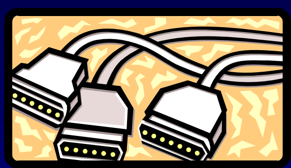
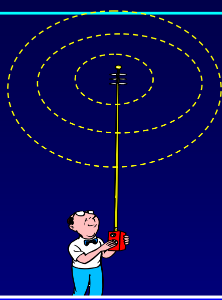
Digital Wireless Communication Basics:
Overview of basic concepts

Wired Vs. Wireless Communication





Wired	Wireless
Each cable is a different channel	One media (cable) shared by all
Signal attenuation is low	High signal attenuation
No interference	High interference noise; co-channel interference; adjacent channel interference

Why go wireless ?

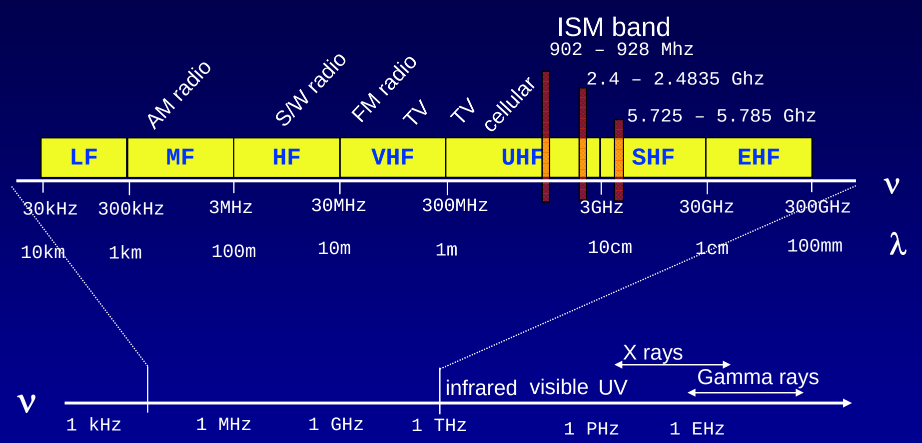
Advantages

- Sometimes it is impossible/impractical to lay cables
- User mobility
- Cost

Limitations

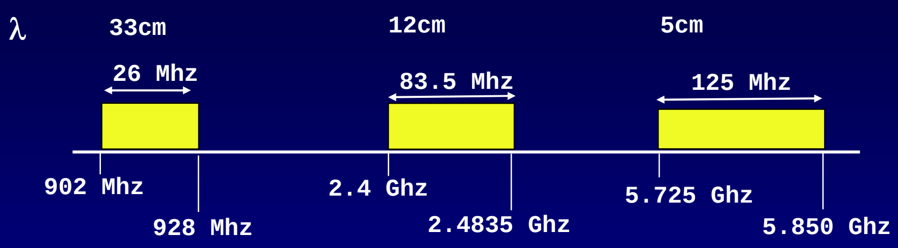
- Bandwidth
- Power
- Security

EM Spectrum



Propagation characteristics are different in each frequency band

Unlicensed Radio Spectrum

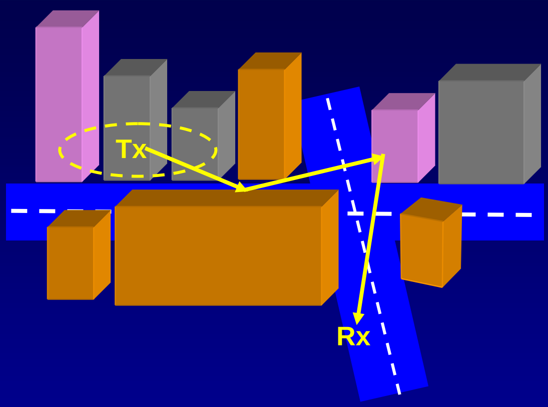


cordless phones
baby monitors
WaveLan

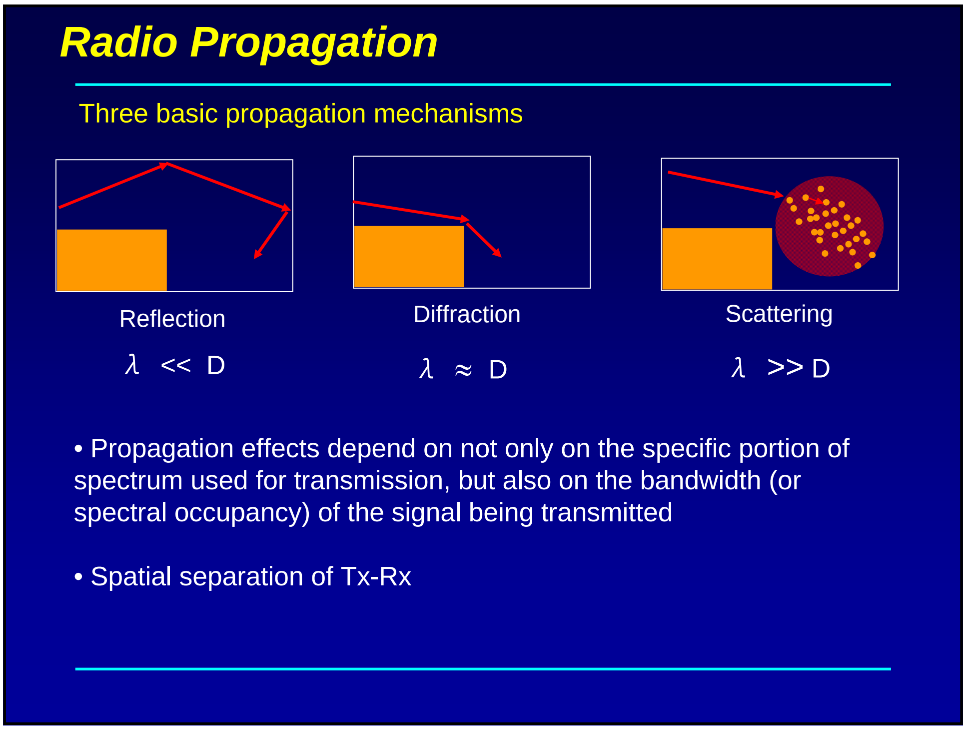
