

# Last Lecture

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

# This Lecture

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## Nuts-and-bolts description of the Internet

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

# A illustrative slice of the Internet

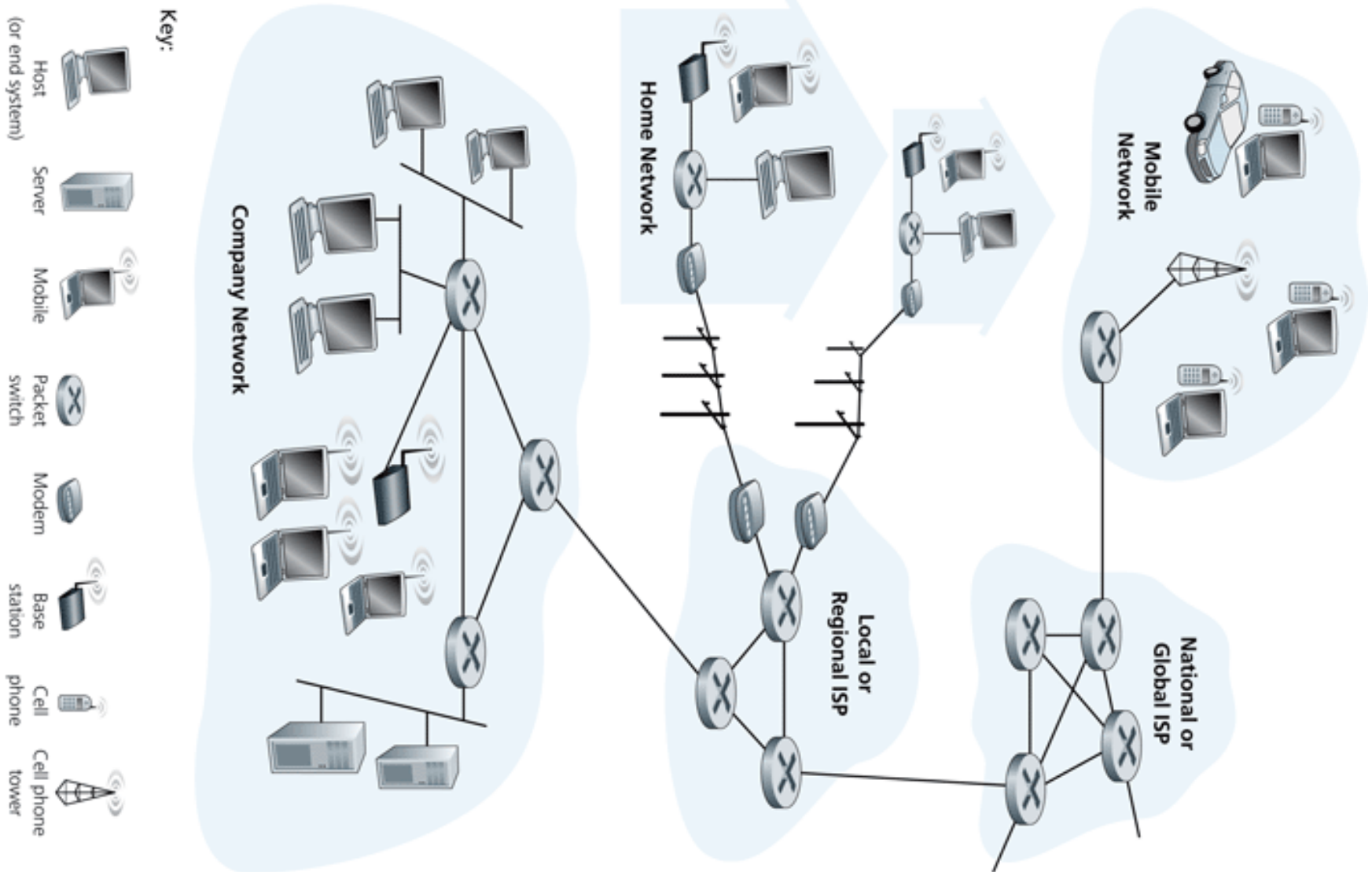


Figure 1.1 ♦ Some pieces of the Internet

# The Core and the Edge Nodes

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

# This Lecture

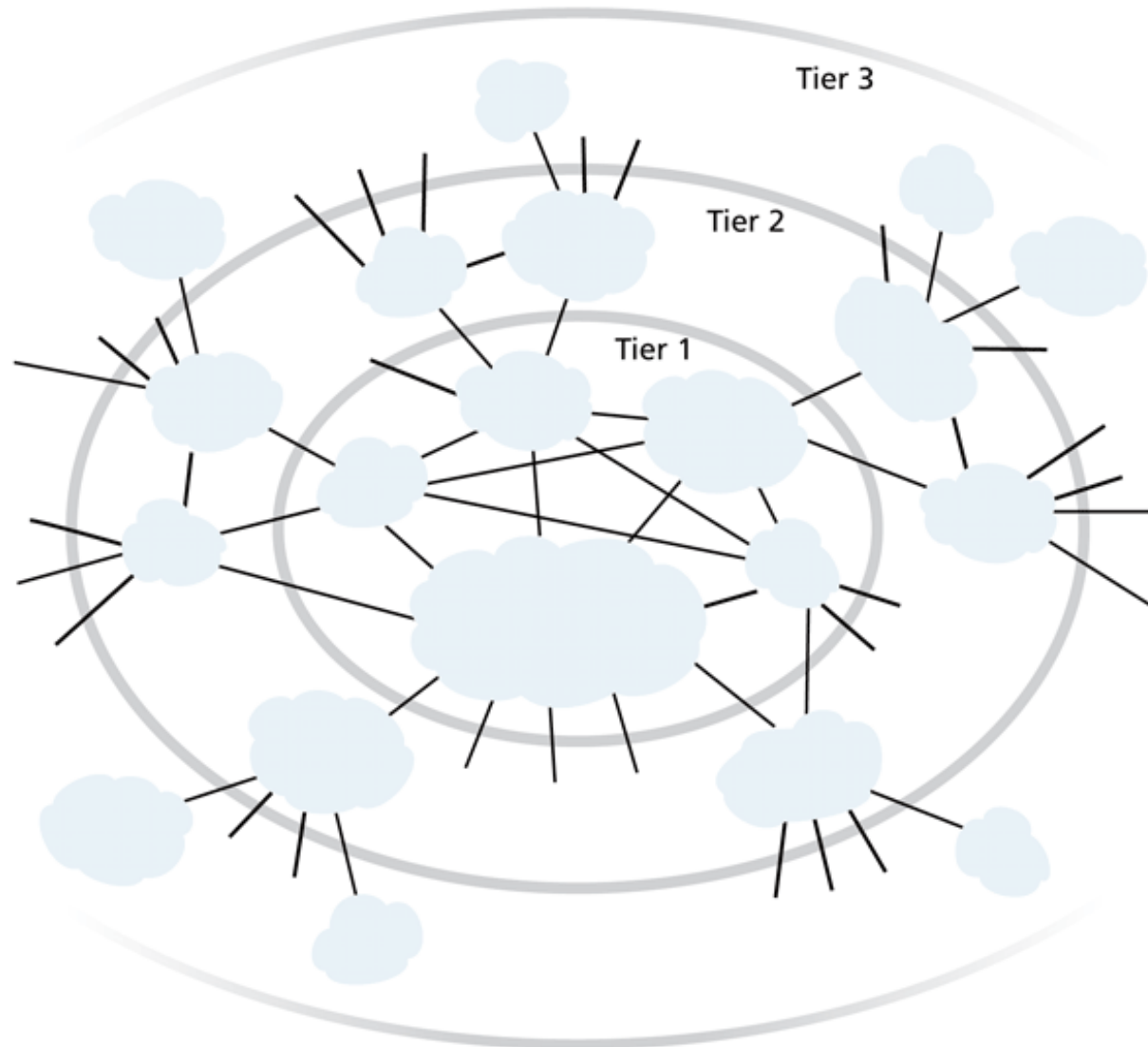
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## Nuts-and-bolts description of the Internet

- The topology
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# The Core: ISPs' Networks are Interconnected

