Fundamentals of Wireless Communications

Advanced Data Communications and Wireless Networks

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Contents

- Course Contents
- Communication Process, and Communication Resources
- Analog and Digital Types of Communication
- Shannon's Information Capacity Theorem
- Spectrum Allocation
- Theory of Radio Communication Channels

Course Contents

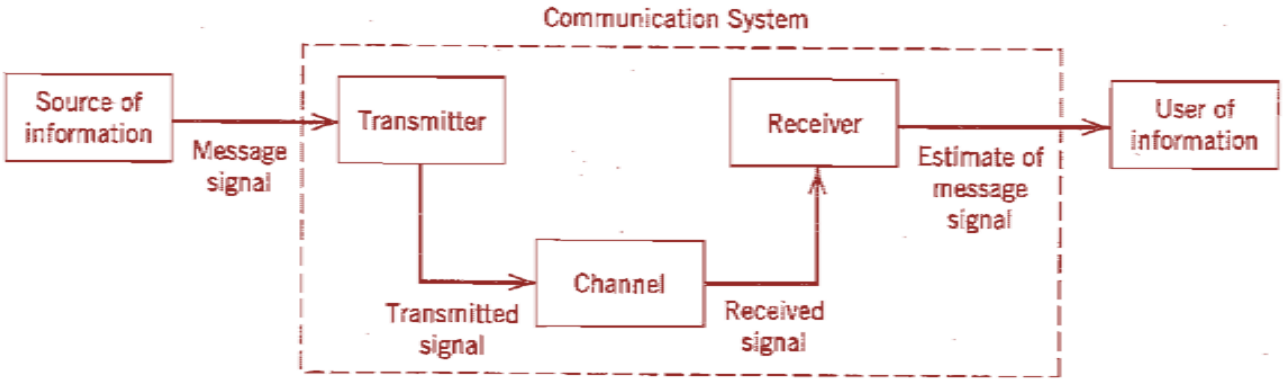
- Basic concepts of Wireless Communications
- Antenna Types
- Satellite Communications (types, parameters, configuration, and capacity)
- Cellular Networks (Frequency reuse, cell capacity, frequency reuse, propagation model, power control, GSM, CDMA, TDMA, 3G etc)
- WLAN, and WPAN (PHY and MAC)
- Date communication: Wireless ATM
- Digital Switching

Books…

- Reference Books:
  - Next Generation Wireless Systems and Networks- Chen & Guizani.
  - Satellite Communication Engineering– M.O. Kolawole
  - Satellite Communications– P Bostian
  - Wireless Communications- Andrea Goldsmith.
  - Data and Computer Communications—William Stallings
  - Wireless Communications and Networking– VK Carg.

Communication Process

- Communications applications and area
- Tx-to-Rx
  - Message signals: voice, music, computer date, picture, video, volume data
  - Symbols: Electrical, aural or visual
  - Encoding
  - Decoding and reproduction
  - Re-creation
- Elements? Modes=Broadcast & pt-to-pt



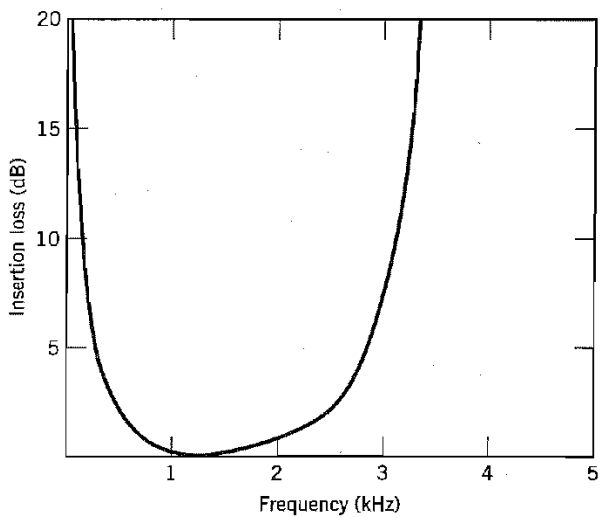
Communication Resources

- Tx power and Channel BW
- Band limited (Telephone circuit) and Power limited (space com link or satellite channel)
- Voice articulation over 300 to 3100 Hz
- Noise(external or internal)
- SNR and dB

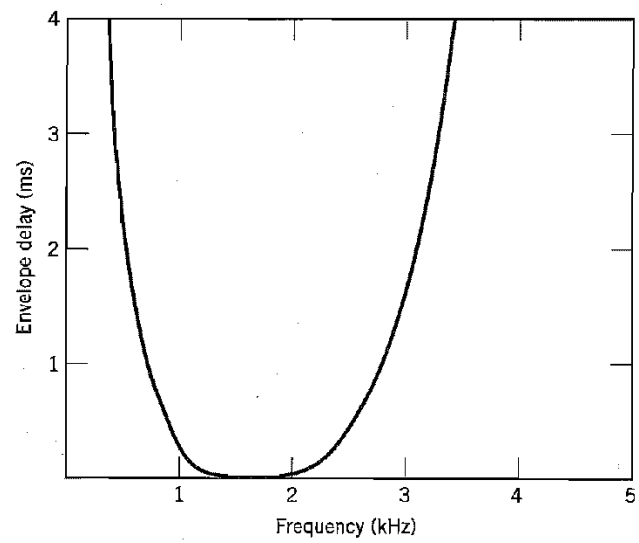
Communication Channels

- Free space or Guided
- Telephone channel (Band limited); Coaxial cable, Optical Fiber

EMI Immunity



(a)

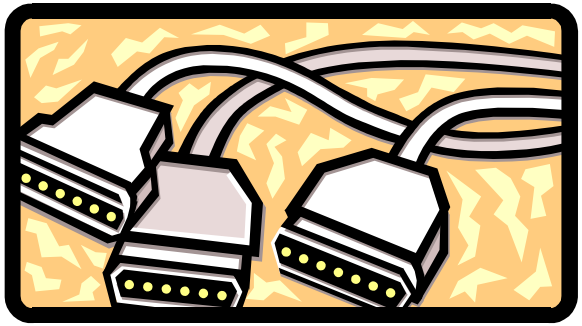


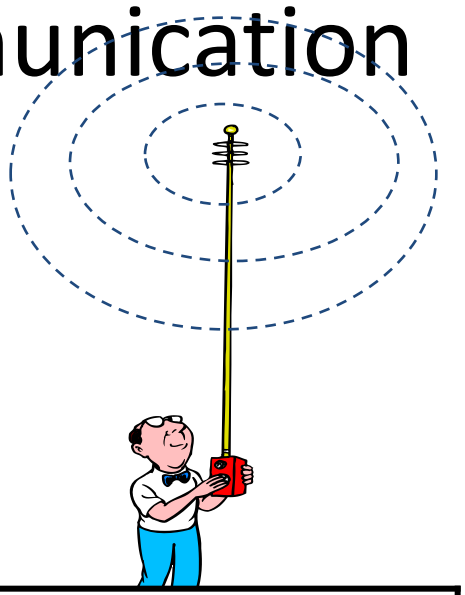
(b)

- Wireless channel, mobile radio, satellite channel

Linearity
Time variance
Resource Limit

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 impractical to lay cables
- User mobility
- Cost

