Lec3-mwf

Thursday, January 10, 2008 12:45 PM

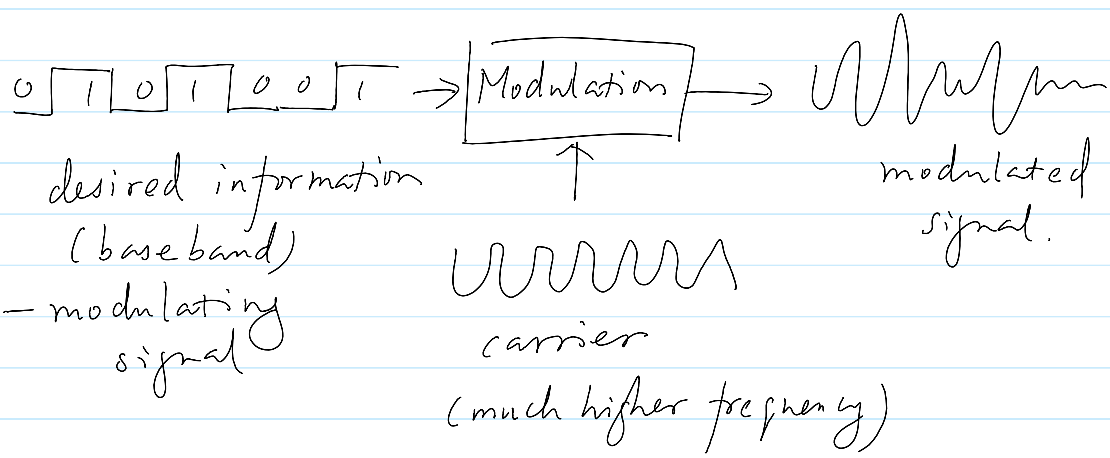
Modulation - 20min

Sunday, March 02, 2008 10:56 AM

In all wireless networks, we need to transmit information over ~~the~~ wireless medium.

Usually, communication is carried out using a specific carrier frequency.

Various "modulation" schemes are used to transmit the "desired information" over the carrier.

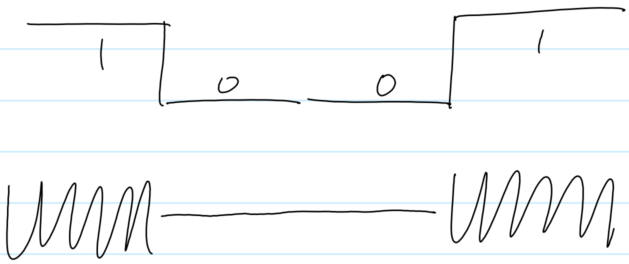


Carrier is at a much higher frequency
- better channel characteristic
- easier filter design
- small footprint of antenna

Let $c(t) = A\cos(\omega_c t + \varphi)$ be the carrier.

Modulation can happen at the

① Amplitude (Amplitude Shift Keying)
On-Off Keying

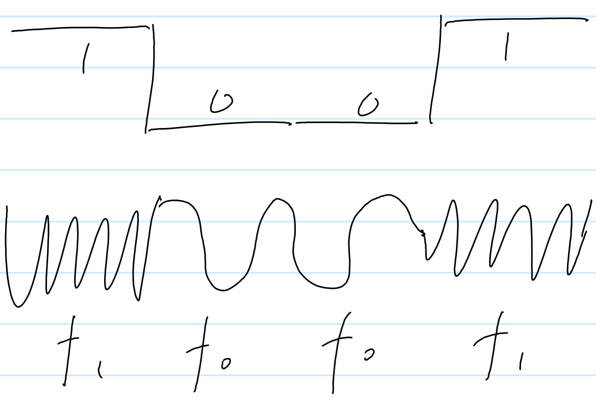


Detection:

