History and architecture of internet

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Internet: life-changing technology

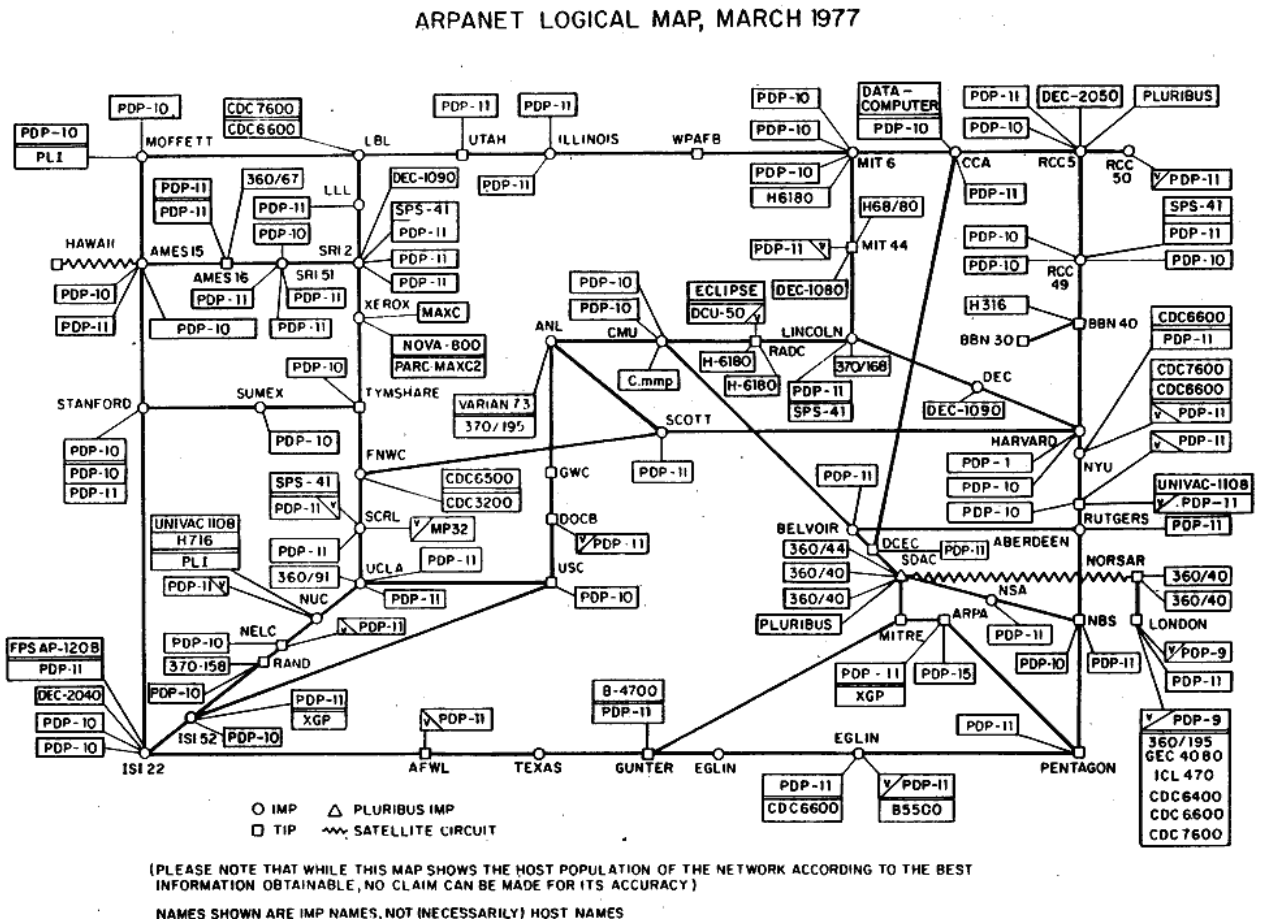
- Many of our daily activities go through internet: work, socialize, sharing, entertainment, buying things, looking for information, teaching/learning…
- Number of internet users: 3.4 billion and growing
  http://www.internetlivestats.com/internet-users/
- Internet of Things
- Very few technologies make as much impact on our society

Brief history – when was it born?

