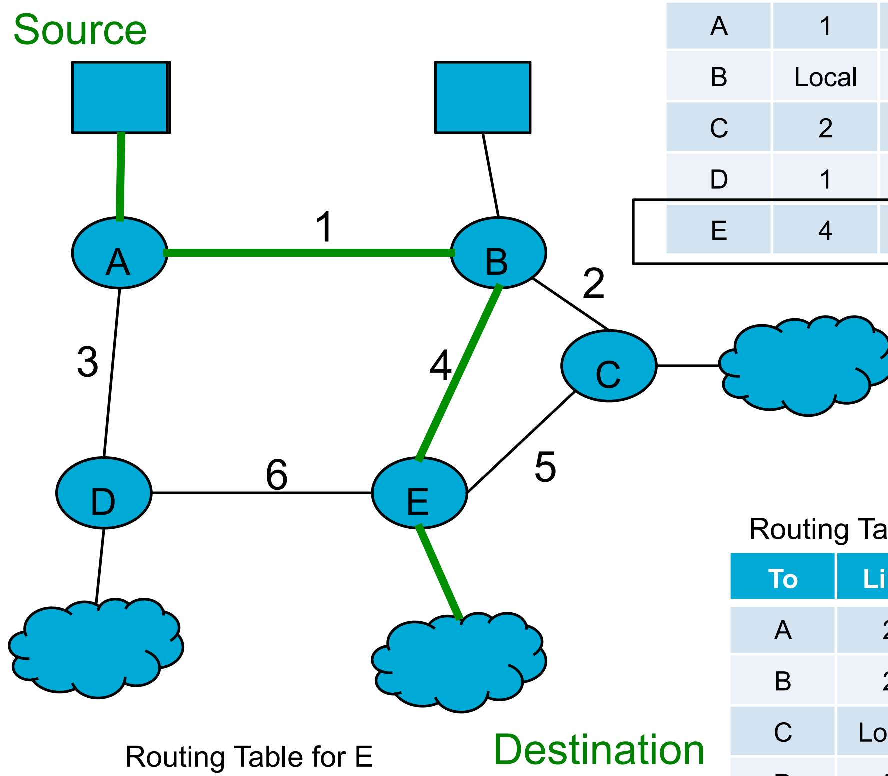
Routing example

Routing Table for A

To	Link	Cost
A	Local	0
B	1	1
C	1	2
D	3	1
E	1	2

Routing Table for D

To	Link	Cost
A	3	1
B	3	2
C	6	2
D	Local	0
E	6	1



Routing Table for B

To	Link	Cost
A	1	1
B	Local	0
C	2	1
D	1	2
E	4	1

Routing Table for C

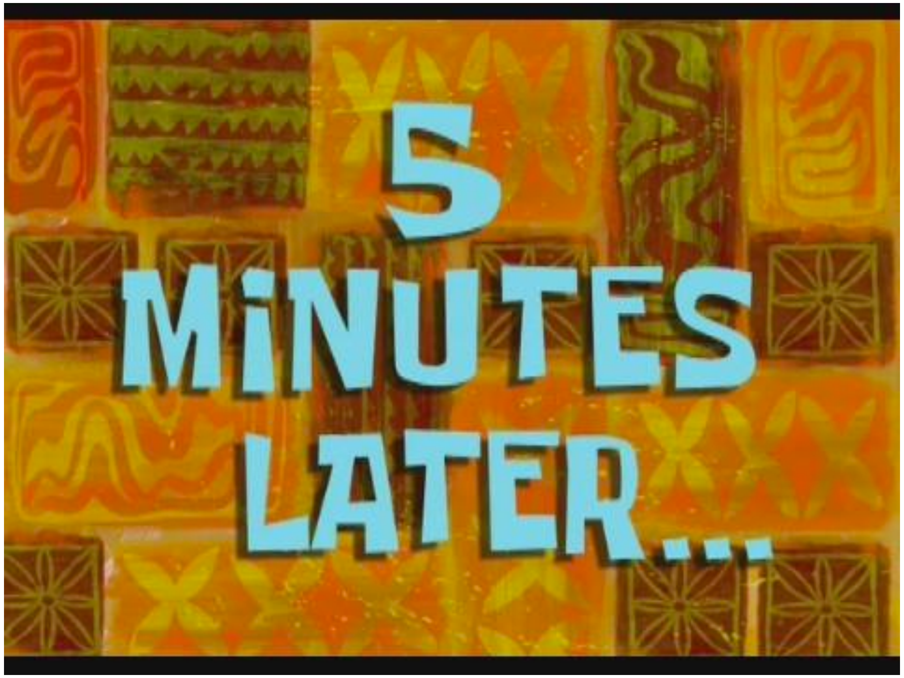
To	Link	Cost
A	2	2
B	2	1
C	Local	0
D	5	2
E	5	1

