UNIK4230: Mobile Communications

Abul Kaosher
abul.kaosher@nsn.com

Propagation characteristis of wireless channel - I

Agenda

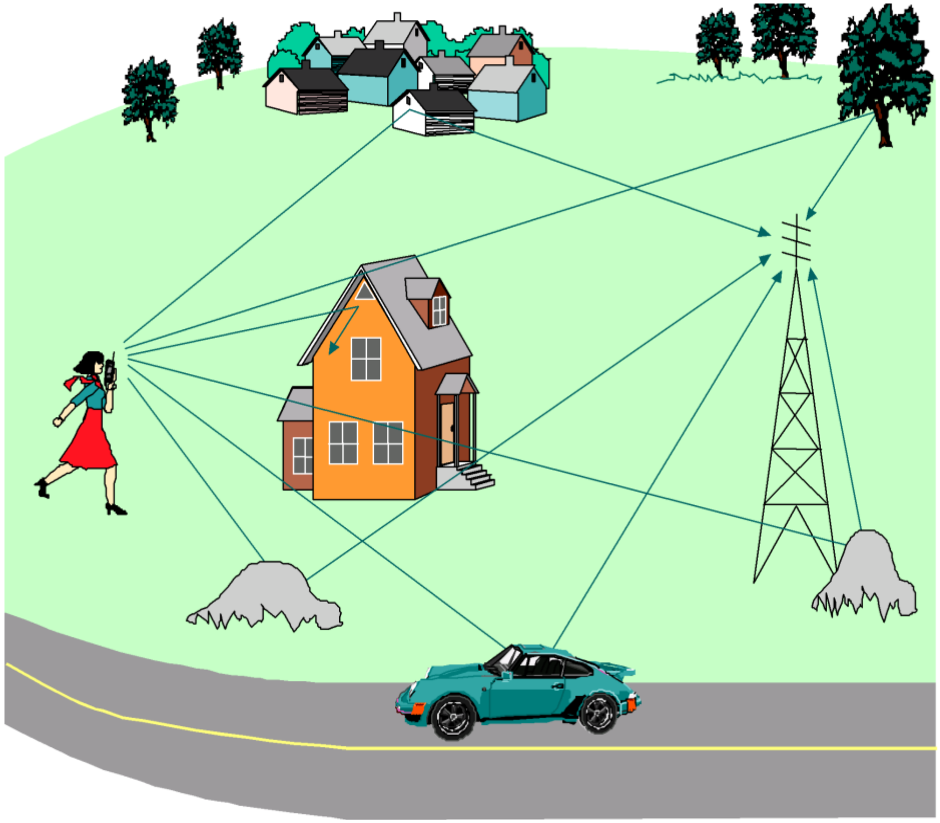
- Radio wave propagation phenomena
  - Reflection
  - Refraction
  - Diffraction
  - Scattering
- Signal attenuation
  - Attenuation and fading
  - Path loss
  - Hata model
- Indoor propagation
- More on fading

Agenda

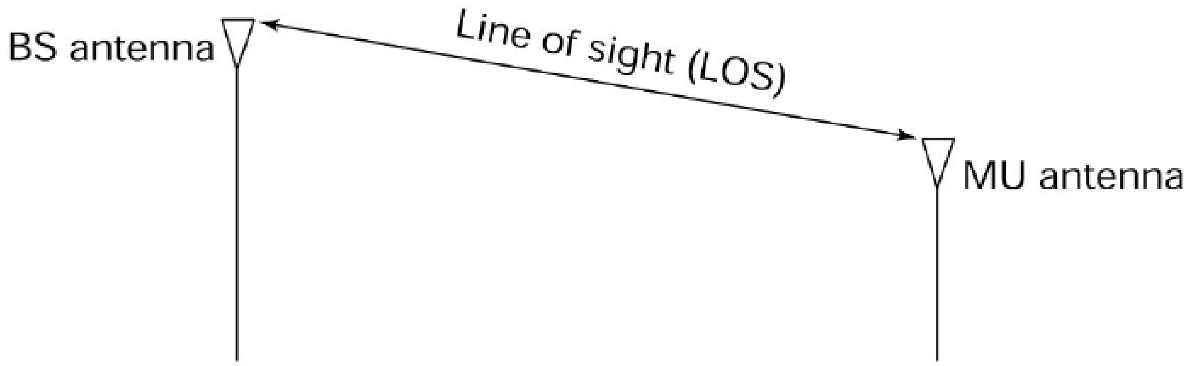
- Radio wave propagation phenomena
  - Reflection
  - Refraction
  - Diffraction
  - Scattering
- Signal attenuation
  - Attenuation and fading
  - Path loss
  - Hata model
- Indoor propagation
- More on fading

Radio channel

- The transmitted signal arrives at the receiver from different directions at different times over a number of ways
  - Line of sight or non-line of sign

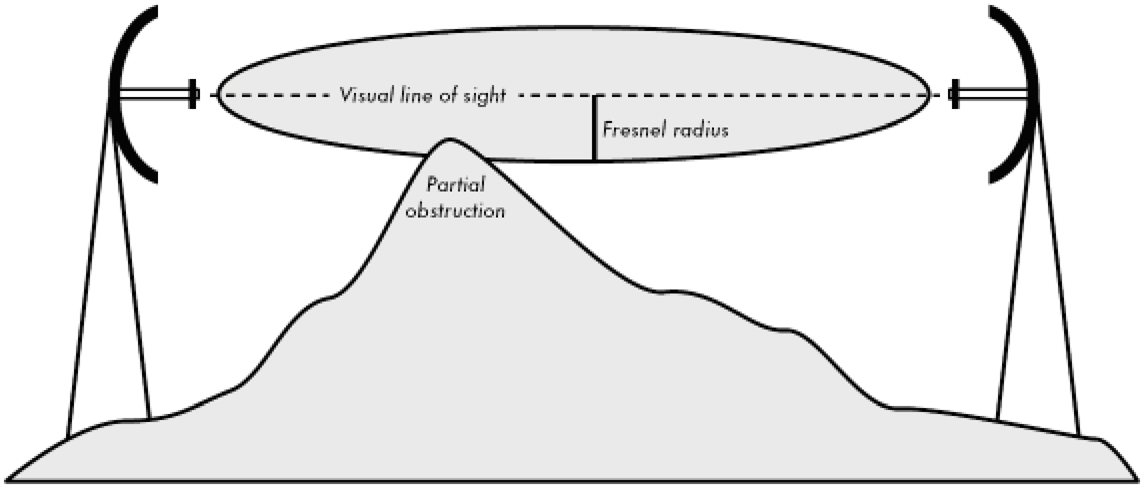


Line of sight propagation



- 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



The Fresnel zone is partially blocked on this link, although the visual line of sight appears clear..

- Fresnel zones determine whether a given obstacle will cause a constructive or desctructive 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 first Fresnel zone, r = 17.31 * sqrt(N(d1*d2)/(f*d)) ...where r is the radius of the zone in meters, N is the zone to calculate, d1 and d2 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.

