Last Time:

- servers
  - addresses, of interfaces
- sockets and ports, sample programming basics
- transmission
  - doing ‘work’ at a distance, requires power
  - simple overview of analog signal properties
- wire as transmission medium
  - characteristics
  - advantages
  - obstacles, impediments
This Time

- other transmission media & their characteristics
  - fiber (short-, long-haul)
  - RF (microwave, satellites)
- basic message unit
  - that we’re interested in
- the Internet

Power in Numbers

- basic model:
  - sender
  - receiver
  - signal carrying message
  - (original signal + transmission artifacts) carrying message
Power in Numbers

- suppose receiver needs SNR of at least 3 dB to ensure correct interpretation of input signal

- suppose we know noise power at receiver is 15 mW
- how powerful must signal be at receiver for good results?

Power in Numbers

- does this mean that sender needs only send out 30 mW of signal power?

- ‘wire’ causes loss of signal power independently of noise
  - so signal is weaker arriving at receiver than when it left sender

- suppose we know ‘wire’ reduces signal power by factor of 4; how much power must sender use to ensure satisfactory SNR at receiver?
Power in Numbers

- $-6 = \frac{\text{gain}_{\text{dB}}}{10 \log_{10}} = \frac{\text{measured power}}{\text{reference power}}$

---

Power in Numbers

- does this mean that sender needs only send out 30 mW of signal power?
- knowing loss over wire, 30 mW at sender becomes 7.5 mW at receiver
  - so SNR at receiver is $-3$ dB
- so sender needs to send 120 mW to ensure adequate signal at receiver
- or ...
Power in Numbers

- insert amplifier in ‘wire’:

- use of logarithms in ratios of powers lets us simply add:
  - so sender → receiver ‘wire’ has net gain of −2 dB

Transmission Media: Fiber

- instead of electrical signaling, use light:
  - pulses
  - variation in intensity
- how propagated?
  - TIR: total internal reflection
Transmission Media: Fiber

- suppose you have two media A and B
  - have different optical densities
  - the interface is where the two media contact each other
  - light travels slower in more optically dense medium

Transmission Media: Fiber

- light arrives at interface at some angle $\alpha_i$
- some of the light energy:
  - reflects at angle $\alpha$ back into medium A
  - refracts onward, across interface, at angle $\beta$
Transmitting Media: Fiber

- if:
  - medium B much more optically dense than medium A
  - we choose α, carefully, then:
  - 'all' of the light energy:
    - reflects back at angle α back into medium A
    - total internal reflection: TIR

**Diagram:**

- Fiber
- Ultra-pure glass
- Cladding around fiber
- Light inserted into one end of fiber
- Propagates by TIR along fiber and emerges at other end
Transmission Media: Fiber

- simplest fiber: *step-index multimode*
  - finite number of angles at which light is accepted

- core diameter: 50 to 62.5 microns
  - usually LED driven
- problem: modal dispersion

Transmission Media: Fiber

- problem: modal dispersion
- solution: mitigate using *graded-index multimode fiber*
  - cladding has gradient refractive index, less dense farther from center
  - light travels faster in less dense medium
Transmission Media: Fiber

- problem: modal dispersion
- solution: eliminate completely using single mode fiber

- much smaller diameter fiber: 8 to 10 microns
  - driven by LD

Transmission Media: Fiber

- characteristics:
<table>
<thead>
<tr>
<th></th>
<th>850 nm</th>
<th>1300 nm</th>
<th>1550 nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>db/km</td>
<td>3</td>
<td>1</td>
<td>0.5</td>
</tr>
</tbody>
</table>

- bandwidth drops with distance (mostly because of modal dispersion)
- typical bandwidth for fiber:
  * few hundreds MHz for standard multimode
  * few thousands MHz for single mode
- losses with bends in fiber
  * no bend have radius < 1 inch
Transmission Media: Fiber

- cable:
  [Image of fiber optic cable construction](http://www.arcelect.com/fibercable.htm)

- LDs:
  - single λ
  - commonly: 850, 1310, 1550 nm
  - power typically in 100s of mW (can be 1000s)
  - needs temperature stabilization
  - high speed
  - can reach switching speeds of 1000s of MHz
  - limited life span
  - small area of illumination
  - expensive

