ECS455 Chapter 1

Review & Introduction

1.3 Wireless Channel (Part 1)

Office Hours:
BKD 3601-7
Tuesday 10:00-11:30
Thursday 9:30-11:30

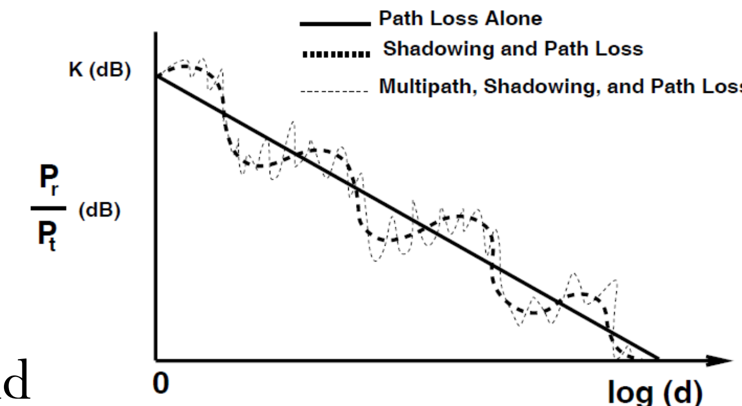
Wireless Channel

A • **Large-scale** propagation effects

A. 1. Path loss

A. 2. Shadowing

- Typically frequency independent



[Goldsmith, 2005, Fig 2.1]

B • **Small-scale** propagation effects

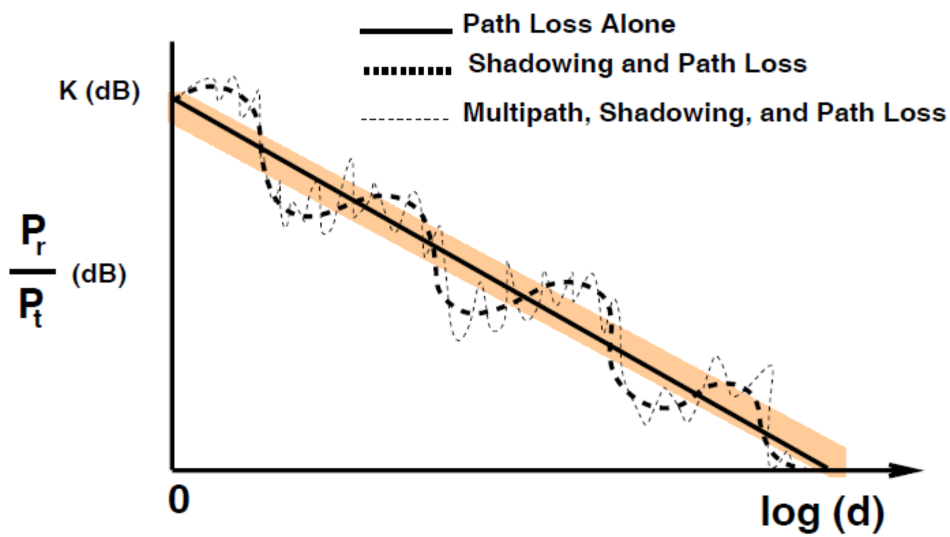
- Variation due to the constructive and destructive addition of **multipath** signal components.
- Occur over very short distances, on the order of the signal wavelength.

