Notes

3 Mobile Radio Propagation Model, Small Scale Fading and Diversity

Syllabus

Large scale path loss : - Free Space Propagation loss equation, Path loss of NLOS and LOS systems, Reflection, Ray ground reflection model, Diffraction, Scattering, Link budget design, Max. Distance Coverage formula, Empirical formula for path loss, Indoor and outdoor propagation models, Small scale multipath propagation, Impulse model for multipath channel, Delay spread, Feher's delay spread, upper bound Small scale, Multipath Measurement parameters of multipath channels, Types of small scale Fading, Rayleigh and rician distribution, Statistical for models multipath fading channels and diversity techniques in brief.

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3.1 Introduction to Radio Wave Propagation

- Mobile radio channel is an important controlling factor in wireless communicatio systems.
- Transmission path between transmitter and receiver can vary in complexity.
- Wired channels are stationary and predictable, whereas radio channels are extremely random and have complex models.
- Modeling of radio channels is done in statistical fashion based on measurements for each individual communication system or frequency spectrum.

3.1.1 Problems Unique to Wireless Systems

1. Paths can vary from simple line-of-sight to ones that are severely obstructed by buildings, mountains, and foliage.
2. Radio channels are extremely random and difficult to analyze.
3. Interference from other service providers
   - out-of-band non-linear transmitter emissions
4. Interference from other users (same network)
   a. Co-channel interference (CCI) due to frequency reuse
   b. Adjacent Channel Interference (ACI) due to Tx/Rx design limitations and large users sharing finite BW
5. Shadowing
   - Obstructions to line-of-sight paths cause areas of weak received signal strength
6. Fading
   a. When no clear line-of-sight path exists, signals are received that are reflections off obstructions and diffractions around obstructions
   b. Multipath signals can be received that interfere with each other
   c. Fixed Wireless Channel ? random and unpredictable
      1. Must be characterized in a statistical fashion
      2. Field measurements often needed to characterize radio channel performance
7. The Mobile Radio Channel (MRC) has unique problems that limit performance
   a. A mobile receiver in motion influences rates of fading :
      - The faster a mobile moves, the more quickly characteristics change

3.2 Propagation Models

1. Large scale propagation models

- To predict the average received signal strength over large transmitter-receiver (T-R) separation distances (Several hundreds or thousands of meters).
- Typically, the local average received power is computed by averaging signal measurements over a measurement track of 5 to 40 wavelengths.

2. Small scale propagation models (or fading models)

- To characterize the rapid fluctuations of the receiver signal strength over very short distances (a few wavelengths) or short time durations (on the order of seconds).
- In small scale fading, the received signal power may vary by as much as three to four orders of magnitude (30 to 40 dB).
- Fig. 3.2.1 shows small-scale and large-scale fading.

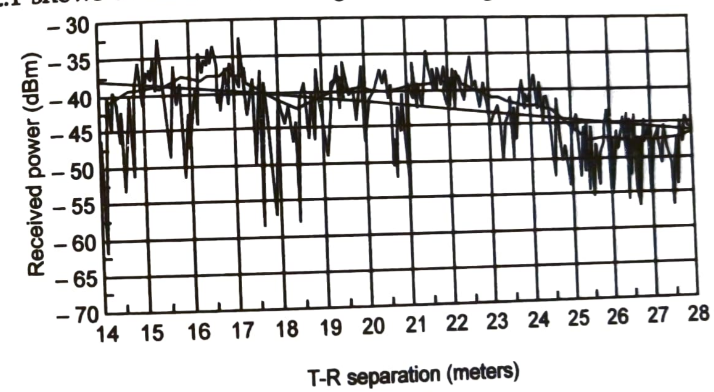

Fig. 3.2.1

- The smoothed line is the average signal strength. The actual is the more jagged line.
- Actual received signal strength can vary by more than 20 dB over a few centimeters.
- The average signal strength decays with distance from the transmitter, and depends on terrain and obstructions.
- Two basic goals of propagation modeling :
  1. Predict magnitude and rate (speed) of received signal strength fluctuations over short distances/time durations. Short typically refers to a few wavelengths (λ) or seconds at 1 GHz,

$$\lambda = c / f = 3 \times 10^8 / 1 \times 10^9 = 0.3 \text{ meters}$$

At this distance, received signal strength can vary drastically by 30 to 40 dB.

- Small-scale fluctuations caused by received signal coming from a sum of many signals coming together at a receiver.
- Multiple signals come from reflections and scattering. These signals can destructively add together by being out-of-phase.

2. Predict average received signal strength for given Tx/Rx separation.

- To characterize received signal strength over distances from 20 m to 20 km. Large-scale radio wave propagation model needed to estimate coverage area of base station.
- In general, large scale path loss decays gradually with distance from the transmitter will also be affected by geographical features like hills and buildings.

3.3 Free-Space Propagation Model

GTU : Summer-15, Winter-15

Path-loss Gradient

- In most environments, the radio signal strength falls as some power α of the distance called as power distance gradient or path-loss gradient.
- The signal strength is proportional to $P_t \, d^{-\alpha}$, where P_t is transmitted power and d is distance in meters.
- When an antenna radiates signal in all direction, the signal strength density at a sphere of radius d is the total radiated signal strength divided by the area of the sphere ($4 \pi d^2$). Also, there are losses dependent on frequency.
- The relation between transmitted power (P_t) and received power (P_r) is given by :

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

where,

G_t = Transmitter antenna gain in the direction from transmitter to receiver

G_r = Receiver antenna gain

d = Distance between transmitter and receiver

λ = Wavelength of carrier

- By the Friis free space equation :

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

Where; L is system loss factor not related to propagation (L >=1)

- Received power at a distance d is given by -

$$P_r(d) \text{ dBm} = 10 \log \left[\frac{P_r(d_0)}{0.001\text{W}} \right] + 20 \log \left(\frac{d_0}{d} \right) \qquad d \geq d_0 \geq d_f$$

3.3.1 Two Ray Model of Mobile Environment

- In free space, the signal travels from the transmitter to receiver along the single path but in realistic environment, the signal reaches the receiver through several different paths.
- The two-ray model is shown in Fig. 3.3.1.

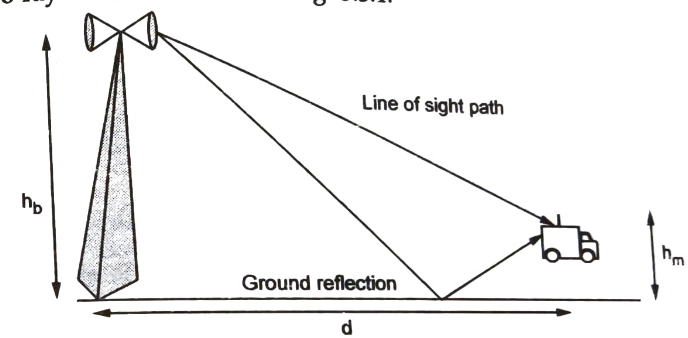

Fig. 3.3.1 Two-ray model

- The Line of Sight (LOS) component between base station and mobile terminal carries the signal similar to as in free space.
- Another path of signal is through the reflection off the earth's surface. These two paths travel different distances based on height of base station antenna (h_b) and height of mobile terminal antenna (h_m).
- At receiver these two signals and added constructively or destructively. The relation between transmit power for two-ray model can be approximated by expression :

$$P_r = P_t G_t G_r \frac{h_b^2 h_m^2}{d^4}$$

- It can be observed that the signal strength falls as the fourth power of distance (d) between the transmitter and receiver. In other words, there is a loss of 40 dB per decade or 12 dB per octave.