Transmission Media: Fiber

- LEDs:
  - not so purely monochromatic
  - comparable power
  - no special infrastructure
  - medium speed: several hundred MHz
  - very long lifespan
  - large area of illumination
  - really inexpensive

Transmission Media: Fiber

- usually packaged as “coupled” sources
  - LD switching circuitry
  - thermal stabilization
  - optical coupling
- may be simple “in-line” for shorter distances

http://www.agilent.com
http://www.edmunds.com
Transmission Media: Fiber

- Receivers for fiber: more generic
  - Photodiode based, typically

Transmission Media: Fiber

- Connectors:

<table>
<thead>
<tr>
<th>Fiber Connector Styles</th>
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</thead>
<tbody>
<tr>
<td>ST Connector</td>
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<tr>
<td>SC Connector</td>
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<td>PC Connector</td>
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<td>SMA Connector</td>
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<tr>
<td>E200 Connector</td>
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<tr>
<td>SC-Quad Connector</td>
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<tr>
<td>ST-Quad Connector</td>
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<tr>
<td>E200-Quad Connector</td>
</tr>
<tr>
<td>LC Connector</td>
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<tr>
<td>SC-LC Connector</td>
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<tr>
<td>E200-LC Connector</td>
</tr>
<tr>
<td>SC-Quad-LC Connector</td>
</tr>
<tr>
<td>E200-Quad-LC Connector</td>
</tr>
</tbody>
</table>

http://www.arcelect.com/fibercable.htm
Transmission Media: Fiber

- splices: problem because disturbs optical properties of medium, reflectivity
  - mechanical
  - fusion
- either kind has good loss characteristics: between 0.15 to 0.10 dB

Transmission Media: Fiber

- advantages of fiber:
  1) optical signalling
     - does not generate electrical interference
     - not susceptible to electrical interference/noise
  2) signalling keeps energy in medium
     - signal travels greater distance before needs reinforcement
  3) much higher frequency signalling
     - fiber carries more data
  4) doesn’t corrode
     - suitable for use in wider range of environments
  5) lightweight
     - easier to run in buildings and conduits
Transmission Media: Fiber

- disadvantages of fiber:
  1) hard to splice
     - requires special splicing tool/equipment to join ends
  2) flexible, but not as 'bendable' as wire
     - can break fiber inside
  3) hard to locate breaks
     - fiber carries more data
  4) currently use in “spark” mode
     - wastes capacity

Transmission Media: Fiber

- running fiber:
  • what is total optical signal loss over run?
    - cable loss
    - splice loss
    - connector loss
  • what is optical loss budget of receiver?
    - suggest allow ≥ 3dB extra margin
  • is fiber bandwidth adequate for signalling needs?
    - if not, use different wavelength and/or fiber
Terrestrial Microwave

- transmission media: wire, fiber
- what about “ether”

Terrestrial Microwave

- transmission media: wire, fiber
- what about “ether”
- radiate EM signal into ‘space’ in RF spectrum
  - e.g., radio, television
- for data use microwave RF
  - typically: 2 – 40 GHz
  - get good bit rates (10s Mbps)
- can be short distance
- can be long distance
  - e.g., up to 50 km
- sender needs ‘high’ power

http://www.harris.com (Microstar)
Terrestrial Microwave

- use modulated carrier to convey one or more signals
  - QAM
  - FSK
  - QPSK

Terrestrial Microwave

- straight line-of-sight only
- typically: 2 – 40 GHz
  - 150 cm – 0.75 cm
  - wavelengths short enough to be disrupted by everyday objects
- higher infrastructure operating costs
  - e.g., antenna maintenance

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**Terrestrial Microwave**

- **advantages of microwave:**
  - no medium to lay down
  - high bit rates, low error rates
  - fairly easy to set up

- **disadvantages of microwave:**
  - more infrastructure at sending, receiving end
  - need clear path for signal
  - set-up must include antennas
    - can be very expensive
    - must be maintained
  - security
  - distance limitation

---

**Terrestrial Microwave**

- **straight line-of-sight only**

- **repeater has transponder**
  - receiver and sender together operating at different frequencies

---

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Satellite

- Put transponder platform high over earth
  - 35,680 km
  - Over equator
  - Geosynchronous

