Chapter 3

Mobile Radio Propagation

Outline

- Types of Waves
- Radio Frequency Bands
- Propagation Mechanisms
- Free-Space Propagation
- Land Propagation
- Path Loss
- Fading: Slow Fading / Fast Fading
- Doppler Shift/Delay Spread
- Intersymbol Interference
- Coherence Bandwidth/Co-Channel Interference

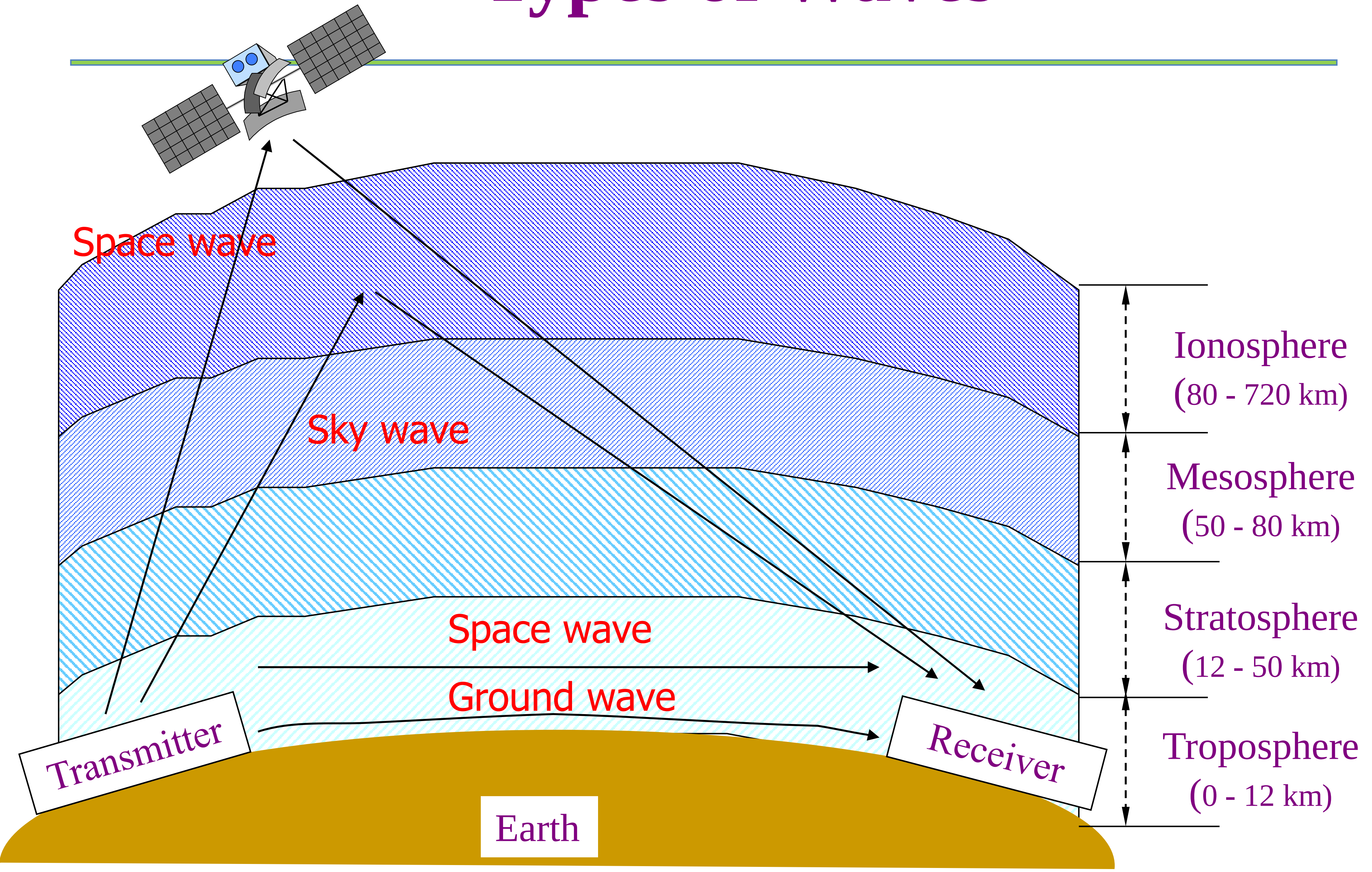
Speed, Wavelength, Frequency

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	6 G Hz	50 mm
Ka band satellite	20 GHz	15 mm
Ultraviolet light	10^{15} Hz	10^{-7} m

