# Propagation characteristics of wireless channels

Lecture 2

# Introduction

- Attenuation is a major limitation on performance of mobile systems
- If path is line of sight then signal loss may not be severe
- In urban surroundings the path may be indirect and signal would reach final destination after reflection, diffraction, refraction and scattering

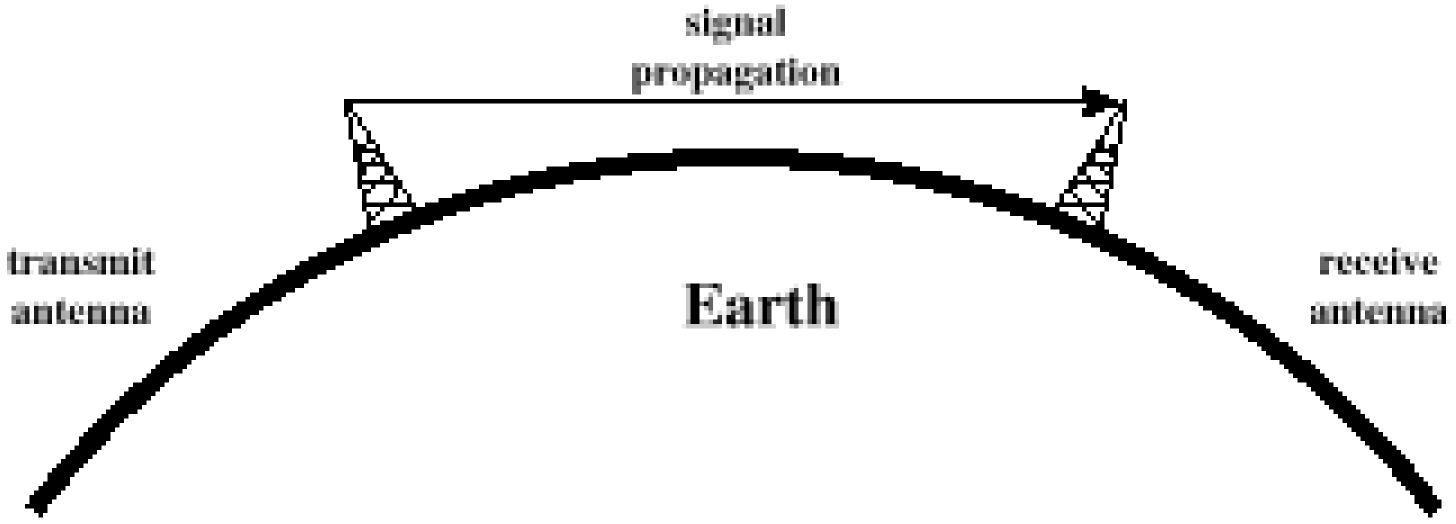
# LOS Wireless Transmission Impairments

- Attenuation and attenuation distortion
- Free space loss
- Noise
- Atmospheric absorption
- Multipath
- Refraction

# Other Impairments

- Atmospheric absorption – water vapor and oxygen contribute to attenuation
- Multipath – obstacles reflect signals so that multiple copies with varying delays are received
- Refraction – bending of radio waves as they propagate through the atmosphere