Routing Table for E

To	Link	Cost
A	4	2
B	4	1
C	5	1
D	6	1
E	Local	0

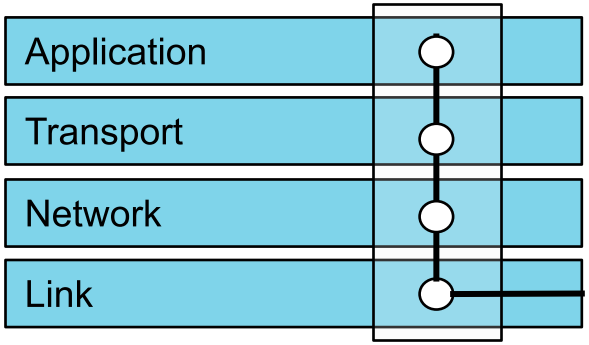
A 5′ break …

- Details of Internet operation
  - New challenges
  - Addressing
  - Routing
  - Organization



Internet protocols

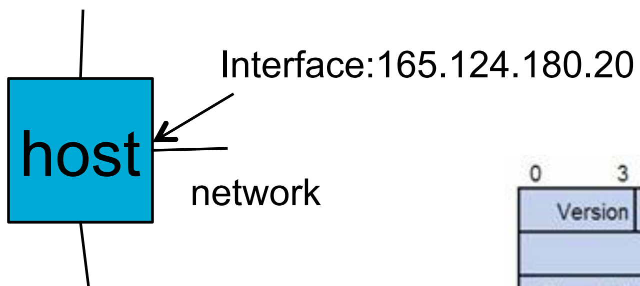
- Three higher layers ➔ Just one
- Transport layer provides inter-process communication
  - Transport address = net add + port
  - Two key protocols
    - TCP – Transmission Control Protocol – connection oriented, reliable stream communication
    - UDP – Universal Datagram protocol – connectionless, unreliable datagram communication
- Network protocol provides communication host to host
- Link layer – physically interface with communication medium

