2 Channel Capacity
- Some number of symbols per second (baud rate). Each symbol does not necessarily correspond to a bit.
- Nyquist: symbol rate = $2H$ sym/sec
  - $H$ bandwidth
- Shannon: data rate = $H \log(1+S/N)$ b/s
  - $S$ is signal power, $N$ is noise power

3 Some Comm Theory
- So, with Nyquist, we cannot hope to send binary data even over a noiseless 3-kHz channel at more than 6000 b/sec:
  - $2H = 2(3000) = 6000$ b/sec
- With Shannon, bit rate over an analog phone line is limited to about 30kb/s
  [assuming 30dB $S/N$ ratio]:
  - $H\log(1+S/N) = 3000\log(1 + 1000) = 30$kb/s

4 Transmission Time
5 Latency
- Slower channels "stretch out" bits in time:
  - a bit on a 1Mb/s link is 1 µsec wide
  - a bit on a 10Mb/s link is 0.1 µsec wide
- Total Latency = tx time + queue
  - transmit time = { last slide }
  - queue delay = { depends! }

6 Low Speed Links
- Small $R$ -> large $Tx$ Time ($M/R$)
- Ex: Dialup ($D = 10$ms, $R = 56$Kb/s)
  - $Tx$ Time = $0.010 + ((1024\times8)/(56\times1024)) = 0.153$ sec = $153$ msec (1KB msg@56Kb/s)

7 High Speed Links
- Large $R$ -> small $Tx$ Time ($M/R$)
- Ex: OC-3 ($D = 10$ms, $R = 155$Mb/s)
  - $Tx$ Time = $0.010 + ((1024\times8)/(155\times1024\times1024)) = 0.01005$ sec = $0.01005$ sec = $10.05$ ms ($D >> M/R$)

8 Total (one way) Latency
- Propagation Delay ($D$) = distance/speed-of-light
- Transmission delay = ($M / R$)
- Queueing delay ($Q$) (using statistical multiplexing) depends on utilization
- Total Latency = $D + (M/R) + Q$
Beware of Overheads

Measuring Latencies (1)

Measuring Latencies (2)

Measuring Latencies (3)

What Happens on the Web?
• Click on a link (http://foo.bar.com/xx)
• Conversion from name to address
• Open connection to remote machine
• Pass arguments to process
• Retrieve contents from server
• Display locally

So, What does this Require?
• Name mapping service (DNS)
• Addressing/routing (IP)
• Reliable delivery (TCP)
• Representation of content (HTTP)
• Local display (application)

Naming Computers
• Need a way to locate services; easier for humans than numbers
• Flat Name Space:
  - every computer has unstructured name
  - must coordinate not to stomp on eachother
  - examples: ucbvax, sdcvax, sri-nic
  - didn’t scale very well

Hierarchical Naming
• First real growth problem of Internet
  - rule of thumb: things break if they grow 2 orders of magnitude (5-7 years in today's Internet!)
  - Common Idea: hierarchies scale well
• Divide up space into “Domains”
  - examples: EDU, COM, MIL, ORG, NET
  - (ISO3166-based): FI, JP, DK, US, ..

Benefits of Naming Hierarchy
• much better scaling
• decentralized administration
• redundant databases
• recursive, can subdivide each subdivision

URLs: New Names
A Problem with HTTP

- In version 1.0 of HTTP, the host name is not passed to the web server
- What about “web hosting” multiple sites?
- Utilizes more IP addresses than necessary!

IP (v4) Addresses

- Every interface has at least 1 IP address
- IP addresses are 32-bit numbers (4.3 billion of them!)
- Divided into parts: (network prefix, host number)
- Classical structure use net/subnet/host partitioning where hosts on same subnet share net and subnet number

Expressing Addresses

- 4 decimal numbers, called “dotted quad”
- Each (decimal) number is one byte
- Example: 128.32.25.12
- Can generally be used in place of names
- Classically, parts of “Classes”

IP Address Classes (historical)

Special IP Addresses

Example Assignments

Subnet Addressing

- Historical, but terminology is consistent and still used
- Allows one site to have multiple subnetworks of their main network. Practical result: multiple segments.
- Subnetting scheme is a local decision
- Requires a “subnet mask”

Subnet Structure

- Idea is to steal host bits and use them for numbering subnets
- Rest of Internet only sees classes (or their aggregates--- later)
- Mask indicates which bits are network/subnet part, and which are host part

Subnet Example

- 128.32.25.12 is a “Class B” address
- 16 bits of network, 16 bits of host
• So, need 10 bits to indicate subnet
• Use a subnet mask of \(16+10=26\) bits

28 Subnet Example (cont)
• 26 bit mask: \(0xffffffc0\) or simply “/26”
• So, 128.32.25.12/26 is:
  - 10000000 00100000 00011001 00001100
  & 11111111 11111111 11111111 11000000
  • Subnet 100 of net 128.32, host 12

29 Subnet Partitioning (ex cont)
• 128.32.0.0/26 gives \(2^{26-16}=1024\) subnets of \(2^{32-26}-2=62\) hosts each
• First usable address: 128.32.0.1 (see RFC1812, page 48)
• Last usable address: 128.32.255.254
• Any address with all “1” bits in host part is a (subnet) broadcast

30 Subnet Partitioning (ex cont)
• 128.32.25.12/26 is:
  - 10000000 00100000 00011001 00001100
• 128.32.0.65/26 is:
  - 10000000 00100000 00000000 01000001
• 128.32.255.190/26 is:
  - 10000000 00100000 11111111 10111110

31 Common Subnet?
• Is 128.32.25.12 and 128.32.25.85 on the same subnet using a /26 mask?
• 128.32.25.12 is:
  - 10000000 00100000 00011001 00001100
• 128.32.25.85 is:
  - 10000000 00100000 00011001 01010101
• Prefixes differ, so not on same subnet (need router to reach)

32 Classless Inter-domain Routing (CIDR)
• About 1993, remove strict classes from architecture
• Generalized notion of “network prefix”
• Requires “longest prefix” match routing
• Subsumes and generalizes subnetting
• (will discuss when we cover IP routing)