Last Lecture

- Administrative aspects
- A brief overview of the course
- Desired features of the Internet

This Lecture

Nuts-and-bolts description of the Internet

- The topology
  - The core
  - The edge
- The communication links

A illustrative slice of the Internet

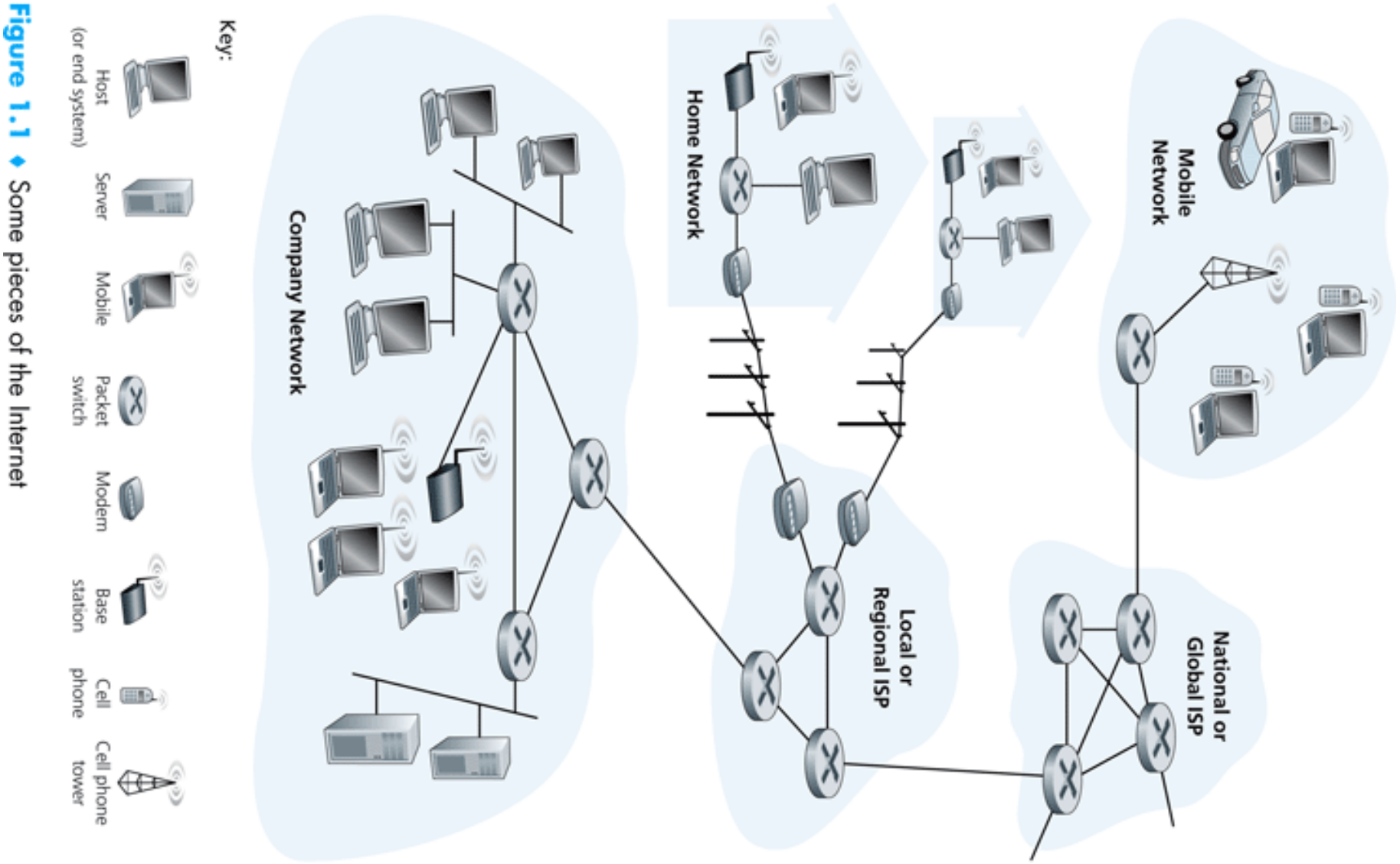

Figure 1.1 ♦ Some pieces of the Internet

The Core and the Edge Nodes

- The core:
  - Interconnected ISPs' networks of routers/switches
- The edge:
  - Users' nodes (i.e. end systems, hosts) "tap" into the core via access networks

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The Core: ISPs' Networks are Interconnected

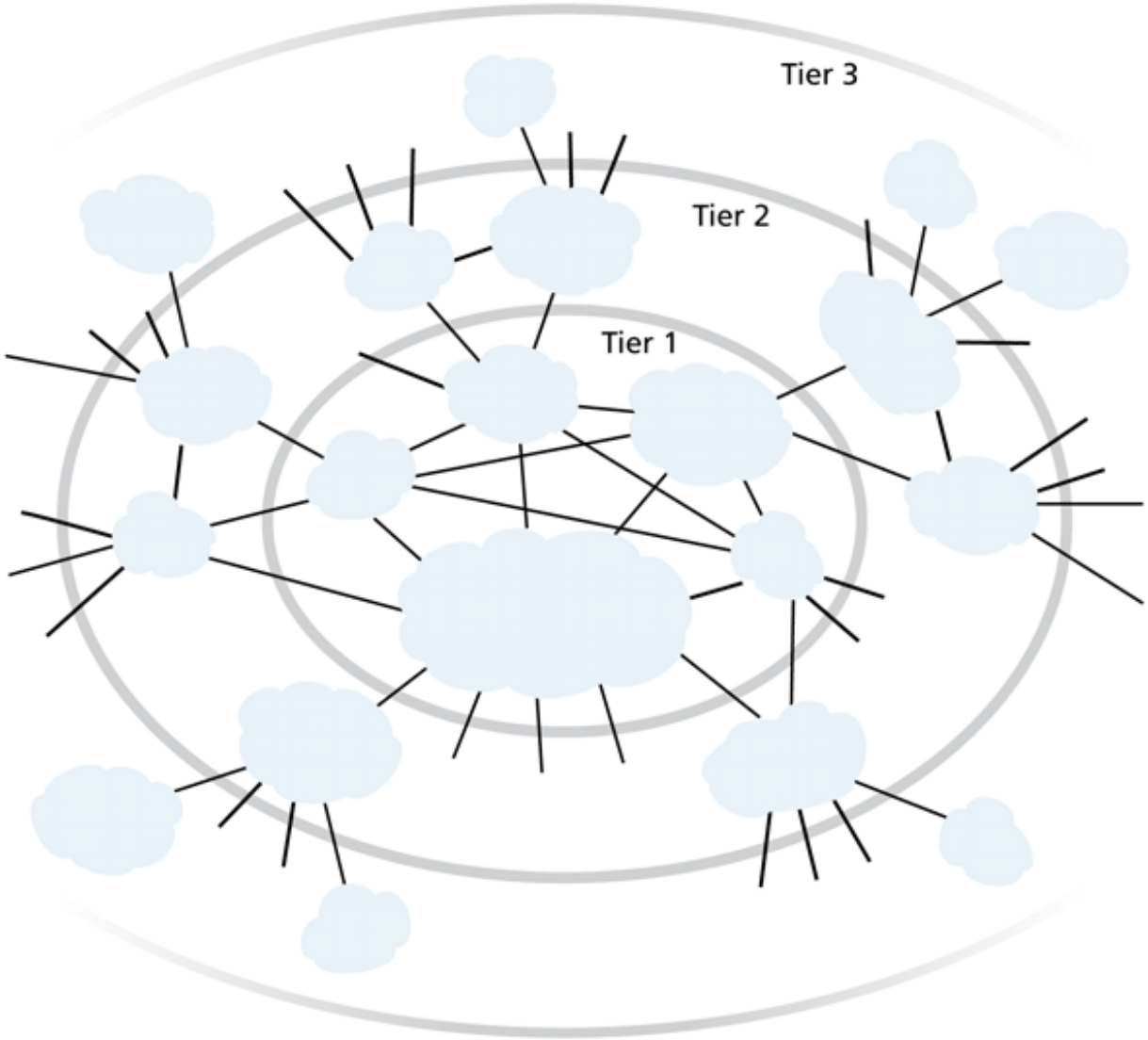
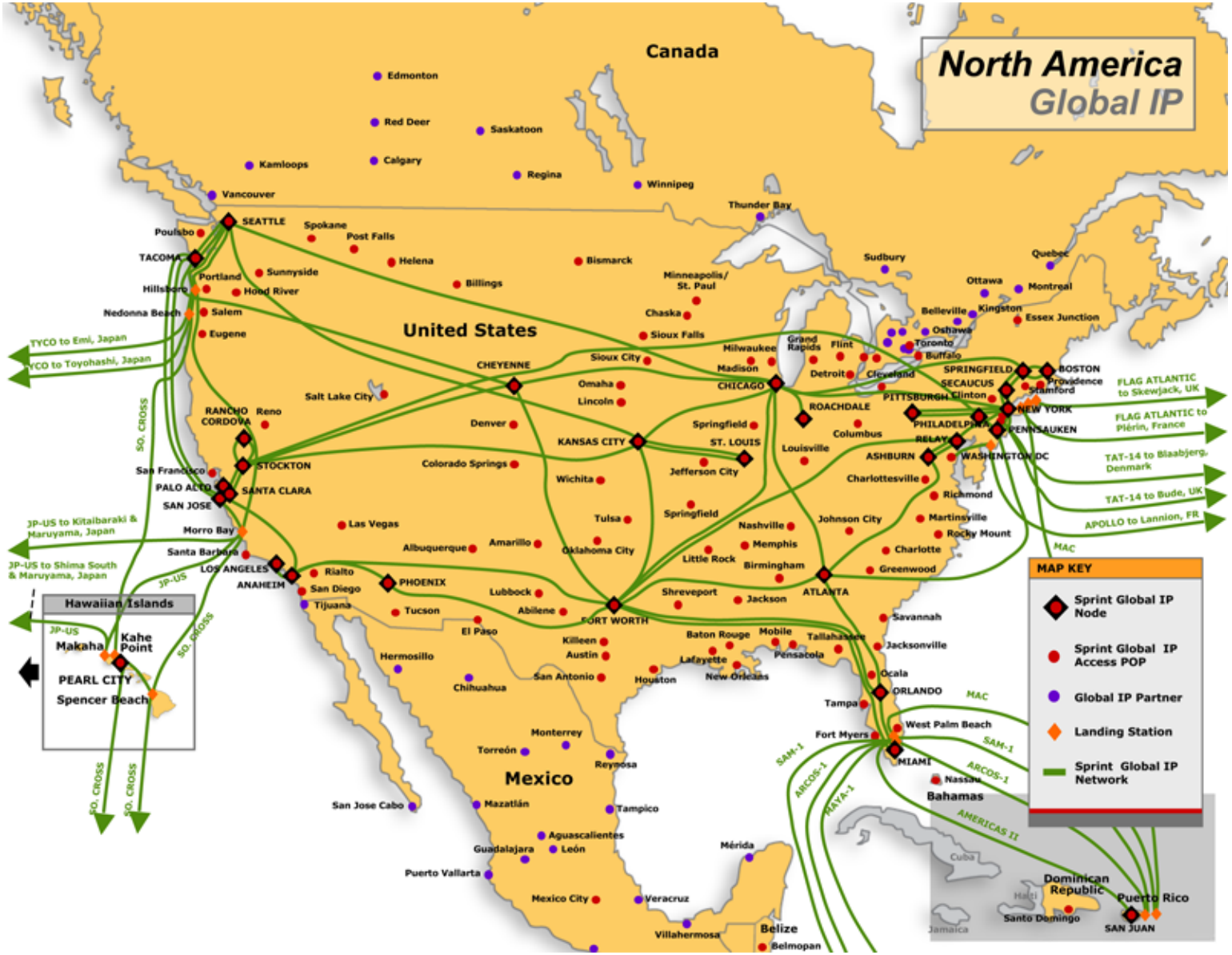