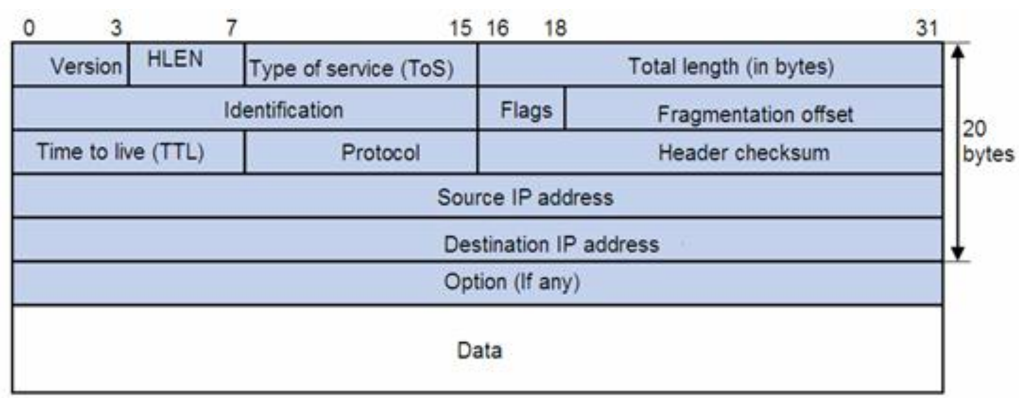


Internet protocols – IP

- Internet Protocol – primary network layer protocol
  - Best effort service – unreliable, no guarantees
  - Connection between a host and network is called interface
  - Each interface has an address; format defined by IP; in IPv4 are 32b expressed as four decimals (165.124.180.20)
  - IP addresses often grouped by their prefixes – initial set of bits that all addresses in the group have in common

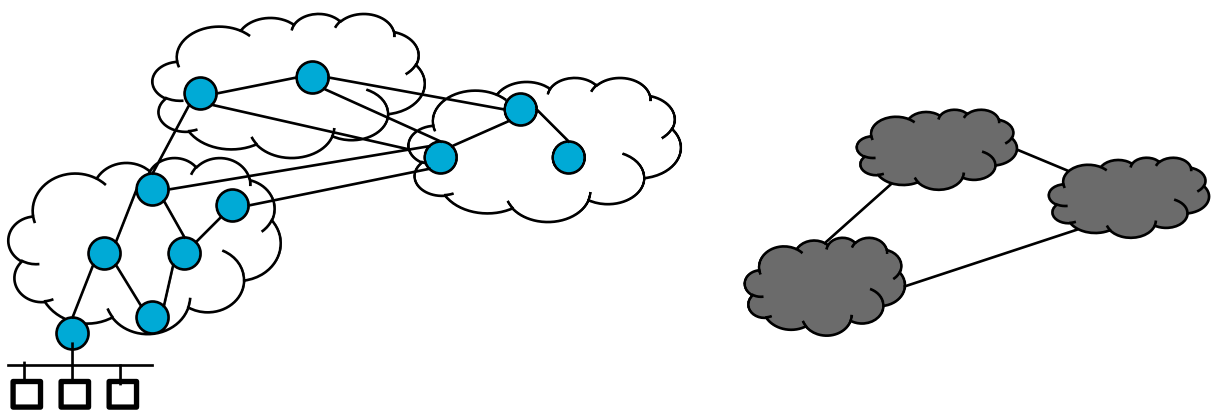
    e.g. 165.124.0.0/16 – all addresses with first 16b equal to 165.124





Internet as a set of ASes

- Internet
  - A collection of separately, usually competing, managed networks
- Autonomous system (AS)
  - Set of network elements under a single organization’s control
  - 1 ISP can operate *N* ASes; no AS is managed by more than one ISP
- ASes exchanged traffic at connection points, aka peering or exchange points
  - Connections formed by establishing a link between “gateway” routers in each AS



Routing in the Internet

- RIP-1, the first routing algorithm used in the Internet
  - A version of the distance-vector algorithm we discussed
  - Slow convergence, potential instability, Floyd & Jacobson's* observation on 30s peak on latency
- Open Shortest Path First (OSPF), a better option
  - Routers maintain a network map, updated when links change
  - Each router monitor the links to which is connected and initiates a flooding protocol upon change
  - Router talks to everyone, but only tells them what it knows for sure (state of directly connected links)
- To compute path to destination
  - Each computes best path from it to every destination – path with the lowest sum of link weights ➔ routing table