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):

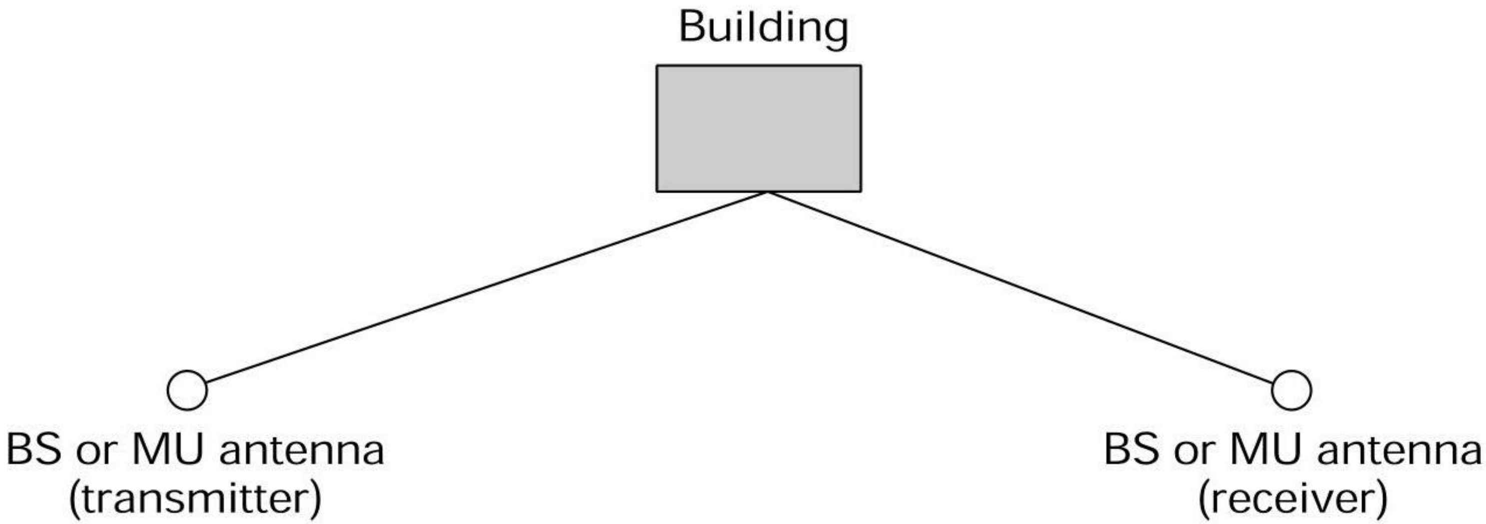
r = 17.31 sqrt(1 * (1000 * 1000) / (2437 * 2000))
r = 17.31 sqrt(1000000 / 4874000)
r = 7.84 meters

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

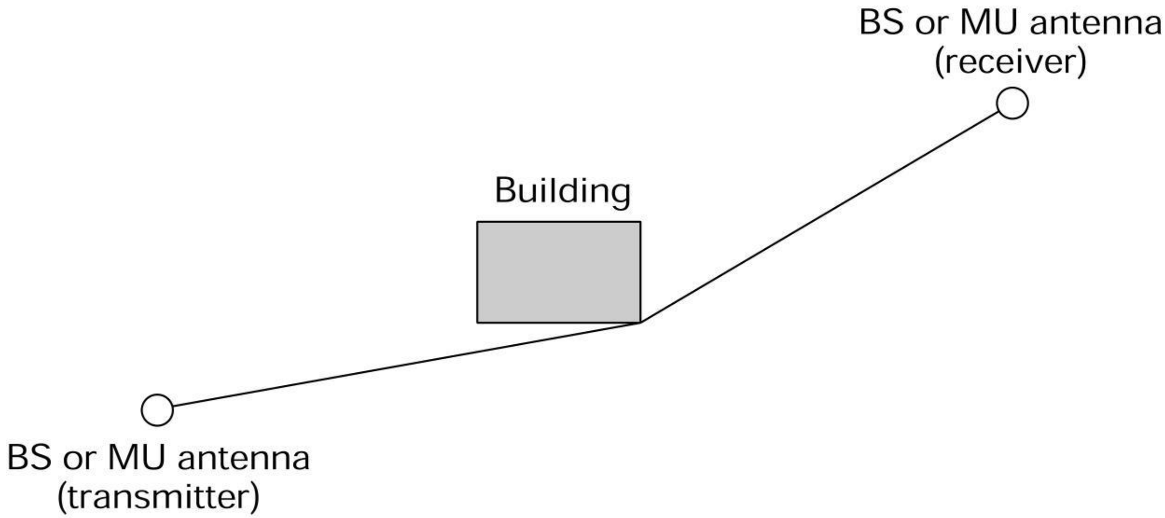
- How tall could a structure in the middle of a 2km point be to clear 60% (N=0.6) of the first Fresnel zone? Transmitter is transmitting at 2.437GHz (802.11b channel 6)

Reflection



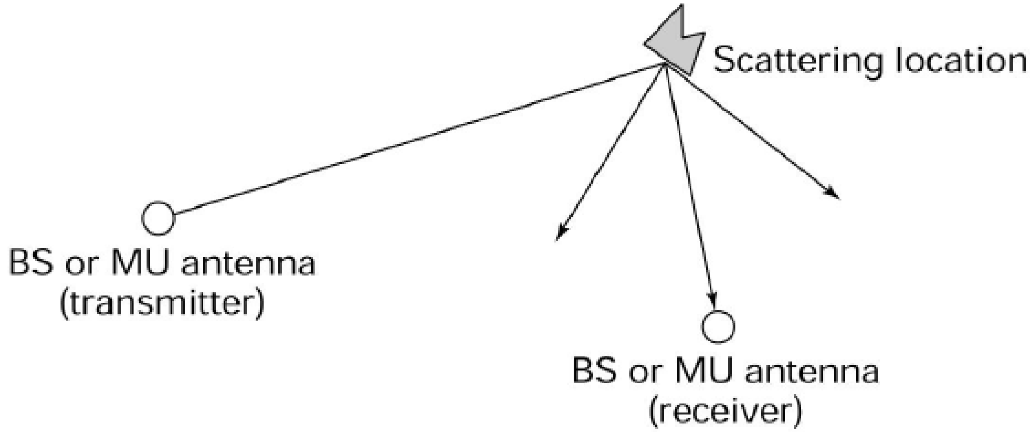
- Reflection occurs when a radio wave strikes a barrier with a dimension larger than the wave length of the wave
  - E.g. Buildings, ground, vehicles etc.