Figure 1.11 ♦ Interconnection of ISPs

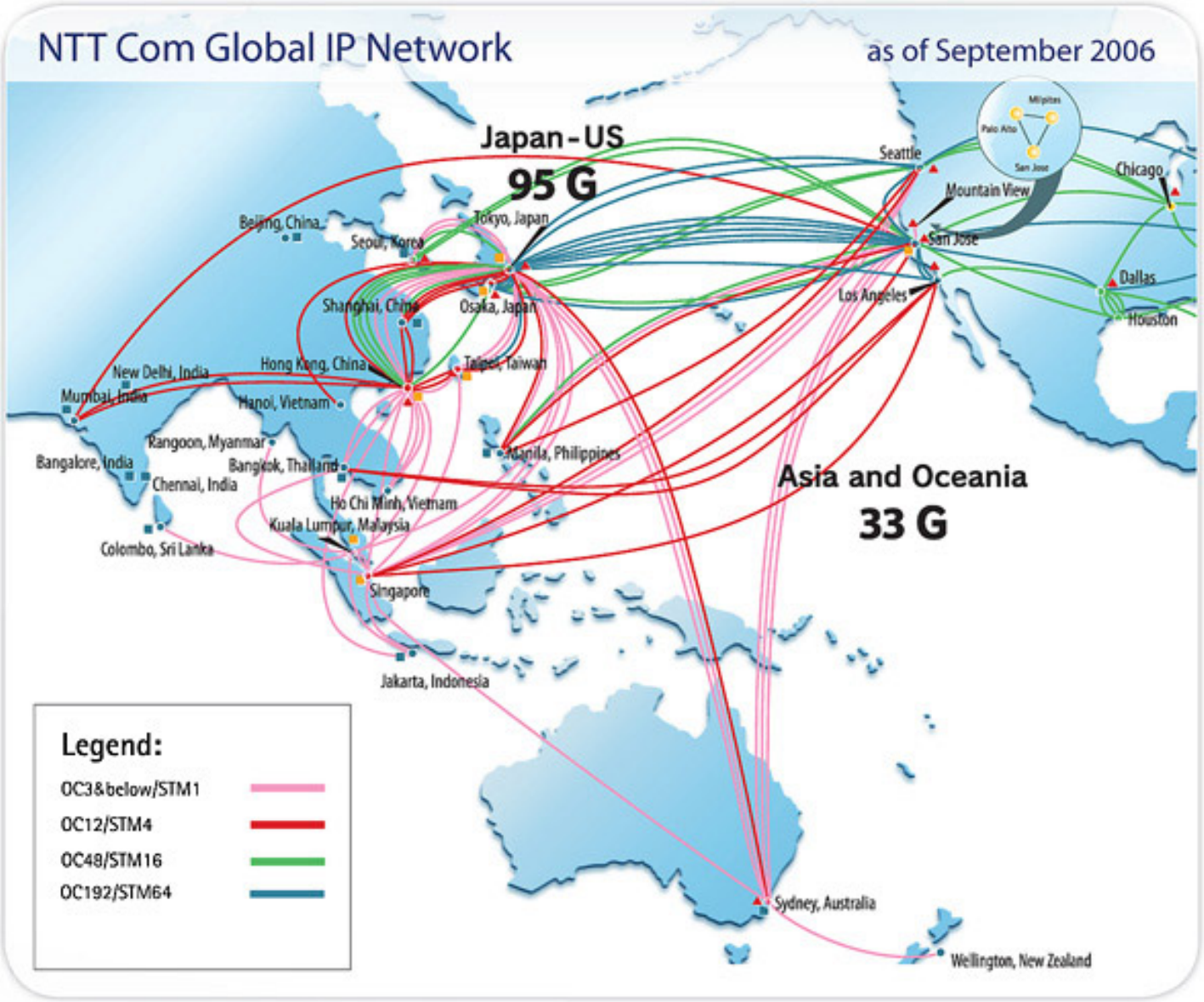
Tier 1 ISPs' Networks

- Also called *Internet backbone networks*
- Unofficially, the following are tier 1 ISPs
  - *Sprint*
  - *Verizon business* (acquired UUNet/(MCI) Worldcom)
  - *AT&T*
  - *Level 3*
  - *Qwest*
  - *NTT communications*
  - *Global Crossing*
  - *SAVVIS*
  - *TeliaSonera*
  - *Tata communications*