$$\boxed{\lambda = \frac{c}{f}} \quad c \approx 3\times10^{8}\ \text{[m/s]}$$

$f = 3$ GHz → $\lambda = 0.1$ m

A.1 Path loss

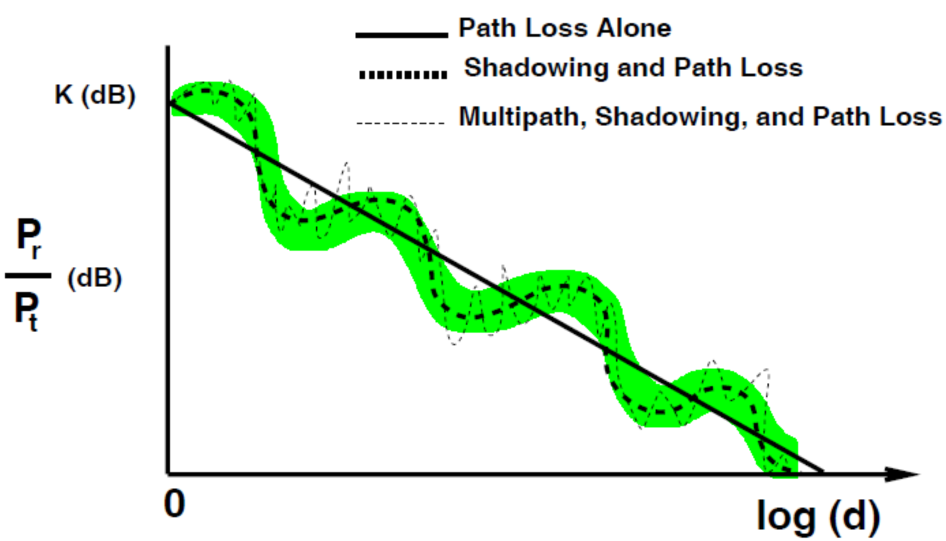
- Caused by
  - dissipation of the power radiated by the transmitter
  - effects of the propagation channel
- Models generally assume that it is the same at a given transmit-receive distance.
- Variation occurs over very large distances (100-1000 meters)



[Goldsmith, 2005, Fig 2.1]

A. 2 Shadowing

- Caused by obstacles (large objects such as buildings and hills) between the transmitter and receiver.
  - Think: cloud blocking sunlight
- Attenuate signal power through absorption, reflection, scattering, and diffraction.
- Variation occurs over distances proportional to the length of the obstructing object (10-100 meters in outdoor environments and less in indoor environments).



[Goldsmith, 2005, Fig 2.1]

A.1 Path Loss

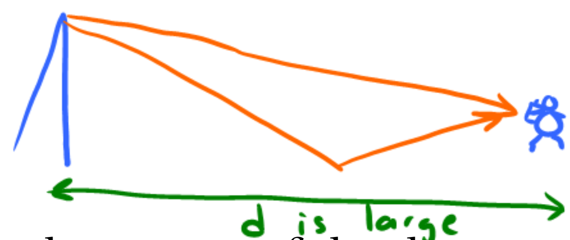
$$P_L = \frac{\text{Transmitted power}}{\text{Average received power}} = \frac{P_t}{P_r}$$

(Power Loss
Path loss)

Averaged over any random variations due to shadowing

- **Free-Space Path Loss**:

$$\frac{P_r}{P_t} \propto \frac{1}{d^2}$$



$\frac{1}{d^4}$

  - the P_r falls off inversely proportional to the square of the distance d between the Tx and Rx antennas.
  - For other signal propagation models, P_r falls off more quickly relative to d.
- Simplified Path Loss Model:

$$\frac{P_r}{P_t} = K\left(\frac{d_0}{d}\right)^{\gamma}$$

Simplified Path Loss Model

$$\frac{P_r}{P_t} = K\left(\frac{d_0}{d}\right)^{\gamma}$$

← we will revisit this when we talk about cell planning.

Captures the essence of signal propagation without resorting to complicated path loss models, which are only approximations to the real channel anyway!

- K is a unitless constant which depends on the antenna characteristics and the average channel attenuation
- d_0 is a reference distance for the antenna far-field
  - Typically 1-10 m indoors and 10-100 m outdoors.
- γ is the **path loss exponent**.
  - 2 in free-space model
  - 4 in two-ray model [Goldsmith, 2005, eq. 2.17]

Environment	γ range
Urban macrocells	3.7-6.5
Urban microcells	2.7-3.5
Office Building (same floor)	1.6-3.5
Office Building (multiple floors)	2-6
Store	1.8-2.2
Factory	1.6-3.3
Home	3

[Goldsmith, 2005, Table 2.2]

Doppler Shift: 1D Move

$A_0 \cos(2\pi f t + \phi)$

- At distance $d = 0$, suppose we have

$$A_0 \cos\left(2\pi f t + \phi\right)$$

- At distance r, we have

Time to travel a distance of r

$2\pi f\left(1 - \frac{1}{c}\frac{d}{dt} r(t)\right)$

$\uparrow \frac{d}{dt}$

$$A_r \cos\left(2\pi f\left(t - \frac{r}{c}\right) + \phi\right)$$

- If moving, r becomes $r(t)$. $\rightarrow A_{r(t)} \cos\left(2\pi f\left(t - \frac{r(t)}{c}\right) + \phi\right)$
- If moving ***away*** at a constant velocity v, then $r(t) = r_0 + vt$.