802.11b+g+n
Bluetooth
Microwave oven

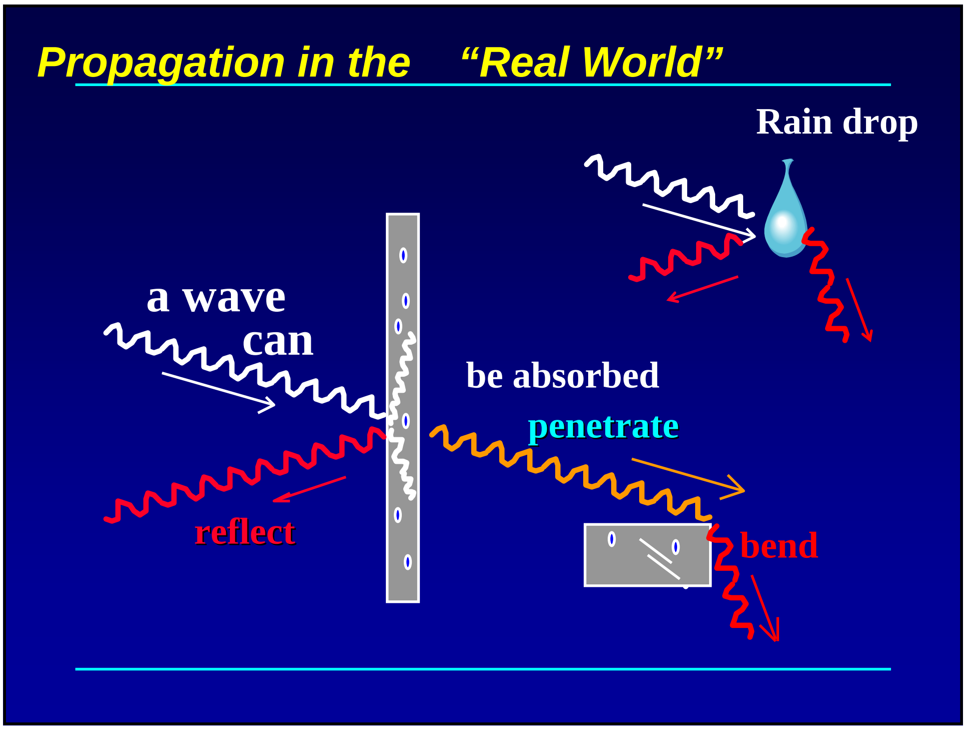
802.11a+n

Understanding wireless communication



- How does signal propagate ?
- How much attenuation take place ?
- How does signal look like at the receiver ?

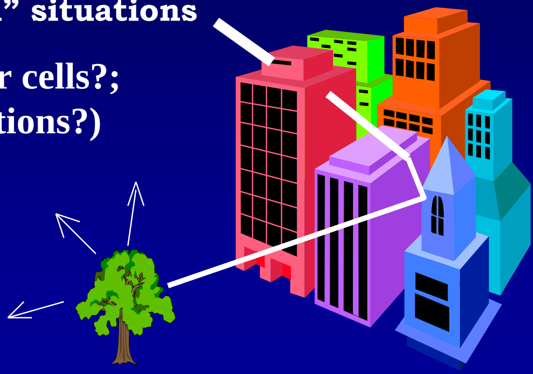

Radio Propagation
Three basic propagation mechanisms
Reflection
λ << D
Diffraction
λ ≈ D
Scattering
λ >> D
• Propagation effects depend on not only on the specific portion of spectrum used for transmission, but also on the bandwidth (or spectral occupancy) of the signal being transmitted
• Spatial separation of Tx-Rx


Propagation in the "Real World"
Rain drop
a wave
can
be absorbed
penetrate
reflect
bend

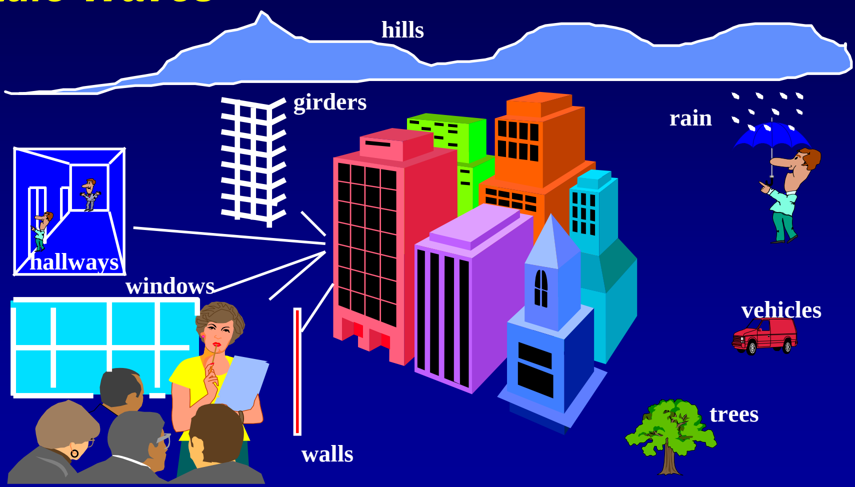
Propagation

And, the higher frequencies will usually encounter more “loss” in “real world” situations

(again, smaller cells?; more base stations?)