Types of Waves



Radio Frequency Bands

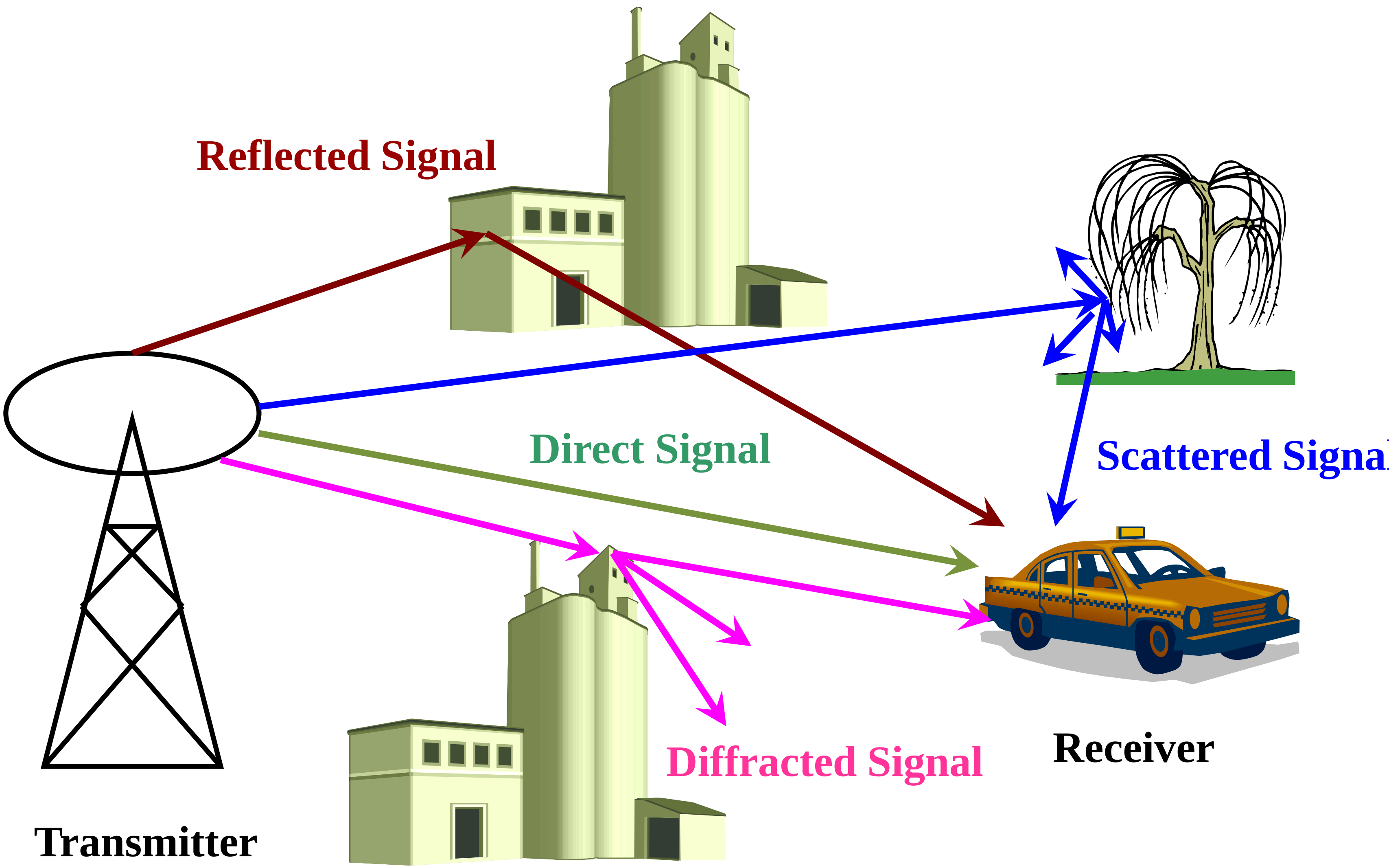
Classification Band	Initials	Frequency Range	Characteristics
Extremely low	ELF	< 300 Hz	Ground wave
Infra low	ILF	300 Hz - 3 kHz	
Very low	VLF	3 kHz - 30 kHz	
Low	LF	30 kHz - 300 kHz	
Medium	MF	300 kHz - 3 MHz	Ground/Sky wave
High	HF	3 MHz - 30 MHz	Sky wave
Very high	VHF	30 MHz - 300 MHz	Space wave
Ultra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