Solved Examples

Example 3.3.1 *If a transmitter produces 50 W of power, express the transmit power in units of (i) dBm and (ii) dBW. If 50 W is applied to a unity gain antenna with a 900 MHz carrier frequency, find the received power in dBm at a free space distance of 100 m from the antenna. What is P_r(10 km)? Assume unity gain for the receiver antenna.*

GTU : Summar-15; Winter-15, Marks 7

Solution : Given : $P_t = 50$ W; $f_c = 900$MHz

$$\text{Transmitter power } P_t(\text{dBm}) = 10\log\left[\frac{P_t(\text{mW})}{1\text{ mW}}\right] = 10\log[50\times10^3] = 47\text{ dBm}$$

$$\text{Transmitter power } P_t\text{ (dBW)} = 10\log\left[\frac{P_t(\text{W})}{1\text{ W}}\right] = 10\log[50] = 17\text{ dBW}$$

Received Power at 100 meters :

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} = \frac{50(1)(1)(1/3)^2}{(4\pi)^2(100)^2(1)}$$

$$= 3.5\times10^{-6}\text{ W} = 3.5\times10^{-3}\text{ mW}$$

$$P_r(\text{dBmM}) = 10\log P_r(\text{mW})$$

$$P_r(100\text{ m}) = 10\log(3.5\times10^{-3}\text{ mW}) = \mathbf{-24.5\ dBm} \qquad \text{... Ans.}$$

The received power at 10 km can be expressed in terms of dBm using equation

$$P_r(d)\text{ dBm} = 10\log\left[\frac{P_r(d_0)}{0.001\text{W}}\right] + 20\log\left(\frac{d_0}{d}\right) \qquad d \ge d_0 \ge d_f$$

where $d_0 = 100$ m and $d = 10$km

$$P_r(10\text{ km}) = P_r(100) + 20\log\left[\frac{100}{10000}\right]$$

$$= -24.5\text{ dBm} - 40\text{ dB} = \mathbf{-64.5\ dBm} \qquad \text{... Ans.}$$

Example 3.3.2 *Assume a receiver located 10 km from a 50 W transmitter. The carrier frequency is 900 MHz. Free space propagation is assumed. $G_t = 1$ and $G_r = 2$. Find :*

1) The power at the receiver.

2) The magnitude of E field at the receiver antenna.

3) The rms voltage applied to the receiver input assuming that the receiver antenna has a purely real impedance of 50 Ω and is matched to the receiver. **GTU : Winter-15, Marks 7**

Solution : Given :

Transmitter power, $P_t = 50$ W

Carrier frequency, $f_c = 900$ MHz

Transmitter antenna gain, $G_t = 1$

Receiver antenna gain, $G_r = 2$

Receiver antenna resistance $= 50\ \Omega$

1) The power received at a distance d = 10 km is given by equation:

$$P_r(d) = 10\log\left(\frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2}\right)$$

$$= 10\log\left(\frac{50\times1\times(1/3)^2}{(4\pi)^2 10000^2}\right)$$

$$= -91.5\text{ dBW} = \mathbf{-61.5\ dBm} \qquad \text{... Ans.}$$

2) The magnitude of the received E-field is given by equation:

$$|E| = \sqrt{\frac{P_r(d)\,120\pi}{A_e}} = \sqrt{\frac{P_r(d)\,120\pi}{G_t\lambda^2/4\pi}}$$

$$= \sqrt{\frac{7\times10^{-10}\times120\pi}{2\times0.33^2/4\pi}} = \mathbf{0.0039\ V/m} \qquad \text{... Ans.}$$

3) The open circuit rms voltage at the receiver input is given by equation:

$$V_{ant} = \sqrt{P_r(d)\times4R_{ant}}$$

$$= \sqrt{7\times10^{-10}\times4\times50} = \mathbf{0.374\ mV} \qquad \text{... Ans.}$$

University Question

1. *With necessary equations explain free space propagation model in detail.* **GTU : Winter-15, Marks 7**

3.4 Basic Radio Propagation Mechanism **GTU : Winter-14,15, Summer-16**

- The radio propagation can be explained by three basic mechanisms :
  1. Reflection and transmission
  2. Diffraction
  3. Scattering.

3.4.1 Reflection and Transmission

- Reflection occurs when electromagnetic wave impinges on object larger than the wavelength λ. The electromagnetic wave bounces off the object. Examples : Walls, buildings, ground.
- The electromagnetic signal is attenuated by a reflection factor. Attenuation depends on -
  1. Nature of material
  2. Frequency of the carrier
  3. Angle of incidence
  4. Nature of the surface.
- Usually transmission through an object leads to larger losses (absorption) than reflection. Multiple reflections can result in a weak signal.

3.4.2 Diffraction

- Diffraction occurs when radio wave is incident upon the edge of a sharp object. Examples : Wall, roof edge, door.
- Each such object becomes a secondary source of emission. In this case, the losses are much larger than with reflection or transmission.
- Diffraction is important in micro-cells for non-line of sight transmission i.e. propagation into shadowed regions.
- Diffraction is not significant in indoor areas because of large losses in diffracted signal.

3.4.2.1 Fresnel Zone Symmetry

- For reliable Line of Sight (LOS) communication, the path between transmitter and receiver must be free of obstruction (clear). It gives minimum or negligible multipath reception. This is called fresnel zone clearance.
- The Fresnel zone concept says that any small element of zone in the LOS path of electromagnetic wave may be considered as the source of secondary wavelet and radiated field may be built up by algebric sum of these wavelets.
- There are series of concentric circles around the direct LOS path between transreceiver. Any obstacle in first circle produce adverse effects.
- Let an obstacle in LOS path between transmitter and receiver as shown in Fig. 3.4.1.

d_1 is distance between transmitter and obstacle.

d_2 is distance between receiver and obstacle.

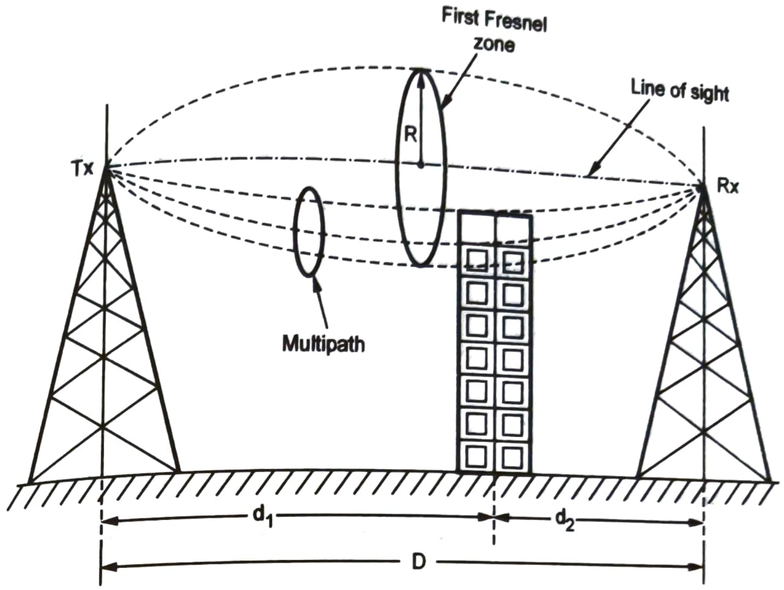

Fig. 3.4.1 First Fresnel zone clearance

- The radius 'R' of first Fresnel zone clearance is given by :

$$R = \sqrt{\frac{\lambda d_1 d_2}{(d_1 + d_2)}} \qquad \because d_1 + d_2 = D$$

$$R = \sqrt{\frac{\lambda d_1 (D - d_1)}{D}}$$

where,

R is radius of first Fresnel zone in meters

D is total distance between Tx and Rx

λ is wavelength of signal in meters

- From experiments, it is found that if there is no obstacle within 0.6 times the radius of first Fresnel zone then there will be negligible signal attenuation. Therefore, height of transreceiver is kept such that no obstacle along the LOS path within 0.6 times of the radius of first Fresnel zone.
- Three special cases of Fresnel zone clearance.

