Lect8: The Wireless Channel

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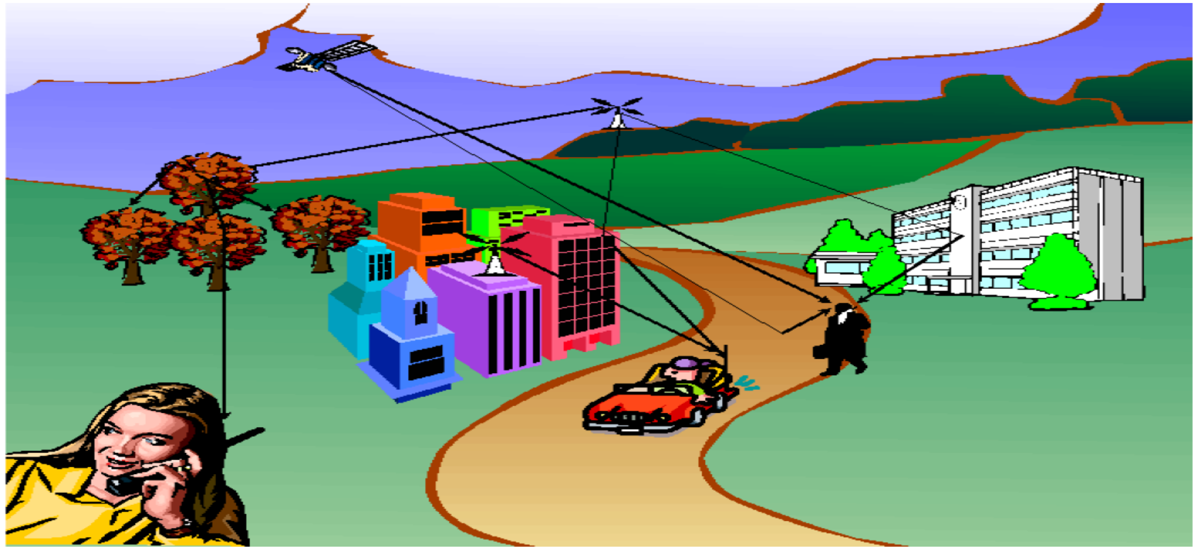
The wireless channel

- Understanding the *operation*, *design*, *and* *performance analysis* of wireless communication systems requires first better understanding for the wireless channel characteristics.
- These characteristics are specified by the *many interactions between EM waves, antennas, and surrounding environment (should be taken into account).*
- These interactions causes *fading (or multiplicative noise).*
- Also needed to put *propagation models*?



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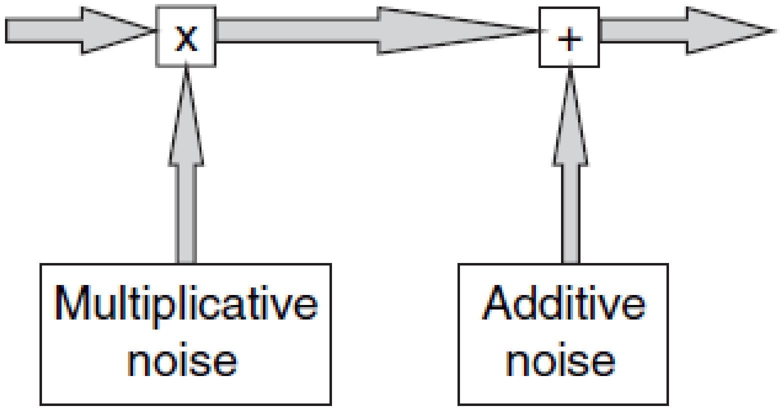
- **In wireless systems; the noise sources are:**

➢ **<u>Additive</u> (**like in guided channels**):**

- Internal (thermal, shot,..) or external (atmospheric, cosmic radiation, interference, electrical appliances).

