Lecture 6

Plan: finish QAM, modem speed, transmission media, multiplexing, switching
Review: Chapter 2 deals with physical layer (more like data communication material)

The need of modulation (shift keying). We have digital data, we will send it through an analog signal

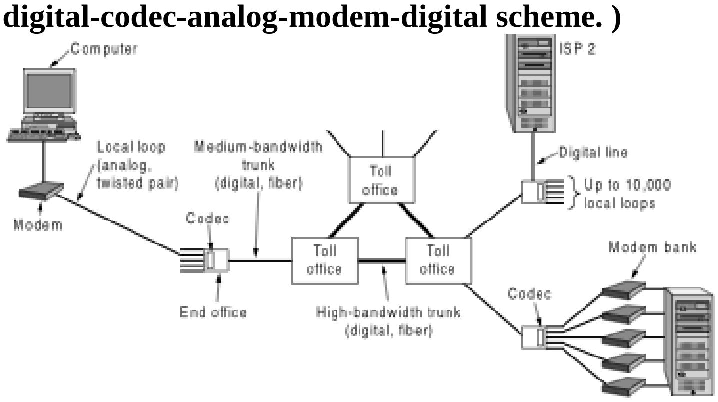
Q:/ Difference between binary and digital?

A:/ digital means discrete values. Binary is just one of digital type (the fundamental one)

2. Nyquist theorem. $C=2H\log_2(V)$ where V is the # of discrete signal levels (symbols, like greyness) ← → to transmit binary data, our sample frequency doesn't have to be greater than twice of the highest frequency in our original data.→ can't increase V too much so increase H is very important
Shannon'e theorem: The stronger the signal is compared with noise, the more information can be sent.

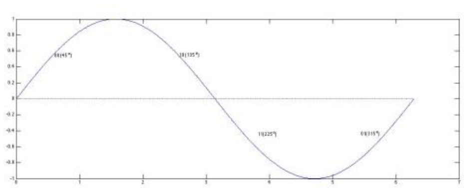
Today, we will finish the physical medium part then on Thursday, we will look at three dominant communication systems

1. QAM (Used in phone line modem / DSL modems stress on digital-modem-analog-codec-digital-codec-analog-modem-digital scheme.)

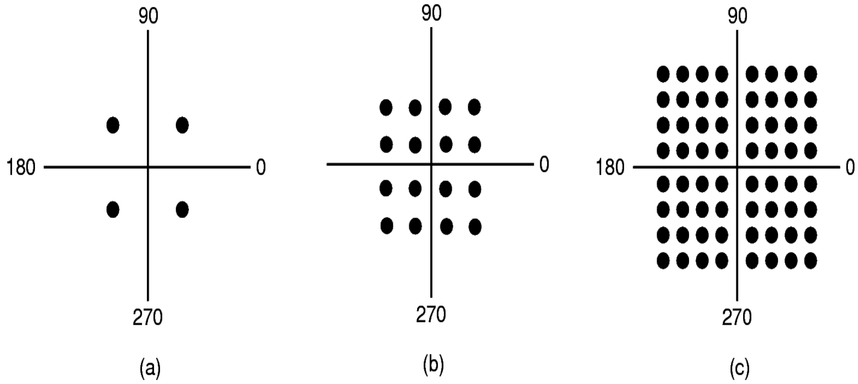


From Nyquist theorem → more digital symbols, more bit rate.
Q:/ how to generate more symbols.
A:/ One way is to achieve higher data rates, a combination of amplitude modulation and phase-shift modulation can be used.

Starting from quadrature phase shift keying (QPSK).
The phases are shifted 90 degrees for each symbol.
(basically starts at 45 degrees and add 90 degrees for each symbol change)



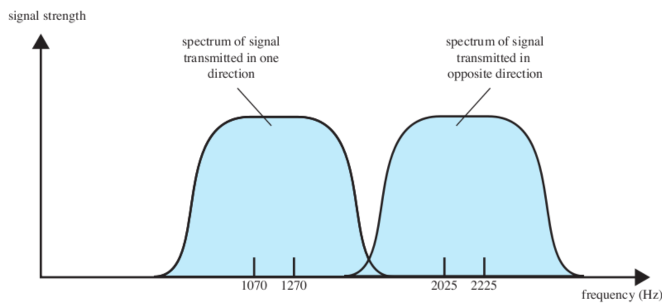
As the extension of QPSK, Quadrature Amplitude Modulation (QAM) are designed as a combination of PSK and ASK.