Sprint's North America IP Network

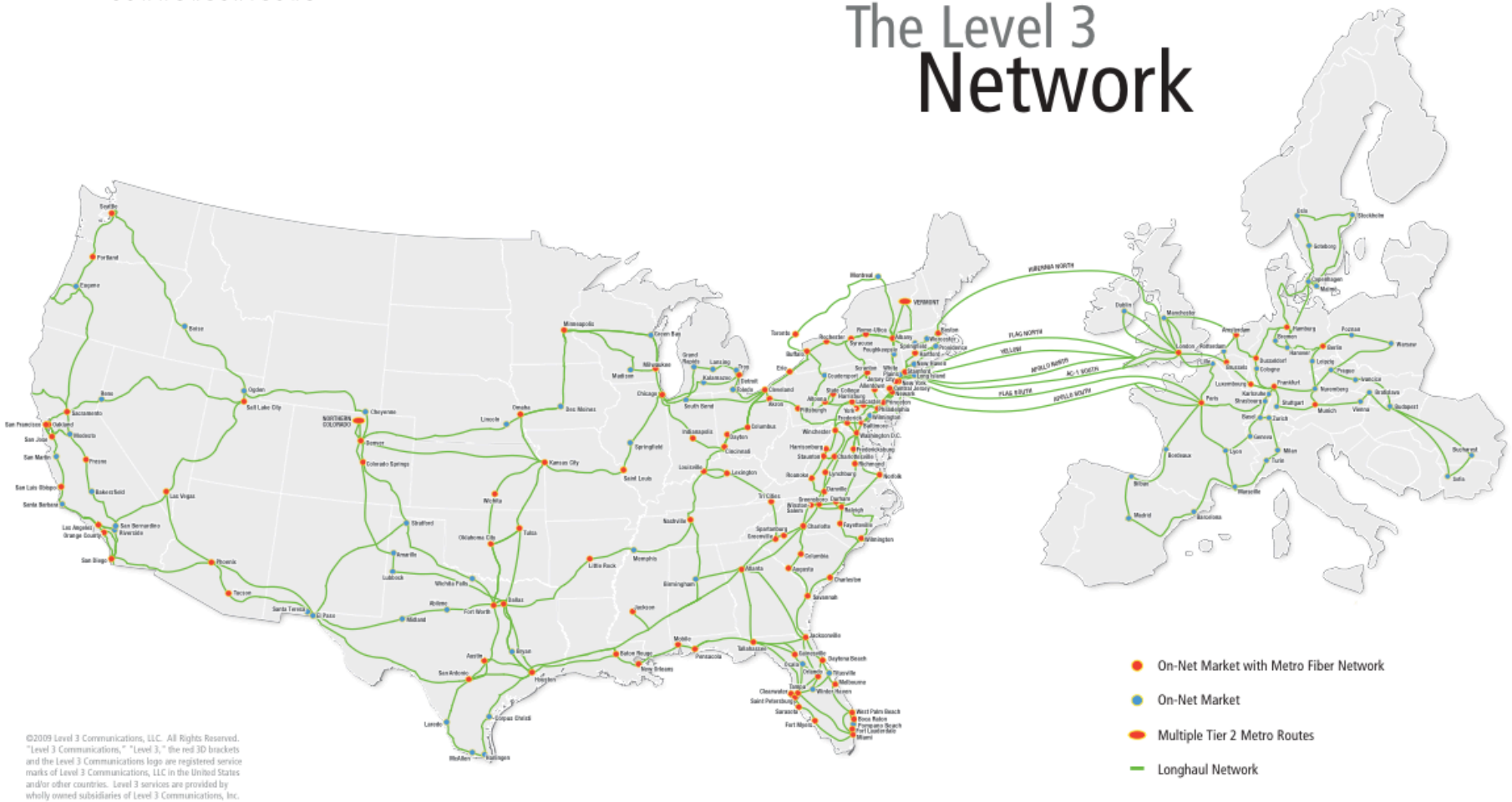


NTT's Global IP Network

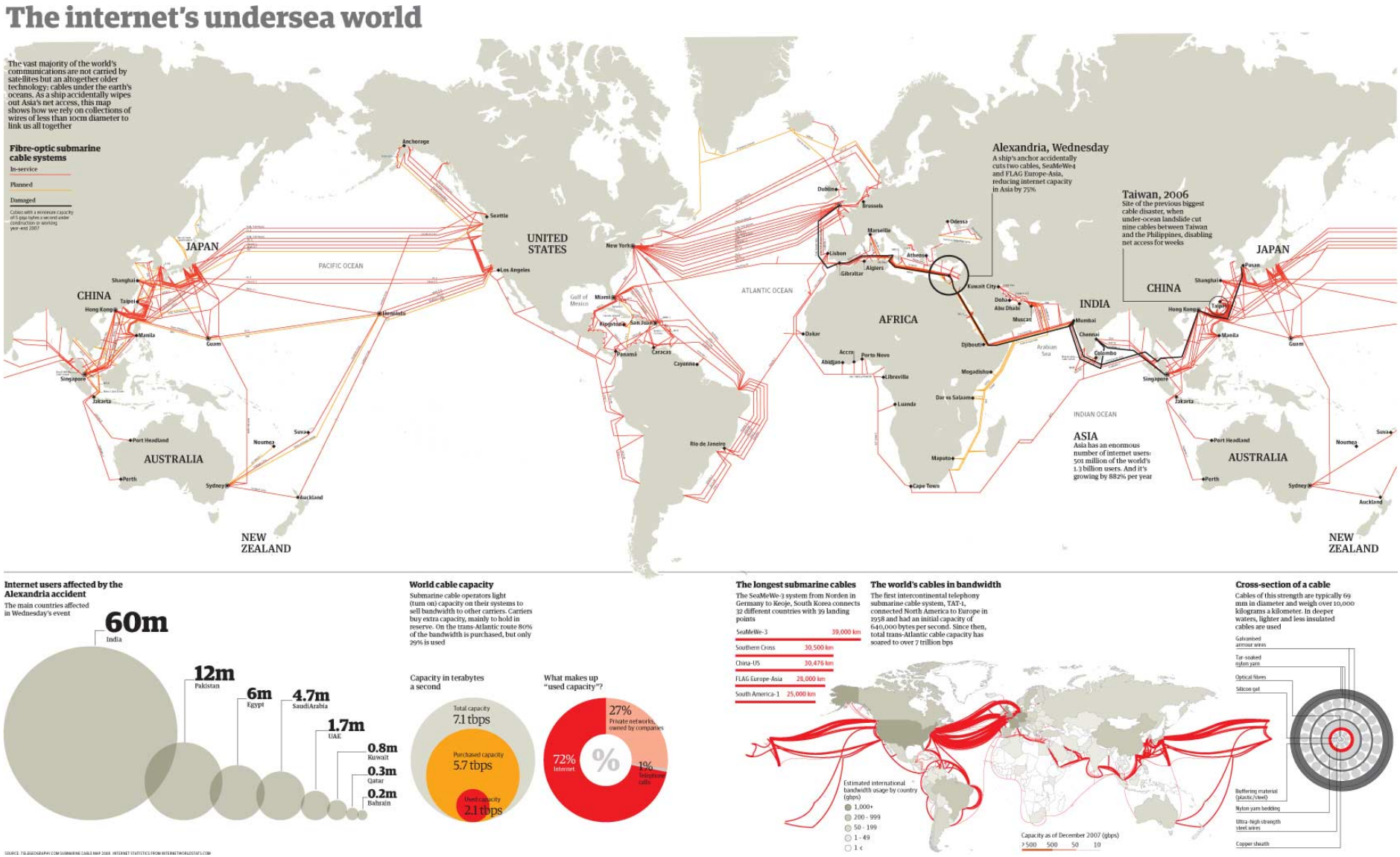


Level 3 COMMUNICATIONS

The Level 3 Network

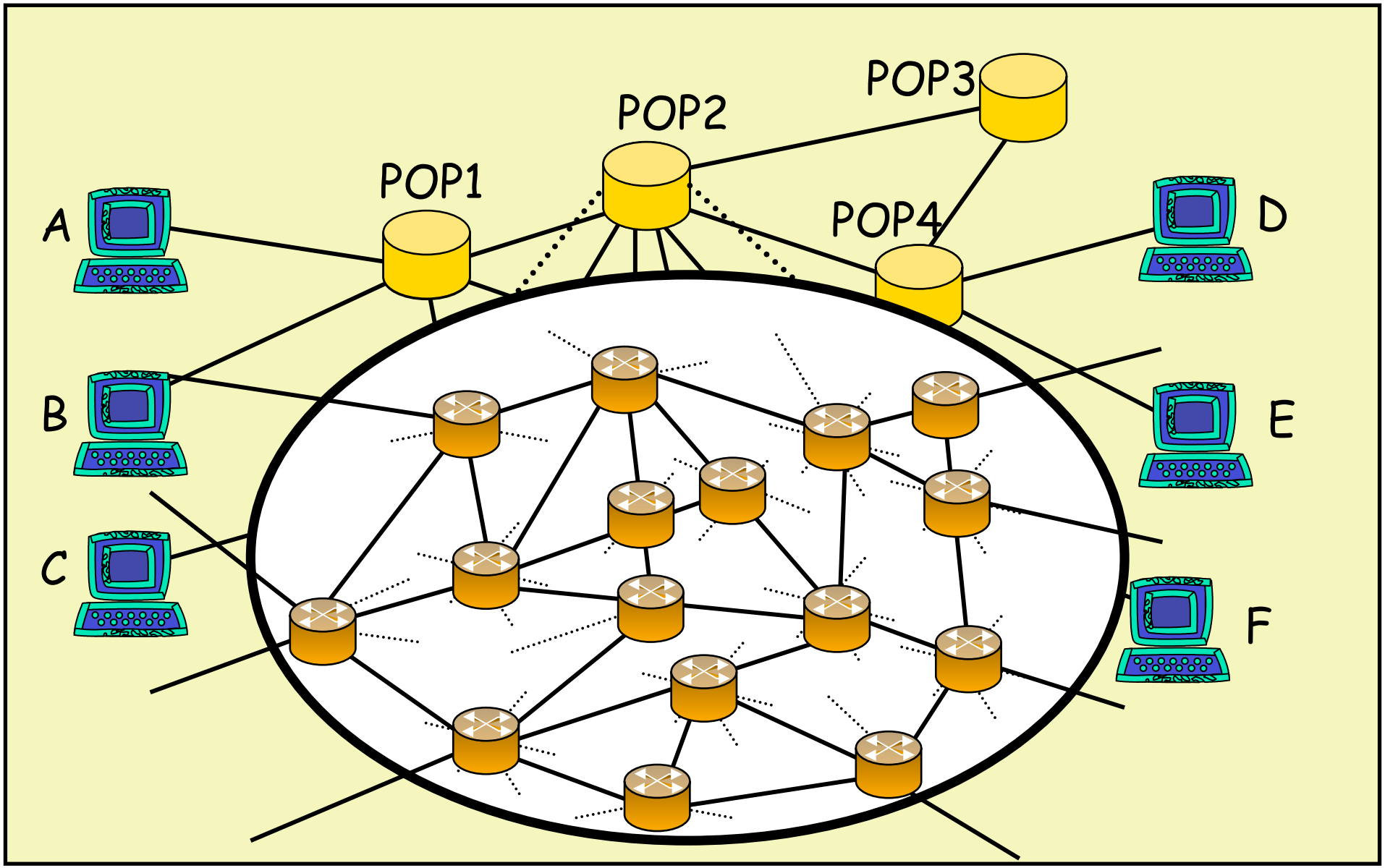


The Internet's Undersea World

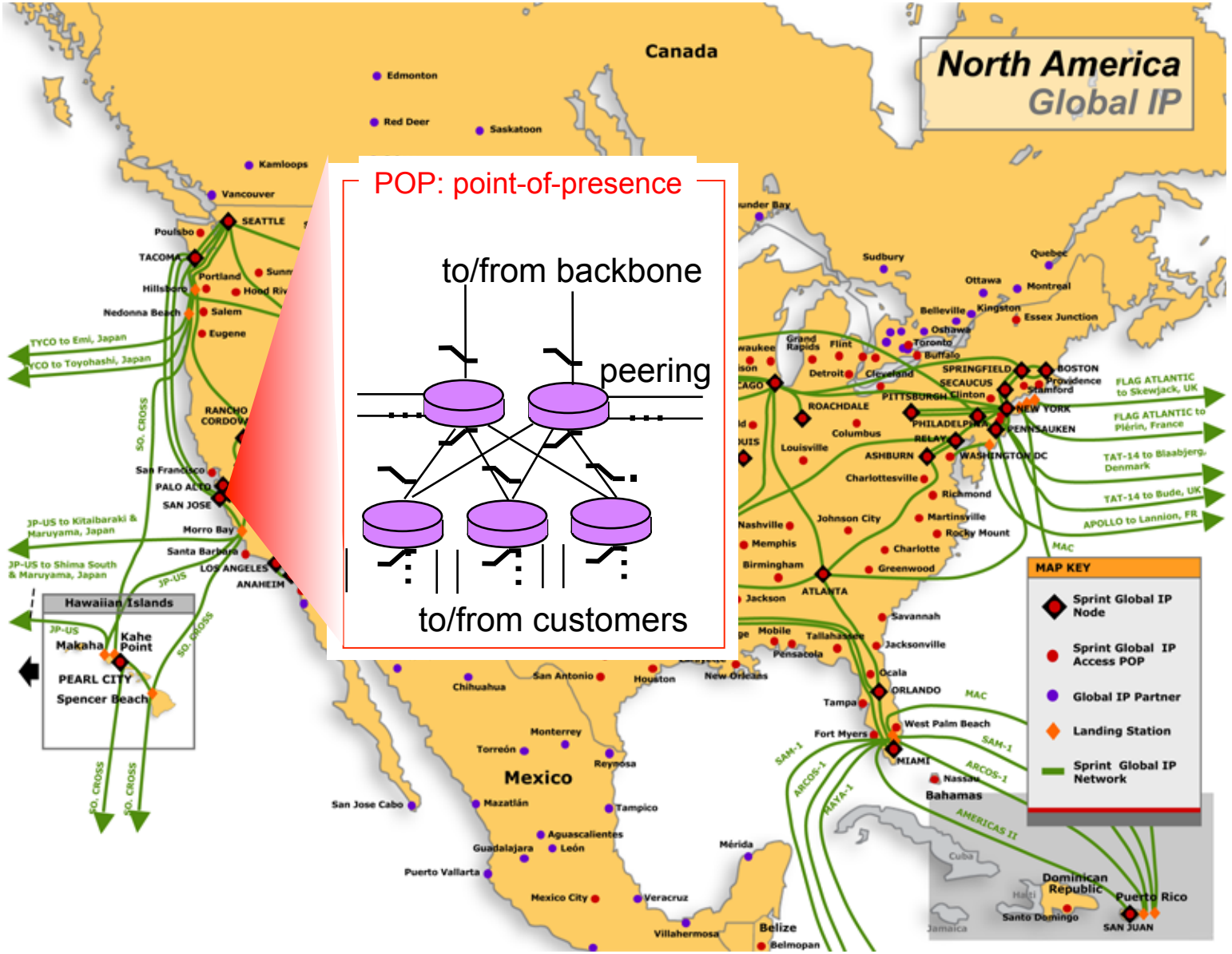