➢ **<u>Multiplicative or Fading</u>:** *the rate of change of the received signal as a function of the distance between BS and MS. Causes are:*

- Antennas' directional characteristics.
- Reflection.
- Absorption (by walls, trees and by the atmosphere).
- Scattering.
- Diffraction.
- Refraction.
- Mobility.



$$y = \alpha x + n$$

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❑**Multiplicative fading further subdivide into:**

I. <u>Large scale fading:</u>

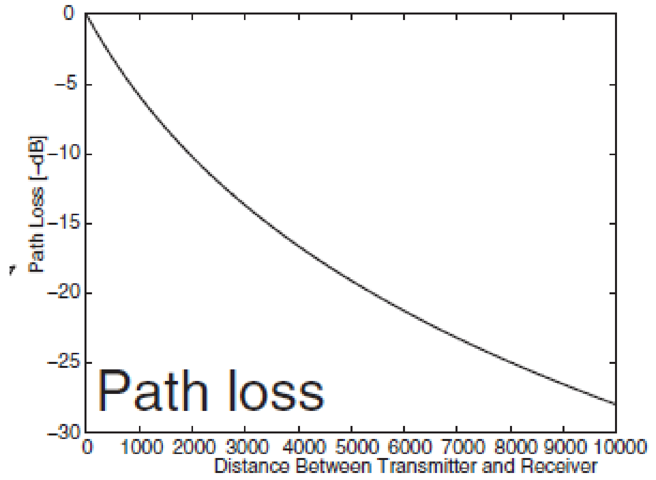
➢Very slow or slow (order of seconds) variation over time.

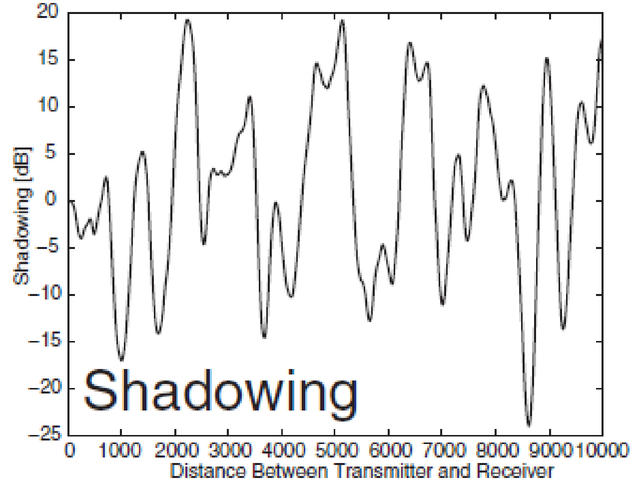
➢Critical for coverage and cell-cite planning.

➢Causes:

○ *Path loss (very slow or gradual) .*

○ *Shadowing (slow).*





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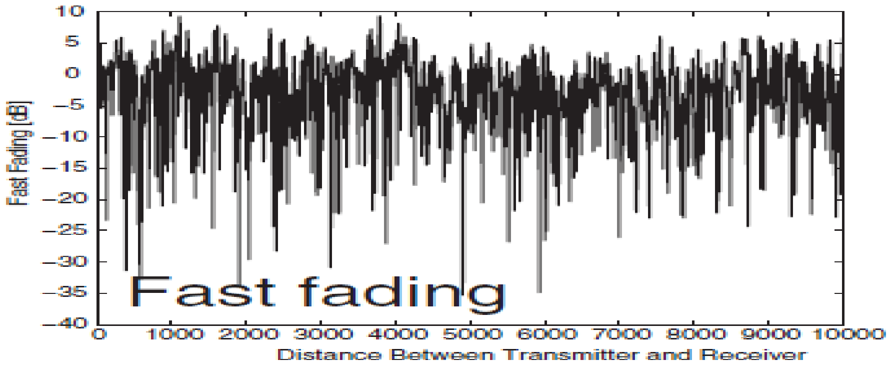
II. <u>Small scale (or multipath) fading</u>:

- One of the worst sources of fading.
- Very fast variation: channel varies when the *mobile* moves a distance of the order of the carrier wavelength. *e.g: carrier frequency of 1GHz, wavelength = 33 cm*.
- Order of hundreds of microseconds variation over time
- Critical for design & analysis of communication systems.
- Causes:



- *Constructive/destructive interference of waves.*
- *Mobility.*

- Parameters: *carrier frequency, signaling BW, coherence time, Doppler spread, coherence BW, delay spread,..*