- When was internet designed?
- When was it first deployed?
- When was Hong Kong, and China connected to the global internet?

Brief history – when was it born?

- Research, design and deployment: 1960s and 1970s, e.g.
  - ALOHAnet, U of Hawaii, 1971
  - X.25 network of ITU (CCITT), 1976
  - Computer vendor networks, such as SNA, DECnet
  - ARPAnet, based on TCP/IP
- Hong Kong and China connected to internet: early 1990s
  - CUHK's role
  - My visit to Tsinghua in 1992



Brief history – the competitors

- The internet protocols, TCP/IP, was not the only candidate vying to become the protocol for global networking. Other contenders:
  - OSI network (OSI reference model)
  - Large computer vendor protocols, such as SNA (IBM), DECnet (DEC)
  - ATM network
- It was not clear which protocol suit will win out, through most of 1980s

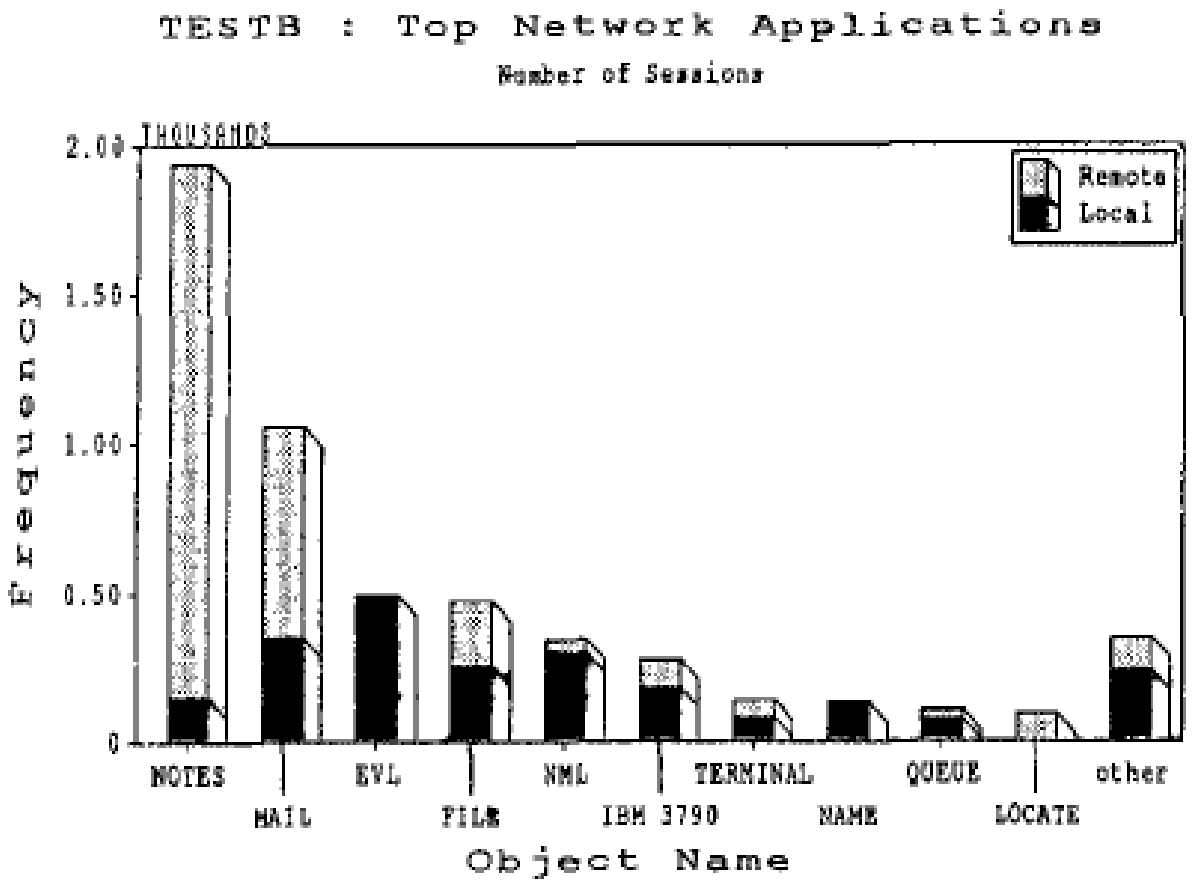
Brief history – what was it used for?