1. Hyper reflectivity

- Hyper-reflectivity may occur in wave propagation over water, metal, objects and large flat surfaces, this is the reason why additional path clearance is required.

2. Bending

- The dielectric permittivity varies with height over the earth so bending occurs. If the effective earth radius is $\frac{4}{3}$ times the actual earth radius i.e. $K = \frac{4}{3}$, then sig gets bent downward. This condition is called **Earth Buldge**.
- For K = 1, the earth is completely flat and signal travels in a straight line.
- For $K = \frac{2}{3}$, signal bents upward and may cause interference at longer distance.

The Fresnel zone clearance for different value of K is given by,

$$R \geq \frac{d_1 d_2}{2} \quad ; \quad \text{for } K = \frac{4}{3}$$

$$R \geq d_1 d_2 \quad ; \quad \text{for } K = \frac{2}{3}$$

3. Microwave Antenna Location

- The antenna location may cause reception even though it is mounted at a height

Solved Examples

Example 3.4.1 *A general design rule for microwave links is to have 55% clearance of the first Fresnel zone. For a 1 km link at 2.5 GHz, what is the maximum first Fresnel zone radius ? What clearance is required for this system ?* **GTU : Winter-14; Marks 7**

Solution :

$$r_n = \sqrt{\frac{n\lambda d_1 d_2}{d_1 + d_2}} \text{ to maximizer } r_w \text{ maximize } \frac{d_1 d_2}{d_1 + d_2} = \frac{d_1(1000 - d_1)}{1000}$$

To maximize this, get its derivative with respect to d_1 and equate it with zero.

$$\frac{d}{d_1}\left(\frac{d_1(1000-d_1)}{1000}\right) = 0$$

$$\frac{1000-d_1}{1000} + \frac{d_1(-1)}{1000} = 0$$

$$\frac{1000-d_1-d_1}{1000} = 0$$

$$1 - \frac{2d_1}{1000} = 0$$

$$\frac{2d_1}{1000} = 0$$

$$d_1 = 500 \text{ m} \rightarrow d_2 = 500 \text{ m}$$

$$r_{n,\,max} = \sqrt{\frac{1 \times 0.12 \times 500 \times 500}{1000}} = 5.477 \text{ m } (\lambda = 0.12)$$

$$\text{Clearance} = 5.477 \times \frac{55}{100} = \mathbf{3.012\ m}$$

... **Ans.**

Example 3.4.2 *In a two-ray ground reflection model, assume that phase difference must be kept below 6.261 radians for phase cancellation reasons. Assuming a receiver height of 2 m, and given a requirement that angel of incidence must be less than 5°, what are the minimum allowable values for the Transmitter-Receiver separation distance and the height of the transmitter antenna? Take the carrier frequency as 900 MHz.* **GTU : Winter-14; Marks 7**

Solution : Condition 1 : $\theta_\Delta < 6.26$

$$\theta_\Delta = \Delta\frac{2\pi}{\lambda} = \frac{2h_t h_r}{d} \times \frac{2\pi}{\lambda} < 6.26$$

$$\frac{h_t}{d_{min}} = \frac{6.26 \times \lambda}{4\pi h_r} = \frac{6.26 \times \frac{3\times 10^8}{900 \times 10^6}}{4\pi \times 2} = \frac{313}{1200\pi}$$

$$h_t = \frac{313}{1200\pi} \times d_{min}$$

$$\boxed{h_t = \frac{313}{1200\pi} \times d_{min}} \quad \ldots (1)$$

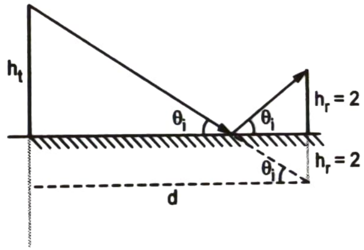

Fig. 3.4.2

Condition 2 : $\theta_t < 5°$

From the geometry :

$$\tan\theta_i = \frac{h_t + h_r}{d}$$

$$\tan\theta_i < \tan 5°$$

$$\frac{h_t + 2}{d} < \tan 5°$$

$$\frac{h_t + 2}{d_{min}} = \tan 5°$$

$$d_{min} \times \tan 5 = h_t + 2$$

$$\boxed{h_t = d_{min} \times \tan 5 - 2} \quad \ldots (2)$$

Equating equations (1) and (2)

$$d_{min} \times \tan 5 - 2 = \frac{313}{1200\pi} \times d_{min}$$

$$d_{min} \times \tan 5 - \frac{313}{1200\pi} \times d_{min} = 2$$

$$d_{min} = \frac{2}{\tan 5 - \frac{313}{1200\pi}} = \mathbf{448.146\ m} \quad \text{... A}$$

$$h_t = \frac{313}{1200\pi} \times 448.146 = \mathbf{37.208\ m} \quad \text{... A}$$

3.4.2.2 Knife-Edge Diffraction Model

- Knife-edge diffraction model is one of the simplest diffraction model to estim the diffraction loss. It considers the object like hill or mountain as a knife ed sharp object. The electric field strength, E_d of a knife-edge diffracted wave is giv by :

$$E_d / E_0 = F(v) = (1+j)/2 \int_v^{\infty} (\exp((-j\pi t^2)/2)dt$$

The diffraction gain due to presence of knife edge can be given as

$$G_d(db) = 20\log|F(v)|$$

$$G_d(db) = 0v <= -1$$

$$G_d(db) = 20\log(0.5 - 0.62) - 1 <= v <= 0$$

$$G_d(db) = 20\log(0.5\exp(-0.95v)) \quad 0 <= v <= 1$$

$$G_d(db) = 20\log(0.4 - \text{sqrt}(0.1184 - (0.38 - 0.1v^2))) \quad 1 <= v <= 2.4$$

$$G_d(db) = 20\log(0.225/v) \quad v > 2.4$$

- When there are more than one obstruction, then the equivalent model can found by one knife-edge diffraction model as shown in Fig. 3.4.3.