Propagation Mechanisms

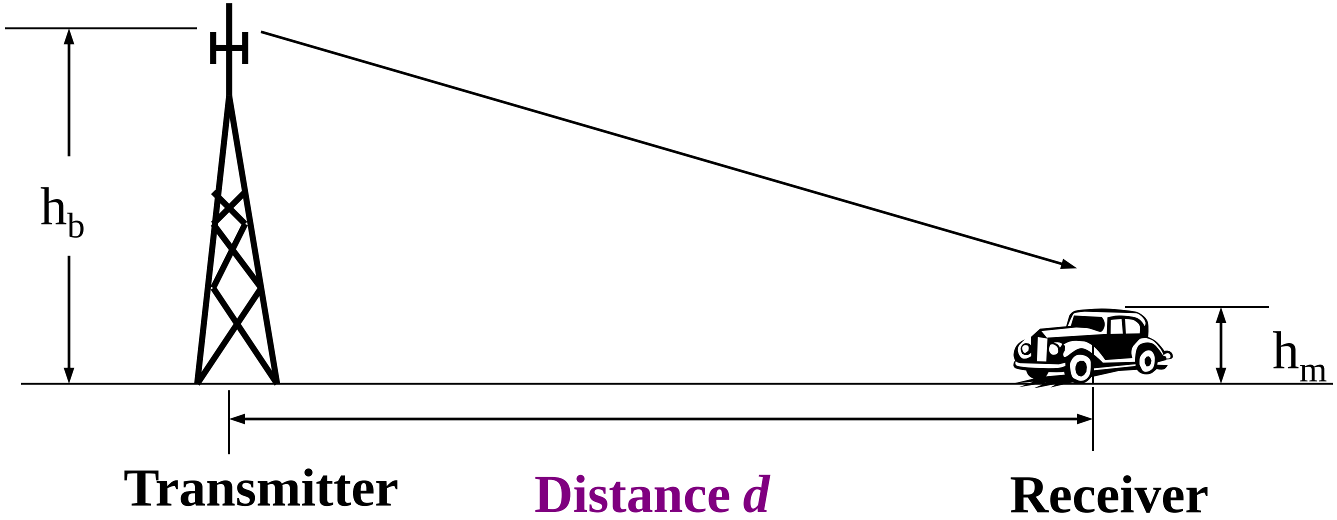
- **Reflection**
  - Propagation wave impinges on an object which is large as compared to wavelength, e.g., the surface of the Earth, buildings, walls, etc.
- **Diffraction**
  - Radio path between transmitter and receiver obstructed by surface with sharp irregular edges
  - Waves bend around the obstacle, 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 P_r at distance d:**

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

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

Antenna Gain

- **Relationship between antenna gain and effective area:**
  - Gain $G = 4\pi A_e / \lambda^2 = 4\pi f^2 A_e / c^2$, λ = carrier wavelength, f = carrier frequency, and c = speed of light

- **Example:**
  - **Antenna with $A_e = 0.55\ \pi$, frequency = 6 GHz, wavelength = 0.05 m $\rightarrow$ G = 39.4 dB**
  - **Frequency = 14 GHz, same diameter, wavelength = 0.021 m $\rightarrow$ G = 46.9 dB**

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

Decibel- dB

- Decibel is the unit used to express relative differences in signal strength
- It is expressed as the base 10 logarithm of the ratio of the powers of two signals:
  - **dB = 10 log (P1/P2)**
- Logarithms are useful as the unit of measurement
  - **signal power tends to span several orders of magnitude**
  - **signal attenuation losses and gains can be expressed in terms of subtraction and addition**

Example

- Suppose that a signal passes through two channels is first attenuated in the ratio of 20 and 7 on the second. The total signal degradation is the ratio of 140 to 1. Expressed in dB, this become 10 log 20 + 10 log 7 = 13.01 + 8.45 = 21.46 dB

The Order of dB

- The following table helps to indicate the order of magnitude associated with dB:
  - 1 dB attenuation means that 0.79 of the input power survives.
  - 3 dB attenuation means that 0.5 of the input power survives.
  - 10 dB attenuation means that 0.1 of the input power survives.
  - 20 dB attenuation means that 0.01 of the input power survives.
  - 30 dB attenuation means that 0.001 of the input power survives.
  - 40 dB attenuation means that 0.0001 of the input power survives.

Land Propagation

- **The received signal power:**

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

where *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)

- **Path Loss: The signal strength decays exponentially with distance *d* between transmitter and receiver;**

  The loss could be proportional to somewhere between d^2 and d^4 depending on the environment.