Limitations

- Bandwidth
- Fidelity
- Power
- (In)security

Shannon's Capacity Theorem

Information capacity of the channel

Channel BW

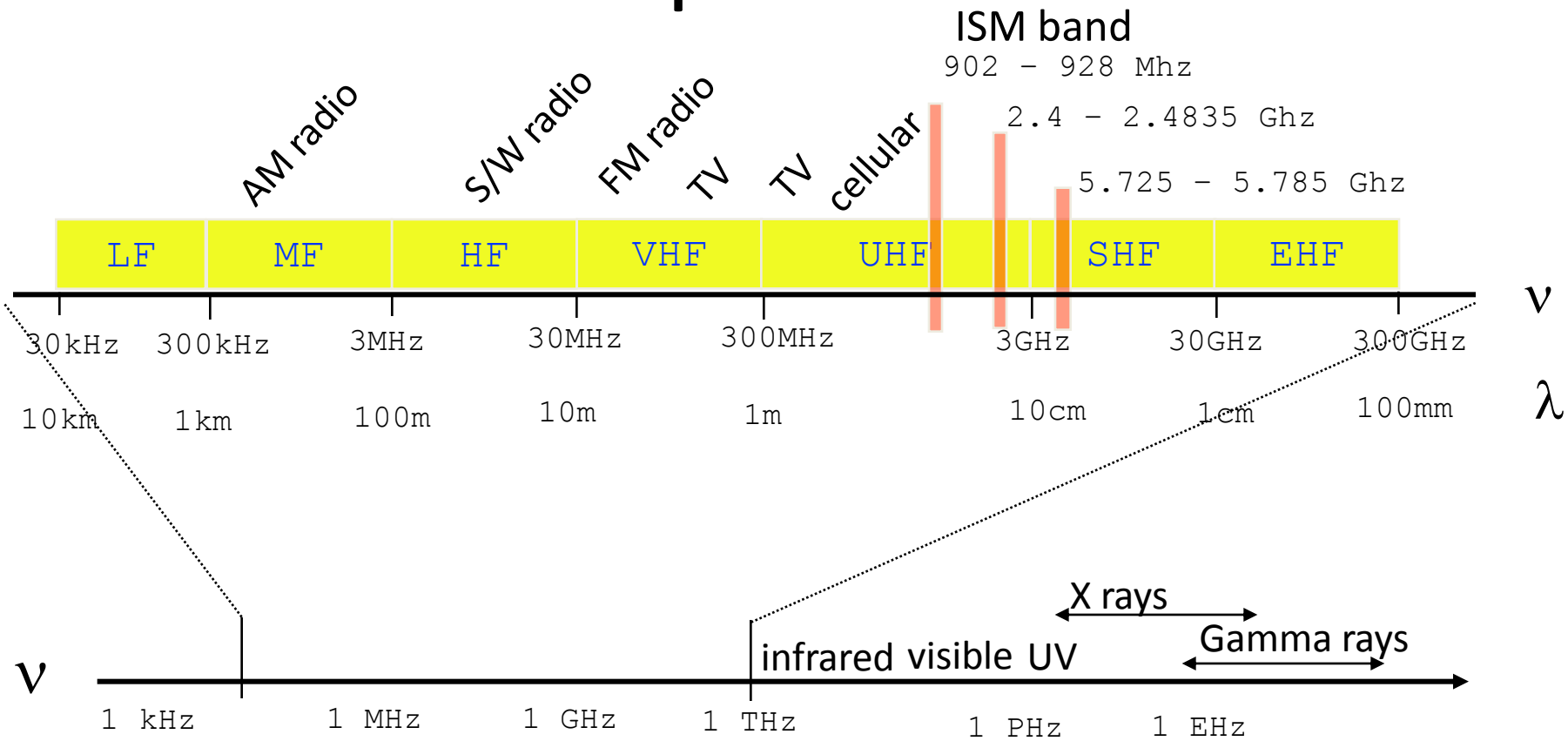
$$C = B \log_2(1 + \mathrm{SNR}) \text{ b/s}$$

- Efficiency of a digital com sys $\eta = \frac{R}{C}$
- Trade-off between channel BW and SNR
- Idealized framework for performance comparisons

Spectrum Allocation

- FCC, OSM: Office of spectral management (OSM), BTCL, ITU, ETSI
- Spectral auctions?
- License and unlicensed spectrum
- Spectral underlay system: UWB
- Cognitive Radio

EM Spectrum

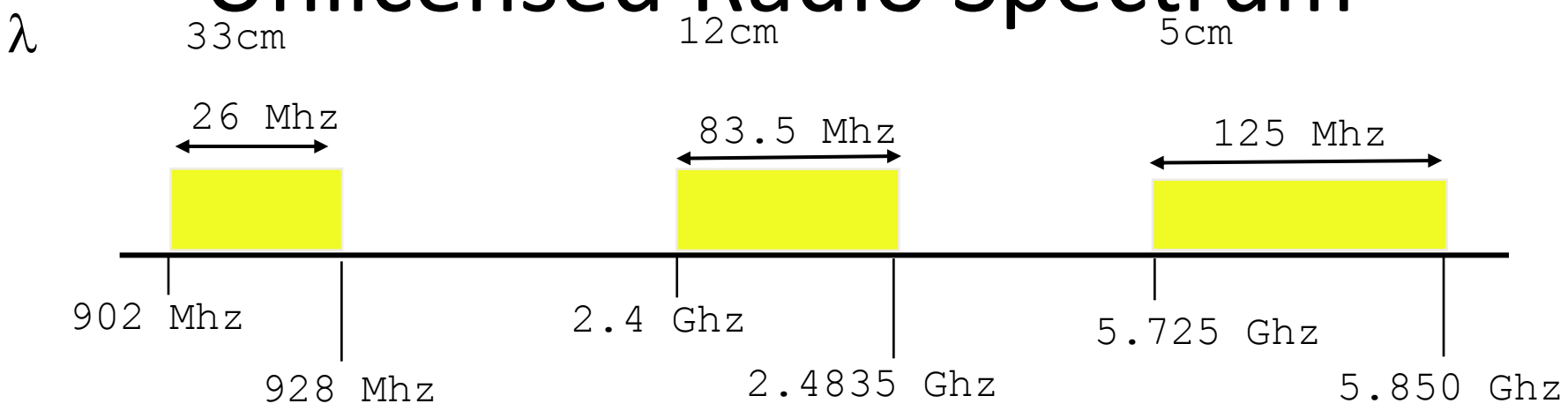


Propagation characteristics are different in each frequency band

Existing Licensed spectrum

AM Radio	535-1605 KHz
FM Radio	88-108 MHz
Broadcast TV (Channels 2-6)	54-88 MHz
Broadcast TV (Channels 7-13)	174-216 MHz
Broadcast TV (UHF)	470-806 MHz
3G Broadband Wireless	746-764 MHz, 776-794 MHz
3G Broadband Wireless	1.7-1.85 MHz, 2.5-2.69 MHz
1G and 2G Digital Cellular Phones	806-902 MHz
Personal Communications Service (2G Cell Phones)	1.85-1.99 GHz
Wireless Communications Service	2.305-2.32 GHz, 2.345-2.36 GHz
Satellite Digital Radio	2.32-2.325 GHz
Multichannel Multipoint Distribution Service (MMDS)	2.15-2.68 GHz
Digital Broadcast Satellite (Satellite TV)	12.2-12.7 GHz
Local Multipoint Distribution Service (LMDS)	27.5-29.5 GHz, 31-31.3 GHz
Fixed Wireless Services	38.6-40 GHz

Unlicensed Radio Spectrum



cordless phones
baby monitors
WaveLan

802.11b
Bluetooth
Microwave oven

802.11a

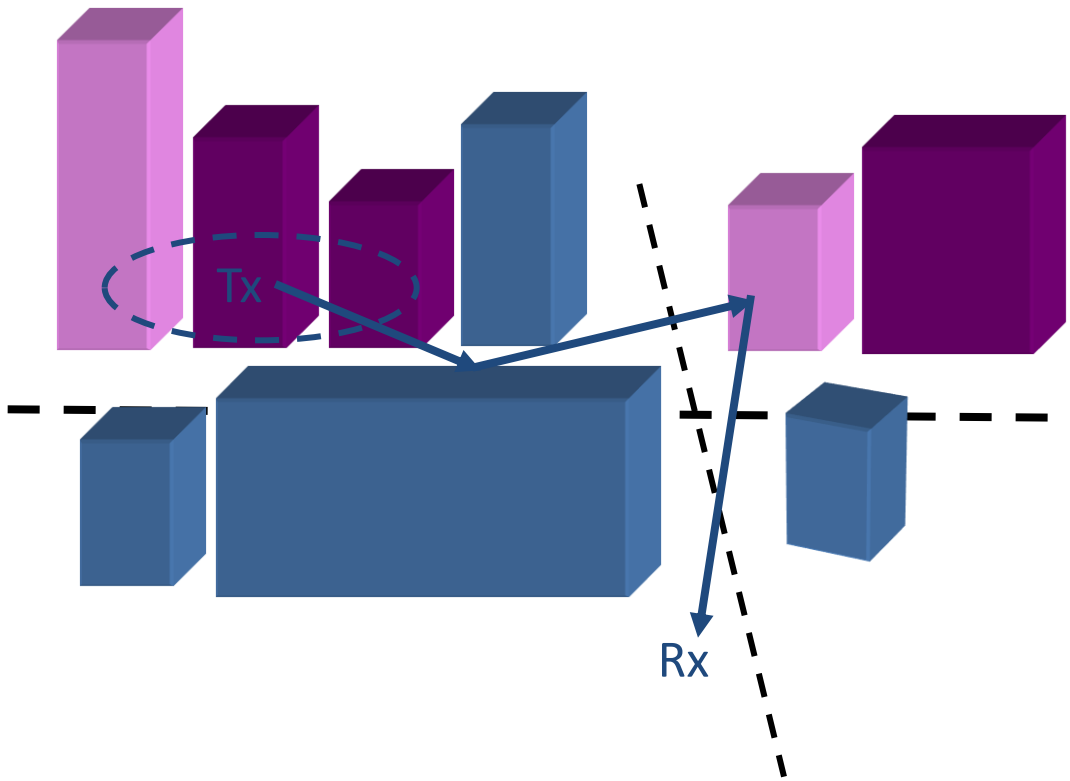
Unlicensed spectrum

ISM Band I (Cordless phones, 1G WLANs)	902-928 MHz
ISM Band II (Bluetooth, 802.11b WLANs)	2.4-2.4835 GHz
ISM Band III (Wireless PBX)	5.725-5.85 GHz
NII Band I (Indoor systems, 802.11a WLANs)	5.15-5.25 GHz
NII Band II (short outdoor and campus applications)	5.25-5.35 GHz
NII Band III (long outdoor and point-to-point links)	5.725-5.825 GHz