Use of QAM

(1)Early modems used 300 baud.

- FSK - Frequency shift keying
- send: 1070 Hz = 0, 1270 Hz = 1
- receive: 2025 Hz = 0, 2225 Hz = 1
- data rate = baud rate = 300 bps



(2)V.32bis

- 2400 baud
- 128-QAM   ($128 = 2^7$, so this method achieved 7 bits per baud, with 1 bit used as a parity bit)
- data rate = 14400 bps =2400*6

(3)V.34

- 2400 baud
- 14 bits/baud
- data rate = 33600 bps (maximum based on the shannon theorem)

(4)V.90

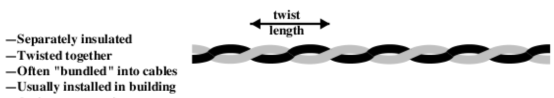
- upstream, same as V.34bis (33600 bps)
- downstream, all digital up to the subscriber-side local loop, capable of 56K bps (in US, the standard is 8bits/baud with 1 bit for error control). Since the lines are all digital signal, 8000 baud rate can be achieved (H is 4000Hz for telephone line,

according to Nyquist theory, 8000 symbols per second can be achieved). Thus 8000*7=56000bps

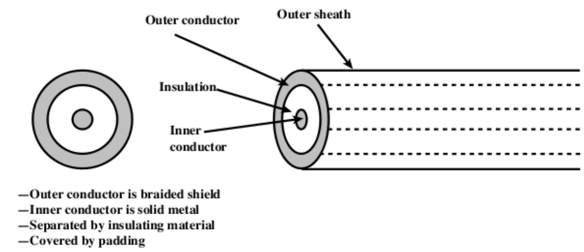
- no analog-to-digital on ISP side
- lower noise level

2. Transmission media:

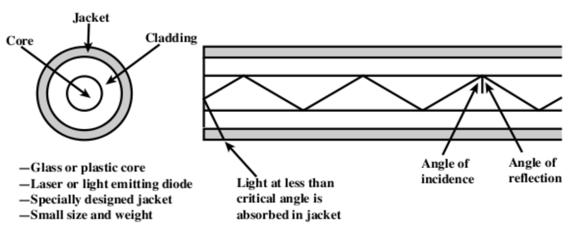
- **Guided Media**



(a) Twisted pair



(b) Coaxial cable



(c) Optical fiber

Copper wire (most common)

analog or digital,

widely used, such as in CPUs for transmission line, LAN, WANs

Use electrical current to send information. Need transmitter and receiver.

One problem is interference. A current in one wire generates an electromagnetic wave. This can generate currents (signals) in other nearby wires.

Answer to interference: twisted pair and coaxial cable.

- twisted pair
  - Two wires are insulated and wrapped around each other.
  - Twisted pair is used throughout the telephone system.
- coaxial cable
  - used by cable TV.
  - provides better shielding from interference
  - Offers better bandwidth than regular twisted pair

Optical fiber (fiber optics)

Use LED(light emitting diode) or ILD (injection laser diode) at the transmitter side
pulse = 1, no pulse = 0