The Cluttered World of Radio Waves



Exercise

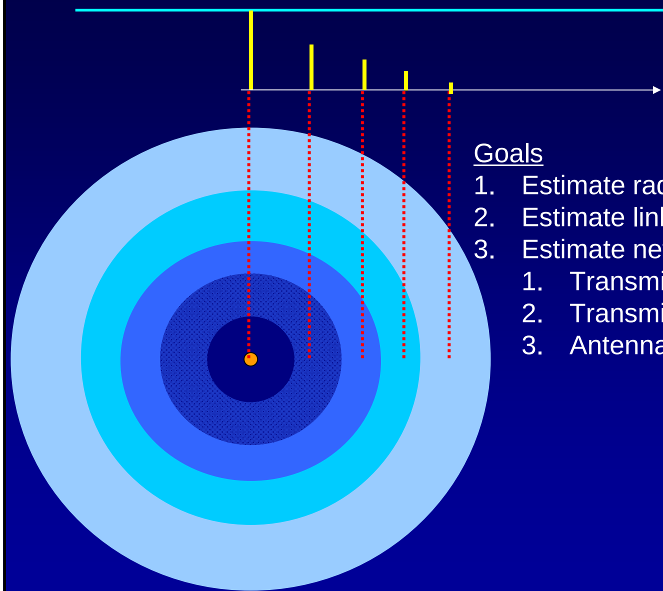
- Selection of the spectrum is one of the important part of the network design
  - What are the trade-off factors for the spectrum selection?
    - If you select lower frequency
      - Good for ____(Use case), reason _______
      - Bad/Difficult for _____(Use case), reason ______
    - If you select higher frequency
      - Good for ____(Use case), reason _______
      - Bad/Difficult for _____(Use case), reason ______

Evaluating Frequencies

- 50 MHz- Good for range outdoors (antenna size, bending and penetrating), no foliage problems. “Sees” metallic building structures, doesn’t pass through windows or down corridors, needs large antenna (2 meter). TV?
- 450 MHz to 2 GHz - Good compromise for cellular-type systems. Antenna small, but big enough for outdoor range. Minor foliage effects. OK for windows walls and corridors. (450 might be best, but ...) (Range issue for 2 GHz systems- more bases)
- 5-20 GHz- Antenna too small for range. Foliage and rain effects. Indoor microcells? Point-to-point? Satellites to ground stations?