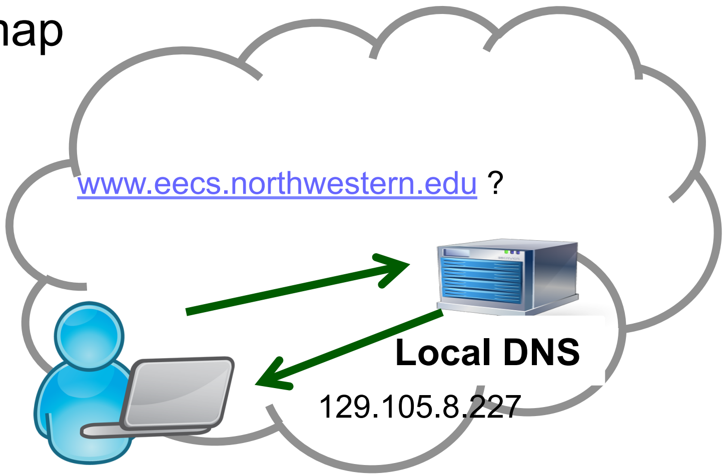
*S. Floyd and V. Jacobson, The Synchronization of Periodic Routing Messages, ACM ToN 1994

Routing messages needs addresses

- Challenge of Internet protocol design: naming and addressing scheme and routing
- Scheme for assigning addresses has to be
  - Universal – any host can send packets to any other
  - Use address space efficiently – no idea of eventual size
    - 2^{32} or ~4 billion addressable hosts sounds like enough?!?
  - Enable flexible routing but addresses themselves shouldn't carry much information for routing
- Most of the Internet still on IP version 4 (IPv4)

Domain names

- Hard to remember IPs, some mechanism for using symbolic names (and mapping them)
- Naming for the Internet before 1983
  - Each computer retrieved HOST.TXT from a computer at SRI
  - Legacy – a host file still exist in most modern OS
- DNS by Paul Mockapetris (1983)
  - Names organized into name spaces
  - Name space partitioned organizationally and geographically
  - A distributed system implements the hierarchical name space
    - Each server holds a partial map of the domain name tree bellow their domain
    - Lots of caching!



IP communication model and some fixes

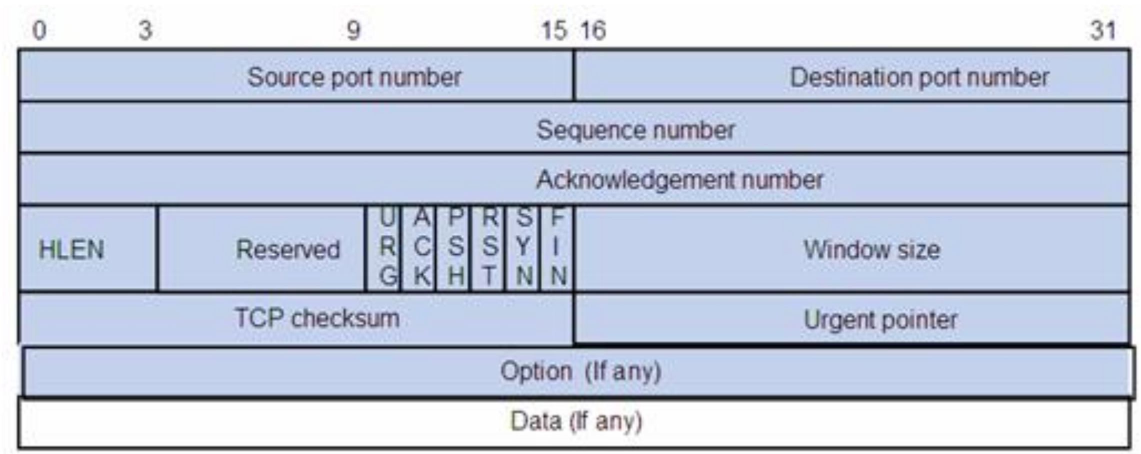
- IP model
  - Messages may be lost, reo-ordered, corrupted

- Can you build a reliable, in-order, mostly non-corruption, stream-oriented communication service?
  - Data corruption – add checksums
  - Lost data – timeout and retry
  - Data out of order – Add sequence numbers

