SOME PHYSICAL LAYER ISSUES

Lecture Notes 2A

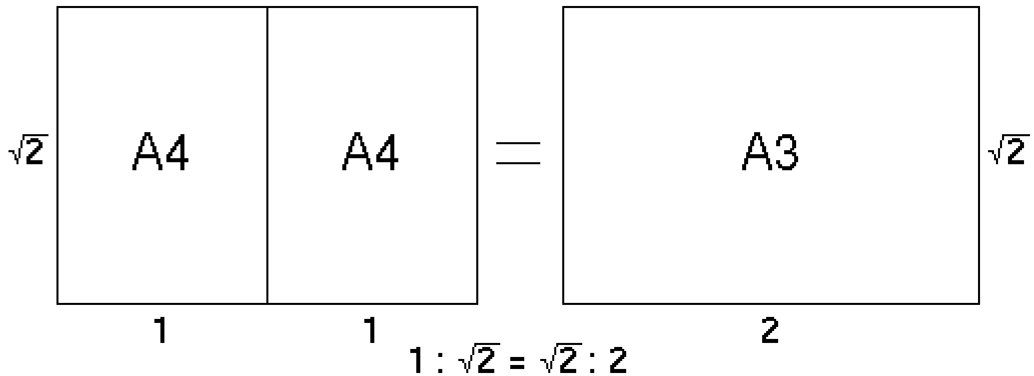
Delays in networks

- Propagation time or propagation delay, t_{prop}
  - Time required for a signal or waveform to propagate (or move) from one point to another point. It is defined as d/v where d is the distance between the two points and v is the velocity of the signal.
  - Electromagnetic signal sent through space from the Sun to the Earth.
    - Velocity is the speed of light, 3×10^8 meters per second.
    - Say distance is 148.8 million kilometers.
    - Propagation time is $(148.8 / 3) \times 10^9 / 10^8 = 496$ seconds.
- Transmission time, t_{trans}
  - Links or channels for digital transmission are defined in bits/second or bps. This is called the Data Rate, R, and is the rate at which the transmitter can push bits onto the transmission line. Transmission time is the time it takes to send some number, say B bits, or B/R. Note that to be clear we can check that bits / (bits/sec) = sec.
  - What is the transmission time for a packet of 1500 bytes on a 10 Megabit link.
    - $1500 \times 8 / 10^7 = 1.2$ milliseconds.
- Queuing time or queuing delay, t_{queue}
  - Any time related to processing or waiting of packets in buffers.

Representation of Information Types

- Block Oriented Information: specific length blocks
  - Text files
  - Fax documents
    - Example: An A4 page is approximately 100 square inches
    - 200 pixels per inch (horizontal) by 100 pixels per inch (vertical) requires approximately 250 kilobytes prior to compression (a pixel is black or white). Compression reduces by a factor of 8 to 16. (typically lossless eg. G4)
  - JPEG color images
    - 8 x 10 inch photo uncompressed is 38.4 Mbytes before compression and about 1.2 – 8 Mbytes after compression. Assumes 400 pixels/inch horizontal and vertical, and 3 colors (RGB) with 1 byte for each color per pixel.

      8 x 10 x 400 x 400 x 3 bytes
- Stream Oriented Information: continuous stream of data
  - Voice PCM: 4 kilohertz voice is 64 kbps, standard voice channel
  - Voice ADPCM, compression technique reduces rate to 16-32 kbps
  - Audio MP3 compression
  - Video MPEG 2
    - 1920 x 1080 pixel frames at 30 frames /second requires about 1.5 Gbps (includes 20 bits/pixel and vertical/horizontal blanking and embedded audio) uncompressed is reduced to 19-38 Mbps compressed



A4 Fax Document Standard

1/16 m^2, 5 grams / page typically

210 millimeters x 297 millimeters
(slightly bigger than 8 1/2 by 11)

Note the importance of being clear on the units used for measurement (

Importance of Units

- International system of units or SI.
  - Length - meter (m)
  - Time - **second (s)**
  - Amount of substance - mole (mole)
  - **Electric current - ampere (A)**
  - Temperature - **kelvin (K)**
  - Luminous intensity - **candela** (cd)
  - Mass - **kilogram** (**kg**)