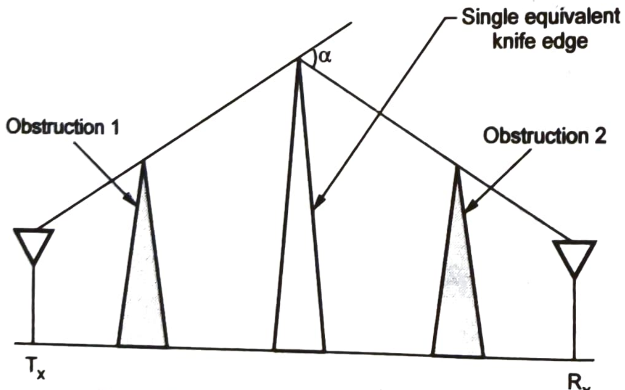

Fig. 3.4.3 Knife-edge diffraction model

3.4.3 Scattering

- Scattering is caused by irregular objects comparable in size to the wavelength. These objects scatter rays in all directions. Each scatterer acts as a source resulting in -
  1. Signal propagates in all directions 2. Large losses in signal strength
  3. Insignificant except when the transceiver is in very cluttered environments
- Examples of scatterers : Foliage, furniture, lampposts, vehicles.
- Fig. 3.4.4 and Fig. 3.4.5 illustrates all three mechanisms for outdoor and indoor applications.

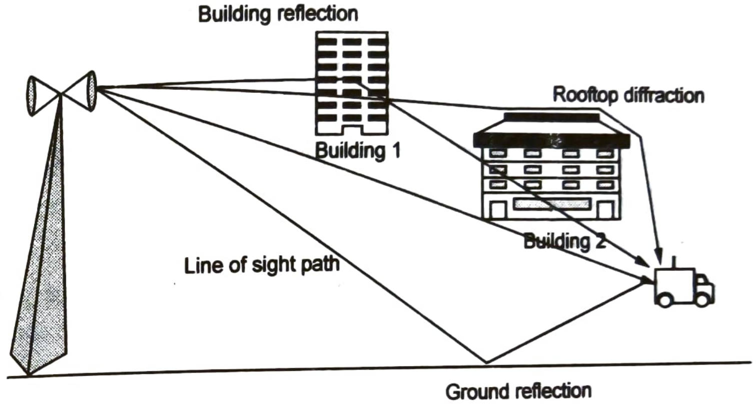

Fig. 3.4.4 Radio propagation mechanisms in an outdoor area

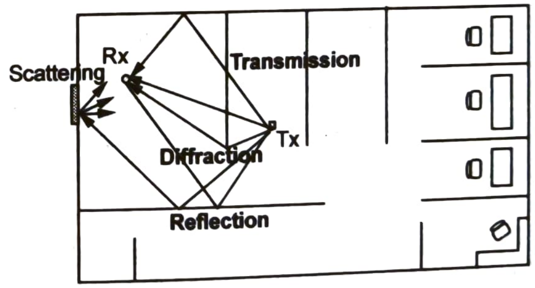

Fig. 3.4.5 Radio propagation mechanisms in an indoor area

University Questions

1. *What is a Fresnel Zone ?* **GTU : Winter-14, Marks 3**
2. *With figure explain Knife-edge diffraction model in detail. Write the equation for diffraction gain.* **GTU : Winter-15, Marks 7**
3. *Enumerate various radio propagation model and explain any two of them.* **GTU : Summer-16, Marks 7**

3.5 Link Budget Analysis

GTU : Summer-1

3.5.1 Path Loss Modelling and Signal Coverage

- Path-loss models are commonly used to estimate link budgets, cell sizes a shapes, capacity, handoff criteria etc.
- The path-loss models used to estimate macroscopic or large scale variation Received Signal Strength (RSS).

Path-loss = Loss in signal strength as a function of distance

- Path loss is :
  1. Terrain dependent (urban, rural, mountainous), ground reflection, diffracti etc.
  2. Site dependent (antenna heights for example)
  3. Frequency dependent
  4. Line of sight or not
- By path-loss models, radio engineers calculate the coverage area of wireless b stations and Access Points (APs) also the maximum distance between t terminals in ad-hoc networks.

3.5.2 Log-distance Path Loss Model

- According to this model the received power at distance d is given by

$$PL(d)\left(\frac{d}{d_0}\right)^n \Rightarrow \overline{PL}\,(dB) = \overline{PL}\,(d_0) + 10\ n\log\left(\frac{d}{d_0}\right)$$

- The value of n is called as **path loss exponent** and it varies with propagati environments. The value of n is 2 for free space. The value of n varies from 4 to for obstruction of building, and 3 to 5 for urban scenarios.
- The important factor is to select the correct reference distance d_0. For large c area it is 1 Km, while for micro-cell system it varies from 10m-1m.

Limitations :

- Surrounding environmental clutter may be different for two locations having t same transmitter to receiver separation. Moreover it does not account for t shadowing effects.

3.5.3 Log Normal Shadowing

- The equation for the log normal shadowing is given by,

$$PL\,(dB) = \overline{PL}\,(dB) + X_\sigma = \overline{PL}\,(d_0) + 10n\log\left(\frac{d}{d_0}\right) + X_\sigma$$

Where X_σ is a zero mean Gaussian distributed random variable in dB with standard deviation σ also in dB. In practice n and σ values are computed from measured data.

Average received power

- The 'Q' function is given by,

$$Q(z) = 0.5\left(1-\text{erf}\left(\frac{z}{\sqrt{2}}\right)\right)$$

$$Q(z) = 1 - Q(-z)$$

- So the probability that the received signal level (in dB) will exceed a certain value γ is:

$$P(P_d > \gamma) = Q\left(\frac{\gamma - \overline{P_r}}{\sigma}\right)$$

University Question

1. *Describe empirical formula for path loss in mobile networks.* GTU : Summer-16, Marks 7

3.6 Outdoor Propagation Models

GTU : Summer-15

- There are many empirical outdoor propagation models such as Longley-Rice model, Durkin's model, Okumura model, Hata model etc.
- Longley-Rice model is the most commonly used model within a frequency band of 40 MHz to 100 GHz over different terrains.
- Certain modification over the basic model like an extra urban factor (UF) due to urban clutter near the reciever is also included in this model.

3.6.1 Longley-Rice/ITS Irregular Terrain Model

- The Longley-Rice model is valid for frequency range of 40 MHz to 60 GHz.
- Techniques used for Longley model are:
  1. Geometric optics (i.e., 2-ray ground-reflection model)
  2. Knife-edge diffraction

3. Far-field scatter
4. Van der Pol-Bremmer far-field diffraction

- Modes of operation used for Longley-Rice model:
  1. Point-to-point mode : uses detailed terrain path profile
  2. Area mode : estimates path-specific parameters

3.6.2 Okumura Model

- The Okumura model is used for Urban Areas is a Radio propagation model that used for signal prediction. The frequency coverage of this model is in the range of 200 MHz to 1900 MHz and distances of 1 km to 100 km.
- It can be applicable for base station effective antenna heights (ht) ranging from 30 m to 1000 m.
- Okumura used extensive measurements of base station-to-mobile signal attenuation throughout Tokyo to develop a set of curves giving median attenuation relative to free space (A_{mu}) of signal propagation in irregular terrain.
- The empirical pathloss formula of Okumura at distance d parameterized by the carrier frequency f_c is given by:

$$\boxed{P_L(d)dB = L(f_c, d) + A_{mu}(f_c, d) - G(h_t) - G(h_r) - G_{AREA}}$$

Where, $L(f_c, d)$ is free space path loss at distance d and carrier frequency f_c,

$A_{mu}(f_c, d)$ is the median attenuation in addition to free-space path loss across all environments,

$G(h_t)$ is the base station antenna height gain factor,

$G(h_r)$ is the mobile antenna height gain factor,

G_{AREA} is the gain due to type of environment.

