File name: vimm9084_21channel06.pdf

References: Lecture notes

2.1 CHANNEL CONDITIONS IN INDOOR AND MOBILE RADIO COMMUNICATIONS

Limits on radio communications

- Deep space communications: Thermal noise
- Indoor and mobile communications: Multipath propagation

Networking devices of embedded systems: Indoor radio and mobile applications

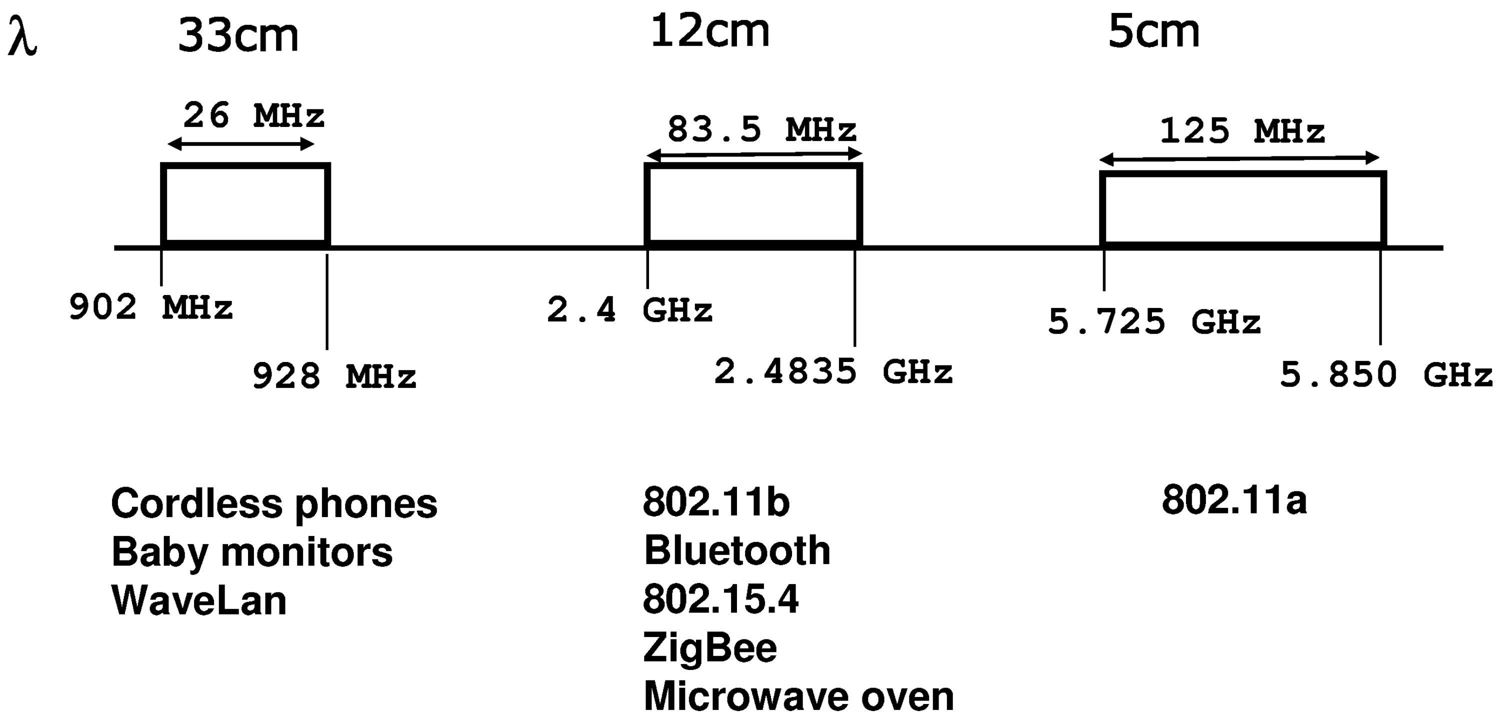
- Distance covered by radio communications is very short (10–100 m)
- Wideband signals must be used for communications to overcome multipath propagation problem
- Channel is time-varying (Mobile communication and varying channel)
- Random access to the radio channel, frequency re-use

CONTENTS:

2.1.1 Basic concepts in radio wave propagation

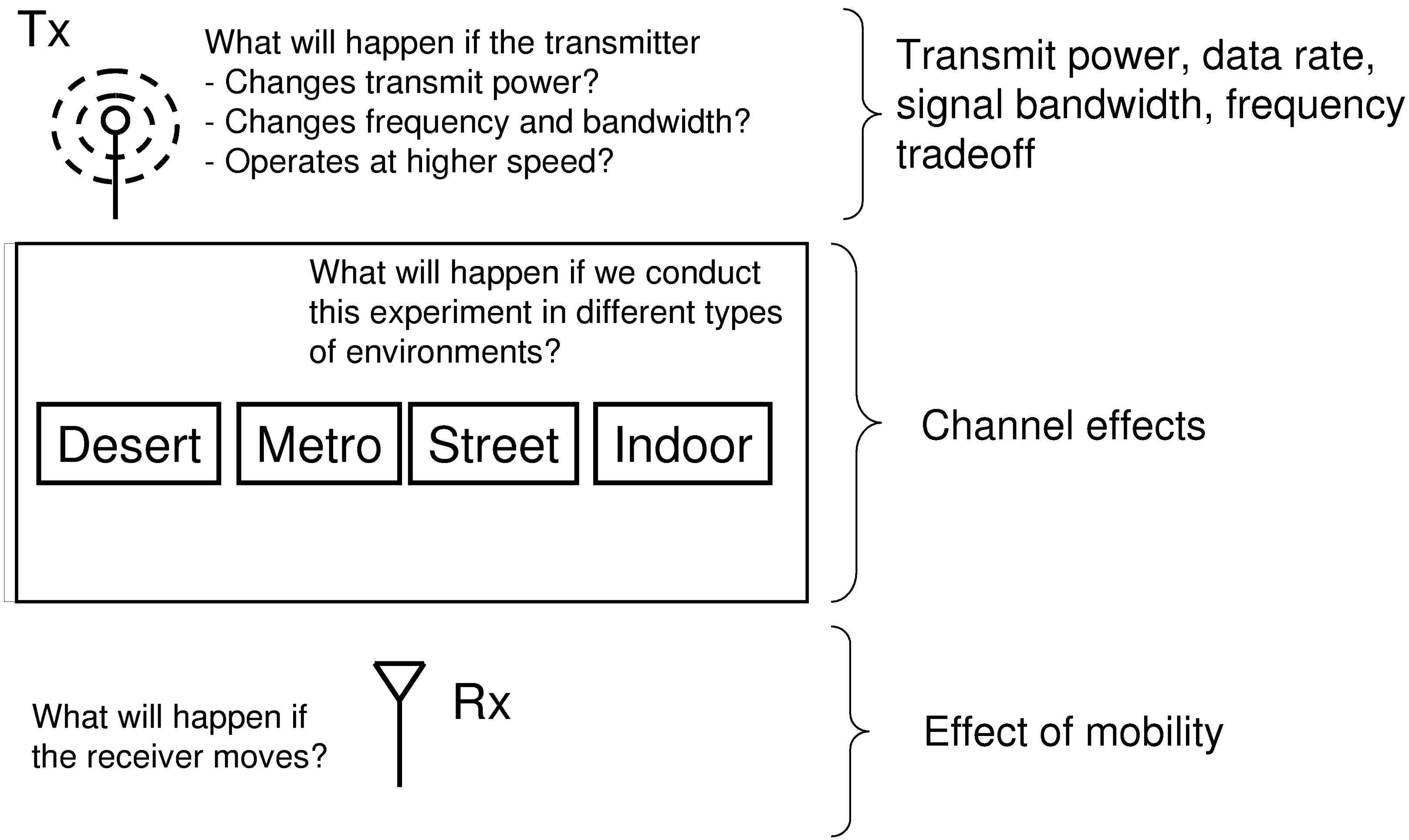
UNLICENSED RADIO BANDS

No need for governmental approval, usage is free of charge



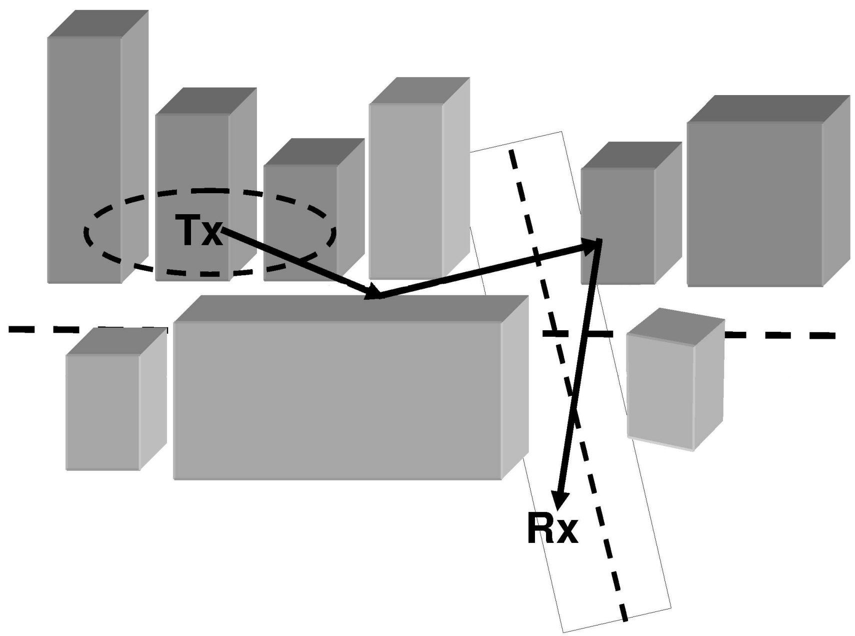
Note: Compared to the size of typical obstacles, the wavelength is small

EFFECTS INFLUENCING THE STRENGTH OF RECEIVED SIGNAL

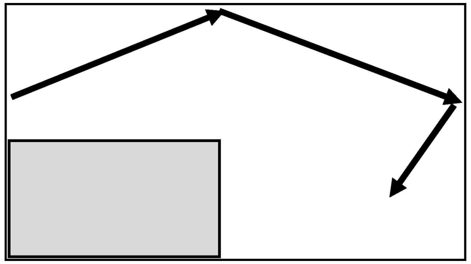


BASIC QUESTIONS TO BE ANSWERED

- How does the signal propagate?
- How much attenuation has the channel?
- How does the signal look like at the receiver input?
- Which model is suitable for modeling the radio channel?

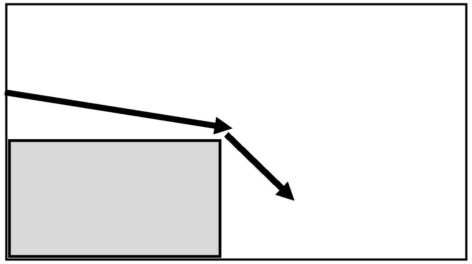


Three basic mechanisms of radio wave propagation



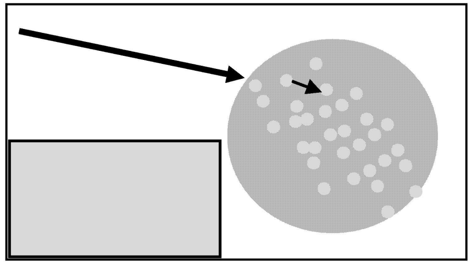
Reflection

$\lambda \ll D$



Diffraction

$\lambda \approx D$



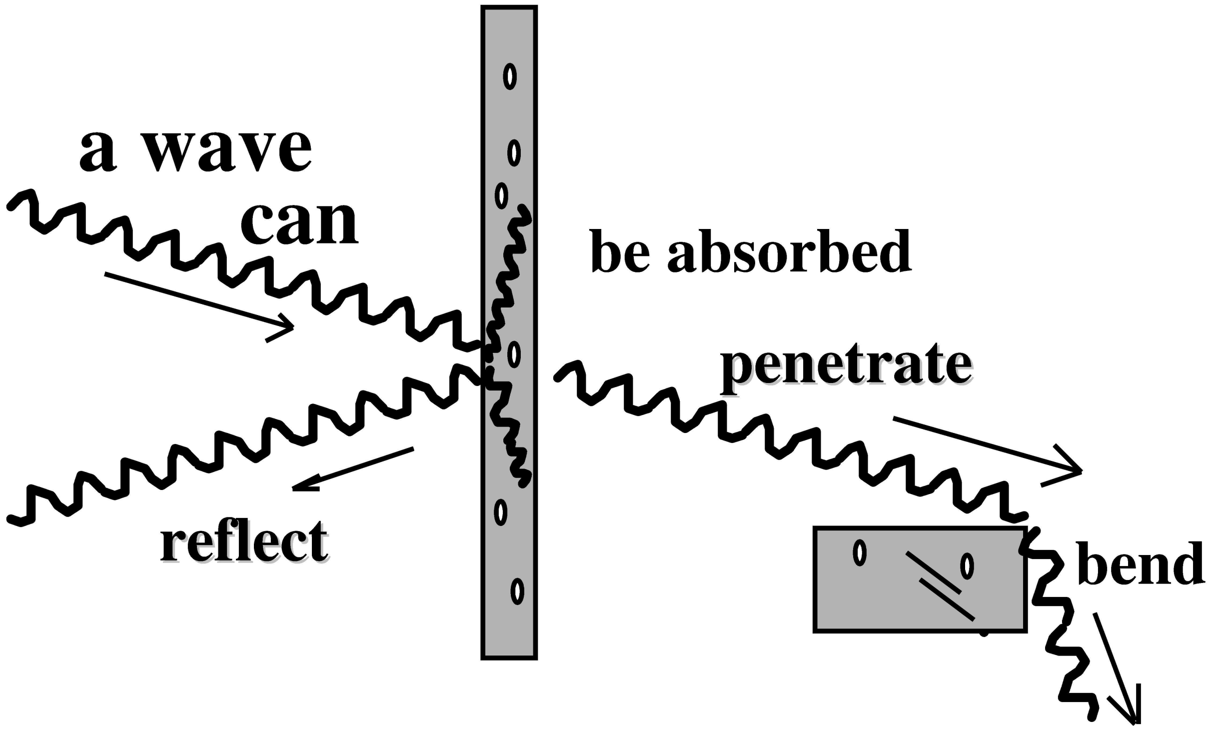
Scattering

$\lambda \gg D$

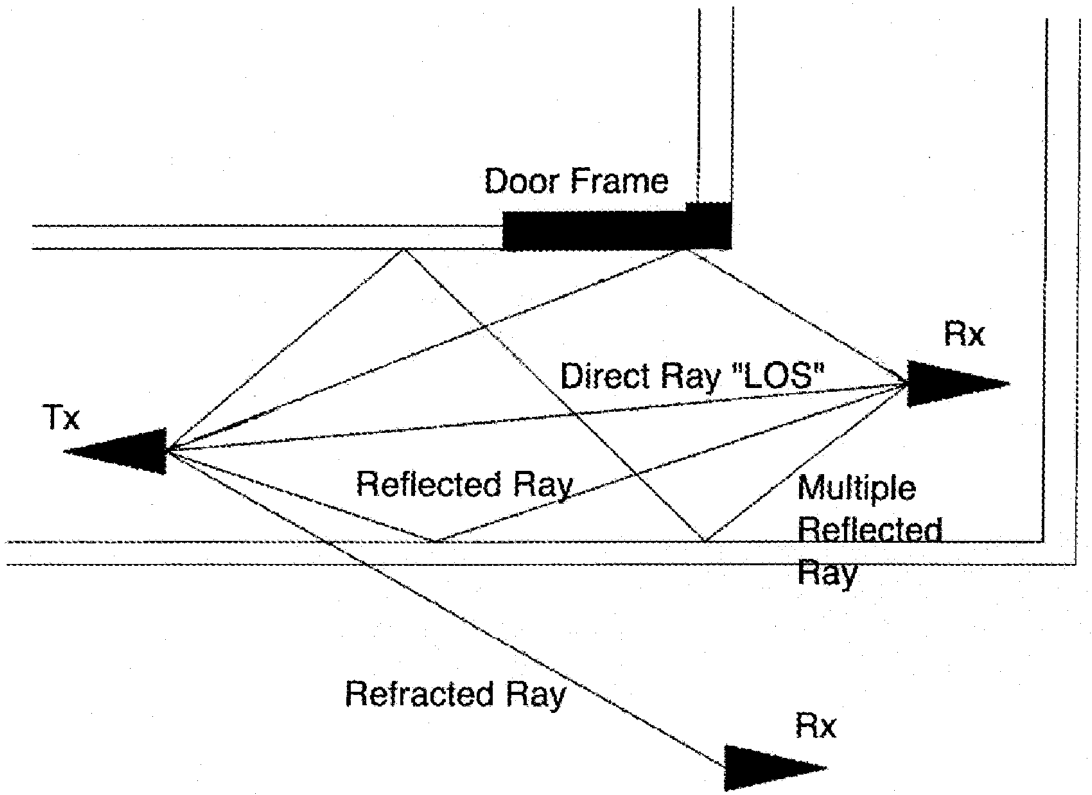
Remark:

- In indoor and metropolitan radio communications, many parallel propagation paths exist
- Consequently, the overall channel attenuation depends strongly on the bandwidth of transmitted signal

Propagation in a “Real World” environment



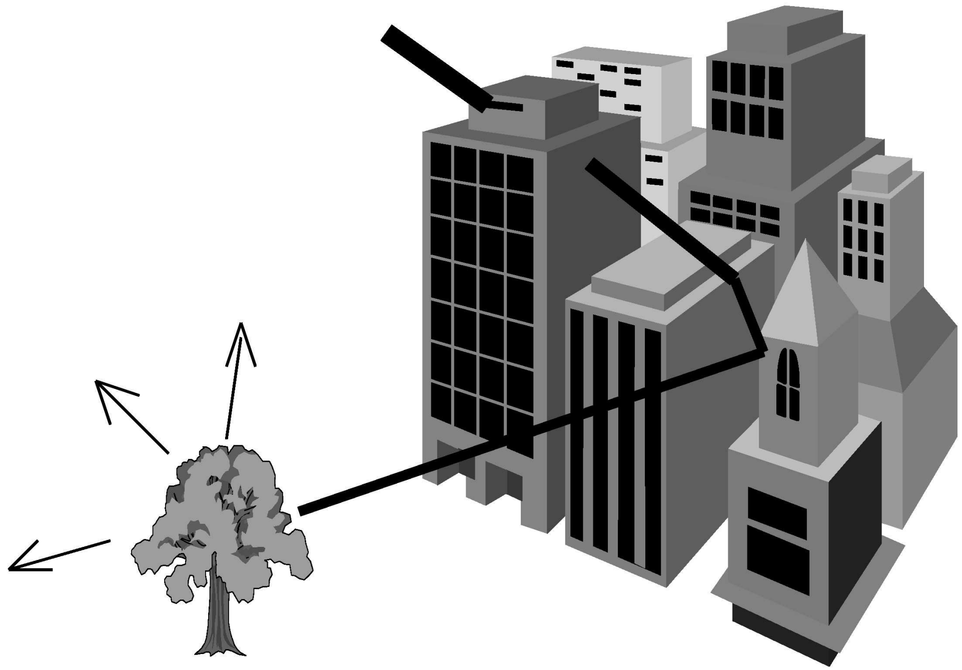
A summary of indoor propagation mechanisms



Direct path exists between transmitter and receiver: Line-of-Sight (LOS)

No direct path between transmitter and receiver: Non-Line-of-Sight (NLOS)

A summary of outdoor propagation mechanisms

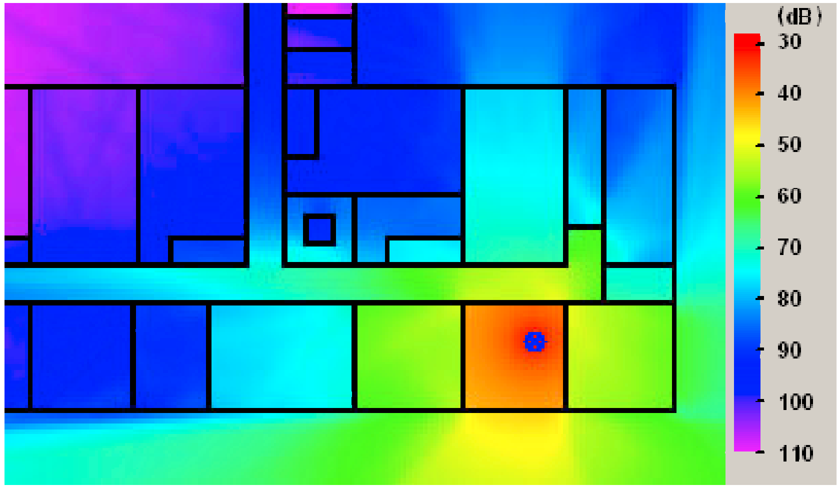


Additional effects:

- The higher the carrier frequency, the larger the free space attenuation
- A multipath propagation exists in indoor and metropolitan communications
- Doppler effect has to be considered in mobile communications

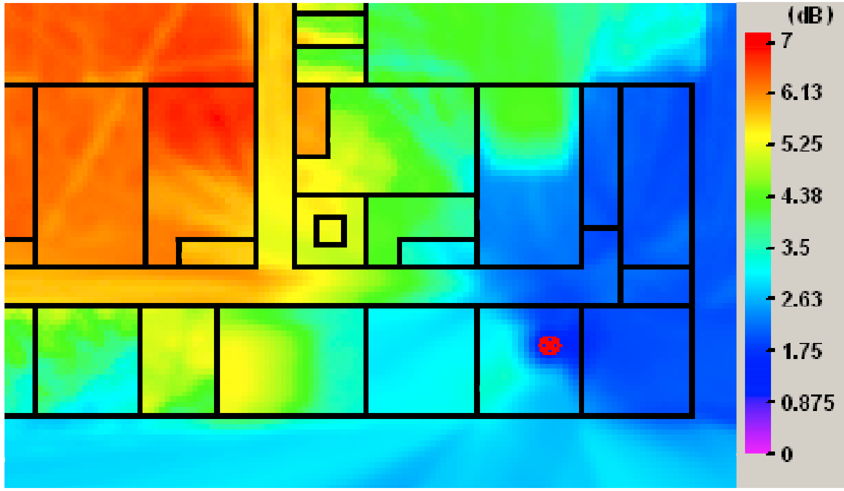
STRENGTH OF RECEIVED SIGNAL IN OFFICE ENVIRONMENT

Mean value of path loss



Note: Attenuation varies from 50 dB to 110 dB

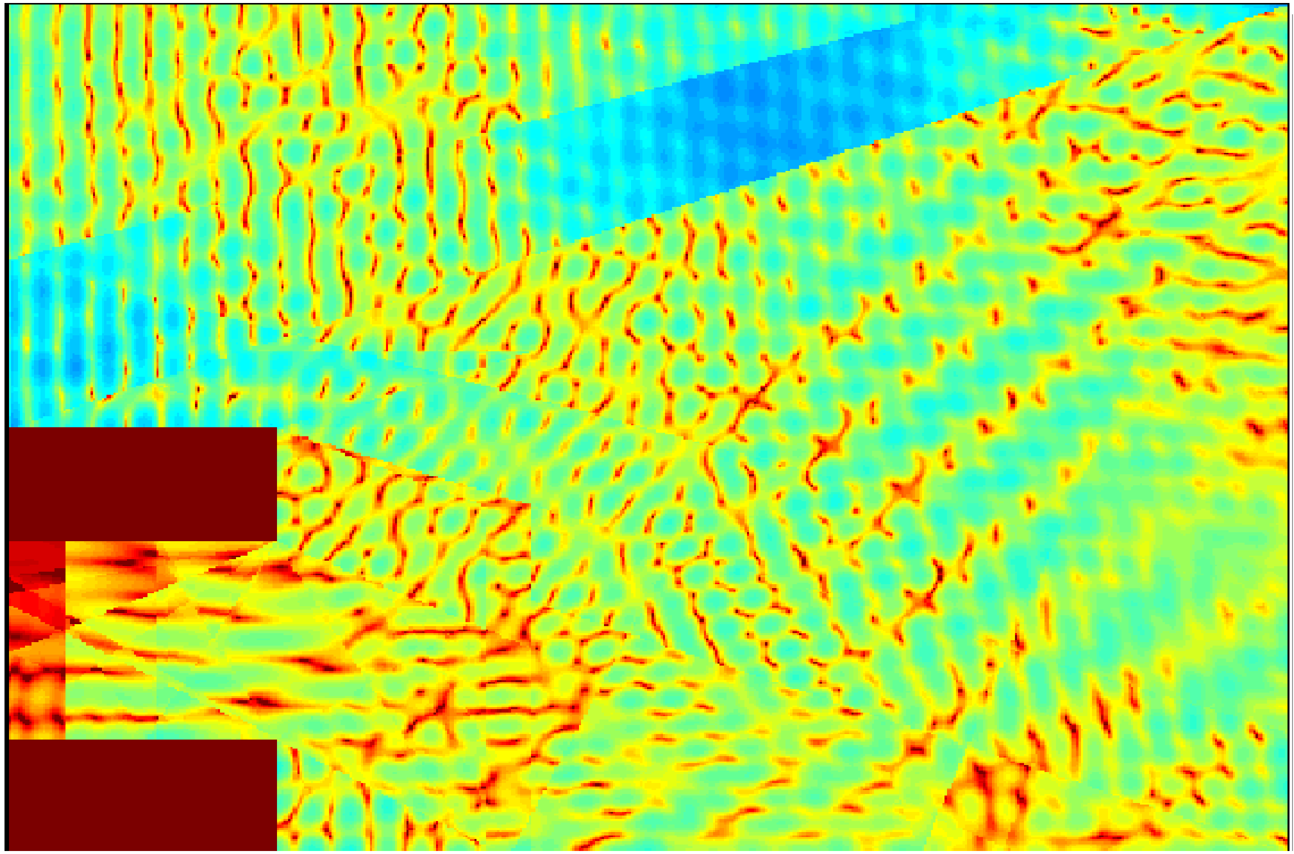
Standard deviation of signal fluctuation due to shadowing by moving people