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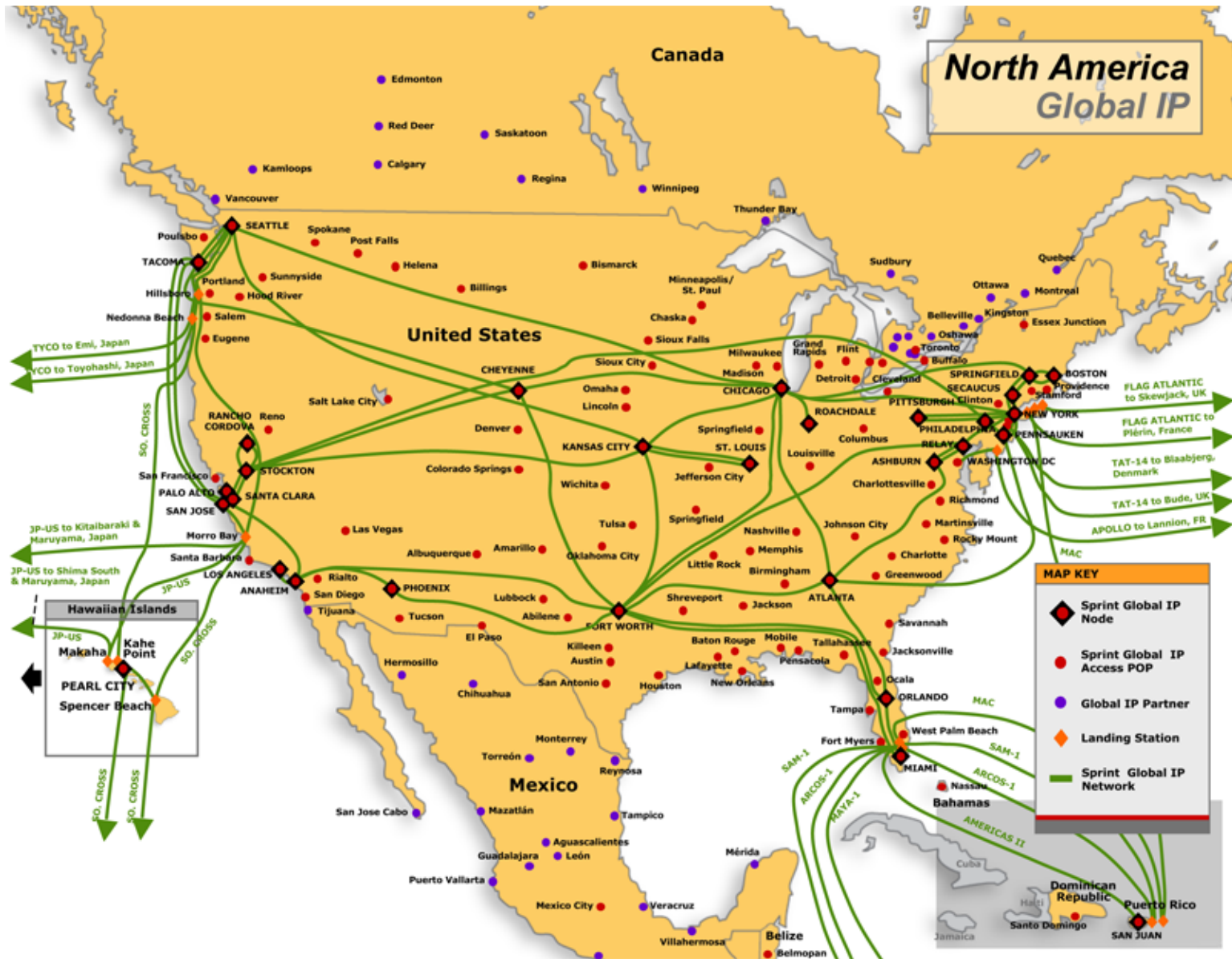
**Figure 1.11** ♦ Interconnection of ISPs

# Tier 1 ISPs' Networks

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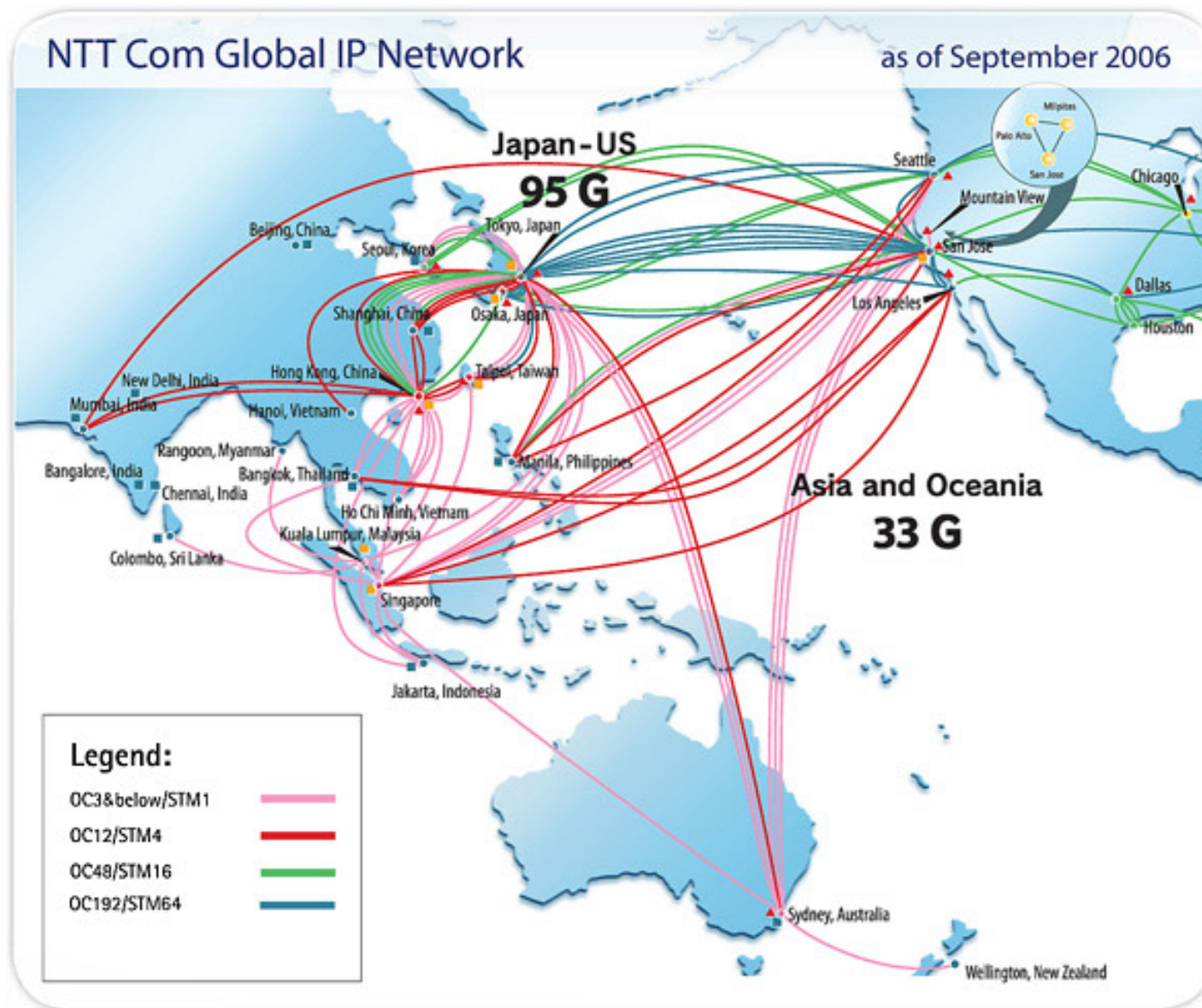
- Also called *Internet backbone networks*
- Unofficially, the following are tier 1 ISPs
  - *Sprint*
  - *Verizon business* (acquired UUNet/(MCI) Worldcom)
  - *AT&T*
  - *Level 3*
  - *Qwest*
  - *NTT communications*
  - *Global Crossing*
  - *SAVVIS*
  - *TeliaSonera*
  - *Tata communications*

# Sprint's North America IP Network

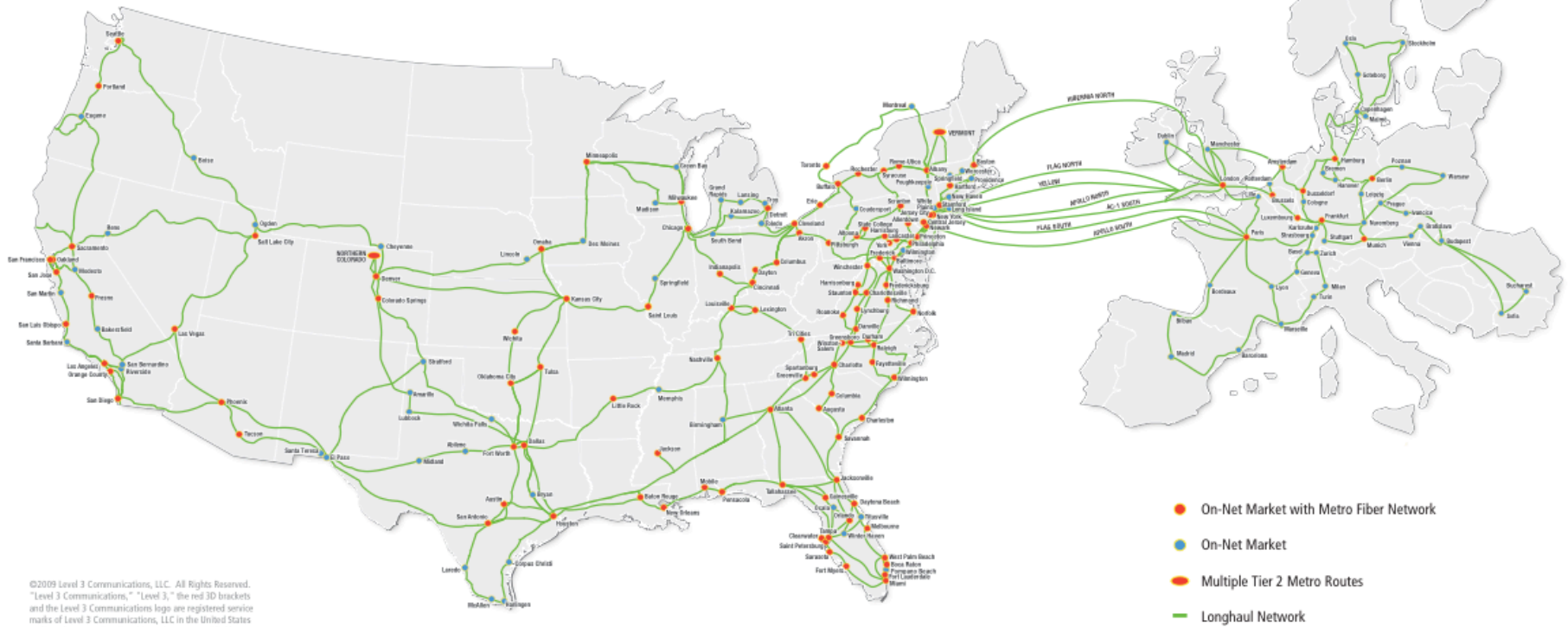




# NTT's Global IP Network



# The Level 3 Network



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# The Internet's Undersea World