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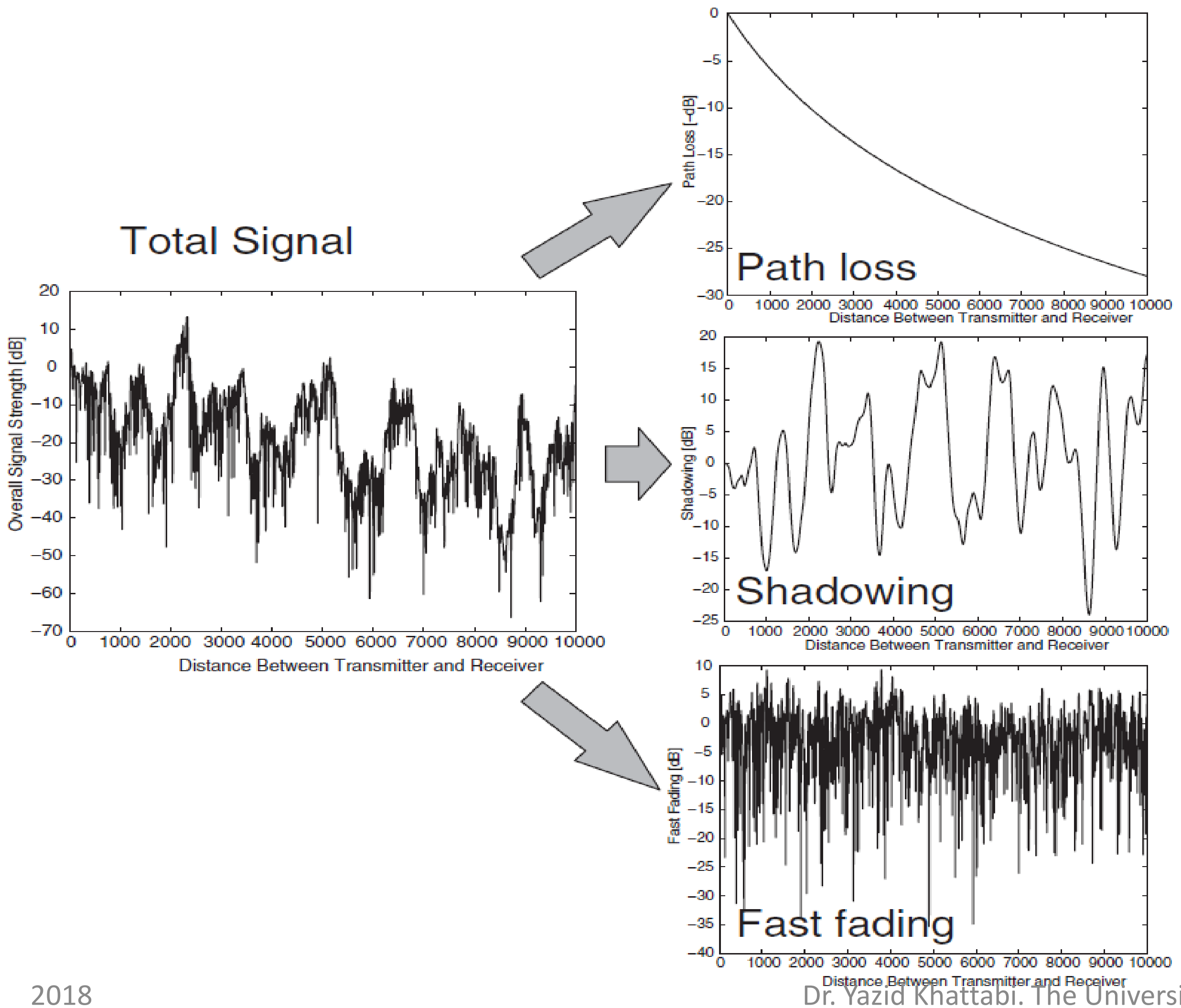