http://www.youtube.com/watch?v=v1JEuzBkOD8

Routers and POPs

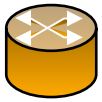


Sprint's North America IP Network



POPs reside in buildings like this London IXP

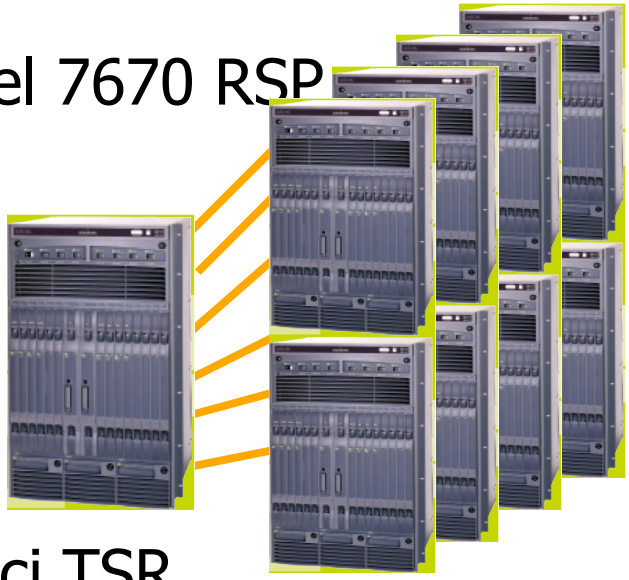
Internet Core Routers Look Like These



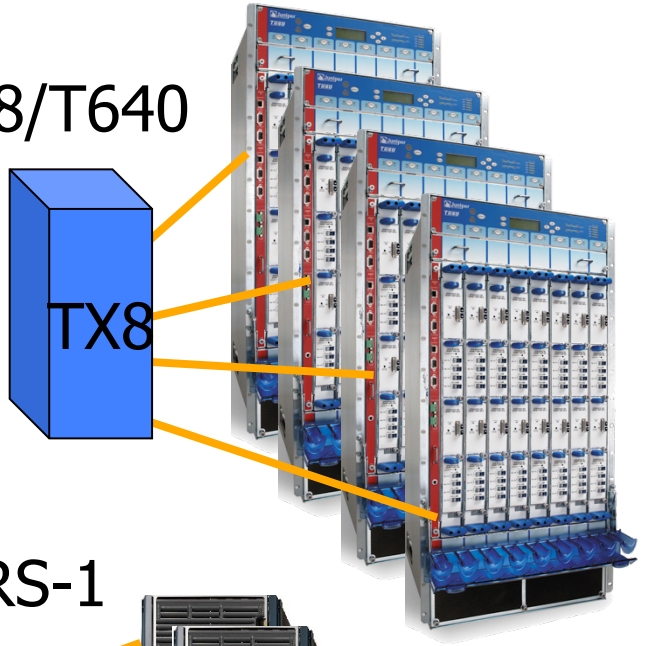
Router on "paper"