- The values of $A_{mu}(f_c, d)$ and G_{AREA} are obtained from Okumura's empirical plots. Okumura derived empirical formulas for $G(h_t)$ and $G(h_r)$ as follows:

$$G(h_t) = 20 \log_{10}(h_t/200), \quad 30m < h_t < 1000m$$

$$G(h_r) = 10 \log_{10}(h_r/3), \quad h_r \leq 3m$$

$$G(h_r) = 20 \log_{10}(h_r/3), \quad 3m < h_r < 10m$$

- Correlation factors related to terrain are also developed in order to improve the models accuracy. Okumura's model has a 10-14 dB empirical standard deviation between the path loss predicted by the model and the path loss associated with one of the measurements used to develop the model.

3.6.3 Hata Model

- The Hata model is an empirical formulation of the graphical path-loss data provided by the Okumura and is valid over roughly the same range of frequencies, 150-1500 MHz.
- This empirical formula simplifies the calculation of path loss because it is closed form formula and it is not based on empirical curves for the different parameters.
- The standard formula for empirical path loss in urban areas under the Hata model is

$$\boxed{\begin{aligned} P_{L,\,urban}(d)dB &= 69.55 + 26.16 \log_{10}(f_c) - 13.82 \log_{10}(h_t) - a(h_r) \\ &\quad + (44.9 - 6.55 \log_{10}(h_t) \log_{10}(d) \end{aligned}}$$

- The parameters in this model are same as in the Okumura model, and $a(h_r)$ is a correction factor for the mobile antenna height based on the size of coverage area. For small to medium sized cities this factor is given by-

Where,

f_c in MHz : $150 < f_c < 1500$ MHz

h_b in meters - base station antenna height : $30 < h_b < 200$ m

h_m in meters - mobile antenna height : $1 < h_m < 10$ m

d in kilometers - distance : $1 < d < 20$ km

- The correction factor for the mobile antenna height is given by

1. Small-medium city :

$$a(h_m) = (1.1 \log f_c - 0.7)\, h_m - (1.56 \log f_c - 0.8)$$

2. Large city :

$$a(h_m) = 8.29 (\log 1.54\, h_m)^2 - 1.1, \quad f_c \leq 200 \text{ MHz}$$

$$a(h_m) = 3.2 (\log 11.75\, h_m)^2 - 4.97, \quad f_c \leq 400 \text{ MHz}$$

3. For a suburban area :

$$L_p = L_p(\text{Urban}) - \left[2\log\left[\frac{f_c}{28}\right]^2 - 5.4\right]$$

For an open area :

$$L_p = L_p(\text{Urban}) - 4.78 (\log f_c)^2 + 18.33 \log f_c - 40.94$$

- Unlike the Okumura model, the Hata model does not provide for any specific path correlation factors. The Hata model well approximates the Okumura model for distances d > 1 km. Hence it is a good model for first generation cellular systems, but it does not model propogation well in current cellular systems with smaller cell sizes and higher frequencies. Indoor environments are also not captured by the Hata model.

University Question

1. *Which are commonly used wireless propagation models? How do they differ ?*

GTU : Summer-15, Marks 7

3.7 Indoor Propagation Models

- The indoor radio channel differs from the traditional mobile radio channel in ways the distances covered are much smaller, and the variability of the environment is much greater for smaller range of Tx-Rx separation distances.
- Features such as lay-out of the building, the construction materials, and the building type strongly influence the propagation within the building.
- Indoor radio propagation is dominated by the same mechanisms as outdoor reflection, diffraction and scattering with variable conditions. In general, indoor channels may be classified as either line-of-sight or obstructed.

3.7.1 Path-Loss Models for Microcellular Areas

- The microcellular area spans from 100 meters to few of kilometres. These are usually supported by base station height which is approximately equals to roof tops or lampposts.
- The propagation characteristics are quite complex with the propagation of signals affected by reflection from buildings, grounds and scattering from vehicles.

3.7.2 Path-Loss Models for Picocellular Indoor Areas

- The picocells are radio cells covering buildings or parts of buildings. The picocell spanning between 30 and 100 m.
- The applications of picocells are : WLANs, wireless PBX, PCS

3.7.3 Multifloor Attenuation Model

- Multifloor attenuation model is expressed as -

$$L_p = L_0 + nF + 10 \log(d)$$

where,

F is signal attenuation per floor.

L_0 is the path-loss at first meter.

d is distance in meters.

n is number of floors.

- Typical values for F = 10 dB and 16 dB for measurements at 900 MHz and 1.7 GHz, respectively.
- Furniture objects cause shadowing approximately of 4 dB.

3.7.4 Path-Loss Models for Femtocellular Area

- The femtocellular area span is between 2 and 10s of meters.
- The femtocells exist in individual residences using low power devices for applications : bluetooth, home RF. Since femtocells are usually deployed in residential areas, JTC model may apply to predict the coverage of femtocell at 1.8 GHz. For operation at 2.4 GHz and 5 GHz (unlicensed bands) -

$$L_p = L_0 + 10 \alpha \log(d)$$

where,

L_0 is the path-loss at first meter.

d is distance in meters.

α is the path-loss exponent.

- Selected measurements of indoor path loss models are shown in Table 3.7.1.

f_c (GHz)	Environment	Scenario	Path Loss at d = 1 m (dB)	Path loss gradient α
2.4	Indoor office	LOS	41.5	1.9
		NLOS	37.7	3.3
5.1	Meeting room	LOS	46.6	2.22
		NLOS	61.6	2.22
5.2	Suburban residences	LOS and same floor	47	2 to 3
		NLOS and same floor		4 to 5
		NLOS and room in the higher floor directly above Tx		4 to 6
		NLOS and room in the higher floor not directly above the Tx		6 to 7

Table 3.7.1 Path-loss models for femtocells at 2.4 GHz, 5.1 GHz and 5.2 GHz

3.8 Small-Scale Multipath Propagation

GTU : Winter-15

- Radio waves arrive at the receiver from different directions with different delays. At the receiver antenna they combine via vector addition.
- Received signal level varies (10s of dBs) due to short-term (rapid) variations and long-term (slow) variations.

Fading

- The term **fading or small-scale fading**, means rapid fluctuations of the amplitudes, phases, or multipath delays of a radio signal over a short period or short travel distance. This might be so severe that large scale radio propagation loss effects might be ignored.

3.8.1 Multipath Fading Effects

- Rapid fluctuation is caused by three important effects:
  1. **Rapid changes in signal strength over a small travel distance or time interval.**
  2. **Random frequency modulation due to varying Doppler shifts on different multipath signals** - Movement of mobile terminal toward or away from the base station transmitter is called as **Doppler.**
  3. **Time dispersion caused by multipath propagation delays** - Addition of signals arriving via different paths called as **multipath fading.**

3.8.2 Factors Influencing Fading

- The following physical factors influence small-scale fading in the radio propagation channel:

(1) Multipath propagation

- Multipath is the propagation phenomenon that results in radio signals reaching the receiving antenna by two or more paths.
- The effects of multipath include constructive and destructive interference, and phase shifting of the signal.

(2) Speed of the mobile

- The relative motion between the base station and the mobile results in random frequency modulation due to different doppler shifts on each of the multipath components.

(3) Speed of surrounding objects

- If objects in the radio channel are in motion, they induce a time varying Doppler shift on multipath components.

- If the surrounding objects move at a greater rate than the mobile, then this effect dominates fading.

Transmission Bandwidth of the signal

- If the transmitted radio signal bandwidth is greater than the "bandwidth" of the multipath channel (quantified by coherence bandwidth), the received signal will be distorted.