Satellite

- Each transponder ≥ 3 Mbps
- Operating frequencies:
  - C-band: 4 – 6 GHz (7.5 cm – 5.0 cm)
  - Ku-band: 12 - 14 GHz (2.5 cm – 2.14 cm)
  - Ku-band signals perturbed by heavy rain
- Use powerful ground stations
  - Use high power to reach ‘bird’
Satellite

- e.g., Hughes Galaxy 1R:
- operating frequencies:
  - C-band: 4 – 6 GHz (7.5 cm – 5.0 cm)
  - uplink: 5.925 - 6.425 GHz
  - downlink: 3.700 - 4.200 GHz
  - 24 x 36 MHz - 16 Watt Output
- coverage area: North America, Caribbean
- users include:

<table>
<thead>
<tr>
<th>Cinemax</th>
<th>Comedy Central</th>
<th>Disney</th>
<th>ESPN</th>
</tr>
</thead>
<tbody>
<tr>
<td>HBO</td>
<td>MSNBC</td>
<td>Starz - Encore</td>
<td>Univision</td>
</tr>
</tbody>
</table>

Satellite

- coverage area Hughes Galaxy XI:

Satellite

- need rocket to launch (position) bird
  - current cost = $6,000/kg
  - ANIK-C (Hughes HS376) 563 kg ≈ $3.4M
- operate from ground-based control stations

Satellite Links

- up-links: ground stations
  - collect data for uplink
  - uplink
    - transmitter
    - antenna: dish, ≤ 10m in diameter
- small uplink facilities
  - your local TV news
  - VSAT (very small aperature terminal) 2m antenna
  - use TDMA or FTDMA to handle multiple users per transponder
Value of VSAT

- VSAT good for areas with sparse population
  - no other high-speed networking infrastructure
  - relatively easy set-up
  - not so high speed as ‘full-sized’ sat systems
- often uses star topology connection model
  - main ground station as hub
  - individual VSAT users as nodes connected to hub via satellite link
  - other topologies possible

Example VSAT Setting

Satellites

- impediments
  - electrical noise
  - RF noise
  - rain
  - space perils:
    - meteoroids
    - solar flares/magnetic storms
    - 1998 Galaxy failure: 45M US pagers failed
    - 1994 ANIK-E1 and E2 failures
    - alignment

Satellites

- advantages:
  - can provide coverage to areas otherwise not feasible to service
    - e.g., northern Canada
  - 'cheap' broadcast mechanism
  - reasonably good performance:
    - e.g., $10^{-9}$ BER at > 3 Mbps
  - pretty good reliability
    - if space weather is not severe
Satellites

- disadvantages of satellites:
  - expensive to get off the ground
  - actual bird itself
  - launching it into space: it is rocket science
  - finite life span (about 15 years)
  - susceptibility to weather effects
    - in space, affects satellite itself
    - on planet, affects signals
  - specialized equipment needed
  - latency

Very Long ‘Wire’

- can also do intercontinental via undersea cable
- first undersea cable in 1850
- first all-optical cable in 1996
- can go up to 400 km without repeater
  - current repeaters are pure optical
- cable includes power to run repeaters
  - about 40V per repeater
  - 7,500 km cable needs 10,000 V
- built to run 25 years without repair at depths down to 7 km
Undersea Cable: what’s it cost?

- costs of some undersea cables:

<table>
<thead>
<tr>
<th>Cable</th>
<th>BW</th>
<th>Length (km)</th>
<th>Cost: Gbps/Km</th>
</tr>
</thead>
<tbody>
<tr>
<td>TAT-9</td>
<td>565 Mbps</td>
<td>9,310</td>
<td>$85,548</td>
</tr>
<tr>
<td>TPC-4</td>
<td>560 Mbps</td>
<td>9,860</td>
<td>$67,553</td>
</tr>
<tr>
<td>CiS</td>
<td>622 Mbps</td>
<td>281</td>
<td>$61,598</td>
</tr>
<tr>
<td>TPC-5</td>
<td>5 Gbps (max 20)</td>
<td>25,000</td>
<td>$8,960</td>
</tr>
<tr>
<td>FLAG</td>
<td>10 Gbps</td>
<td>27,000</td>
<td>$5,600</td>
</tr>
<tr>
<td>Columbus III</td>
<td>10 Gbps</td>
<td>11,000</td>
<td>$2,700</td>
</tr>
</tbody>
</table>

data from: [http://www-dsg.stanford.edu/holbrook/CableCosts.html](http://www-dsg.stanford.edu/holbrook/CableCosts.html)

Example: TPC-5CN

- usually do loop instead of point-to-point, like:

![Diagram of undersea cable network](http://www.apricot.net/apricot97/apill/Presentations/SubmarineswCable/sub017.htm)
Undersea Cable

- advantages:
  - low latency
  - high reliability
  - high bit rates
- disadvantages:
  - expensive to lay
  - time consuming to repair
  - hard to find breaks, hard to find cable!