Note: Variation due to shadowing goes from 4 dB to 7 dB

Variation in received signal strength

Simulation, a single office room, at desktop level



CONTENTS:

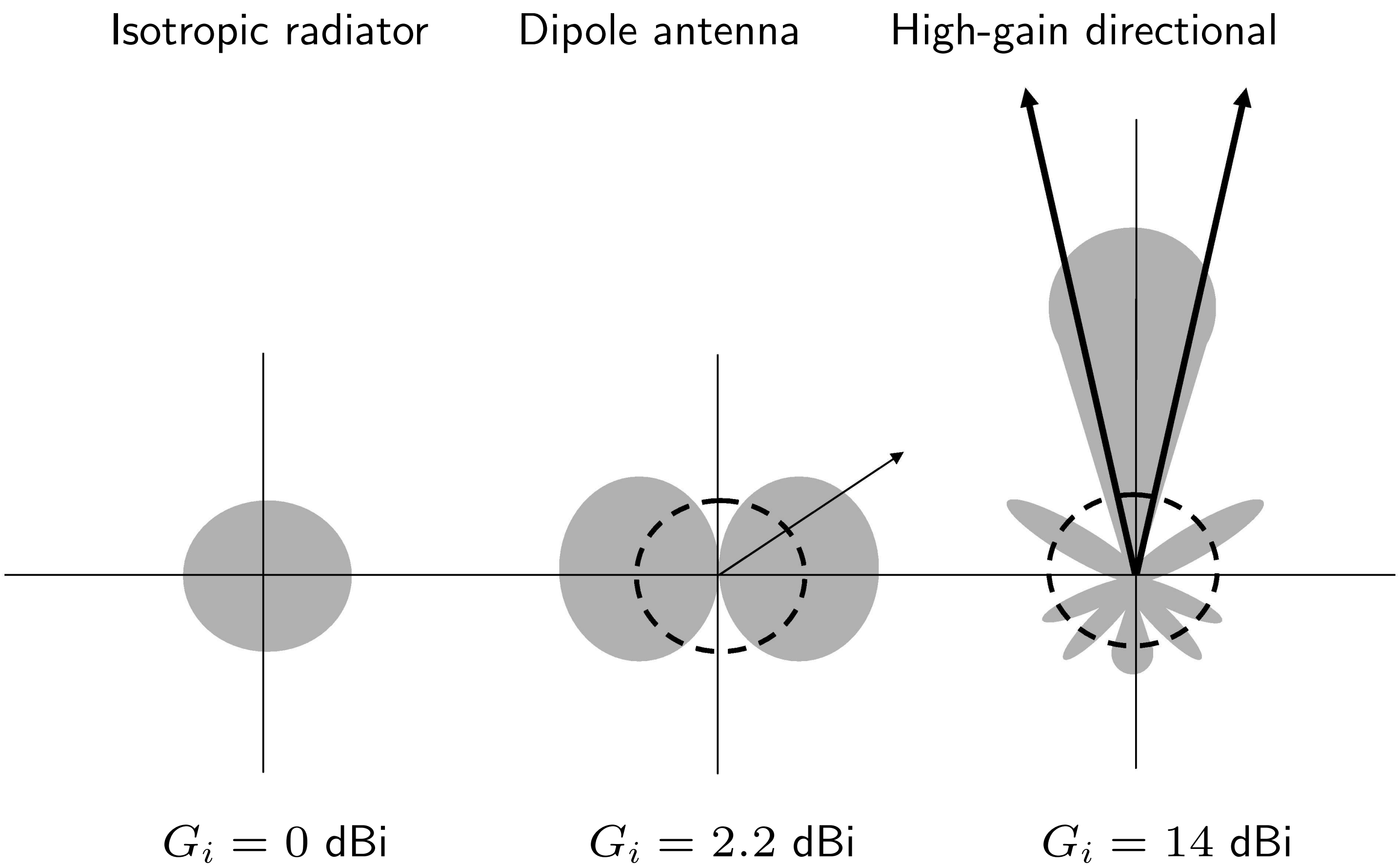
2.1.2 Calculation of free space attenuation

ANTENNA RADIATION PATTERNS AND ANTENNA GAIN

Radiation pattern

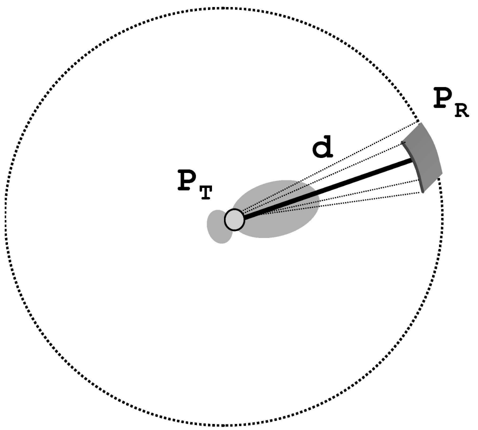
Antenna gain:

$$G_i = \frac{P_{directional}}{P_{isotropic}}$$



FRIIS FREE SPACE FORMULA

Predict the received signal strength when transmitter and receiver have a clear Line-of-Sight (LOS) path between them



Isotropic power density: $P_{Di} = \frac{P_T}{4\pi d^2} \quad \left[\frac{\mathrm{W}}{\mathrm{m}^2}\right]$

Power density along the direction of max. radiation: $P_D = \frac{P_T G_T}{4\pi d^2}$

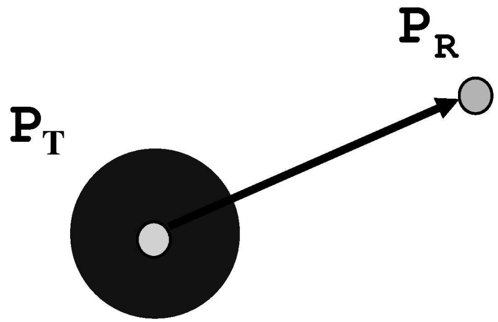
Power received by the antenna: $P_R = P_D A_{eff} \quad [\mathrm{W}]$

where the effective area of an antenna is defined by $\frac{A_{eff}}{G} = \frac{\lambda^2}{4\pi}$

Received power (also known as Friis free space Formula)