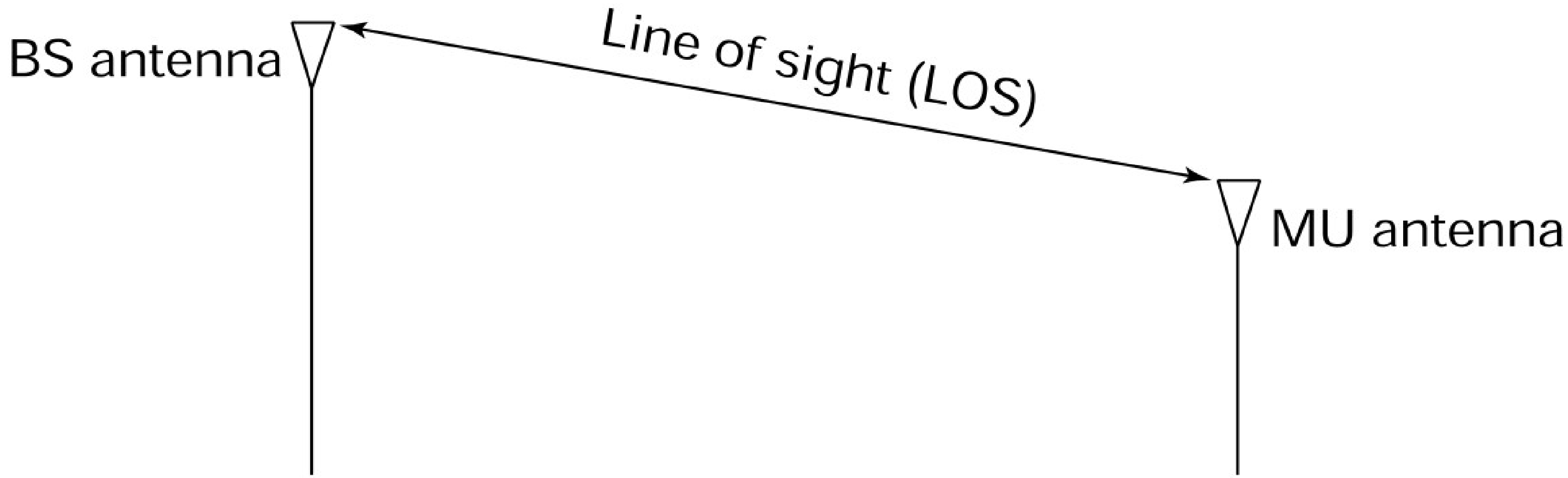
# Line of sight propagation



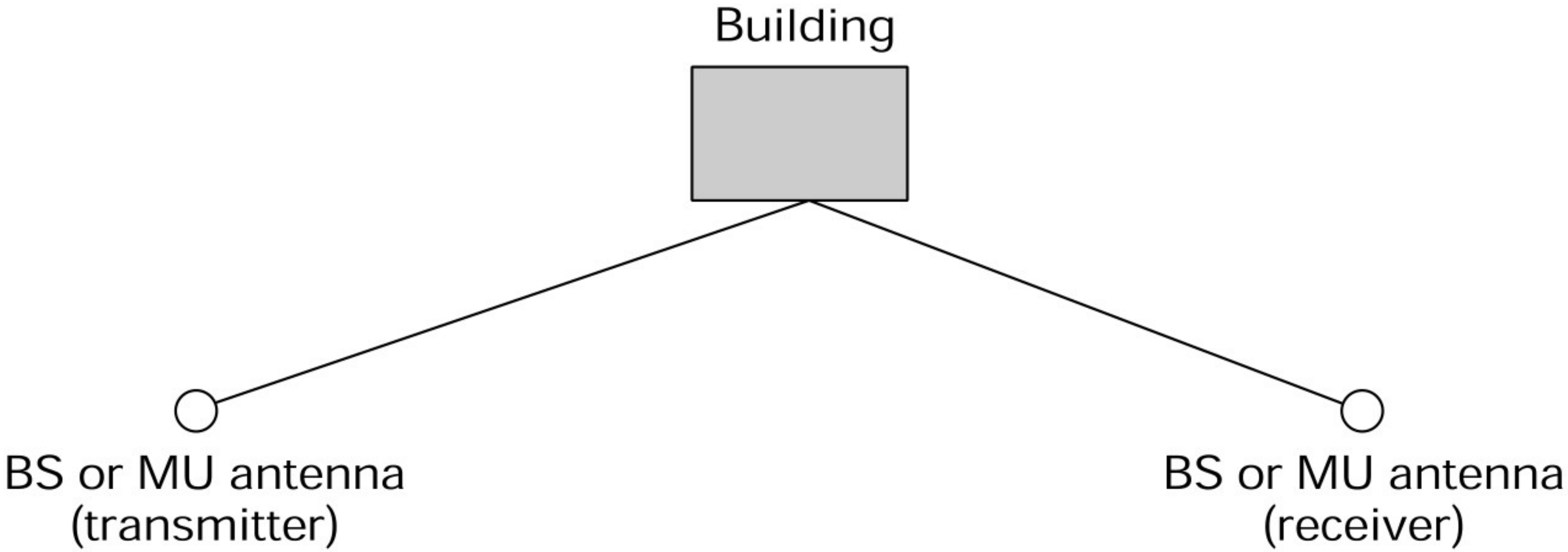
# Introduction

- Most mobile transmissions are characterize by these non-LOS conditions
  - Reflection
  - Diffraction
  - Refraction
  - Scattering

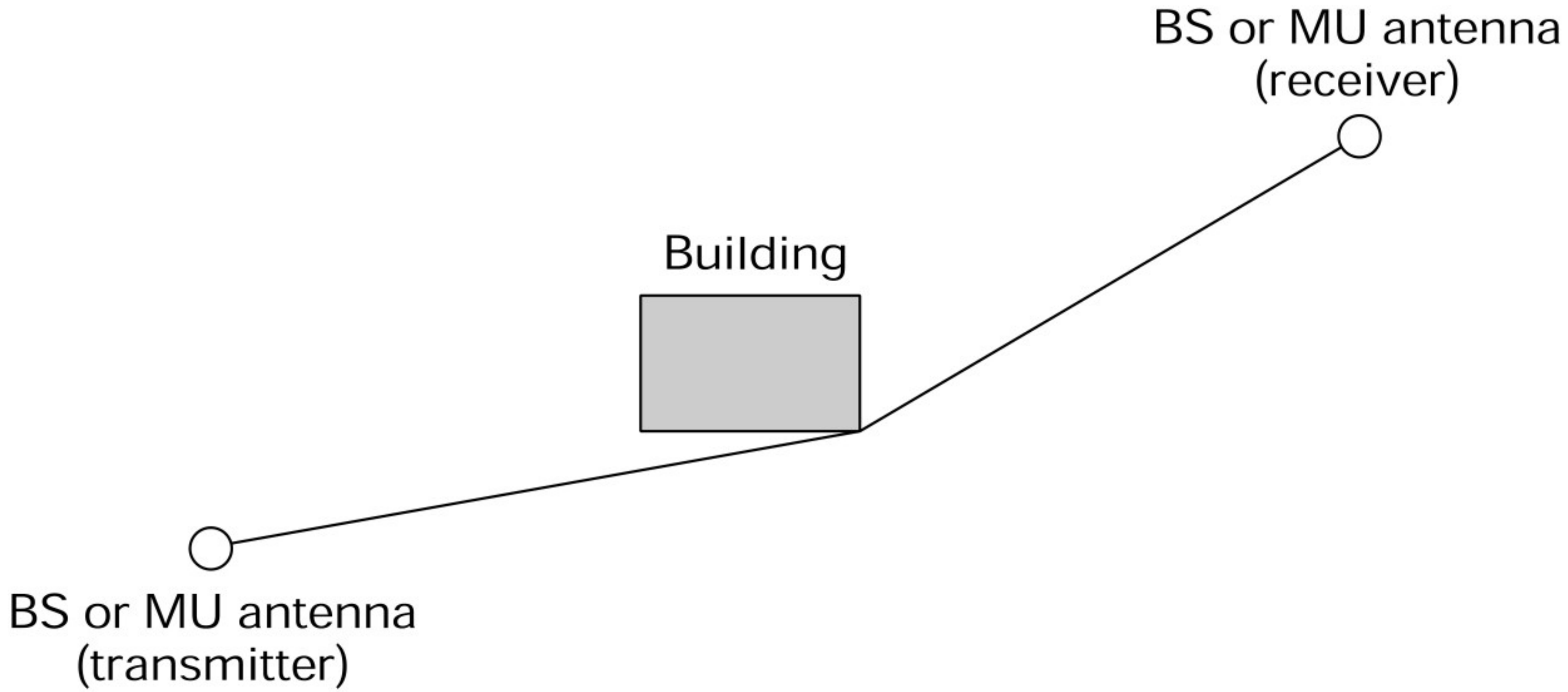
# A direct (line of sight) between two antennae.



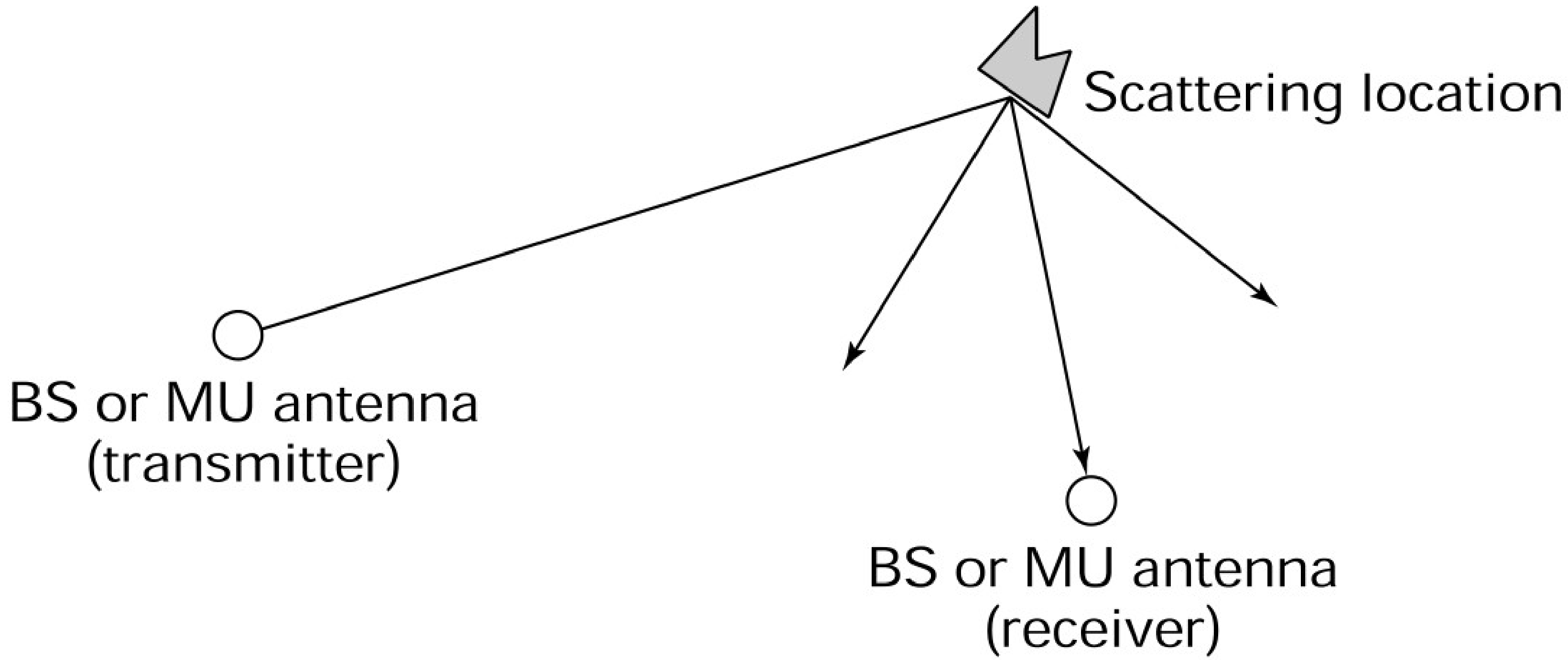
# Reflection of the electromagnetic wave at a boundary.



