



# UNIK4230: Mobile Communications

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# Propagation characteristics of wireless channel

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# Agenda

## Radio wave propagation phenomena

- Reflection
- Refraction
- Diffraction
- Scattering

## Signal attenuation

- Attenuation and fading
- Path loss
- Hata model

## Indoor propagation

## More on fading

# Agenda

## Radio wave propagation phenomena

- Reflection
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- Diffraction
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## Signal attenuation

- Attenuation and fading
- Path loss
- Hata model

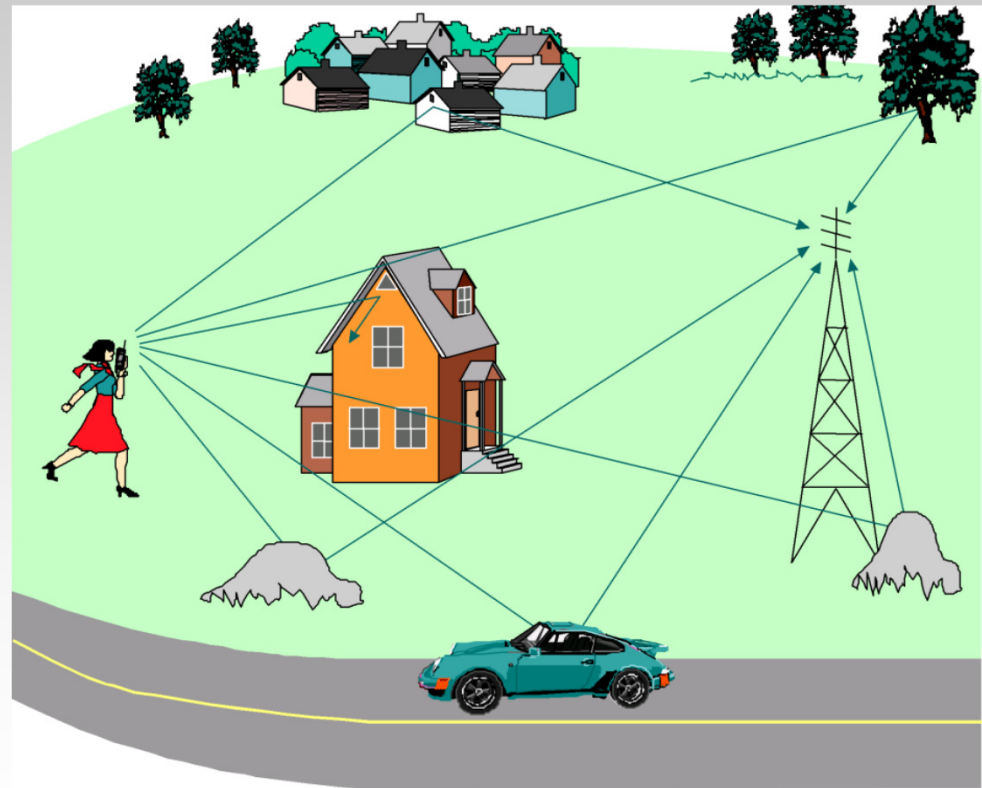
## Indoor propagation

## More on fading

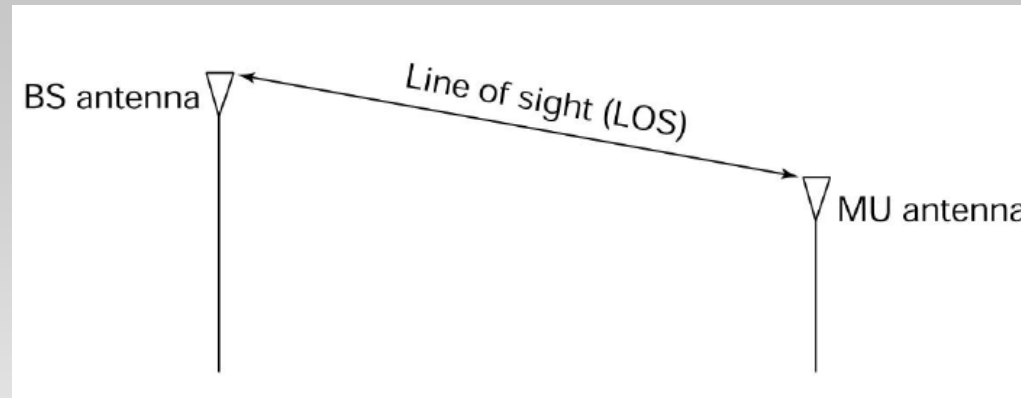
# Radio channel

The transmitted signal arrives at the receiver from different directions at different times over a number of ways

- Line of sight (LOS) or
- Non-line of sight (NLOS)



# Line of sight propagation



Unobstructed line of sight propagation between the transmitter and receiver

- Lower attenuation
- There must be no obstruction on LOS
- Objects not even on direct LOS can interfere radio transmission (see Fresnel Zone)

# Fresnel zones

Fresnel zones determine whether a given obstacle will cause a constructive or destructive interference at the receiver due to reflection

- Reflection can enhance received signal if reflected and direct signals arrive in-phase
- Its important to clear obstruction from first Fresnel zone