More Internet Core Routers

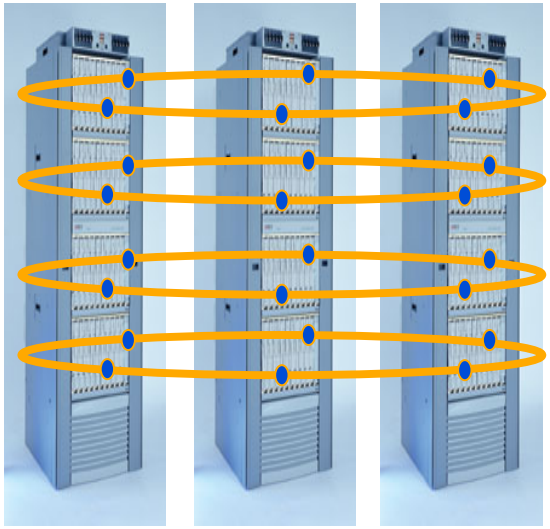
Alcatel 7670 RSP



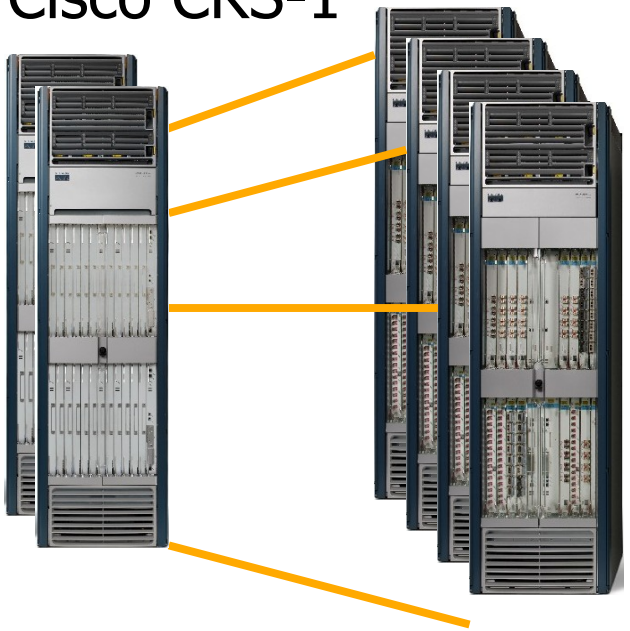
Juniper TX8/T640



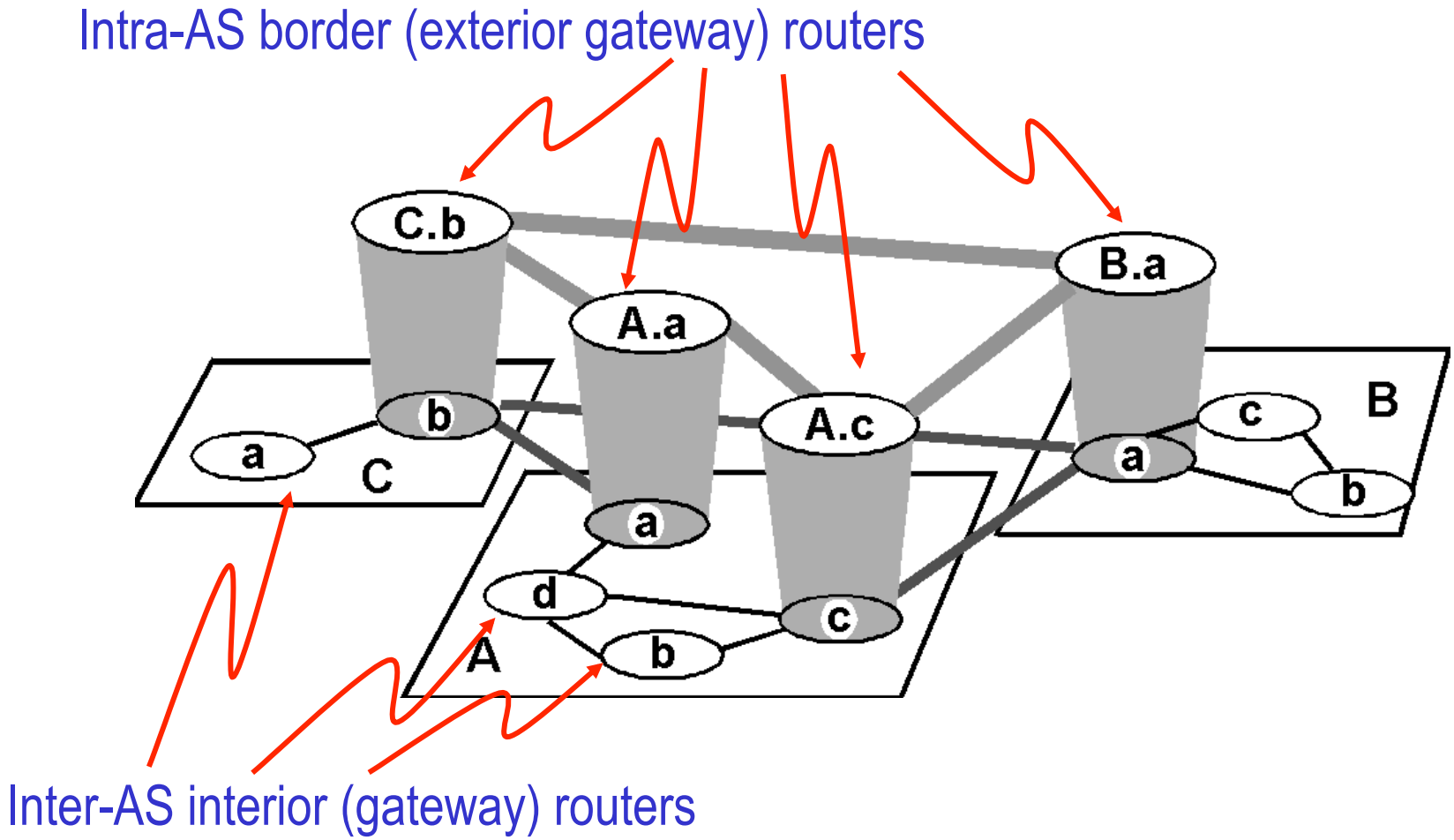
Avici TSR



Cisco CRS-1



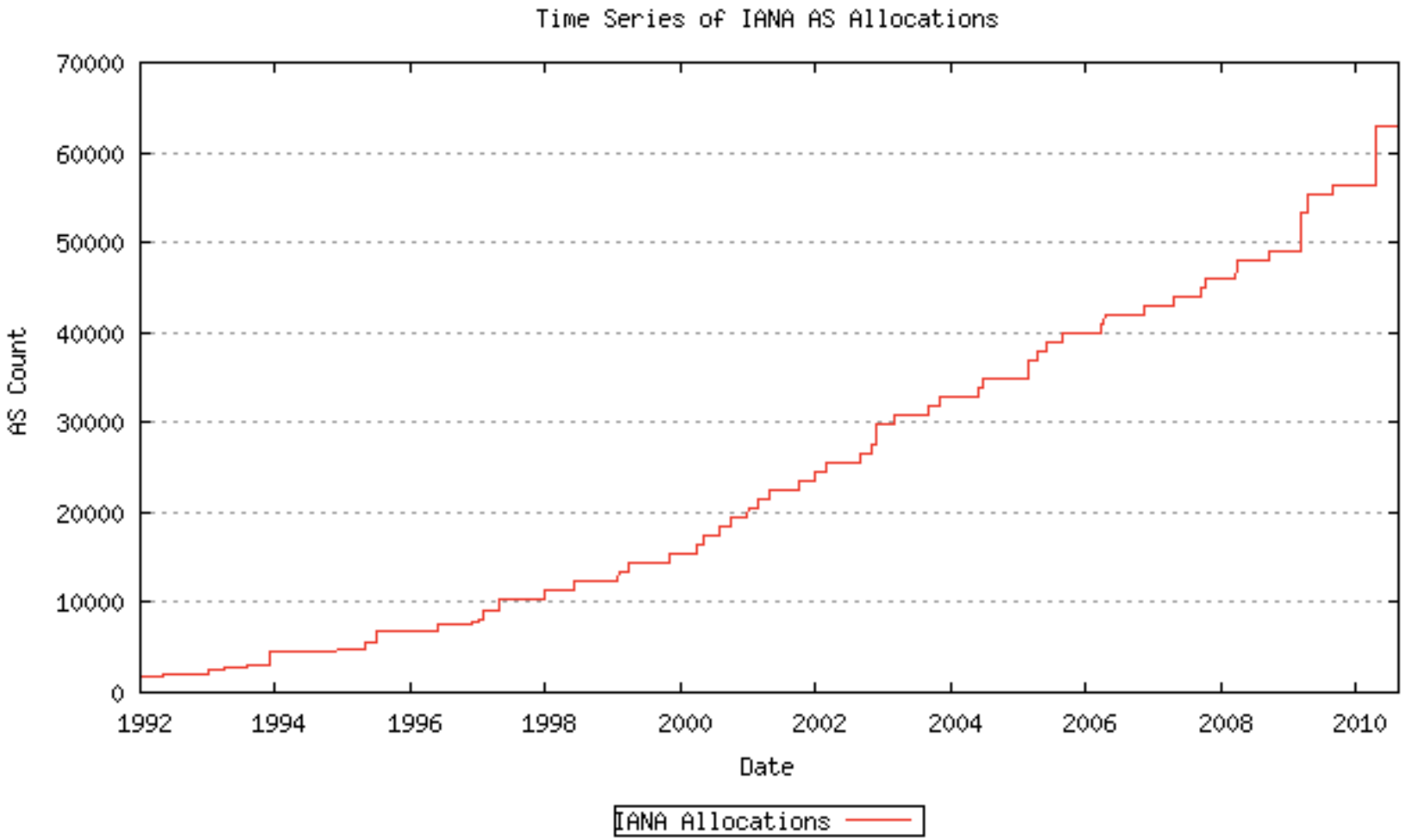
Autonomous Systems (AS)



AS and AS Numbers

- AS, according to RFC4271:
  "a set of routers under a single technical administration, using an interior gateway protocol (IGP) and common metrics to determine how to route packets within the AS, and using an inter-AS routing protocol to determine how to route packets to other ASs"
- Types of AS
  - Multihomed AS: connections to > 1 ISP (no transit traffic)
  - Stub AS: connection to 1 ISP (waste of AS number)
  - Transit AS
- Each AS assigned a 16-bit AS number by the IANA (*Internet Assigned Number Authority*)
  - Public ASNs: 1 – 64511
  - Private ASNs: 64512 – 65536 (used internally in an AS)