# Diffraction of the electromagnetic wave at the edge of a building.



# Scattering of the electromagnetic wave.

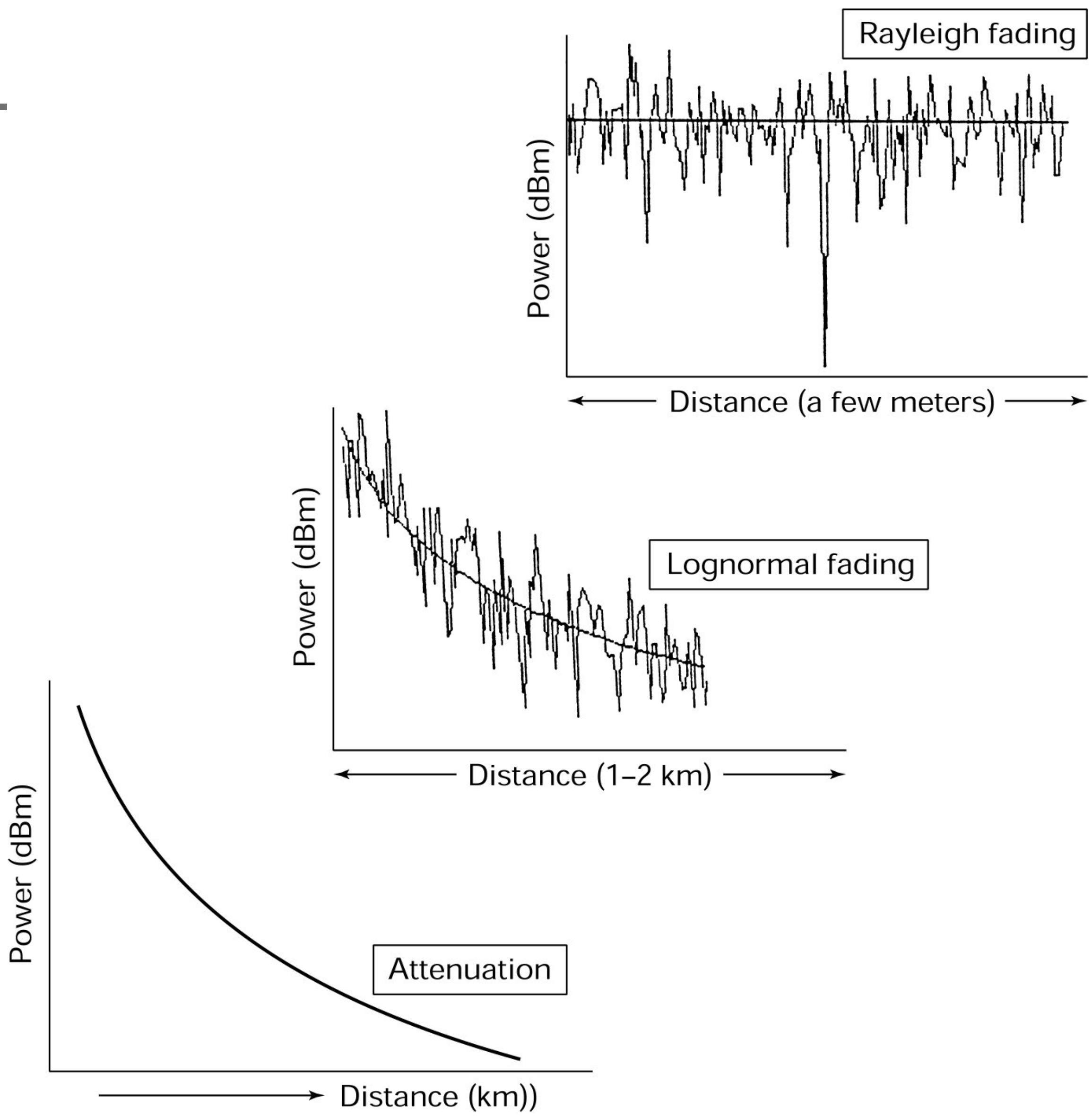


- Most mobile communication systems are characterized by these N-LOS conditions:
  - Reflection
  - Diffraction
  - Scattering
- Free space propagation models are not suited to calculate the attenuation

# Multipath Propagation

- Reflection - occurs when signal encounters a surface that is large relative to the wavelength of the signal
- Diffraction - occurs at the edge of an impenetrable body that is large compared to wavelength of radio wave
- Scattering – occurs when incoming signal hits an object whose size in the order of the wavelength of the signal or less