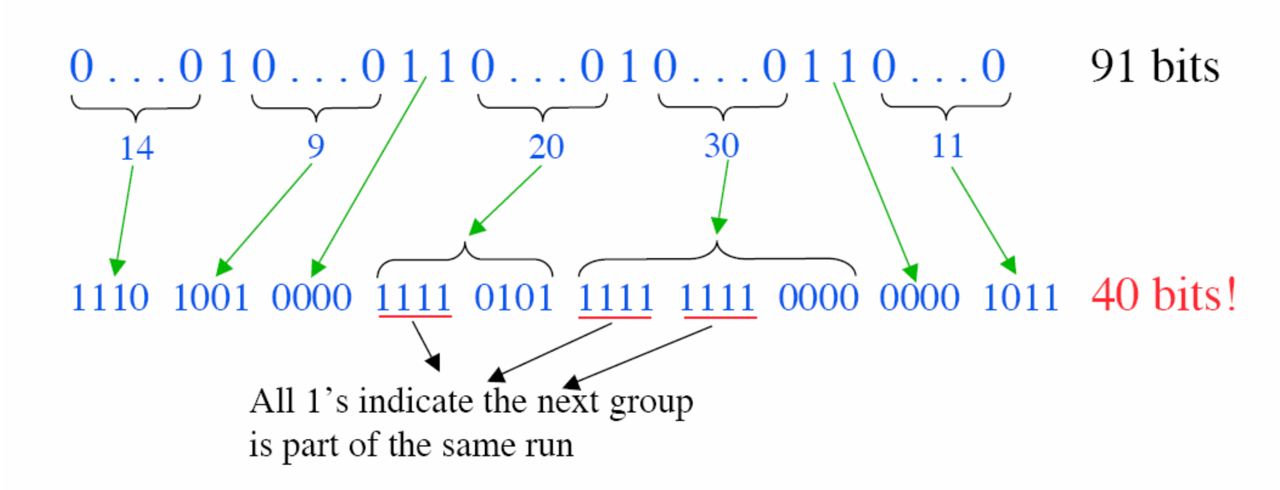
- As shown before, we can multiply and divide the units as needed to be sure we are doing things right.
  - For example, the unit of power is called watt or W.
  - 1 watt = 1 W = 1 kg · m^2 / s^3

Data Compression Techniques

- Why data compression? reduce amount of storage space required to represent the document
  - Compression ratio: size of uncompressed / size of compressed
  - Lossless data compression
    - Example: run length encodings
      - Sequences of likely symbols encoded into runs
      - Many different ways to do this.
      - Example: Use two bytes, where the first byte is the symbol and the second byte is the length of the run
  - Lossy data compression
    - Compressed file is an approximation of the original data
    - Better compression ratio is achieved.
    - For example, MP3 can achieve a factor of 14 reduction.
    - Example: unencoded MP3 requires about 1.4 Mbits/sec (2 channels, 16 bits per sample, at a rate of 44100 samples per second). Thus, 1 hour is about 317 MB (about ½ of an audio CD and 1/14 of common DVDs) Through MP3 compression, we can compress to say 128 kbits /second.

Example of run length encoding

- Binary data
  - Code the run length of 0's using k bits.
  - Transmit the code; do not transmit runs of 1
  - Runs of 1's are separated by 0 runs of 0 (ie. by the 4 bit value 0000).
  - (Example due to Thinh Nugyen): k =4, max run length in 4 bits is 15.



What are worst case and best case behaviors of this coding scheme?

Analog Information

- Based on a wave that varies continuously with time

- Example
  - Sound
  - Electromagnetic radiation

- Periodic signal repeats over time

- representation of analog signals
  - Amplitude versus time
  - Frequency representation
  - Representation as sums of sines and cosines

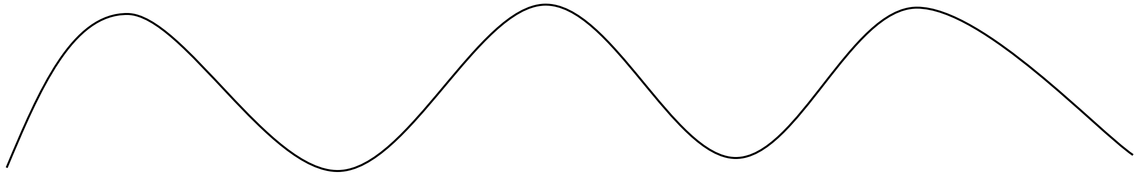
The frequency spectrum

- Frequency: cycles per second, ie Hertz, of a sinusoidal signal
- Bandwidth: usable range of frequencies high – low: $f_2 - f_1$
- Typical telephone voice channel is 4k Hz