If Amplitude $\overset{1}{\underset{0}{\gtrless}}$ threshold

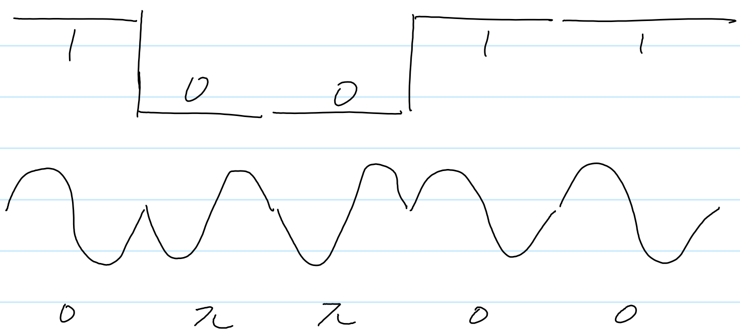
- Optimal threshold is half the maximum amplitude (if there is no fading)
- When there is significant noise or interference, error could occur.

② Frequency (Frequency Shift Keying)



how to decode?

③ Phase (Phase Shift Keying)

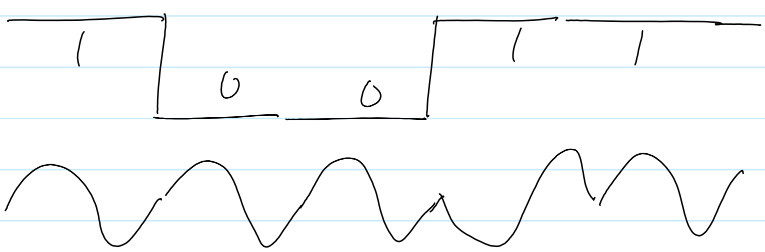


Standard phase shift keying need knowledge of the phase reference

If phase reference is incorrect, all bits may be inverted.

DPSK is more robust to incorrect phase reference:

- 1 = phase shift
  0 = no phase shift



Both FSK & PSK has constant envelop in the modulated waveform

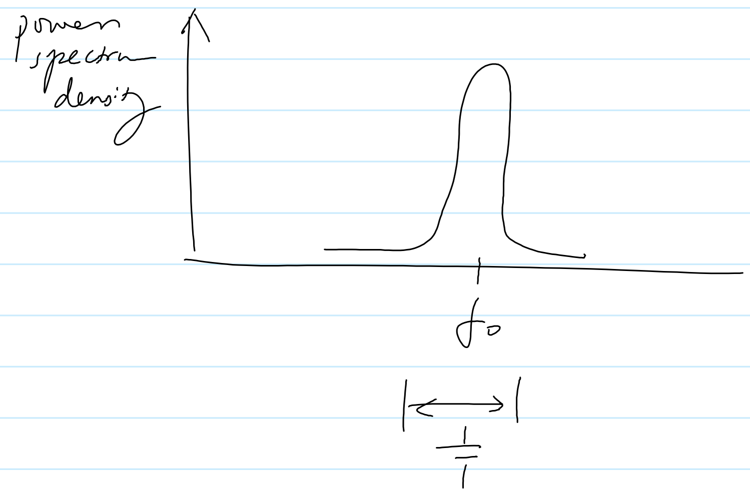
$\Rightarrow$ resilent to fading

$$c(t) = \underset{\substack{\uparrow \\ \text{ASK}}}{A} \cos(\underset{\substack{\uparrow \\ \text{FSK}}}{\omega_c} t + \underset{\substack{\uparrow \\ \text{PSK}}}{\varphi})$$

Bandwidth

- When information is carried on a carrier frequency, the resulting modulated signal will occupy some bandwidth

- Rule of thumb, if the modulating signal changes once every T, the modulated signal occupies a bandwidth that is $\approx \frac{1}{T}$



- Thus, data rate $\propto$ symbol rate $\propto$ bandwidth

- This provides the basic idea of frequency channels or FDMA

Example: AMPS : 1G Cellular Analog System in US

Uplink	824 – 849 MHz	25M
Downlink	869 – 894 MHz	25M

Each channel is 30k Hz (FDMA)

25M/30k = 832 channels

- In practice, there needs to be guardbands between channels, so the real info of each channel $\leq$ 25kHz.