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

PATH LOSS ALSO REFERRED TO AS CHANNEL ATTENUATION



Received power (Friis formula)

$$P_R = P_T G_T G_R \left(\frac{\lambda}{4\pi d}\right)^2 = P_T G_T G_R \frac{0.57 * 10^{-3}}{(df)^2}$$

where f and d are measured in GHz and m, respectively

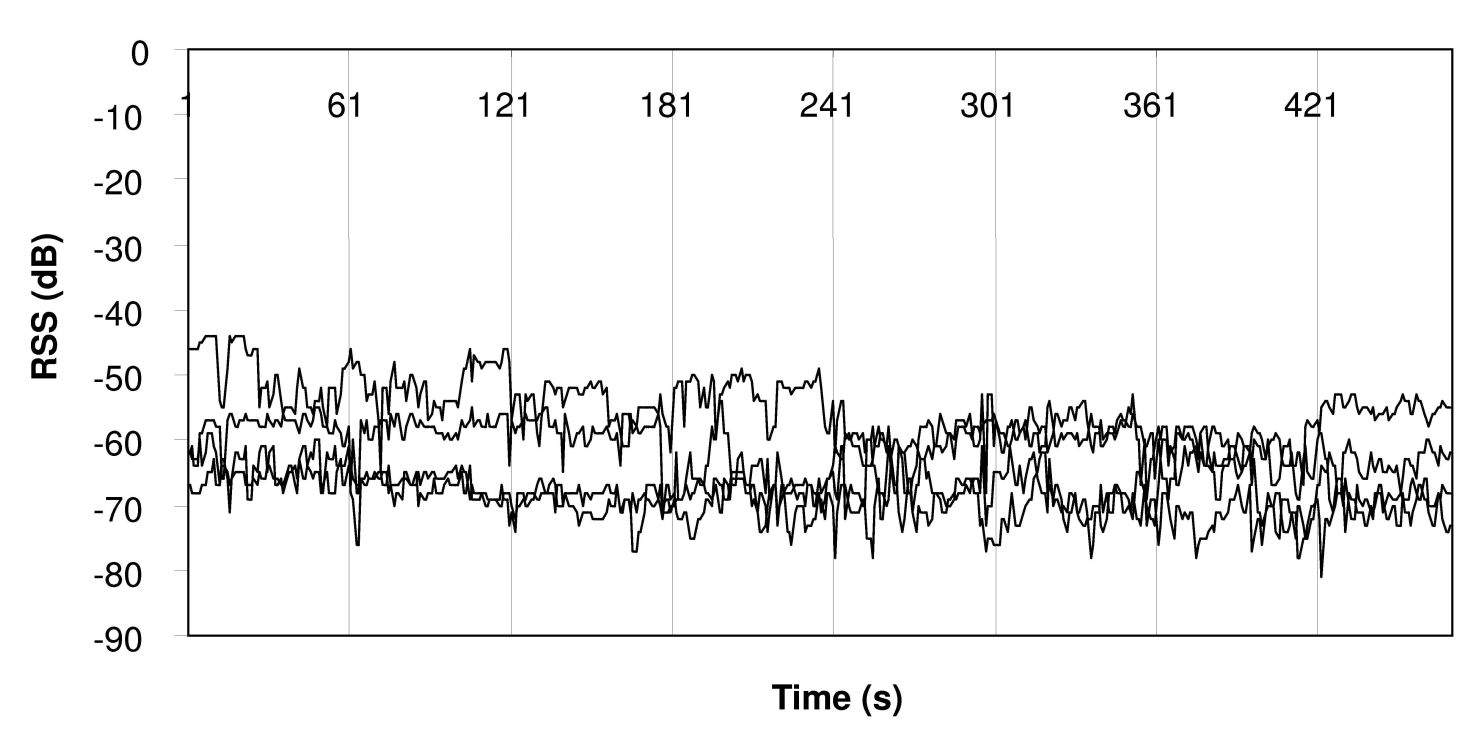
$$P_R^{[\text{dBm}]} = P_T^{[\text{dBm}]} + G_T^{[\text{dB}]} + G_R^{[\text{dB}]} - 32.5 - 20\log_{10} d^{[\text{m}]} - 20\log_{10} f^{[\text{GHz}]}$$

Path loss represents the signal attenuation along the channel (antenna gains are excluded)

$$P_{loss}^{[\text{dB}]} = 32.5 + 20\log_{10} d^{[\text{m}]} + 20\log_{10} f^{[\text{GHz}]}$$

Measured Received Signal Strength (RSS) in indoor channel

Same location but four different channel frequencies in the 2.4-GHz ISM band



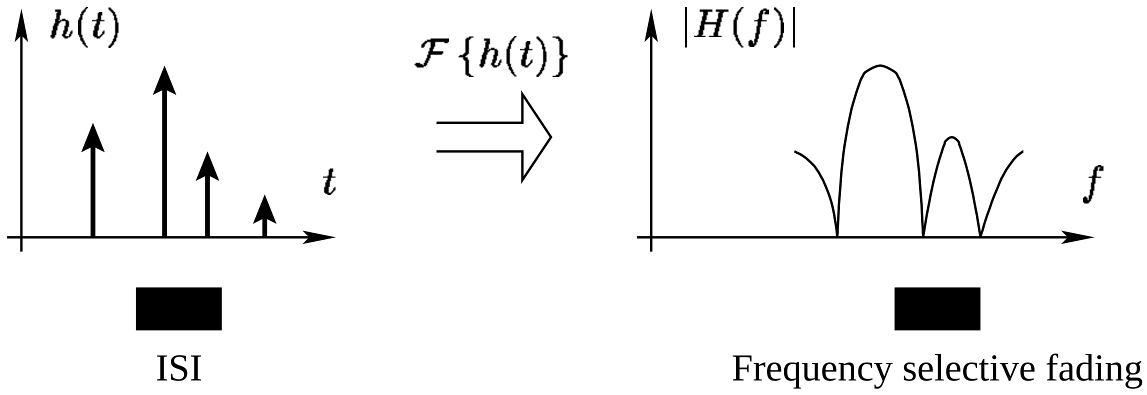
Problems not considered by Friis formula:

- Multipath propagation
- Near field behavior of the antenna

CONTENTS:

2.1.3 Characterization of multipath channel

Output of a multipath channel characterized by the impulse response $h(t)$

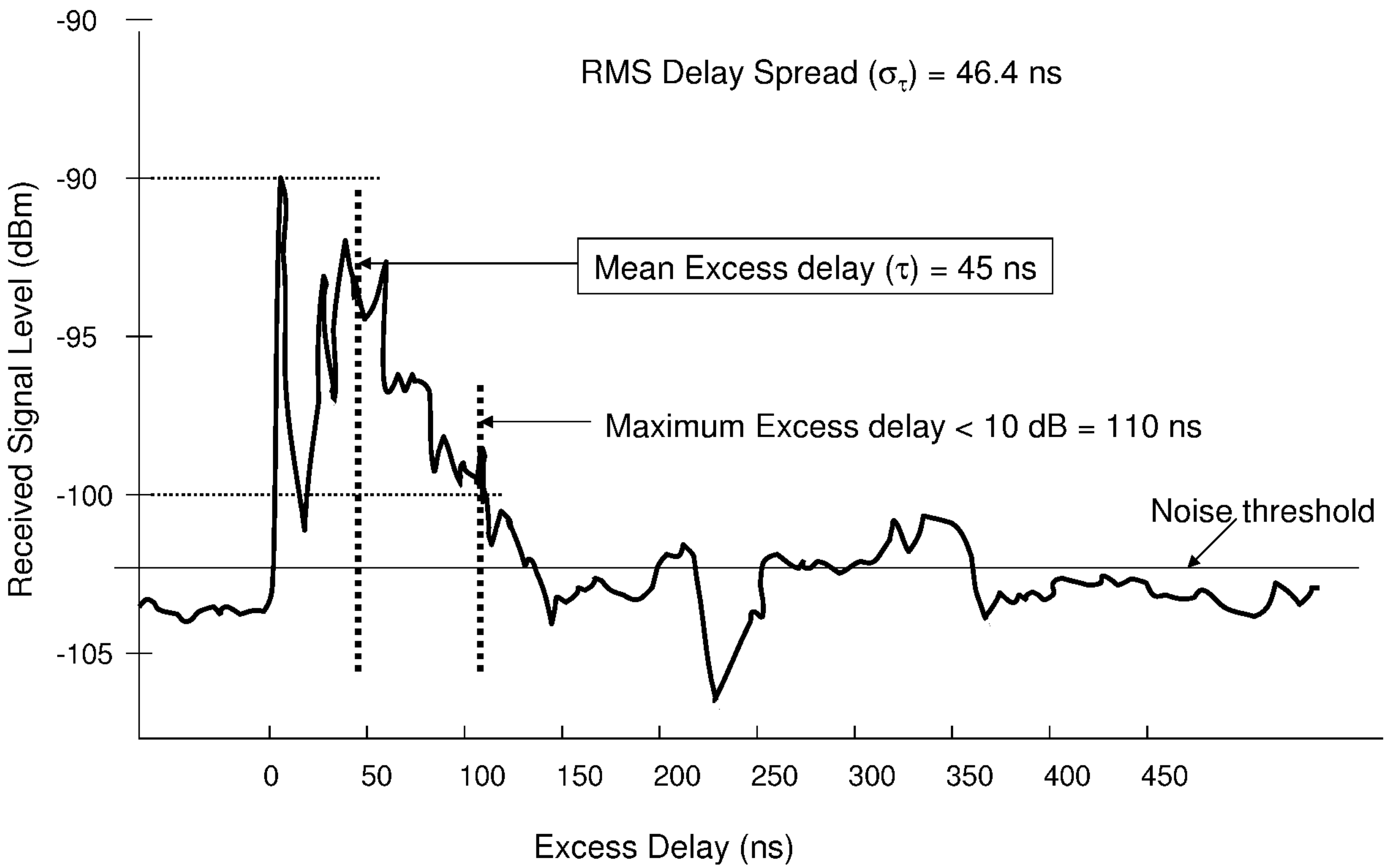


Multipath propagation causes:

- **Delay spread:** Causes intersymbol interference (ISI)
  Solution: OFDM, i.e., ISI-free subchannels; channel equalization; UWB radio
- **Frequency selective fading:** Attenuates the symbol to be received
  Solution: Communications with wideband signal [SS, chaotic and UltraWideband (UWB) radio]

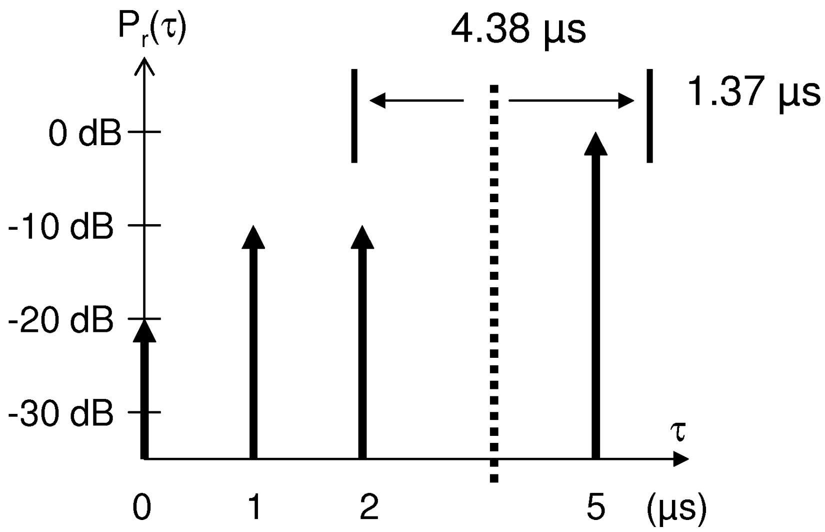
POWER DELAY PROFILE

Received signal when a very narrow pulse is transmitted



Characterization of power delay profile

Measured channel response:



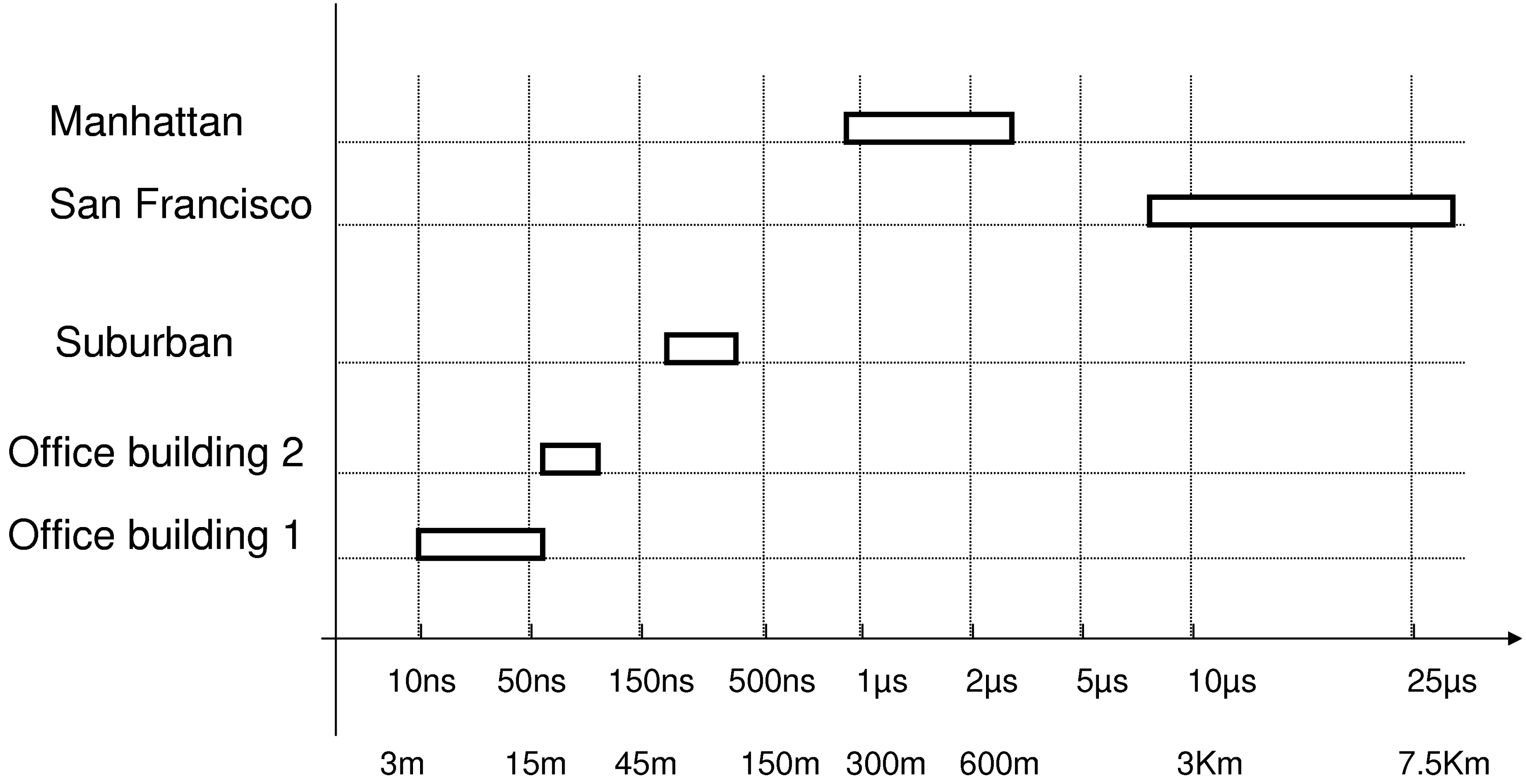
Excess delay is considered as a statistical variable

Mean excess delay: $\overline{\tau} = \frac{0.01*0+0.1*1+0.1*2+1*5}{0.01+0.1+0.1+1} = 4.38\ \mu$s

Weighted RMS of excess delay: $\overline{\tau^2} = \frac{0.01*0^2+0.1*1^2+0.1*2^2+1*5^5}{0.01+0.1+0.1+1} = 21.07\ \mu$s

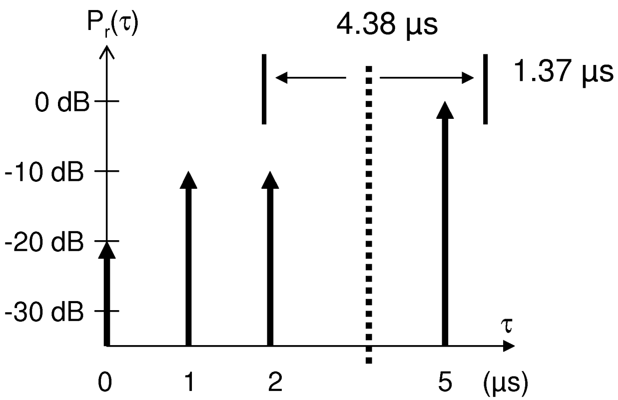
RMS delay spread: $\sigma_\tau = \sqrt{\overline{\tau^2} - \overline{\tau}^2} = \sqrt{21.07 - (4.38)^2} = 1.37\ \mu$s

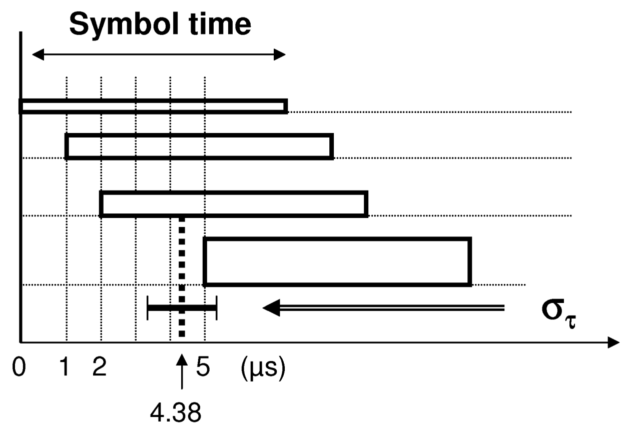
RMS DELAY SPREAD: MEASURE OF ISI CAUSED BY MULTIPATH