Unlicensed National Info Infrastructure

MICS- Medical implant comm service (401-406 MHz)

Understanding wireless communication



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

Theory of Radio Communication Channel

- Not only noise and external interference
- Radio Signal Propagation
  - Free-space propagation model (SAT, MICRO, Deep Space)

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{16\pi^2 d^2 L}$$

Loss Factor: Tx line, filter attenuation, antenna loss

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

Effective aperture

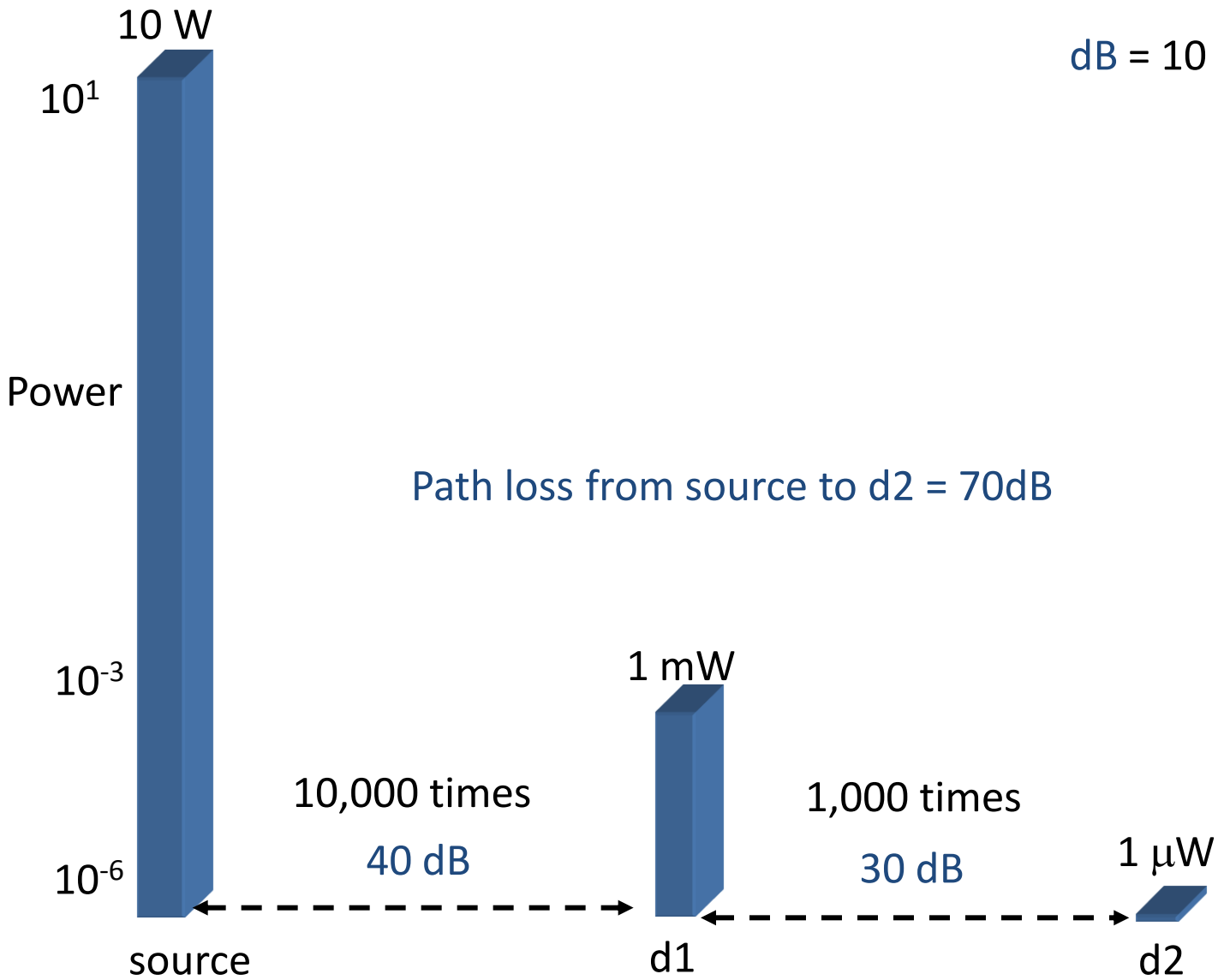
$$\lambda = \frac{c}{f} = \frac{2\pi c}{\omega_c}$$

Effective size of the antenna

Power of d?