3.8.3 Doppler Effect

- Doppler effect implies that the frequency of a wave when transmitted by a source is not necessarily the same as the frequency of the transmitted wave when picked up by a receiver.
- The received frequency depends upon the relative motion between the transmitter and receiver.
- If the transmitter and receiver both are moving towards each other, the received frequency is higher. This is true even if one is moving. If they are moving apart, the received signal frequency decreases. If both are stationary, the frequency remains the same. This change in frequency is known as **Doppler shift.**
- Doppler shift depends upon the relative velocity between the two.

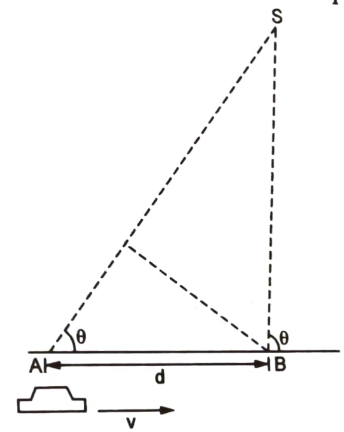

Fig. 3.8.1 Doppler effect

Doppler shift is given by $f_d = \frac{1}{2\pi}\frac{\Delta\phi}{\Delta t} = \frac{v}{\lambda}\cos\theta$

- The difference in path length $= \Delta l = v\,\Delta t\cos\theta$
- The phase change in the received signal due to the difference in path lengths is given by:

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

- The Doppler frequency is a function:
  1. The mobile velocity.
  2. The spatial angle between the direction of motion of the mobile and the direction of arrival of the wave.
  3. The wavelength of the signal.

Solved Example

Example 3.8.1 *Consider a transmitter which radiates a sinusoidal carrier frequency of 1850 MHz. For a vehicle moving 60 mph, compute the received carrier frequency if the mobile is moving :*

1) Directly toward the transmitter.

2) Directly away from the transmitter.

3) In a direction which is perpendicular to the direction of arrival of transmitted signal.

GTU : Winter-15, Marks 7

Solution : Given :

$$\text{Carrier frequency } f_c = 1850 \text{ MHz}$$

$$\text{Wavelength } \lambda = \frac{c}{f_c}$$

$$= \frac{3 \times 10^8}{1850 \times 10^6} = 0.162 \text{ m}$$

$$\text{Vehicle speed } v = 60 \text{ mph} = 26.82 \text{ m/s}$$

1. The vehicle is moving directly towards the transmitter. The Doppler shift in this case is positive and the received frequency is given by equation $f = f_c + f_d$

$$f_c = 1850 \text{ MHz} = 1850 \times 10^6 \text{ Hz}$$

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

$$f = 1850 \times 10^6 + \frac{26.82}{0.162}$$

$$f = 1850.00016 \text{ MHz}$$

2. The vehicle is moving directly away from the transmitter. The Doppler shift in this case is negative and hence the received frequency is given by

$$f = f_c - f_d$$

$$= 1850 \times 10^6 - \frac{26.82}{0.162} = \mathbf{1849.999834 \text{ MHz}}$$

3. The vehicle is moving perpendicular to the angle of arrival of the transmitted signal. In this case, $\theta = 90°$, $\cos\theta = 0$, and there is no Doppler shift. The received signal frequency is the same as the transmitted frequency of 1850 MHz (i.e. no Doppler frequency).

University Question

1. *Describe the factors influenc ing small scale fading.* **GTU : Winter-15, Marks 7**

3.9 Impulse Response Model of a Multipath Channel

- Mobile radio channel may be modeled as a linear filter with time varying impulse response in continuous time. To show this, consider time variation due to receiver motion and time varying impulse response h(d, t) and x(t), the transmitted signal.
- The received signal y(d, t) at any position d would be

$$y(d, t) = x(t) * h(d, t) = \int_{-\infty}^{\infty} x(\tau)\, h(d, t-\tau) d\tau$$

- For a causal system :

$$h(d, t) = 0, \text{ for } t < 0 \text{ and}$$

- For a stable system :

$$\int_{-\infty}^{\infty} | h(d, t) | \, dt = \infty$$

- Applying causality condition in the above equation, $h(d, t - \tau) = 0$ for $t - \tau < 0 \Rightarrow \tau > t$, i.e. the internal limits are changed to

$$y(d, t) = \int_{-\infty}^{t} x(\tau)\, h(d, t - \tau)\, d\tau$$

Since the receiver moves along the ground at a constant velocity v, the position of the receiver is d = vt i.e.

$$y(vt, t) = \int_{-\infty}^{t} x(\tau)\, h(vt, t - \tau)\, d\tau$$

Since v is a constant, y(vt, t) is just a function of t. Therefore the above equation can be expressed as,

$$y(t) = \int_{-\infty}^{t} x(\tau)\, h(vt, t - \tau)\, d\tau = x(t) * h(vt, t) = x(\tau) * h(d, t) \quad \text{...(3.9.1)}$$

It is useful to discretize the multipath delay axis τ of the impulse response into equal time delay segments called excess delay bins, each bin having a time delay width equal to $(\tau_{i+1} - \tau_i) = \Delta\tau$ and $\tau_i = i\Delta\tau$ for $i \in \{0,1,2,...N-1\}$ wher N represents the total number of possible equally-spaced multipath components, including the first arriving component. The useful frequency span of the model is $2/\Delta\tau$. The model may be used to analyze transmitted RF signals having bandwidth less than $2/\Delta\tau$.

If there are N multipaths, maximum excess delay is given by $N\Delta\tau$.

$$\{y(t) = x(t) * h(t, \tau_i) \mid i = 0, 1, \ldots N-1\}$$

Bandpass channel impulse response model is

$$x(t) \rightarrow h(t,\tau) = \mathrm{Re}\{h_b(t,\tau)e^{j\omega_c t} \rightarrow y(t) = \mathrm{Re}\{r(\tau)e^{j\omega_c t}\}$$

Baseband equivalent channel impulse response model is given by

$$c(t) \rightarrow \frac{1}{2}h_b(t,\tau) \rightarrow r(t) = c(t) * \frac{1}{2}h_b(t,\tau)$$

Average power is,

$$\overline{x^2(t)} = \frac{1}{2}|c(t)^2|$$

The baseband impulse response of a multipath channel can be expressed as,

$$h_b(t,\tau) = \sum_{i=0}^{N-1} a_i(t,\tau)\exp[j(2\pi f_c T_i(t) + \varphi_i(t,\tau))]\,\delta(\tau - \tau_i(t))$$

Where $a_i(t, \tau)$ and $\tau_i(t)$ are the real amplitudes and excess delays, respectively, of the τ multipath component at time t. The phase term $2\pi f_c \tau_i + \varphi_i(t,\tau)$ in the above equation represents the phase shift due to free space propagation of the ith multipath component, plus any additional phase shifts which are encountered in the channel.

It the channel impulse response is wide sense stationary over a small-scale time or distance interval, then

$$h_b(\tau) = \sum_{i=0}^{N-1} a_i \exp[j\theta_i]\,\delta(\tau - \tau_i)$$

For measuring $h_b(\tau)$, we use a probing pulse to approximate $\delta(t)$ i.e.

$$p(t) \approx \delta(t-\tau)$$

Power delay profile is taken by spatial average of $|h_b(t,\tau)|^2$ over a local area. The received power delay profile in a local area is given by

$$p(\tau) \approx \overline{k|h_b(t;\tau)|^2}$$

3.10 Multipath Channel Parameters

GTU : Summer-15

- To compare the different multipath channels and to quantify them, we define some parameters. They all can be determined from the power delay profile. These parameters can be broadly divided in to two types.