- What was computer network used for initially?
- What application popularized internet, when?

Brief history – early applications

- Initial applications:
  - File transfer, Email, Terminal…
  - Connecting computers (main frame, or mini computers) to create a bigger computing environment
  - "Local area" vs "Wide area" networks (LAN vs WAN)

Chiu & Sudama, "A Case Study of DECnet Applications and Protocol Performance", ACM Sigmetrics 1988



Brief history – the game-changing application

- The application that changed internet: WWW, early 1990s
  - Developed early in Europe at CERN, led by Tim Berners-Lee
  - Developed Hypertext Transfer Protocol (HTTP) = hypertext + TCP + domain names
  - Open source NCSA web server and browser
  - By mid 1990s, more and more applications appear, notably Yahoo, Google etc.

Brief history: conference and standardization

- What is the annual conference most influential to internet's development?
- What is the standardization body for internet protocols?

Brief history: conference and standardization

- The most influential conference is ACM Sigcomm.
  - Single track conference, more focused on discussion of "architecture" issues
  - Many influential papers
  - Location rotates between US, Europe, Others (Asia & Lat Am)
  - In 2013, the conference was held in CUHK, Hong Kong, ~800 people attended
- The standard body for internet protocols is Internet Engineering Task Force (IETF)
  - https://www.ietf.org/
  - Open process for anyone interested to participate
  - "Rough consensus and running code"
  - Produce many specifications, known as RFCs
  - Non-engineering issues handled in Internet Society

Architecture: what is it?

- Analogous to building a house, building, bridge, or any other complex object
  - Need to make some high level design choices
  - These are based on various considerations: efficiency, reliability, robustness, cost, flexibility for long term evolution, economics, political reasons, etc
- Network optimization
  - In the past 10-20 years, a lot of academic papers on network optimization
  - Usually valid on a component of the network only
  - The network “system” is too complicated to derive from an optimization model
  - It is like choosing between “capitalism” and “socialism”