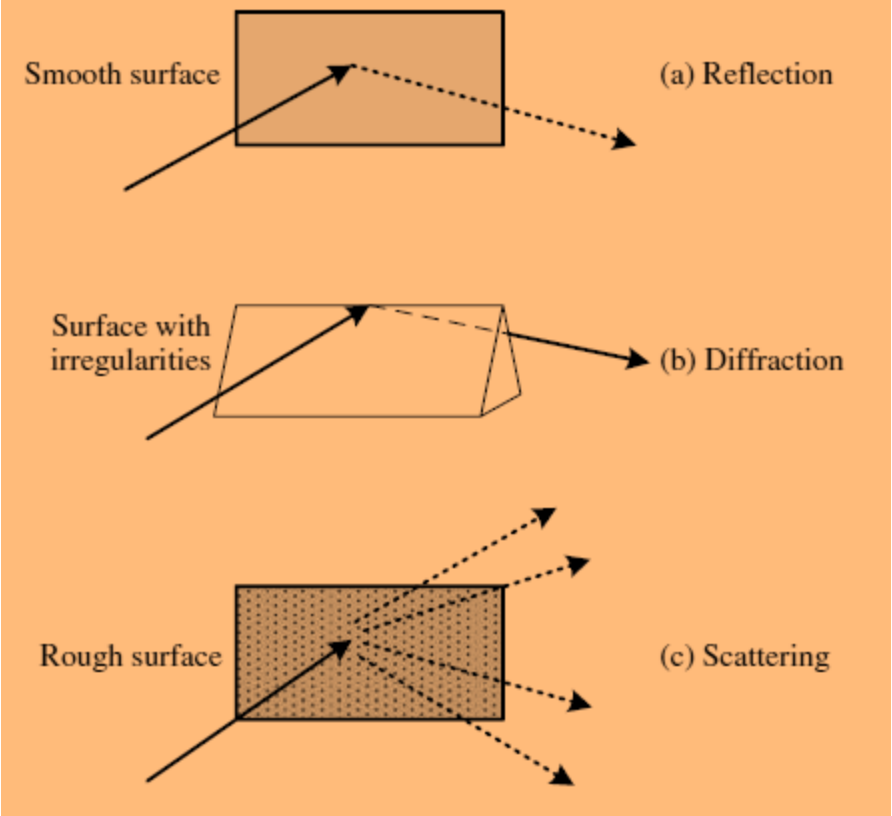
Path loss in dB

$$dB = 10 \log \left(\frac{P_1}{P_2}\right)$$



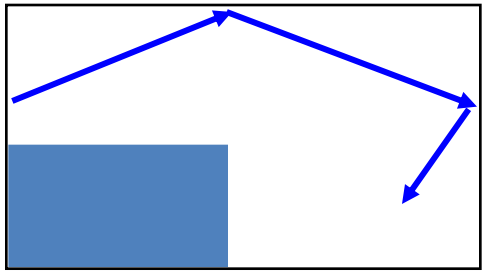
Path loss from source to d2 = 70dB

Reflection, Diffraction, Scatering



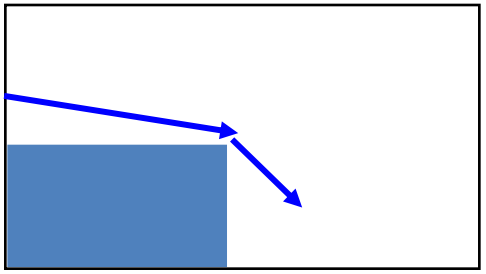
Radio Propagation

Three basic propagation mechanisms



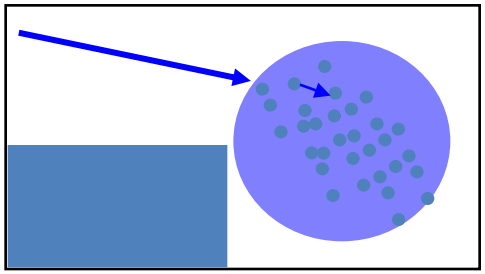
Reflection

$\lambda << D$



Diffraction

$\lambda \approx D$



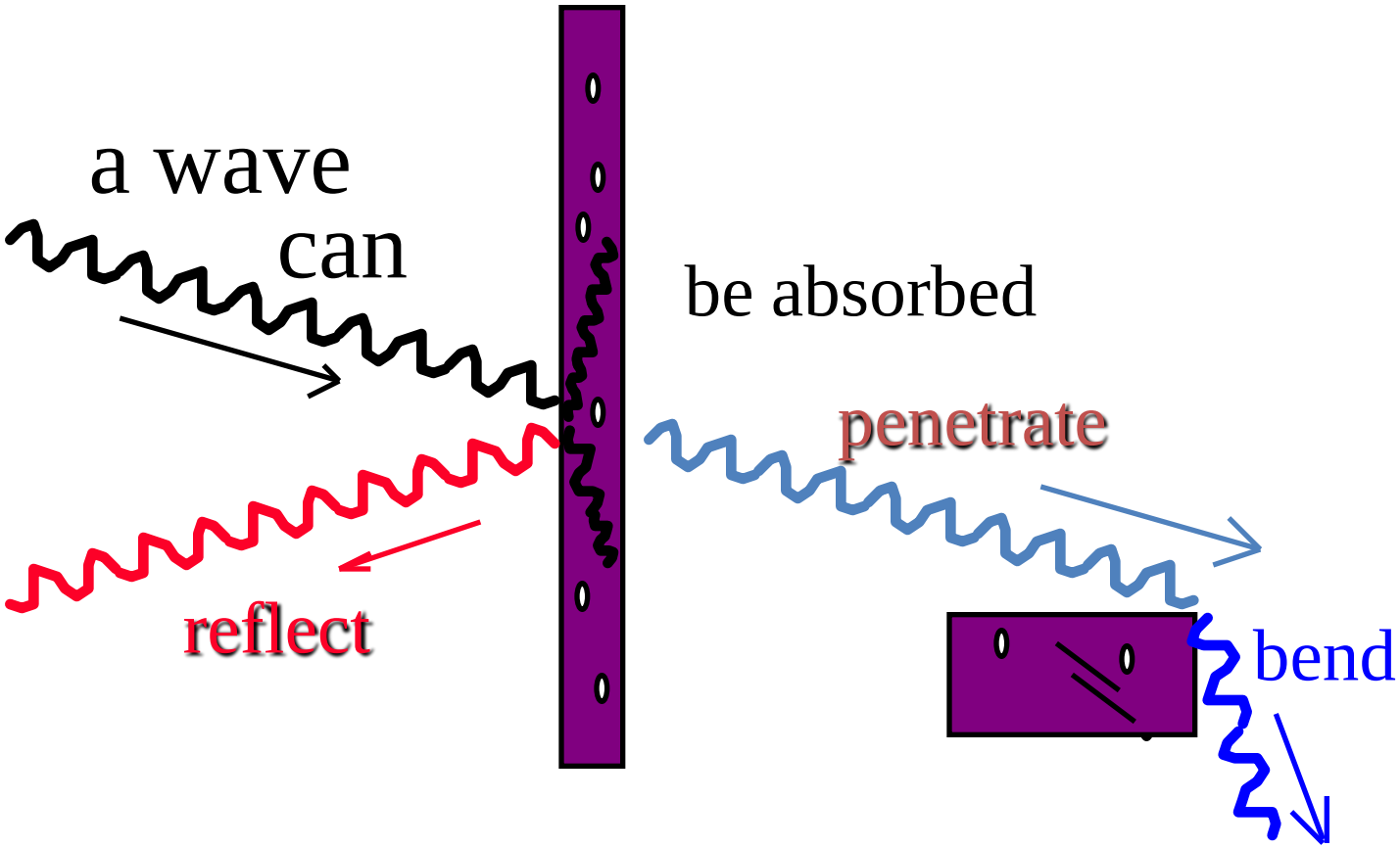
Scattering

$\lambda >> D$

- 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

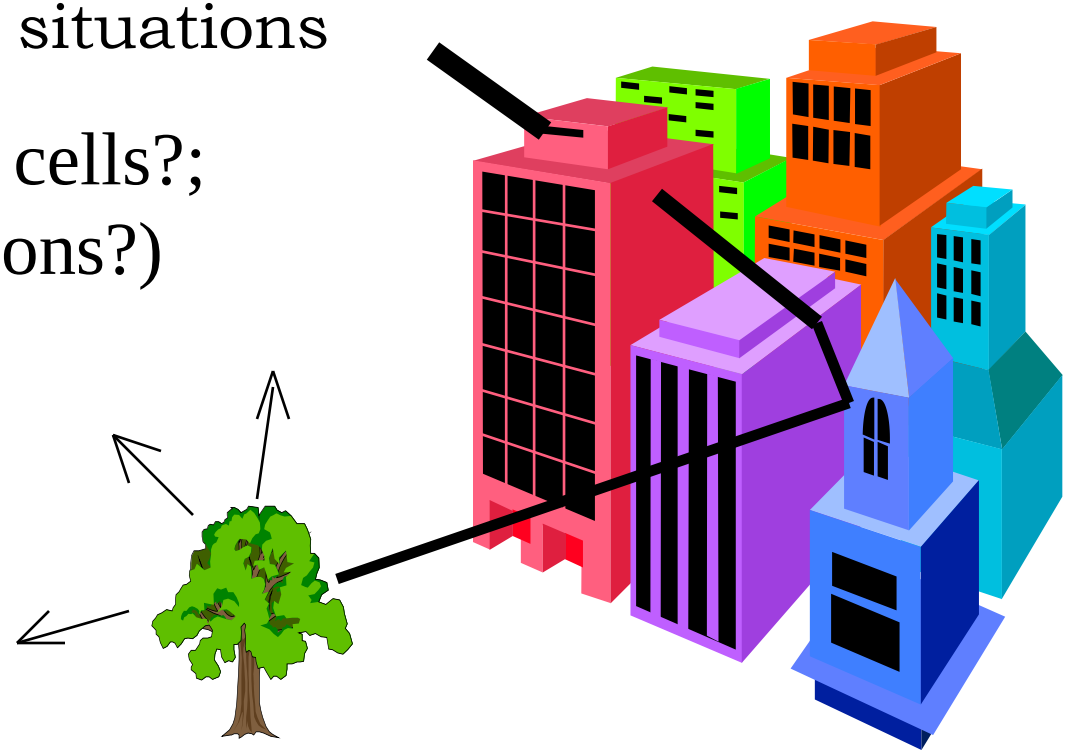
Propagation in the "Real World"