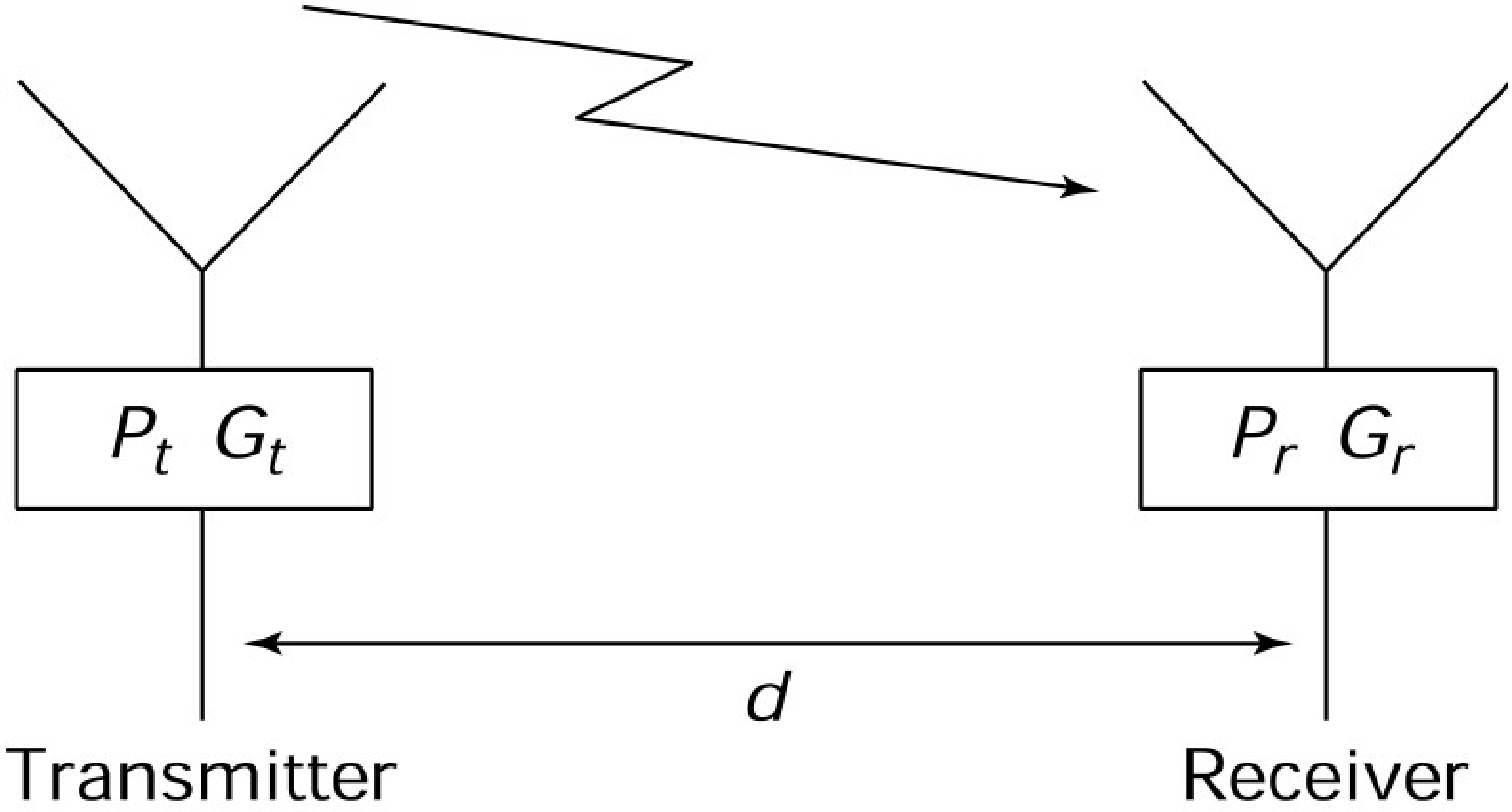
Power loss showing the three major effects: attenuation, long-term fading, and short-term fading.



# Attenuation

- Strength of signal falls off with distance over transmission medium
- Attenuation factors for unguided media:
  - Received signal must have sufficient strength so that circuitry in the receiver can interpret the signal
  - Signal must maintain a level sufficiently higher than noise to be received without error
  - Attenuation is greater at higher frequencies, causing distortion

# Free-space propagation geometry.



**For direct path**

$$_{r} \quad d^{2}$$

**so that power received at a distance *d***

$$_{r}\ d \qquad \frac{P_t G_r G_t \ ^{2}}{4 \quad ^{2} d^{2} L}$$

**Free space loss is given as**

$$L_{free} \qquad 20\log_{10} \frac{}{4 \ d} \ dB$$

**This can be rewritten as**

$$L_{free} \quad 32.44 \quad 20\log_{10} f \qquad 20\log_{10} d$$

This is an ideal case. The attenuation is much faster than predicted by inverse square law.

$$ {}_r \qquad d^{\,v} $$

**Given that the power at a reference point is**

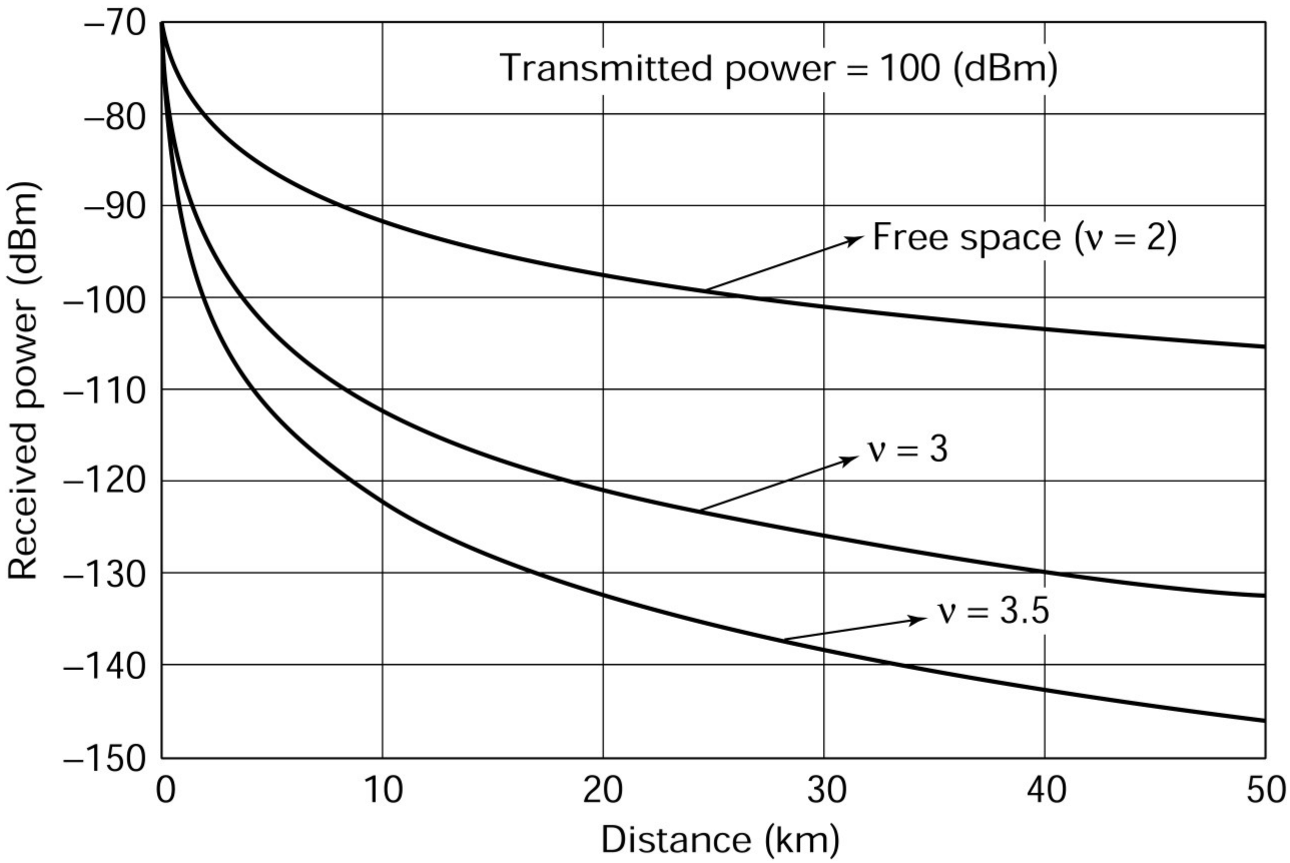
$$ {}_r\, d \qquad {}_r\, d_{ef} \quad {\frac{d_{ef}}{d}}^{2} $$