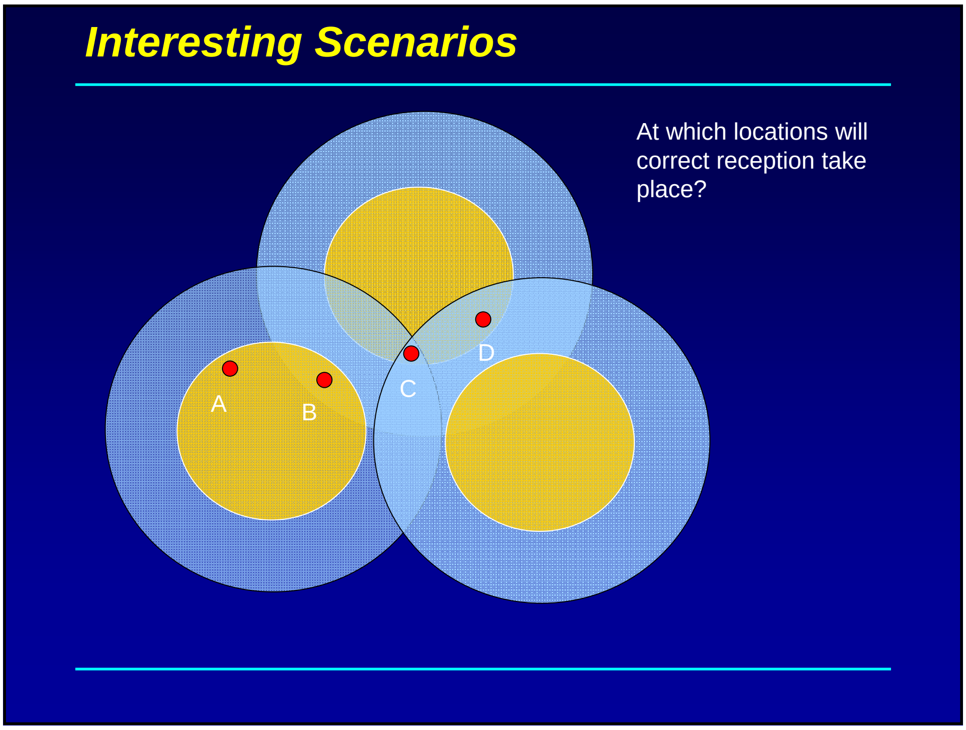
Summary of Path Loss in Propagation

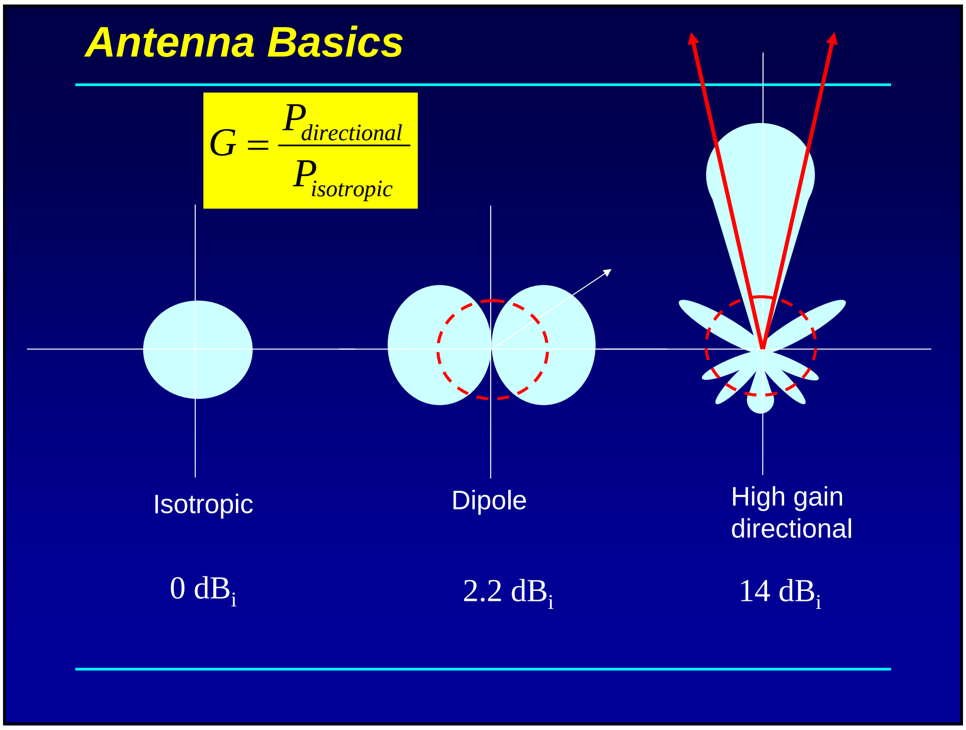
Understanding RF Propagation



Goals

1. Estimate radio coverage area
2. Estimate link performance
3. Estimate network design parameters
    1. Transmitters and their location
    2. Transmit power
    3. Antenna type

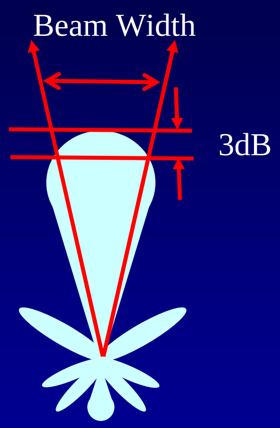

Interesting Scenarios
At which locations will correct reception take place?
A
B
C
D


Antenna Basics
$G = \frac{P_{directional}}{P_{isotropic}}$
Isotropic
Dipole
High gain directional
0 dB$_i$
2.2 dB$_i$
14 dB$_i$

Antenna performance

- half-power beam width
- Sample calculation
  - Parabolic antenna for sat com

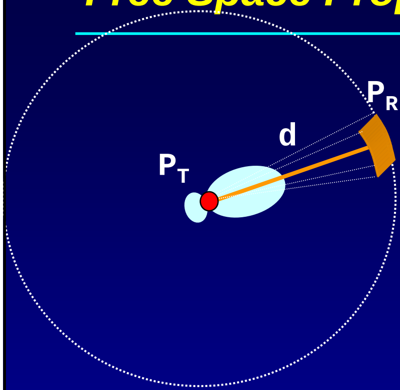
$$BW = \frac{70 \times \lambda[m]}{D[m]}$$



Sample calculation

- You have 1.8m antenna for satellite communication
- The antenna receive and transmit the signal in Ku band (UL 14GHz, DL 12GHz) and also can be used in C band (UL 6GHz, DL 4GHz)
- Calculate the half beam power width (angle)
  - Ku band ______ deg
  - C band ______ deg
- Compare with Yagi-antenna BW for terrestrial TV service

Free Space Propagation Model



Predict received signal strength when the transmitter and receiver have a clear line-of-sight path between them

$$P_{Di} = \frac{P_T}{4\pi d^2} W / m^2$$

Isotropic power density

$$P_D = \frac{P_T G_T}{4\pi d^2}$$

Power density along the direction of maximum radiation

$$P_R = P_D A_{eff}$$

Power received by Antenna

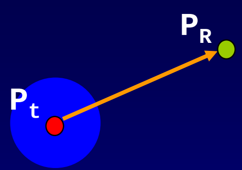
$$P_R = \frac{P_T G_T}{4\pi d^2} A_{eff}$$

$$\frac{A_{eff}}{G} = \frac{\lambda^2}{4\pi}$$

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

Also known as Friis free space formula

Path Loss (relative measure)



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

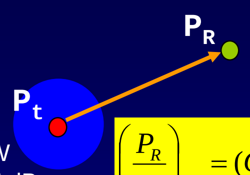
$$\frac{P_R}{P_T} = G_T G_R \frac{0.57 * 10^{-3}}{(df)^2}$$

f is in MHz
d is in Km

$$\left(\frac{P_R}{P_T} \right)_{dB} = (G_T)_{dB} + (G_R)_{dB} - (32.5 + 20\log_{10} d + 20\log_{10} f)$$

Path Loss represents signal attenuation (measured on dB) between the effective transmitted power and the receive power (excluding antenna gains)

Path Loss (Example)



50 W
= 47 dBm

Assume that antennas are isotropic.
Calculate receive power (in dBm) at free space distance of 100m from the antenna.
What is P_R at 10Km?