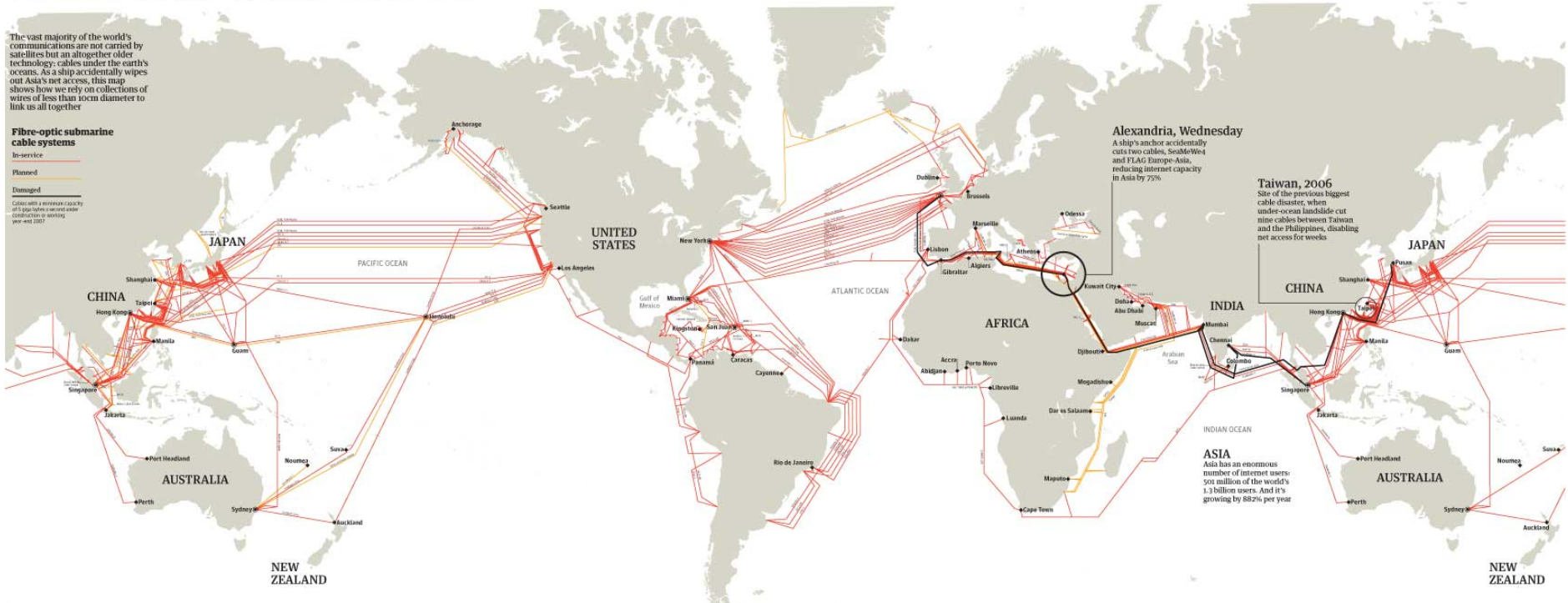
## The internet's undersea world

The vast majority of the world's communications are not carried by satellites but an altogether older technology, cables under the earth's oceans. As a ship accidentally wipes out Asia's net access, this map shows how we rely on collections of wires of less than 1cm diameter to link us all together

**Fibre-optic submarine cable systems**

- In-service
- Planned
- Damaged

Capacities in terabits per second (Tbps) as of 2007

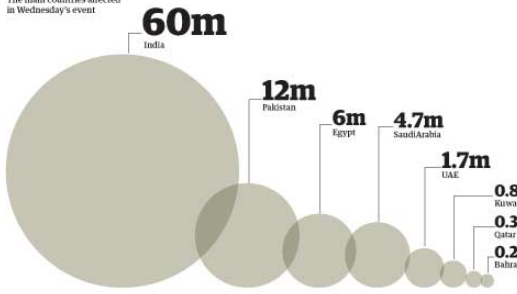


**Alexandria, Wednesday**  
A ship's anchor accidentally cuts two cables, SeacomW4 and FLAG Europe-Asia, reducing internet capacity in Asia by 70%.

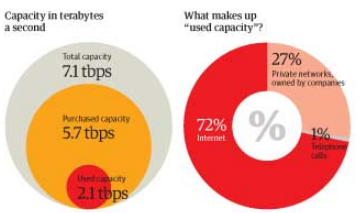
**Taiwan, 2006**  
Site of the previous biggest cable disaster, when under-ocean landslide cut nine cables between Taiwan and the Philippines, disabling net access for weeks

**ASIA**  
Asia has an enormous number of internet users: 500 million of the world's 1.3 billion users. And it's growing by 88% per year

**Internet users affected by the Alexandria accident**  
The main countries affected in Wednesday's event



**World cable capacity**  
Submarine cable operators light (turn on) capacity on their systems to sell bandwidth to other carriers. Carriers buy extra capacity, mainly to hold in reserve. On the trans-Atlantic route 80% of the bandwidth is purchased, but only 20% is used



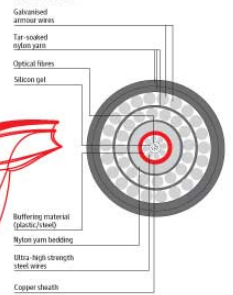
**The longest submarine cables**  
The SeacomW-3 system from Norden in Germany to Keeloo, South Korea connects 32 different countries with 39 landing points

Cable System	Length (km)
SeacomW-3	39,000
Southern Cross	30,500
China-US	30,476
FLAG Europe-Asia	28,000
South America-1	25,000

**The world's cables in bandwidth**  
The first intercontinental telephony submarine cable system, TAT-1, connected North America to Europe in 1956 and had an initial capacity of 640,000 bytes per second. Since then, total trans-Atlantic cable capacity has soared to over 7 trillion bps