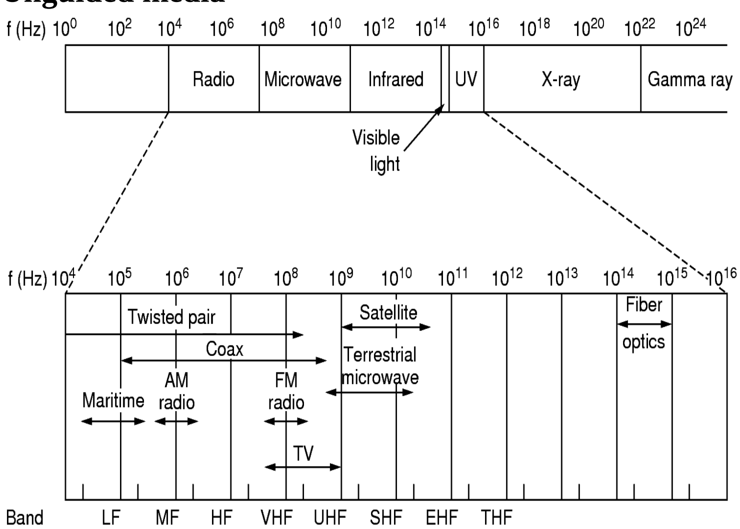
Q:/ Why light can be held in a wire?
A:/ "total internal reflection" (require a specific light (frequency) with the material)

Comparison with copper

- Advantages
  - Dramatically higher bandwidth ==> higher data rates
    - Use infrared light in the range or around 10^{14} Hz
    - Achievable bandwidth in excess of 50,000 Gbps
  - Low attenuation (i.e., loss of power)
    - Repeaters every 30 km (copper wire needs every 5 km)
  - No electromagnetic interference, corrosion, power surges
  - Lightweight
  - Does not need a circuit
- Disadvantages
  - New
    - Lack of people with skill in working with fiber
    - Higher maintenance costs
  - Unidirectional
  - More fragile

Fiber is used primarily for backbones

Unguided media



That is, wireless transmission

Physics: the higher the frequency, the shorter the wavelength.

If f increases, then wavelength decrease, less penetrable, more focused, unidirectional

- Radio waves (30 MHz - 1 GHz)
  - like radio and TV broadcast (AM between 1.5M to 20M, FM 88-108M) Q:/ why are all FM bands odd? A:/ 200K as a frequency band. The center is odd.
  - can penetrate buildings
  - travel long distances
  - omnidirectional
- Microwave (2 - 40 GHz)
  - higher frequency than radio waves
  - unidirectional - can be aimed
  - do not bend with the curvature of the earth, so tall towers and repeaters are needed (line-of-sight)
  - do not pass through buildings well
  - used for long-haul telephone transmission, mobile phones
- Infrared
  - higher frequency than microwave
  - directional
  - do not pass through solid objects
  - used for small single-room networks or indoor wireless LANs
- Microwaves can also use satellites for transmission

  The satellite acts as a "transponder" - it receives signals, then retransmits them back to earth. A "big repeater in the sky".

  Two types of satellite:
  Geosynchronous
  - remains stationary above some point on earth
  - must be at specific altitude, approximately 36000 km above the equator
  - good for broadcast
  - not good for security

  Low-orbit
  - only 200-400 miles up
  - satellites move in orbit
  - many satellites are needed to cover the earth
  - at any given time, use the closest satellite

In comparison with fiber, satellite has much lower bandwidth, so it is limited to niche applications:(satellite phone)

Q:/ **How can we make the best use of our valuable physical medium?**
A:/ **enable multiple signals to transmit on the same wire -- Multiplexing**

Don't confuse multiplexing with duplexing
multiplexing deals with multiple signals while duplexing deals with two directions.

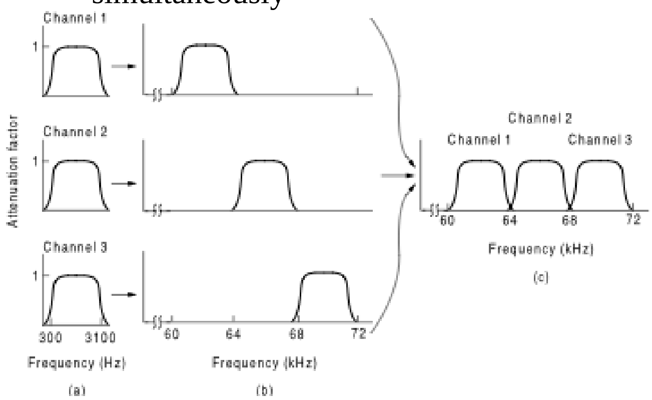
two general applications:

- multiple independent channels on a single (high bandwidth) line
- high bit rate for a single conversation, but running on multiple channels in parallel