1. Time Dispersion Parameters
2. Frequency Dispersion Parameters

3.10.1 Time Dispersion Parameters

- These parameters include the mean excess delay, rms delay spread and excess delay spread.
- The **mean excess delay** is the first moment of the power delay profile and is defined as :

$$\bar{\tau} = \frac{\sum a_k^2 \tau k}{\sum a_k^2} = \frac{\sum P(\tau_k)\,\tau_k}{\sum P(\tau_k)}$$

Where a_k is the amplitude,

τ_k is the excess delay and

$P(\tau_k)$ is the power of the individual multipath signals

- The **mean square excess delay spread** is defined as :

$$\bar{\tau}^2 = \frac{\sum P(\tau_k)\tau_k^2}{\sum P(\tau_k)}$$

- The **rms delay spread** is the square root of the second central moment of the power delay profile, it can be written as

$$\sigma_\tau = \sqrt{\bar{\tau}^2 - (\bar{\tau})^2}$$

- As a rule of thumb, for a channel to be flat fading the following condition must be satisfied

$$\frac{\sigma_\tau}{T_S} \leq 0.1$$

Where;

T_S is the symbol duration.

- For this case, no equalizer is required at the receiver.

3.10.2 Frequency Dispersion Parameters

- To characterize the channel in the frequency domain, we have the following parameters.
  (1) Coherence bandwidth
  (2) Coherence time

3.10.2.1 Coherence Bandwidth (B_c)

- The **Coherence bandwidth** is a statistical measure of the range of frequencies o which the channel can be considered to pass all the frequency components w almost equal gain and linear phase. When this condition is satisfied then we the channel to be flat.
- Practically, coherence bandwidth is the minimum separation over which the t frequency components are affected differently. If the coherence bandwidth considered to be the bandwidth over which the frequency correlation function above 0.9, then it is approximated as-

$$B_C \approx \frac{1}{50\,\sigma_T}$$

- However, if the coherence bandwidth is considered to be the bandwidth o which the frequency correlation function is above 0.5, then it is defined as-

$$B_C \approx \frac{1}{5\,\sigma_T}$$

- The coherence bandwidth describes the time dispersive nature of the channel the local area. A more convenient parameter to study the time variation of the channel is the coherence time. This variation may be due to the relative moti between the mobile and the base station or the motion of the objects in t channel.

3.10.2.2 Coherence Time

- The **Coherence time** is a statistical measure of the time duration over which t channel impulse response is almost invariant. When channel behaves like this, it said to be slow faded.
- Essentially it is the minimum time duration over which two received signals a affected differently. For an example, if the coherence time is considered to be t bandwidth over which the time correlation is above 0.5, then it can approximated as

$$T_C \approx \frac{9}{16\pi f_m}$$

Where; f_m is the maximum doppler spread given be $f_m = v/\lambda$.

- Another parameter is the Doppler spread (B_D) which is the range of frequenc over which the received Doppler spectrum is non zero.

3.10.3 Doppler Spread and Coherent Time

- Doppler spread and coherent time are parameters which describe the time varying nature of the channel in a small-scale region.
- When a pure sinusoidal tone of f_c is transmitted, the received signal spectrum, called the Doppler spectrum, will have components in the range ($f_c - f_d$) and ($f_c + f_d$), where f_d is the Doppler shift.

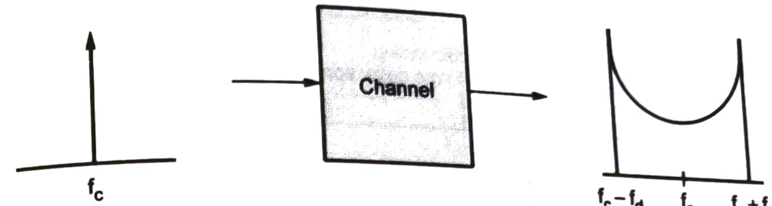

Fig. 3.10.1 Doppler spectrum

- f_d is a function of the relative velocity of the mobile and the angle between the direction of motion of the mobile and direction of arrival of the scattered waves.
- Coherent time T_c is the time domain dual of Doppler spread.
- Coherent time is used to characterize the time varying nature of the frequency dispersiveness of the channel in the time domain.

$$T_C \approx \frac{1}{f_m}$$

Where f_m is maximum Doppler shift given by $f_m = v/\lambda$

v : Speed of the mobile

- Two signals arriving with a time separation greater than T_c are affected differently by the channel
- A statistic measure of the time duration over which the channel impulse response is essentially invariant.
- If the coherent time is defined as the time over which the time corrleation function is above 0.5, then

$$T_C \approx \frac{9}{16\pi f_m}$$

University Questions

1. *Define and explain mean excess delay. rms delay spread and excess delay spread.* **GTU : Summer-15, Marks 7**
2. *Explain coherence time and coherence bandwidth.* **GTU : Summer-15, Marks 7**

GTU : Winter-14,15, Summer-16

3.11 Types of Small-Scale Fading

- The type of fading experienced by the signal through a mobile channel depend on the relation between the signal parameters (bandwidth, symbol period) and th channel parameters (rms delay spread and Doppler spread). Hence there are fou different types of fading.
- Classification based on multipath time delay spread is shown in Fig. 3.11.1 Ther are two types of fading due to the time dispersive nature of the channel.

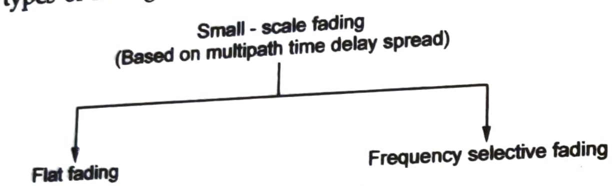

Fig. 3.11.1

- Classification based on doppler spread is shown in Fig. 3.11.2

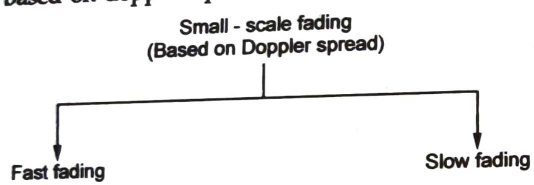

Fig. 3.11.2

- Multipath delay spread leads to time dispersion and frequency selective fading.
- Doppler spread leads to frequency dispersion and time selective fading.
- Multipath delay spread and Doppler spread are independent of one another

3.11.1 Fading Effects due to Multipath Time Delay Spread

- Time dispersion due to multipath causes the transmitted signal to undergo eith flat or frequency selective fading.

3.11.1.1 Flat Fading

- Such type of fading occurs when the bandwidth of the transmitted signal is le than the coherence bandwidth of the channel.
- If the channel has a constant gain and linear phase response over a bandwid which is greater than the bandwidth of the transmitted signal, the received sign will undergo flat fading.
- The received signal strength changes with time due to fluctuations in the gain the channel caused by multipath.

- The received signal varies in gain but the spectrum of the transmission is preserved. Fig. 3.11.3 shows flat fading channel characteristics.