$$\left(\frac{P_R}{P_T}\right)_{dB} = (G_T)_{dB} + (G_R)_{dB} - (32.5 + 20\log_{10} d + 20\log_{10} f)$$

$$\left(\frac{P_R}{P_T}\right)_{dB} = 0 + 0 - (32.5 + 20\log_{10} 0.1 + 20\log_{10} 900)$$

59

-20 (for d = 0.1)

$$\left(\frac{P_R}{P_T}\right)_{dB} = -71.5dB$$

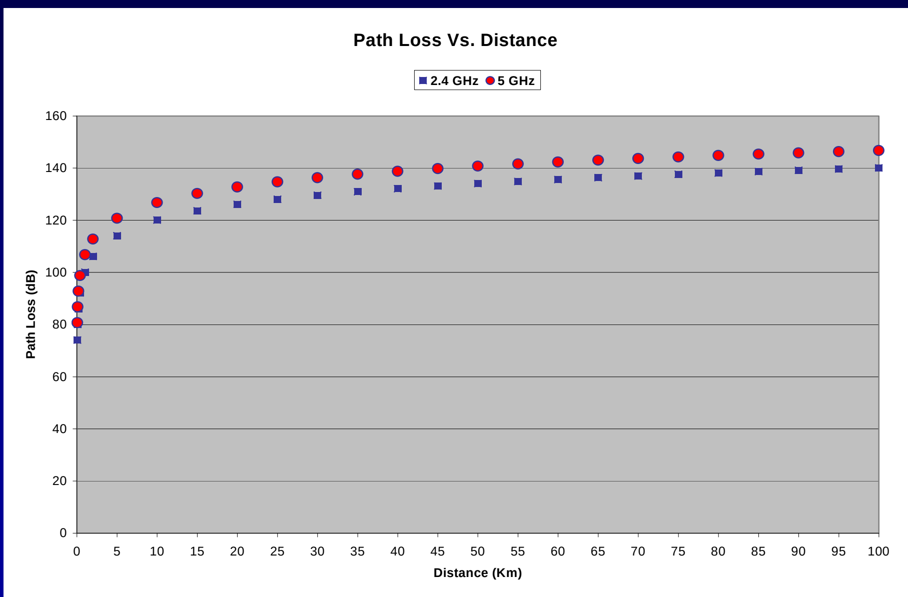
$$(P_R)_{dBm} = 47 - 71.5 = -24.5dBm$$

20 (for d = 10)

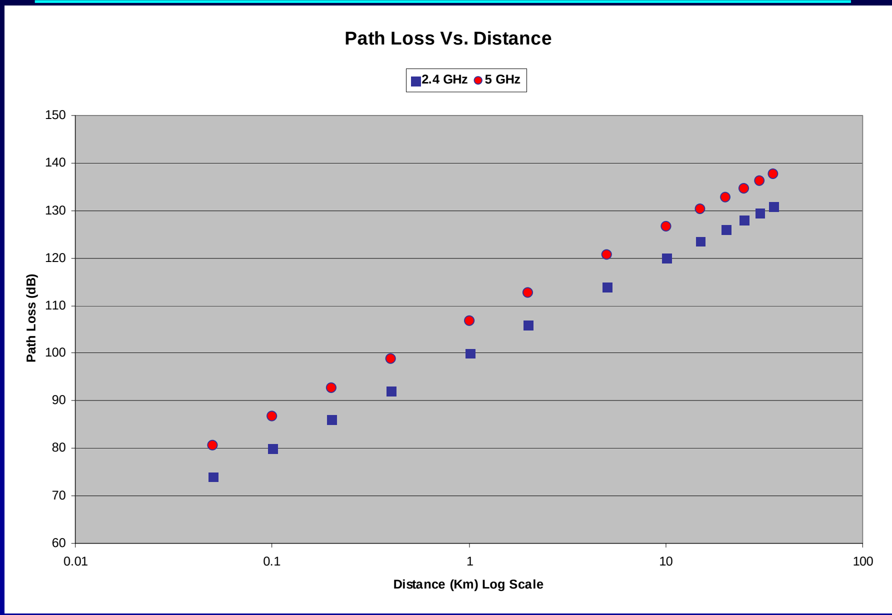
$$\left(\frac{P_R}{P_T}\right)_{dB} = -111.5dB$$

$$(P_R)_{dBm} = 47 - 111.5 = -64.5dBm$$

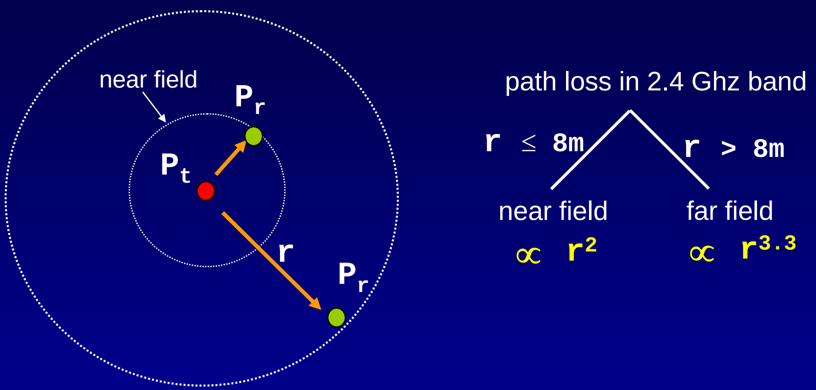
Path Loss (another example)



Path Loss (another example)



Radio propagation: path loss



path loss $= 10 \log (4\pi r^2/\lambda)$ $\quad r \leq 8m$

$= 58.3 + 10 \log (r^{3.3}/8)$ $\quad r > 8m$

Basics of Small Scale Fading: Towards choice of PHY

Basic Questions

T_x

What will happen if the transmitter
- changes transmit power ?
- changes frequency ?
- operates at higher speed ?