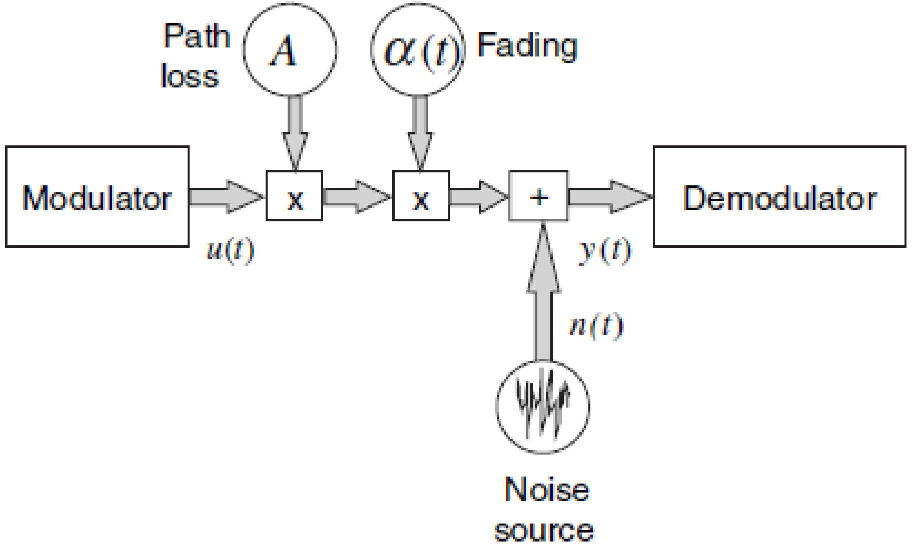

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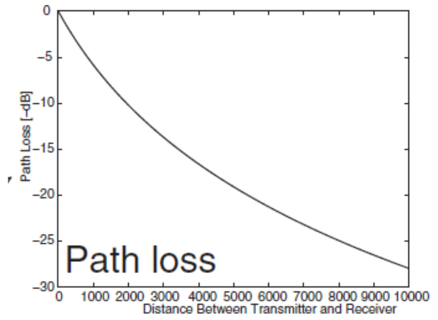
➢ **<u>The path loss</u>**

- Leads to an overall decrease in signal strength as the distance between Tx and Rx increases.

- Function only of parameters (physical processes) such as :

1. *Distance (outward spreading of waves from the transmitter antenna (free-space* $P_r \propto \frac{1}{d^2}$*),*
2. *Antenna heights (two-ray* $P_r \propto \frac{1}{d^4}$*),*
3. *Environment (long-distance path loss model* $P_r \propto \frac{1}{d^n}$*).*

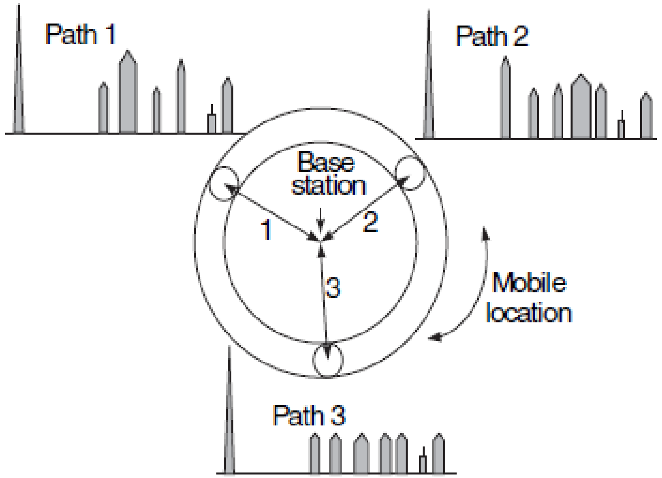
- In a particular environment, the predicted system's path loss will be constant for a given base-to-mobile distance.