The radius of  $N$ th Fresnel zone,

$$r = 17.31 * \text{sqrt}(N(d_1 * d_2)/(f * d))$$

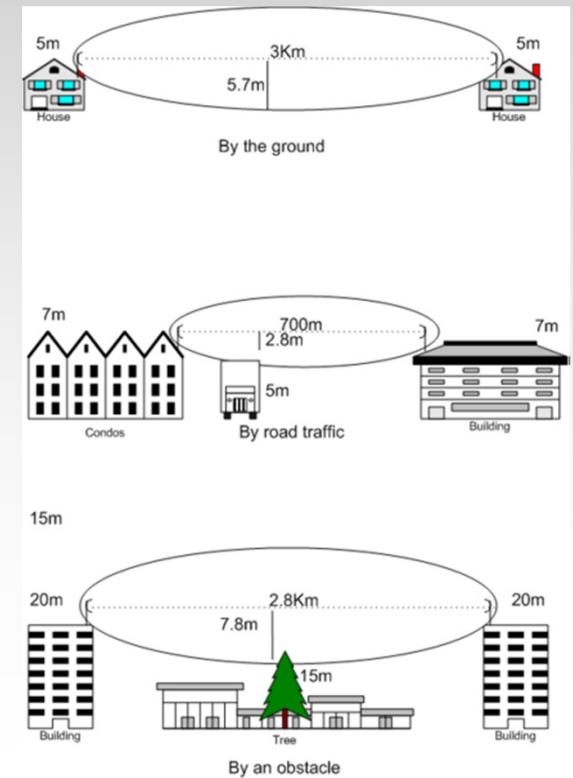
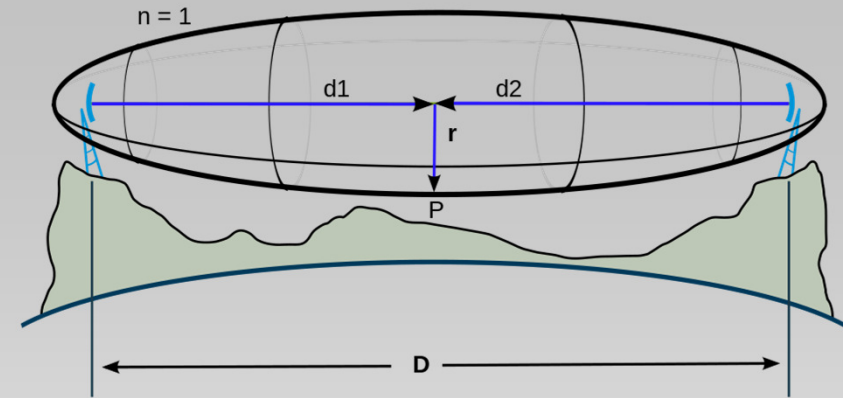
...where  $r$  is the radius of the zone in meters,  $N$  is the zone to calculate,  $d_1$  and  $d_2$  are distances from obstacle to the link end points in meters,  $d$  is the total link distance in meters, and  $f$  is the frequency in MHz.

$$F_n = \sqrt{\frac{n\lambda d_1 d_2}{d_1 + d_2}}$$

All units are meter

1st Fresnel zone while  $D$  in km and  $f$  in GHz

$$r = 8.657 \sqrt{\frac{D}{f}}$$



## Fresnel zones

For example, let's calculate the size of the first Fresnel zone if the first Fresnel zone in the middle of a 2km link, transmitting at 2.437GHz (802.11b channel 6):

$$\begin{aligned}r &= 17.31 \sqrt{1 * (1000 * 1000) / (2437 * 2000)} \\r &= 17.31 \sqrt{1000000 / 4874000} \\r &= 7.84 \text{ meters}\end{aligned}$$

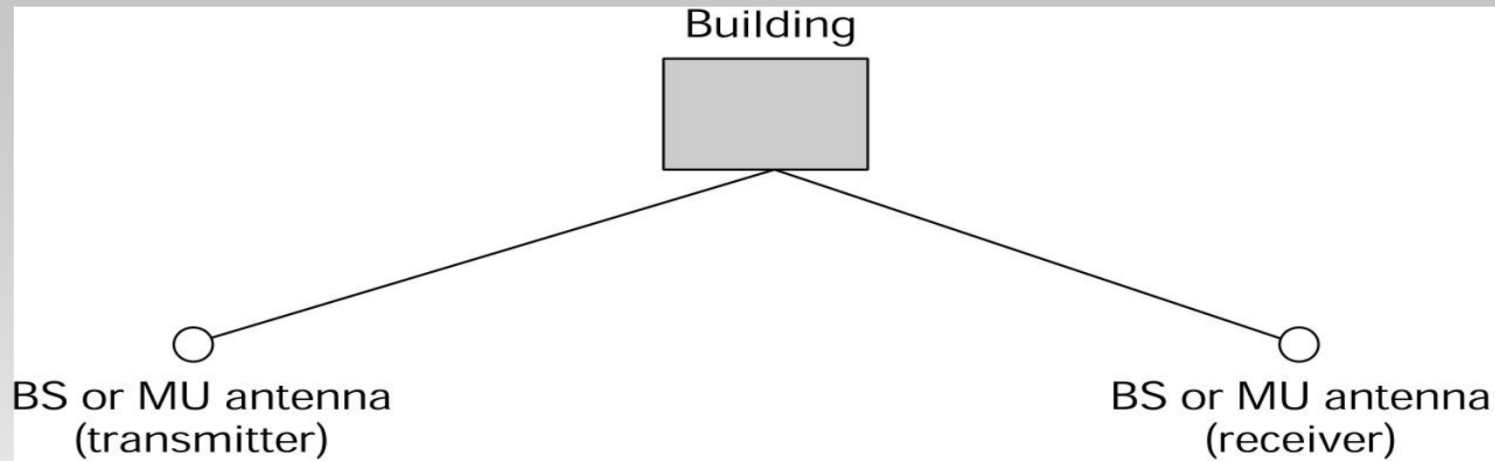
Assuming both of our towers were ten meters tall, the first Fresnel zone would pass just 2.16 meters above ground level in the middle of the link.



## Fresnel zone: exercise

How tall could a structure in the middle of a 2km point be to clear 60% ( $N=0.6$ ) of the first Fresnel zone? Transmitter is transmitting at 2.437GHz (802.11b channel 6)

