Chapter 3

Mobile Radio Propagation

Outline

- Speed, Wavelength, Frequency
- Types of Waves
- Radio Frequency Bands
- Propagation Mechanisms
- Radio Propagation Effects
- Free-Space Propagation
- Land Propagation
- Path Loss
- Fading: Slow Fading / Fast Fading
- Delay Spread
- Doppler Shift
- Co-Channel Interference
- The Near-Far Problem
- Digital Wireless Communication System
- Analog and Digital Signals
- Modulation Techniques

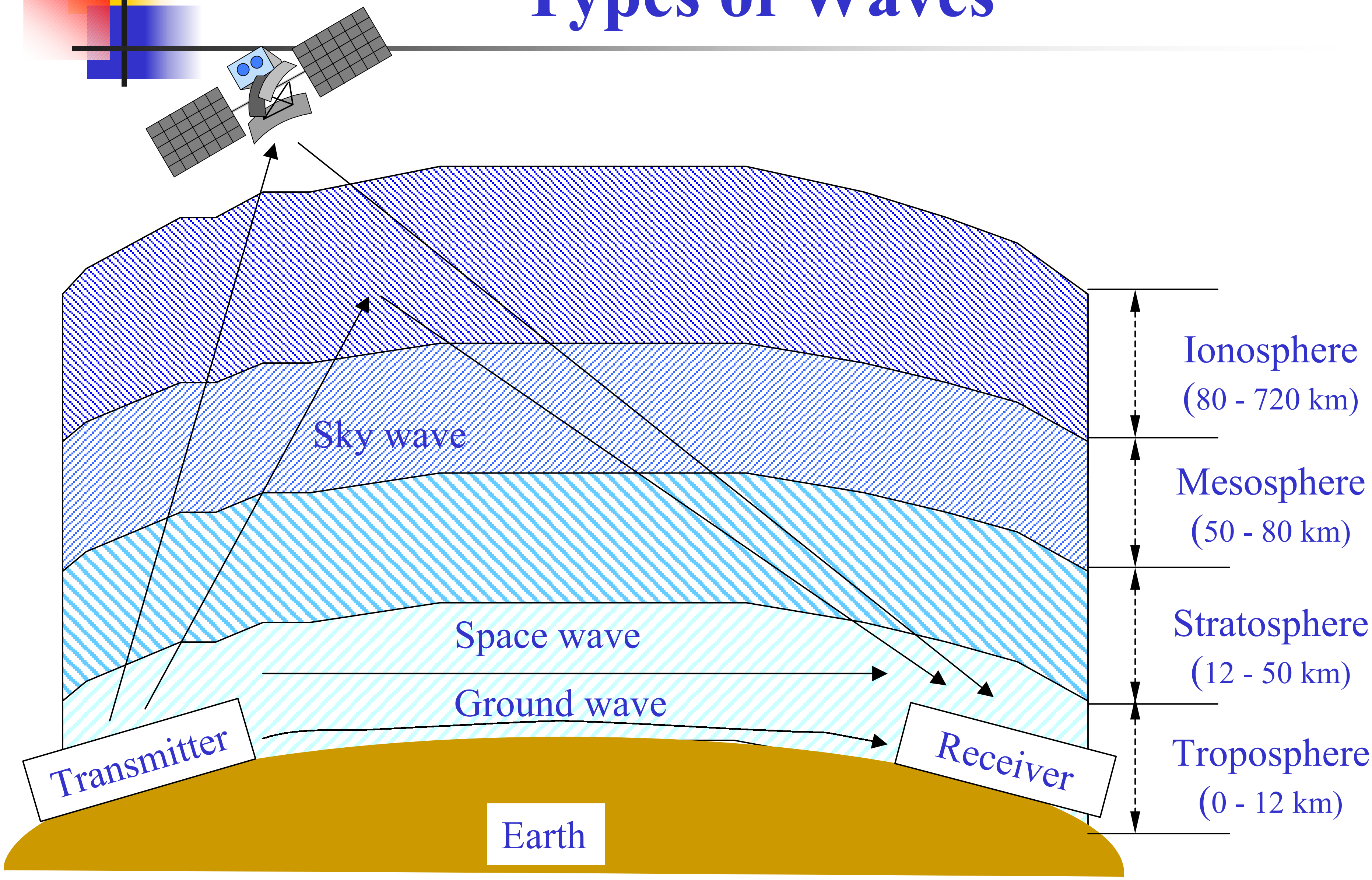
Speed, Wavelength, Frequency

Light speed = Wavelength x Frequency

$= 3 \times 10^8$ m/s = 300,000 km/s

System	Frequency	Wavelength
AC current	60 Hz	5,000 km
FM radio	100 MHz	3 m
Cellular	800 MHz	37.5 cm
Ka band satellite	20 GHz	15 mm
Ultraviolet light	10^{15} Hz	10^{-7} m

Types of Waves



Radio Frequency Bands

Classification Band	Initials	Frequency Range	Characteristics
Extremely low	ELF	< 300 Hz	
Infra low	ILF	300 Hz ~ 3 kHz	
Very low	VLF	3 kHz ~ 30 kHz	
Low	LF	30 kHz ~ 300 kHz	Surface/ground wave
Medium	MF	300 kHz ~ 3 MHz	
High	HF	3 MHz ~ 30 MHz	Sky wave
Very high	VHF	30 MHz ~ 300 MHz	Space wave
Ultra high	UHF	300 MHz ~ 3 GHz	
Super high	SHF	3 GHz ~ 30 GHz	
Extremely high	EHF	30 GHz ~ 300 GHz	Satellite wave
Tremendously high	THF	300 GHz ~ 3000 GHz	

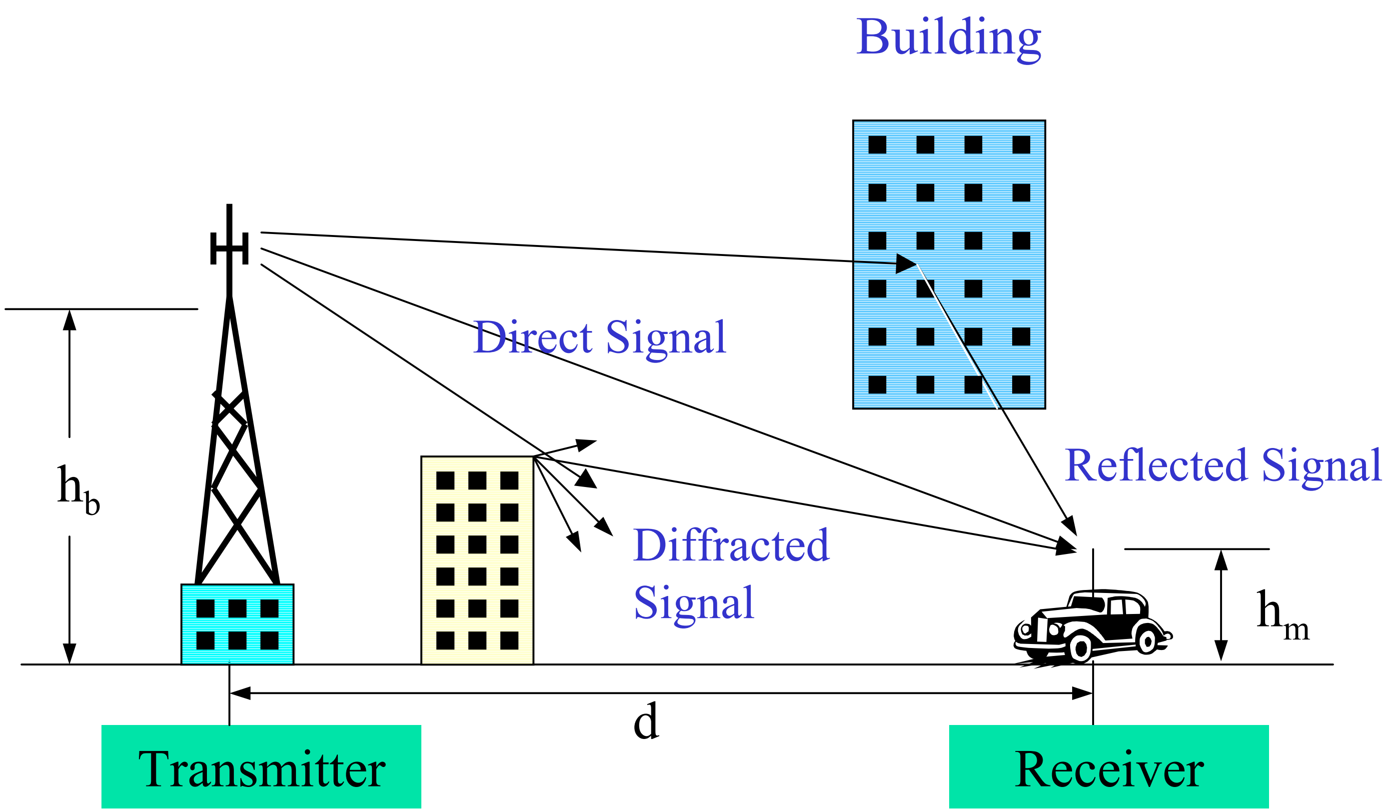
Propagation Mechanisms

- Reflection
  - Propagation wave impinges on an object which is large as compared to wavelength