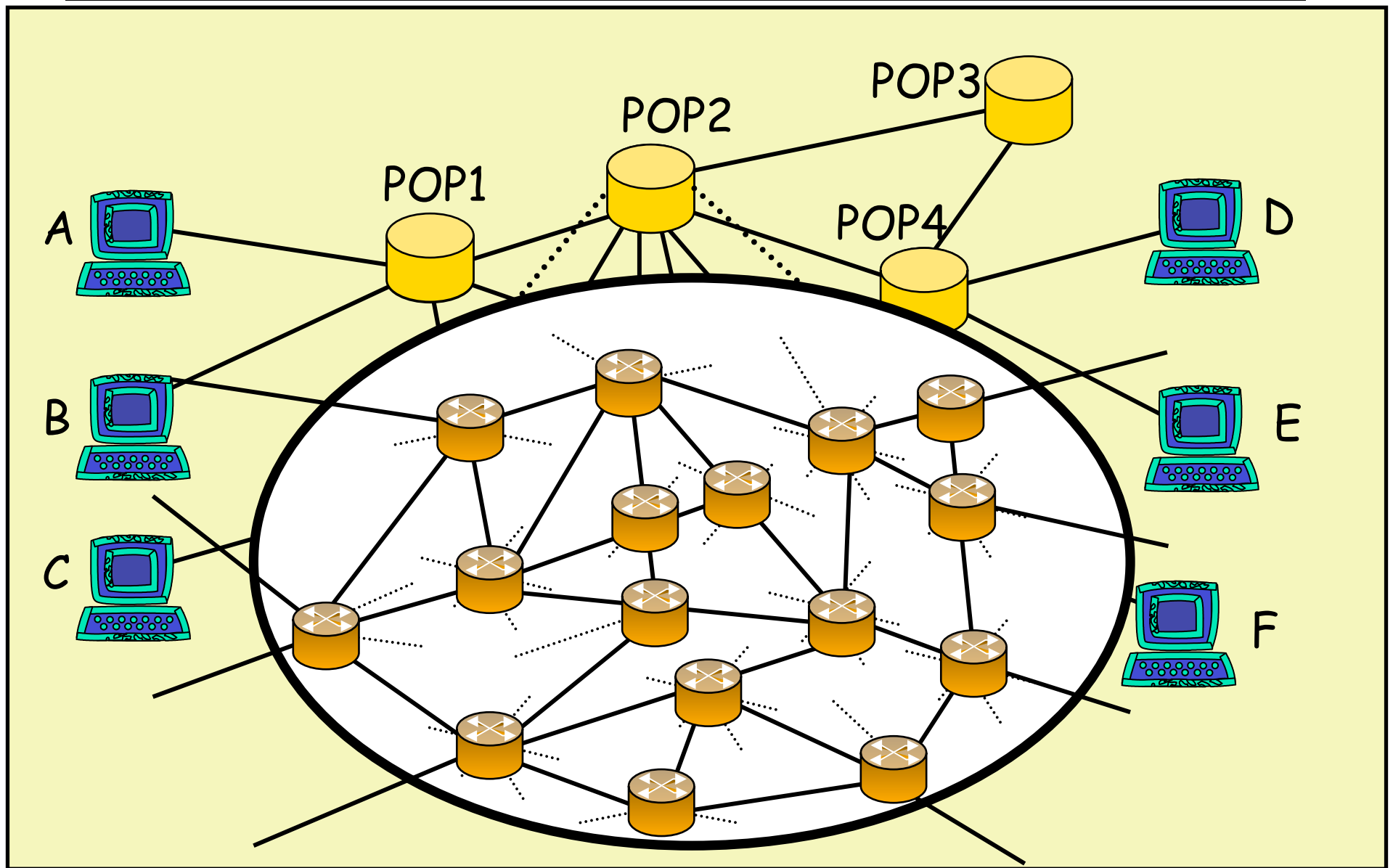


**Cross-section of a cable**  
Cables of this strength are typically 69 mm in diameter and weigh over 10,000 kilograms a kilometer. In deeper waters, lighter and less insulated cables are used

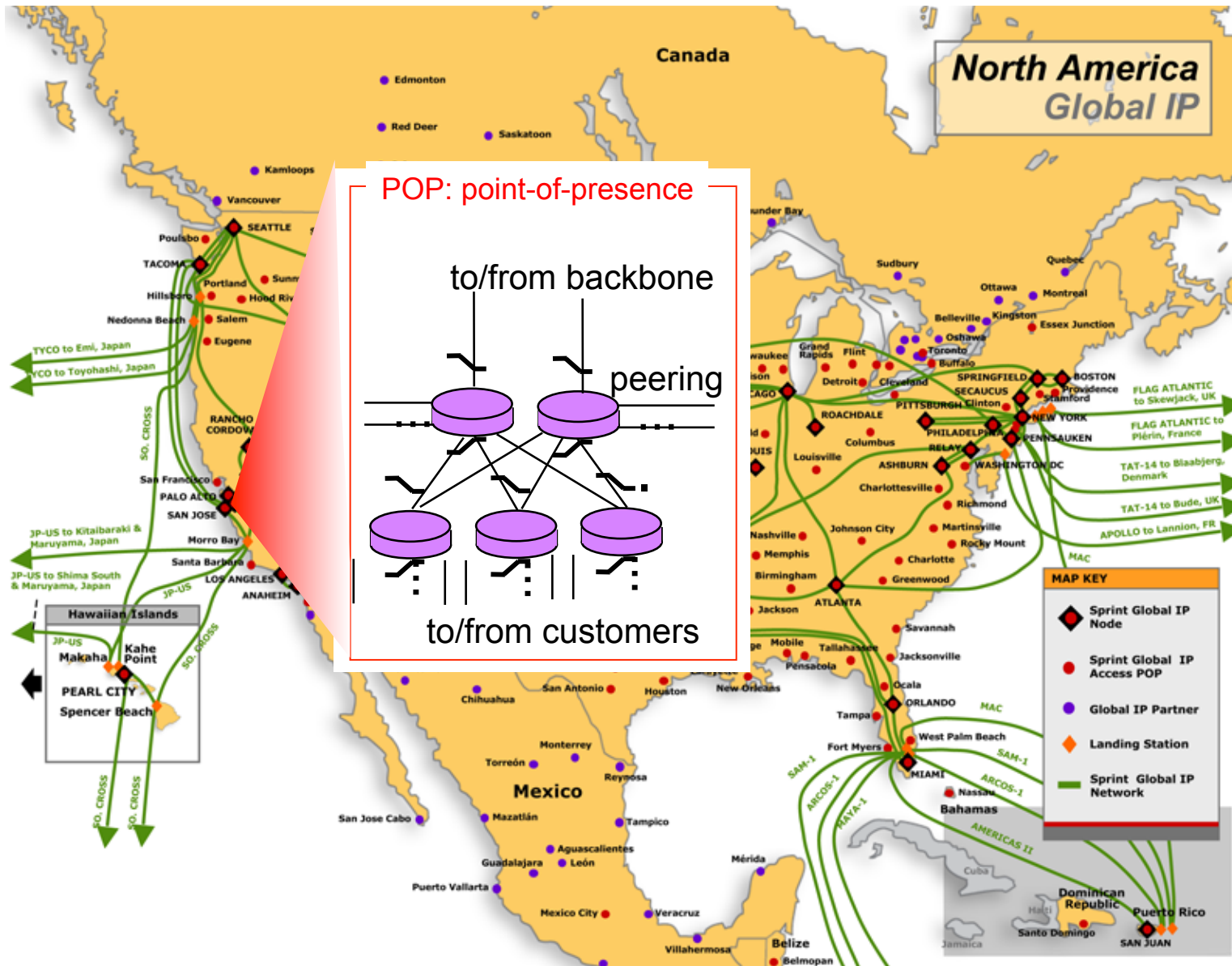


<http://www.youtube.com/watch?v=v1JEuzBkOD8>

# Routers and POPs



# Sprint's North America IP Network



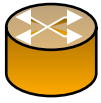
# POPs reside in buildings like this London IXP

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# Internet Core Routers Look Like These

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Router on  
“paper”