AS Numbers Assigned as of Aug 23, 2010



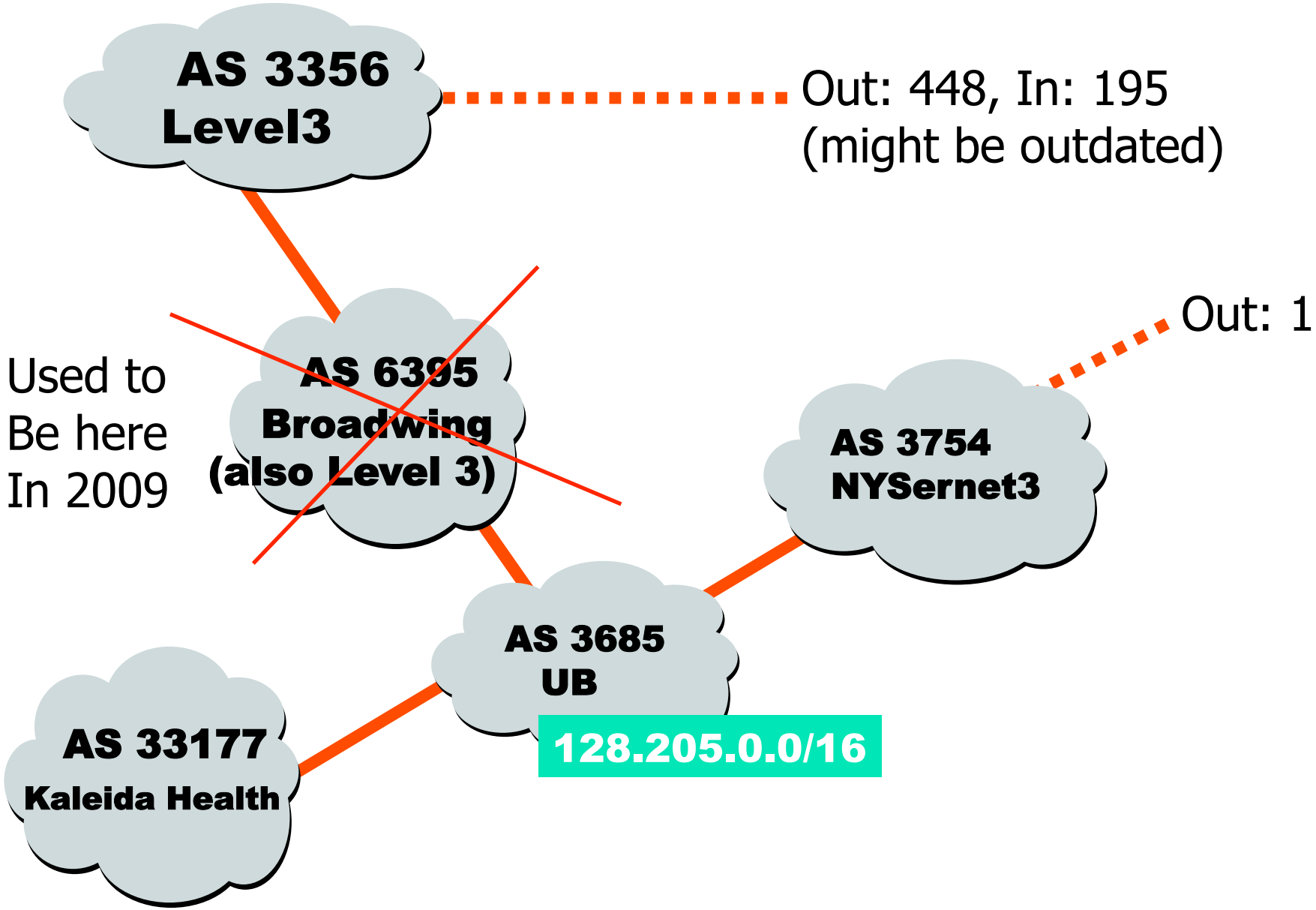
http://www.potaroo.net/tools/asns/

Examples of AS Numbers

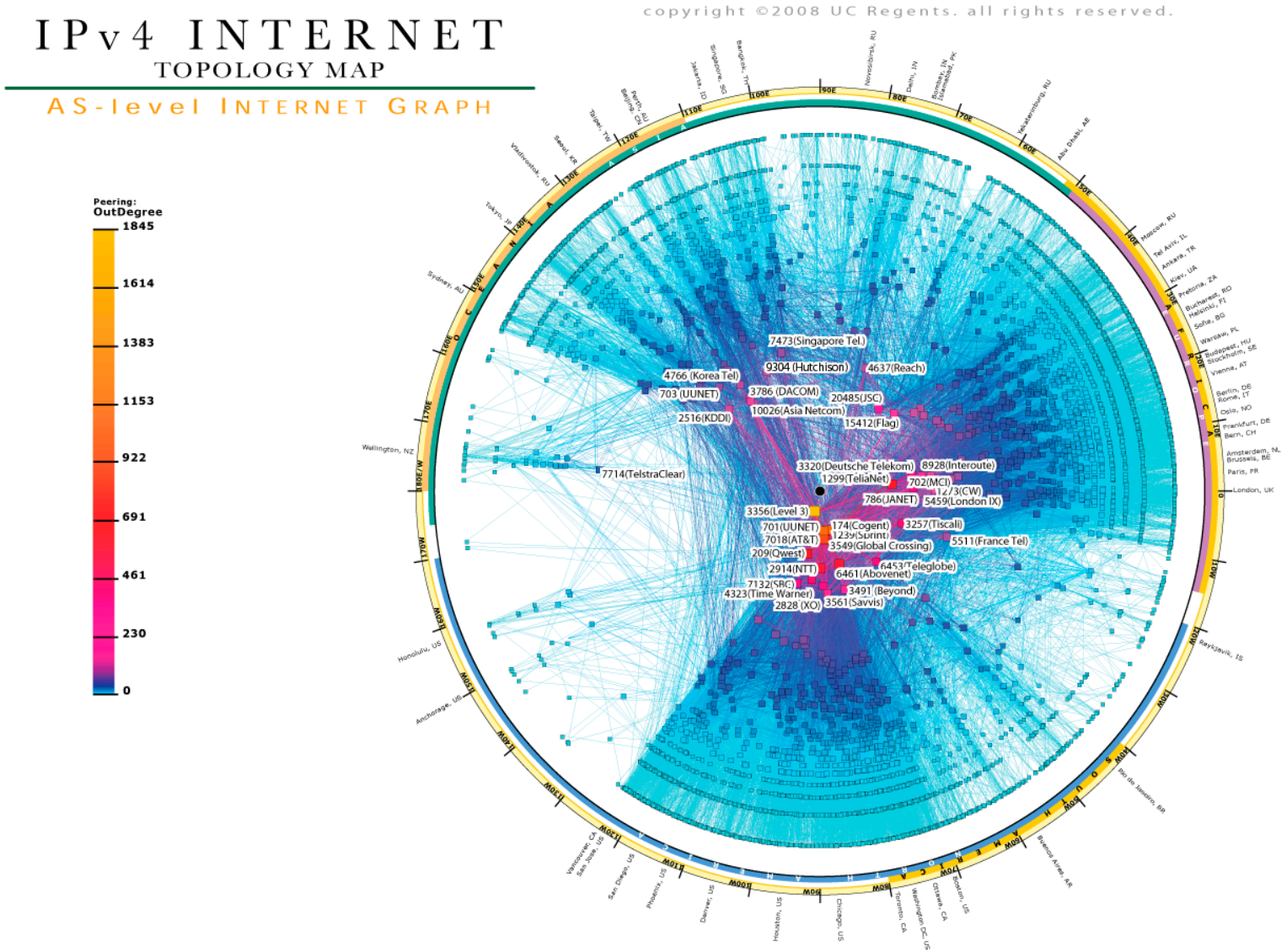
Currently almost 50,000 in use. (Running out!)

- LVLT-1 - Level 3 Communications, Inc.: 1
- MIT: 3
- Harvard: 11
- AT&T: 7018, 5075, …, 6341, …
- UUNET (i.e. MCI, i.e. Verizon): 702, 284, 12199, …
- Sprint: 1239, 1240, 6211, 6242, …
- University at Buffalo: **3685** (since 1994)
- …

Neighborhood of UB's Network (Sep 2010)



AS-Level Internet Graph (2008)



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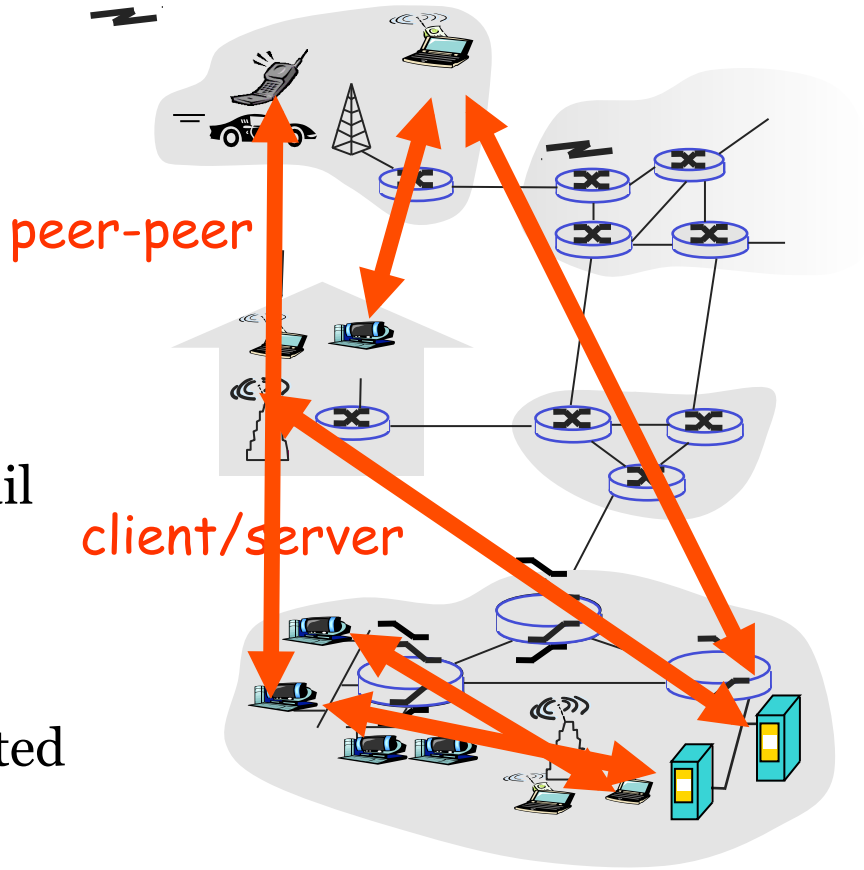
The Edge

- *End systems (hosts):*
  - run application programs
  - e.g. Web, email
  - at "edge of network"
- *Client/server model*
  - client host requests, receives service from always-on server
  - e.g. Web browser/server; email client/server
- *Peer-peer model:*
  - minimal (or no) use of dedicated servers
  - e.g. Skype, BitTorrent

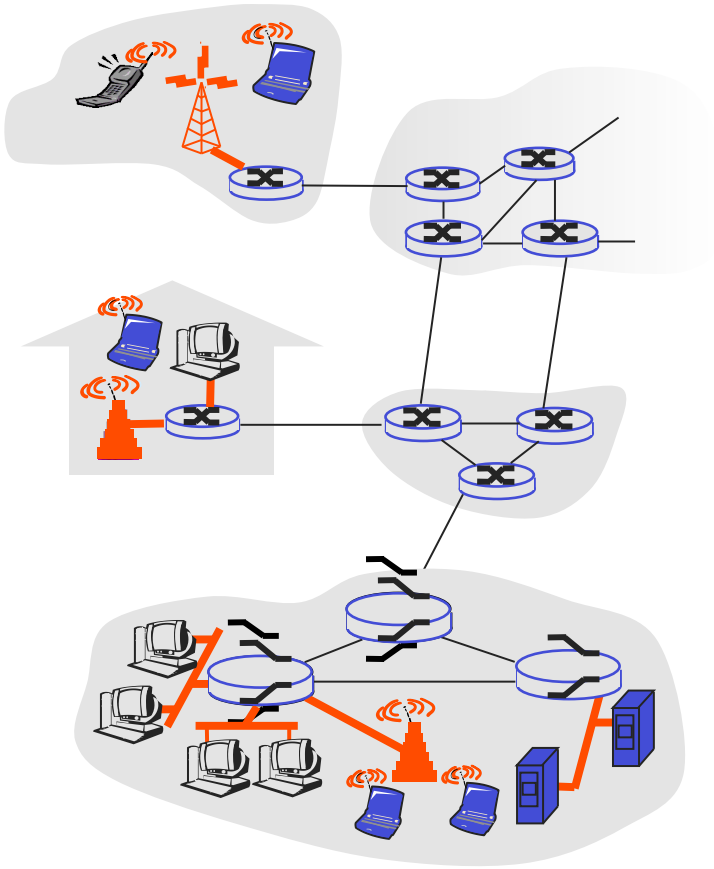


Access Networks

Q: How to connect end systems to edge router?

