University of Glasgow

Case Studies

Networked Systems 3
Lecture 3

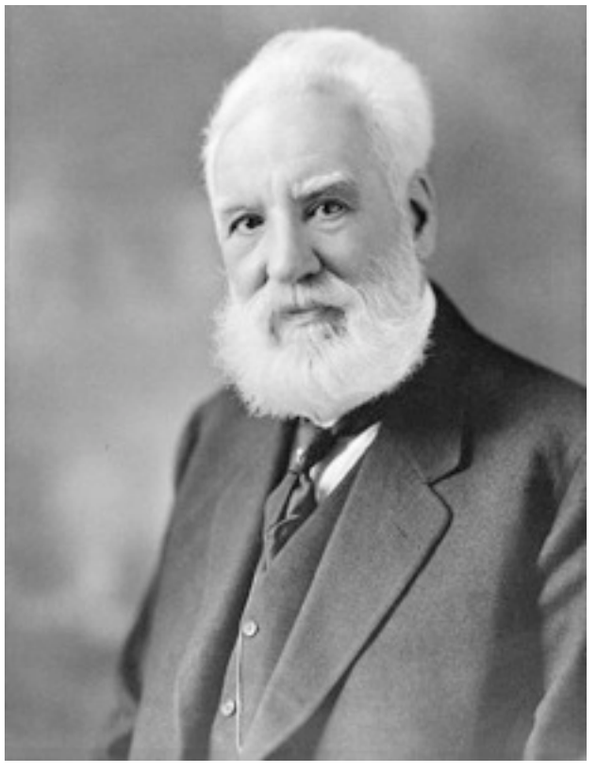
Lecture Outline

- Case Studies: Network Design Choices
  - The Telephone Network
  - The Internet

The Telephone System

- Public switched telephone network (PSTN)
  - Voice phones
  - Fax machines
  - Dial-up modems
- Ignoring (for now):
  - Mobile phones, VoIP