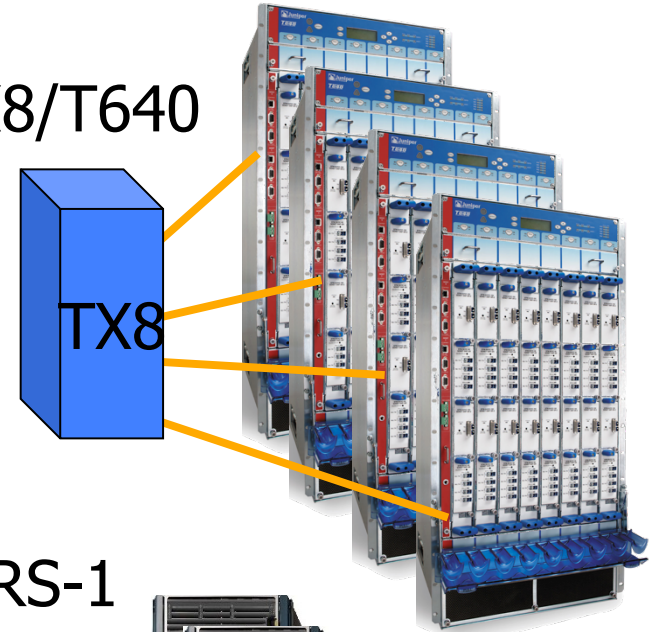


# More Internet Core Routers

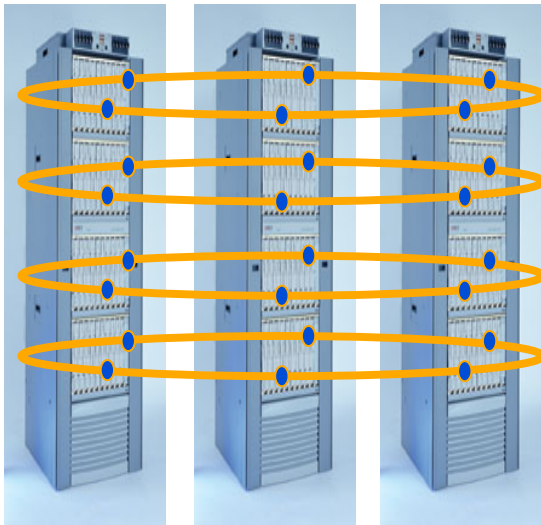
Alcatel 7670 RSP



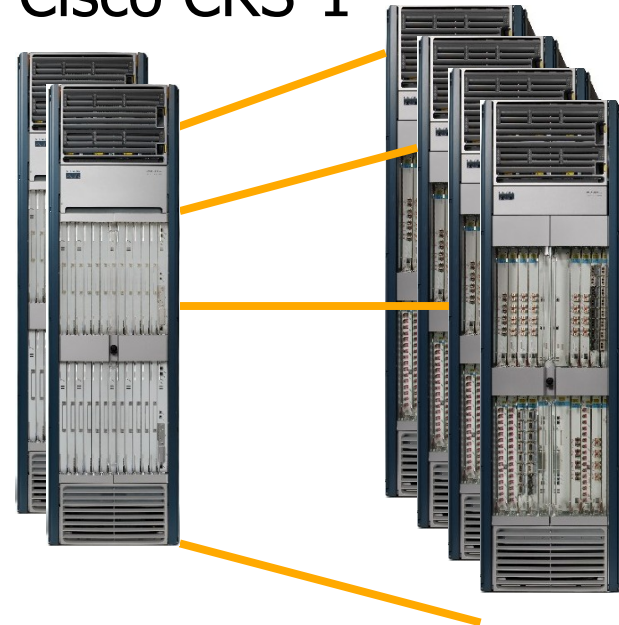
Juniper TX8/T640



Avici TSR



Cisco CRS-1

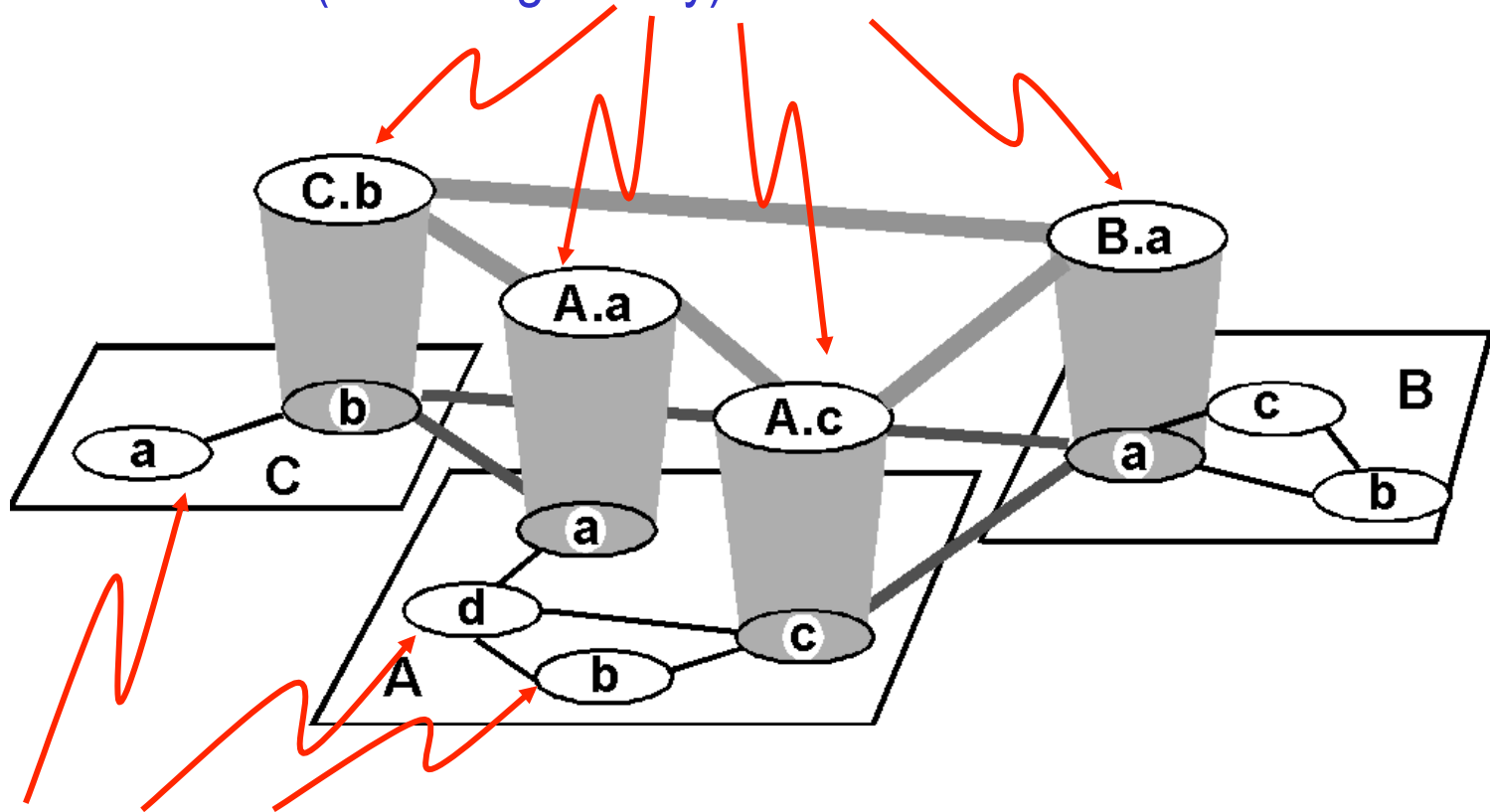




# Autonomous Systems (AS)

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Intra-AS border (exterior gateway) routers



Inter-AS interior (gateway) routers

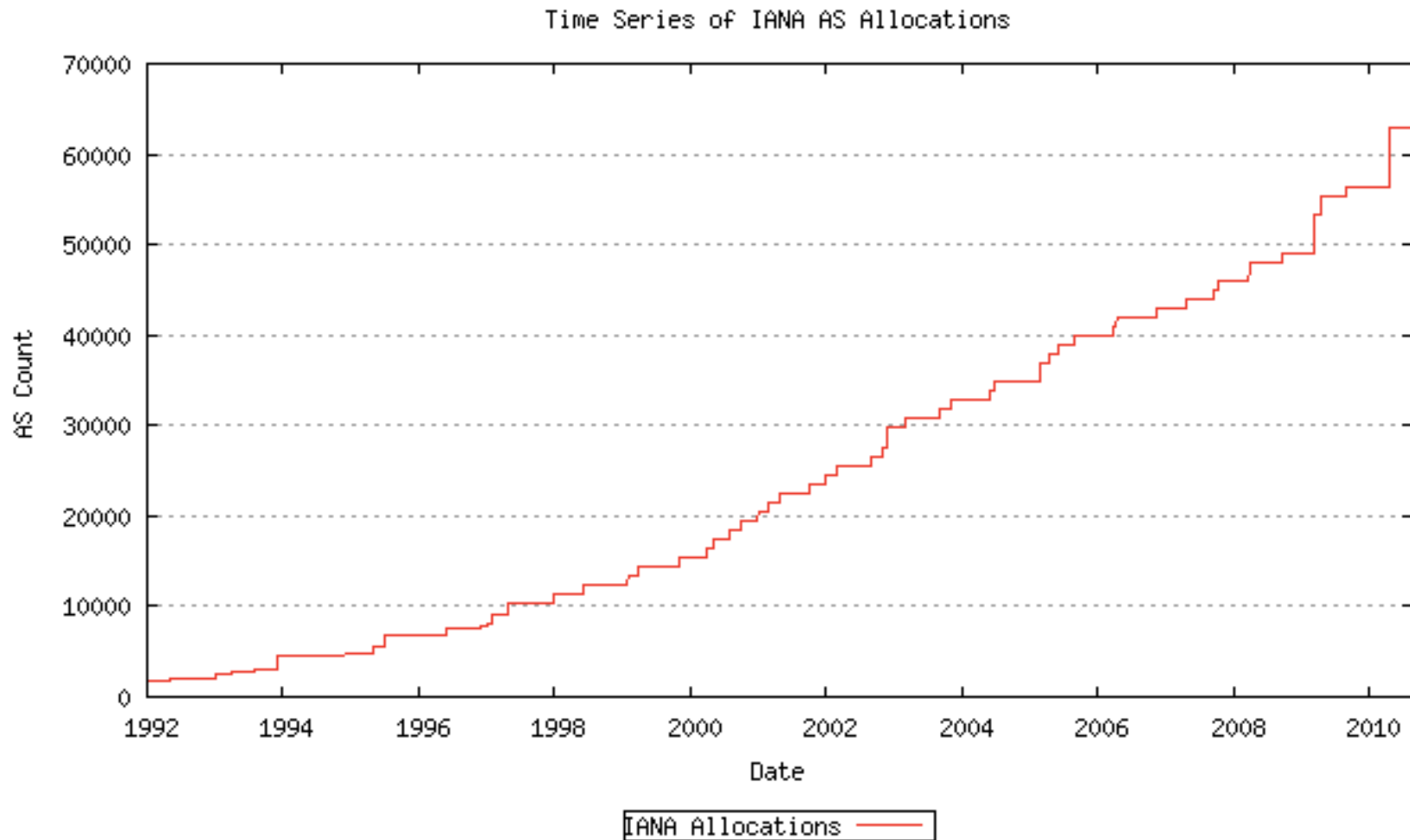
# AS and AS Numbers

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- 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