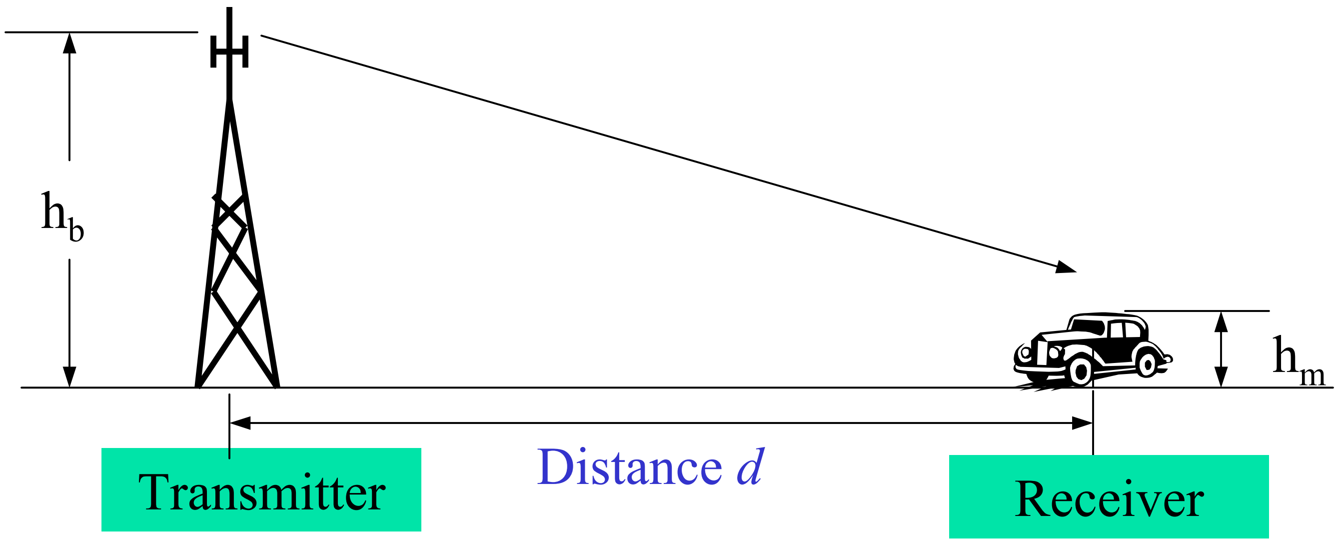
    - e.g., the surface of the Earth, buildings, walls, etc.
- Diffraction
  - Radio path between transmitter and receiver obstructed by surface with sharp irregular edges
  - Waves bend around the obstacle, even when LOS (line of sight) does not exist
- Scattering
  - Objects smaller than the wavelength of the propagation wave

    - e.g, foliage, street signs, lamp posts

Radio Propagation Effects



Free-space Propagation



- The received signal power at distance d:

$$P_r = \frac{A_e G_t P_t}{4\pi d^2}$$

where P_t is transmitting power, A_e is effective area, and G_t is the transmitting antenna gain. Assuming that the radiated power is uniformly distributed over the surface of the sphere.

Antenna Gain

- For a circular reflector antenna

  $G = \eta(\pi D / \lambda)^2$

  η = net efficiency (depends on the electric field distribution over the antenna aperture, losses, ohmic heating , typically 0.55)

  D = diameter

  thus, $G = \eta\,(\pi D f / c)^2$, $c = \lambda f$ (c is speed of light)

Example:

- Antenna with diameter = 2 m, frequency = 6 GHz, wavelength = 0.05 m

  G = 39.4 dB

- Frequency = 14 GHz, same diameter, wavelength = 0.021 m

  G = 46.9 dB

* Higher the frequency, higher the gain for the same size antenna

Land Propagation

- The received signal power:

$$P_r = \frac{G_t G_r P_t}{L}$$

where G_r is the receiver antenna gain,

L is the propagation loss in the channel, i.e.,

$$L = L_P \, L_S \, L_F$$

Fast fading

Slow fading

Path loss

Path Loss (Free-space)

- Definition of path loss L_P:

$$L_P = \frac{P_t}{P_r},$$

Path Loss in Free-space:

$$L_{PF}(dB) = 32.45 + 20\log_{10} f_c(MHz) + 20\log_{10} d(km),$$

where f_c is the carrier frequency.

This shows greater the f_c, more is the loss.

Path Loss (Land Propagation)

- Simplest Formula:

$$L_p = A\, d^{-\alpha}$$

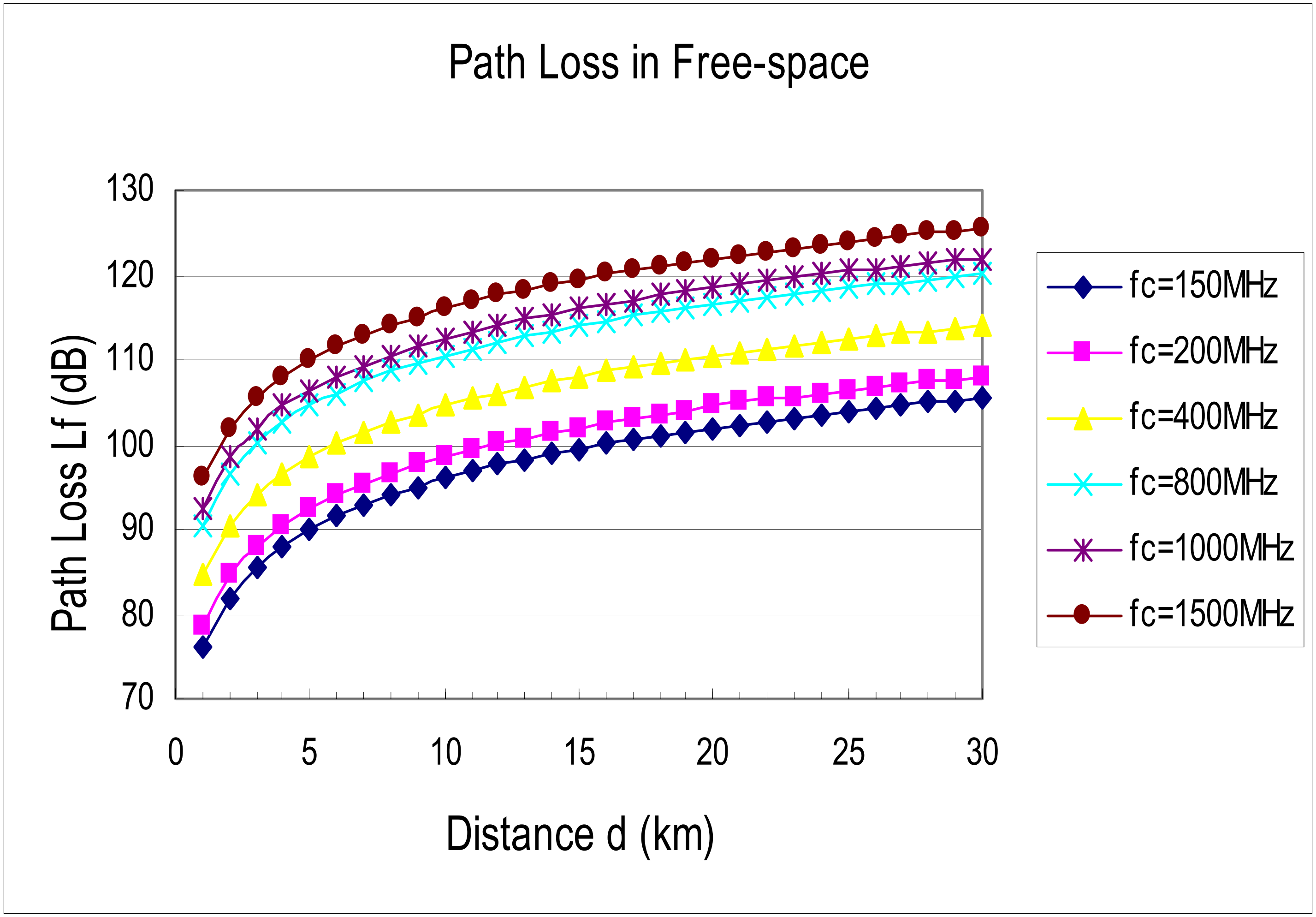
where

A and α: propagation constants

d : distance between transmitter and receiver

α : value of 3 ~ 4 in typical urban area

Example of Path Loss (Free-space)



Path Loss (Urban, Suburban and Open areas)

- Urban area:

$$L_{PU}(dB) = 69.55 + 26.16\log_{10} f_c(MHz) - 13.82\log_{10} h_b(m) - \alpha\left[h_m(m)\right] + \left[44.9 - 6.55\log_{10} h_b(m)\right]\log_{10} d(km)$$

where

$$\alpha\left[h_m(m)\right] = \begin{cases} \left[1.1\log_{10} f_c(MHz) - 0.7\right]h_m(m) - \left[1.56\log_{10} f_c(MHz) - 0.8\right], & for\ large\ city \\ \left.\begin{array}{ll} 8.29\left[\log_{10} 1.54h_m(m)\right]^2 - 1.1, & for \quad f_c \le 200MHz \\ 3.2\left[\log_{10} 11.75h_m(m)\right]^2 - 4.97, & for \quad f_c \ge 400MHz \end{array}\right\}, & for\ small\ \&\ medium\ city \end{cases}$$

- Suburban area:

$$L_{PS}(dB) = L_{PU}(dB) - 2\left[\log_{10}\frac{f_c(MHz)}{28}\right]^2 - 5.4$$

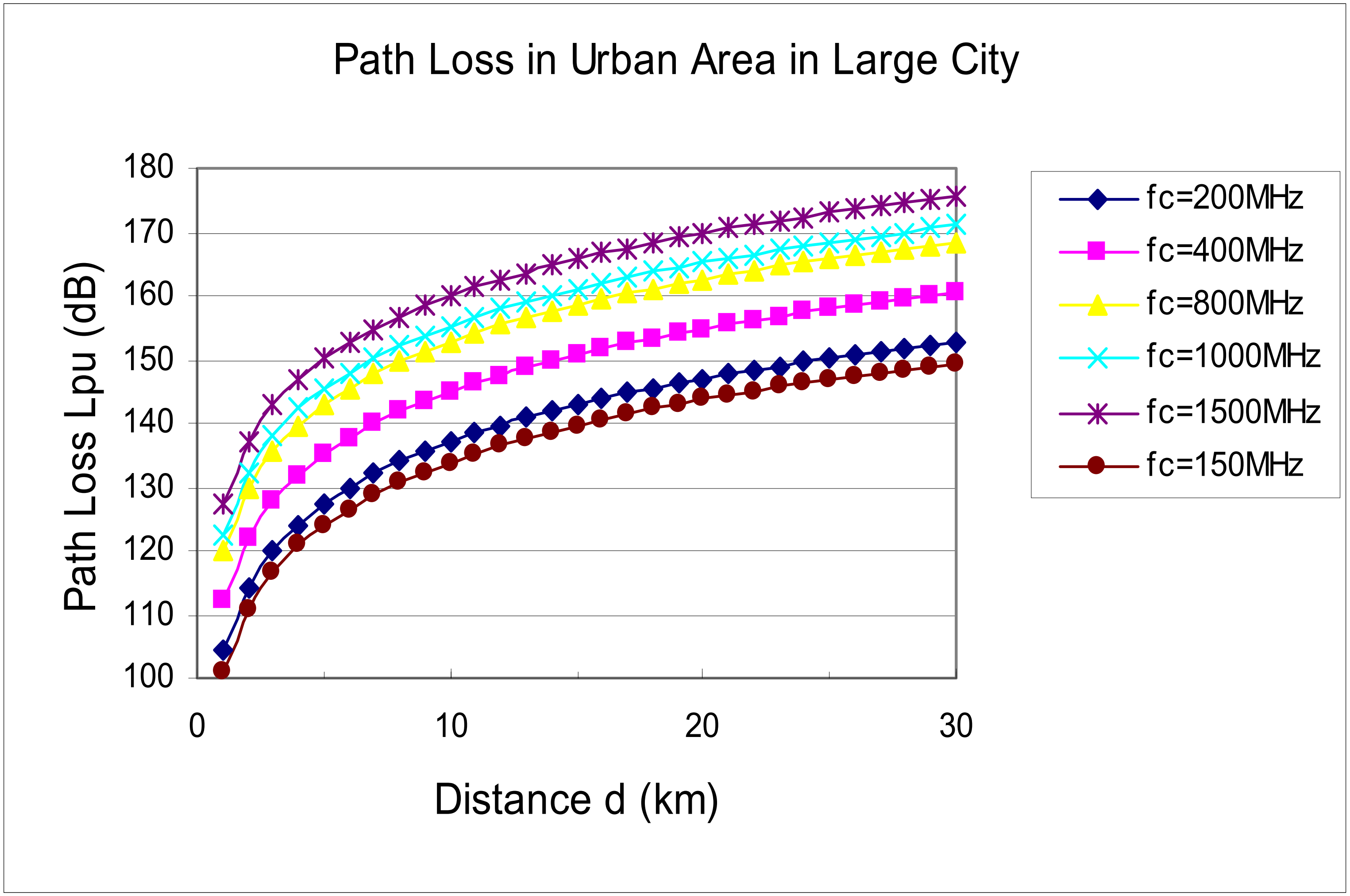
- Open area:

$$L_{PO}(dB) = L_{PU}(dB) - 4.78\left[\log_{10} f_c(MHz)\right]^2 + 18.33\log_{10} f_c(MHz) - 40.94$$