Architecture – the key ideas

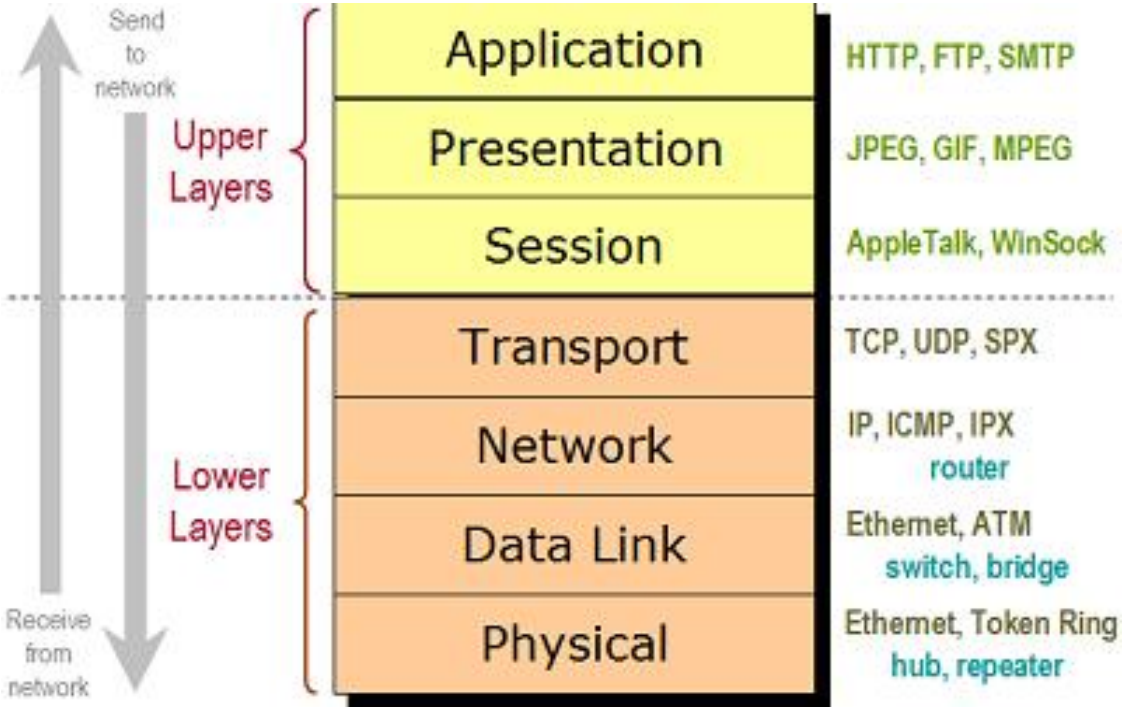
- What are the key architectural ideas of the internet?
- Are they the reasons for internet's success?

Architecture – the key ideas

- Layering
- Open API
- Use of name (instead of address)
- Packet switching
- End-to-end principle
- Best effort service
- Fair congestion control
- Distributed routing
- Policy-based routing
- Both datagram and TCP services

Layering

- Modular design
- Change (add) to a layer without affecting other layers
- E.g. ATM and wireless protocols added to the data link layer over the years



Open API

- Socket API
- Anyone can create application
- WWW's URL
- Make it even more universal
- Compare this to the telephone network
  - Proprietary
  - Only phone company can build value-added services

Name vs address

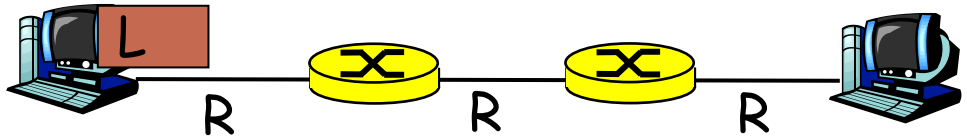
- Address is tied to a machine
- Name is a logical reference
  - Possible to move
  - Allows “redirection”, used in many scenarios, e.g. load balancing, firewalls

