

دانشگاه بین‌المللی امام خمینی



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Wireless Channel Propagation Model Large-scale Fading

What have we covered in last 2 lectures

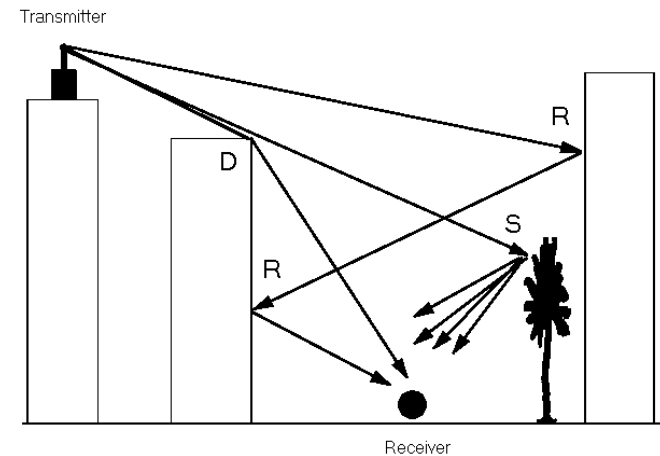
- An overview of wireless technologies
 - Evolution of wireless
- Today, we will cover
 - Basic concepts of wireless communications and
 - Wireless channel propagation models

Wireless Communication

- What is wireless communication?
 - Basically the study of how signals travel in the wireless medium
 - To understand wireless networking, we first need to understand the basic characteristics of wireless communications
 - How further the signal can travel
 - How strong the signal is
 - How much reliable would it be (how frequently the signal strength vary)
 - Indoor propagation
 - Outdoor propagation and
 - Many more...
 - Wireless communication is significantly different from wired communication

Wireless Propagation Characteristics

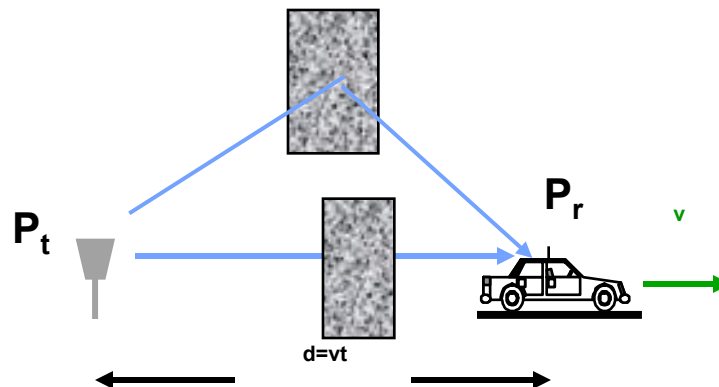
- Most wireless radio systems operate in urban area
 - No direct line-of-sight (los) between transmitter and receiver
- Radio wave propagation attributed to
 - Reflection
 - Diffraction and
 - Scattering
- Waves travel along different paths of varying lengths
 - Multipath propagation
 - Interaction of these waves can be constructive or destructive



Reflection (R), diffraction (D) and scattering (S).

Wireless Propagation Characteristics(contd.)

- Strengths of the waves decrease as the distance between Tx and Rx increase
- We need Propagation models that predict the signal strength at Rx from a Tx
- One of the challenging tasks due to randomness and unpredictability in the surrounding environment