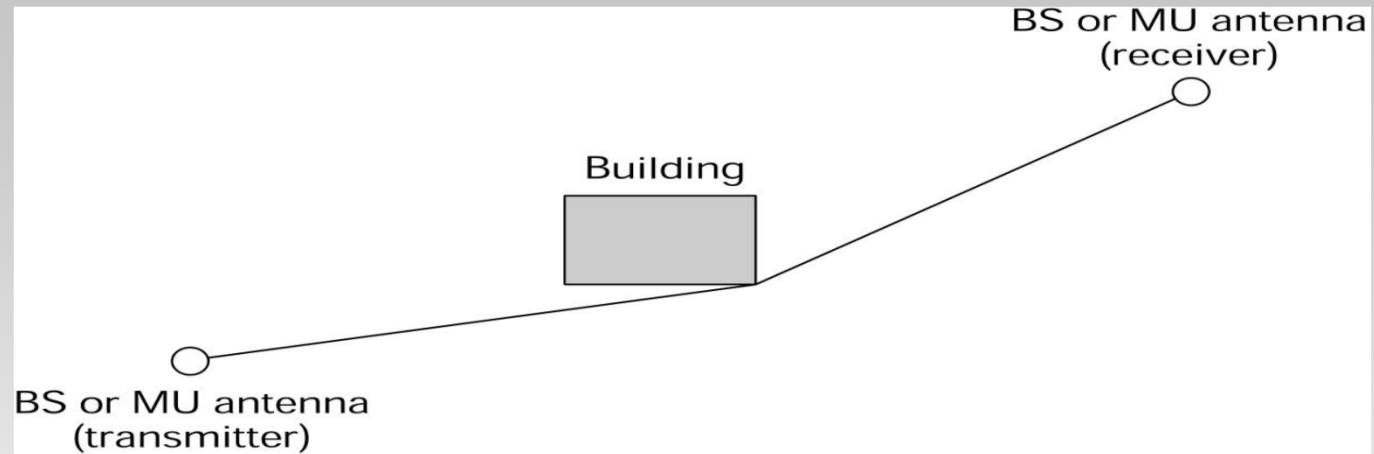
# Reflection



Reflection occurs when a radio wave strikes a barrier with a dimension larger than the wave length of the radio wave

- E.g. Buildings, ground, vehicles etc.

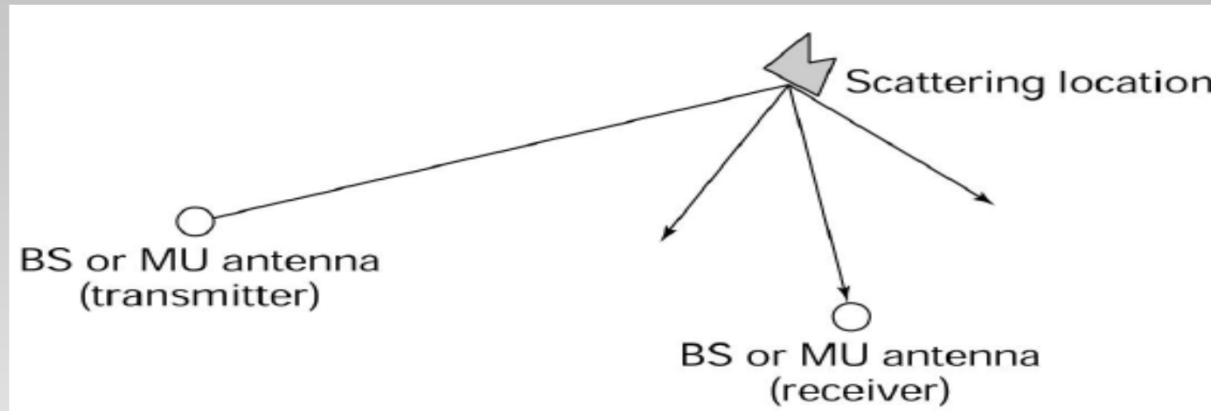
# Diffraction



Diffraction occurs when the radio wave hits an obstacle with sharp irregularities, edge, small gap

- Size of the object (e.g. edge) must be comparable to or smaller than the wavelength of the radio wave
- E.g. Bending around the object (typically corner of the houses or hills)

# Scattering



Scattering occurs when the radio wave strikes the obstacles with dimension smaller than the wave length of the radio wave

- E.g. Vegetation, street signs etc.