History and Development

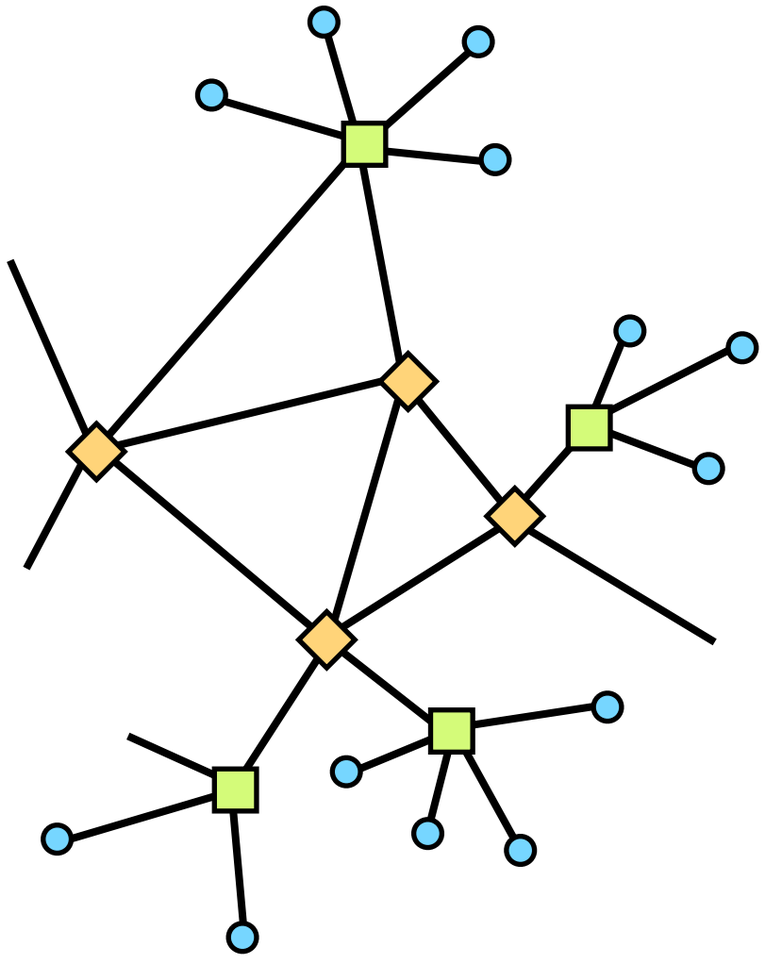


Source: Public domain

Alexander Graham Bell

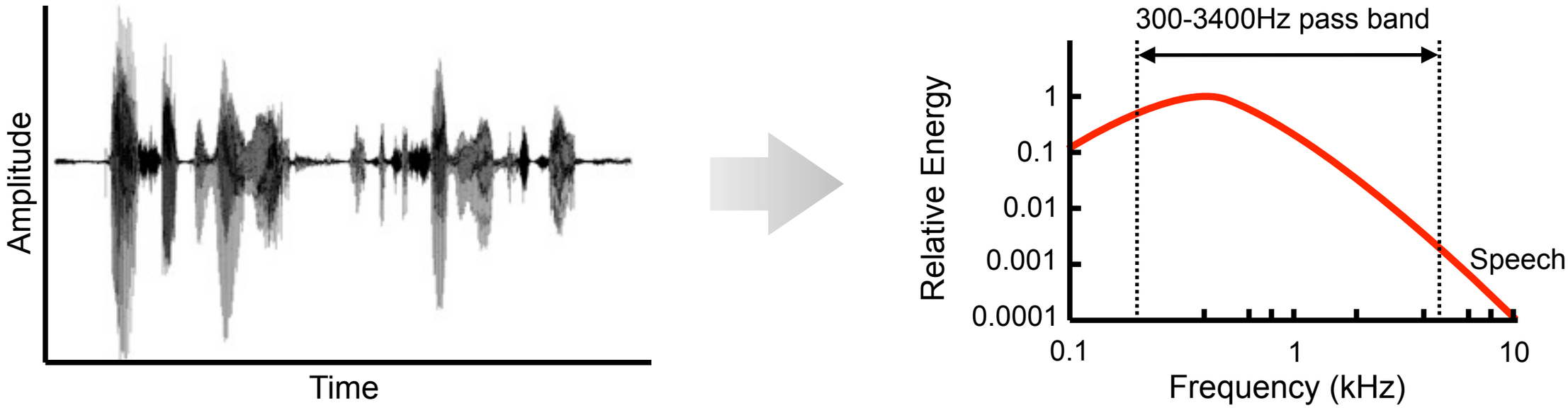
- 1876: Alexander Graham Bell
  - Telephone controversially patented hours before similar invention by Elisha Gray
- Bell Telephone Company → AT&T
- National telephone monopolies
  - Strong governmental regulation
  - Slow pace of innovation and service change
- Liberalisation, competition, and opening of the local loop

Basic Concepts



- Multi-level circuit switched network
  - Analogue circuits transport speech to exchange
  - Sampled at exchange, digital circuits in the core
- Optimised for speech traffic
  - Only a single service provided: convey speech data
  - Circuit capacity based on speech characteristics
  - Network dimensioned using typical call duration

Physical and Link Layers



- Single twisted pair cable forms the local loop
- Analogue circuit, band limited to 30 – 3,400Hz
  - Acceptable quality speech; not suitable for music

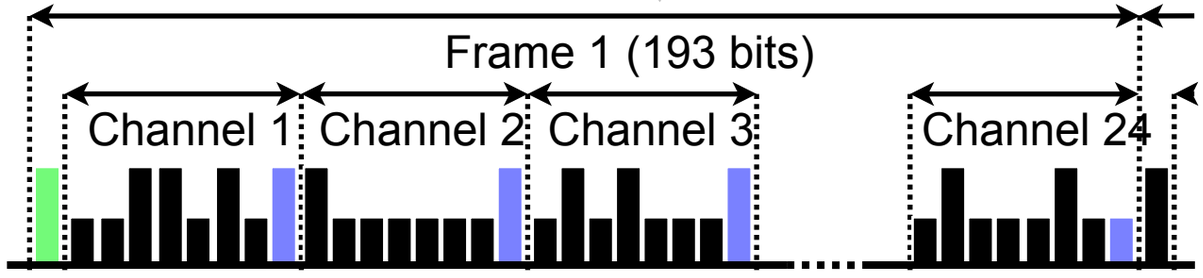
Network Layer

- Local loop terminates at exchange
- Structured hierarchical circuit switching and addressing to route call to destination
  - Calls block if no capacity at intermediate circuit
  - Structured addressing: +44 141 330 4256