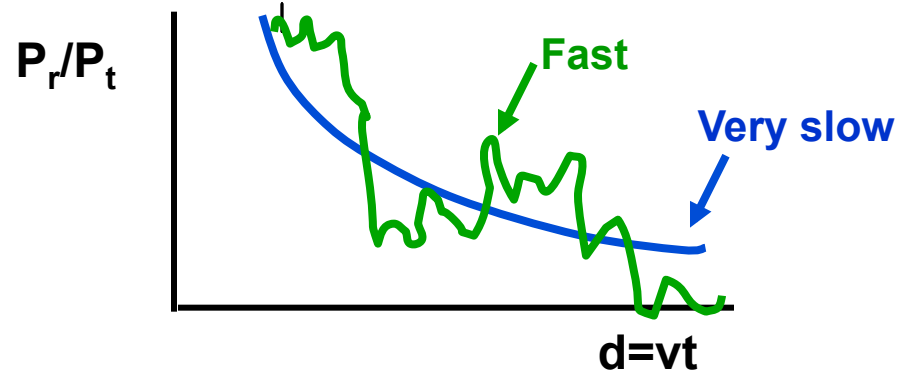
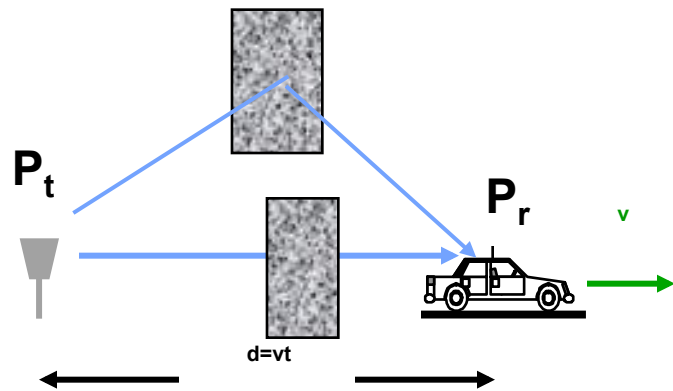


Wireless Propagation Models

- Can be categorized into two types:
 - Large-scale propagation models
 - Small-scale propagation models
- Large-scale propagation models
 - Propagation models that characterize signal strengths over Tx-Rx separation distance
- Small-scale propagation models
 - Characterize received signal strengths varying over short scale
 - **Short travel distance of the receiver**
 - **Short time duration**

Wireless Propagation Models (contd.)

- Large-scale propagation
- Small-scale propagation



Large-scale propagation model

- Also known as Path loss model
- There are numerous path loss models
 - Free space path loss model
 - Simple and good for analysis
 - Mostly used for direct line-of-sight
 - Not so perfect for non-LOS but can be approximated
 - Ray-tracing model
 - 2-ray propagation model
 - Site/terrain specific and can not be generalized easily
 - Empirical models
 - Modeled over data gathered from experiments
 - Extremely specific
 - But more accurate in the specific environment