- **The path loss L_P is the average propagation loss over a wide area.**

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

- **Slow fading is long-term fading and fast fading is short-term fading.**

Free Space Loss

- Free space loss, ideal isotropic antenna

$$\frac{P_t}{P_r} = \frac{(4\pi d)^2}{\lambda^2} = \frac{(4\pi f d)^2}{c^2}$$

  - P_{t} = signal power at transmitting antenna
  - P_{r} = signal power at receiving antenna
  - λ = carrier wavelength
  - d = propagation distance between antennas
  - c = speed of light (3×10^8 m/s)

  where d and λ are in the same units (e.g., meters)

Path Loss (Land Propagation)

- **Simplest Formula:**

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

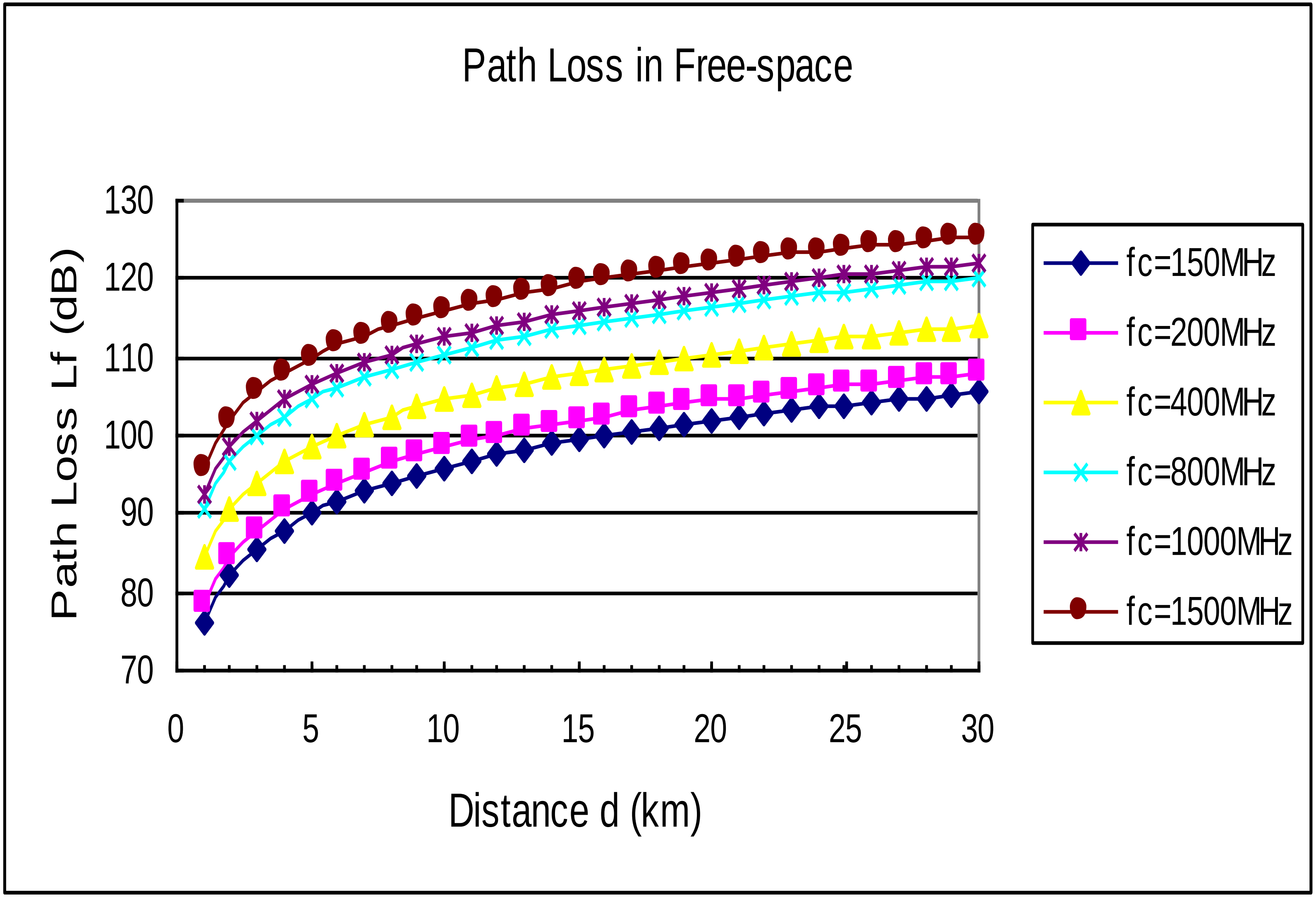
where

A and α: propagation constants

d **: distance between transmitter and receiver**

α : value of 3 ~ 4 in typical urban area