- S... ... been done in radio, TV, etc.

Similar FDMA has ... done in ..., ..., etc.

Signal to Noise and Interference Ratio (SINR)

- How high a data rate that a fixed amount of bandwidth can support then depends on:
  - The bandwidth W, symbol rate, etc.
  - The modulation scheme
  - The amount of noise and interference that will cause errors
  - Any channel coding scheme that is used to combat errors, at the cost of increased redundancy in the information.
- It turns out that there is a limit that any modulation & coding scheme can do, which is known as Shannon's Capacity

$$R \le W \lg (1 + SINR)$$

can be achieved asymptotically by infinite-long codes.

- In practice (esp. in earlier generations of wireless systems), the data rate may be quite-far from the Shannon Capacity
- Nonetheless, R is usually still a function of W & SINR, which allows us to analyze the

the network capacity.

Characterizing the Wireless Channel -15min

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Why is channel characterization important

- it determines the quality of the signal as well as the level of interference

Unlike wireline networks where there is a clear notion of a link, In wireless networks it is just a bunch of stations sharing the radio frequency.

We need to know how signals propagate, and how interference accumulate in order to

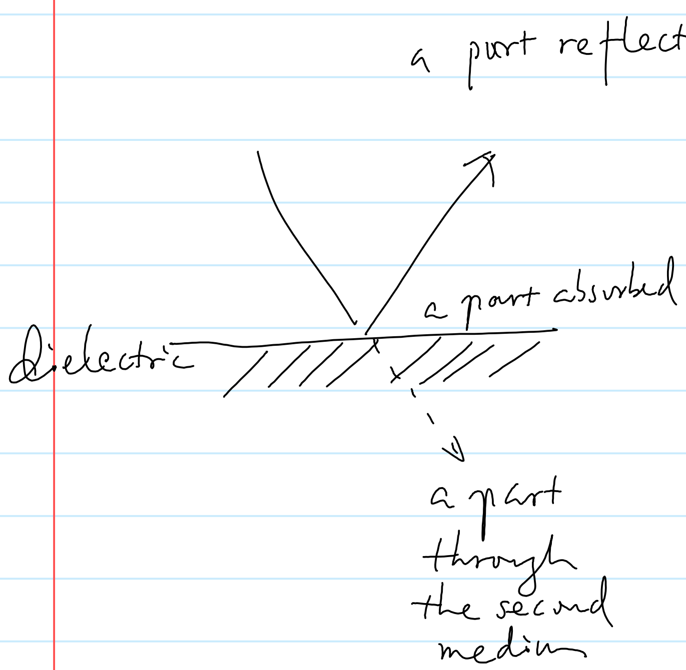
- ensure good coverage
- plan the size & location of cells
- determine the spectrum reuse pattern
- choose the right modulation/coding/multi-access schemes.

Radio transmissions over wireless channels are in general very difficult to characterize.

① EM signal generated at either end will encounter obstacles during the

transmission, causing
- reflection
- diffraction
- scattering

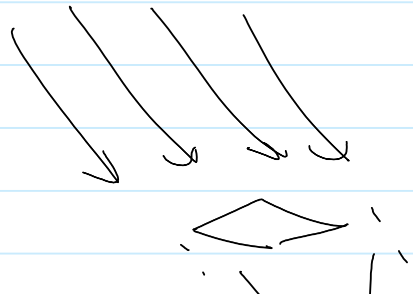
Reflection



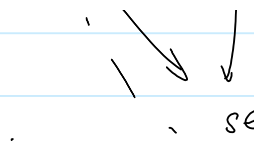
When a plane wave is incident on a dielectric, part of the wave is reflected back to the first medium, part of the wave is transmitted through the second medium, part of the wave is absorbed.