Transmit power, data rate, signal bandwidth, frequency tradeoff

What will happen if we conduct this experiment in different types of environments?

Desert | Metro | Street | Indoor

Channel effects

What will happen if the receiver moves?

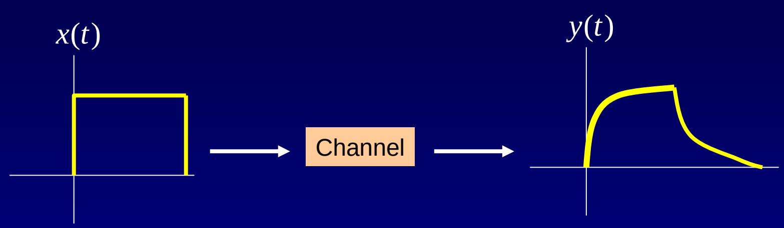
R_x

Effect of mobility

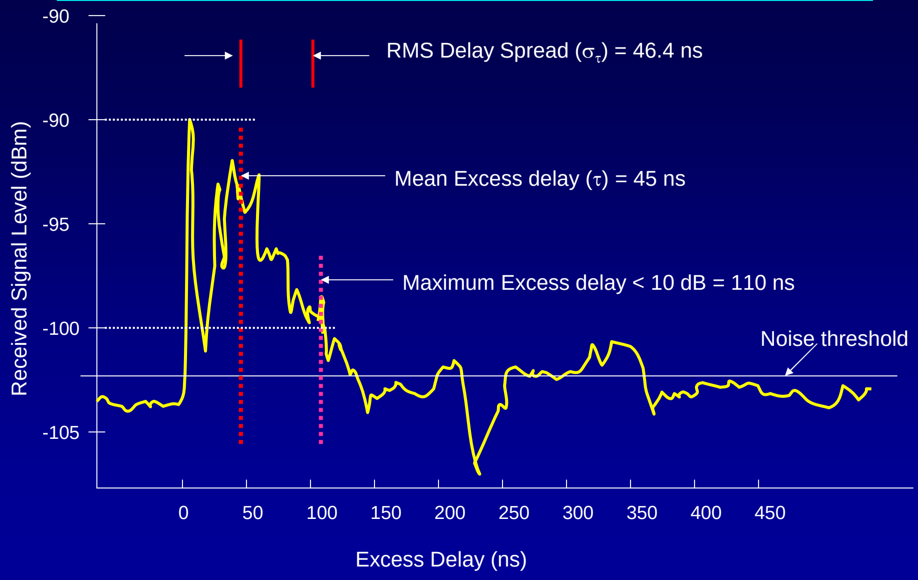
Review of basic concepts

- Channel Impulse response
- Power delay profile
- Inter Symbol Interference
- Coherence bandwidth
- Coherence time

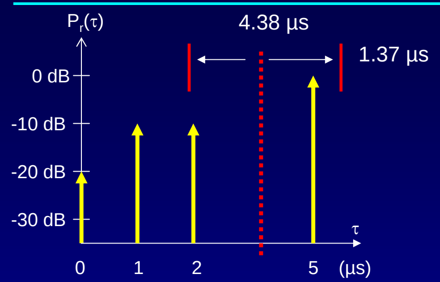
Channel Impulse Response



Power delay Profile



Example (Power delay profile)



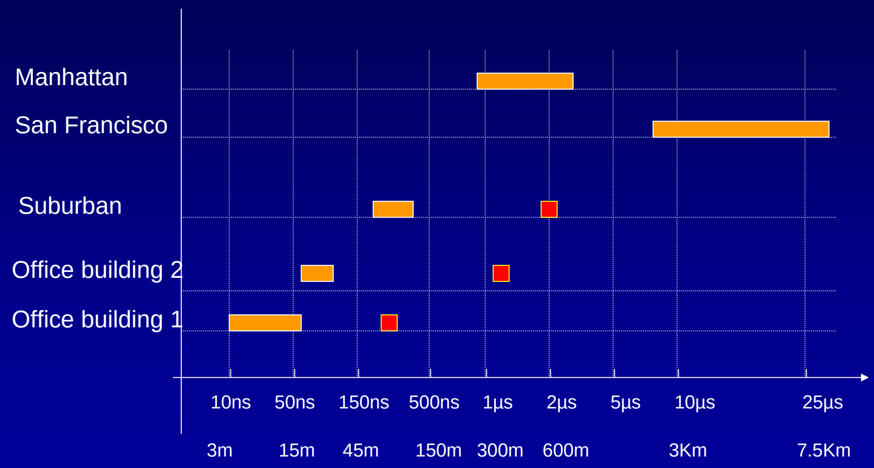
$$\bar{\tau} = \frac{(1)(5)+(0.1)(1)+(0.1)(2)+(0.01)(0)}{[0.01+0.1+0.1+1]} = 4.38\mu s$$

$$\overline{\tau^2} = \frac{(1)(5)^2+(0.1)(1)^2+(0.1)(2)^2+(0.01)(0)^2}{[0.01+0.1+0.1+1]} = 21.07\mu s^2$$