Signals to Bits

- however conducted to receiver, signal must be converted to bits
- conversion samples the signal at regular intervals
  - each sample communicates $\geq 1$ bit
  - depends on representation used
Bits and Baud

- suppose we use twisted-pair wire
- we want to send bits from A to B over wire
- only electrical signals, not bits, travel over wire
- use signals to carry bits, i.e., vary properties of signal
  - amplitude (e.g., AM, ASK)
  - frequency (e.g., FM, FSK)
  - phase (e.g., PM, PSK)
  - combinations of these: quadrature (e.g., QAM, QPSK)

use signals to carry bits, e.g., FSK

- we measure (sample) medium at regular intervals: each measurement = 1 baud
- each baud tells us about 1 (or more) bits
**Bits and Baud**

- **baud rate**: how many samples of transmission medium per second
- **bit rate**: how many bits we see per second
  - if > 1 bit per sample, then bit rate > baud rate
  - generally do multiple bits per baud

---

**A Layered Networking Model**

<table>
<thead>
<tr>
<th>Application</th>
<th>Session</th>
<th>Presentation</th>
<th>Transport</th>
<th>Network</th>
<th>DLC</th>
<th>Physical</th>
</tr>
</thead>
<tbody>
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</tbody>
</table>
Network Performance

- how do we measure how “good” network performance is?

  vs.

- we measure speed in **bits per second**

---

Network Performance

- is speed all we’re interested in?
- **bit error rate (BER):** probability that a particular bit is wrong
  - BER of $10^{-9}$ implies $P(\text{this bit is wrong}) = 10^{-9}$
    - usually interpreted to mean 1 bit in $10^9$ is wrong
- how many errors per second if
  - bit rate is 1000 Mbps
  - BER is $10^{-9}$
An Analogy

- current international ship freight has become highly efficient, cost-effective way to move goods large distances over water
  - why?

photo © 2004 World Container Mart, Inc.
A Data Container

- the analogous ‘standard’-sized data container is the packet
  - ‘standard:’ there are lots of different ones
  - has some maximum size
  - may have a minimum size
- generic packet format:
  
  ![Packet Format Diagram]

Packets

- header typically contains:
  - address information: sender, receiver
  - message identifier
  - special notes or instructions
- almost always fixed-length
Packets

- data payload contains the message data the packet communicates
  - may be another packet for a different target recipient
  - often variable length, not always
  - no restriction on content format
  - other than length

Packets

- trailer typically contains:
  - error checking information
  - usually fixed length
A Layered Networking Model

- Application
- Session
- Presentation
- Transport
- Network
- DLC
- Physical

Encapsulation: one packet-style message becomes the entire message data of another packet-style message.

Internet data: in the beginning
Internet data: in the beginning

Internet and Encapsulation

- Internet Protocol is the “common” protocol that others speak in order to use the Internet
- essential feature: messages sent as packets
- each packet contains all or part of a message
  * possibly expressed in a different (proprietary) protocol
- encapsulation: the data msg is encapsulated within the IP packet
  * like a letter in a FedEx envelope
IP in different flavours

- the “current” protocol used on the Internet is version 4
  - written IPv4
- a newer version is slowly gaining popularity
  - will eventually replace IPv4
  - IPv6
- we look mostly at IPv4

IPv4 Packet

- IPv4 datagram (see RFC791)
IPv4 Header

- What does length really tell you?
- What is minimum value for length?
### IPv4 Header

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>VERS</td>
<td>Version number, 4 bits, identifies the IP version (IPv4)</td>
</tr>
<tr>
<td>HLEN</td>
<td>Header length, 4 bits, indicates the length of the header in units of 32 bits</td>
</tr>
<tr>
<td>SVC TYP</td>
<td>Service type, 8 bits, identifies the type of service</td>
</tr>
<tr>
<td>31</td>
<td></td>
</tr>
</tbody>
</table>

**Total length** [16]: length of entire packet (header + data) in 8-bit bytes

- What is the maximum value for packet? for data?
- Is there a minimum length?