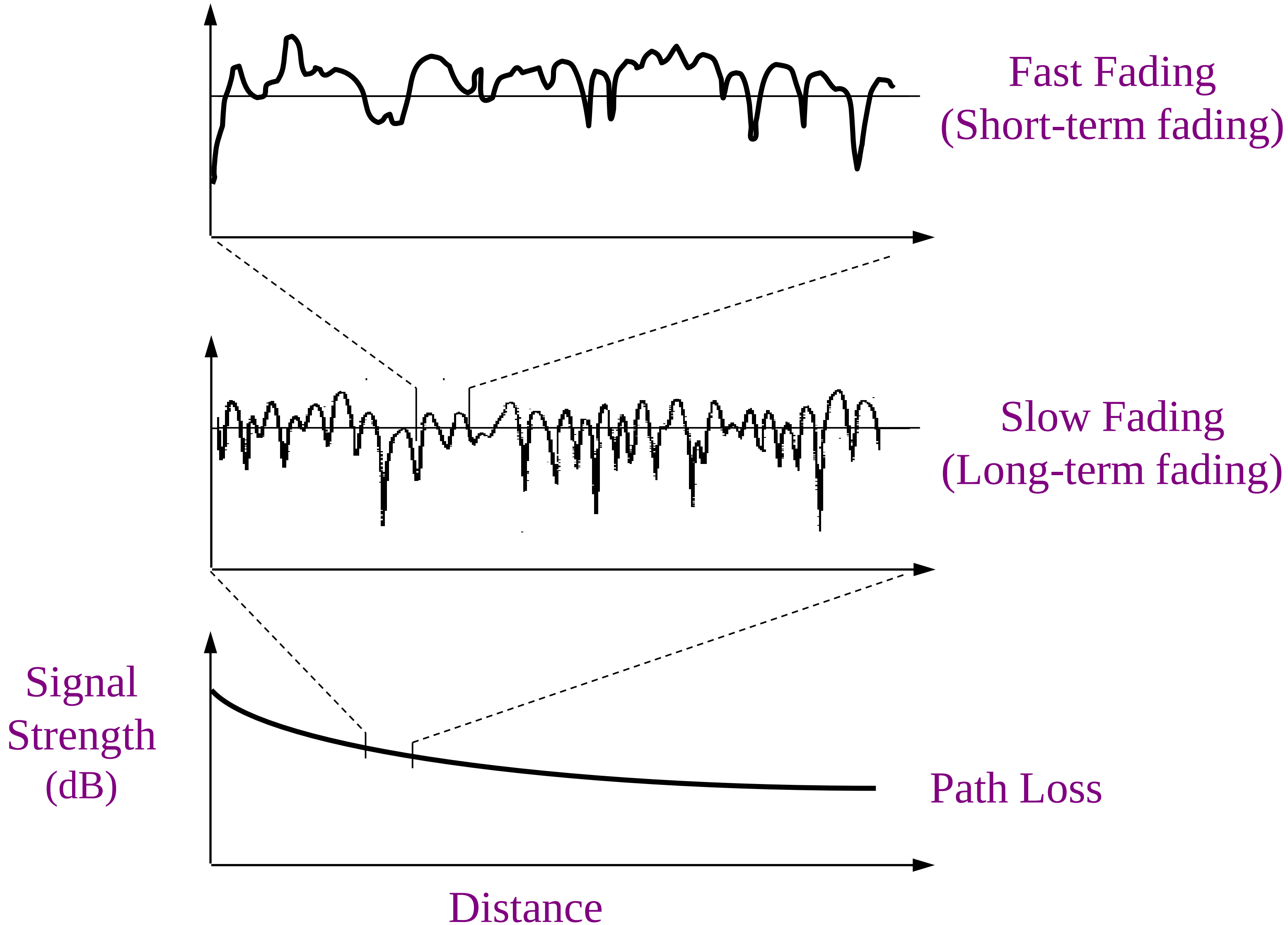
Example of Path Loss (Free-space)



Path Loss

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

Fading



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

Slow Fading

- Slow fading is caused by the long-term spatial and temporal variations over distances large enough to produce gross variations in the overall path between transmitter and receiver.

- The long-term variation in the mean level is known as slow fading. Slow fading is also called shadowing or log-normal fading.

Shadowing

- **Shadowing:**
  - Often there are millions of tiny obstructions in the channel, such as water droplets if it is raining or the individual leaves of trees. Because it is too cumbersome to take into account all the obstructions in the channel, these effects are typically lumped together into a random power loss.