**If we combine this with the previous equation we obtain**

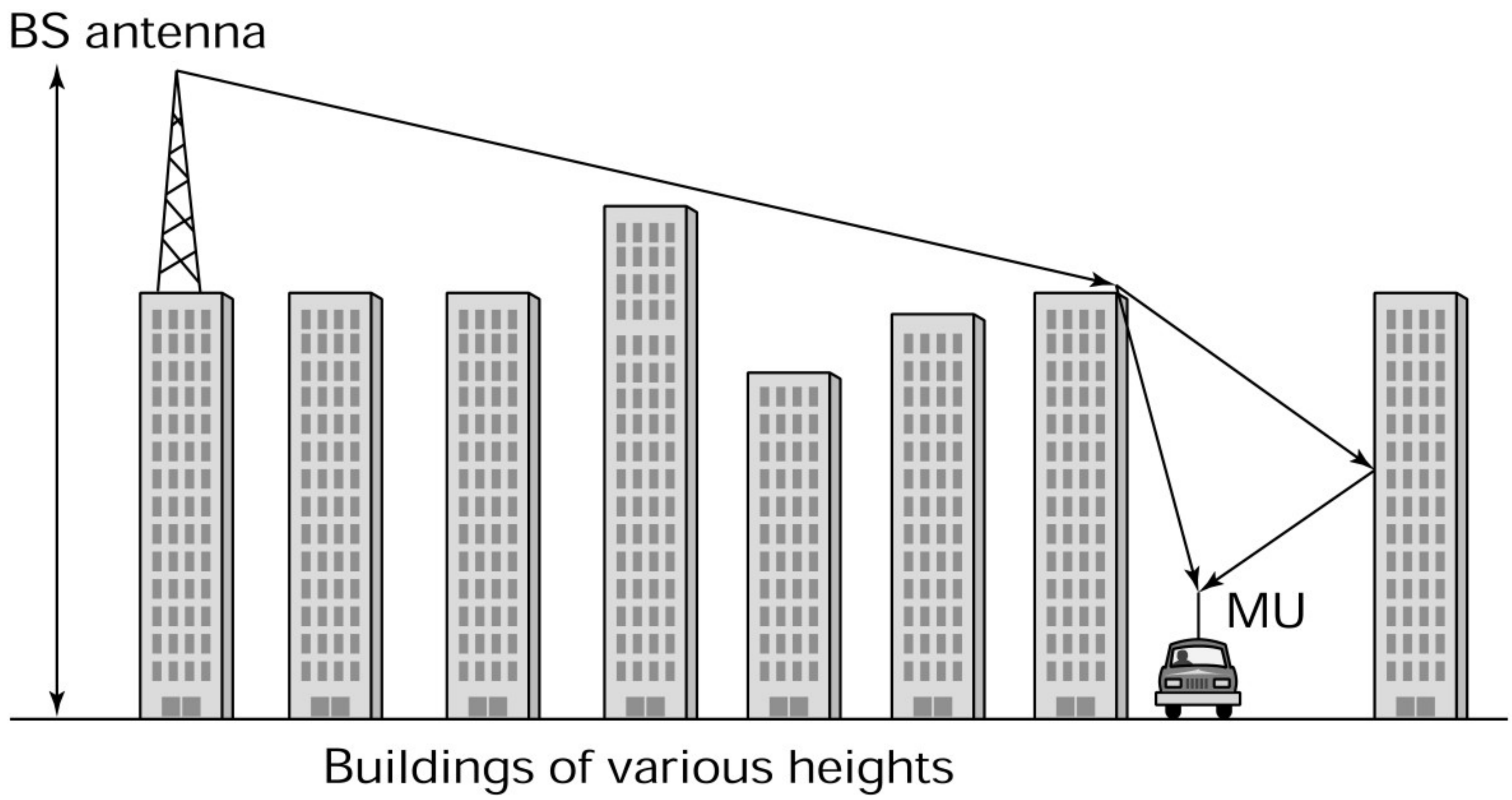
$$ {}_r\, d\ dBm \quad 10\log_{10}\ {}_r\, d_{ef} \qquad v\log_{10}\frac{d_{ef}}{d} $$

$d_{ef}$ **this is the reference distance (100m)**

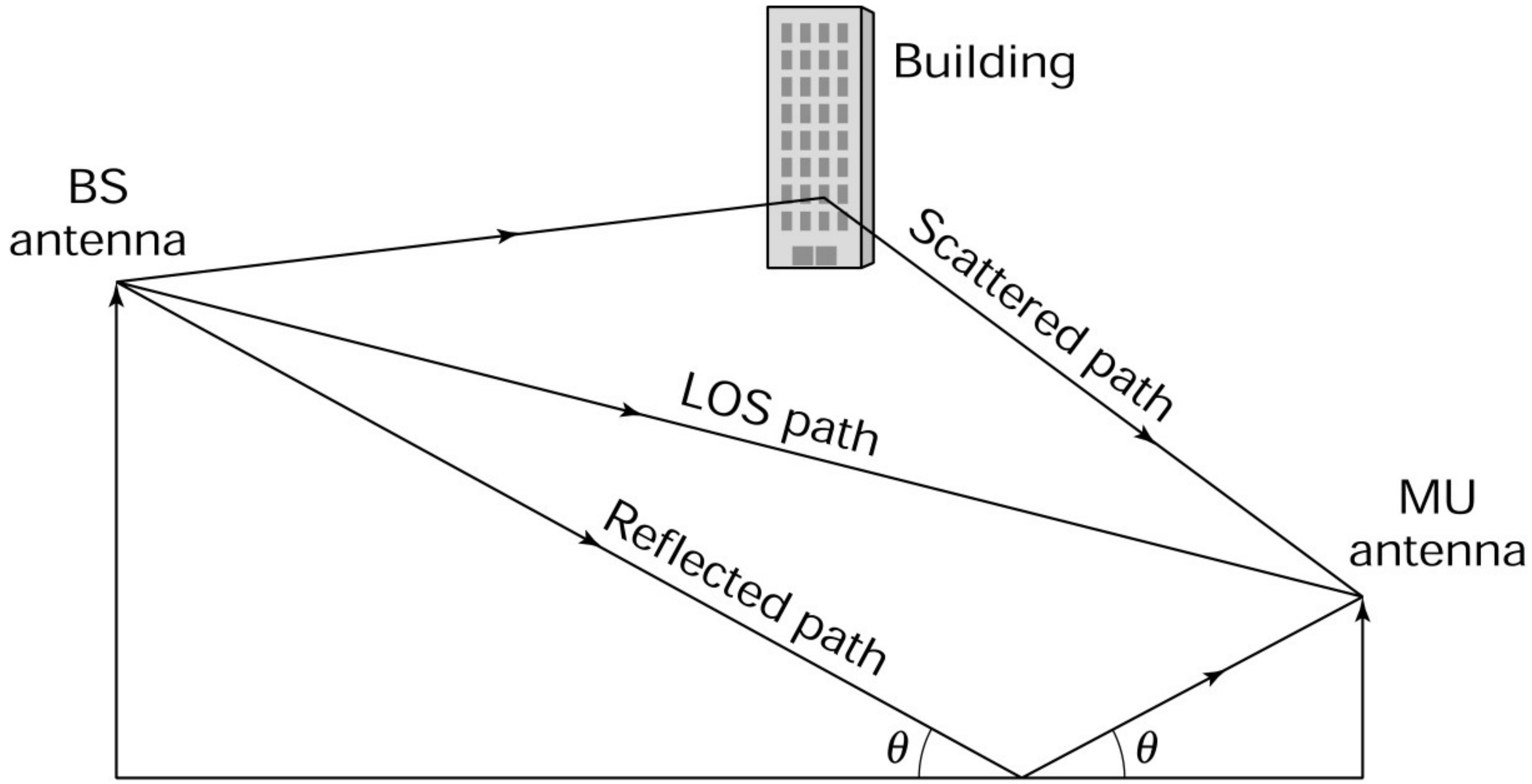
# Received power for different values of loss parameter *v*(*v*=2 corresponds to free space). Increased loss is seen as *v* goes up.