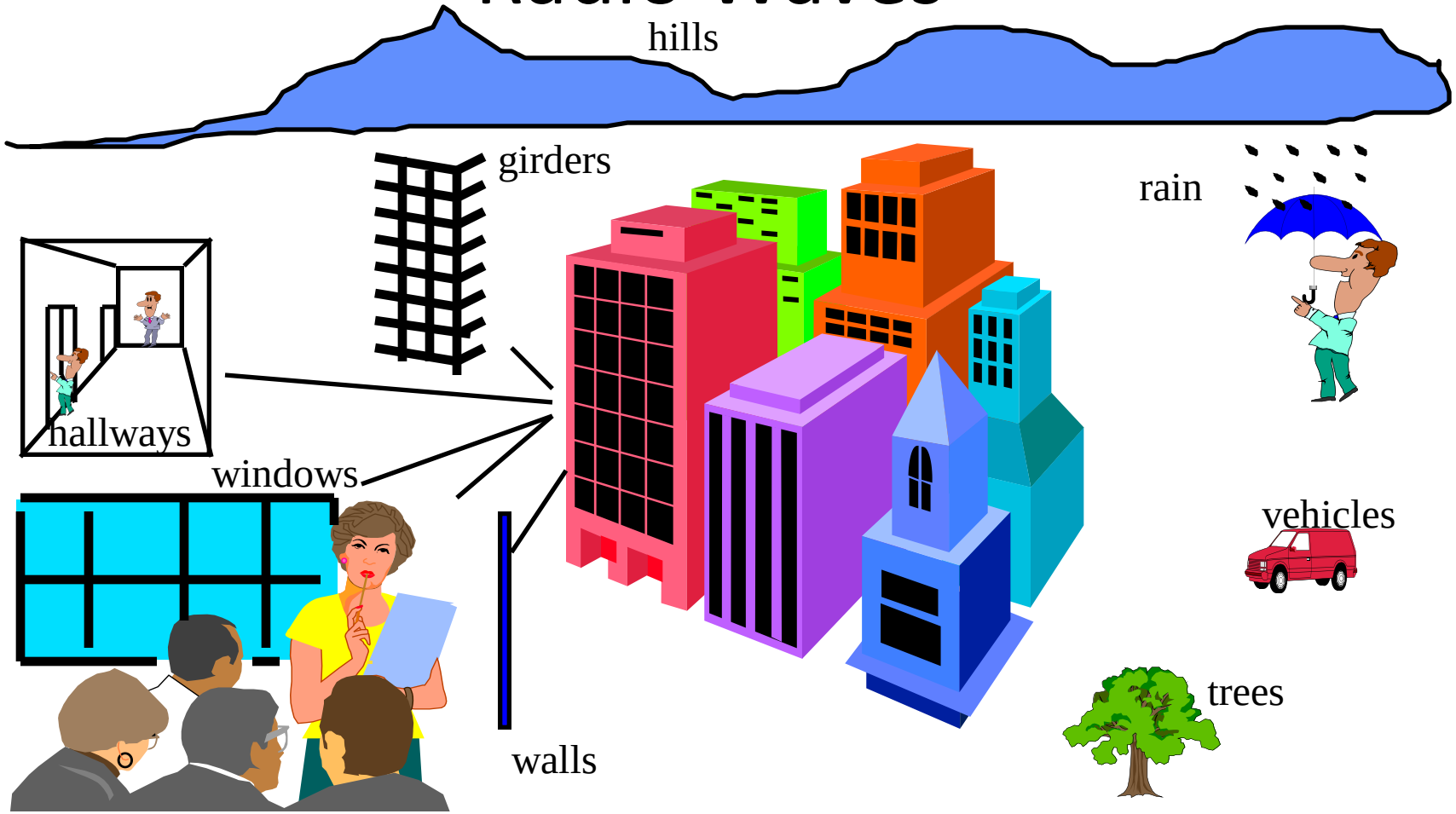
Propagation

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

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

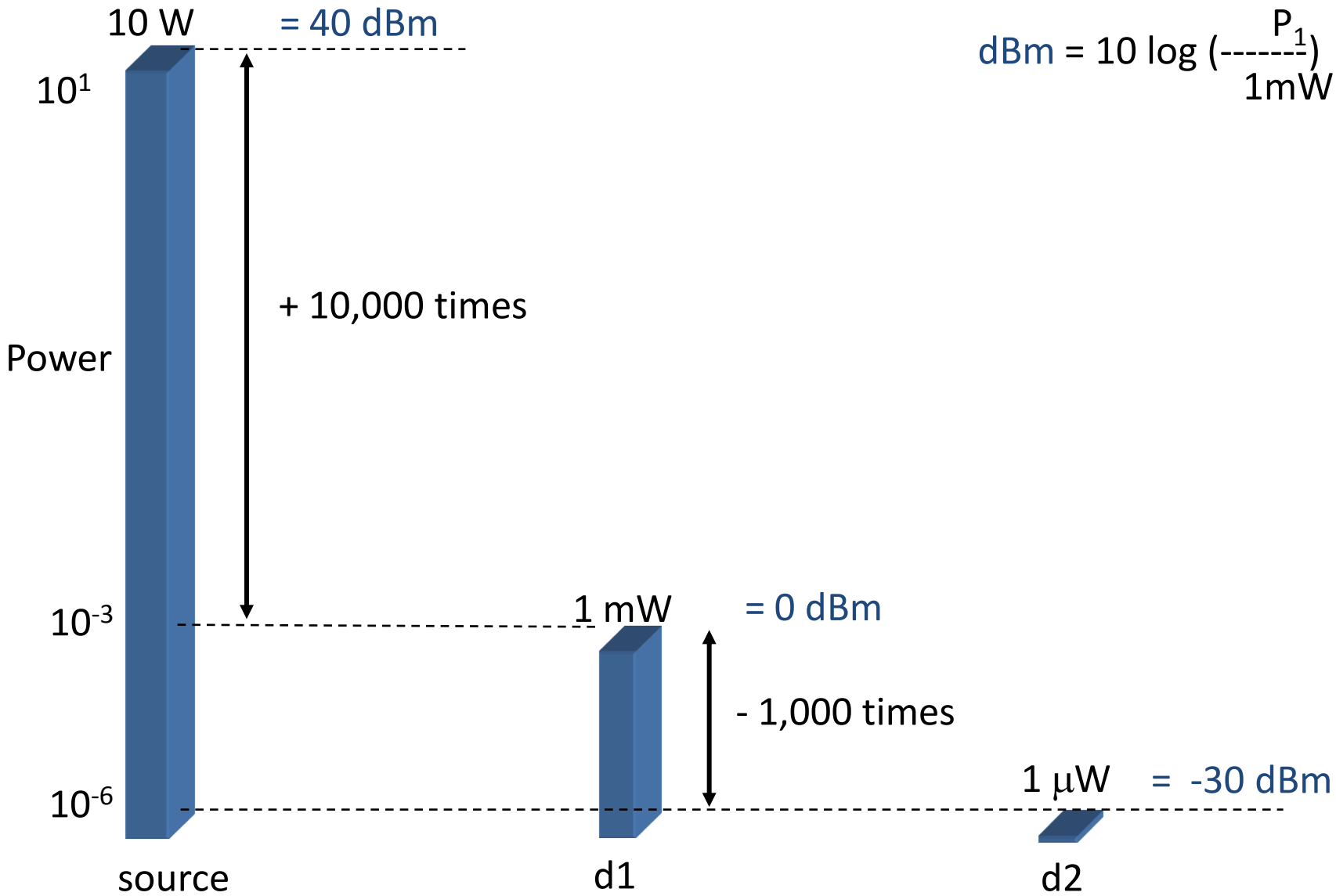


The Cluttered World of Radio Waves



dBm (absolute measure of power)

$$dBm = 10 \log \left(\frac{P_1}{1mW}\right)$$



Fading Channel Models

- Amplitude, phase or both
- Coherent and non-coherent Rx
- Local & Global point of view: Complex Gaussian distribution
- Rayleigh fading

rms value of Rx signal

$$f_{Rayleigh}(r) = \frac{r}{\sigma^2} e^{\left(-\frac{r^2}{2\sigma^2}\right)} \qquad (0 \le r < \infty)$$

Amplitude

Avg power of Rx fading sig

$$f_{Uniform}(\theta) = \frac{1}{2\pi} \qquad (0 \le \theta \le 2\pi)$$

Phase

Fading Channel

- Rician

$$f_{Rician}(r) = \frac{r}{\sigma^2} e^{-\frac{r^2+A^2}{2\sigma^2}} I_0\left(\frac{Ar}{\sigma^2}\right) \qquad (0 \le r < \infty,\ 0 \le A < \infty)$$

Peak envelope level of dominant LOS component

Phase?

- Nakagami-m fading; m=1/2, m=1, m=infinity?