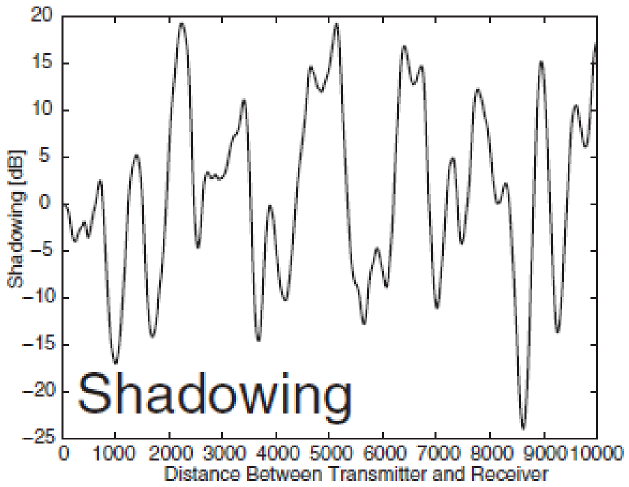


Wireless channel characteristics

➢ **Shadowing**

- Superimposed on the path loss.
- Changes more rapidly, with significant variations over distances of hundreds of metres.
- The particular clutter (buildings, trees) along a path at a given distance will be different for every path, causing variations with respect to the nominal value given by the path loss models





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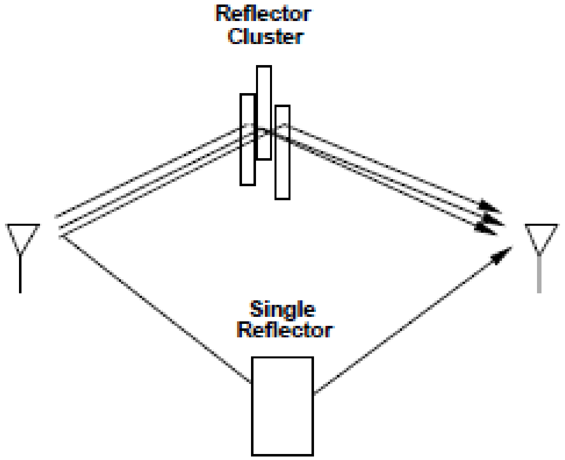
➢ **Multipath fading**

- Surrounding objects reflect and scatter the transmitted energy.
- Several waves (replicas) to arrive at the receiver via different routes.



- It results from the constructive and destructive interference between multiple waves reaching the mobile from the base station.

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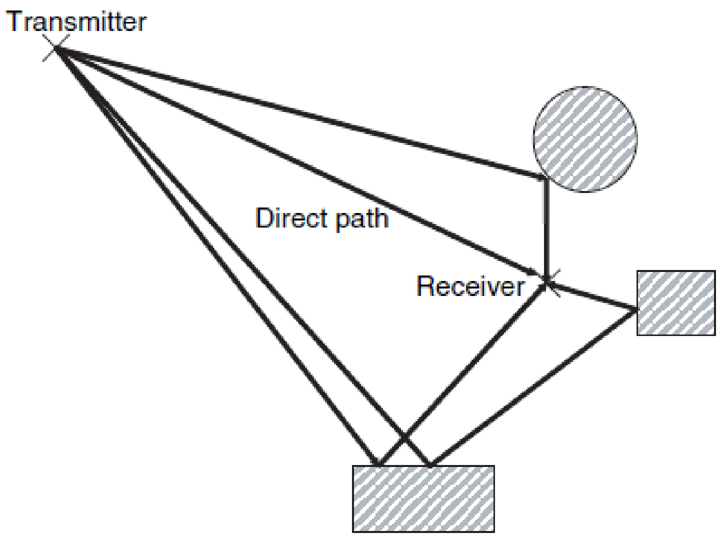
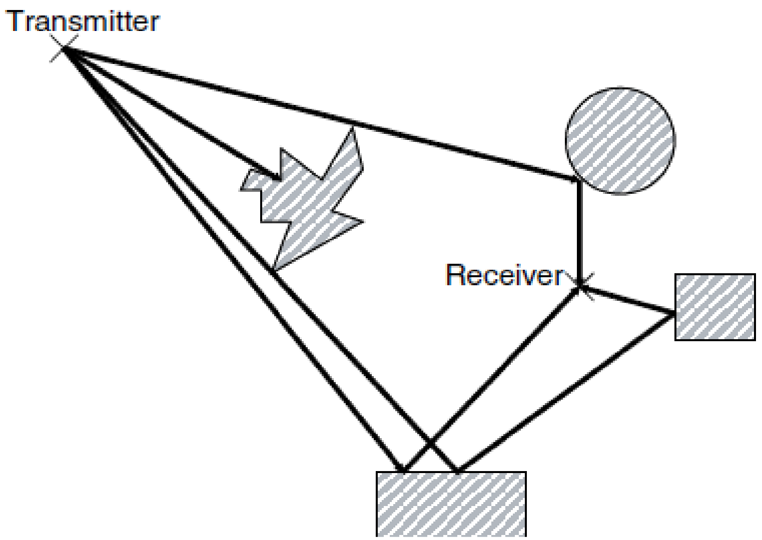
➢ **<u>Multipath fading</u>**