Fast Fading

- The signal from the transmitter may be reflected from objects such as hills, buildings, or vehicles. Fast fading is due to scattering of the signal by object near transmitter.
- Fast fading (short-term fading)
  - ✓ Observe the distance of about half a wavelength
  - ✓ Such as multipath propagation

Doppler Shift (1/2)

- 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

$$f_R = f_C - f_D$$

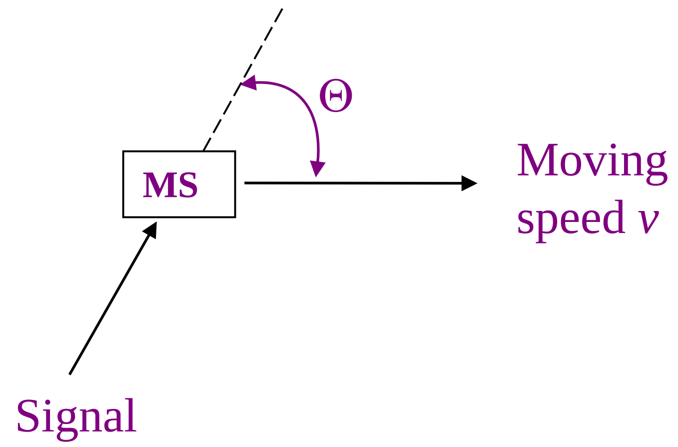
where f_C is the frequency of source carrier, f_D is the Doppler frequency.

Doppler Shift (2/2)

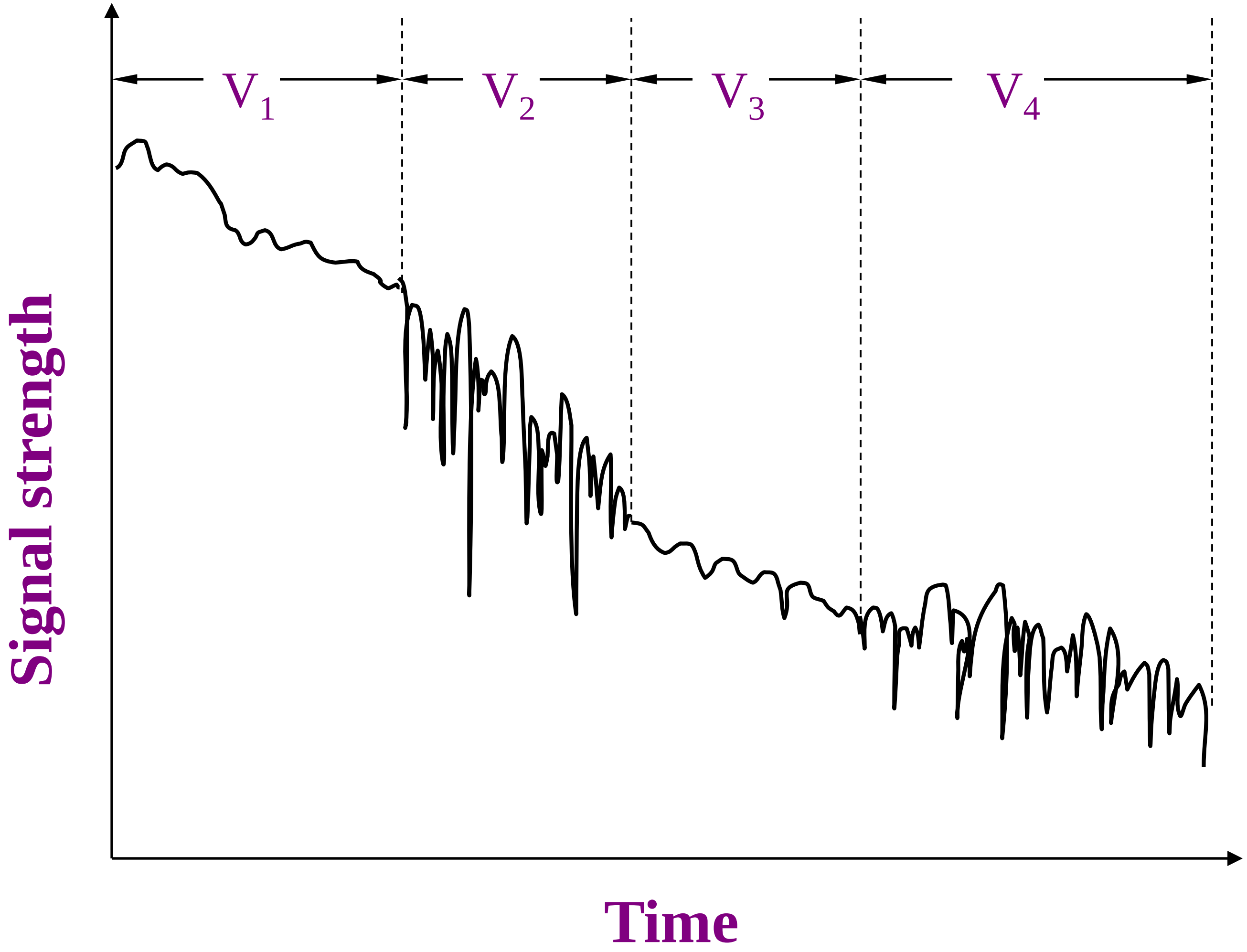
- Doppler Shift in frequency:

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

where v is the moving speed, λ is the wavelength of carrier.



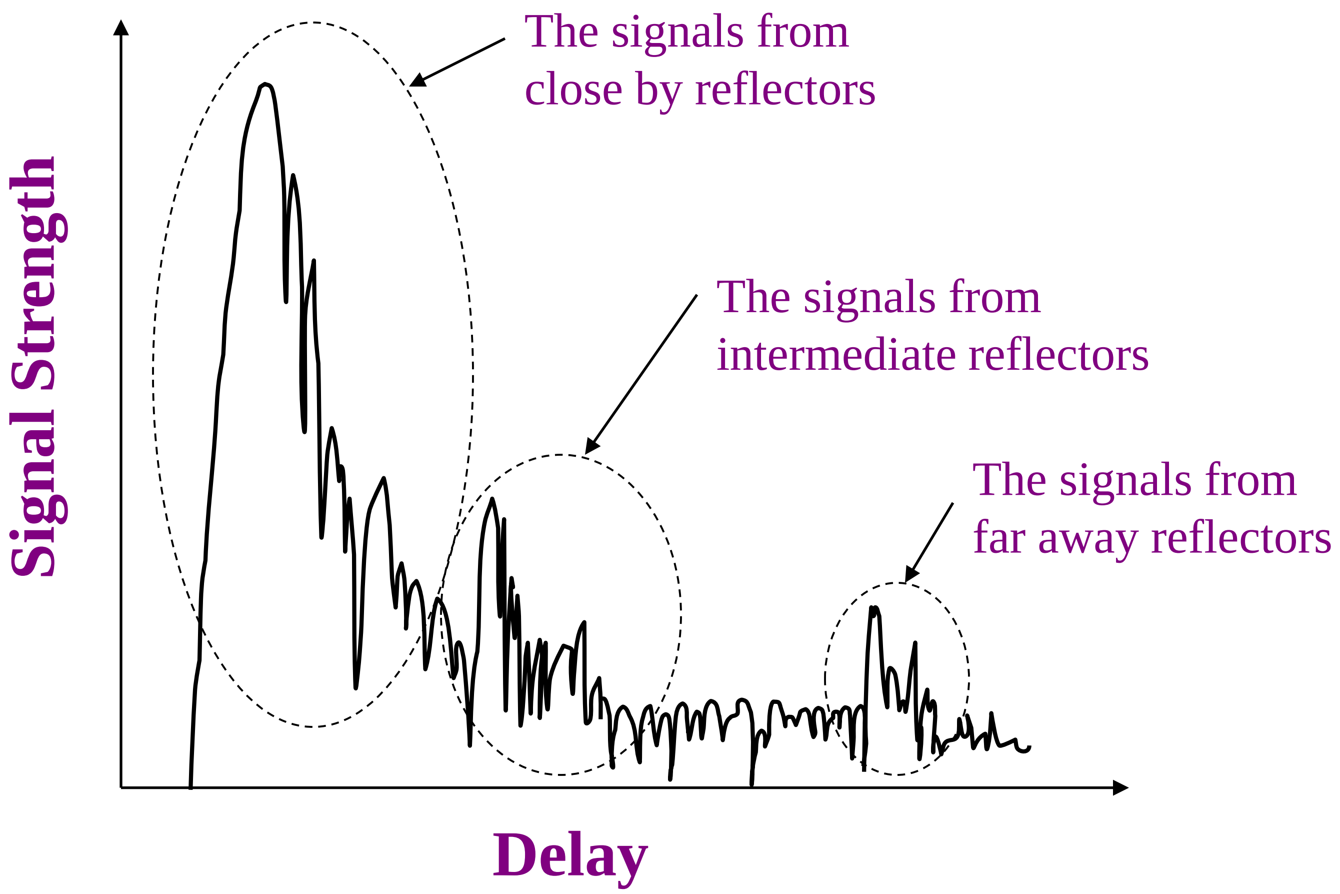
Moving Speed Effect



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".