# Agenda

## Radio wave propagation phenomena

- Reflection
- Refraction
- Diffraction
- Scattering

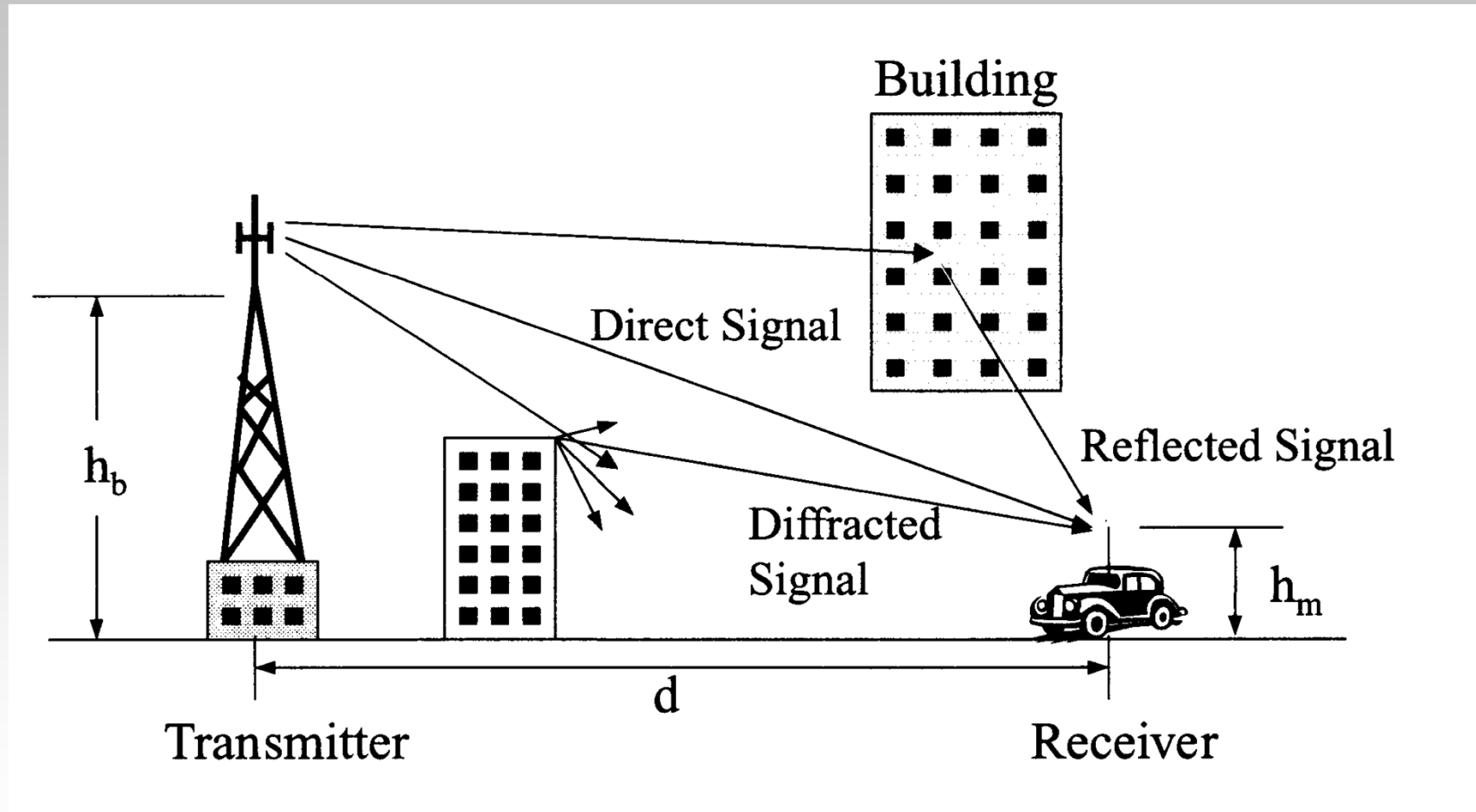
## Signal attenuation

- Attenuation and fading
- Path loss
- Hata model

## Indoor propagation

## More on fading

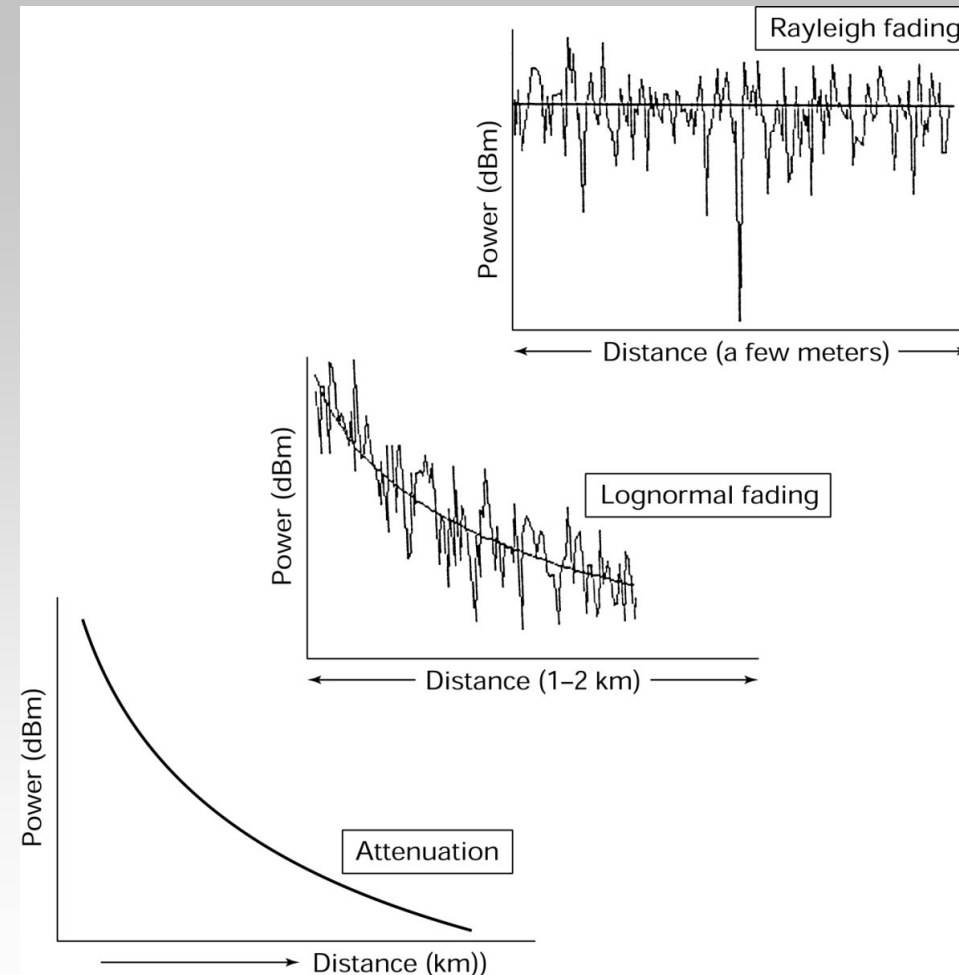
# Attenuation and fading



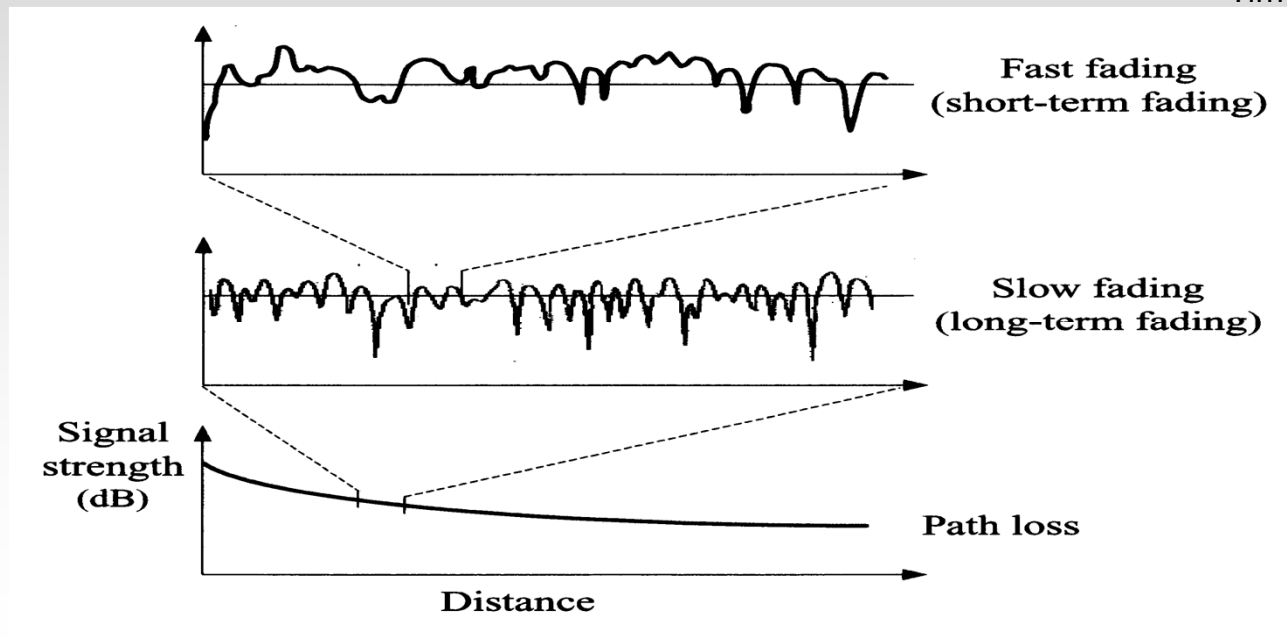
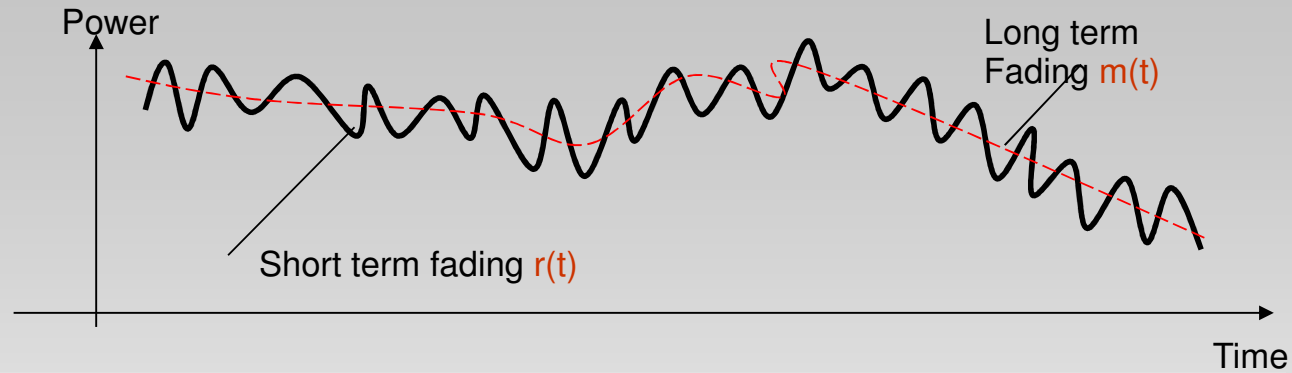
# Attenuation and fading