Some approximate frequencies

300 Hz – 20,000 Hz	human voice / sound
50 kHz	navigation (ships, submarines, etc)
1 MHz	AM radio (20 k Hz channels)
10 MHz	CB, short wave
100 MHz	FM radio, TV
1 GHz	UHF TV, mobile telephony
10 GHz	amateur satellite
100 GHz	upper microwave – many uses (up to about 300 GHz)

10 T Hz = 10^{13} Hz Infrared, 10^{15} Hz Visible light, 10^{18} X-rays, ...



Frequency and Wavelength

Frequency f: measured in oscillations (cycles) / second or Hz

Wavelength λ: measured in meters (distance)

Speed of light c: 3×10^8 m/sec

Fundamental relationship: $\lambda f = c$

CB radio: at 10 M Hz or 10^7 Hz has a wavelength of 30 meters

Amateur satellite: 10 GHz wavelength is 30 millimeters

Visible light: wavelength 600 nm (.6 micron) or 6×10^{-7} meters

has a frequency of 5×10^{14} Hz

BASICS of ANALOG SIGNALS

A typical signal is function of time $x(t)$ with time on the x-axis and amplitude (or power) on the y-axis.

Examples: $y = \sin t$, $y = \cos(2\pi\,(400t))$

Periodic Signals

frequency f is the number of complete cycles in 1 second

period is the time for 1 complete cycle

frequency is measured in Hz (hertz)

Let $y = \sin\,(2\pi\, 5\, t)$: frequency is 5 Hz, period is 1/5

Let $y = \cos\,(2\,\pi\, 4000\, t)$: 4000 Hz or 4 k Hz

Bandwidth W of a signal

Range of frequencies containing non-negligible power.

Suppose there is power at frequencies from f_1 to f_2.

Then bandwidth $f_2 - f_1 = W$.

Shannon Capacity Theorem - How does bandwidth relate to channel capacity

- Answer relates to how fast signals (short pulses) can be sent and the characteristics of the channel such as the signal to noise ratio
- The Shannon channel capacity theorem give the theoretical maximal capacity
- Shannon's theorem: maximum bit rate for noisy channel

$$C = Bandwidth * \log_2 (1 + S/N)$$

- 4 kHz voice channel equates to 56 or 64 k bits / second.
  - This is achievable by modern modems
- From now on, will usually discuss channel capacity in bits / second.
- Some sample bit rates

Radio LAN in the 2.4GHz band: 2 Mbps

Fast Ethernet: 100 Mbps, Gigabit Ethernet,

Optical fiber transmission: 2.4 – 9.6 Gbps over one wavelength

Nyquist Theorem - Sampling Rate

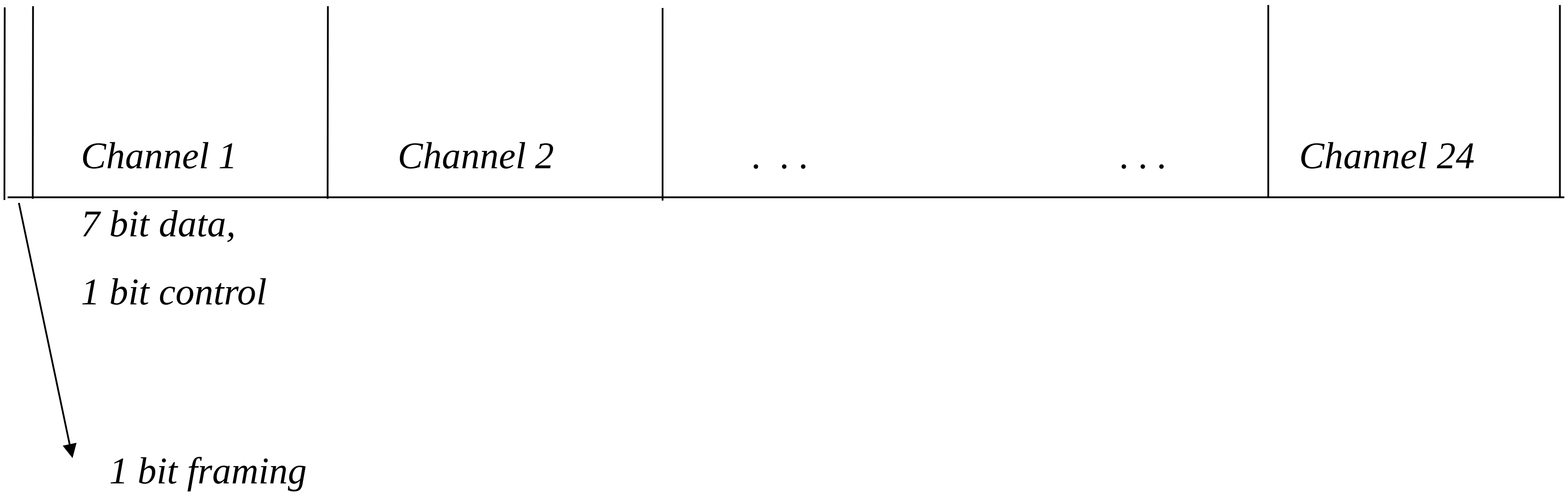
- To accurately sample a periodic (analogue) waveform in order to digitize it, need to sample at twice the highest frequency
- Sampling rate is thus $2 \times W$, where W is the bandwidth in Hz
- Example: for a 4kHz voice channel, need to sample at 8000 times a second or every 125 μ sec.
- Example: MP3 – wish to get high quality audio
  - About 44,000 samples per second
  - Assuming two channels (stereo) and 16 bit samples to determine amplitude precisely, get about 1.4 Mbits per second