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

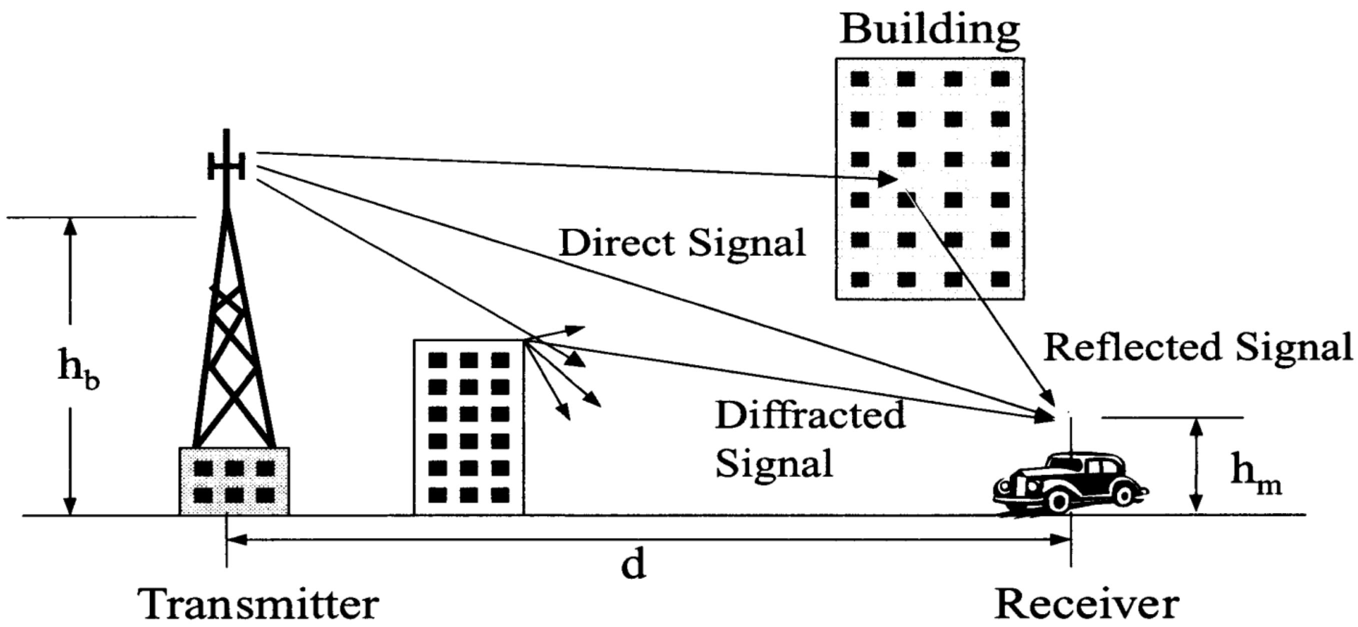


- Scattering occurs when the radio wave strikes the obstacles with dimension smaller than the wave length of the radio wave
  - E.g. Vegetation, street signs etc.

Agenda

- Radio wave propagation phenomena
  - Reflection
  - Refraction
  - Diffraction
  - Scattering
- Signal attenuation
  - Attenuation and fading
  - Path loss
  - Hata model
- Indoor propagation
- More on fading

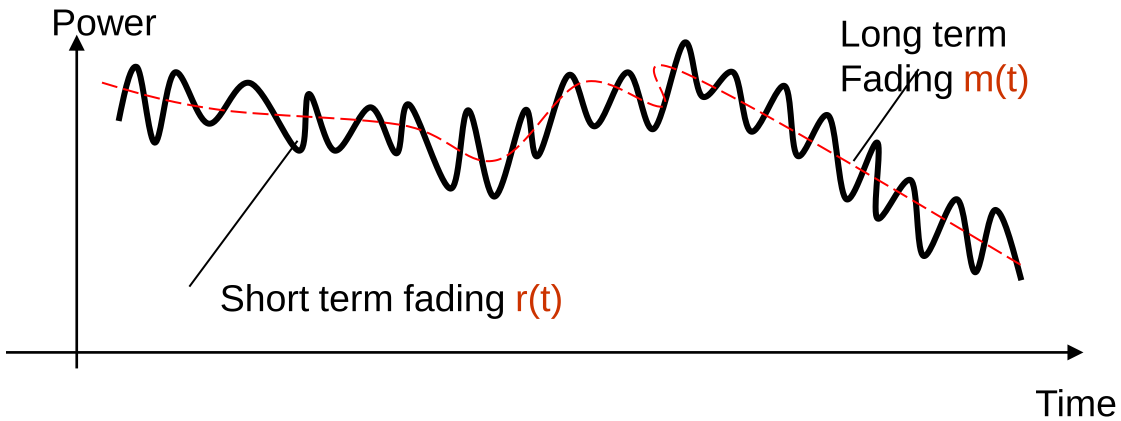
Attenuation and fading

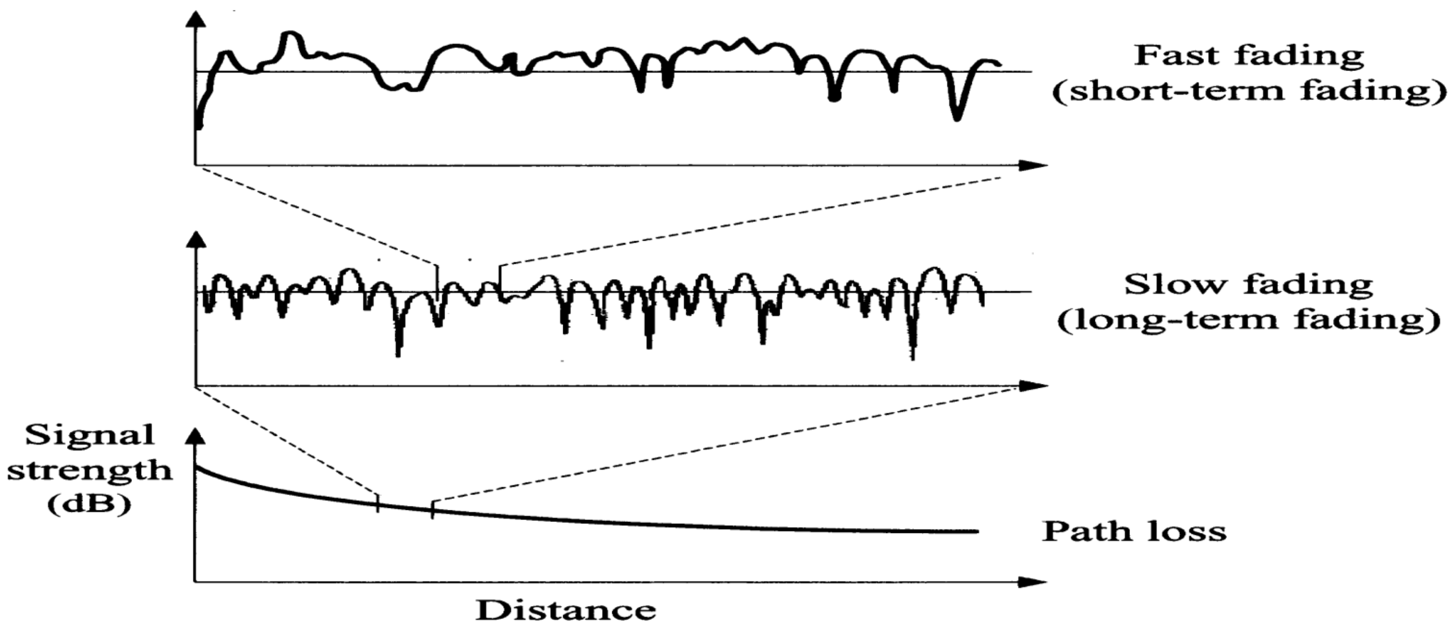


Attenuation and fading

- Fading is devation 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 caracterized 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 characterize worst case urgan 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 buidling or hills
    - Shadowing is modeled using 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:

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

- Example:

Ratio = 0.1 = -10 dB

= 1 = 0 dB

= 10 = 10 dB

= 100 = 20 dB

- Decibel (dB) is a dimensionless Unit

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

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 option network.
  - dBm can measure both very small and very large values in short form
- To measure an arbitrary power P_a as x dBm:

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

- Example:

  P_a = 1 mW, x = o dBm

  P_a = 1 W, x = 30 dBm, maximum outout power of GSM 1800 mobile phone

  x = 33 dBm, P_a = 2 W

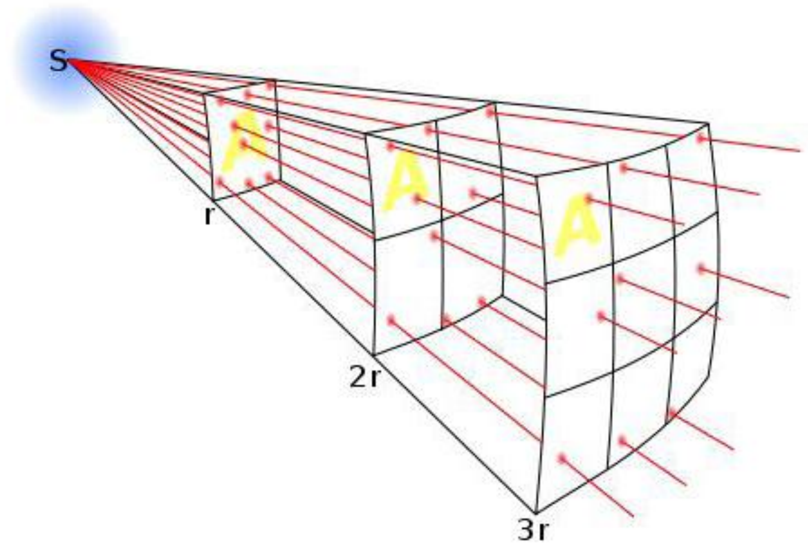
  x = 80 dBm, P_a = 100 KW, P_{tx} of FM radio transmitter with 50km range

- dBm is an absolute measure of power in mW

Attenuation in free space

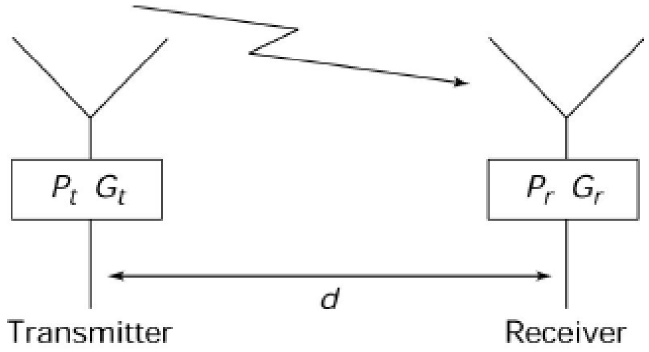
- When there is line of sight between transmitter and receiver, received power follows inverse square law:

$$P_r \propto d^{-2}$$



Attenuation in free space

- Received power in free space can be expressed as:



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

$$P_t = transmit\ power$$

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

$$L = other\ losses\ (e.g.\ filtertap, antennatap)$$

Attenuation in free space

- Free space path loss:

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

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

$d = dis\tan ce\ from\ transmitter\ (m)$

$\lambda = signal\ wavelength\ (m)$

$f = signal\ frequency\ (Hz)$

$c = speef\ of\ light$

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

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

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:

Path Loss (dB) = Transmit Power (dBm) – 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:

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

v=2 for free space

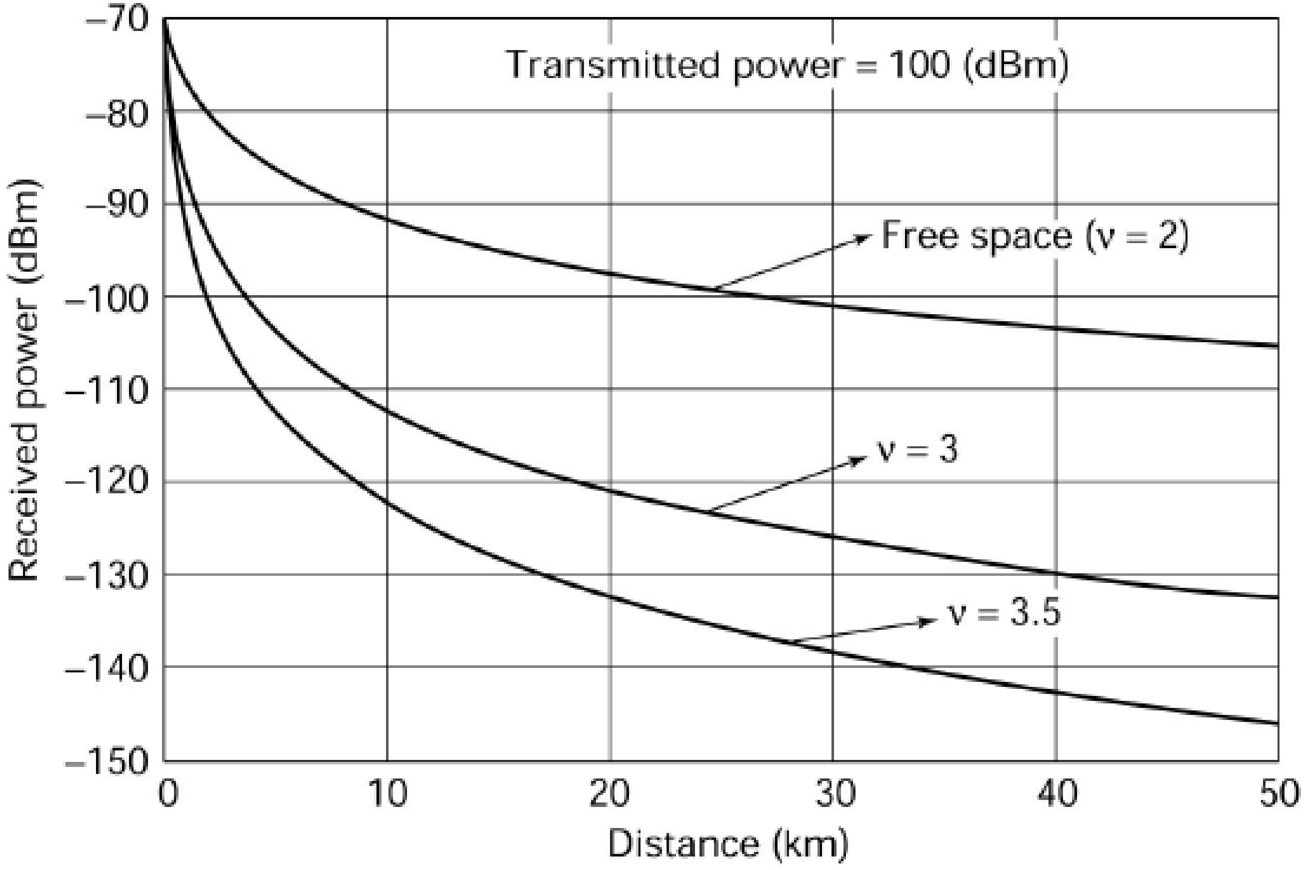
Typical values for urban areas are 3-5

- With reference distance one can write:

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

Attenuation factor

- Received as a function of distance for different values of v:



About channel model

- Models are mathemetical 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 behavior rather most likely behavior of the channel
  - Analytical model: takes into account link specific geometri (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

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

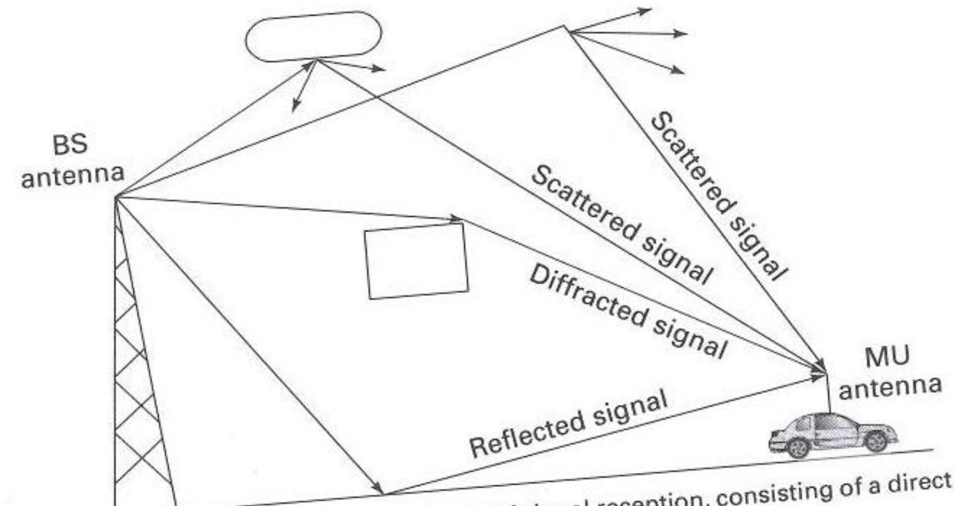


FIGURE 2.10 The most general case of signal reception, consisting of a direct path, a reflected path, a scattered path, and a diffracted path.

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 BTS and MU* (*km*); $d \geq 1\,km$

$h_b =$ *height of the BTS antenna* (*m*)

$h_{mu} =$ *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:

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

- 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:

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

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

$$where\, L_p \text{ } is\ the\ loss\ in\ small-to-medium\ citites.$$

Hata model

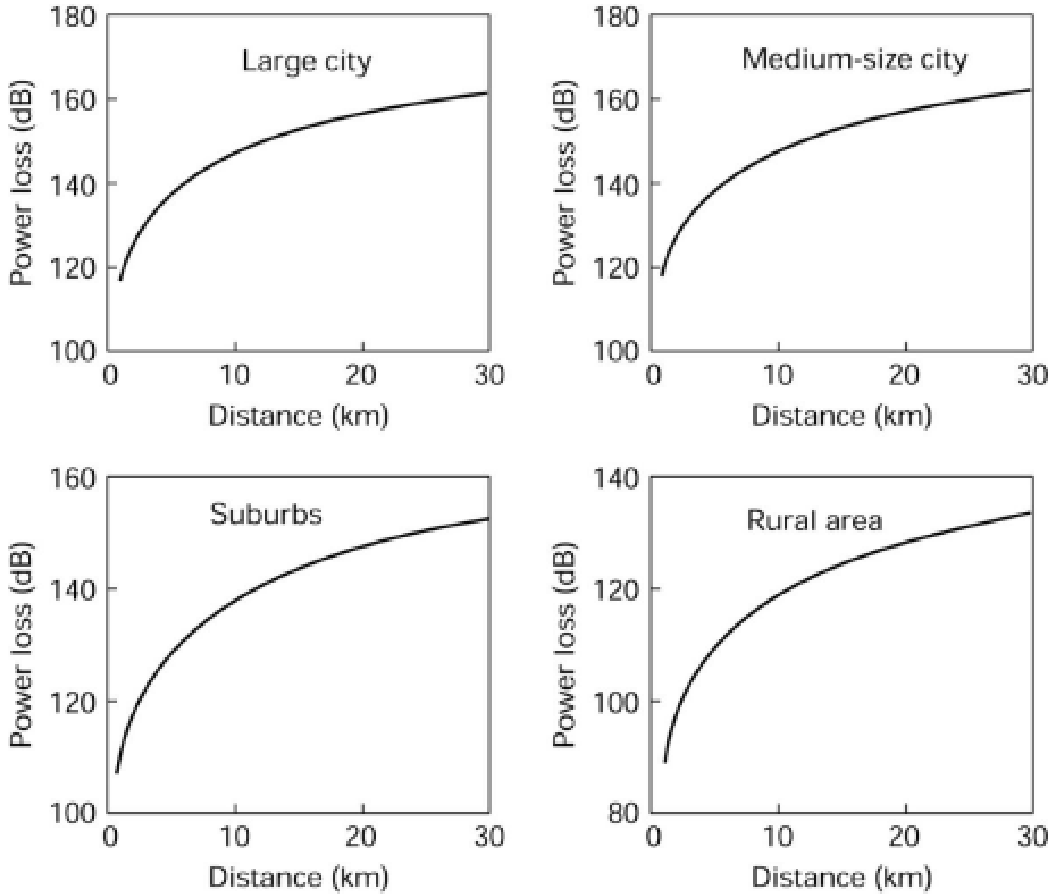


Figure shows loss calculation based on hata model for four different environments given that f_0=900MHz, h_b=150m, h_{mu}=1.5m

