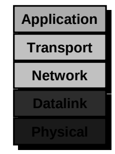
15-441 Computer Networking

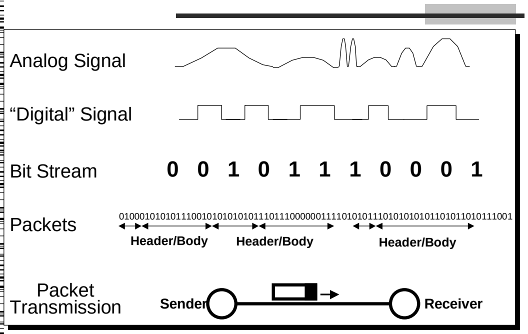
Lecture 17 - Physical Layer,
Link Layer Basics

Links

- How to make computers talk across a "wire"
- How to share the wire

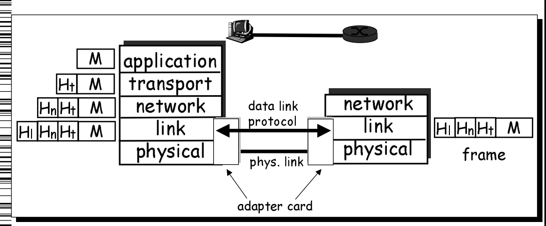


From Signals to Packets



Link Layer: Implementation

- Implemented in "adapter"
  - E.g., PCMCIA card, Ethernet card
  - Typically includes: RAM, DSP chips, host bus interface, and link interface



Outline

- Physical media is analog
  - Modulation – signals to bits
- Bit stream vs. packets
  - Framing – how to make packets
- Corruption
  - Error detection & recovery
- Sharing
  - Media access

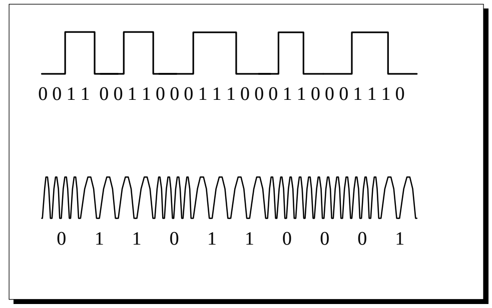
Why do we care?

- How much bandwidth can I get out of a specific wire (transmission medium)?
- What limits the physical size of the network?
- How can multiple hosts communicate over the same wire at the same time?
- How can I manage bandwidth on a transmission medium?
- How do the properties of copper, fiber, and wireless compare?

Modulation

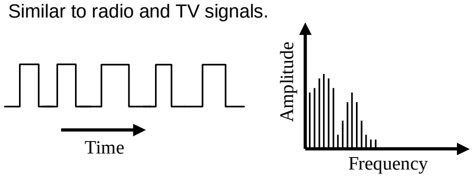
- Modulation : method of encoding digital (or analogue) signals onto a waveform
- Sender changes the nature of the signal in a way that the receiver can recognize.
  - Similar to radio: AM or FM
- Digital transmission: encodes the values 0 or 1 in the signal.
  - It is also possible to encode multi-valued symbols
- Amplitude modulation: change the strength of the signal, typically between on and off.
  - Sender and receiver agree on a “rate”
  - On means 1, Off means 0
- Similar: frequency or phase modulation.
- Can also combine modulation types.

Amplitude and Frequency Modulation



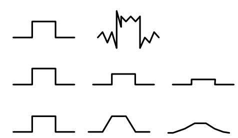
Modulation

- A (periodic) signal can be viewed as a sum of sine waves of different strengths.
  - Corresponds to energy at a certain frequency
- Every signal has an equivalent representation in the frequency domain.
  - What frequencies are present and what is their strength (energy)
- Similar to radio and TV signals.