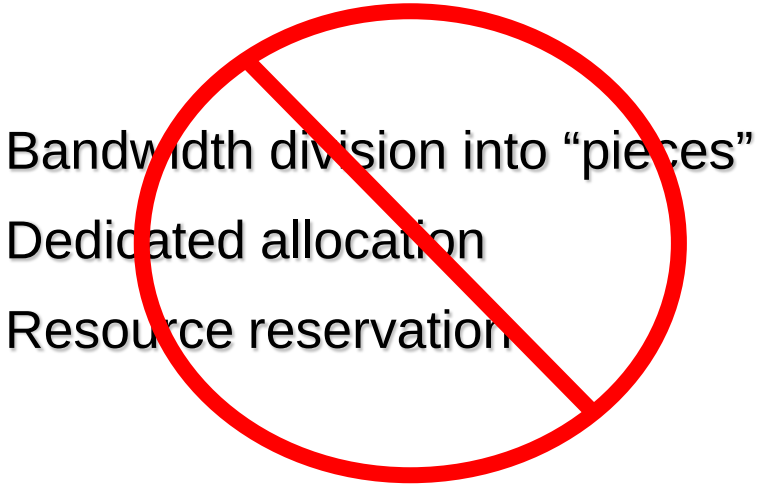
Packet switching

- This is a fundamental design choice
  - It is like a long job has to be divided into a sequence of short jobs, and the network only serves short jobs
  - What is the benefit and ramification of this?
- The alternative is “circuit switching”
  - Telephone network is based on circuit switching;
  - Network bandwidth must be allocated and committed to serve each circuit
  - In order to not exceed system’s capacity, there needs to be “admission control” for circuit switching

Implementation of packet switching

- Packets
  - data + metadata (header) = self-describing data
- Store and forward
  - Metadata allows us to forward packets when we want
  - Like letters at a post office headed for main post office
  - Efficient use of critical resources





Some challenges for packet switching

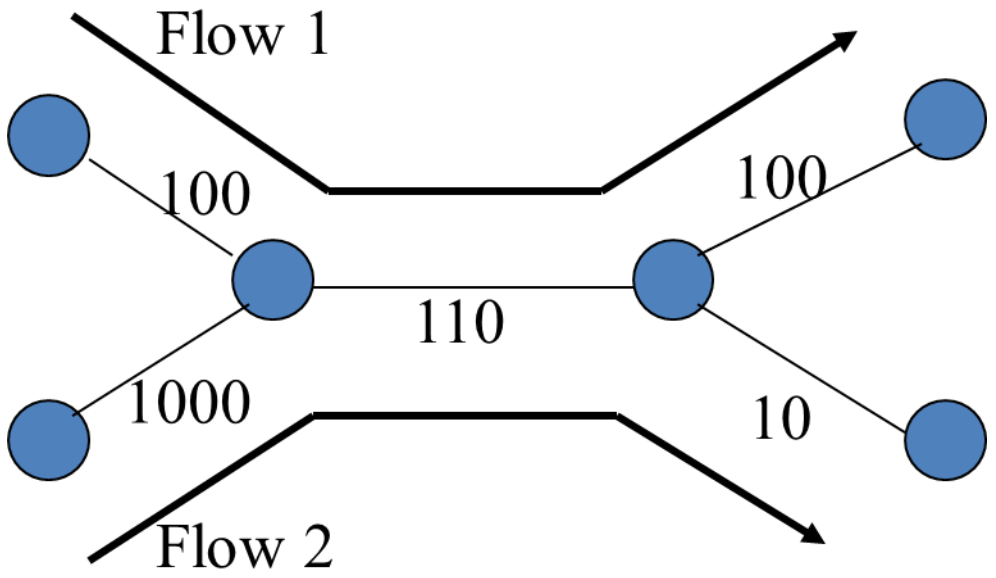
- Packet switching incurs some additional overhead, due to packet headers
- Packets may be lost, get out-of-order, on the way to destination
- Some links/nodes may become congested

End-to-end principle

- First published in a paper by Saltzer, Reed & Clark, “End-to-end Arguments in System Design”
  - Clark widely considered as most influential architect of internet
- The idea is to handle packet error control, out-of-order, flow and congestion control, and other problems at end nodes
- This governs the design of TCP

Best effort service

- Because of packet switching, the internet service is often referred to as “best effort service”
- For best-effort service, it is always possible to deal with performance problem by increasing capacity
  - This is known as the “over-provisioning” solution
- But for instantaneous congestion, e2e principle + best effort service can lead to “congestion collapse”



End-to-end congestion control

- Each sending node tries to detect network congestion somehow
- If congestion detected, buffer traffic at the sending node rather than in the network
- If no congestion detected, tries to send faster

- One alternative is “hop-by-hop” congestion control
  - Congestion is detected at each hop
  - When detected, back-pressure the upstream hop, all the way back to the source
  - What are the pros and cons of HBH and E2E congestion controls?
- Another alternative is via routing
  - Prone to oscillation, abandoned

Fairness

- If two flows share the same congested link, other things being equal, we try to allocate same bottleneck bandwidth to both flows
  - The AIMD algorithm is adopted by TCP
  - Is this necessary or only desirable?