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

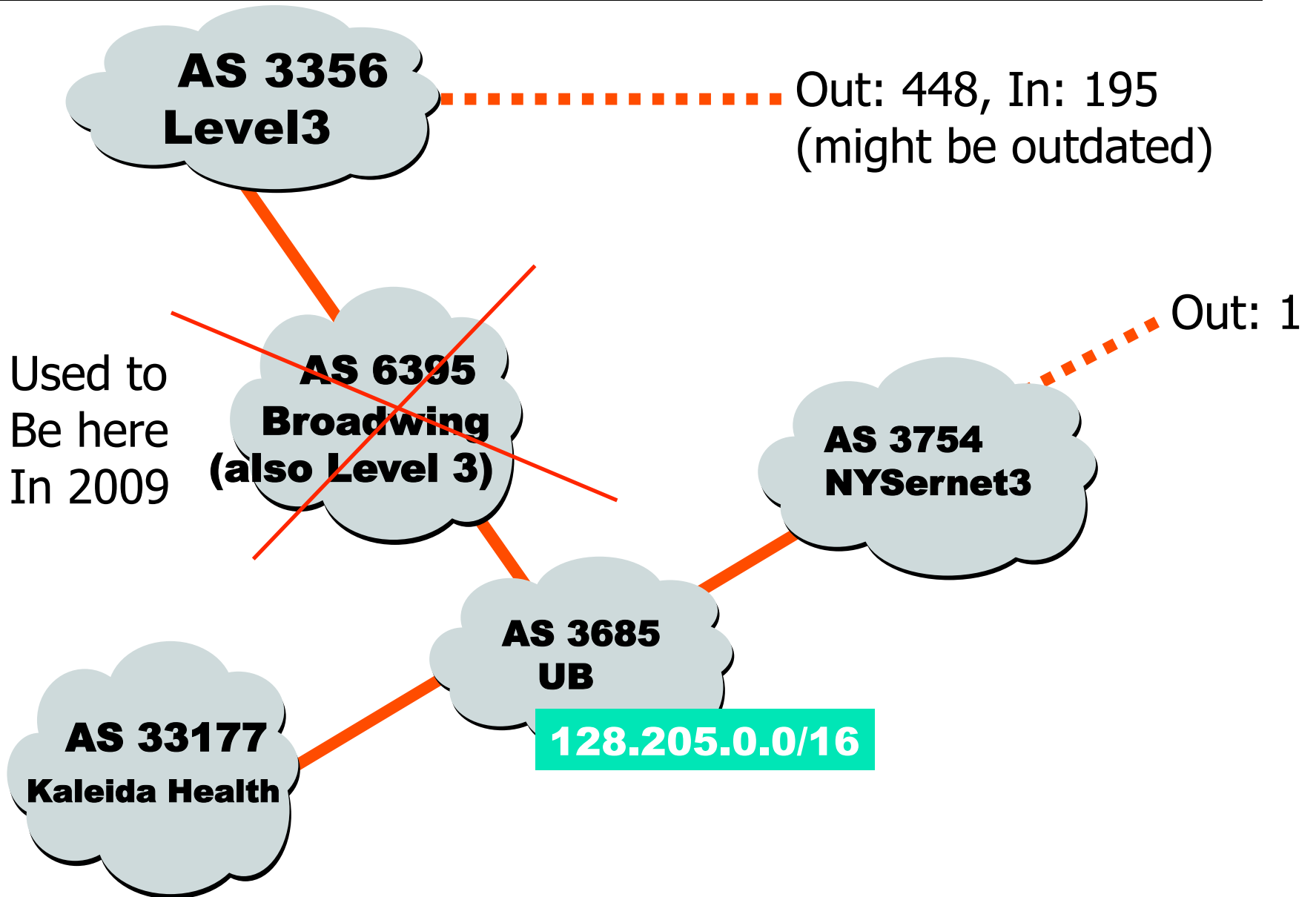
# Examples of AS Numbers

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

- LVL1-1 - 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)
- ...

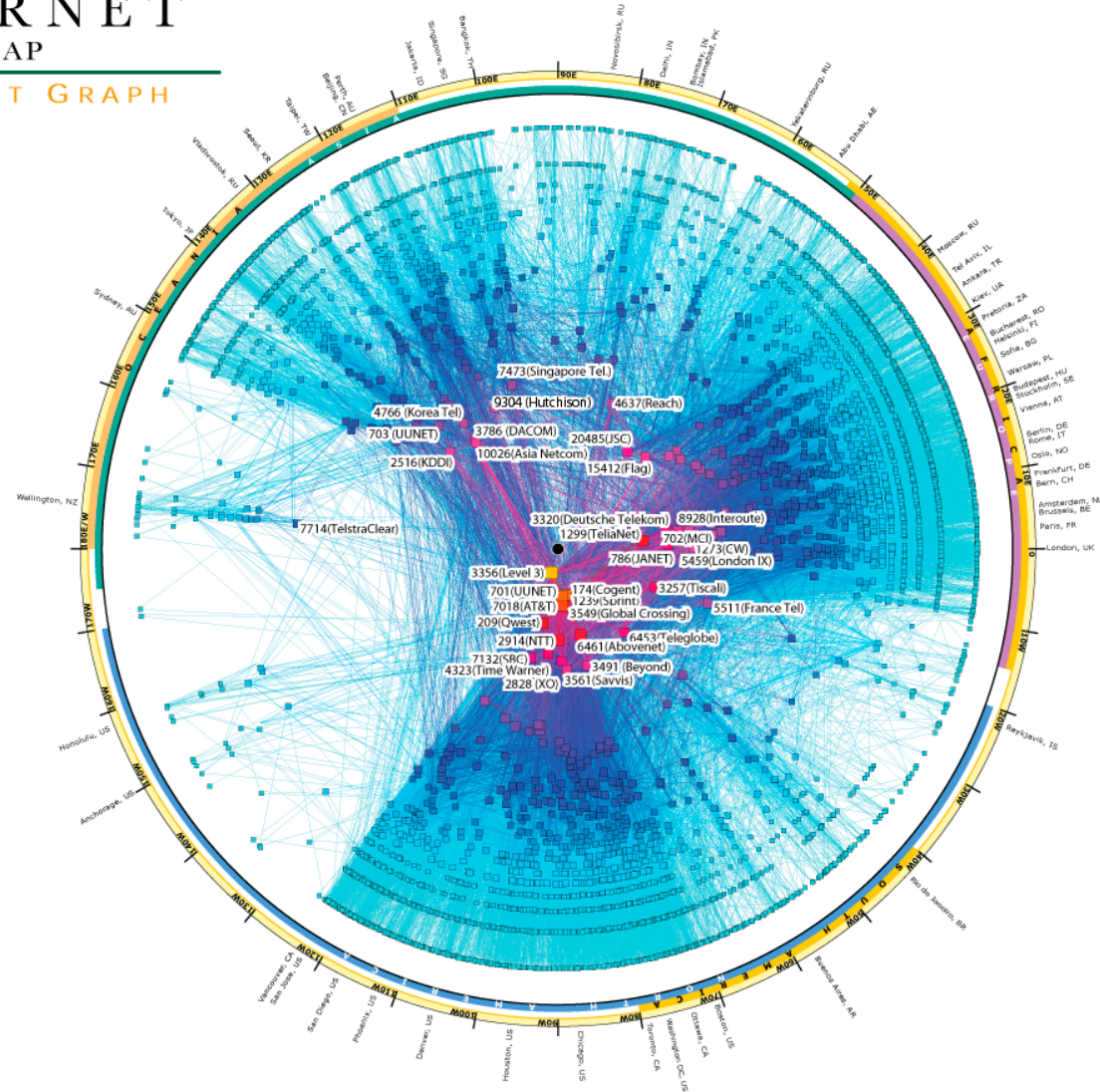
# Neighborhood of UB's Network (Sep 2010)



# AS-Level Internet Graph (2008)

## IP<sub>v</sub>4 INTERNET TOPOLOGY MAP AS-level INTERNET GRAPH

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# This Lecture

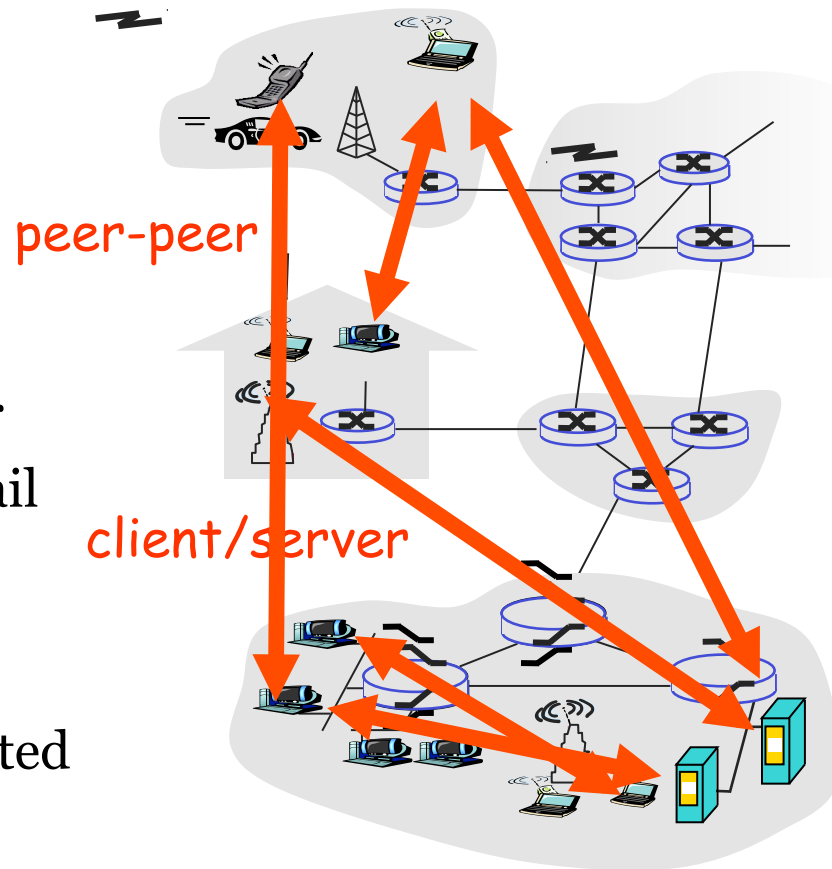
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## Nuts-and-bolts description of the Internet