Note: RMS delay spread characterizes the application very well

How to avoid intersymbol interference (ISI)





Rule of thumb:
- Symbol time $> 10\sigma_\tau$ $\Longrightarrow$ No channel equalization is required
- Symbol time $< 10\sigma_\tau$ $\Longrightarrow$ Channel equalization is required to avoid ISI

In the above example, symbol time should be longer than 14 μs to avoid ISI. Consequently, symbol rate must be less than $\sim$ 70kb/s

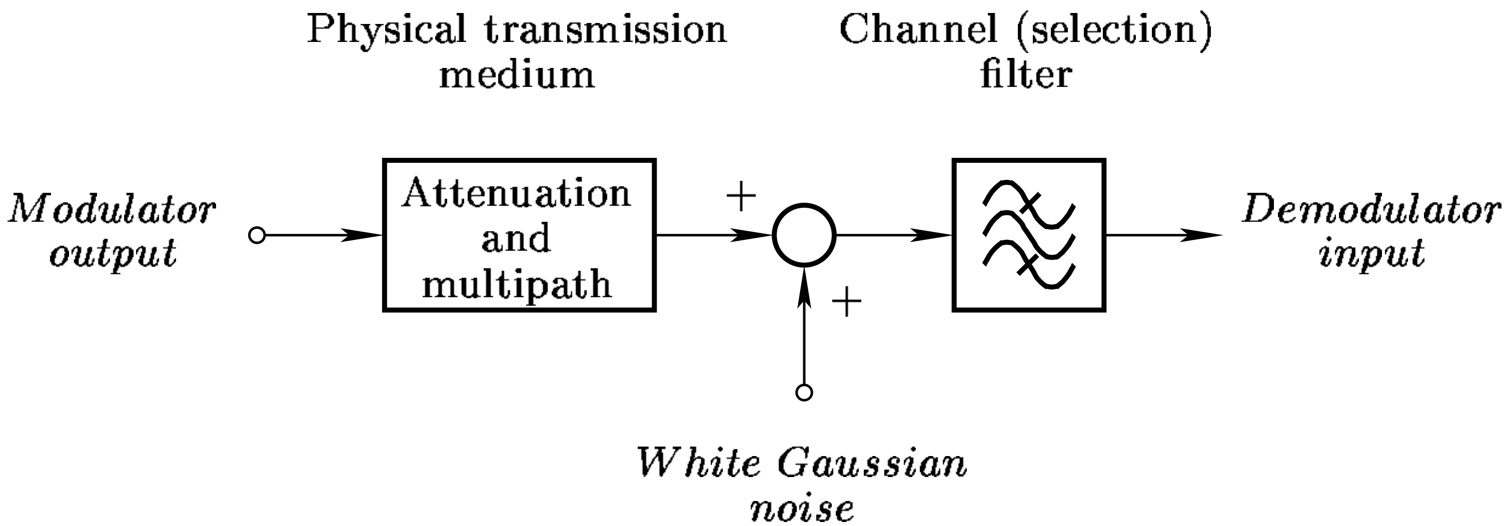
Solutions:
- Apply channel equalization
- Reduce data rate: OFDM and ADSL
- Use ultra-narrow pulses (UWB impulse radio) and apply a guard time after each pulse transmitted

CONTENTS:

2.1.4 Channel modeling

AWGN: Additive White Gaussian Noise
RF: Radio Frequency

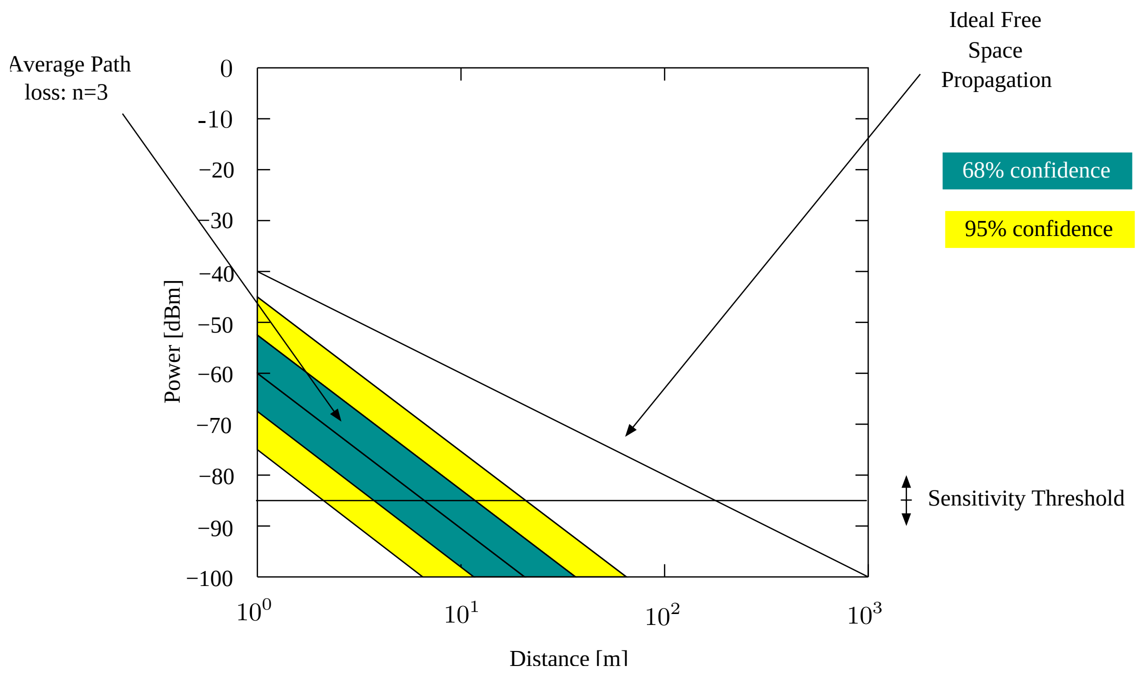
MODEL OF AWGN RF CHANNEL INCLUDING THE EFFECT OF MULTIPATH AND CHANNEL SELECTION



MEASURED PATH LOSS IN INDOOR RADIO

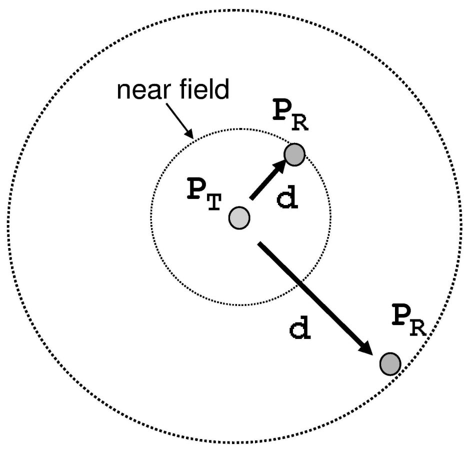
In indoor communications the received power is a statistical variable

Parameters
- Transmit power 0 dBm, 2.4-GHz ISM frequency band
- Receiver sensitivity $\leq$ -85 dBm



In case of many propagation paths the received power may be modeled by a Gaussian distribution where the variance σ varies from 3 to 11