Chiu & Jain, “Analysis of the Increase and Decrease Algorithm for Congestion Avoidance in Computer Networks”, 1989

Distributed routing

- Each router does “routing” and “forwarding”
- For routing, a router
  - Auto-detects local reachability information
  - Exchanges local reachability information with other routers, and creates a forwarding table

  Both done in a background process
- For forwarding, a router forward arriving packets based on forwarding table

- An alternative is to separate routing and forwarding
- Routing information can be collected by a “controller”, that creates the forwarding table for all routers
- What are the pros and cons of these two approaches?

Policy-based routing

- “Policy-based routing” is essentially the same as distributed routing, except, reachability information is not auto-detected, but configured according to policy
- What is “policy”? – those agreements (e.g. whether ISP A forwards packets for ISP B) between ISPs who peer with each other

Datagrams vs TCP

- Datagram service (UDP) provides end-to-end delivery of individual packets independently
- TCP delivers in-sequence, error-corrected service of a flow of packets
- There are needs for both, though most applications need TCP
- Internet decided to provide both service

Success of internet = triumph of the architecture?

- Yes
  - It has “defeated” the other candidates
  - It has worked well in most cases
- But
  - As application requirements change over time, some internet architecture ideas are questioned time and again

- Biggest “new” application requirements:
  - Video and multimedia;
  - Data centers
  - Multicast/broadcast
  - Mobility

The battle for QoS

- Multimedia applications supporting human interaction are sensitive to performance, e.g.
  - Voice communication
  - Streaming video
- Best effort service does not provide Quality of Service (QoS)
- Many efforts to change Internet to provide QoS during 1990s:
  - ATM
  - Integrated Service
  - Differentiated Service
- These attempts mostly failed
  - The “solution” – over-provisioning

Software Defined Networking

- Distributed routing good for auto-configuration, and unpredictable traffic
- Fair congestion control adapts well in distributed environment
- But what if we have regular or predictable traffic, and want more optimal bandwidth allocation?
- One solution is centralized routing, done by a controller
- This is one of the motivation for Software Defined Networking (SDN)
- It is being used in “private networks” – data centers

Multicast

- Another requirement by many application is Multicast – content sent simultaneously to multiple destinations
  - It can be more scalable if duplicating is done in the network (or via a broadcast media)
- It was a big project in IETF during 1990s
  - Various multicast routing protocols proposed
  - Reliability mechanisms added at the end nodes
  - It did not succeed due to many reasons, including complexity and economic reasons
  - What is the solution? OTT services

Over-the-top services

- Instead of implementing multicast in the network, build a network of servers in the application layer: Content Distribution Networks (CDN)
  - This is the solution for today's Video-on-demand, and video streaming services
  - IP multicast is used only in local contexts

DASH

- DASH = Dynamic Adaptive Streaming over HTTP
- Video streaming requires steady bandwidth, but Best Effort Service cannot guarantee that
- DASH means creating multiple copies of each video segment, with different resolution
  - Dynamically decide which resolution to use based bandwidth availability

Future internet

- Researchers continue to work on Future internet
  - IPv6
  - Internet2
  - NSF's Future Internet Architecture projects:
    - Content Centric Networking
    - Mobility First
    - Cloud networking
    - Etc

  http://www.nets-fia.net/

- How to evaluation these initiatives?
- How to decide which camp to join, if you work on networking?

Summary

- We reviewed history and key design choices and issues of internet
- We will delve deeper into selected topics
- The design of the internet comes with some value judgements by the architects, researchers and engineers who worked on the internet
  - It is not purely engineering