Introduction to Radio Wave Propagation

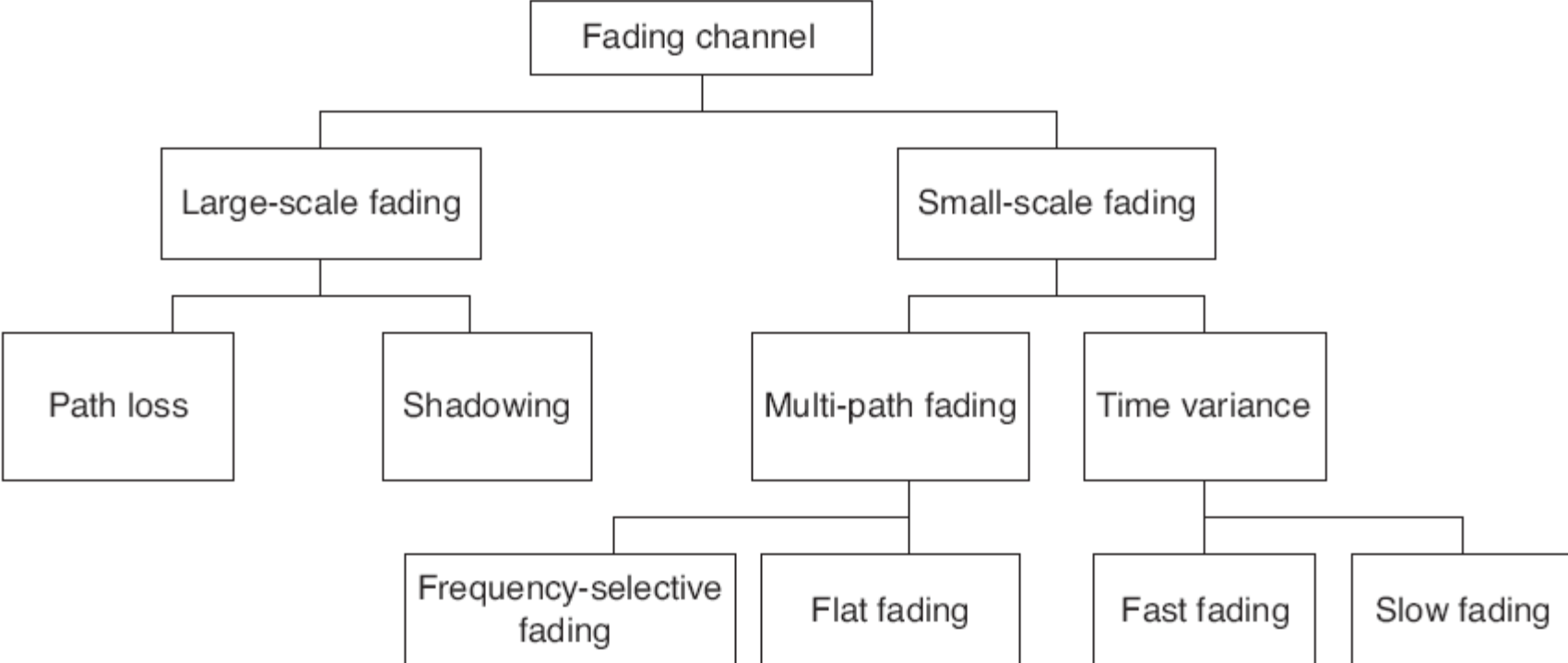
Large Scale Propagation Models

Propagation models are usually required to predict the average received signal strength at a given distance from the transmitter and estimating the coverage area (averaged over meters).

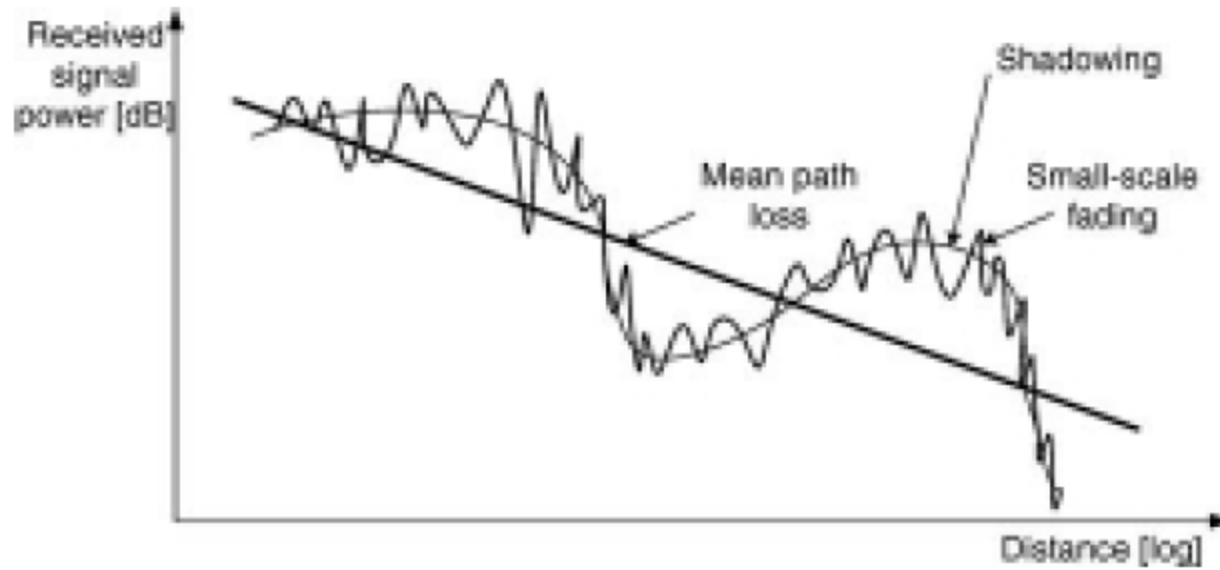
Small-Scale models (fading models)

Propagation models that characterize rapid fluctuations of the received signal strength over very short travel distances (few wavelengths) or short time duration (on the order of seconds).