- perfect dielectric: no absorption
- perfect conductor: only reflection

Diffraction



obstruction surface with sharp irregularities (edges)



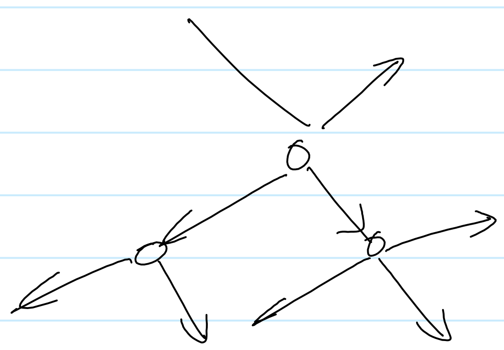
secondary waves present even behind the obstacle

- Diffraction occurs when the radio path between the transmitter & recv is obstructed by a surface that has sharp irregularities (edges)

- The secondary waves resulting from the obstructing surface are present throughout the space & even behind the obstacle

- Less so for small wavelength (becomes more like light).

Scattering



- objects that are small (compared to wavelength
- # of objects per unit volume is large
- e.g. rough surface,

leaves, street signs
light posts, winter
snow.

- Scattering occurs when the medium through which the EM wave travels consists of objects that are small compared to the wavelength and where the # of the obstacles per unit volume is large

- EM wave goes in all directions.

(2) Mobility: As terminals move, the conditions of reception at either end change.

(3) Different paths of the EM signals can enhance or cancel each other, depending on their amplitude/phase

Fading: the received signal strength can fluctuate significantly over time and space.

As a result, the radio propagation can be very complicated.

There are three approaches to model

radio channel & propagation:

- EM modelling via Maxwell Equation (deterministic approach)

  Too complex in practice, lack of insights

- Ray-tracing, using geometry

  Can also be quite complex

- Probablistic models

  Simple, give good rule of thumb.

  Analogy: throwing a coin. Since there are too many factors that affect which side of the coin will land, instead of using a complex deterministic model based on mechanics, we use a simple probablistic model that the coin lands on its head side i.i.d with prob. p.

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Probabilistic Models

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Using probablistic models, we can identify 3 components that affect the signal once it is transmitted

- Path loss (i.e., attenuation)
- Shadow fading (log-normal fading, large-scale fading)
- Multipath fading (small-scale fading)

Path loss-5min

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Attenuation of the EM signal due to distance.

We will study 2 models:

- Free-space model
- 2-ray model

In both cases:

constant

$$L = K/d^n$$

distance from the transmitter

- Free-space model, $n = 2$
- 2-ray model, $n = 4$
- In general, $2 < n < 4$

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Free-space model-15min

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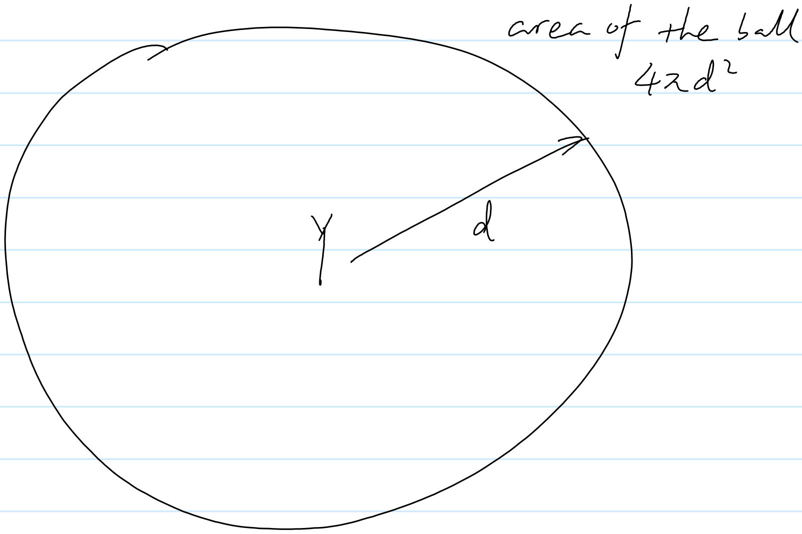
- No obstacles



First, assume that power emitted from the transmitting antenna isotropically. (omni-directional)

P_T = transmission power

From the conservation of power, the receiver power density at distance d is

$$\delta p_r(d) = \frac{P_T}{4\pi d^2}$$

If the receiving antenna has an effective area (or aperture) A_R, the received power is

$$P_r(d) = \frac{P_T}{4\pi d^2} \cdot A_R \cdot \eta_R$$

$\eta_R < 1$ is the efficiency parameter of the receiving antenna, due to

- transmission line attenuation
- filter loss
- antenna loss, etc.