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

# 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





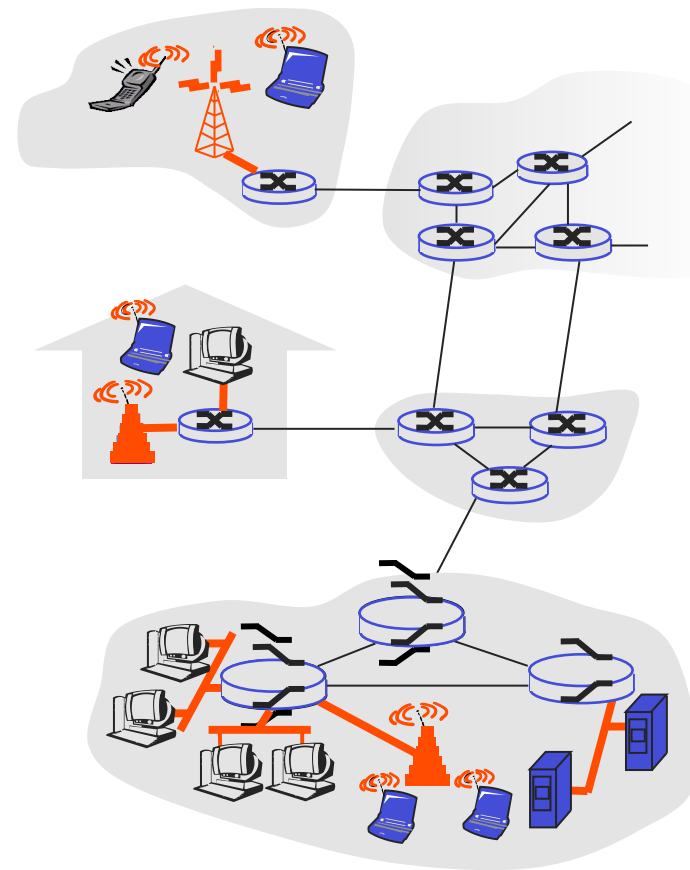
# Access Networks

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*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



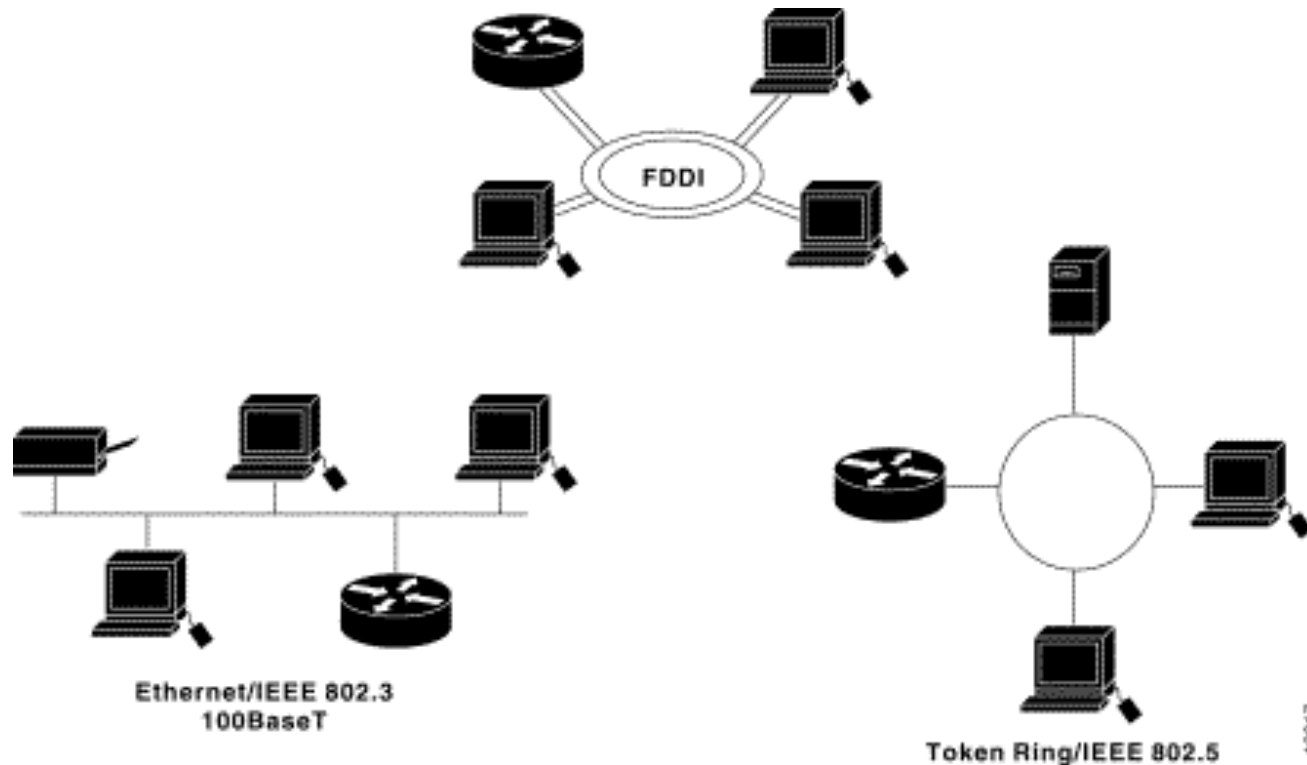
# Residential Access

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- 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

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

# Wireless Access Networks

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- 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

# This Lecture

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## Nuts-and-bolts description of the Internet

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

# Physical Links

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

Two main types of media

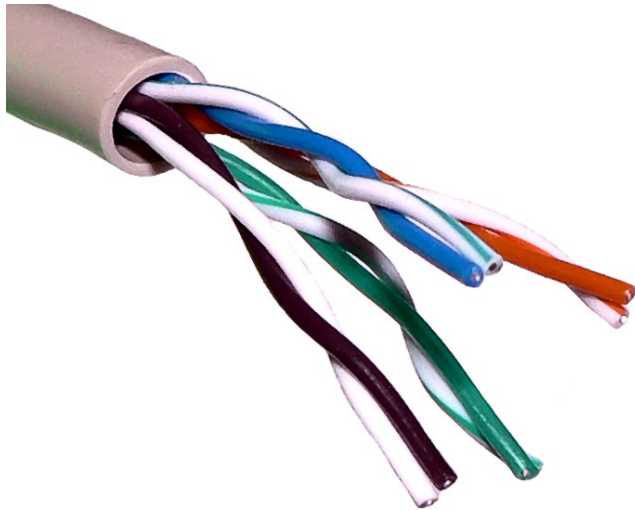
- **Guided media:** signals propagate in solid media, e.g., copper, fiber, coax
- **Unguided media:** signals propagate freely through the air (or vacuum), e.g., radio signals or light

# Guided Media: Twisted Pair

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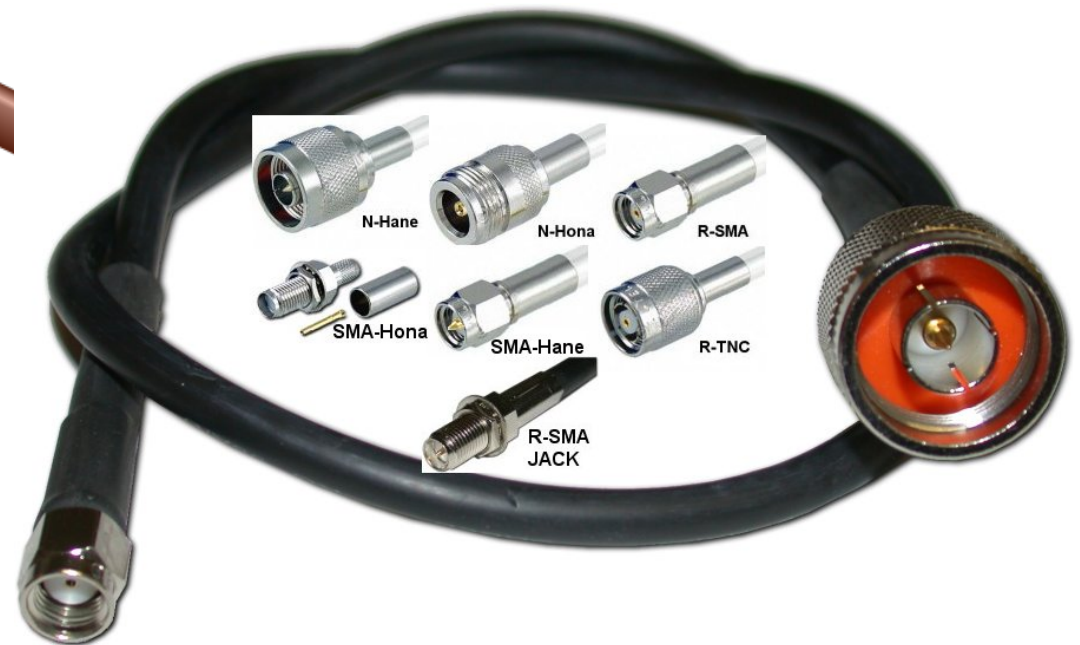
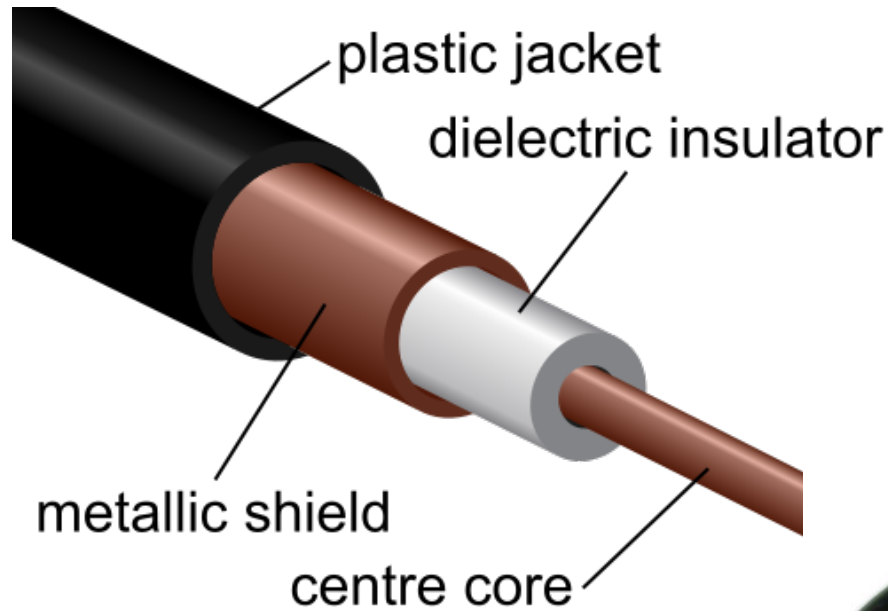
## ■ Twisted pair:

- 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

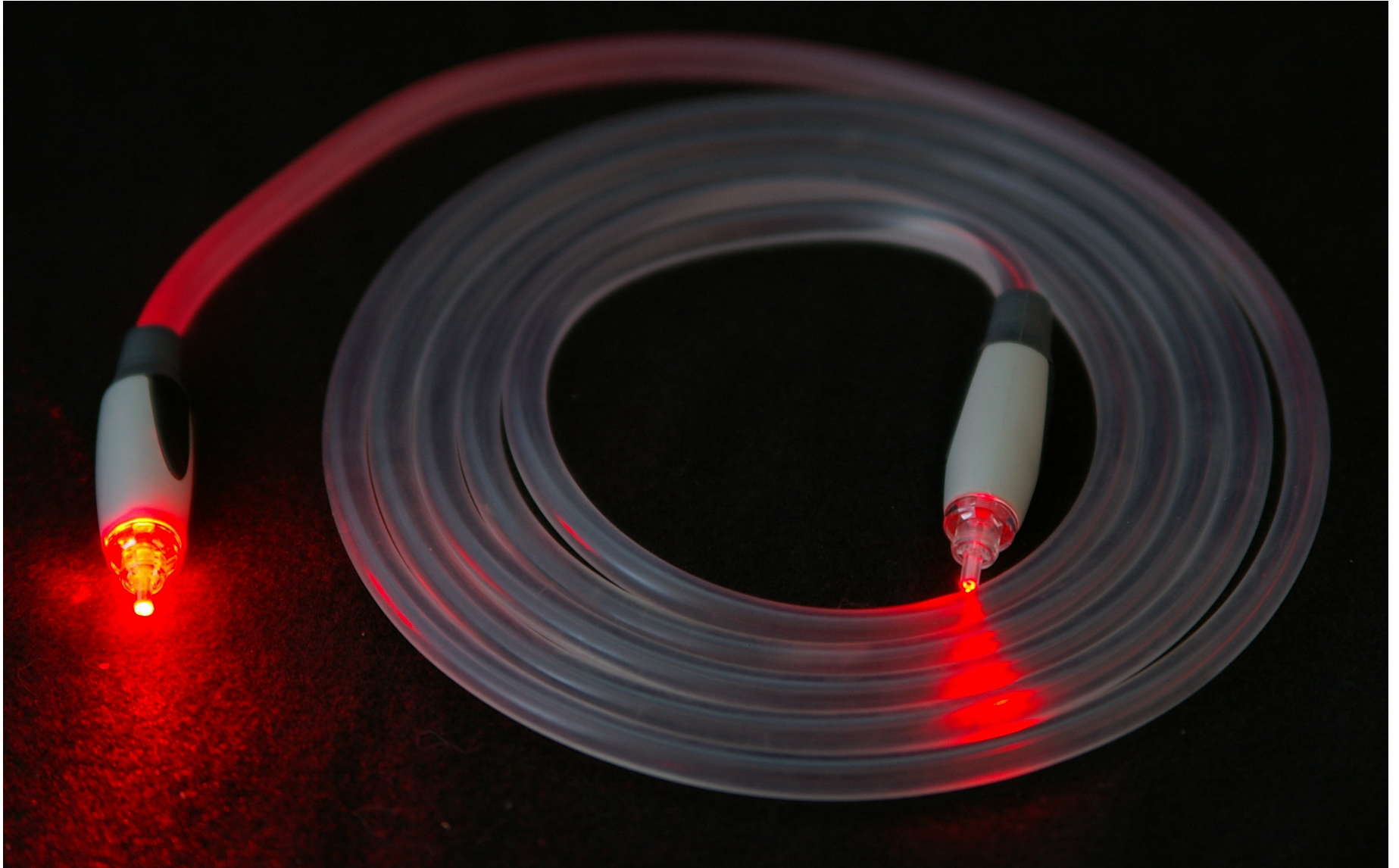
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# Guided Media: Optical Fiber

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# Optical Fiber

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# Unguided Media

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

## Many radio link types:

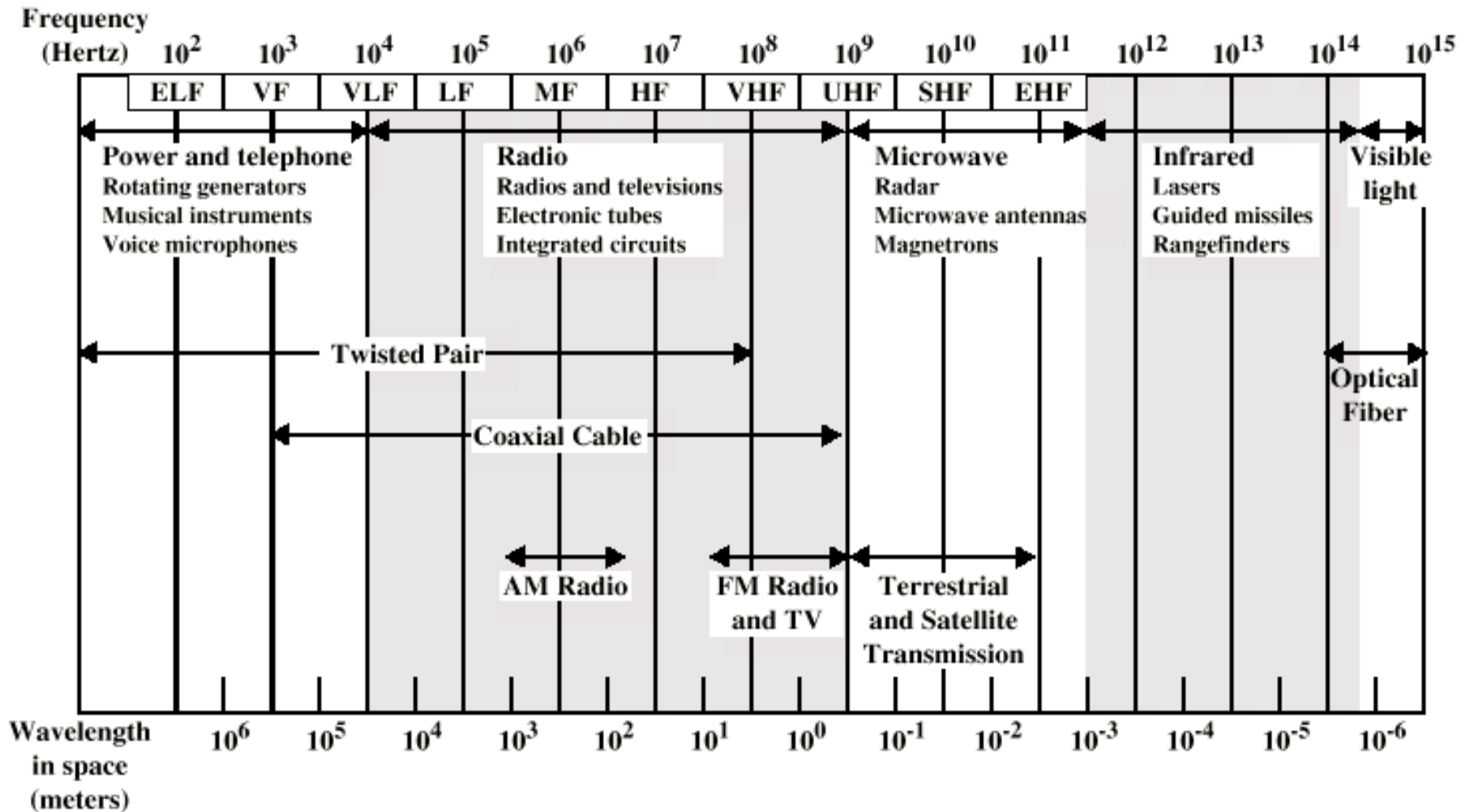
- **Terrestrial microwave**
  - e.g. up to 45 Mbps channels
- **LAN** (e.g., Wifi)
  - 11Mbps, 54 Mbps, 400Mbps
- **Wide-area** (e.g., cellular)
  - 3G cellular: ~ 1 Mbps
- **Satellite**
  - Kbps to 45Mbps channel (or multiple smaller channels)
  - 270 msec end-end delay
  - geosynchronous versus low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

# Data Rate vs Bandwidth

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- 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