Transport Layer

Analogue speech signal is digitised at the exchange:
7 bits × 8000 samples/second = 56kbps channel (US & Japan)
8 bits × 8000 samples/second = 64kbps channel (Elsewhere)

24 voice channels → T1 line (1.544 Mbps)



Outside US & Japan:
32 voice channels,
E1 line (2.048 Mbps)

Each frame comprises:
1 framing bit, 24 channels (7 data bits, 1 control bit)

Multiplexing continues at higher rates
Synchronous Digital Hierarchy (SDH)

All digital circuits in the phone system are defined as synchronous multiples of the voice channel rate

Applications

- Voice telephony — Primary service
- Fax — Encoded as audio tones sent over the voice path
- Video conferencing — Encoded as audio tones sent over the voice path
- Data circuits — Digital path extended to edge

Telephony Standards

- International Telecommunications Union
  - http://www.itu.int/
  - Governmental-level body: part of The United Nations
  - Formal representation and voting process
    - Companies send representatives to national standards bodies (e.g. BSI, ANSI, DIN); national standards bodies cast their country's vote at the ITU plenary meeting
  - Cycle of formal comments on technical protocols between plenary and national standards bodies
  - Liaisons with other standards bodies (e.g. IETF, W3C)

Design Choices

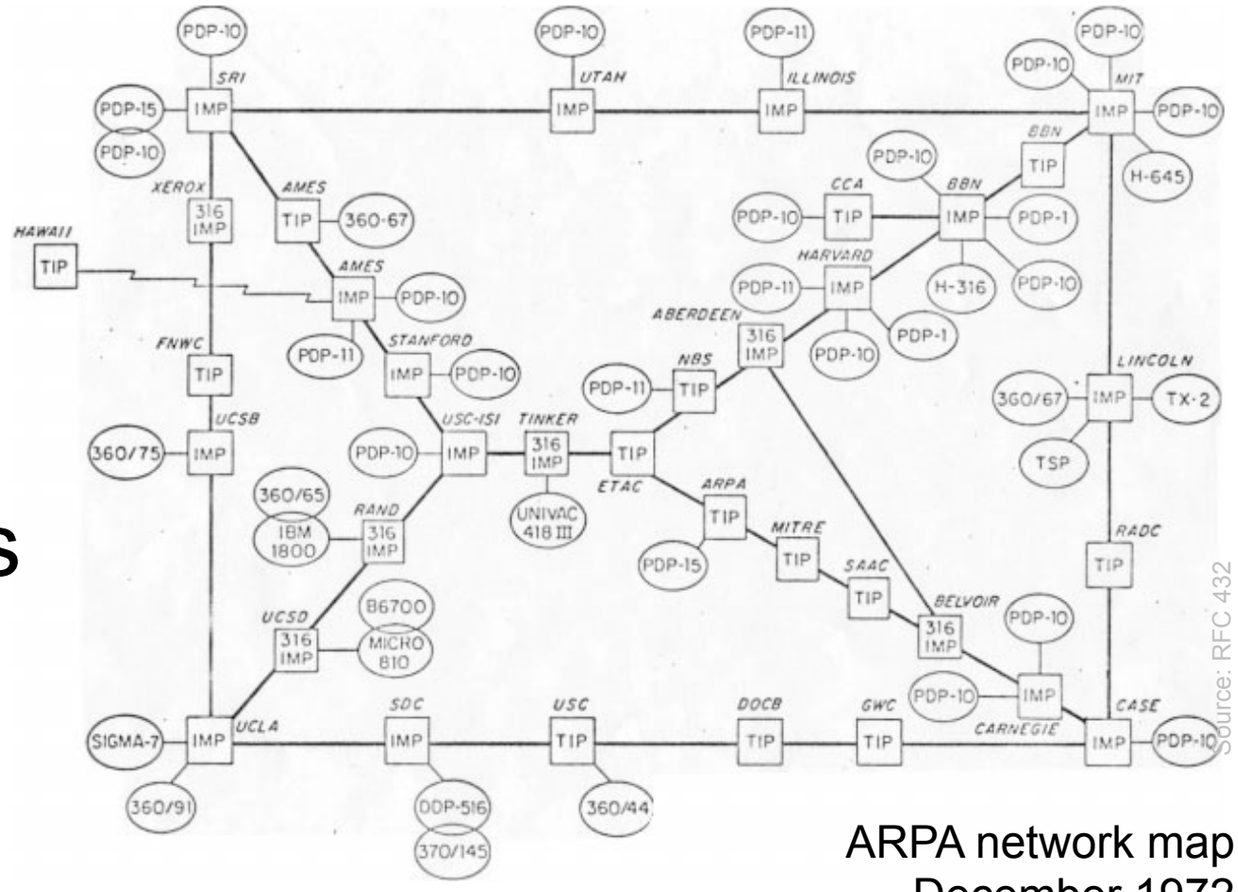
- Circuit switched network
  - Potential blocking; high quality guaranteed if accepted
  - Traditionally strong reliability guarantees
- Highly optimised for voice telephony
- Inflexible architecture, bureaucratic standards
  - Stability and reliability preferred over flexibility