### Joining Many Networks

- Get 2 Kbyte message from A to B:

![Diagram](image-url)
From A to B

- Message must travel across pink network to reach target.
- Message is too large to fit in one transfer unit of pink network.
  - Its MTU is 640 bytes (maximum transfer unit).
- So we break the message into fragments in order to traverse pink network.
- Fragments must be re-assembled into larger message.
- Not all fragments need to be the same size; may not arrive in proper sequence.

From A to B

- Original 2 Kb message
  - Frag 0
  - Frag 1
  - Frag 2
  - Frag 3

Each frag needs to identify itself by number and say where it fits (offset) in overall (reassembled) message.
IPv4 Header

0  31
VERS   HLEN   SVC TYP   LEN

Ident [16]: which fragment number this is

flags [3]: which fragment number this is

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IPv4 Header

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>VERS</td>
<td>HLEN</td>
<td>SVC_TYP</td>
<td>LEN</td>
<td></td>
</tr>
<tr>
<td>IDENT</td>
<td>FLAGS</td>
<td></td>
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</tr>
</tbody>
</table>

frag offset [13]: how far into msg this frag starts (in 8-byte steps)

A to B

as our msg travels...
A to B (almost)

- as our msg travels...

Hops

- a packet moves through network from node to node until reaching destination
- arrival at a node along the route: one hop
- to free packets trapped in routing loops give each packet a counter
  - initialize to maximum number of hops packet should make
  - counter is decremented on each arrival at a node
  - if counter reaches 0, the packet is discarded
    - and error message sent back to originator of pkt
IPv4 Header

<table>
<thead>
<tr>
<th>0</th>
<th>Vers</th>
<th>Hlen</th>
<th>Src IP</th>
<th>Dst IP</th>
<th>LEN</th>
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</tbody>
</table>

**time to live [8]:** max time this packet can be in network (hops)

IPv4 Header

<table>
<thead>
<tr>
<th>0</th>
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<td>Flags</td>
<td>Frag Offset</td>
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</table>

**protocol [8]:** what protocol to use next layer up (who wants this packet’s data)
Getting It Right

- errors arise in transmission medium
  - and elsewhere
- errors result in bits being wrong at destination
- can destination be assured that what it sees is what was sent?

Getting It Right

- can destination be assured that what it sees is what was sent?
  - mostly, yes:
    - **error detection**: determine if data received contains ≥ 1 error
    - **error correction**: detect an error and its location in message, so can correct it
Simple Error Detection: Parity

- arrange value of ‘spare’ bit in ASCII character so that:

<table>
<thead>
<tr>
<th></th>
<th>odd parity</th>
<th>even parity</th>
</tr>
</thead>
<tbody>
<tr>
<td>total number of 1-bits must be odd</td>
<td>total number of 1-bits must be even</td>
<td></td>
</tr>
</tbody>
</table>

- e.g., for ‘K’: ASCII code is 1001011
  - number of 1 bits is even
  - for even parity, send as: 01001011
  - for odd parity, send as: 11001011

Checksum Error Detection

- sender performs arithmetic operation on data: result is checksum
- receiver performs same arithmetic operation on data received
- compares its result with that in data received
  - if different, received data is in error
- for IPv4 packets:
  - compute 1’s complement 16-bit sum of hdr data
    - taken as 16-bit words
  - compute 1’s complement of that 16-bit sum
IPv4 Header

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<tr>
<td>IDENT</td>
<td>FLAGS</td>
</tr>
<tr>
<td>TTL</td>
<td>FRAG OFFSET</td>
</tr>
<tr>
<td>PROTO</td>
<td></td>
</tr>
</tbody>
</table>

**hdr checksum** [16]: checksum value for entire hdr

Who Computes Checksum?

- what do we do at each hop?
IPv4 Header

**source address [32]:** IP address of packet’s originator

**destination address [32]:** IP address of packet’s intended destination

**options [var]:** IP address of packet’s intended destination

**padding:** fill to 32-bit size