A: Typically 3 types of access networks

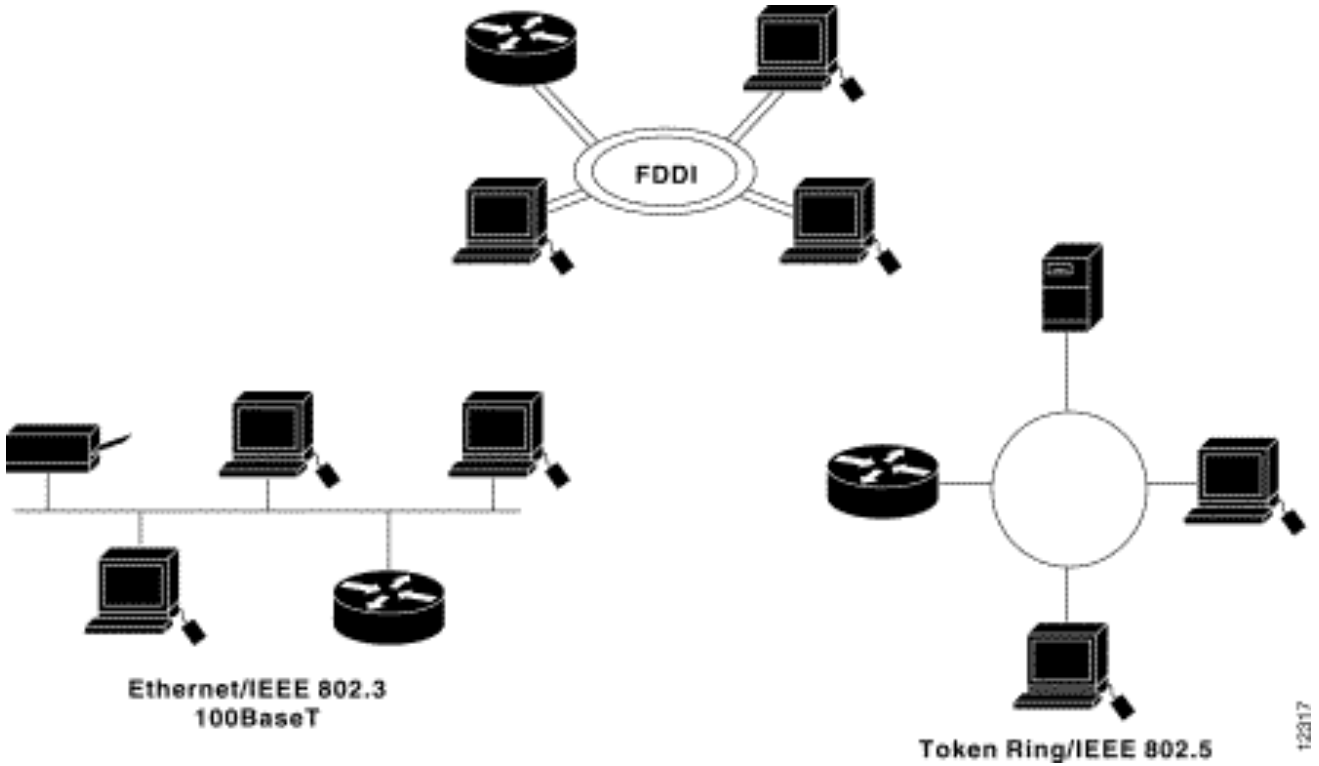
- Residential access networks
- Institutional access networks (school, company)
- Mobile access networks



Residential Access

- Over Ordinary Phone Lines:
  - Dialup Modems: up to 56kbps
  - ISDN (Integrated Services Digital Network): 128Kbps – full duplex
  - ADSL (Asymmetric Digital Subscriber Line): typically 640K - 1.5 Mbps for downloading
  - HDSL (High-bit-rate DSL): symmetric, 1.5 - 2 Mbps
  - BDSL (Broadband DSL): asymmetric, 12 Mbps - 52 Mbps
- Over Cable TV Networks:
  - HFC (Hybrid Fiber Coaxial Cable): bandwidth depends on the number of homes sharing the network, up to 30Mbps downstream, 2 Mbps upstream

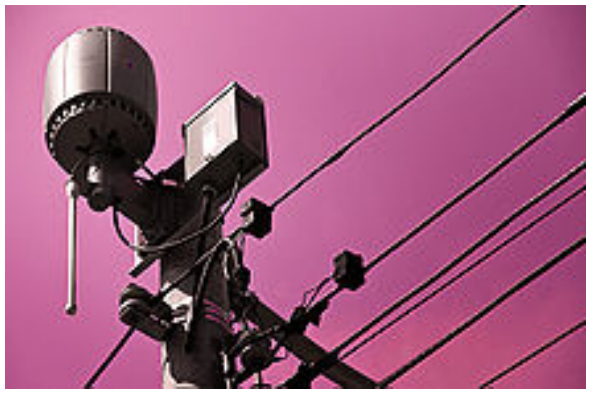
Institutional Access Networks



- Ethernet (IEEE 802.3): Fast-Ethernet, *Gigabit*-Ethernet, Switched-Ethernet
- Token Ring (IEEE 802.5)
- Fiber Distributed Data Interface (FDDI)

Wireless Access Networks

- Shared *wireless* access network connects end system to router
  - Via base station aka "access point"
- *Wireless LANs:*
  - 802.11b/g/n (WiFi): 11/54/400 Mbps
  - Municipal wireless networks (Sunnyvale, CA, was the first)
- *Wider-area wireless access*
  - Provided by telco operator
  - ~1Mbps over cellular system (EVDO, HSDPA)
  - Next up (?): WiMAX (10's Mbps) over wide area



802.11b/g AP
~ $70

802.11n AP
~ $150

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Physical Links

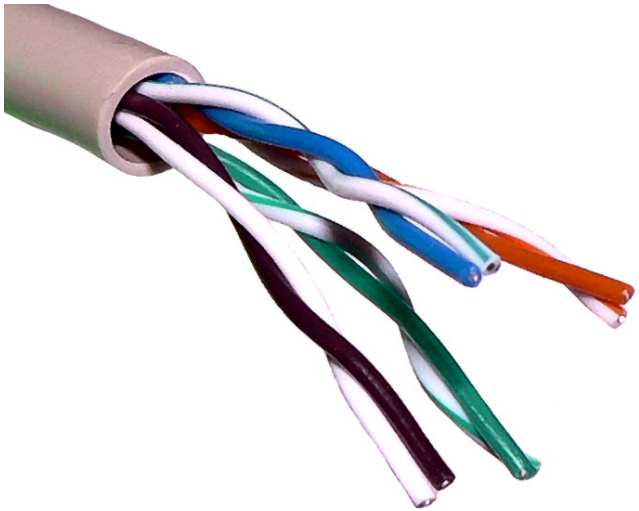
- Physical link: what lies between transmitter & receiver
- Bit: propagates between transmitter/receiver pairs

Two main types of media

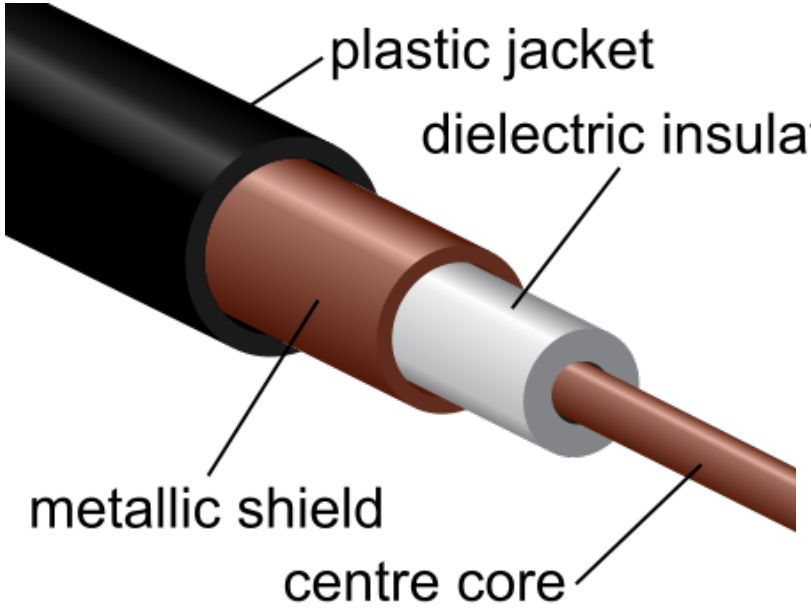
- Guided media: signals propagate in solid media, e.g., copper, fiber, coax
- Unguided media: signals propagate freely through the air (or vacuum), e.g., radio signals or light

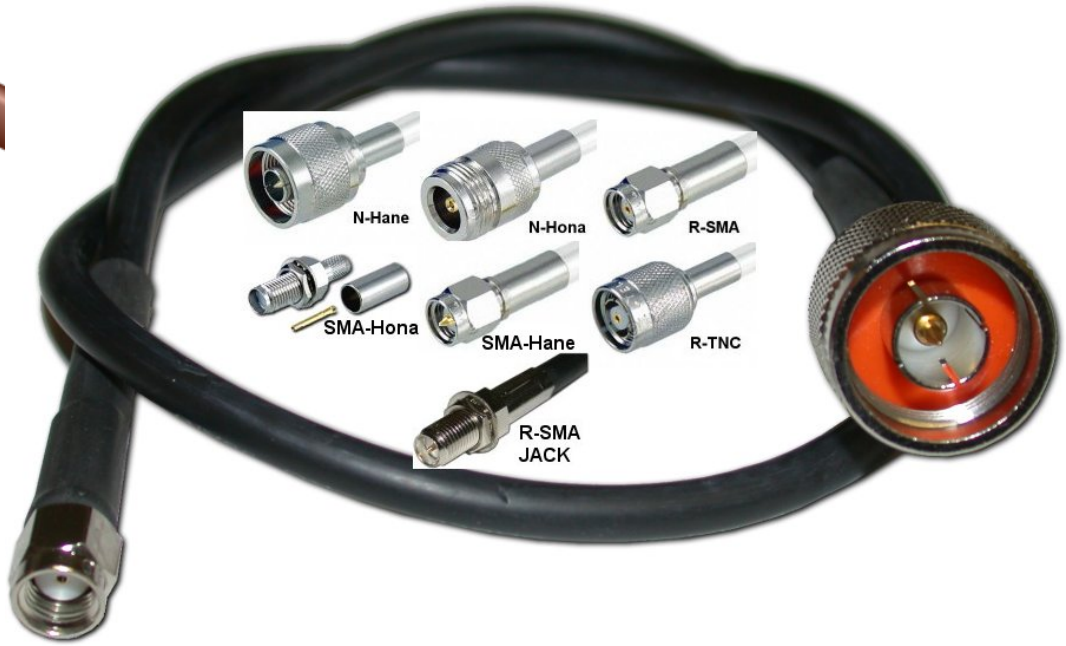
Guided Media: Twisted Pair

- Twisted pair:
  - A type of cabling used for telephone communications and most Ethernets
  - Cable pairs are twisted to reduce crosstalk and interference; Cat3: phone and 10Mbps Ethernets; Cat5: 100Mbps Ethernets