Internet protocols – TCP

- Basic service – a connection
  - A communication channel between two hosts
- Service is provided to app, process to process
- Both senders and receivers create end points: *sockets*
- Application read to/write from sockets
  - Sockets ID are #s: IP + 16b number local to the host, *port*
  - Port numbers [0,1023] are well-known ports, reserved for standard services; [1024,49151] registered ports

Port	**Service**
13	daytime
22	ssh
1025	NFS
1293	IPSec



Internet protocols – TCP

- API provides abstraction of a stream of bytes, hiding
  - Message sizes and destination
  - Lost messages, duplication and ordering
  - Flow control
- General approach to reliability – acknowledgement
  - After sending each segment, source sets timer waiting for ack
- Congestion avoidance
  - TCP will try to match the speed of the processes reading from/ writing to the stream
  - Implemented by varying number of un-acknowledged packets the sender allows (window size)

Internet protocols – UDP

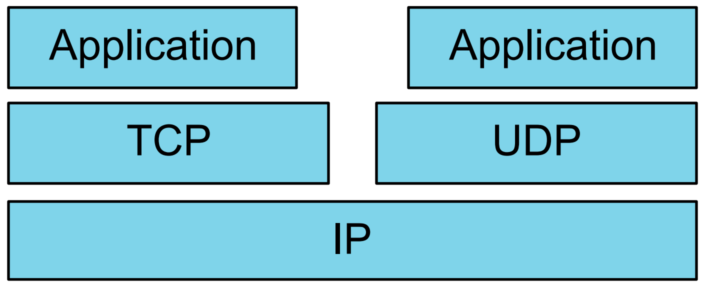
- As TCP, process to process communication
- But simpler, a transport-level replica of IP
- UDP datagram is encapsulated inside a IP packet
  - Header includes src & dest port #s, length field and checksum

<table>
<tr><th>0 15</th><th>16 31</th></tr>
<tr><td>Source port #</td><td>Destination port #</td></tr>
<tr><td>UDP length</td><td>UDP checksum</td></tr>
<tr><td colspan="2">Data (if any)</td></tr>
</table>

- UDP adds no additional reliability to IP
  - No guarantee of delivery (no acks or retries)
  - Too large messages are truncated on arrival
  - Messages may be drop or delivered out of order
- No setup costs, no transmission delays above IP

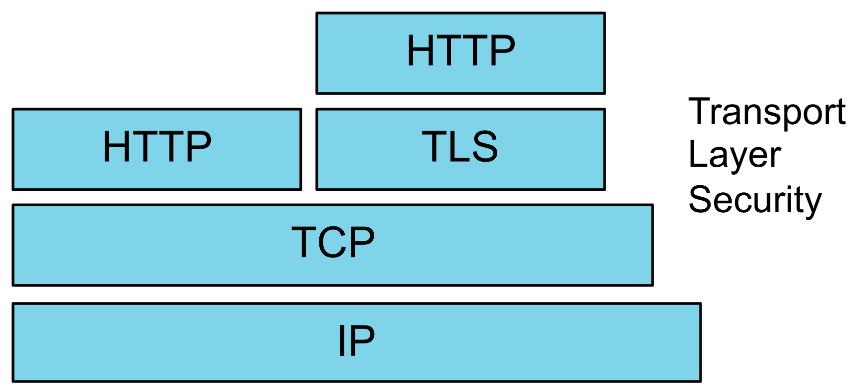
The programmers view

- The TPC/IP stack from a programmers perspective



- Application services and application-level protocols based on TCP/IP
  – Web HTTP
  – Email SMTP, POP
  – Netnews NNTP
  – File transfer FTP