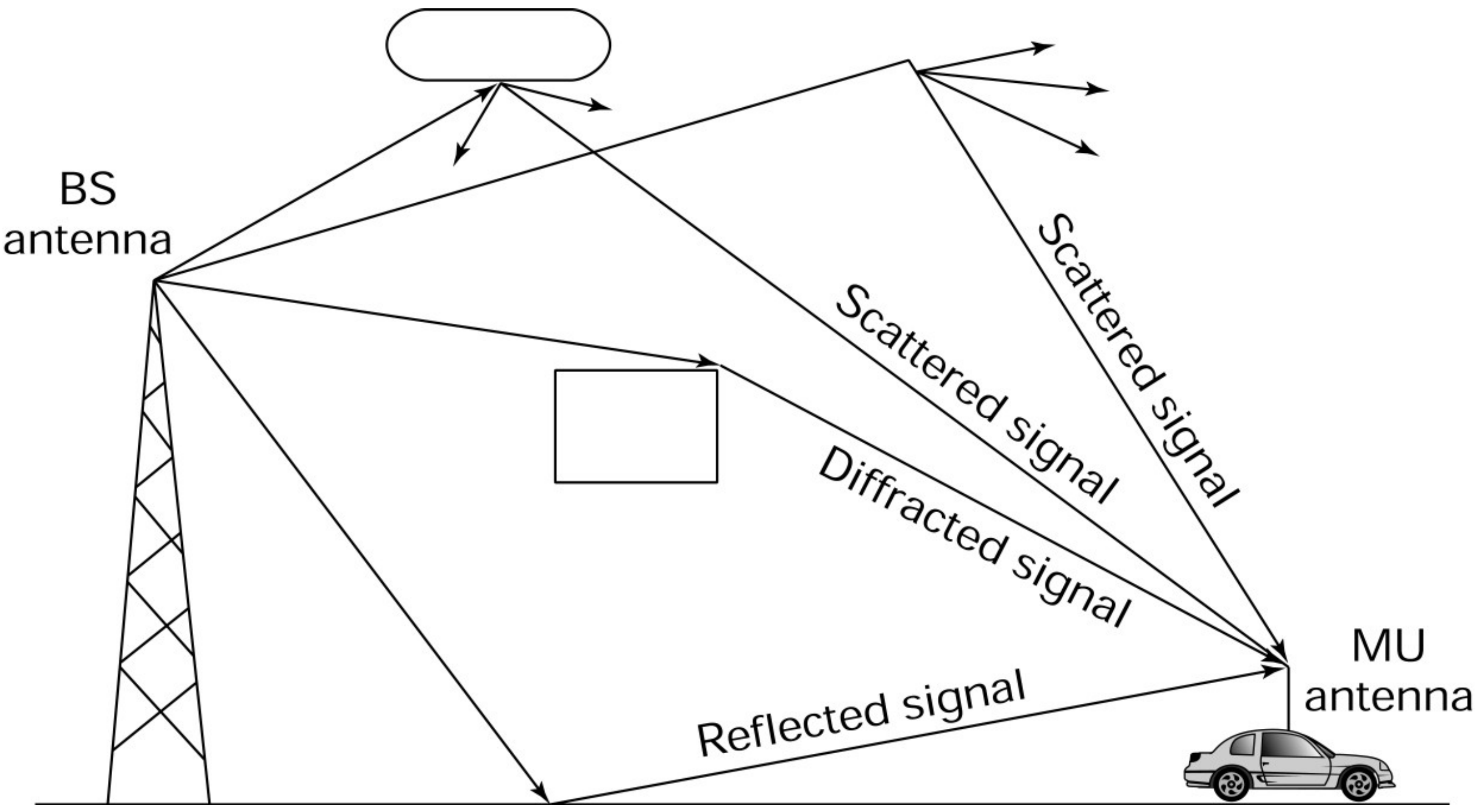
# The signal reaches the receiver through reflection and diffraction.



# The signal reaches the receiver through reflection and scattering, as well as via a direct path.



# The most general case of signal reception, consisting of a direct path, a reflected path, a scattered path, and a diffracted path.



# Loss Prediction Models

A number of models have been proposed to predict the median loss. These models take into account the different ways in which the signal can reach the receiver

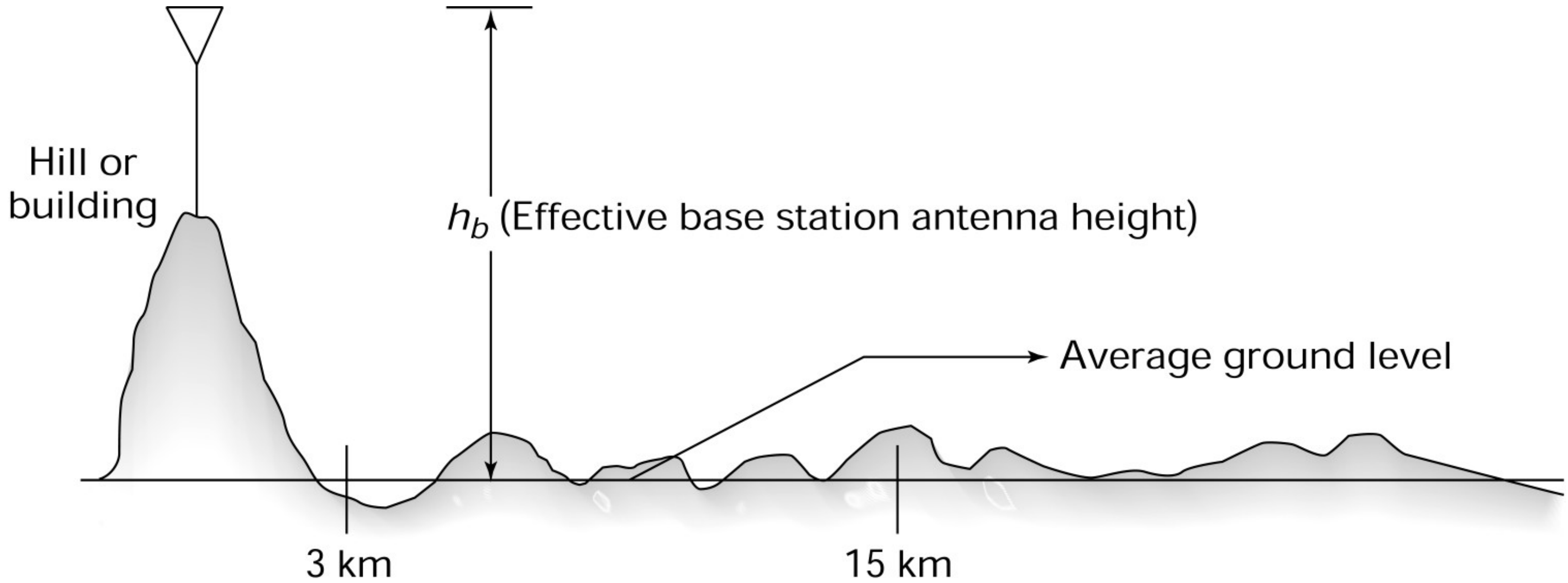
**Okumura Model** : It is possible to calculate the free space loss between any two points BS 200m MU 3m. Correction factors are then added.