Modulation

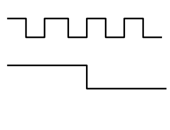
- Noise: “random” energy is added to the signal.
- Attenuation: some of the energy in the signal leaks away.
- Dispersion: attenuation and propagation speed are frequency dependent.
  - Changes the shape of the signal



- **Effects limit the data rate that a channel can sustain.**
  - » **But affects different technologies in different ways**
- **Effects become worse with distance.**
  - » **Tradeoff between data rate and distance**

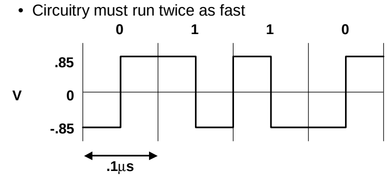
Modulation

- What is the bit pattern?
  - Easy - 101010…
- What about now?
  - 111111000000 or 11110000?
  - Hard to tell where a bit starts and ends
- What about now?
  - 1111111 or 0000000?
  - Hard to tell when what is a 0 and what is a 1
- Any suggestions to solve this?



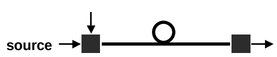
Modulation

- Manchester
  - Used by Ethernet
  - 0=low to high transition, 1=high to low transition
  - Transition for every bit simplifies clock recovery
  - Not very efficient
    - Doubles the number of transitions
    - Circuitry must run twice as fast



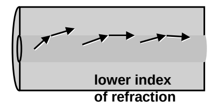
Copper Wire

- Unshielded twisted pair
  - Two copper wires twisted - avoid antenna effect
  - Grouped into cables: multiple pairs with common sheath
- Coax cables.
  - One connector is placed inside the other connector
  - Holds the signal in place and keeps out noise
- At end of span, either regenerate electronically or amplify.
- Electronic repeaters are potentially slow, but can eliminate noise.



Fiber

- Uses total internal reflection
- usually laser diode or LED source
- still subject to chromatic dispersion
- Need repeaters



Wireless Technologies

- Great technology: no wires to install, convenient mobility, ..
- High attenuation limits distances.
  - Wave propagates out as a sphere
  - Signal strength reduces quickly $(1/\text{distance})^3$
- High noise due to interference from other transmitters.
  - Use MAC and other rules to limit interference
  - Aggressive encoding techniques to make signal less sensitive to noise
- Other effects: fading, security, ..

Media Comparison

Media	BW	Range	Wiring Cost
Twisted Pair	100Mbps	100m	10c/ft
Coax	1Gbps	1km	10c/ft
Fiber	1Gbps	10km	30c/ft
Wireless	22Mbps	500ft	0

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Framing

- A link layer function, defining which bits have which function.
- Minimal functionality: mark the beginning and end of packets (or frames).
- Some techniques:
  - frame delimiter characters with character stuffing
  - frame delimiter codes with bit stuffing
  - out of band delimiters (e.g. FDDI control symbols)
  - synchronous transmission (e.g. SONET)

Framing

- Length delimited
  - Beginning of frame has length
  - Single corrupt length can cause problems
    - Must have start of frame character to resynchronize
    - Resynchronization can fail if start of frame character is inside packets as well

Framing

- Byte stuffing
  - Special start of frame byte (e.g. 0xFF)
  - Special escape byte value (e.g. 0xFE)
  - Values actually in text are replaced (e.g. 0xFF by 0xFEFF and 0xFE by 0xFEFE)
  - Worst case – can double the size of frame
- Bit stuffing
  - Special bit sequence (0x01111110)
  - 0 bit stuffed after any 11111 sequence

Ethernet Framing

- Preamble is 7 bytes of 10101010 followed by one byte of 10101011
  - Does not use byte/bit stuffing for preamble
  - Allows receivers to recognize start of transmission after idle channel

Consistent Overhead Byte Stuffing

- Run length encoding applied to byte stuffing
- Encoding
  - Add implied 0 to end of frame
  - Each 0 is replaced with (number of bytes to next 0) + 1
  - What if no 0 within 255 bytes? 255 value indicates 254 bytes followed by no zero
  - Worst case – no 0's in packet – 1/254 overhead
  - Possible optimization to encode series of 0's