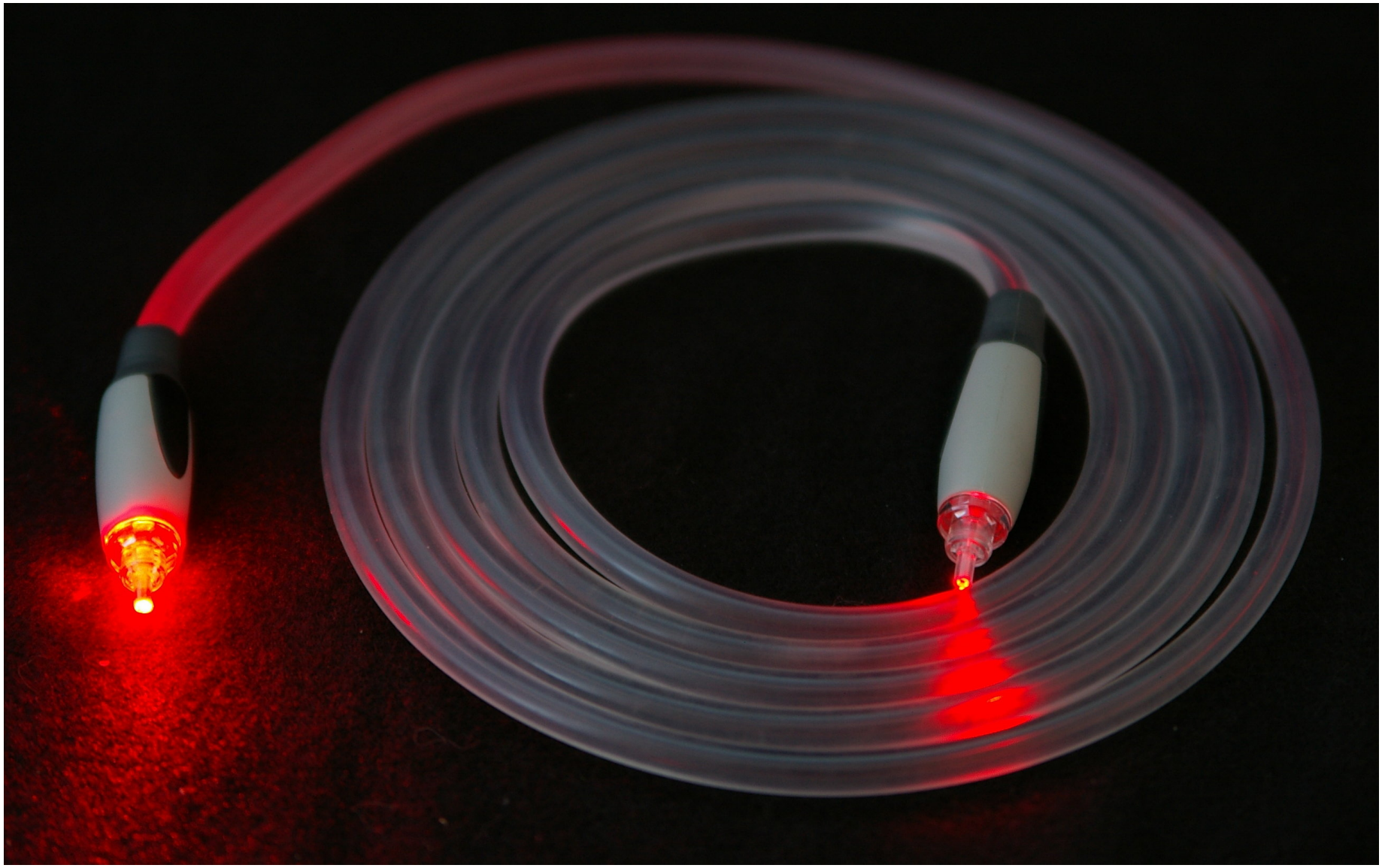


Guided Media: Coaxial Cable





Guided Media: Optical Fiber



Optical Fiber

Unguided Media

- Signal carried in EM spectrum
- No physical "wire"
- Often bidirectional
- Propagation environment effects:
  - reflection
  - obstruction by objects
  - interference

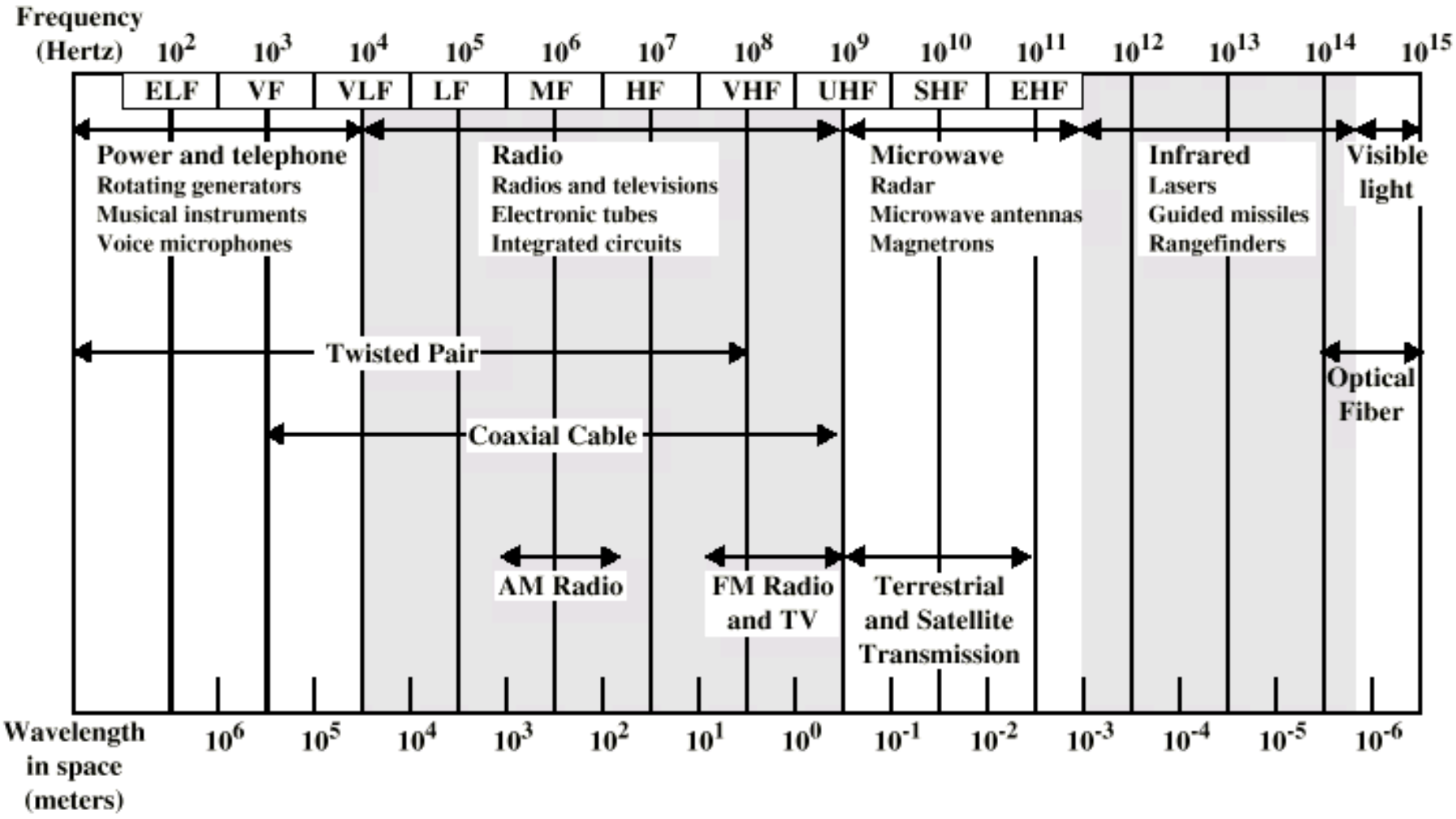
Many radio link types:

- Terrestrial microwave
  - e.g. up to 45 Mbps channels
- LAN (e.g., Wifi)
  - 11Mbps, 54 Mbps, 400Mbps
- Wide-area (e.g., cellular)
  - 3G cellular: ~ 1 Mbps
- Satellite
  - Kbps to 45Mbps channel (or multiple smaller channels)
  - 270 msec end-end delay
  - geosynchronous versus low altitude

Data Rate vs Bandwidth

- Any transmission system has a limited band of frequencies
  - Physical properties of the medium cut off higher frequency components
- The width of the band limits the data rate that can be carried on the medium
  - Depends on the ability of receivers to discern the difference between 0 and 1 in the presence of noise and other impairments
  - Data rate also depends also on the coding scheme
- Many people (and books) use bandwidth to mean data rate

EM Spectrum



ELF = Extremely low frequency
VF = Voice frequency
VLF = Very low frequency
LF = Low frequency
MF = Medium frequency
HF = High frequency
VHF = Very high frequency
UHF = Ultrahigh frequency
SHF = Superhigh frequency
EHF = Extremely high frequency