Fading is deviation of attenuation a radio wave experience over certain propagation media.

- Distance dependent attenuation
- Fast fading: Rapid fluctuation of signal over a small areas. Fast fading occurs due to multipath propagation
  - Fast fading is characterized by Rayleigh and Rician distribution
  - Rayleigh distribution: It assumes infinite reflected path with all possible attenuation and no direct path. E.g. It is used to characterize worst case urban or indoor communications
  - Rician distribution: It assumes a direct path from Tx to Rx as well as infinite reflected paths. E.g. Used to characterize satellite communication channels
- Slow fading: It is long-term fading effect caused by large obstruction (shadowing) such as large building or hills
  - Shadowing is modelled using log-normal distribution.



# Attenuation and fading





# About the term dB

Widely used to measure e.g. gain, attenuation, signal to noise ratio (SNR) etc.

The ratio of power value  $P_a$  to another power value  $P_b$  is calculated as:

Example:

$$X_{dB} = 10 \log_{10} \left( \frac{P_a}{P_b} \right) \text{ dB}$$

$$\text{Ratio} = 0.1 = -10 \text{ dB}$$

$$= 1 = 0 \text{ dB}$$

$$= 10 = 10 \text{ dB}$$

$$= 100 = 20 \text{ dB}$$

$$= 2 = 3 \text{ dB}$$

$$= 0.5 = -3 \text{ dB}$$

Decibel (dB) is a dimensionless unit

$$P_a = 10^{\frac{X_{dB}}{10}} P_b \text{ watt given } P_b \text{ in watt}$$

# About the term dBm

dBm (decibel-milliwatt) is the power unit in dB referenced to 1 mW.

It measures absolute power in radio, microwave and fiber optic network.

- dBm can measure both very small and very large values in short form

To measure an arbitrary power  $P_a$  as  $x$  dBm:

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

Example:

$P_a = 1 \text{ mW}$ ,  $x = 0 \text{ dBm}$

$P_a = 1 \text{ W}$ ,  $x = 30 \text{ dBm}$ , maximum output power of GSM 1800 mobile phone

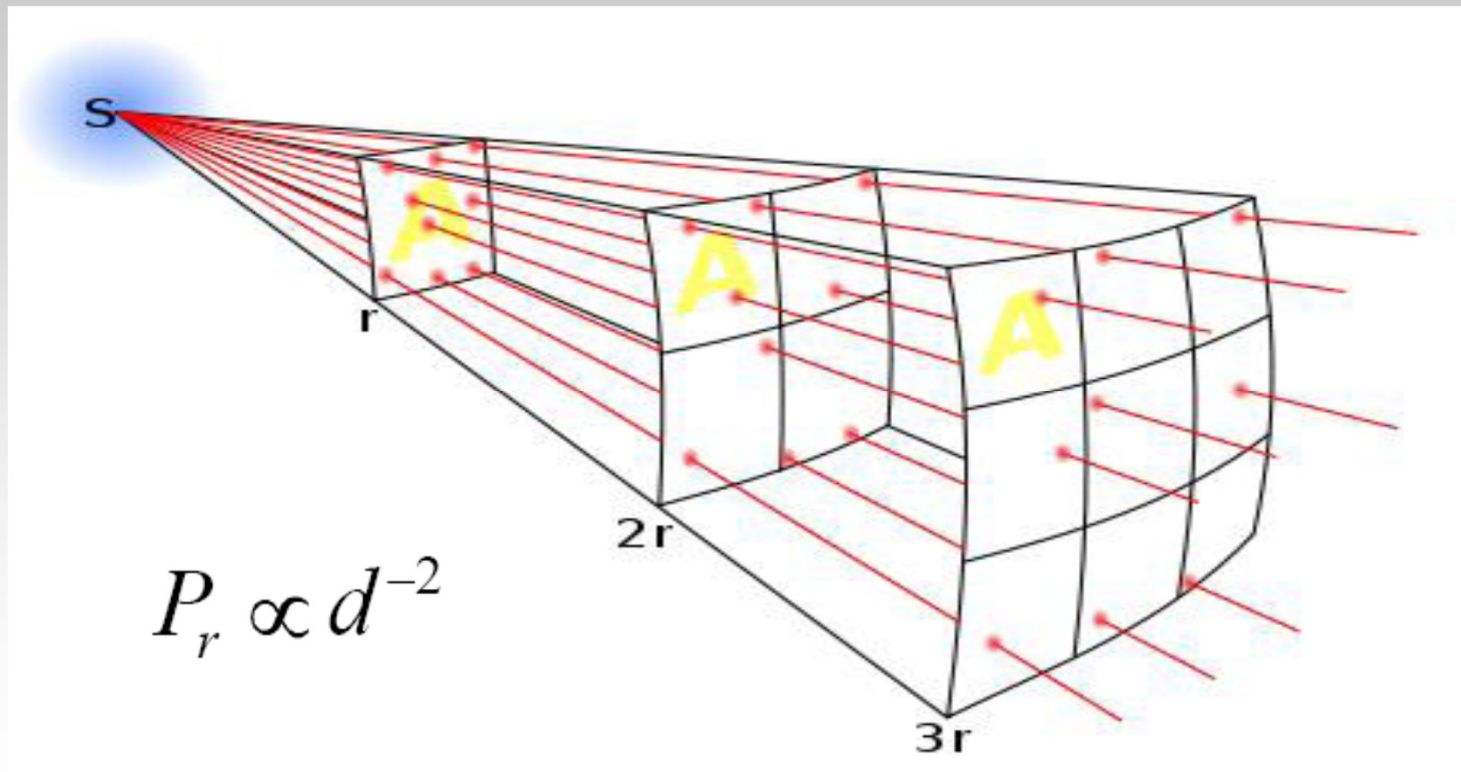
$x = 33 \text{ dBm}$ ,  $P_a = 2 \text{ W}$