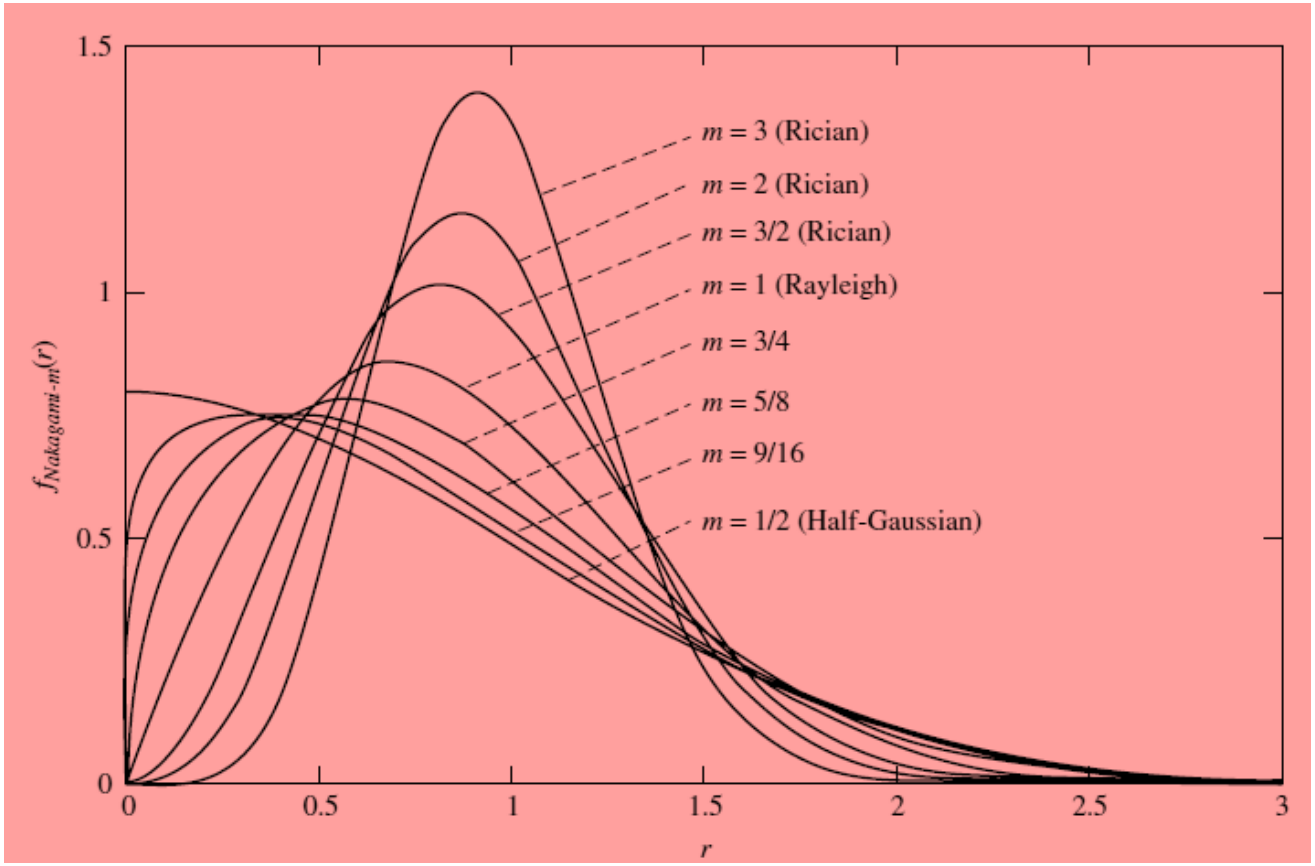
  - Amount of fading (AF) or fading figure

$$AF = \frac{var(r^2)}{\{E[r^2]\}^2} = \frac{E[(r^2 - 2\sigma^2)^2]}{4\sigma^2}$$

$$f_{Nakagami\text{-}m}(r) = \frac{2r^{2m-1}}{\Gamma(m)\Omega^m} e^{-\frac{r^2}{\Omega}} \qquad (0 \le r < \infty)$$

where $\Gamma(\cdot)$ is the Gamma function, $\Omega = \frac{r^2}{m}$ with r^2 being the average received signal power and m representing the inverse normalized variance r^2, which has to satisfy the condition of $m \ge \frac{1}{2}$,

Fading Channel



Fading Channel

- Log-normal fading

$$f_{log\text{-}normal}(r) = \frac{1}{r\sqrt{2\pi\sigma^2}}\, e^{-\frac{(\ln r-\mu)^2}{2\sigma^2}} \qquad (0 \le r < \infty)$$

Normal?

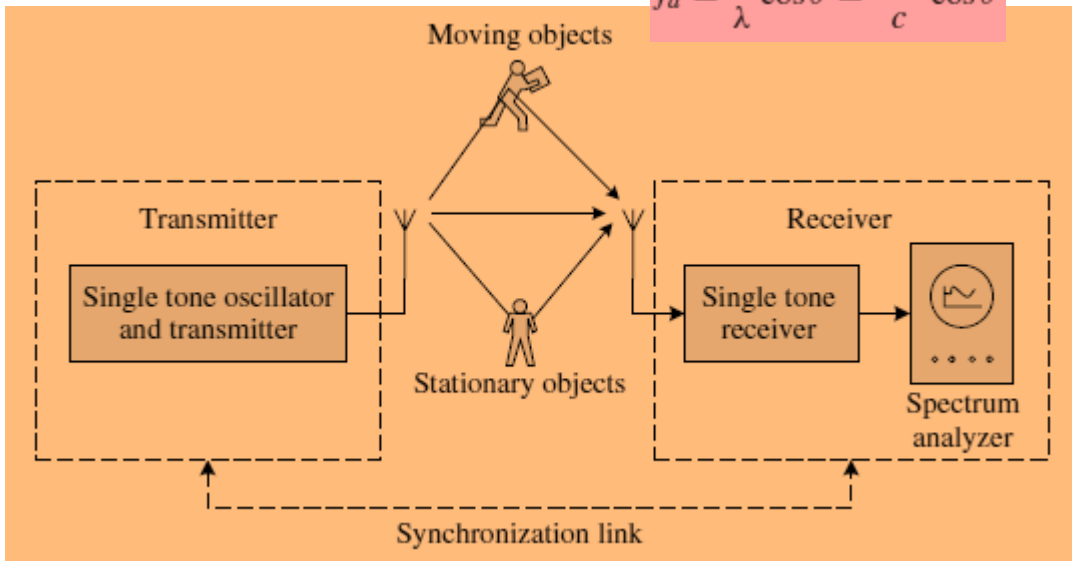
$$f^{(dB)}_{log\text{-}normal}(x) = \frac{1}{\sqrt{2\pi\sigma^2}}\, e^{-\frac{(x-\mu)^2}{2\sigma^2}} \qquad (0 \le x < \infty)$$

NB and frequency-domain channel characteristics

- Experiment-based approach

$$f_d = \frac{v}{\lambda}\cos\theta = \frac{v f_c}{c}\cos\theta$$

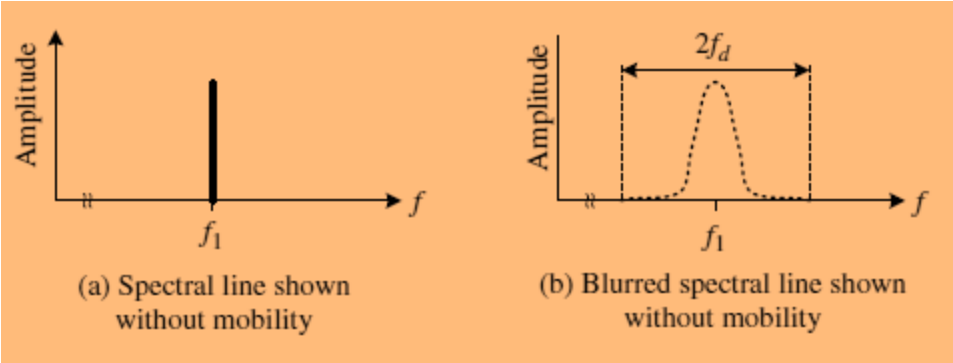
Doppler shift



A generic system setup of a narrowband channel sounding experiment system,

$$r_3(t) = \sin\omega_c t + sin\omega_c(t+\tau) + \sin(\omega_c + 2\pi f_d)(t+\tau)$$

NB and frequency-domain channel characteristics



(a) Spectral line shown without mobility

(b) Blurred spectral line shown without mobility

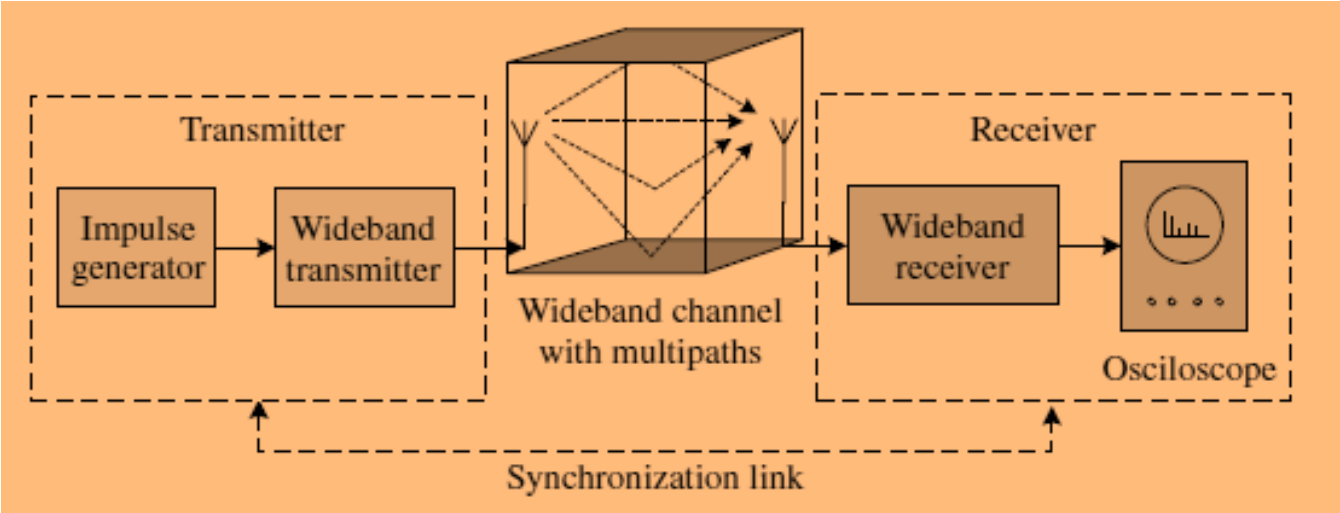
Coherent time ← $T_{co} \cong \frac{1}{\Delta f_d}$ ← Doppler spread