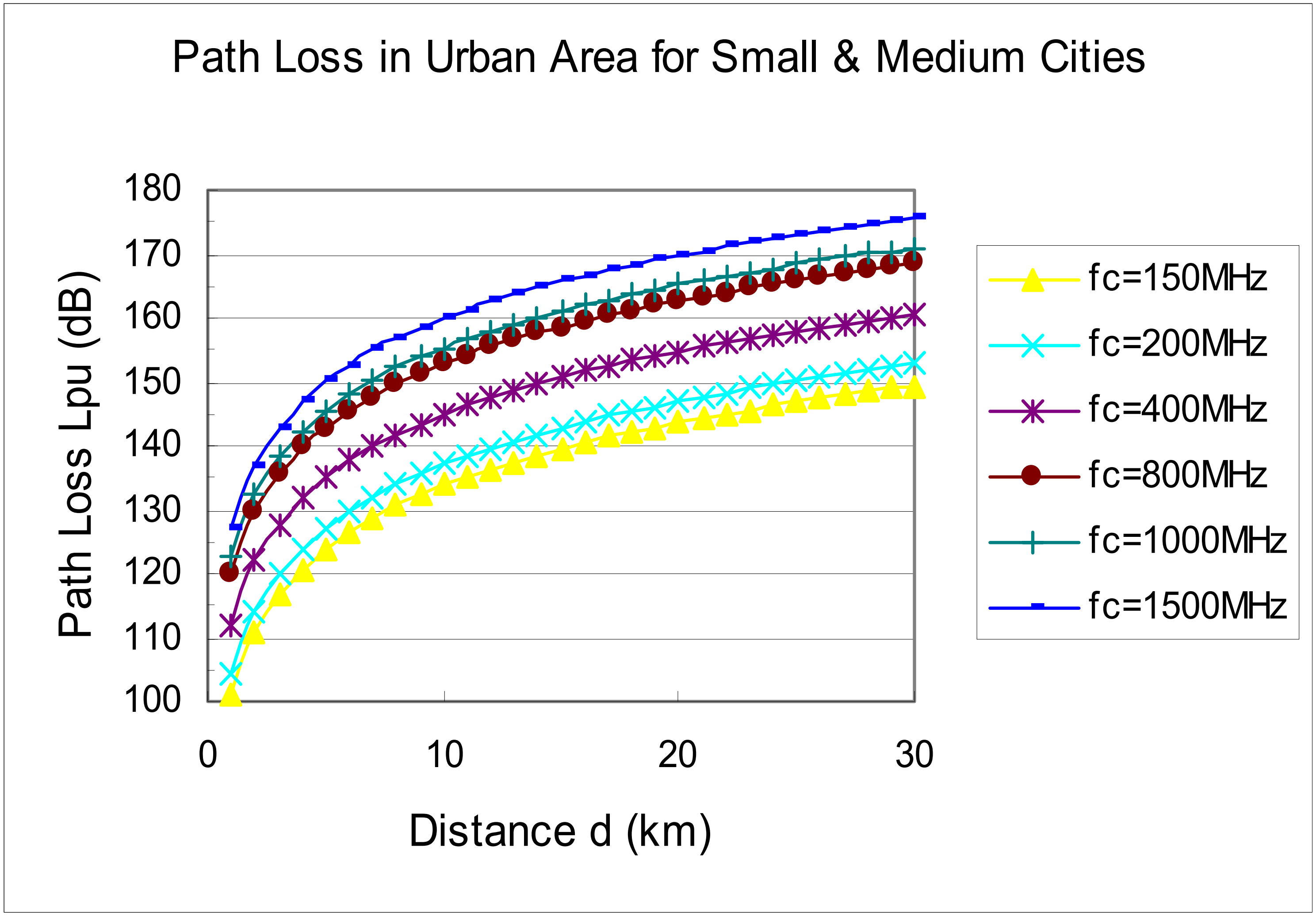
Path Loss

- Path loss in decreasing order:
  - Urban area (large city)
  - Urban area (medium and small city)
  - Suburban area
  - Open area

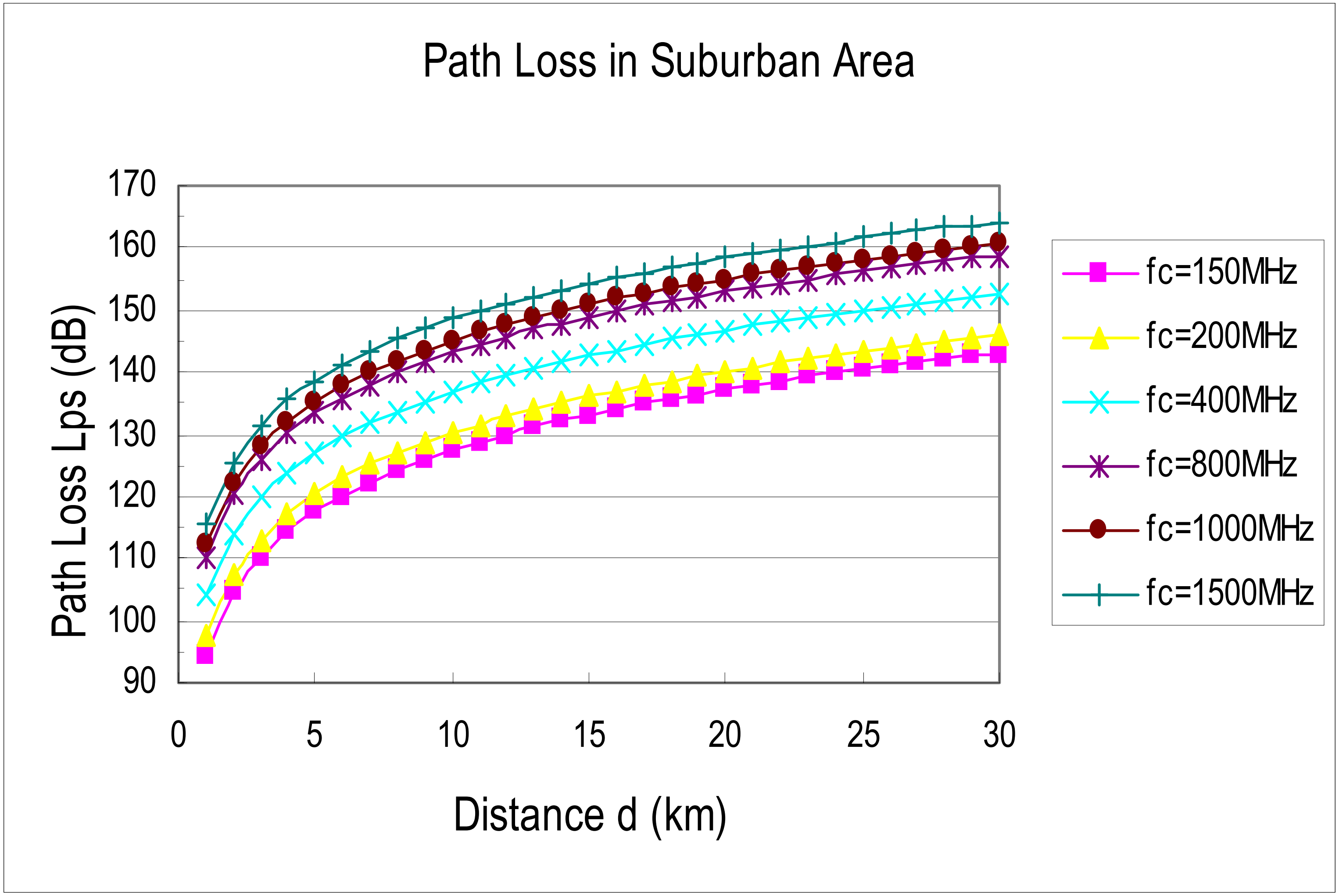
Example of Path Loss (Urban Area: Large City)



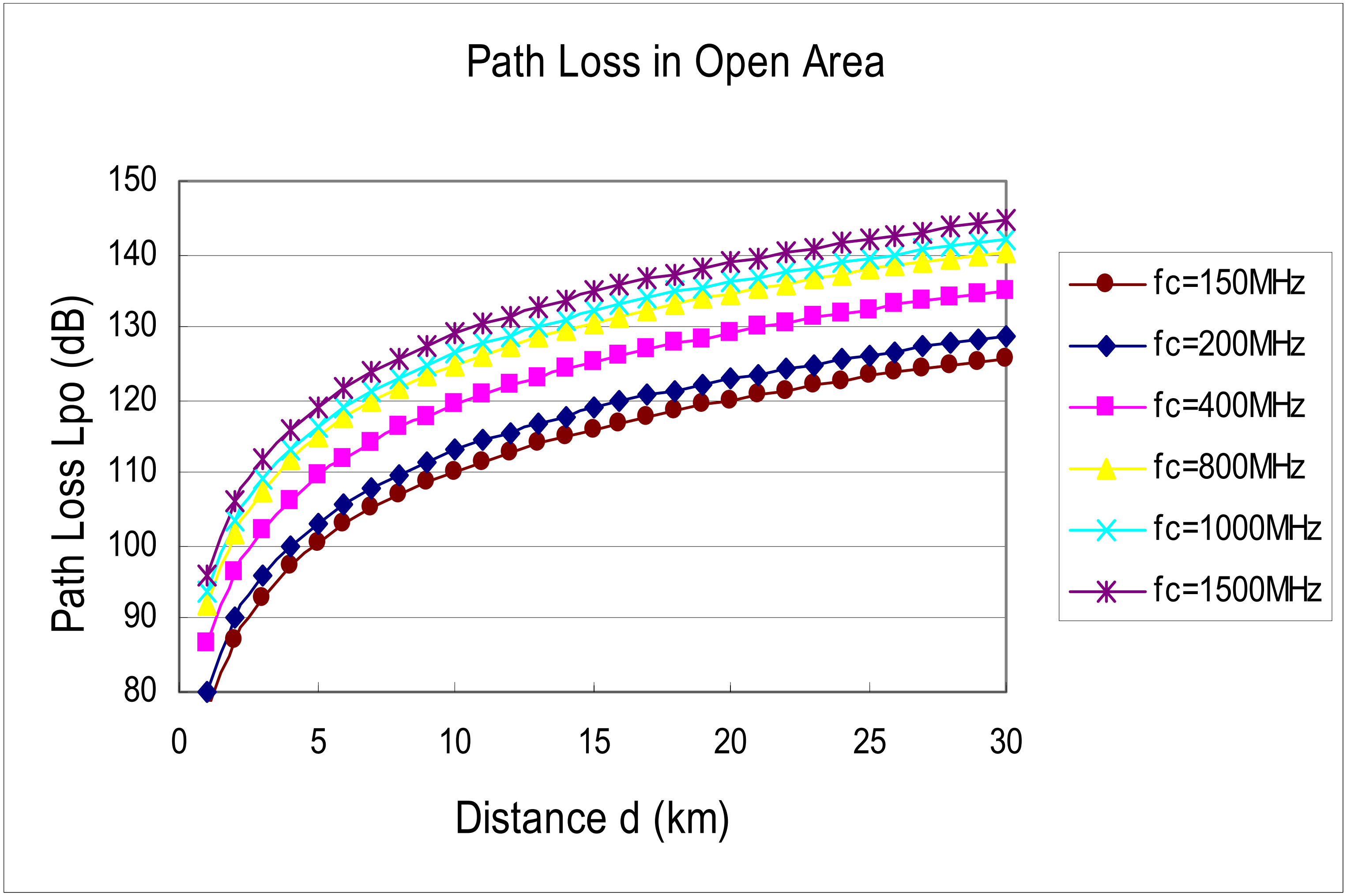
Example of Path Loss
(Urban Area: Medium and Small Cities)