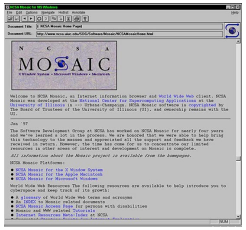
HTTPS: HTTP over TLS



Networking issues for distributed systems

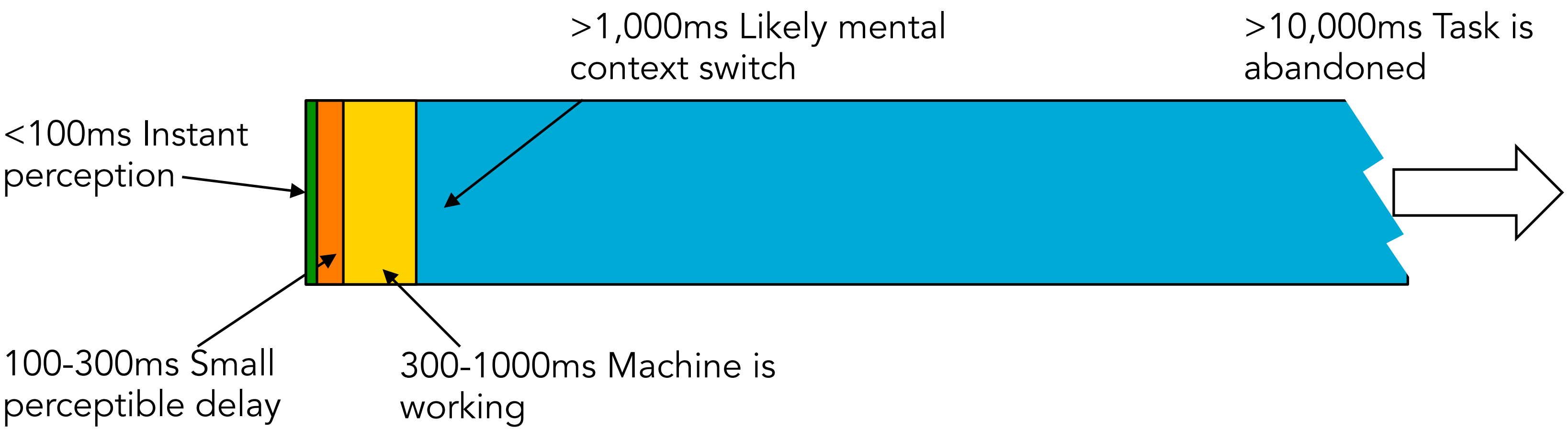
- Early networks designed to meet relatively simple requirements from applications

- Recent uses and growth ➔ higher demands on performance, scalability, reliability, …



Networking issues for distributed systems

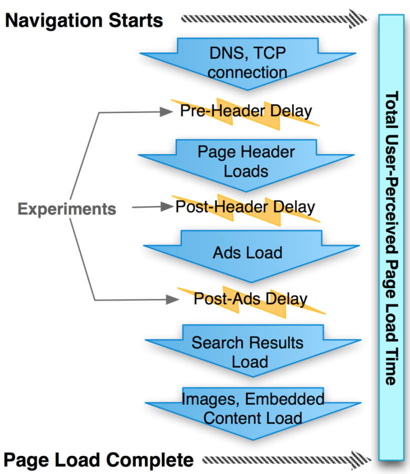
- Performance
  - To access resources on a LAN – 1,000x to access local memory, but faster than local disk
  - Over the Internet – 10-100x >> than a fast local network
  - For Amazon – 100ms extra latency ~1% sale loss*
- Quality of service
  - Higher demands from real-time services