The Internet

- Interconnected set of global networks, running a common network layer
  - The Internet Protocol (IP)
- Supporting technology for application protocols
  - World Wide Web (HTTP)
  - Email (SMTP)
  - Instant Messaging (Jabber, etc.)

History and Development

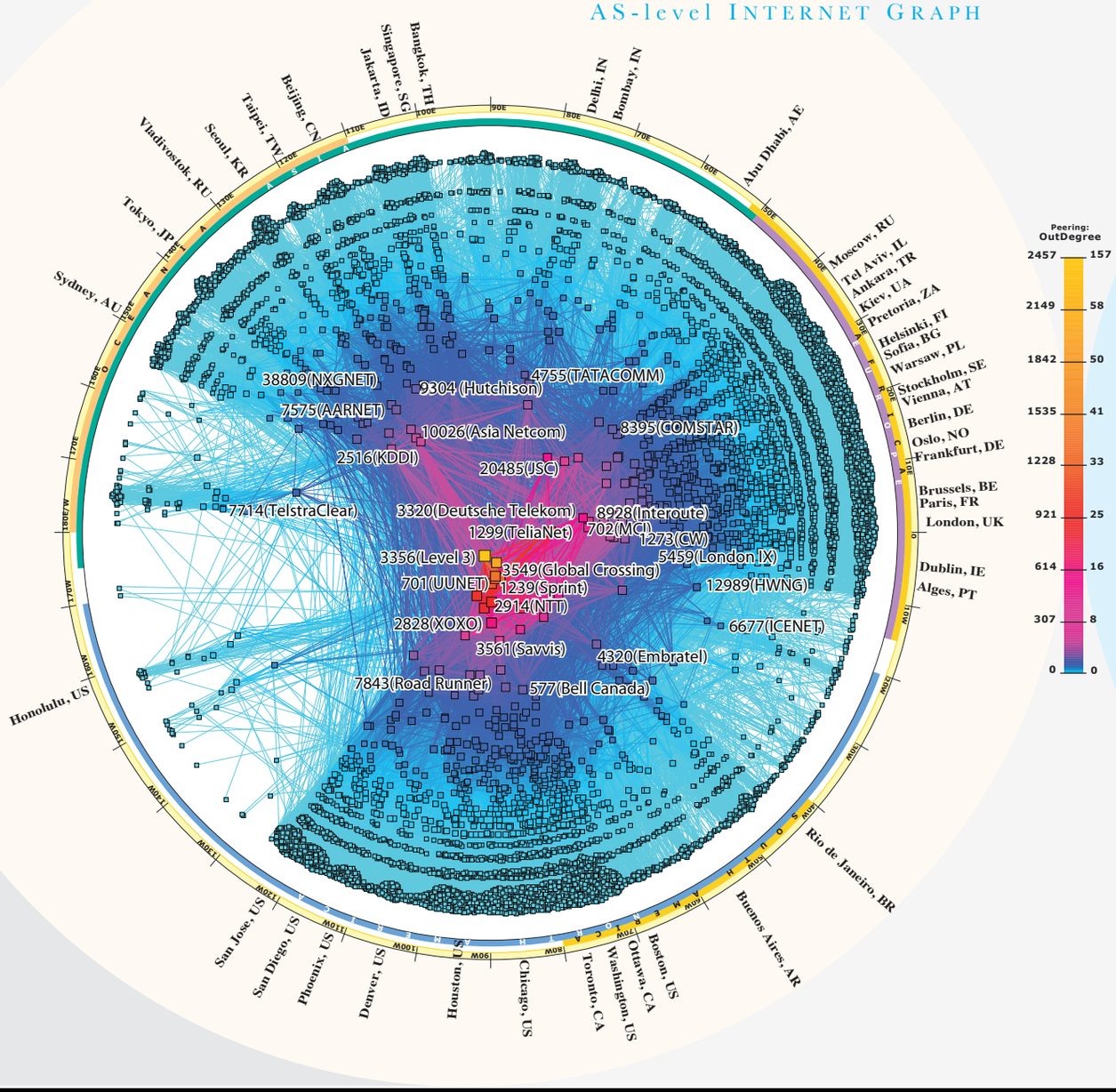
- 1965: Packet switching
  - Paul Baran (RAND),
    Donald Davies (NPL)
- 1969: ARPA funding
  - First link: UCLA – SRI
- 1973: First non-US sites
- 1983: Switch to IPv4
- 1990: World Wide Web
  - Tim Berners-Lee