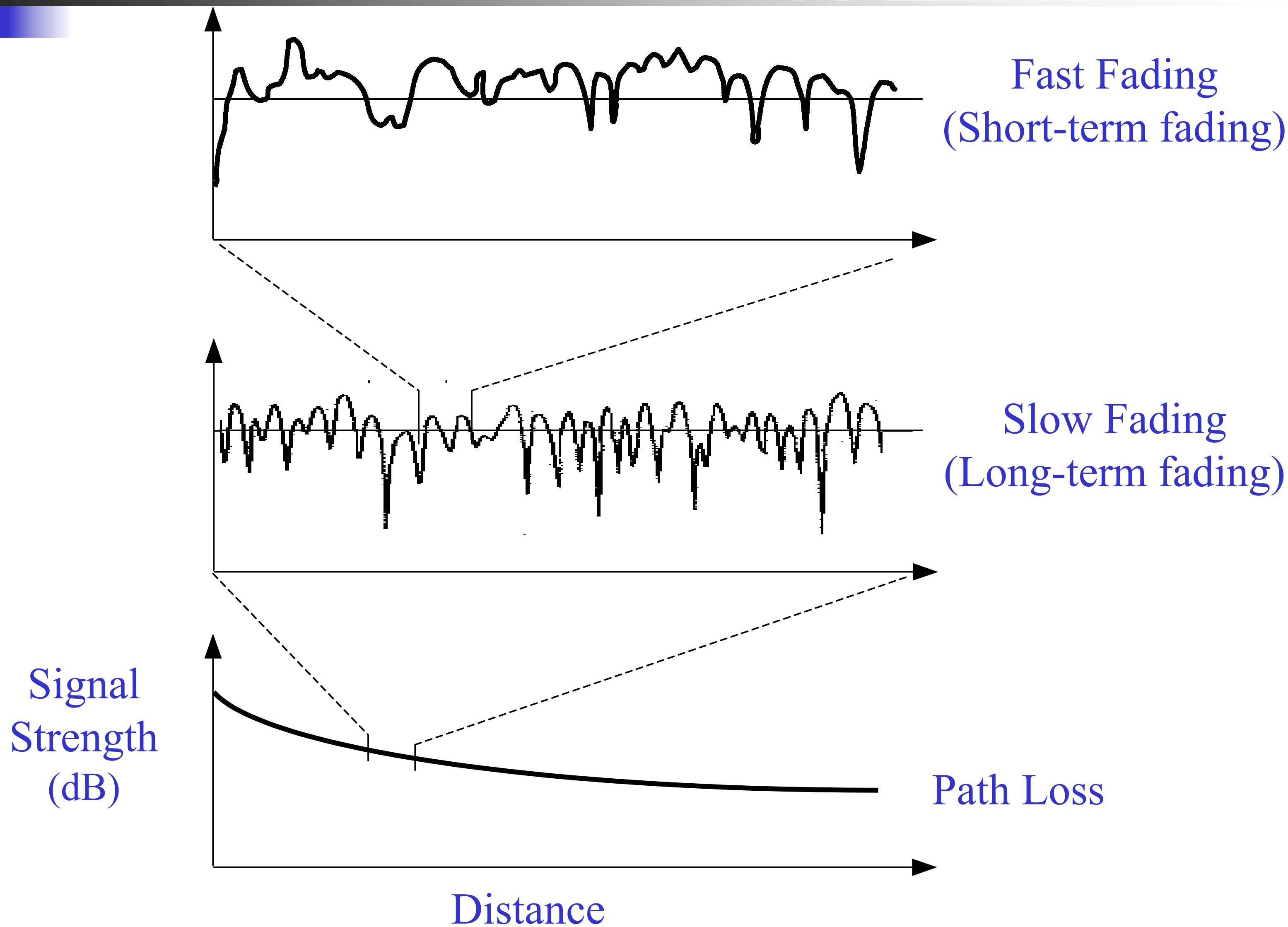
Example of Path Loss (Suburban Area)



Example of Path Loss (Open Area)



Fading



Fast Fading
(Short-term fading)
Slow Fading
(Long-term fading)
Signal
Strength
(dB)
Path Loss
Distance

Slow Fading

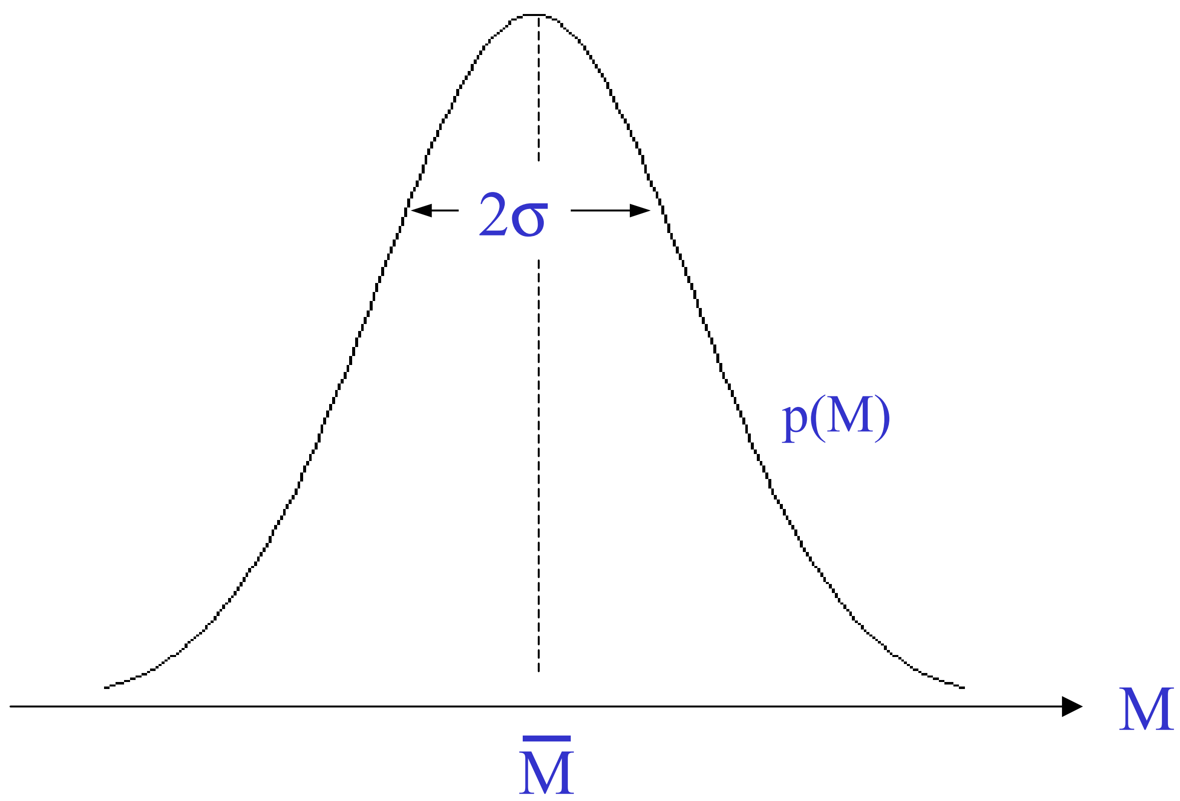
- The long-term variation in the mean level is known as slow fading (shadowing or log-normal fading). This fading caused by shadowing.
- Log-normal distribution:

  - The pdf of the received signal level is given in decibels by

$$p(M) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(M-\overline{M})^2}{2\sigma^2}},$$

where M is the true received signal level m in decibels, i.e., $10\log_{10}m$,
$\overline{M}$ is the area average signal level, i.e., the mean of M,
σ is the standard deviation in decibels

Log-normal Distribution



The pdf of the received signal level

Fast Fading

- The signal from the transmitter may be reflected from objects such as hills, buildings, or vehicles.
  - When MS far from BS, the envelope distribution of received signal is Rayleigh distribution. The pdf is

$$p(r) = \frac{r}{\sigma^2} e^{-\frac{r^2}{2\sigma^2}}, \quad r > 0$$

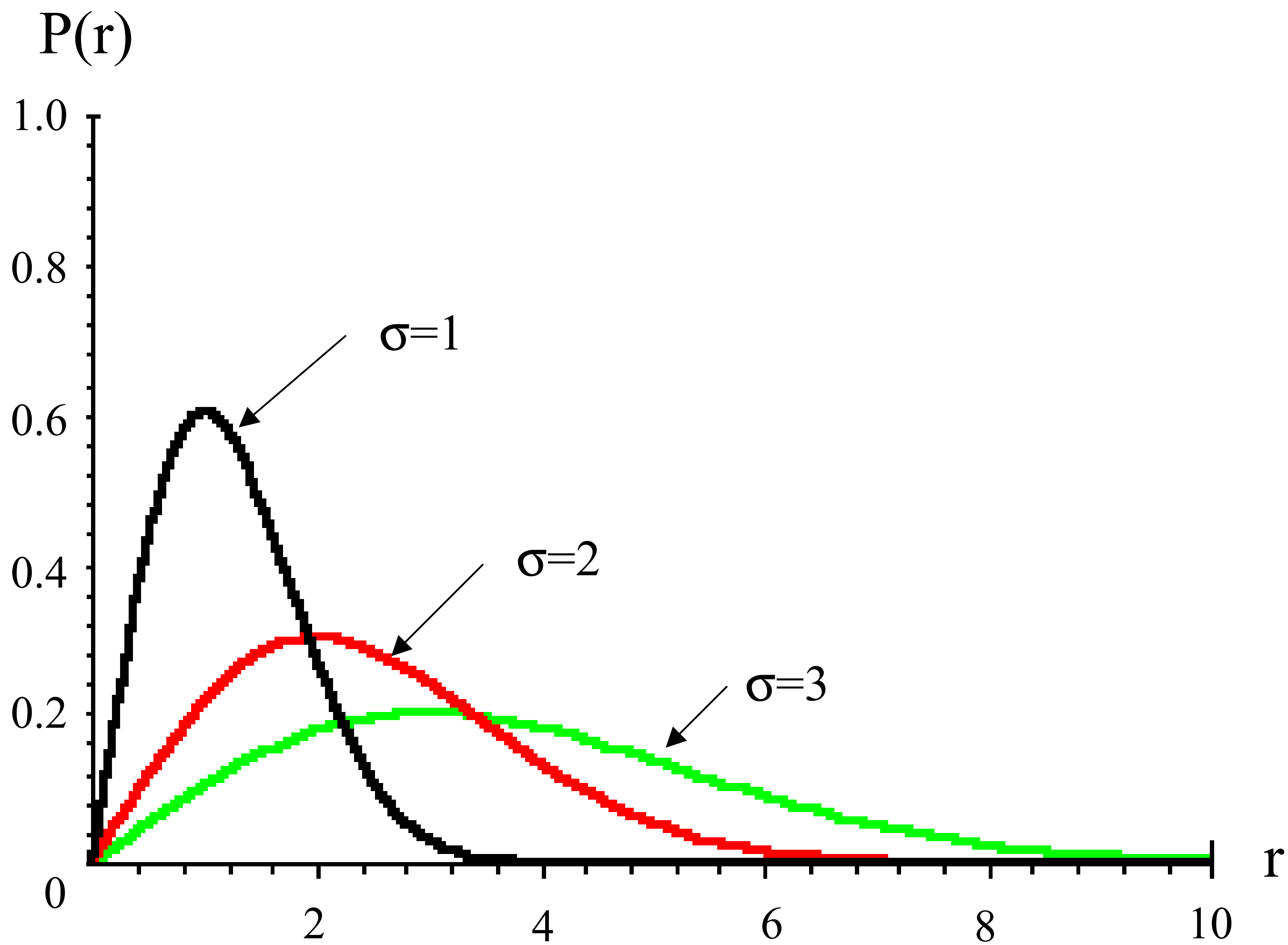
where σ is the standard deviation.

  - Middle value r_m of envelope signal within sample range to be satisfied by

$$P(r \leq r_m) = 0.5.$$

  - We have $r_m = 1.777$s

Rayleigh Distribution



The pdf of the envelope variation

Fast Fading (Continued)

- When MS far from BS, the envelope distribution of received signal is Rician distribution. The pdf is

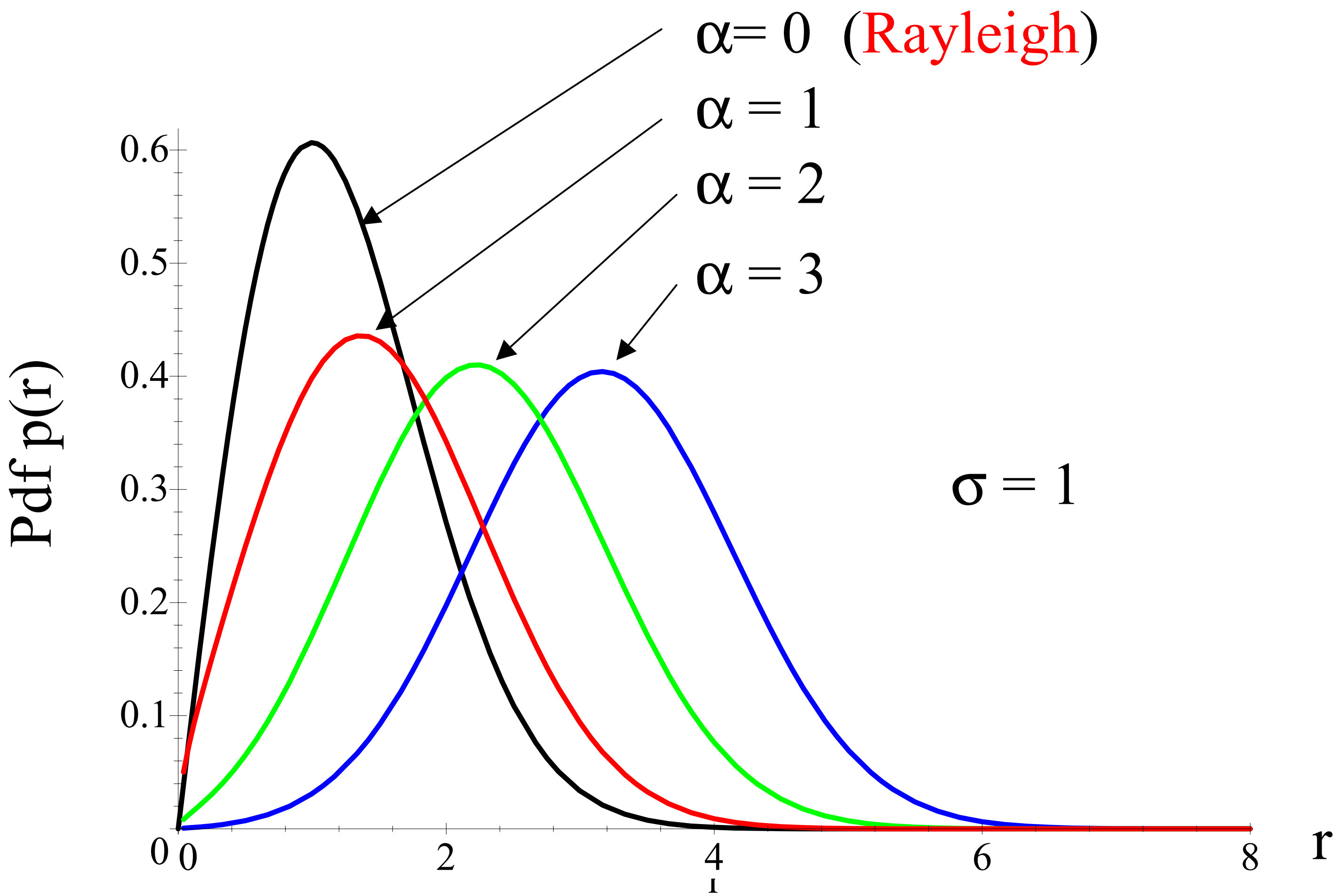
$$p(r) = \frac{r}{\sigma^2} e^{-\frac{r^2+\alpha^2}{2\sigma^2}} I_0\left(\frac{r\alpha}{\sigma}\right), \quad r \geq 0$$