$x = 80 \text{ dBm}$ ,  $P_a = 100 \text{ KW}$ ,  $P_{tx}$  of FM radio transmitter with 50km range

dBm is an absolute measure of power in mW

# Attenuation in free space

When there is line of sight between transmitter and receiver, received power follows inverse square law:



# Attenuation in free space

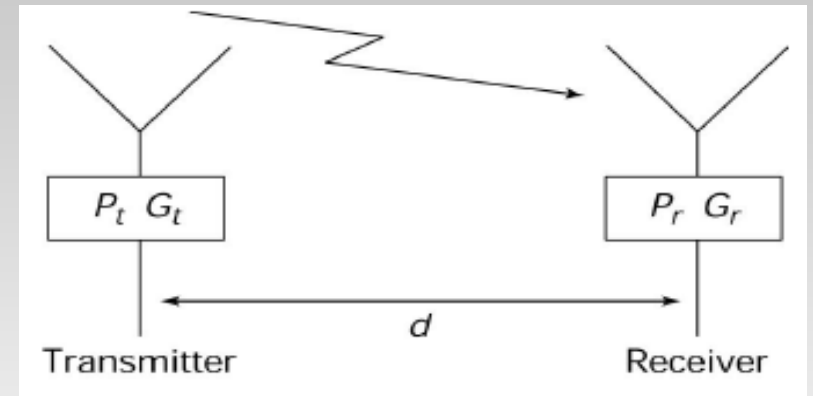
Received power in free space can be expressed as:

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

$P_t$  = transmit power

$G_t, G_r$  = gain of transmitter, receiver antenna

$L$  = other losses (e.g. filter loss, antenna loss)



# Attenuation in free space

Free space path loss:

$$L = \left( \frac{4 \Pi d}{\lambda} \right)^2 = \left( \frac{4 \Pi df}{c} \right)^2$$

$$L_{dB} = 20 \text{ Log}_{10} \left( \frac{4 \Pi d}{\lambda} \right)$$

$d$  = distance from transmitter (m)

$\lambda$  = signal wavelength (m)

$f$  = signal frequency (Hz)

$c$  = speed of light

$$L_{dB} = 32.44 + 20 \log_{10} (f) + 20 \text{ Log}_{10} (d)$$

where  $d$  in km and  $f$  in MHz

# Attenuation in free space

If received power is known in a reference distance  $d_{ref}$ , received power in an arbitrary distance can be calculated:

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

In dBm

$$P_r(d) [dBm] = 10 \log_{10} (P_r(d_{ref})) + 20 \log_{10} \left( \frac{d_{ref}}{d} \right)$$

# Path loss

If transmitted and received power are known, path loss can be calculated:

$$L ( dB ) = 10 \log_{10} \left( \frac{P_t}{P_r} \right)$$

if both transmitter and receiver has no gain, its identical to free space loss

From the above equation, we can also write:

$$\text{Path Loss (dB)} = \text{Transmit Power (dBm)} - \text{Received Power (dBm)}$$

# Attenuation factor

In real case attenuation is much higher because signal propagation path is not really free space.

With attenuation factor, received power:

$\nu = 2$  for free space

Typical values for urban areas are 3 - 5

$$P_r \propto d^{-\nu}$$

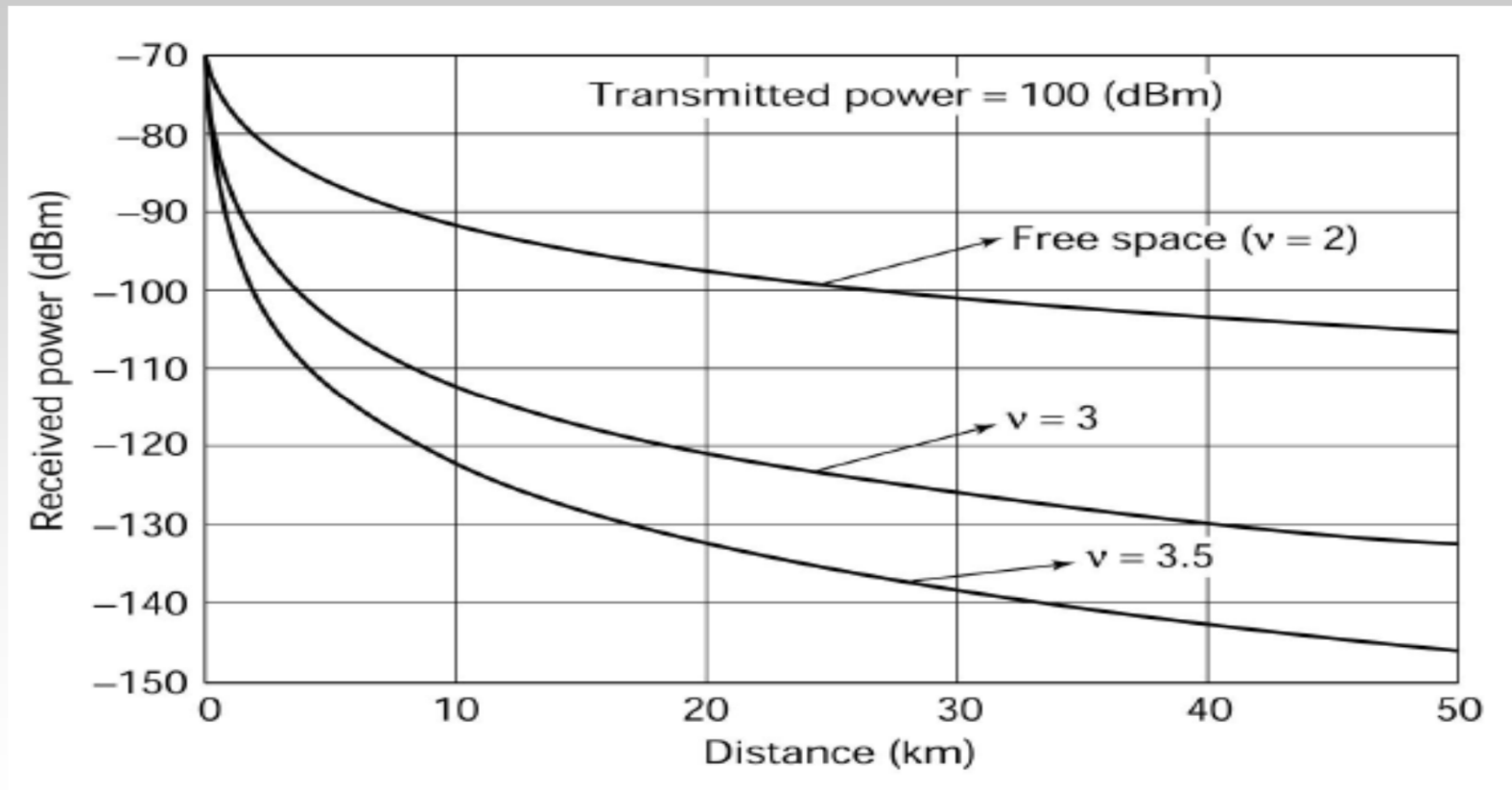
With reference distance one can write:

$$P_r(d) [dBm] = 10 \log_{10} (P_r(d_{ref})) + 10 \cdot \nu \cdot \log_{10} \left( \frac{d_{ref}}{d} \right)$$



# Attenuation factor

Received as a function of distance for different values of  $\nu$ :



# About channel models

Models are mathematical description of attenuation that are used for system design, system simulation or radio planning purposes

Two types of channel model:

- Empirical model: developed based on large collection of data for a specific scenario (e.g. Urban, sub-urban); do not point out exact behaviour rather most likely behaviour of the channel
- Analytical or deterministic model: takes into account link specific geometry (e.g. curve of hills, edges, big buildings etc.)

In practice often takes combination with site-specific correction factors used in addition to empirical models – semi-empirical models

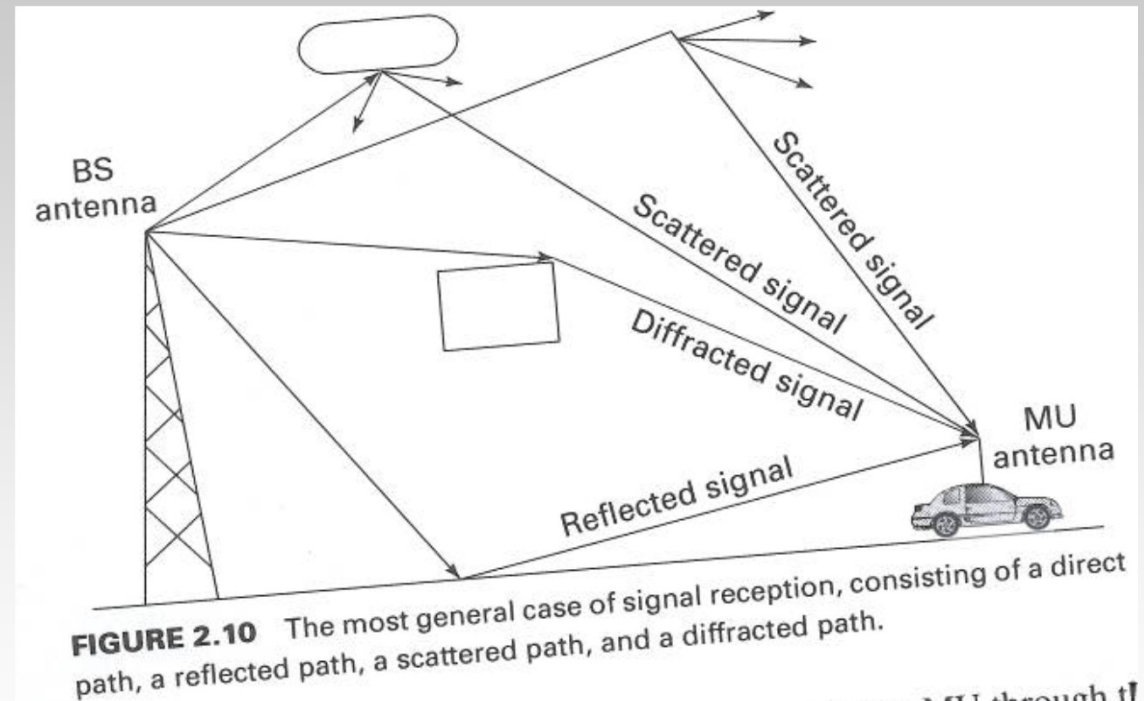
# Okumura model

Combining all these causes (reflection, scattering, and diffraction), Okumura et al. (1968) proposed channel model

The model includes correction factor to account for terrain.