Hata model

- COST 231 extension or extension of hata model to PCS (personal communication system):

$$L(dB) = 46.3 + 33.93\log_{10}(f_0) - 13.82\log_{10}(h_b) - a(h_{mu}) + [44.9 - 6.55\log_{10}(h_b)]\log_{10} d - Corr.$$

where

Corr. is the additional correction factor given by

$Corr. = 0\ dB$ *for medium city and suburban areas*

$Corr. = 3\ dB$ *for metropolitan areas*

This model is valid for the following parameter:

$f_0 : 1500 - 2000 MHz$

$h_b : 30 - 200 m$

$h_{mu} : 1 - 10 m$

$d : 1 - 20 km$

Agenda

- Radio wave propagation phenomena
  - Reflection
  - Refraction
  - Diffraction
  - Scattering
- Signal attenuation
  - Attenuation and fading
  - Path loss
  - Hata model
- Indoor propagation
- More on fading

Indoor propagation model

- Models so far presented are not sufficient to predict signals in indoor
- Indoor propagation sees reflect, scatter, and diffract due to walls, ceilings, furnitures 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
- 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:

- Bulding structure is large and heavily populated (e.g. shopping malls)
- A number of BTSs serve the users

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

Agenda

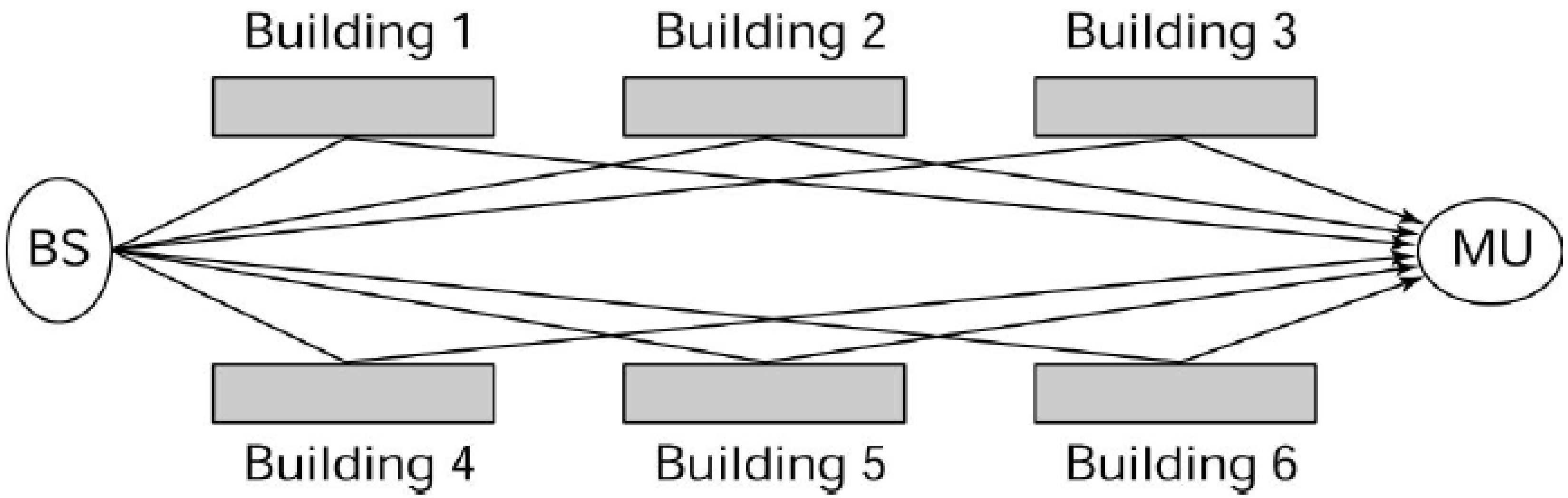
- Radio wave propagation phenomena
  - Reflection
  - Refraction
  - Diffraction
  - Scattering
- Signal attenuation
  - Attenuation and fading
  - Path loss
  - Hata model
- Indoor propagation
- More on fading

Fading

- In addition to propagation loss, attenuation may also fluctuate with position and time
- Propagation fluctuates around mean value
- Fading describes this signal fluctuation around mean value
- Primary cause of fading is signal traversing multiple path
- **Fading can be described in three ways:**
  - Multipath
  - The statistical distribution of the received signal envelope (e.g. Rayleigh)
  - Duration of fading (e.g. long-term, short-term)

Multipath fading

- Signal leaves the transmitting antenna and can take different paths to reach the receiver (due to reflection, deffraction, scattering etc.)



Multipath fading

- Signal components arrive at receive antenna are indepent of each other
  - Hence, signal received at the antenna can be expressed as the vector sum of the signal components
- Assuming Rx stationary & no direct path exists (Tx-Rx), the received signal $e_r(t)$:

$$e_r(t) = \sum_{i=1}^{N} a_i \, p(t - t_i)$$

where

$a_i = \text{amplitude of the received component } i$

$p(t) = \text{transmitted signal shape}$

$t_i = \text{time taken by signal component } i \text{ to reach receiver}$

$N = \text{Number of paths taken by the signal}$

Multipath fading

- Instead of using sum of delayed components, received signal can also showed using phasor notation:

$$e_r(t) = \sum_{i=1}^{N} a_i \cos(2\Pi f_0 t + \phi_i)$$

$$where$$

$$a_i = amplitude\ of\ the\ received\ component\ i$$

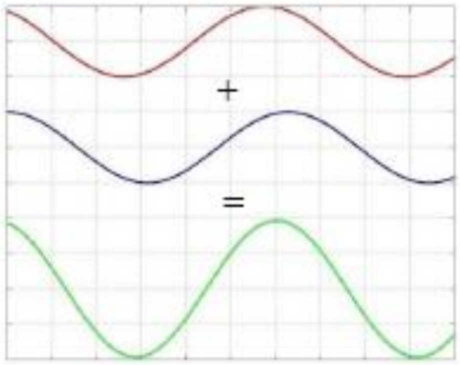
$$f_0 = carrier\ frequency$$

$$\phi_i = Phase\ of\ i^{th}\ signal\ component$$

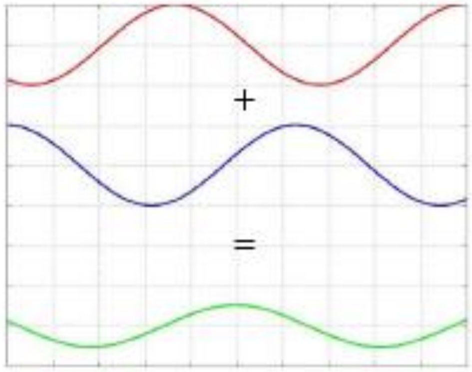
$$N = Number\ of\ paths\ taken\ by\ the\ signal$$

Multipath fading

- Resulting signal is the random summation of different signals (cosine shaped signals)
  - Leads to a random variation depending on the relative phase between signal components
  - Creates constructive and destructive summation