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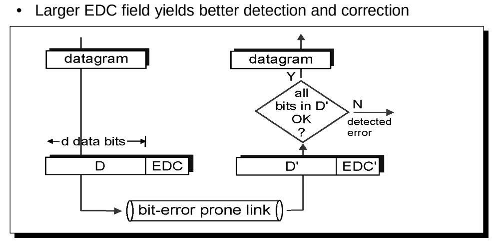
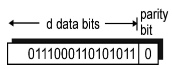
Error Detection

- EDC= Error Detection and Correction bits (redundancy)
- D = Data protected by error checking, may include header fields
- Error detection not 100% reliable!
  - Protocol may miss some errors, but rarely
  - Larger EDC field yields better detection and correction



Parity Checking

Single Bit Parity:
Detect single bit errors



Error Detection - Checksum

- Used by TCP, UDP, IP, etc..
- Ones complement sum of all words/shorts/bytes in packet
- Simple to implement
- Relatively weak detection
  - Easily tricked by common error patterns

Internet Checksum

- Goal: detect "errors" (e.g., flipped bits) in transmitted segment – Already covered in lecture 7

Sender
- Treat segment contents as sequence of 16-bit integers
- Checksum: addition (1's complement sum) of segment contents
- Sender puts checksum value into checksum field in header

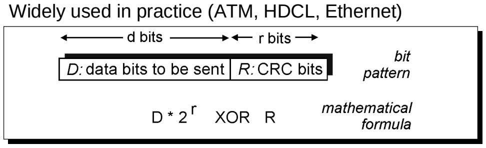
Receiver
- Compute checksum of received segment
- Check if computed checksum equals checksum field value:
  - NO - error detected
  - YES - no error detected. But maybe errors nonethless?

Error Detection – Cyclic Redundancy Check (CRC)

- Polynomial code
  - Treat packet bits a coefficients of n-bit polynomial
  - Choose r+1 bit generator polynomial (well known – chosen in advance)
  - Add r bits to packet such that message is divisible by generator polynomial
- Better loss detection properties than checksums

Error Detection – CRC

- View data bits, D, as a binary number
- Choose r+1 bit pattern (generator), G
- Goal: choose r CRC bits, R, such that
  - <D,R> exactly divisible by G (modulo 2)
  - Receiver knows G, divides <D,R> by G. If non-zero remainder: error detected!
  - Can detect all burst errors less than r+1 bits
- Widely used in practice (ATM, HDCL, Ethernet)



CRC Example

Want:

$D \cdot 2r$ XOR R = nG

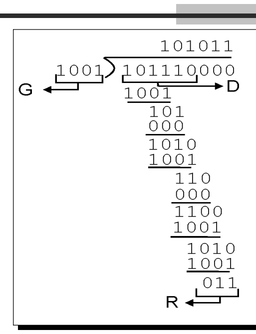
equivalently:

$D \cdot 2r$ = nG XOR R

equivalently:

if we divide $D \cdot 2r$ by G, want reminder R

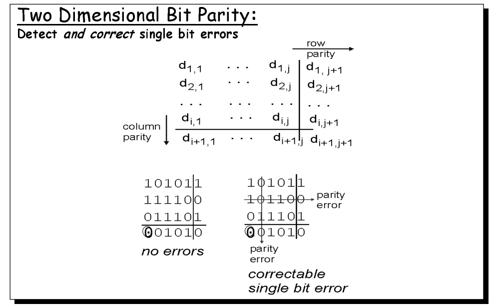
$$R = \text{remainder}\left[\frac{D \cdot 2r}{G}\right]$$



Error Recovery

- Two forms of error recovery
  - Error Correcting Codes (ECC)
  - Automatic Repeat Request (ARQ)
- ECC
  - Send extra redundant data to help repair losses
- ARQ
  - Receiver sends acknowledgement (ACK) when it receives packet
  - Sender uses ACKs to identify and resend data that was lost
  - Issues already studied in transport layer