- In general, two scenarios may be considered:

I. <u>LOS</u>: a strong direct signal is available together with a number of weaker multipath echoes.

II. <u>NLOS</u> (worst scenario): a number of weak multipath echoes is received and no direct signal is available.





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- **Multipath fading LOS:**
  - Occurs in open areas or in very specific spots in city centers, in places such as crossroads or large squares with a good visibility of BS.
  - Occurs in no direct LOS but with a strong specular (shining) reflection off a smooth surface like large building.
  - The variation of the received RF signal envelope: modeled by a Rice distribution.
  - The received signal will be strong and with moderate fluctuations.

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- **Multipath fading NLOS:**

o The direct signal is completely blocked out (only due to multipath).

o Typically, in highly built-up urban environments.

o In rural environments with dense masses of trees.

o The variation of the received RF signal envelope: modeled by a Rayleigh distribution.

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- **Multipath fading LOS vs NLOS:**

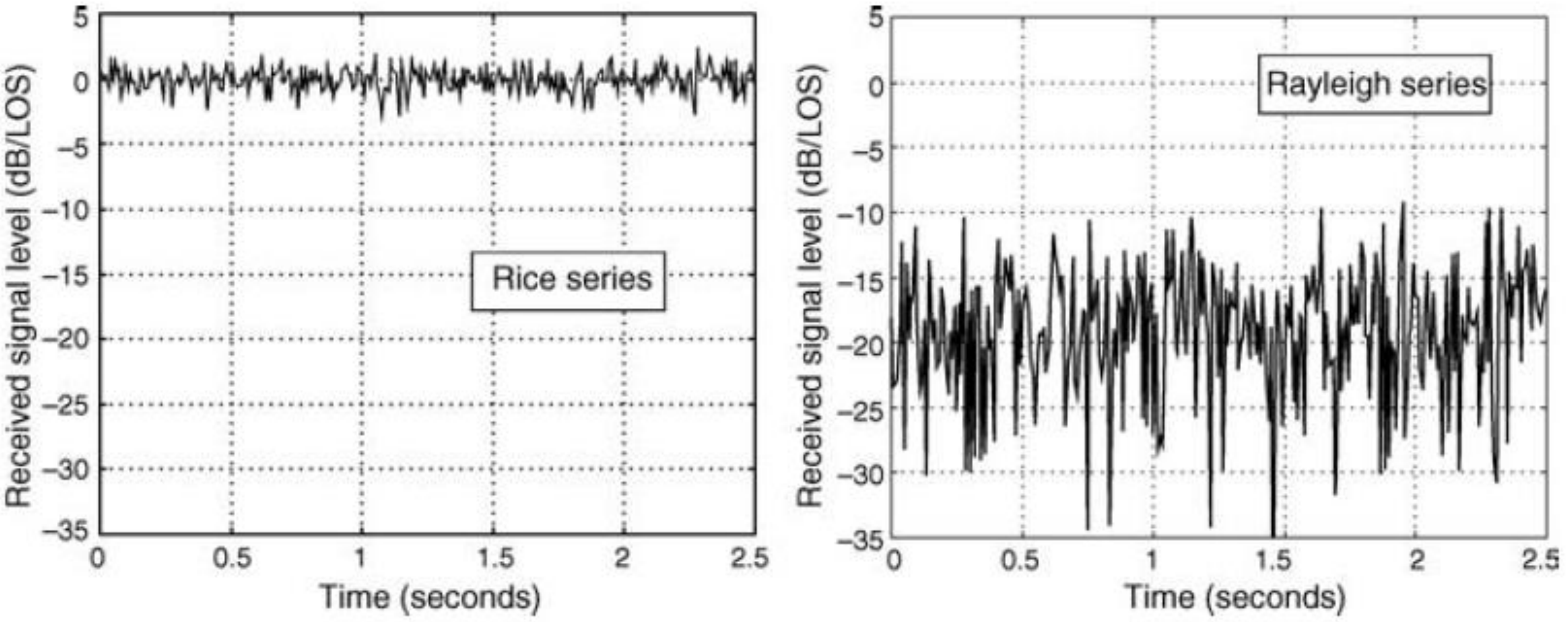

Figure 1.2 Rice and Rayleigh distributed time series. Frequency 900 MHz, mobile speed 10 m/s

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❑ **Multipath fading: mobility & Doppler Shift**

➢ Relative motion between the transmitter and receiver:

- *This introduces a signal frequency change called a Doppler shift.*