↓

Slow fading channel/fast fading channel

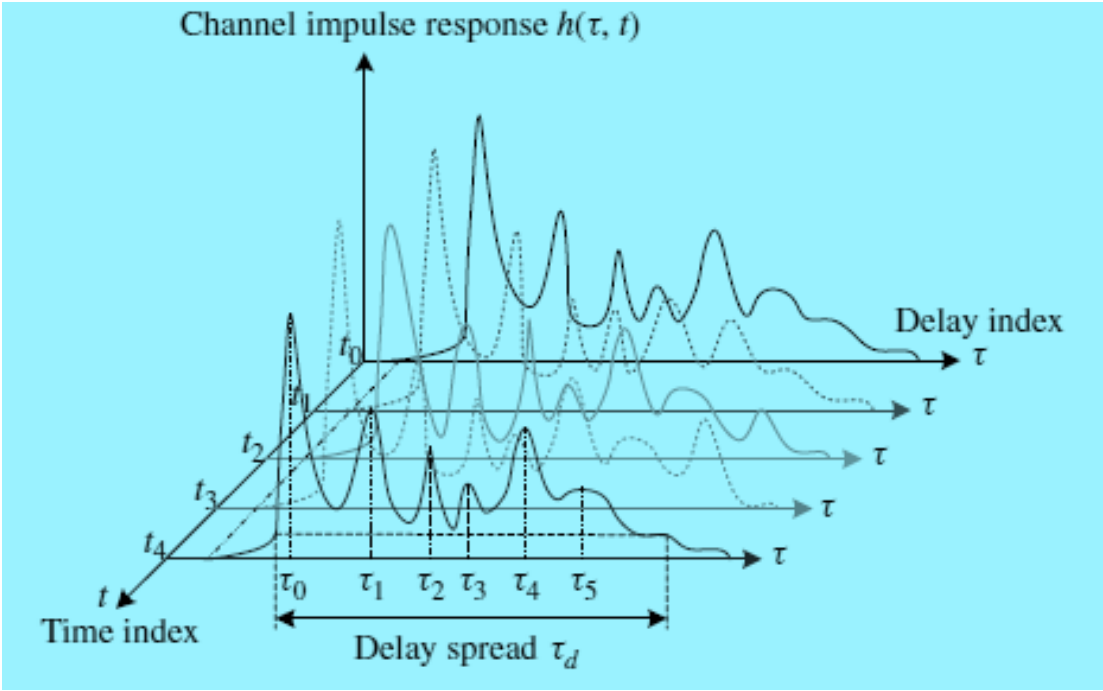
WB and time-domain channel characteristics

- Experiment-based approach
- Indoor environment for simplicity



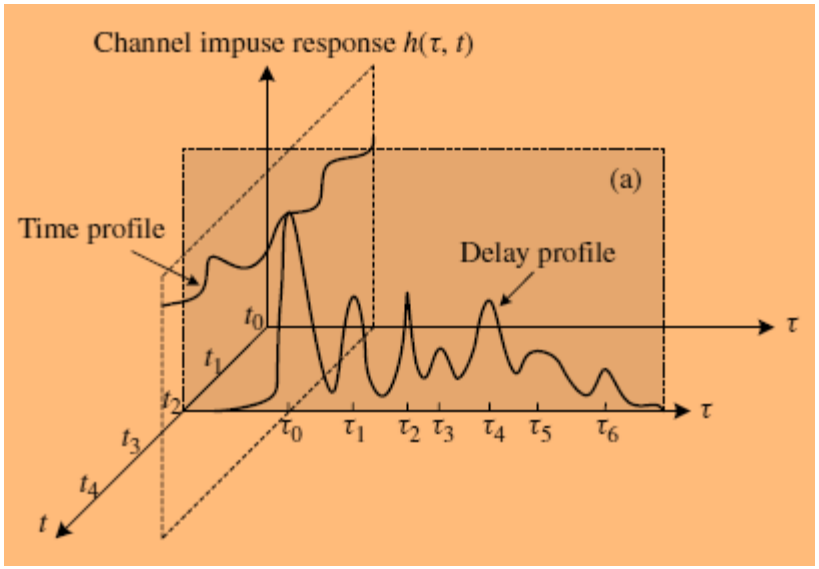
- Perfect synchronization

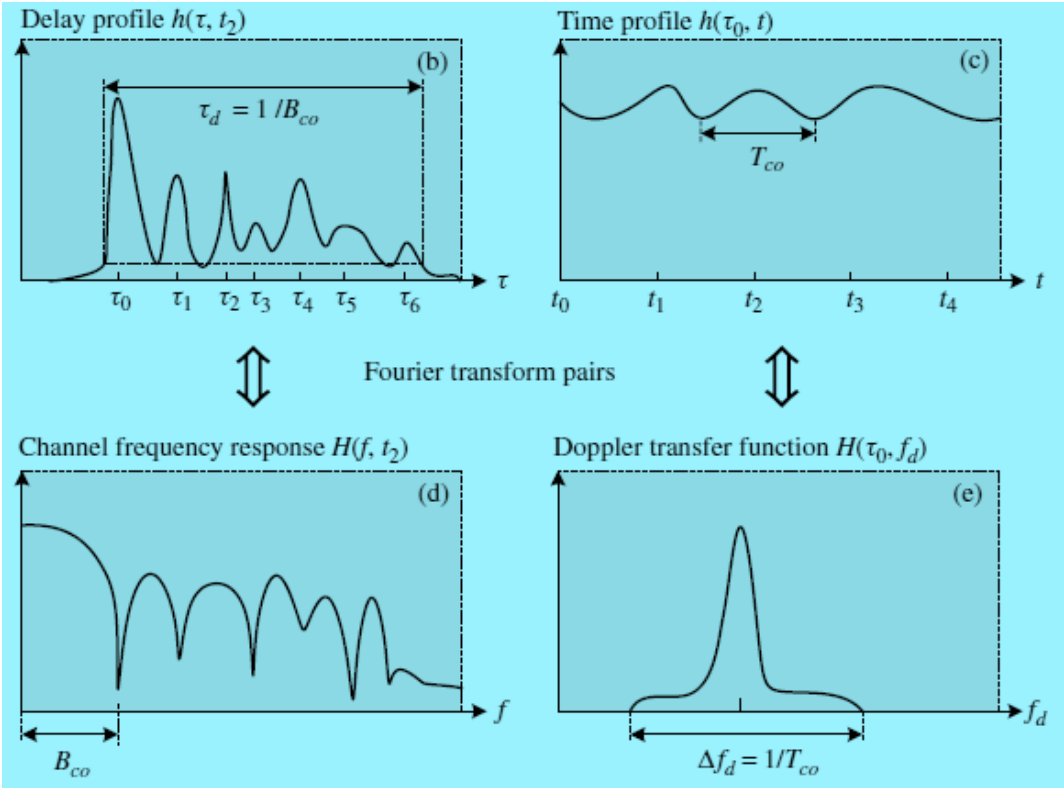
WB and time-domain channel characteristics



Time dispersive channel

WB and time-domain channel characteristics





$\tau_d = \frac{1}{B_{co}}$.

Four Parameters

- The delay spread τ_d is defined as the widest delay span, over which all multipath returns are higher than a certain threshold. The delay spread is approximately equal to the reciprocal of the coherent bandwidth B_{co}.
- The coherence bandwidth B_{co} is defined as the smallest frequency range, within which all signals can pass without suffering serious frequency-selective fading. It is also equal to the reciprocal of the delay spread τ_d.
- The Doppler spread Δf_d is defined as the width of Doppler spectrum caused by mobility in the channel. The Doppler spread is equal to the reciprocal of the coherent time T_{co}.
- The coherent time T_{co} is defined as the time duration, beyond which two signal samples separated longer than T_{co} can usually be considered independent of each other. The coherent time can also be obtained by measuring the average cycle of the signal change in the time profile function $h(\tau_0, t)$, and is equal to the reciprocal of the Doppler spread Δf_d.