Several techniques are used:

FDM - Frequency division multiplexing

- used if bandwidth is available exceeds what is needed for one signal
- on copper wire
- used for TV and radio channels, in DSL for parallel transmission to increase throughput, and used in long distance telephone network trunks to carry multiple conversations simultaneously



WDM - Wave division multiplexing

- analogous to FDM in optical fiber
- use different wavelengths of light for different channels

TDM - Time division multiplexing

- used for digital transmission
- interleave the data streams from multiple sources, then separate them at the other end.
- Synchronous TDM
  - Each of n sources is allocated exactly 1/n -th of the time slots (bit, byte, or whatever).
  - Each frame needs one bit to indicate whether or not it is being used
- Asynchronous (statistical) TDM
  - Each slot needs an address to identify which stream it comes from.

e.g. T lines:

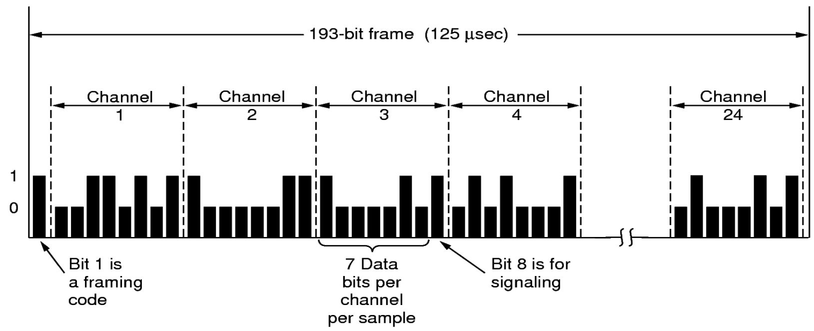
At the codec in the phone line system, PCM is used to transform analog signals back to digital.

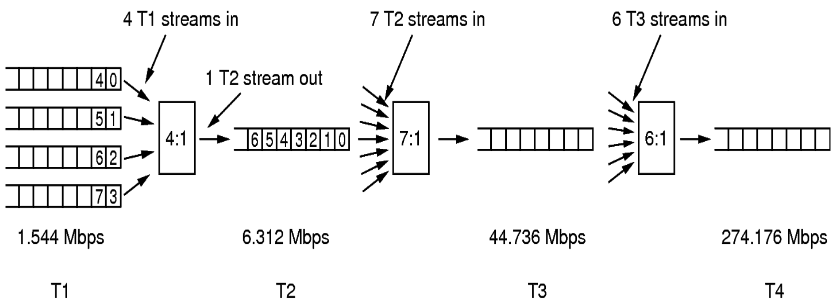
PCM - Pulse Code Modulation

- Analog signal is sampled 8000 times per second.
- (2 * bandwidth of 4000 Hz --> determined by Nyquist theorem)

- Amplitude is quantized into 128 discrete levels
- That level is represented by a 7-bit binary number (in fact there 8 bits and that extra bit is for control)
- These seven bits are sent on a digital channel.

in T1, 193 bits every 125 microsecond. So the speed is 1.544Mbps





	voice channels	bit rate (Mbps)
T-1	24	1.544 (24 channels at 64 Kbps each)
T-2	96	6.312
T-3	672	44.736
T-4	9032	274.176

These are digital signals. If used for voice, the analog voice signal is digitized using PCM. They use TDM.

Switching
1. Circuit switching

(as in the telephone system)

When a call is made, a circuit is made between the phones at each end. That circuit is dedicated to the two end users. We call it an *end-to-end* connection.

Advantage: The setup (and routing) only occurs once.

Disadvantage: Bandwidth is wasted when no one is talking. In case of a crash, we have to start over.

2. Message switching

Each message is switched independently.

A message is sent to the switching office, and routed from office to office, until reaching its destination.

Called "store and forward"

The problem is long blocks, so it is not used in practice. Instead, messages are divided into smaller units, leading to:

3. Packet switching

- Split messages into pieces of some maximum size.
- Each packet is routed to the destination independently of the others.
- No single user can monopolize one router.
- However, now much more routing needs to be done.