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
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
The Internet’s Undersea World

http://www.youtube.com/watch?v=v1JEuzBkOD8
Routers and POPs
Sprint’s North America IP Network

POP: point-of-presence

to/from backbone

peering

to/from customers
POPs reside in buildings like this London IXP
Internet Core Routers Look Like These

Router on "paper"
More Internet Core Routers

- Alcatel 7670 RSP
- Avici TSR
- Juniper TX8/T640
- Cisco CRS-1
Intra-AS border (exterior gateway) routers

Inter-AS interior (gateway) routers
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)
- ...

Currently almost 50,000 in use. (Running out!)
AS 3356
Level3
Out: 448, In: 195
(might be outdated)

AS 6395
Broadwing
(also Level 3)

AS 3754
NYSernet3
Out: 1

AS 3685
UB

128.205.0.0/16

AS 33177
Kaleida Health

SUNY AT BUFFALO; CSE489/589 – MODERN NETWORKING CONCEPTS; Fall 2010; INSTRUCTOR: HUNG Q. NGO
AS-Level Internet Graph (2008)
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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
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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Nuts-and-bolts description of the Internet

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- The physical communication links
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
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

plastic jacket

dielectric insulator

metallic shield

centre core
Guided Media: 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
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

Frequency (Hertz)

- 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

Wavelength in space (meters)

- Power and telephone
- Rotating generators
- Musical instruments
- Voice microphones
- Radio
- Radios and televisions
- Electronic tubes
- Integrated circuits
- Microwave
- Radar
- Microwave antennas
- Magnetrons
- Infrared
- Lasers
- Guided missiles
- Rangefinders
- Visible light
- Optical Fiber