Flat Fading Channel

- Flat fading or frequency nonselective fading channel
- Still multipath effect exist but spectral characteristics of Tx signal are preserved at Rx
- Signal fluctuation due to MP?
- Flat fading in time domain: symbol duration >> delay spread; no ISI
- 20 dB to 30 dB more power to compensate deep fade time to time

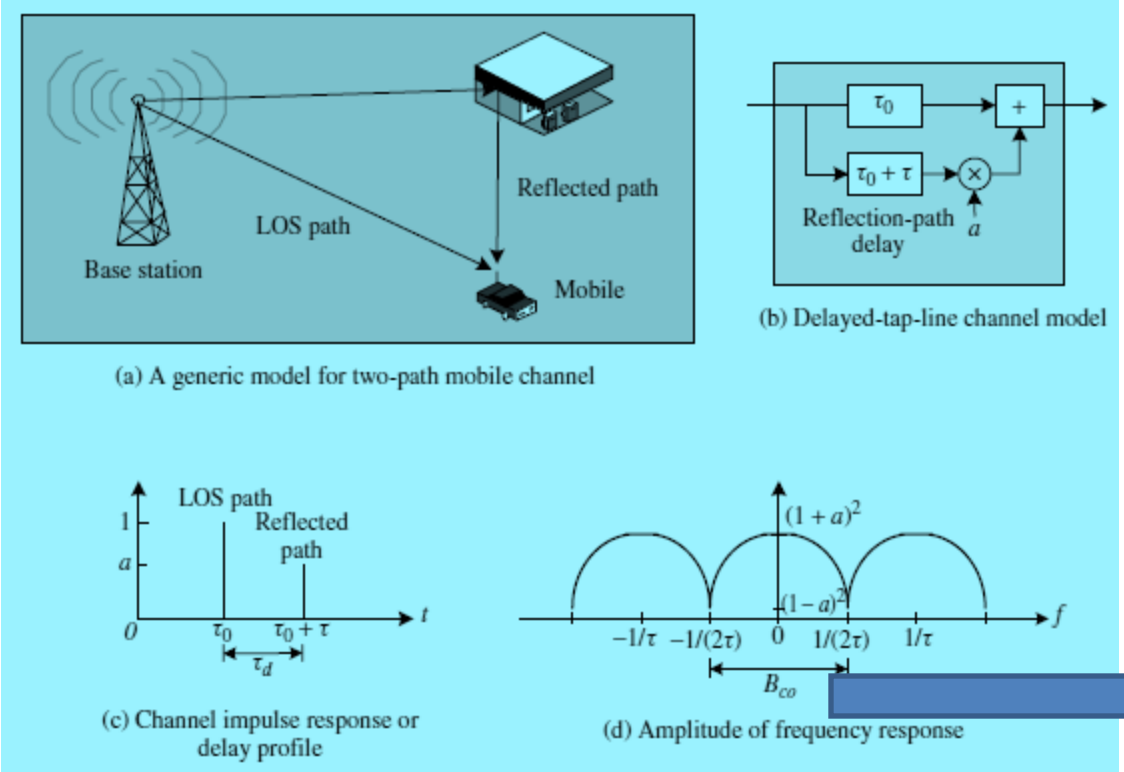
Frequency Selective Fading Channel

- Different attenuation at the Rx signal at different frequencies

- Not only distorts the signal in both time and frequency domain but also ISI; MI

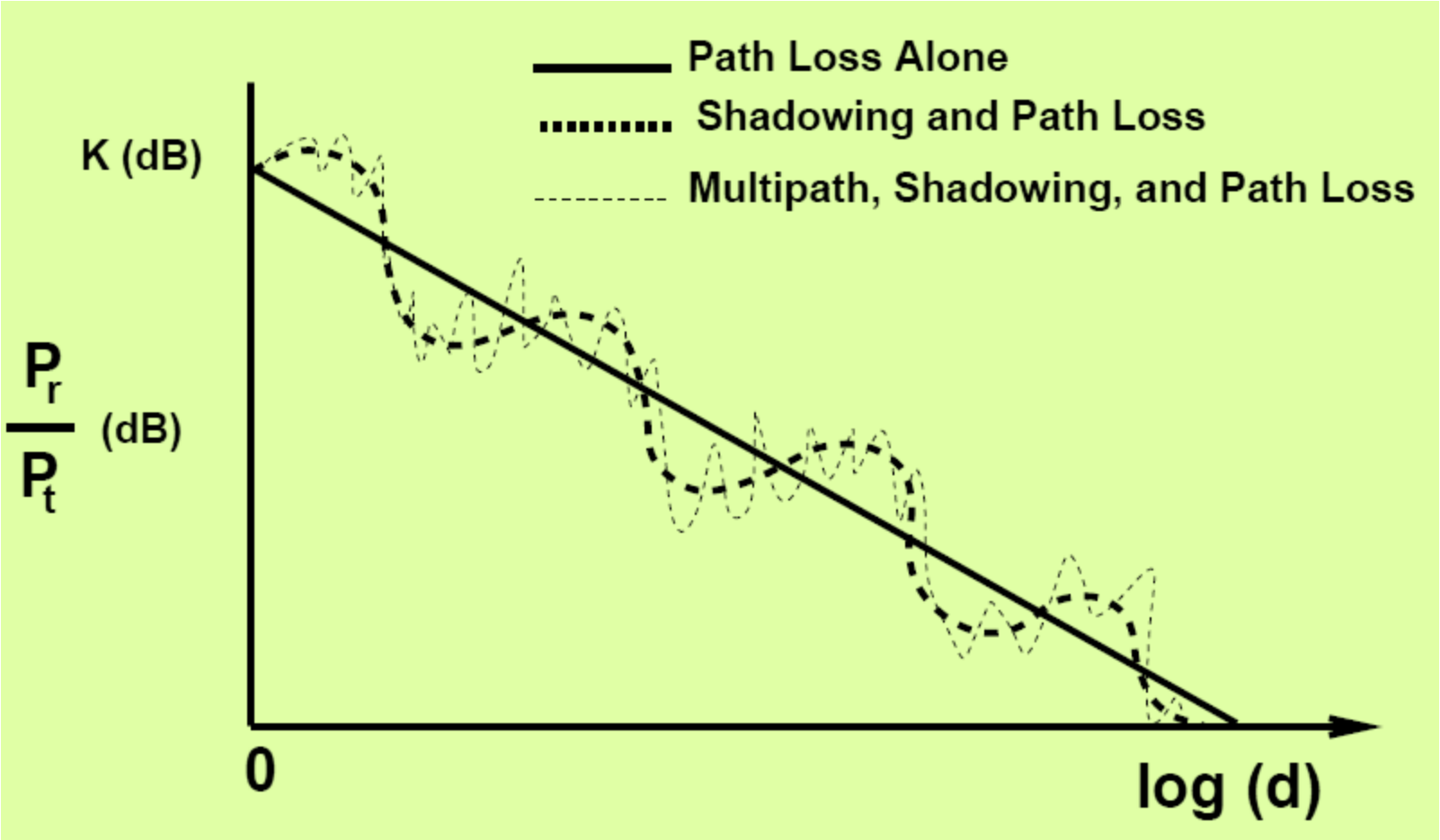
- Clustered arrival at Rx? Many replicas; MP fading: constructive & destructive interference (fast and short-term variation)

MP Modeling



$$\tau_d \cong \frac{1}{B_{co}}$$

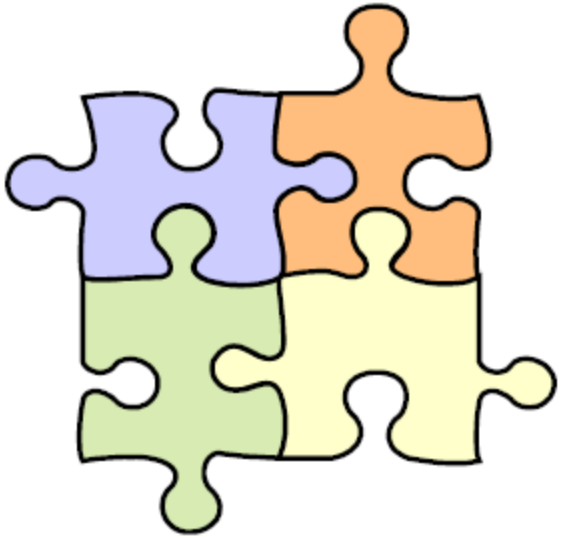
Channel: Path loss, Shadowing & MP



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?

Q & A