Multiplexing

- Multiplexing is fundamentally sharing some amount of bandwidth by many different users, channels, etc.
  - **FDM**: Frequency Division Multiplexing: dividing up the frequency spectrum into multiple channels, each channel dedicated to a particular use
  - **TDM**: Time Division Multiplexing: using the entire frequency bandwidth allotted but uses “logical slots” to transmit different channels at specific points of relative time within a logical frame that is transmitted.
- A digital telephone speech signal (corresponding to a 4 kHz channel) is obtained as follows
  - Sample the signal at twice the maximum frequency or 8000 times a second
  - Quantize the sampled value (the amplitude of the signal) to 7 bits or 128 different value.
  - This gives a bit rate of 56 kbits/second

The T-1 carrier system

- T-1 was developed to carry digitally multiplexed channels between central offices using TDM.
- T-1 multiplexed 24 voice channels in a T-1 frame as follows



Sampling rate: 1 frame is sent every 125 µsec (8000 frames /sec)

8 bits / channel x 24 channels + 1 bit = 193 bits per frame.

Therefore, 193 bits / 125 µsec = 1.544 Mbps

This standard signaling rate became known as DS-1 (digital signal 1)

The DS hierarchy

- DS-1: basic block, 1.544 Mbits/sec
  - Note: to send data, 1 channel is used for sending a sync byte
- DS-2: 6.312 Mbits/sec (4 DS-1 or 96 voice, plus some control)
- DS-3: 44.736 Mbits/sec

- International standards (based on the ITU hierarchy developed in Europe) is somewhat different
  - E1: 2.048 Mbits/sec supporting 30 voice channels at 64 kbits/sec each with two channels for control.

SONET Digital Hierarchy

- OC-1 51.84 Mbps
- OC-3 155.52 Mbps
- OC-6 622.08 Mbps
- OC-12 1244.16 Mbps
- OC-48 2.48832 Gbps
- OC-192 9.95328 Gbps
- OC-768 ≈ 40 Gbps

- Compare to the evolution of standard rates for Ethernet
  - 10 Mbps
  - 100 Mbps
  - 1 Gbps
  - 10 Gbps
  - 40 Gbps

Wavelength division multiplexing (WDM)

- Combining multiple wavelengths over the same optical fiber
- For example 16 wavelengths, each at 2.5 Gbps can provide a rate of about 40 Gbps. (OC-48 x 16)
- Using optical add drop multiplexers
- Optical switches
- A lightpath is a logical connection from a start node to an end node going through intermediate nodes.
  - Same wavelength throughout
  - Reallocating of a wavelength at intermediate nodes (switching)
  - Protection paths
  - Wavelength switching capabilities

Code Division Multiplexing

- Suppose many stations want to transmit and only need a narrow band signal.
- CDMA (code division multiple access) allows multiple stations to transmit “sharing a wide frequency band.
- Each station actually transmits over the entire frequency band and multiple transmissions are separated using coding theory.
- Each bit time is subdivided into *m* chip times (m is generally 64 or 128) . Each station is assigned a chip sequence which is viewed as a code sequence of +1 or -1 of length m.
  - Let m = 8 for an example. A chip sequence might be (-1, -1, -1, +1, +1, -1, +1, +1) and is what the station transmits for sending the 1 bit. To transmit a 0 the station transmits the negation of the chip sequence.
- Chip sequences assigned to stations have mathematical properties that allow stations to simultaneously transmit but still let a receiver figure out what a specific station transmitted as long as you know the transmitters chip sequence.