# Hata Model:

Empirically derived correction factors are incorporated into the model and a formula obtained. The loss is given in terms of effective heights. The starting point is an urban area.

The BS antennae is mounted on tall buildings. The effective height is then estimated at 3 - 15 km from the base of the antennae.

# The effective height of the BS antenna.



## The median path loss in urban areas for the Hata Model is

$$L_p(dB) \quad 69.55 \quad 26.16\log_{10} f_o \qquad 44.9 \quad 6.55\log_{10} h_b \;\; \log_{10} d$$

$$13.82\log_{10} h_b \quad a \;\; h_{mu}$$

## Correction Factors are as follows

Large cities

$$a \;\; h_{mu} \qquad 3.2 \log_{10} 11.75 h_{mu} \quad ^{2} \quad 4.97 \qquad f_o \quad 400\text{MHz}$$

Small and Medium Cities

$$a \;\; h_{mu} \qquad 1.1\log_{10} f_o \qquad 0.7 \; h_{mu} \qquad 1.56\log_{10} f_o \qquad 0.8$$

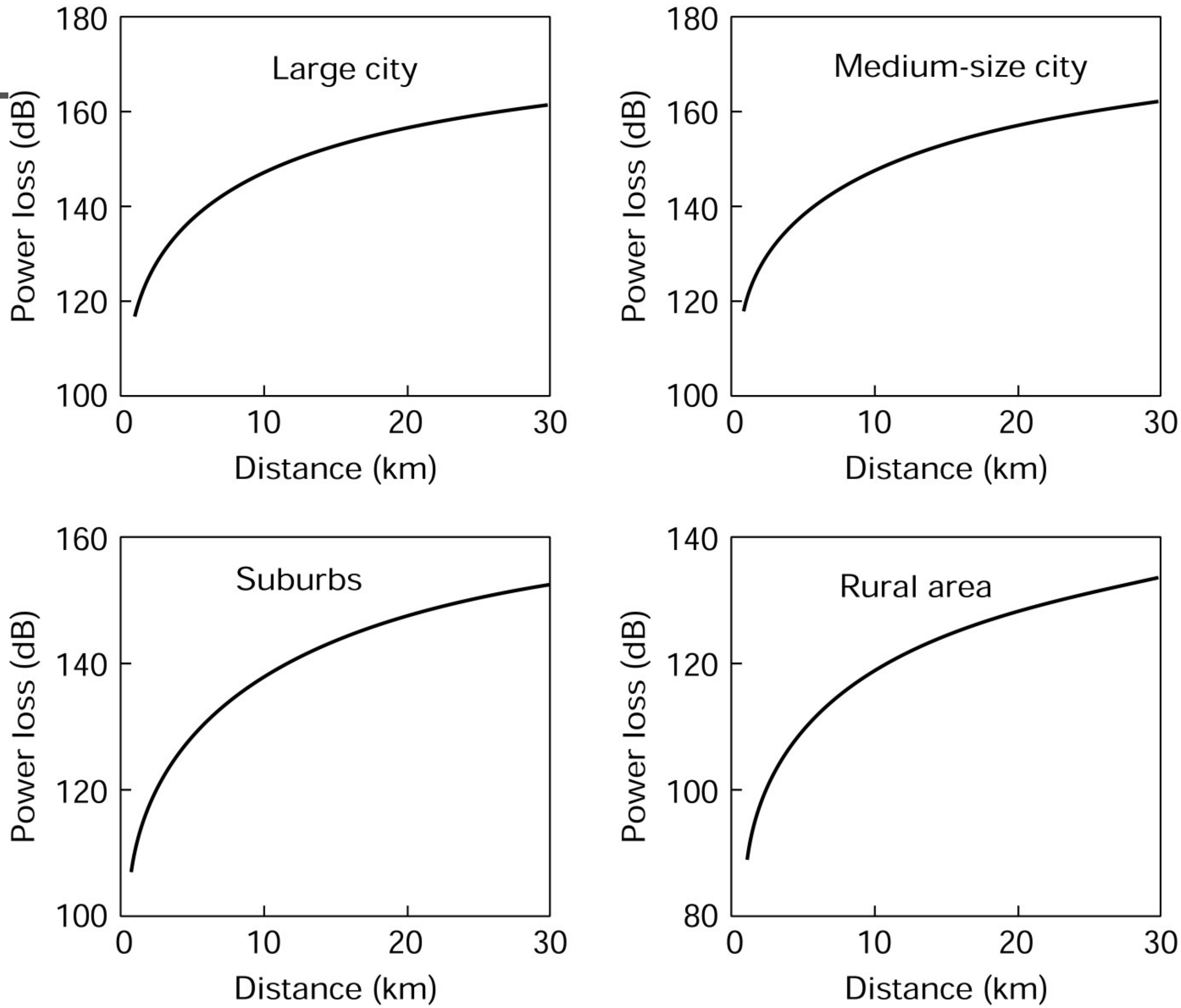
## Median Loss in Suburban areas

$$L_{sub} \; dB \quad L_p \quad 2 \log_{10} \; f_o / 28 \;^{2} \quad 5.4$$

where Lp is the loss in small to medium cities

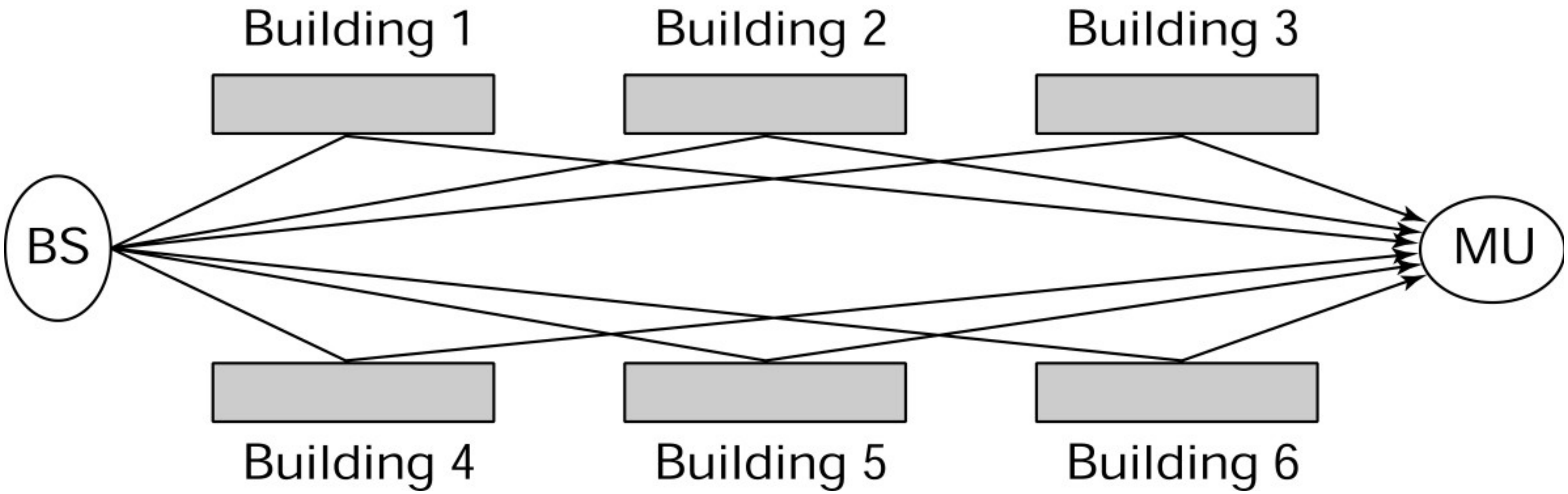
## Median loss in Rural areas

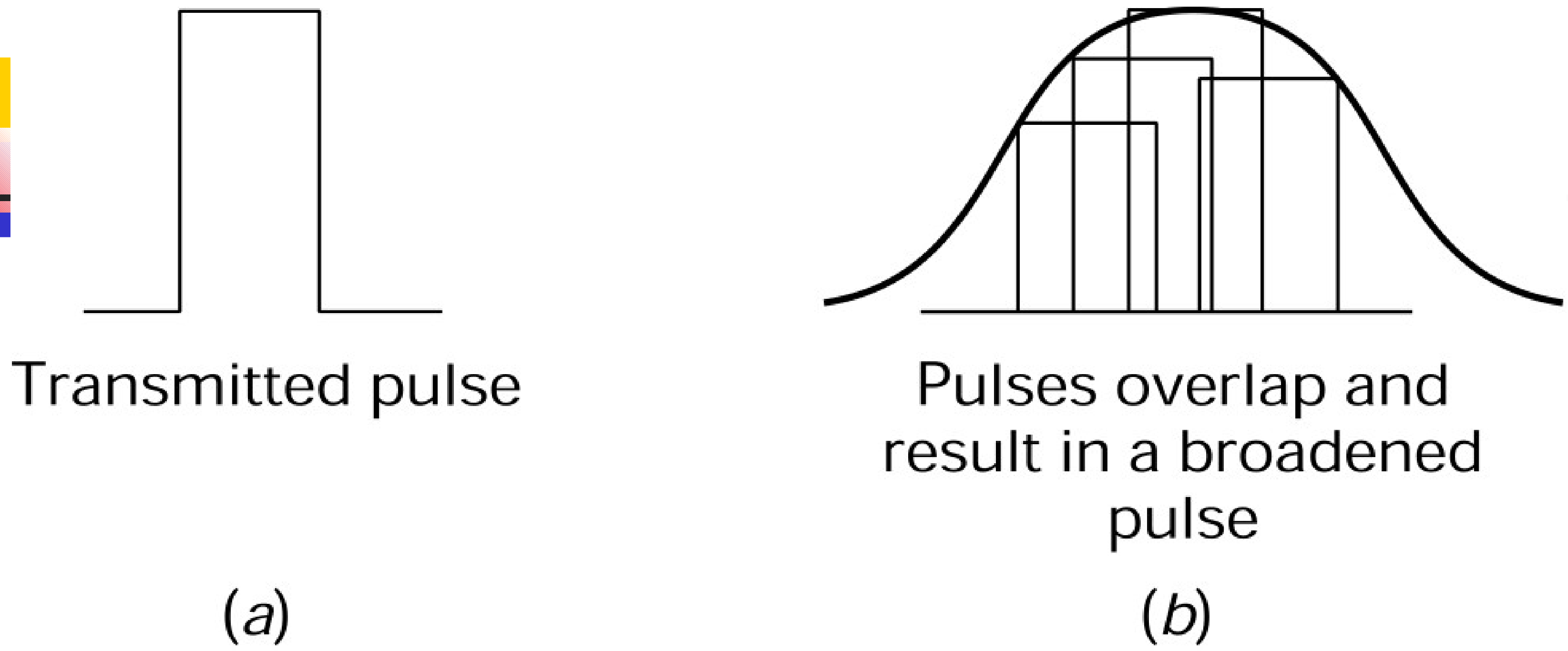
$$L_{sub} \; dB \quad L_p \quad 4.78 \log_{10} \; f_o \;^{2} \quad 18.33 \quad 5.4 \log_{10} \; f_o \; \text{-} \, 40.94$$




Loss calculations based on the Hata model for four different environments. Carrier frequency = 900 MHz, base station antenna height = 150 m, MU antenna height = 1.5m.