Error Recovery – Error Correcting Codes (ECC)



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MAC Protocols: A Taxonomy

Three broad classes:

- Channel partitioning
  - Divide channel into smaller “pieces” (time slots, frequency)
  - Allocate piece to node for exclusive use
- Random access
  - Allow collisions
  - “Recover” from collisions
- **“Taking turns”**
  - Tightly coordinate shared access to avoid collisions

Goal: efficient, fair, simple, decentralized

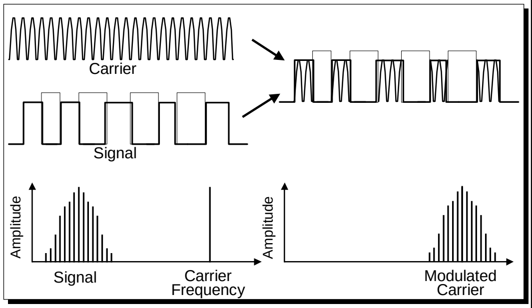
Supporting Multiple Channels

- Multiple channels can coexist if they transmit
  - at a different frequency
  - at a different time
  - in a different part of the space.
  - Three dimensional space: frequency, space, time
- Space can be limited using wires or using transmit power of wireless transmitters.
- Frequency multiplexing means that different users use a different part of the spectrum.
  - similar to radio: 95.5 versus 102.5 station
- Controlling time is a datalink protocol issue.
  - Media Access Control (MAC): who gets to send when?

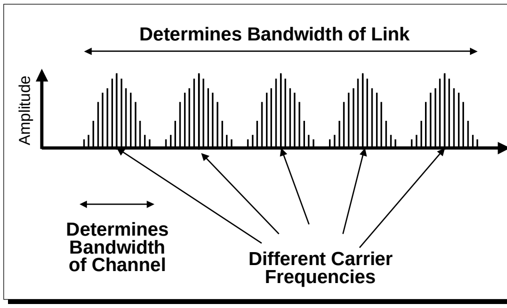
Baseband vs Carrier Modulation

- Baseband modulation: send the “bare” signal.
- Carrier modulation: use the signal to modulate a higher frequency signal (carrier).
  - Can be viewed as the product of the two signals
  - Corresponds to a shift in the frequency domain

Amplitude Carrier Modulation

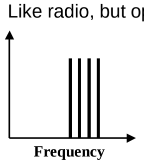


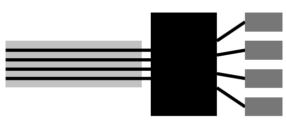
Frequency Division Multiplexing: Multiple Channels



Wavelength Division Multiplexing

- Send multiple wavelengths through the same fiber.
  - Multiplex and demultiplex the optical signal on the fiber
- Each wavelength represents an optical carrier that can carry a separate signal.
  - E.g., 16 colors of 2.4 Gbit/second
- Like radio, but optical and much faster





Multiple Access Protocols

- Single shared communication channel
- Two or more simultaneous transmissions → interference
  - Only one node can send successfully at a time
- *Multiple access protocol:*
  - Distributed algorithm that determines how stations share channel, i.e., determine when station can transmit
  - Communication about channel sharing must use channel itself!
  - What to look for in multiple access protocols:
    - Synchronous or asynchronous
    - Information needed about other stations
    - Robustness (e.g., to channel errors)
    - Performance

Summary

- Bandwidth and distance of networks is limited by physical properties of media.
  - Attenuation, noise, …
- Network properties are determined by transmission medium and transmit/receive hardware.
  - Can do much better with better encoding
- Framing helps provide control functionality
- Error detection and recovery mechanisms depend on error rate of the physical medium
- Multiple users can be supported using space, time, or frequency division multiplexing.
- Next lecture: How to do media access control and much more ☺