But correction factors have to be incorporated for every scenario

- Hata (1980) proposed a model to overcome the problem



... MU through tl

# Hata model

- In Hata model, path loss in urban areas is given by:

$$L_p (dB) = 69.55 + 26.16 \log_{10} (f_0) + (44.9 - 6.55 \log_{10} h_b) \log_{10} d - 13.82 \log_{10} h_b - a(h_{mu})$$

where:

$f_0$  = carrier frequency (MHz)

$d$  = separation between BS (b) and mobile terminal (mu) (km);  $d \geq 1$  km

$h_b$  = height of the BS antenna (m)

$h_m$  = height of the mu-antenna (m)

$a(h_{mu})$  = correction factor for mu antenna height

- For large cities, the correction factor  $a(h_{mu})$  is given by:

$$a(h_{mu}) = 3.2[\log_{10}(11.75 h_{mu})]^2 - 4.97 \quad f_0 \geq 400 \text{ MHz}$$

- For small and medium cities, the correction factor  $a(h_{mu})$  is given by:

$$a(h_{mu}) = [1.1 \log_{10}(f_0) - 0.7] h_{mu} - [1.56 \log_{10}(f_0) - 0.8]$$

# Hata model

For suburban and rural areas following correction factors are used:

$$L_{sub} (dB) = L_p - 2[\log_{10}(\frac{f_0}{28})]^2 - 5.4$$

$$L_{rur} (dB) = L_p - 4.78[\log_{10}(f_0)]^2 + 18.33 \log_{10} f_0 - 40.94$$

where  $L_p$  is the loss in small – to – medium citites.

# Hata model

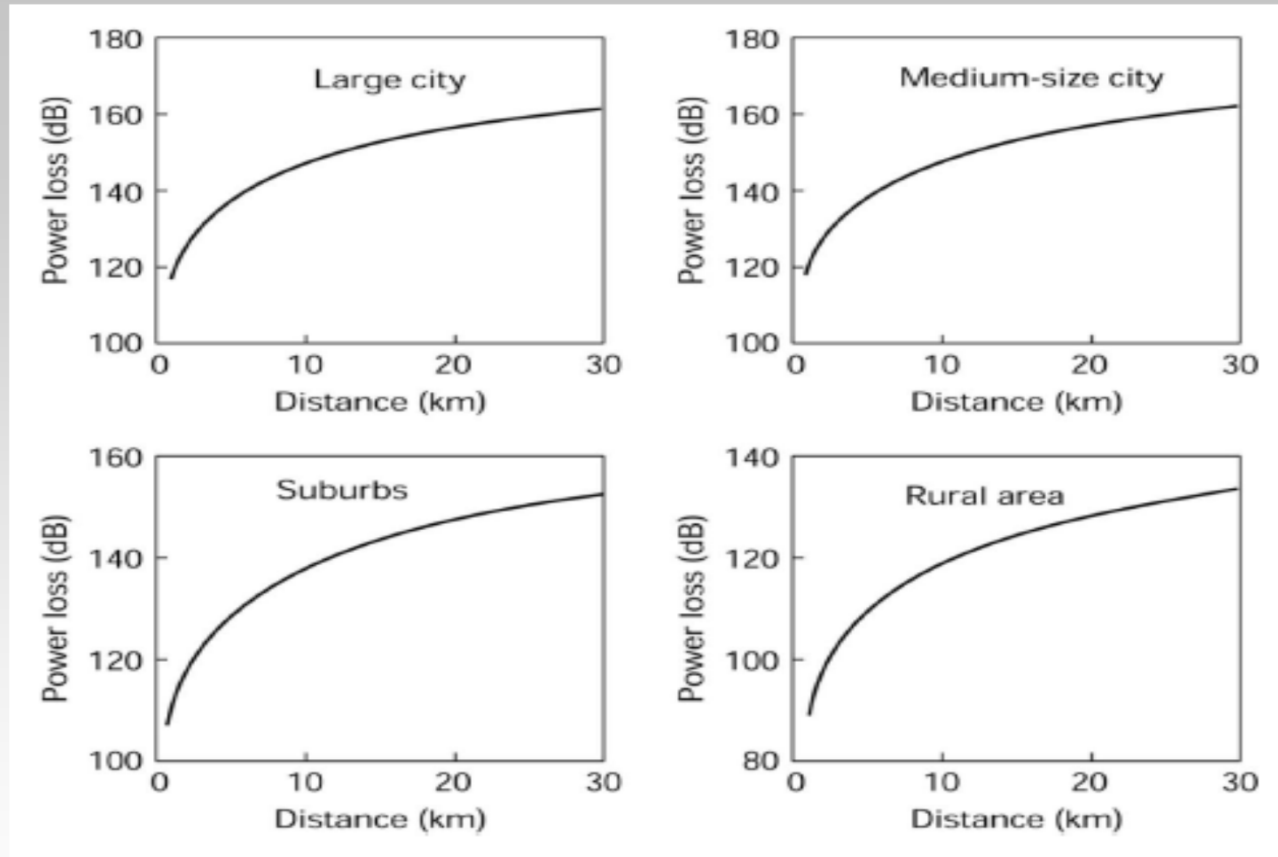


Figure shows loss calculation based on Hata model for four different environments given that  $f_0=900\text{MHz}$ ,  $h_b=150\text{m}$ ,  $h_{mU}=1.5\text{m}$

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# Indoor propagation model

Models so far presented are not sufficient to predict signals in indoor

Indoor propagation sees reflections, scattering, and diffraction due to walls, ceilings, furniture etc. (i.e. many obstacles)

Best approach to model indoor: classify these environments into different `zone' configurations

- Extra large zone
- Large zone
- Middle zone
- Small & microzone



# Indoor propagation model

## **Extra large zone:**

A BTS outside building takes all the traffic in the buildings

Loss = path-dependent losses (from BTS to building) + penetration-dependent losses (penetration of various floors & walls)

## **Large zone:**

Large buildings with small density of users

The building is covered by a single indoor BTS located within the building itself

General formula of path loss can be used.  $L(d) = L_0 (d_0) [d_0/d]^v$

Loss is determined whether users are in the same floor as BTS (attenuation factor 2-3 if Tx and Rx on the same floor, it will be greater than 3 if they are on different floors)

# Indoor propagation model

## **Middle zone:**

Building structure is large and heavily populated (e.g. shopping malls)

A number of BTSs serve the users

Loss = Free space path loss + floor loss + wall loss + reflection loss

## **Small zone and microzone:**

Buildings having many walls and partitions

Loss depends on the material of the walls and partitions

Need the provision of one BTS for each room

Usually heavy traffic in each room

Large-zone model can be used with appropriate path loss exponent:  $v=2$  for LOS,  $v>2$  for NLOS.