# The multipath concept.






(a) A transmitted pulse. (b) The multiple pulses produced due to the multipath arriving at different times and with different powers, leading to a broadened envelope of the pulse.

# The Effects of Multipath Propagation

- Multiple copies of a signal may arrive at different phases
  - If phases add destructively, the signal level relative to noise declines, making detection more difficult
- Intersymbol interference (ISI)
  - One or more delayed copies of a pulse may arrive at the same time as the primary pulse for a subsequent bit

# Decibels and Signal Strength

- Signal Strength is an important parameter in any transmission system
- Signal attenuation is compensated for by use of amplifiers
- Losses and gains are expressed in terms of decibel
- The decibel is a logarithmic ratio
- Attenuation itself occurs logarithmically
- This allows for easy addition and subtraction

The Decibel is given by $G_{dB} \quad 10\log_{10} \frac{P\,\text{[redacted]}}{P_{in}}$

It is a measure of relative and not absolute difference

A measure of absolute difference can be obtained through the use of dBW. It is defined as

$$\text{Power}_{dBW} \quad 10\log_{10} \frac{P\,\text{[redacted]}}{1\text{W}}$$

A power level of 1W is used as the reference

Another common unit is the dBm. In this case the reference power level is 1mW.

$$\text{Power}_{dBm} \quad 10\log_{10} \frac{P\ \text{[redacted]}}{1\text{mW}}$$

Example

Given a system with 4mW input power, calculate the output power if the signal is transmitted over an element with 12 dB loss, an amplifier with 35 dB gain and another element with 10 dB loss