Effective area of isotropic antenna is

$$A_R = \frac{\lambda^2}{4\pi}, \quad P_R(d) = P_T\left(\frac{\lambda}{4\pi d}\right)^2$$

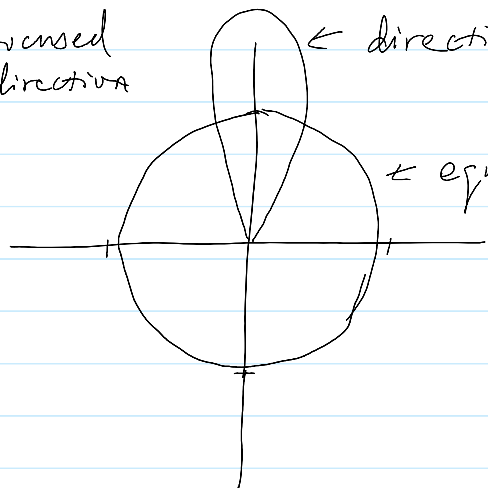
— Note that this decreases as $\lambda \downarrow$ (or $f \uparrow$)

$\lambda = c/f$ c=3*10^8 m/s

Gain due to directional Antennas

Directional antennas can provide a gain factor over omnidirectional antennas

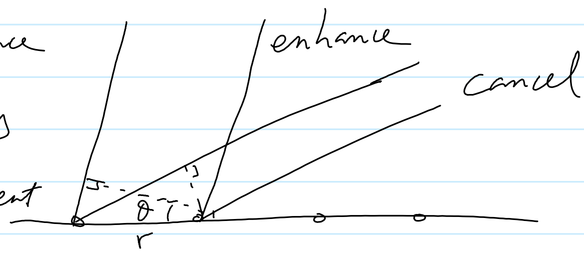
energy focused in one direction



← directional antenna gain

← equal-strength curve

phase difference among the received signals of each antenna element



phase difference $= \dfrac{r \cdot \sin\theta}{\lambda}$

directional antenna built from

antenna arrays

Both transmitter & the receiver can have such type of gains.

At the transmitter side,

G_T = gain factor of the transmitting antenna

G_T is proportional to the effective radiating area A_T (the antenna size in wavelengths) of the transmitting antenna.

$$G_T = \frac{4\pi \eta_T A_T}{\lambda^2}$$

wavelength

η_T = effeciency factor for transmitting antenna. (similar to η_R)

Isotropic Antenna

$$\frac{4\pi}{\lambda^2} \cdot A_T = 1$$

The received power is then

$$P_r(d) = \frac{P_T}{4\pi d^2} G_T A_R \eta_R$$

The effective area A_R obeys a similar relationship.

If we define the attenna gain at the receiver end

$$G_R = \frac{4\pi \eta_R A_R}{\lambda^2}$$

Then

$$P_r(d) = P_T \, G_T G_R \left(\frac{\lambda}{4\pi d}\right)^2$$

then

$$P_r(d) = P_T \, G_T G_R \left(\frac{\lambda}{4\pi d} \right)^2$$

— Friis free-space equation.

Notes:

① The Friis equation is good only for the far field (or Fraunhoefer region)

Far-field distance

$$d_f = \frac{2D^2}{\lambda^2} \quad \text{— in \# of wavelengths}$$

where D is the longest physical linear dimension of the antenna.

② $\lambda = \frac{c}{f}$

③ $P_r(d)$ can be written as

$$P_r(d) = P_r(d_0) \left(\frac{d_0}{d} \right)^2$$

In dB (decibel), $10 \log_{10} X$ the power decreases by 20dB as the distance is increased by 10 dB.

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