- *Movement that causes the transmitter and receiver to get closer to each other causes the signal frequency to increase.*
- *Movement that increases the distance causes a frequency decrease.*
- *Large signal-frequency changes produce lower-level signals because the signals are partially out of the pass-band of the receiver's selective filters.*
- *In digital systems that predominantly use some form of phase-shift modulation, the Doppler shift confuses the demodulator and produces bit errors.*

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- Doppler Shift
  - A mobile moves at a constant velocity v, along a path segment having length d between points X and Y.
  - Path length difference

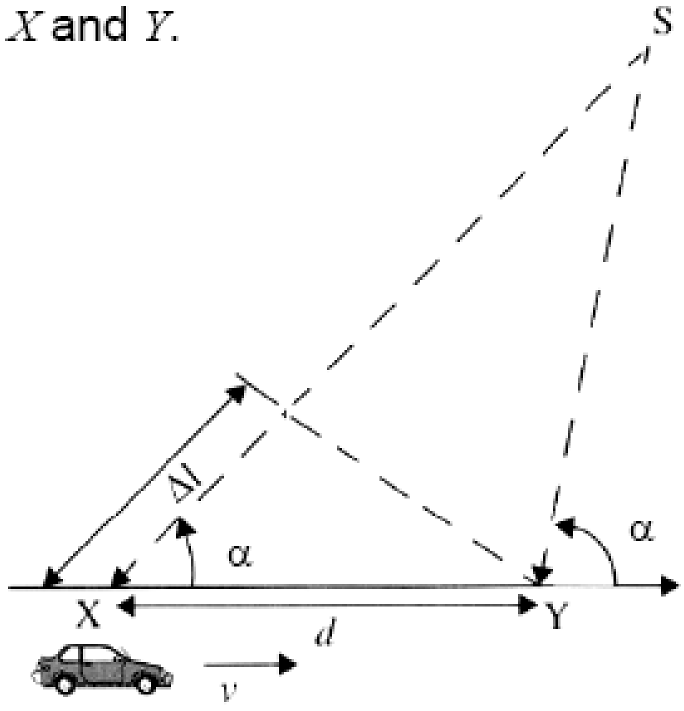
    $$\Delta l = d \cos\alpha = v\Delta t \cos\alpha$$

  - Phase change

    $$\Delta\phi = \frac{2\pi \Delta l}{\lambda} = \frac{2\pi v\Delta t}{\lambda}\cos\alpha$$

  - Doppler shift

    $$f_d = \frac{1}{2\pi}\cdot\frac{\Delta\phi}{\Delta t} = \frac{v}{\lambda}\cos\alpha$$



Doppler frequency depends on the velocity, carrier frequency and the aspect angle.

Doppler frequency is positive when the mobile is moving towards the source S and it is negative if the mobile is moving away from the source

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- The Doppler Shift:
  - If you have ever used a cell phone from a moving car in a changing environment, you know that fading can cause significant signal variations, including no service at all.
  - When digital communication is involved, multipath fading can cause inter-symbol interference.