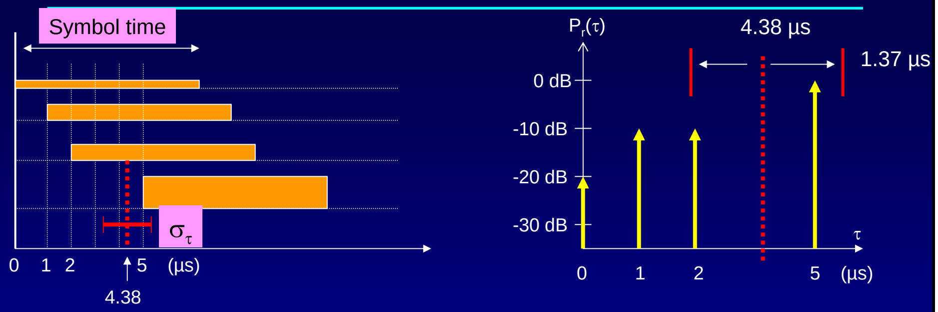
$$\sigma_\tau = \sqrt{21.07-(4.38)^2} = 1.37\mu s$$

RMS Delay Spread: Typical values

Delay spread is a good measure of Multipath



Inter Symbol Interference

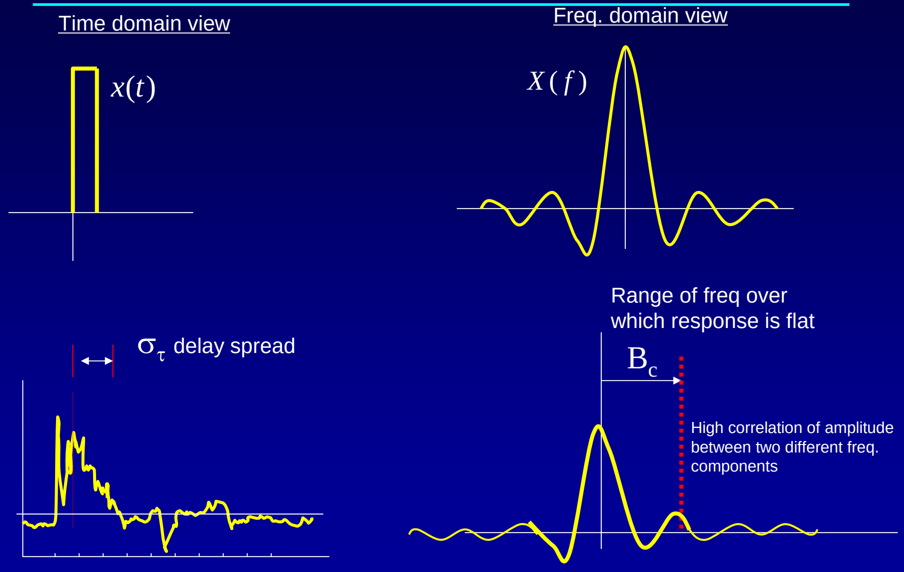


Symbol time > 10* σ_τ --- No equalization required

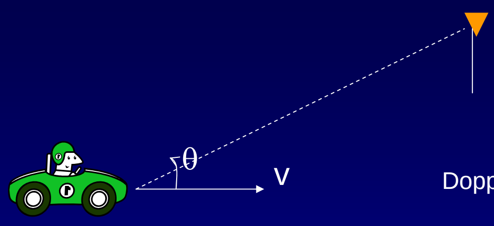
Symbol time < 10* σ_τ --- Equalization will be required to deal with ISI

In the above example, symbol time should be more than 14µs to avoid ISI.
This means that link speed must be less than 70Kbps (approx)

Coherence Bandwidth



Doppler Shift



Doppler shift $\Delta f = \frac{v\cos\theta}{\lambda}$

Example

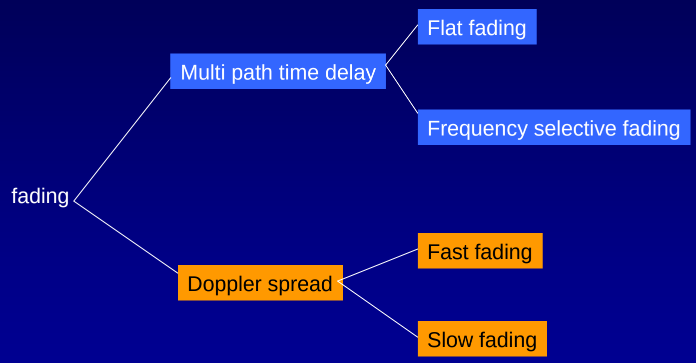
- Carrier frequency f_c = 1850 MHz (i.e. λ = 16.2 cm)
- Vehicle speed v = 60 mph = 26.82 m/s
- If the vehicle is moving directly towards the transmitter

$$\Delta f = \frac{26.82}{0.162} = 165Hz$$

- If the vehicle is moving perpendicular to the angle of arrival of the transmitted signal