Constructive sum



Destructive sum

Rayleigh

$$e_r(t) = \sum_{i=1}^{N} a_i \cos(2\Pi f_0 t + \phi_i)$$

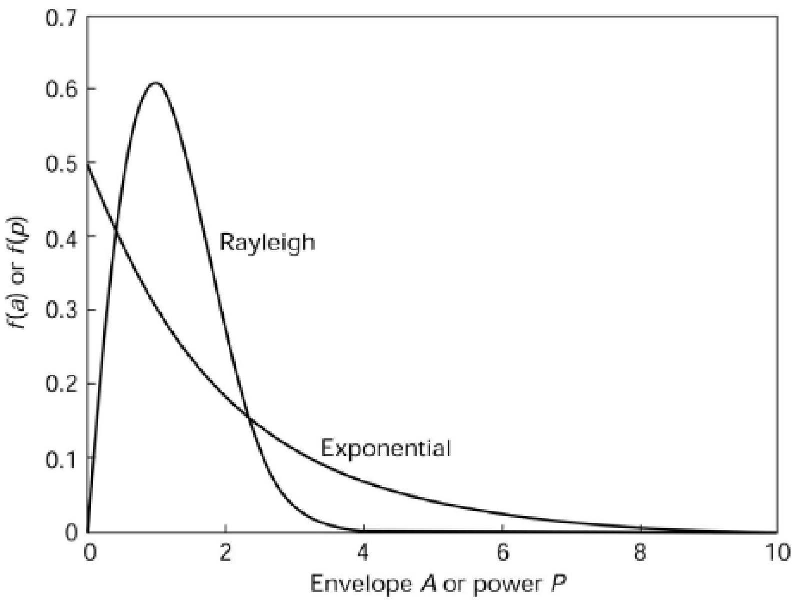
$$= \cos(2\Pi f_0 t) \sum_{i=1}^{N} a_i \cos(\phi_i) - \sin(2\Pi f_0 t) \sum_{i=1}^{N} a_i \sin(\phi_i)$$

$$= X \cos(2\Pi f_0 t) - Y \sin(2\Pi f_0 t)$$

where

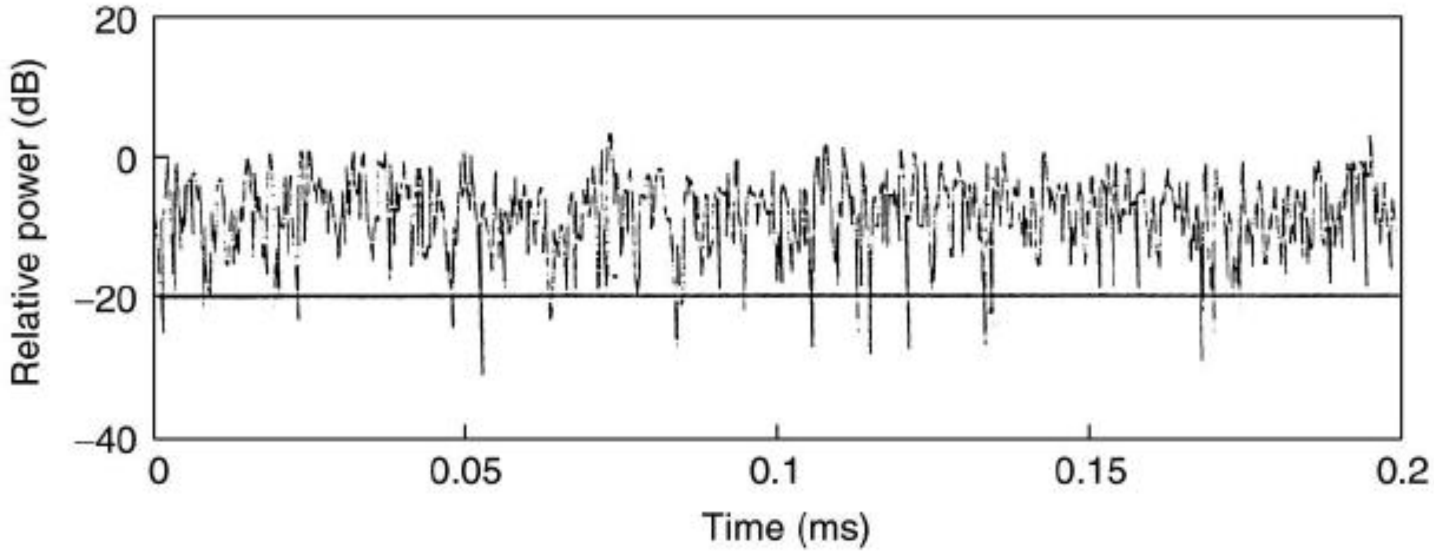
$$X = \sum_{i=1}^{N} a_i \cos(\phi_i), \quad Y = \sum_{i=1}^{N} a_i \sin(\phi_i)$$

- X and Y are independent and identically distributed Gaussian random variable
- Under this condition envelop of the received signal A, given by $(X^2+Y^2)^{1\backslash 2}$, will be Rayleigh distributed



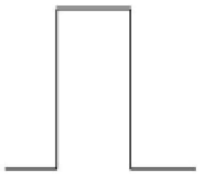
Outage

- Every receiver is designed to operate at an acceptable level only if a certain minimum power, P_{thr}, is being received
- The receiver will be in outage whenever power goes below this threshold value
- Outage is the implication of fading; following system goes into outage if the threshold is set to -20 dB of relative power

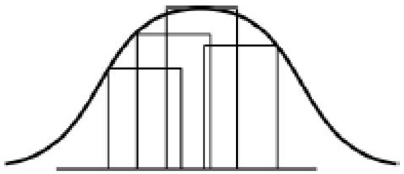


Multipath and Intersymbol interference

- Fading may affect the shape of the received signal pulse
- Figure: four different paths, at the receiver pulse arrives at four different times
- Envelope of the overlapping pulse showed a broadened pulse – leads to intersymbol interference (ISI)