where

σ is the standard deviation,

$I_0(x)$ is the zero-order Bessel function of the first kind.

Rician Distribution



The pdf of the envelope variation

Characteristics of Instantaneous Amplitude

- Level Crossing Rate:
  - Average number of times per second that the signal envelope crosses the level in positive going direction.
- Fading Rate:
  - Number of times signal envelope crosses middle value in positive going direction per unit time.
- Depth of Fading:
  - Ratio of mean square value and minimum value of fading signal.
- Fading Duration:
  - Time for which signal is below given threshold.

Doppler Shift

- Doppler Effect: When a wave source and a receiver are moving towards each other, the frequency of the received signal will not be the same as the source.
  - When they are moving toward each other, the frequency of the received signal is higher than the source.
  - When they are opposing each other, the frequency decreases.

  Thus, the frequency of the received signal is

$$f_R = f_C - f_D$$

  where f_C is the frequency of source carrier,

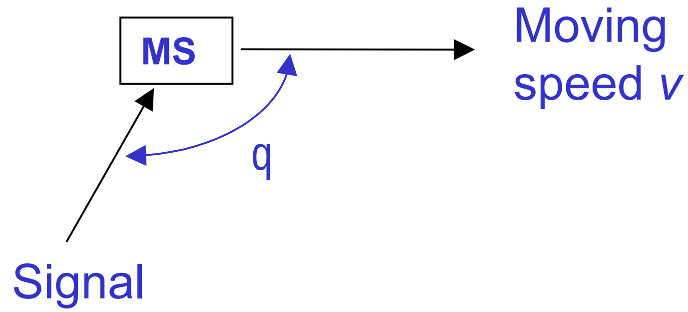
  f_D is the Doppler frequency.

- Doppler Shift in frequency:

$$f_D = \frac{v}{\lambda}\cos\theta$$

  where v is the moving speed,

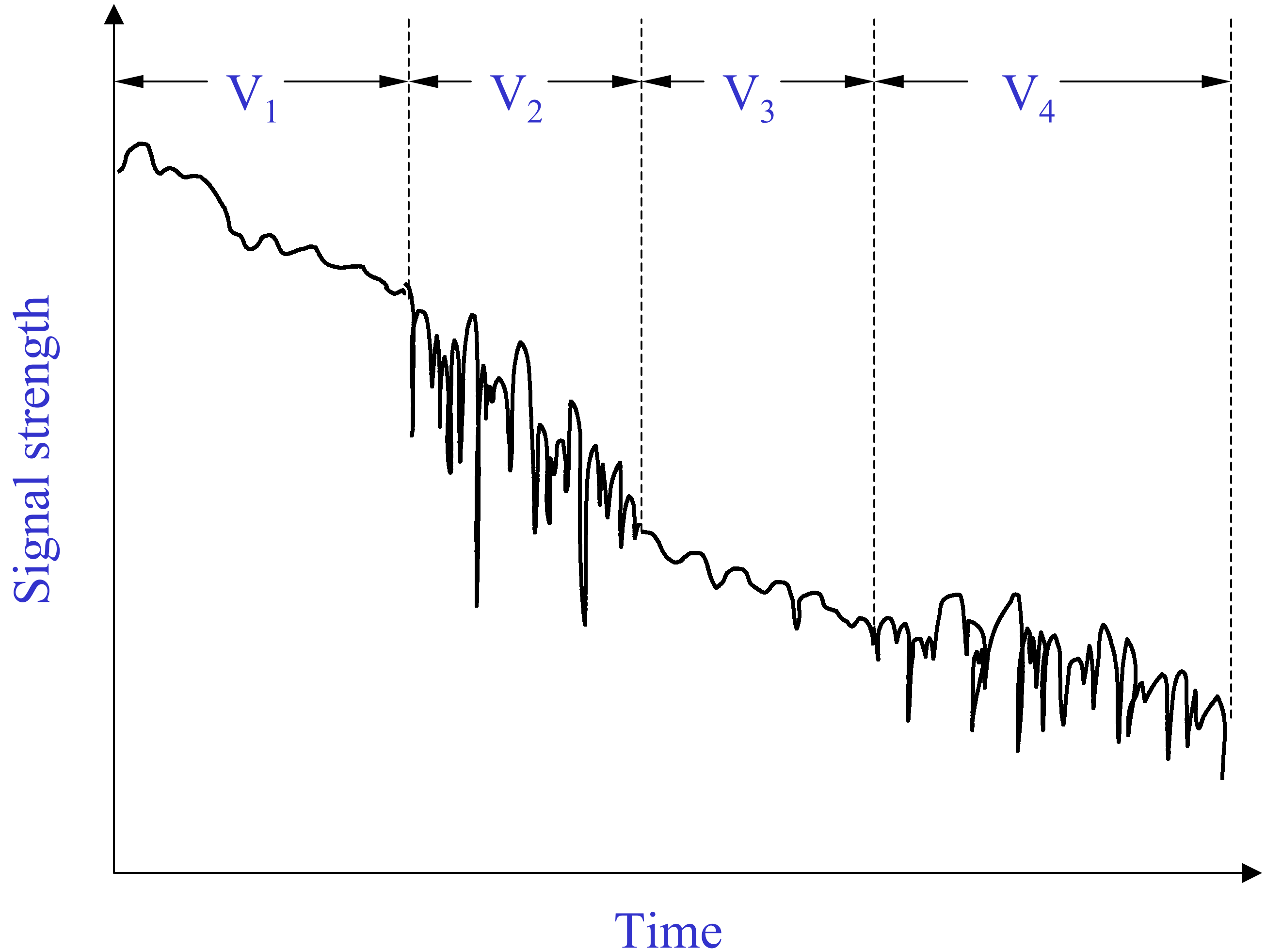
  λ is the wavelength of carrier.