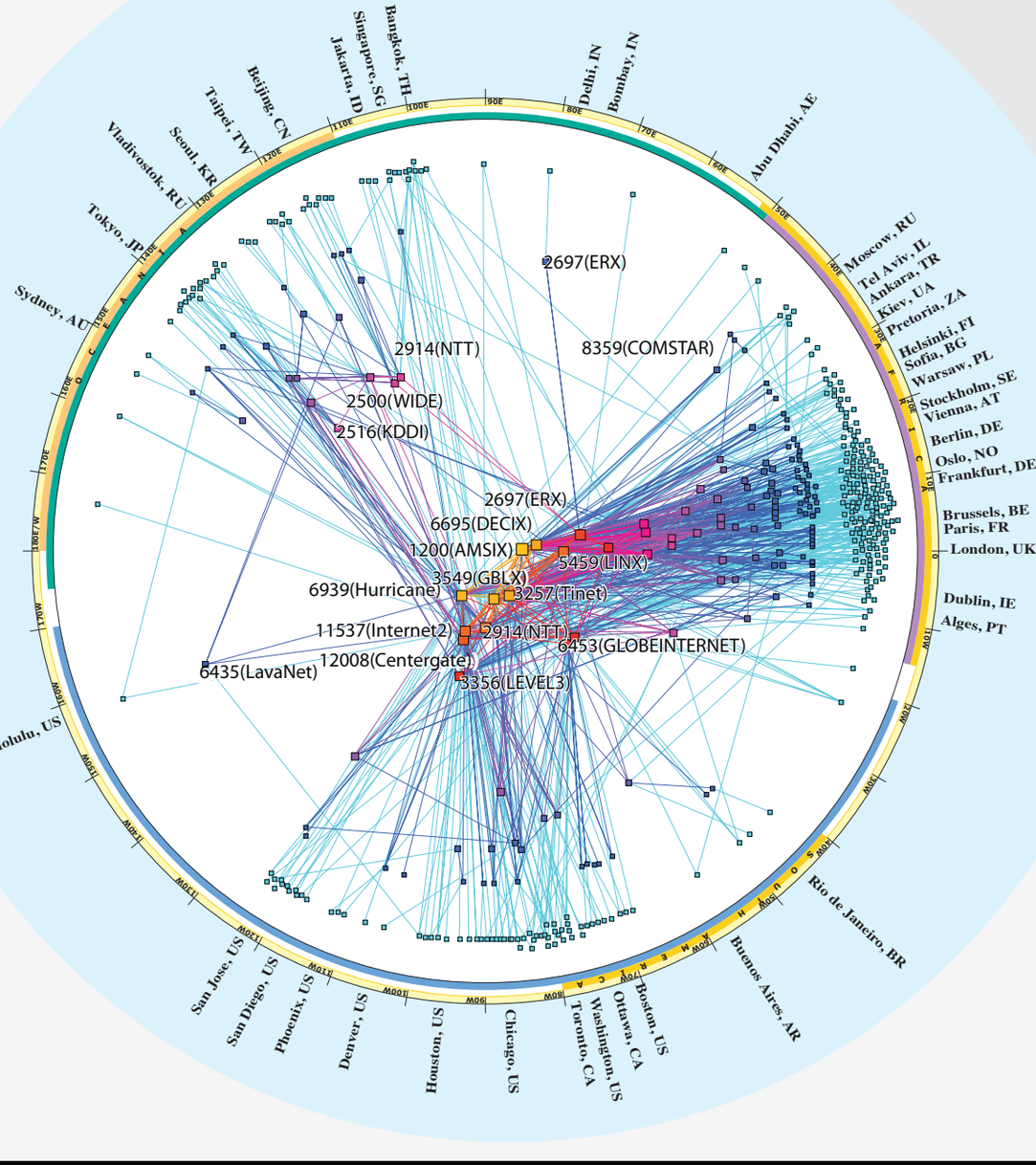


ARPA network map
December 1972

IPv4 & IPv6 INTERNET TOPOLOGY MAP JANUARY 2009

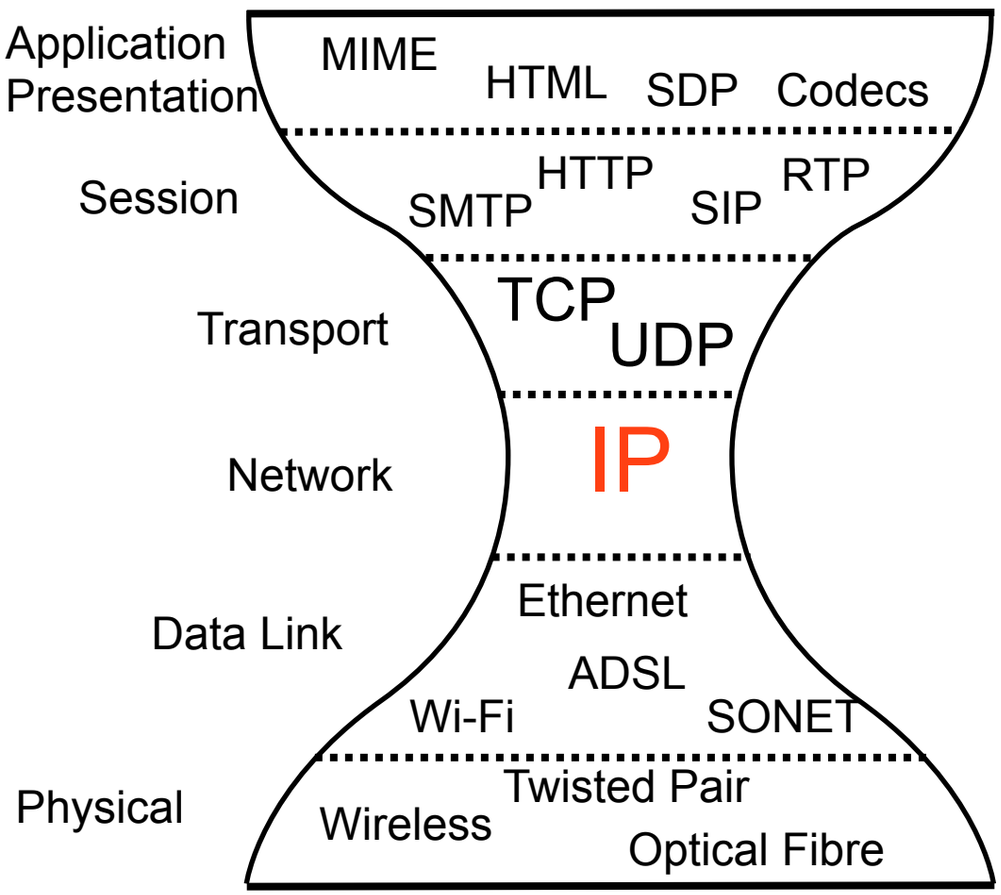
AS-level INTERNET GRAPH





Source: CAIDA

Basic Concepts



- Global inter-networking protocol
- Hour glass protocol stack
  - Single standard network layer protocol (IP)
    - Packet switched network, best effort packet delivery
    - Uniform network and host addressing
    - Uniform end-to-end connectivity (subject to firewall policy)
- Range of transport & application layer protocols
- Range of link-layer technologies supported