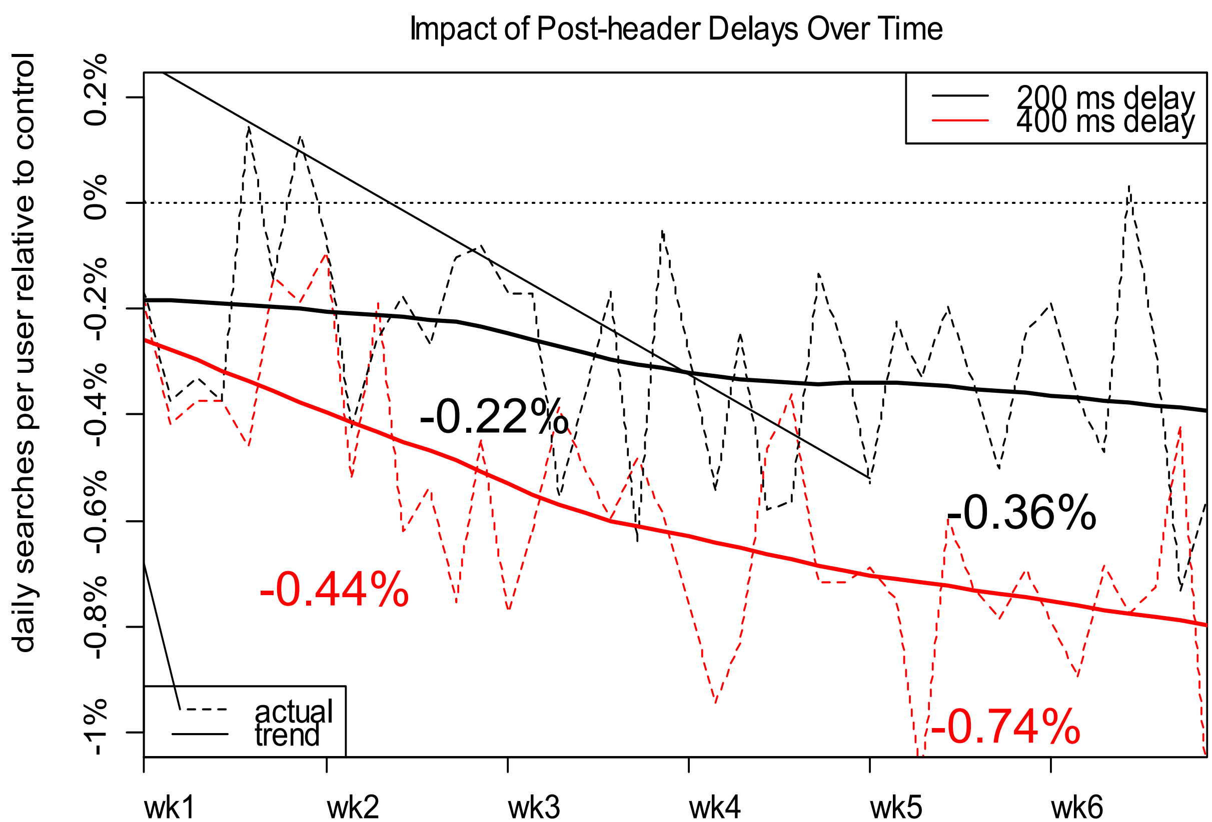


*http://blog.gigaspaces.com/amazon-found-every-100ms-of-latency-cost-them-1-in-sales/

Google/Bing Web search delay experiment

- Measure the impact of latency on user behavior
  - A/B testing (randomly assigning users to experiment and control group), server-side delays
- 400ms extra latency, 0.74% fewer searches over time





E. Shurman, J. Brutlag, http://conferences.oreilly.com/velocity/velocity2009/public/schedule/detail/8523

Networking issues for distributed systems

- Scalability
  - The Internet was not designed for expected or current scale, but yet must handle it
- Reliability
  - Increased dependence ➔higher reliability
- Security
  - Large and more diverse user base + growing dependency ➔Higher security demands – network is first level of defense
- Mobility
  - Addressing and routing schemes developed before mobile devices; not well suited to it
- Multicasting
  - Today’s Internet use is mostly for content distribution with a 1-to-m and m-to-m communication pattern

Summary

- Distributed systems use different networks for communication
- Changes in user requirements have placed new demands on the underlying networks
- At the same time, the characteristics of networks (e.g., performance, reliability, scalability) impact the behavior of and affect the design of distributed systems
- Next: some operational issues and network principles