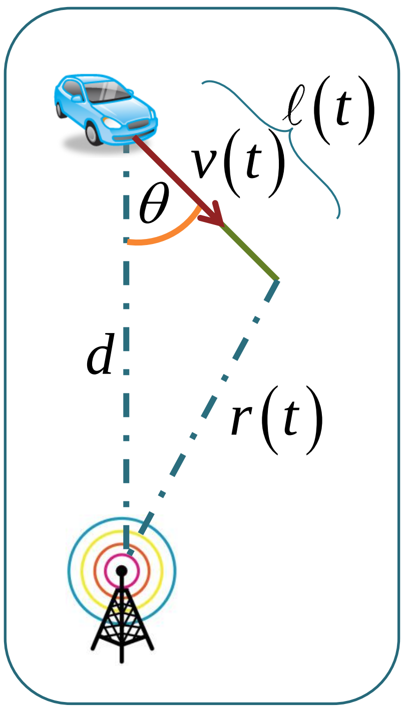
$$A_{r(t)} \cos\left(2\pi f\left(t - \frac{r_0 + vt}{c}\right) + \phi\right) = A_{r(t)} \cos\left(2\pi\left(f - f\frac{v}{c}\right)t - 2\pi f\frac{r_0}{c} + \phi\right)$$

Frequency shift

$$= \frac{v}{\lambda}$$

Doppler Shift: With angle

Rx speed $= v(t)$. At time t, cover distance $\ell(t) = \int_0^t v(\tau)\,d\tau$

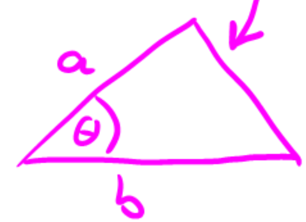


$$r(t) = \sqrt{d^2 + \ell^2(t) - 2d\,\ell(t)\cos\theta}$$

$$\frac{d}{dt}r(t) = \frac{2\ell(t) - 2d\cos\theta}{2\sqrt{d^2 + \ell^2(t) - 2d\,\ell(t)\cos\theta}}\,v(t)$$

$$\left.\frac{d}{dt}r(t)\right|_{t=0} = -\cos\theta\, v(0)$$

$\sqrt{a^2+b^2-2ab\cos\theta}$



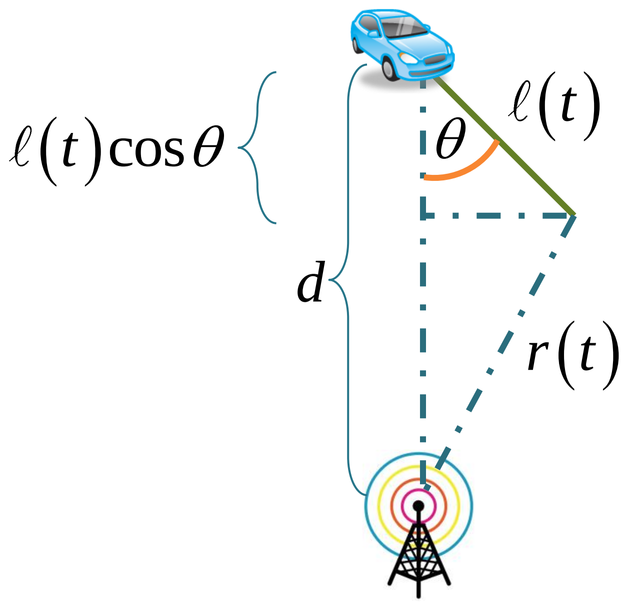
$$f_{\text{new}}(t) = f - \frac{1}{\lambda}\frac{d}{dt}r(t)$$

$$\boxed{f_{\text{new}}(0) = f + \underbrace{\frac{1}{\lambda}\cos\theta\, v(0)}_{\text{Frequency shift}}}$$

Doppler Shift: Approximation

$c = f\lambda$

$\lambda = \frac{c}{f}$



$$r(t) \approx d - \ell(t)\cos\theta$$

$$\frac{d}{dt} r(t) \approx -v(t)\cos\theta$$

$$f_{\text{new}}(t) \approx f + \frac{v(t)\cos\theta}{\lambda}$$

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

100

$\cancel{10^{12}}$

$$\frac{75 \times 1000 \times 1 \times 10^{9}}{3600 \times 3 \times 10^{8}}$$

$\cancel{10^{10}}$

For typical vehicle speeds (75 Km/hr) and frequencies (around 1 GHz), it is on the order of 100 Hz

[Goldsmith, 2005, Fig 2.2]