Lower Layers

- IP runs on any data link/physical layer
  - Ethernet, ADSL, Wi-Fi, optical fibre, carrier pigeon…
  - Anything that can deliver packets, can support IP
  - No requirement for synchronous circuits

The Internet Protocol (IP)

- Gives each host a globally unique address
- Delivers packets from one host to another
  - Best effort delivery – discards packets on failure
  - No performance guarantees
  - Agnostic of packet contents – except firewalls
- Provides uniform network connectivity

The Internet Transport Layer

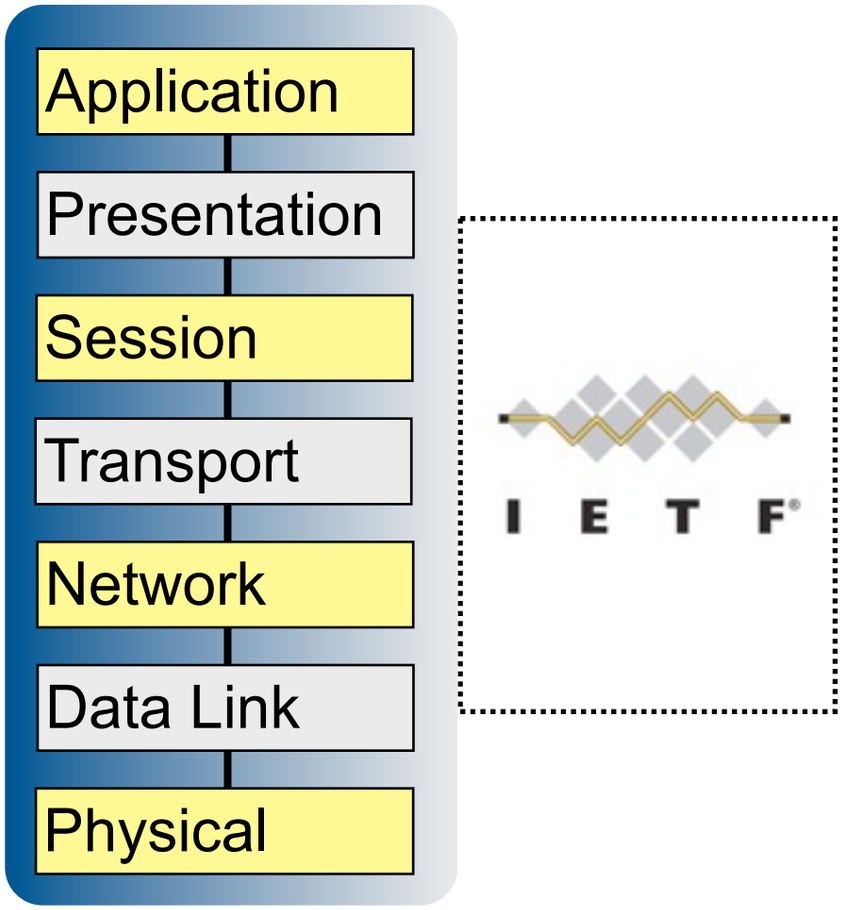
- Hide vagaries of IP layer
  - UDP: unreliable packet (“datagram”) delivery service, with no guarantee of reception
  - TCP: reliable, in-order, byte stream service

IETF

Applications

- End-to-end argument
- Flexible, supports wide range of applications
- Intelligence at edge of the network; dumb core
  - Innovation happens at end hosts
  - Core network doesn’t know or care what application data is being transported
  - Allows rapid change, deployment of new protocols