General Model



Typical Wireless Signal



Free space Path Loss Model

- What is the general principle?
 - The received power decays as a function of Tx-Rx separation distance raised to some power
 - i.e., power-law function
- Path loss for unobstructed LOS path
- Power falls off :
 - Proportional to d^2

$$P_r(d) \propto \frac{P_t}{d^2}$$

Free space Path Loss Model (contd.)

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L}$$

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

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

Free space Path Loss (contd.)

- What is the path loss?
 - Represents signal attenuation

$$\frac{\text{Tx power}}{\text{Rx power}} = \frac{P_t}{P_r}$$

- What will be the order of path loss for a FM radio system that transmits with 100 kW with 50 km range?
- Also calculate: what will be the order of path loss for a Wi-Fi radio system that transmits with 0.1 W with 100 m range?

Path Loss in dB

- It is difficult to express Path loss using transmit/receive power
 - Can be very large or
 - Very small
- Expressed as a positive quantity measured in dB
 - dB is a unit expressed using logarithmic scale
 - Widely used in wireless

$$PL(dB) = 10 \log \frac{P_t}{P_r} = -10 \log \left[\frac{G_t G_r \lambda^2}{(4\pi)^2 d^2} \right]$$

- With unity antenna gain,

$$PL(dB) = 10 \log \frac{P_t}{P_r} = -10 \log \left[\frac{\lambda^2}{(4\pi)^2 d^2} \right]$$

dBm and dBW

- dBm and dBW are other two variations of dB
 - dB references two powers (Tx and Rx)
 - dBm expresses measured power referenced to one mW
 - **Particularly applicable for very low received signal strength**
 - dBW expresses measured power referenced to one watt
 - dBm Widely used in wireless

$$x \text{ dBm} = 10 \log \left(\frac{P}{1mW} \right)$$

- P in mW
- In a wireless card specification, it is written that typical range for IEEE 802.11 received signal strength is -60 to -80 dBm. What is the received signal strength range in terms of watt or mW?

Relationship between dB and dBm

- What is the relationship between dB and dBm?
 - In reality, no such relationship exists
 - dB is dimensionless
 - dB is $10 \log(\text{value}/\text{value})$ and dBm is $10 \log(\text{value}/1\text{miliwatt})$
- However, we can make a quick relationship between dBm and dBW and use the concept wisely!

$x \text{ dBm}$

$10^{\frac{x}{10}} \text{ in } mW$

$10^{\frac{x}{10}} / 10^3 \text{ in } W$

$10^{\frac{x}{10}-3} \text{ in } W$

$10^{\frac{x}{10}-3} \text{ in } W$

$10\left(\frac{x}{10} - 3\right) \text{ in } dBW$

$x - 30 \text{ in } dBW$

Back to Path Loss model

- We saw Path loss expressed in dB

$$PL(dB) = 10 \log \frac{P_t}{P_r} = -10 \log \left[\frac{\lambda^2}{(4\pi)^2 d^2} \right]$$

- Note, the above eqn does not hold for $d=0$
- For this purpose, a close-in distance d_0 is used as a reference point
 - It is assumed that the received signal strength at d_0 is known
 - Received signal strength is then calculated relative to d_0

$$d > d_0$$

- For a typical Wi-Fi analysis, d_0 can be 1 m.

Back to Path Loss model (contd.)