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Solutions of Fading

1. Built-in fading margin. That is, they have a high enough transmitter power and sufficient receiver sensitivity to ensure that the weaker reflective signals do not degrade the direct signal as much.

2. Using highly directive antennas, either at the transmitter or at the receiver or at both. This reduces the multipath fading.

3. Broadband signals (OFDM, CDMA) are much less sensitive to multipath fading than narrowband signals are.

4. Diversity Systems: A diversity system uses multiple transmitters, receivers, or antennas to mitigate the problems caused by multipath signals.

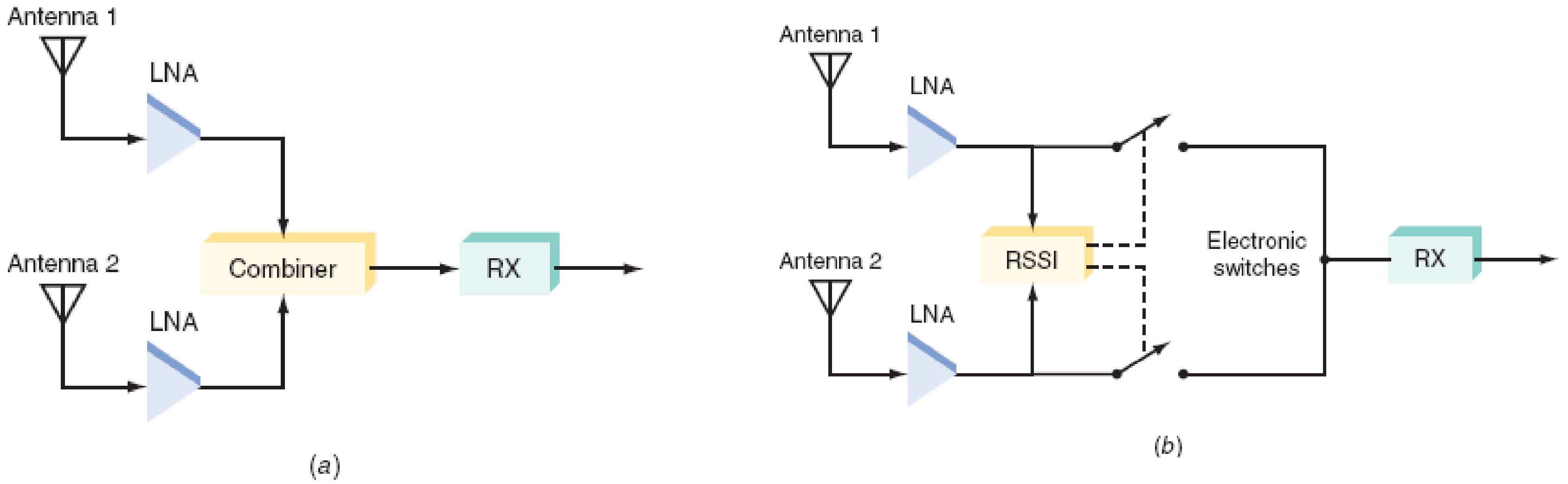
- **Two common types of diversity:**

1. Frequency diversity, two separate sets of transmitters and receivers operating on different frequencies are used to transmit the same information simultaneously. This system is expensive and there is a scarcity of frequency spectrum. Therefore, this system is impractical. It is rarely used except in cases where extreme reliability is a must.

2. Space or Spatial diversity. It uses two receiver antennas spaced as far apart as possible to receive the signals. Diversity systems are used mainly at base stations rather than in portable or handheld units.

- Many systems use the relationship $h/d = 11$ to determine a minimum spacing for antennas. In this relationship, h is the height of the antenna and d is the spacing distance.

- Spatial diversity



RSSI: received signal strength indicators .

- Diversity systems are widely used in the newer cell phone systems and in wireless LANs that work indoors and, in some cases, with mobile wireless units (laptop computers, PDAs (personal-digital-assistants), etc.) that are frequently in motion.

- New techniques such as multiple-input, multiple-output (MIMO), and smart (adaptive) antennas are now being used to further improve transmission in multipath environments.

Thank you