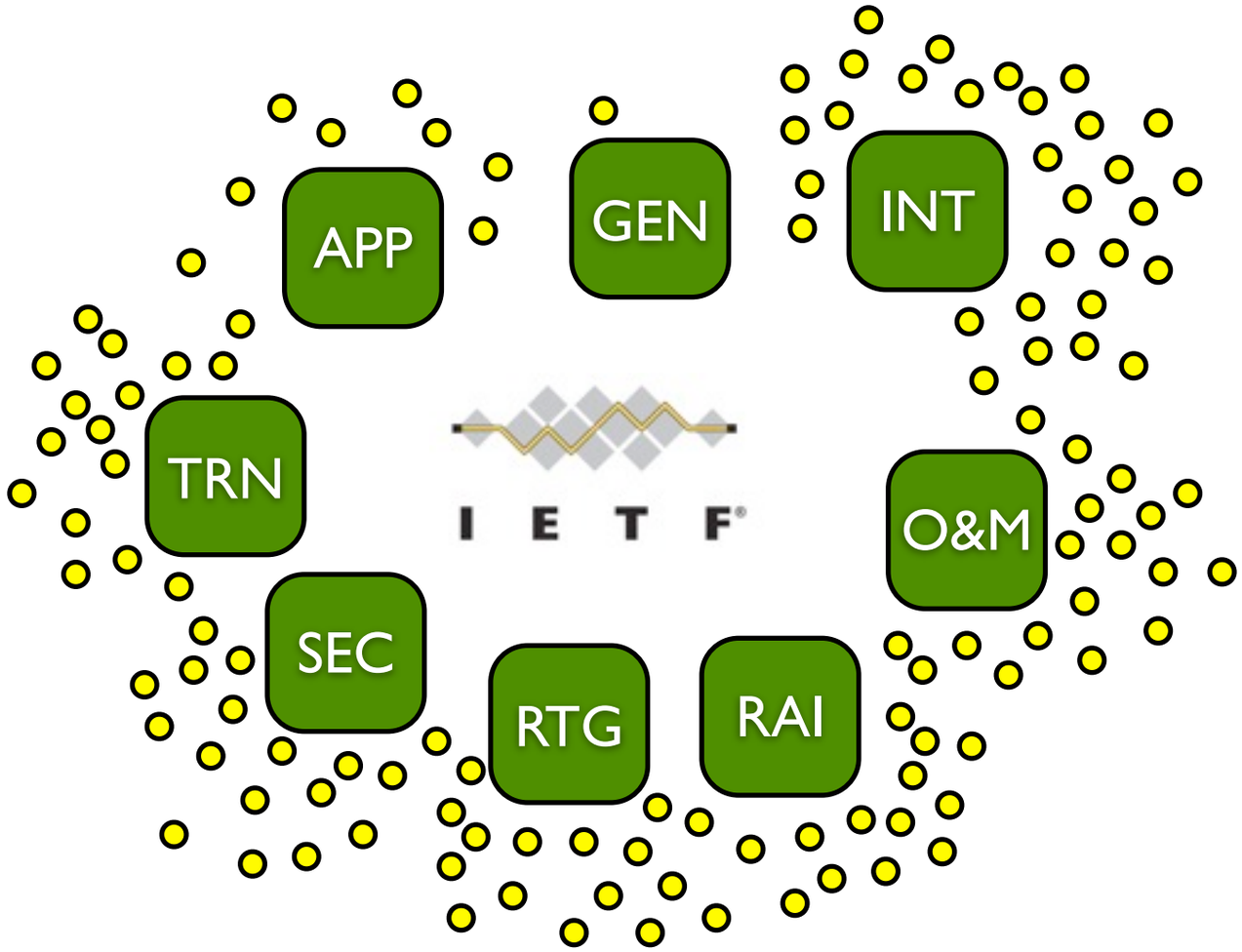
Internet Standards (1)



- Internet Engineering Task Force
  - Volunteer standards body; open membership
    - Mailing lists; 3 physical meetings per year
  - Standards and work-in-progress drafts freely available to all:
    - http://www.ietf.org/
    - http://www.rfc-editor.org/
  - Primary focus: network and transport layers (IP, UDP, TCP), session and presentation layer protocols to support applications (e.g. HTTP, SMTP, SIP), and routing

I E T F

Internet Standards (2)



Internet Society

IRTF

IETF

Design Choices

- Packets rather than circuits
- Single generic best-effort network layer
  - Generic packet delivery service
  - Easy to implement on any link-layer
- The end-to-end argument
  - Transparent network: not optimal for any application
  - Application flexibility at the expense of performance

Flexibility vs. optimality?

Benefits of convergence

Questions?