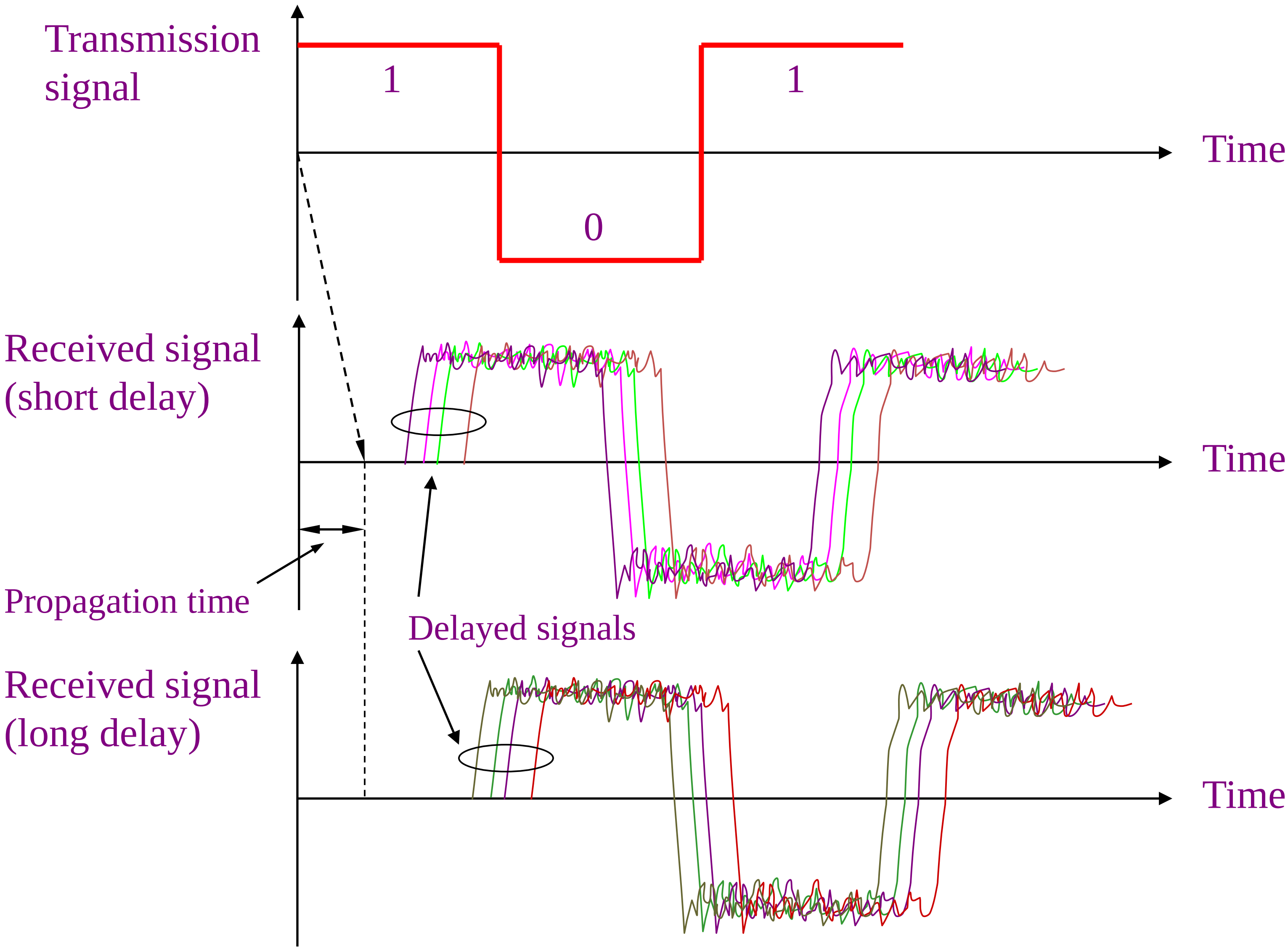
Delay Spread



Inter-Symbol 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

Inter-Symbol Interference (ISI)



Homework

- Problems: 3.3, 3.9, 3.14, 3.18 (Select any one)
- Problems: 3.7, 3.10, 3.12, 3.13 (Select any one)