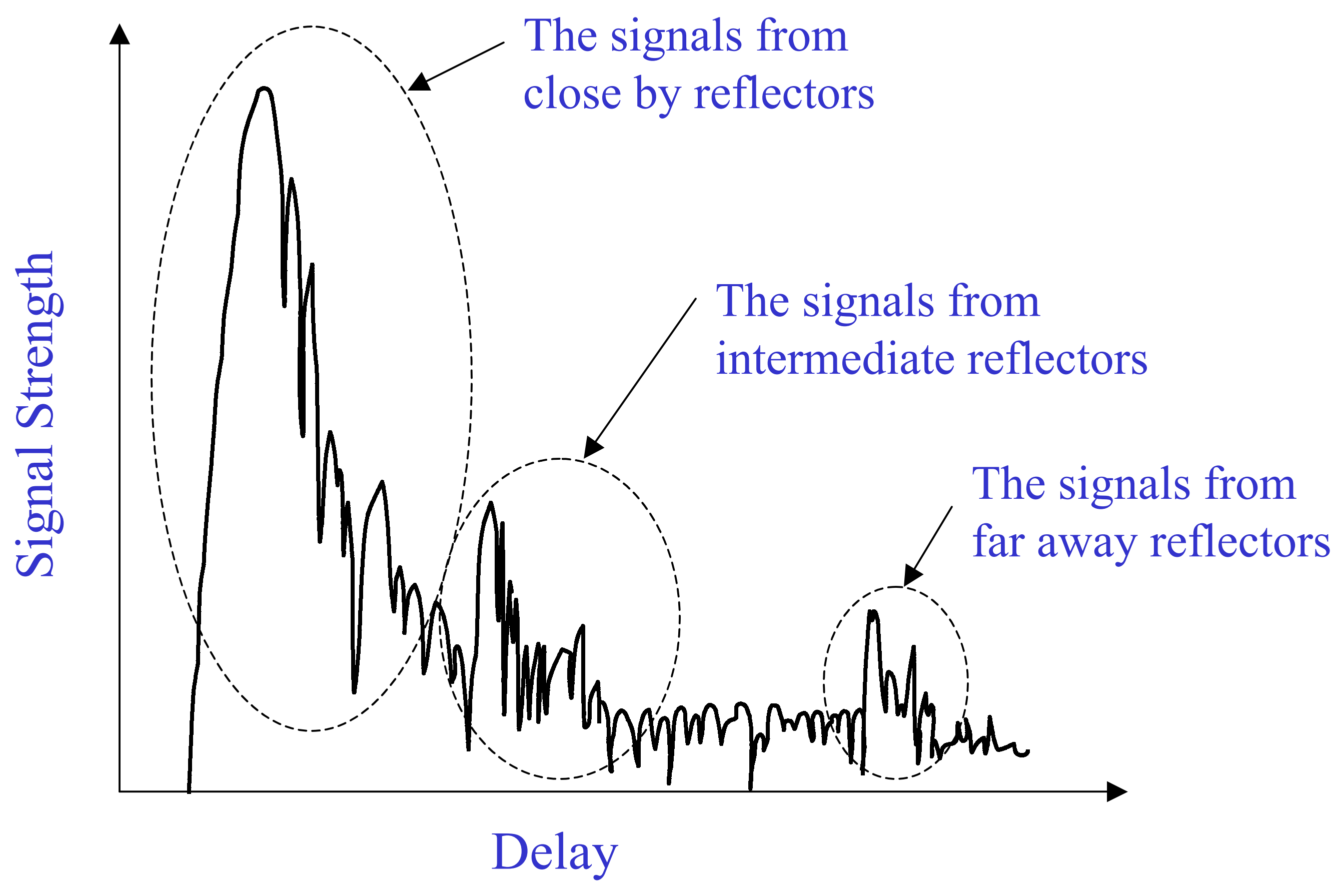
Delay Spread

- When a signal propagates from a transmitter to a receiver, signal suffers one or more reflections.
- This forces signal to follow different paths.
- Each path has different path length, so the time of arrival for each path is different.
- This effect which spreads out the signal is called "Delay Spread".

Moving Speed Effect



Delay Spread



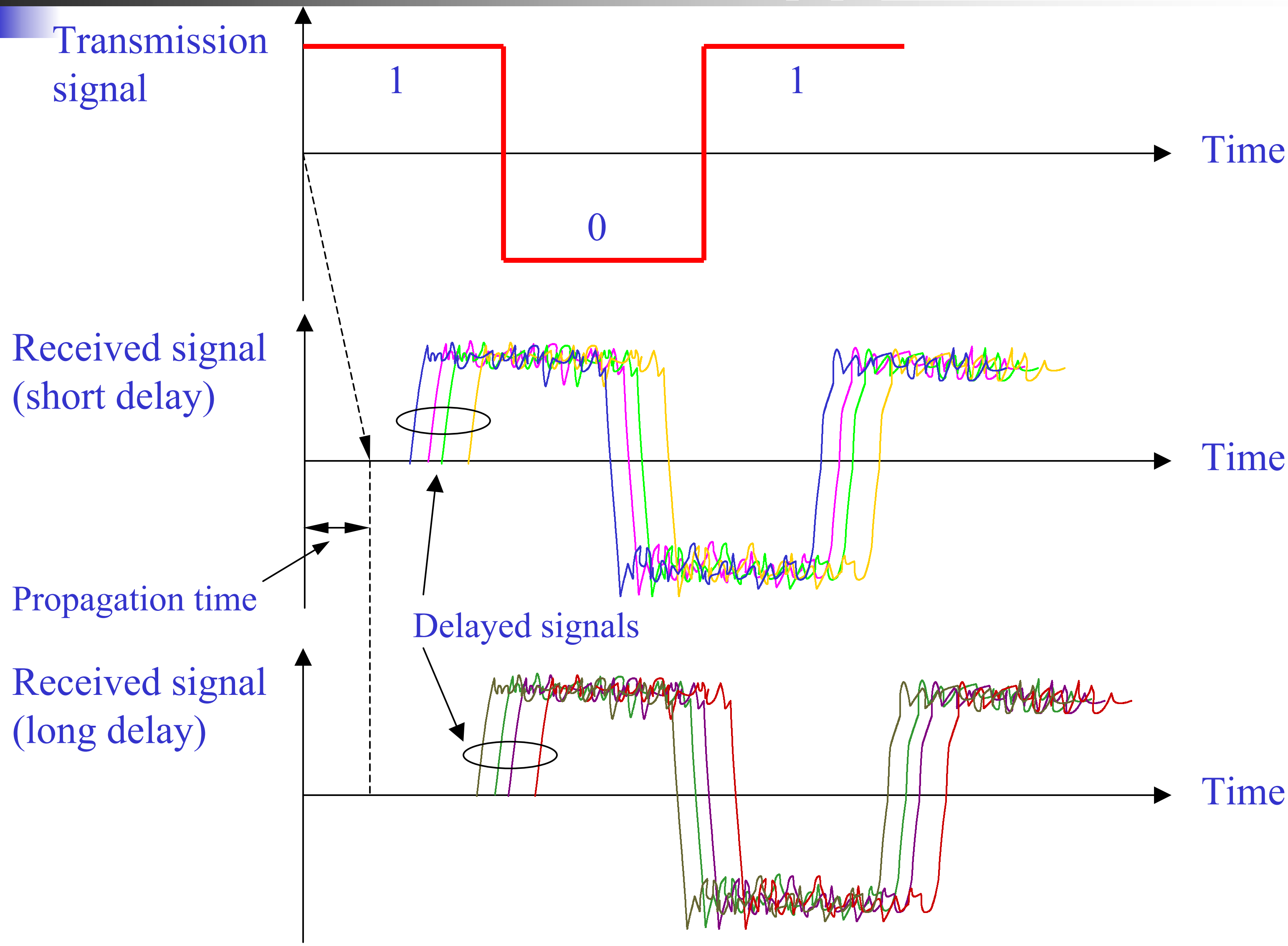
Intersymbol Interference (ISI)

- Caused by time delayed multipath signals
- Has impact on burst error rate of channel
- Second multipath is delayed and is received during next symbol
- For low bit-error-rate (BER)

$$R < \frac{1}{2\tau_d}$$

- *R* (digital transmission rate) limited by delay spread.

Intersymbol Interference (ISI)



Coherence Bandwidth

- Coherence bandwidth B_c:
  - Represents correlation between 2 fading signal envelopes at frequencies f_1 and f_2.
  - Is a function of delay spread.
  - Two frequencies that are larger than coherence bandwidth fade independently.
  - Concept useful in diversity reception
    - Multiple copies of same message are sent using different frequencies.

Cochannel Interference

- Cells having the same frequency interfere with each other.
- r_d is the desired signal
- r_u is the interfering undesired signal
- β is the protection ratio, such that

  $r_d \leq \beta r_u$ (so that the signals interfere the least)
- If P is the probability that $r_d \leq \beta r_u$
- Cochannel probability $P_{co} = P$