$$\Delta f = 0$$

Small scale fading



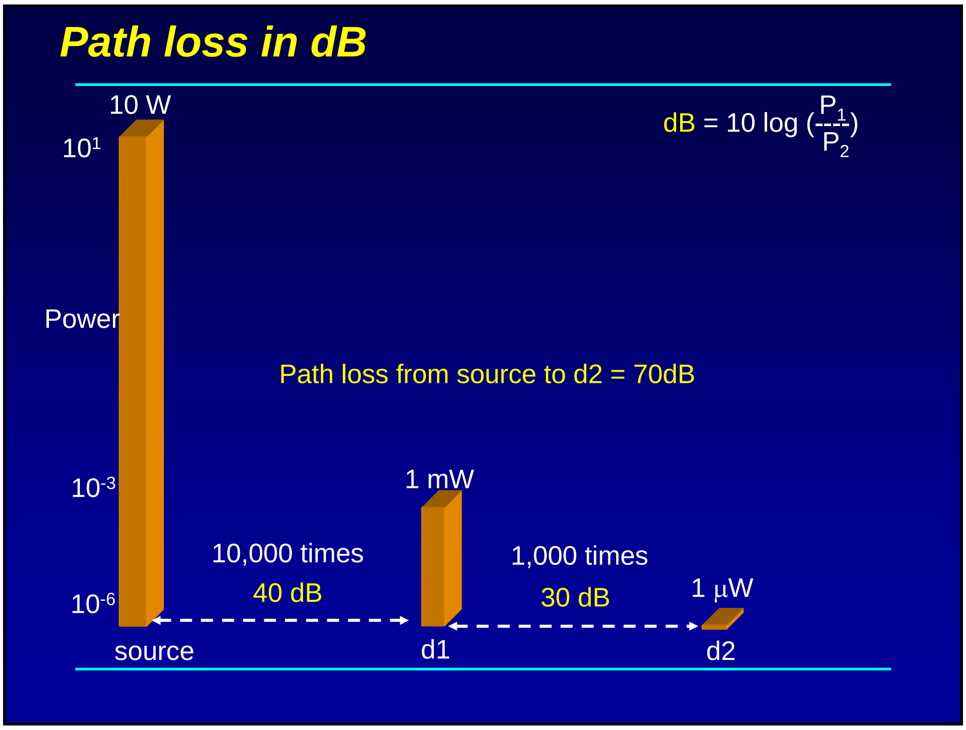
PHY Layer Design Choices ?

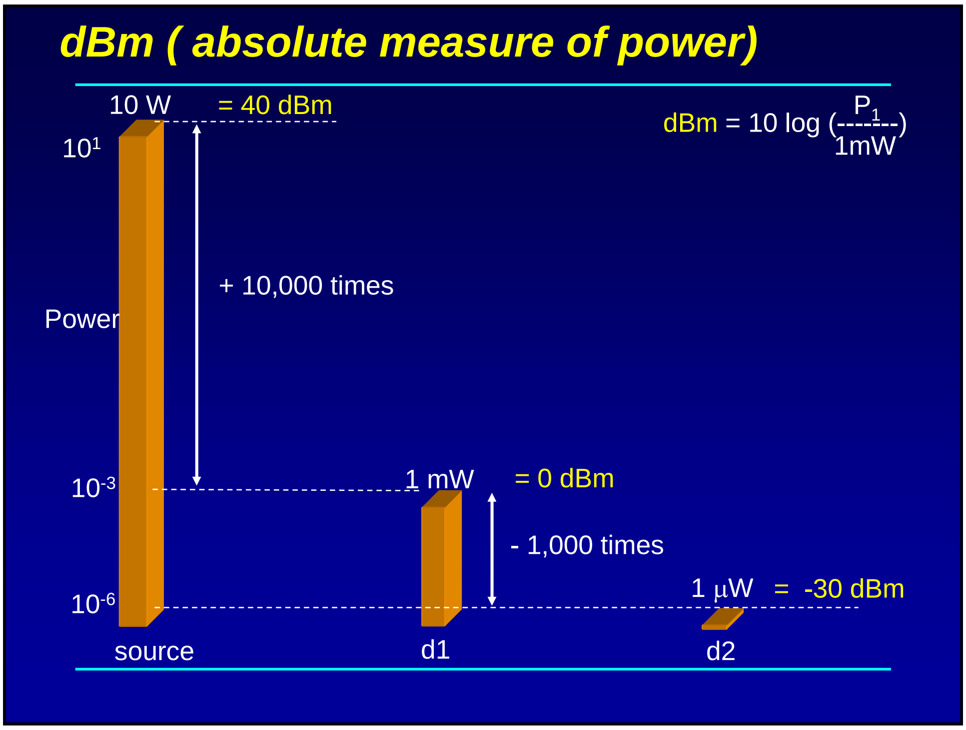
- Required Data Rates
  - Determines channel : frequency selective or flat fading; fast or slow fading
- Required QoS at the PHY: bit-error-rate (BER), packet-error-rate (PER), Frame-error-rate (FER)
  - May be determined by application needs (higher layers)
  - Affected by Interference and Noise levels
- PHY layer choices include selection of
  - Modulation/Demodulation
  - Techniques to mitigate fading: diversity, equalization, OFDM, MIMO
  - Techniques to mitigate interference (if necessary)
  - Error correction Coding

Exercise

- Consider a low earth orbiting satellite network system design. It would have multipath and Doppler shift effect
  - Compare the link environment difference between terrestrial cellar network and low earth satellite network (e.g. orbit altitude 100km and 1000km)
    - Fading, Pass loss, Tracking, Delay, etc.
  - Hint: you have to consider the relative speed between satellite and the terminal on the earth
  - You can set any assumption, such as
    - Number of the satellite
    - Terminal size, mobility
    - Use case
    - Etc.

Back up


Path loss in dB
10 W
10^1
dB = 10 log (P_1 / P_2)
Power
Path loss from source to d2 = 70dB
1 mW
10^{-3}
10,000 times
40 dB
1,000 times
30 dB
1 µW
10^{-6}
source
d1
d2


dBm (absolute measure of power)
10 W
= 40 dBm
10^1
dBm = 10 log (P_1 / 1mW)
+ 10,000 times
Power
10^{-3}
1 mW
= 0 dBm
- 1,000 times
1 µW
= -30 dBm
10^{-6}
source
d1
d2