- The received power at a distance d is then

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

- In dBm,

$$P_r(d) (dBm) = 10 \log \left[\frac{P_r(d_0) \left(\frac{d_0}{d} \right)^2}{1mW} \right]$$

$$P_r(d) (dBm) = 10 \log \left[\frac{P_r(d_0)}{1mW} \right] + 20 \log \left[\frac{d_0}{d} \right]$$

$$P_r(d) (dBm) = P_r(d_0) (dBm) + 20 \log \left[\frac{d_0}{d} \right]$$

Numerical example

- If a transmitter transmits with 50 W with a 900 MHz carrier frequency, find the received power in dBm at a free space distance of 100 m from the transmitter. What is the received power in dBm at a free space distance of 10 km?

Path Loss Model Generalized

- In reality, direct LOS may not exist in urban areas
- Free space Path Loss model is therefore generalized

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

- n is called the Path Loss exponent
- Indicates the rate at which the Path Loss increases with distance d, obstructions in the path, surrounding environment
- The worse the environment is the greater the value of n

Path Loss Exponents for different environments

Environment	Path Loss Exponent, n
Free space	2
Urban area cellular radio	2.7 – 3.5
Urban area cellular (obstructed)	3 – 5
In-building line-of-sight	1.6 – 1.8
Obstructed in-building	4 – 6
Obstructed in-factories	2 – 3

Path Loss Model Generalized (contd.)

- Generalized Path Loss referenced in dB scale

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

$$10 \log \left[\frac{P_t}{P_r(d)} \right] = 10 \log \left[\frac{P_t}{P_r(d_0)} \right] + 10n \log \left[\frac{d}{d_0} \right]$$

$$\overline{PL}(d) = \overline{PL}(d_0) + 10n \log \left[\frac{d}{d_0} \right]$$

- Received signal strength referenced in dBm scale

$$10 \log \left[\frac{P_r(d)}{1mW} \right] = 10 \log \left[\frac{P_r(d_0)}{1mW} \right] + 10n \log \left[\frac{d_0}{d} \right]$$

Path Loss Example

- Consider Wi-Fi signal in this building. Assume power at a reference point d_0 is 100mW. The reference point $d_0=1$ m. Calculate your received signal strength at a distance, $d=100$ m. Also calculate the power received in mW. Assume $n=4$.
- This is a typical Wi-Fi received signal strength.

Large Scale Path Loss

Log-normal shadowing

- averaged received power in log distance model is inconsistent with measured data
- The environmental conditions in Log-Distance model not necessarily to be the same at two different locations having the same T-R separation.
- Measurement have shown that at any value of d , the path loss $PL(d)$ at a particular location is random and distributed log-normally about the mean distance-dependent value.

Log-normal Shadowing

- Thus, $\overline{[PL(d)]dB} = \overline{PL(d)} + X\sigma = \overline{PL(d_0)} + 10n\log(d/d_0) + X\sigma$
where $X\sigma$ is Gaussian distributed random variable with zero mean (in dB) and standard deviation σ (dB).
- The log-normal distribution describes the random shadowing effects which occur over a large number of measurement locations. n and σ are computed from measured data

Log Normal Distribution - describes random [shadowing](#) effects

- for specific Tx-Rx, measured signal levels have [normal](#) distribution about distance dependent mean (in dB)
- occurs over many measurements with same Tx-Rx & different clutter standard deviation, σ (also measured in dB)

Indoor Propagation Model

- The indoor radio channel differs from the traditional mobile radio channel in outdoor
 - Distances covered are much smaller
 - Variability of the environment is much greater
- Propagation inside buildings strongly influenced by specific features
 - Layout and building type
 - Construction materials
 - Even door open or closed
 - Same floor or different floors
- Partition Losses

Partition Losses

- Partition Losses

- Same floor
- Between floors
 - Characterized by a new factor called Floor Attenuation Factors (FAF)
 - Based on building materials
 - FAF mostly empirical (computed over numerous tests)

$$\overline{PL}(d) = \overline{PL}(d_0) + 10n_{SF} \log \left[\frac{d}{d_0} \right] + FAF[dB]$$

- For example,
 - FAF through one floor approx. 13 dB
 - Two floors 18.7 dB
 - Three floors 25 dB and so on...