Approximate formulas for the 2.4-GHz ISM band derived from the measured data



Near field, i.e., close to the antenna where $d \leq 8$ m

$$\text{Path loss} = 10\log_{10}\left(\frac{4\pi d^2}{\lambda}\right)$$

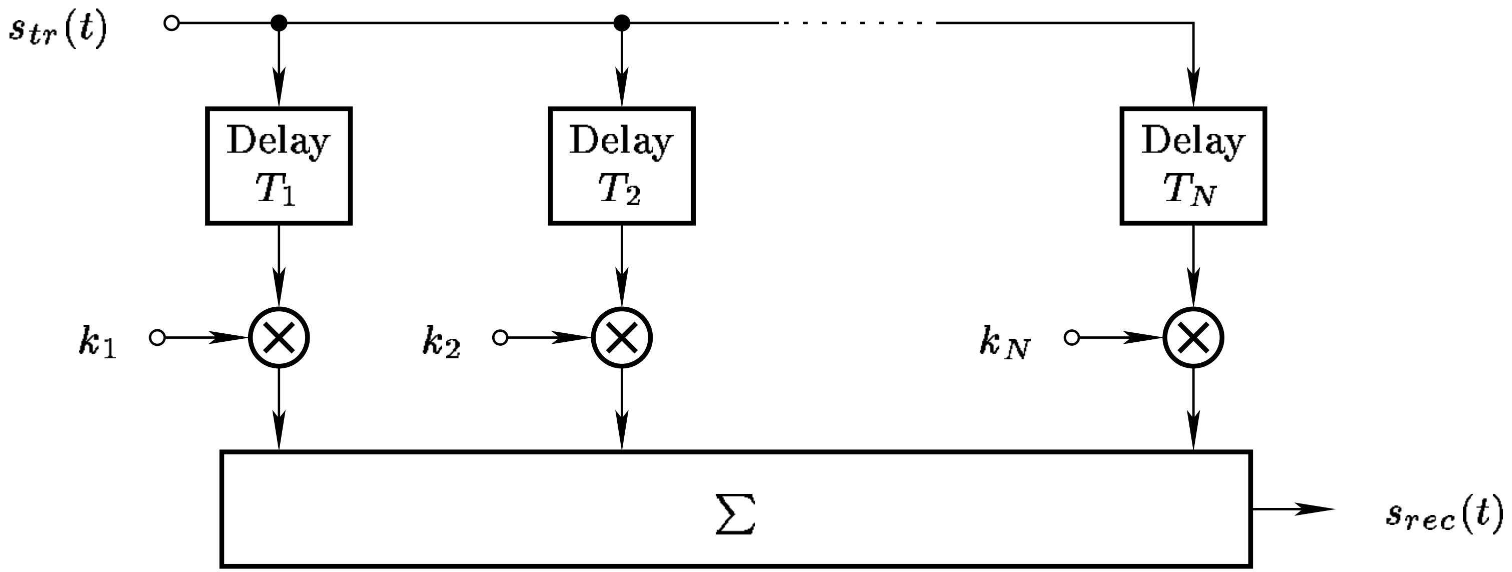
Far field where $d > 8$ m

$$\text{Path loss} = 58.3 + 10\log_{10}\left(\frac{d^n}{8}\right)$$

where constant n describes the effect of multipath propagation:

Free space (Friis formula)	$n = 2$
Indoor office environment	$n = 3.3$
Indoor home environment	$n = 4.5$

TAPPED DELAY LINE MODEL OF AN RF MULTIPATH CHANNEL

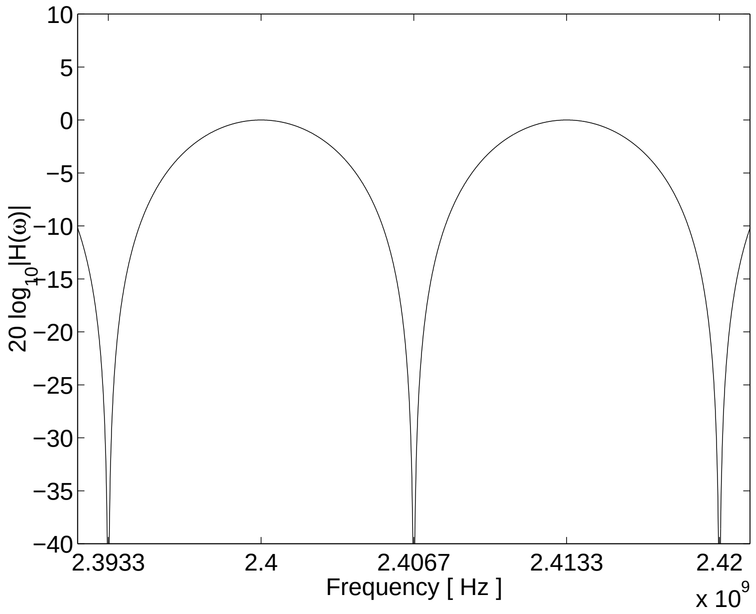


where:
- RF wave travels along the N propagation paths
- Each path is characterized by a delay T_l and gain k_l, where $l = 1, 2, \ldots, N$

Remark: Tapped delay line models are available for many applications. They can be downloaded from the websites of IEEE 802 Working Groups

Frequency response of a two-ray ($k_1 = k_2 = 1/2$) channel

Magnitude of frequency response



2.4-GHz Industrial, Scientific and Medical (ISM) radio band

Let $\Delta\tau = T_2 - T_1$ denote the excess delay of path two. The single-tone received signals cancel each other completely if

$$\Delta\tau\omega_c = (2n+1)\pi, \quad n = 0, 1, \ldots$$

Multipath-related nulls appear at

$$f_{null} = \frac{2n+1}{2\Delta\tau}, \quad n = 0, 1, 2, 3 \ldots$$

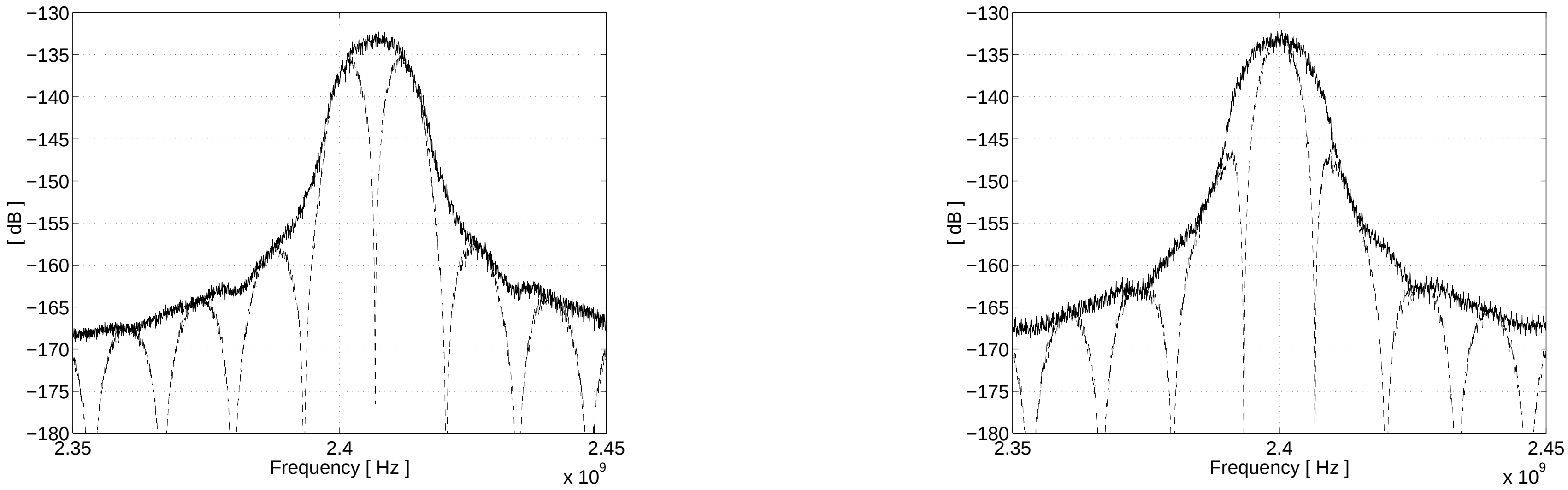
Bandwidth of multipath fading is

$$\Delta f_{null} \approx \frac{0.2}{\Delta\tau}$$

Note: The shorter the excess delay, the wider the bandwidth over which the signal is highly attenuated

Influence of the center frequencies of multipath-related nulls

- FM-DCSK: Frequency modulated differential chaos shift keying. A wideband chaotic communication system operating without carrier recovery
- RF bandwidth is $2B = 17$ MHz, bit duration is $T = 2\ \mu$s, excess delay of path two is $\Delta\tau = 75$ ns
- A wideband signal is transmitted to overcome multipath propagation problem



Transmitted (solid curve) and received (dashed curve) spectra

Conclusions:

- In indoor and mobile systems the BER performance of radio communications is limited by the multipath propagation
- Especially in indoor radio communication, the channel attenuation is almost impossible to predict. Recall, a time-varying channel has to be considered where the parameters are random quantities
- To overcome the frequency selective fading caused by multipath propagation, a wideband signal has to be transmitted (Problem appearing in the frequency domain). Solutions:
  - Spreading the spectrum of a narrowband system: Spread spectrum communications
  - Application of a wideband carrier: Chaotic communications and impulse radio
- Large RMS delay spread limits the maximum attainable data rate since it causes ISI (Problem appearing in the time domain)
- Detection without carrier recovery offers the most robust solution