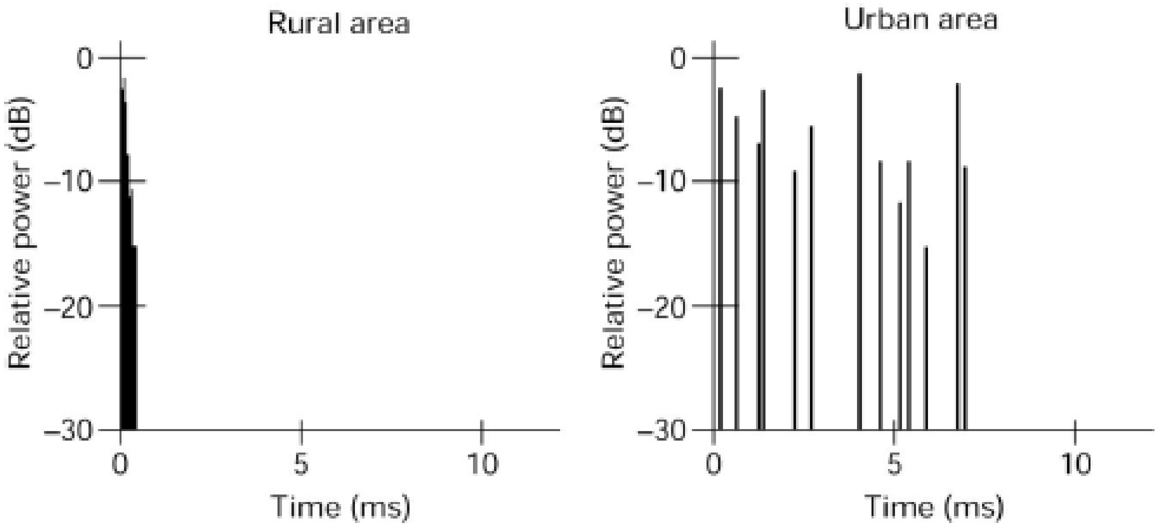
Transmitted pulse



Pulses overlap and result in a broadened pulse

Impulse response

- Impulse corresponding to multiple paths arrive at the receiver at different times and with different power depending on the nature of the channel (e.g. reflection, defraction, scattering etc.)
- These arrival times of signal with different powers can be used to define **the impulse response of the channel**
- Figure:
  - rural areas – due to fewer tall structure, multiple paths are closed to each other
  - Urban areas – multiple paths are more diversed and received signals are spread out



Symbol rate and bandwidth

- There is a direct correlation between symbol rate, R (symbol/s) and information bandwidth, B_s (Hz) in a radio connection:

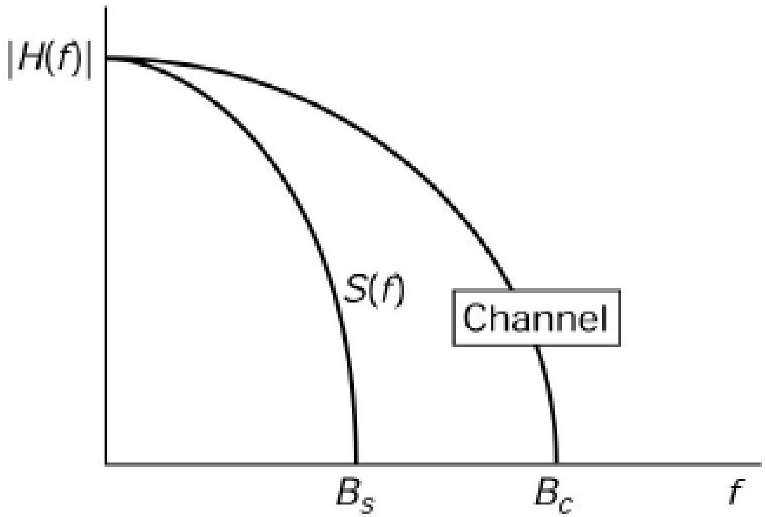
$$R \propto B_s$$

Means,

- High symbol rate (bit rate) -> high bandwidth (broadband)
- Low symbol rate (bit rate) -> low bandwidth (narrowband)

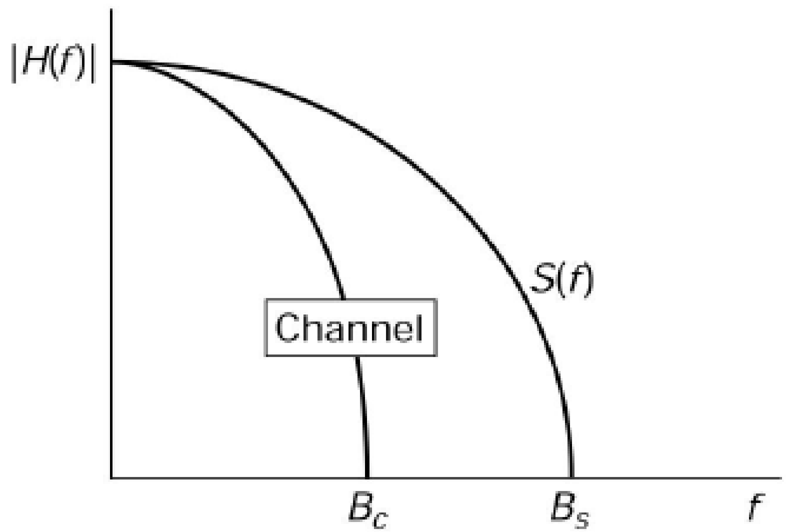
Flat fading channel

- If the channel bandwidth B_c is larger than message bandwidth B_s, all the frequecy components in the message will arrive at the receiver with little or no distortion
- ISI will be neligible
- The channel will be defined as **flat fading channel**
- Rural areas can be characterized as nearly flat fading channel



Frequency selective channel

- If the message bandwidth B_s is larger than channel bandwidth B_c, different frequecy components in the message will arrive at the receiver at different time
- Resulting pulse broadening – ISI
- The channel is classified as **frequency selective channel**
- The flat fading channel can become frequency selective channel if the information is transmitted with higher and higher bandwidth



Doppler effect

- So far, we assumed mobile phone being stationary
- The motion of the mobile unit results a **doppler shift** in the frequency of the received signal
- The maximum doppler shift is expressed as,

$$f_d = f_0 \frac{v}{c}$$

$$\begin{aligned}
&where \\
&c = velocity\ of\ elctromagnetic\ wave\ in\ free\ space \\
&v = velocity\ of\ the\ mobile\ unit\ (m/s) \\
&f_0 = frequency\ of\ the\ signal
\end{aligned}$$

Doppler effect

- Taking all the direction into account, the instantaneous frequency of the doppler shifted signal is:

$$f_{in} = f_0 + f_d \cos(\theta)$$

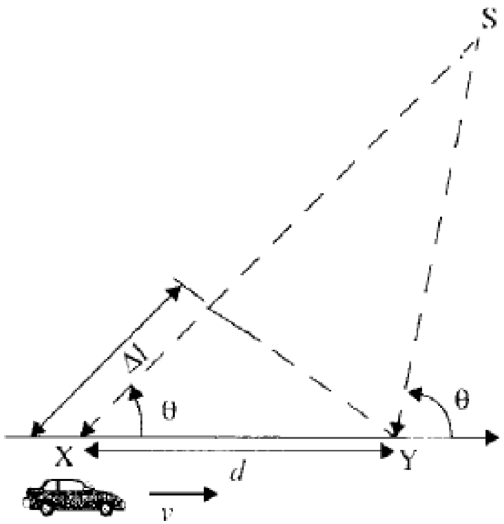


Illustration of Doppler effect.

Doppler effect

This leads to two effects:

- A level of variation at a rate that depends on the speed of the mobile
- A frequency distortion resulting from the doppler shift of the individual multi-path components (arriving at different angle)