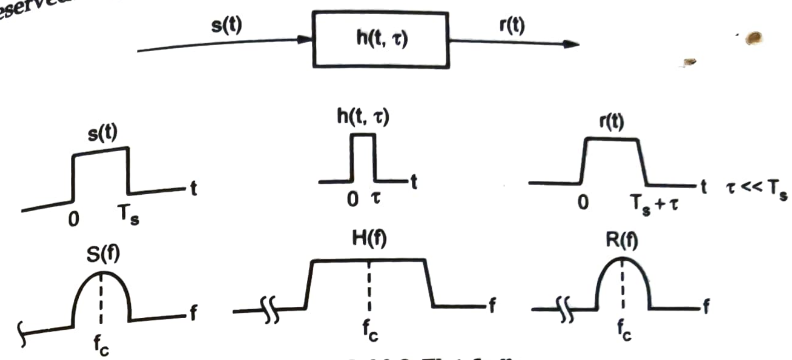

Fig. 3.11.3 Flat fading

- Flat fading channel is also called **amplitude varying channel.** Also called narrow band channel because bandwidth of the applied signal is narrow as compared to the channel bandwidth.
- A signal undergoes flat fading if :

$$B_S << B_C$$

and

$$T_S << \sigma_\tau$$

Where,

T_S : Reciprocal bandwidth (symbol period)

B_S : Bandwidth of the transmitted signal

B_C : Cohernet bandwidth

σ_τ : rms delay spread

- In such a case, mobile channel has a constant gain and linear phase response over its bandwidth.

3.11.1.2 Frequency Selective Fading

- Frequency selective fading occurs when the signal bandwidth is more than the coherence bandwidth of the mobile radio channel or equivalently the symbols duration of the signal is less than the rms delay spread.
- If the channel possesses a constant-gain and linear phase response over a bandwidth that is smaller than the bandwidth of transmitted signal, then the channel creates frequency selective fading.

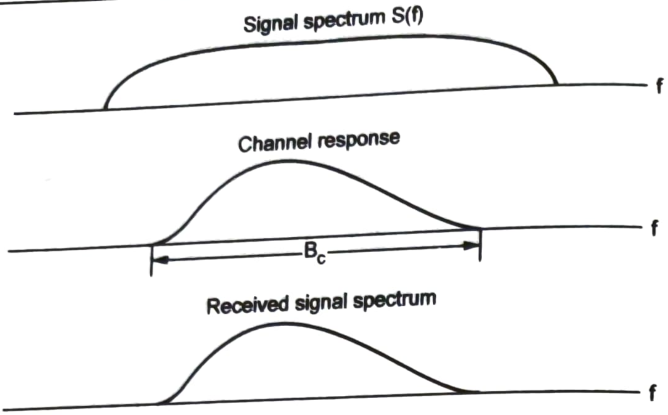

Fig. 3.11.4 Frequency selective fading

- Frequency selective fading is due to time dispersion of the transmitted symbol within the channel. It induces intersymbol interference.
- For frequency selective fading :

$$B_S > B_C$$

and $$T_S > \sigma_\tau$$

- Fig. 3.11.5 shows characteristics of frequency selective fading.
- Frequency selective fading channels are much more difficult to model than flat fading channels.

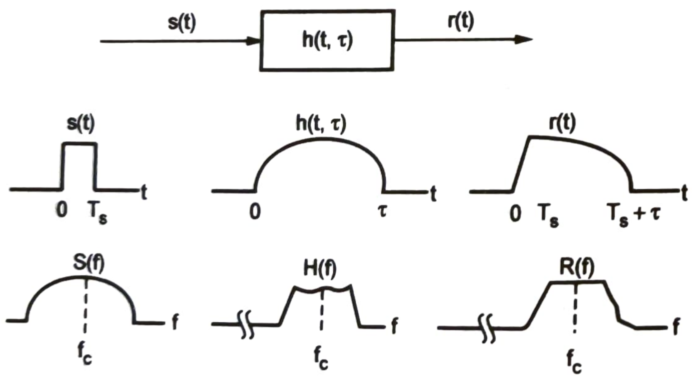

Fig. 3.11.5 Frequency selective fading characteristics

- At the receiver, we obtain multiple copies of the transmitted signal, all attenuated and delayed in time. The channel introduces inter symbol interference. A rule of thumb for a channel to have flat fading is if :

$$\frac{\sigma_\tau}{T_S} \leq 0.1$$

3.11.2 Fading Effects Due to Doppler Spread

3.11.2.1 Fast Fading

- In a fast fading channel, the channel impulse response changes rapidly within the symbol duration of the signal. Due to Doppler spreading, signal undergoes frequency dispersion leading to distortion. Therefore a signal undergoes fast fading if :

$$T_S > T_C$$

and $$B_S < B_D$$

Where,

T_C is the coherence time and

B_D is the Doppler spread

- Transmission involving very low data rates suffers from fast fading.

3.11.2.2 Slow Fading

- In such a channel, the channel impulse response changes at a rate much slower than the transmitted baseband signal s(t).
- The Doppler spread of the channel is much less then the bandwidth of the baseband signal.
- We can consider a slow faded channel a channel in which channel is almost constant over atleast one symbol duration.
- A signal undergoes slow fading if :

$$T_S << T_C$$

and $$B_S >> B_D$$

- The velocity of the user plays an important role in deciding whether the signal experiences fast or slow fading.

University Questions

1. *Give complete classification of small scale fading and summarize the conditions for each type of small scale fading.* **GTU : Winter-14, Marks 7**
2. *Describe briefly the types of small scale fading (based on multipath time delay spread).* **GTU : Winter-15, Marks 7**
3. *What is fading? List and explain various types of small scale fading.* **GTU : Summer-16, Marks 7**

3.12 Rayleigh and Ricean Distributions

3.12.1 Rayleigh Fading Distribution

- Rayleigh fading exists when there is multiple indirect paths between transm and receiver i.e. there is no distinct Line Of Sight (LOS) path.
- Rayleigh fading can be dealt by studying performance characteristics in critical environment.
- The envelope of the sum of two quadrature Gaussian noise signals obeys Rayleigh distribution.
- The Rayleigh distribution has a probability density function (pdf) given by-

$$P(r) = \begin{cases} \dfrac{r}{\sigma^2}\exp\left(\dfrac{r^2}{2\sigma^2}\right) & (0 \le r \le \infty) \\ 0 & (r < 0) \end{cases}$$

Where;

σ is the rms value of the received voltage signal before envelope detection,

σ^2 is the time-average power of the received signal before envelope detection.

- Fig. 3.12.1 illustrates the Rayleigh probability distribution function (pdf).

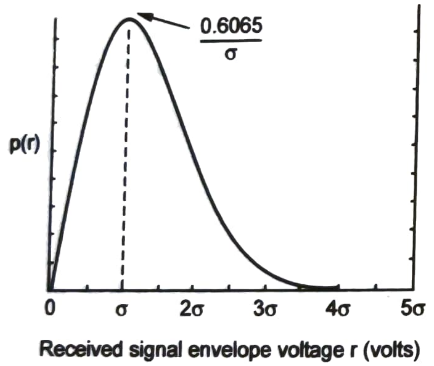

Fig. 3.12.1 Rayleigh probability density function

3.12.2 Ricean Fading Distribution

- When there is a dominant stationary (nonfading) signal component present, su as a line-of-sight propagation path, the small-scale fading envelope distribution Ricean.

3.12.3 Ricing Fading Channel

- Rician fading exists where there is a direct Line Of Sight (LOS) path along wi number of indirect multipath signals. This model is mostly applicable in indo environment whereas Rayleigh fading model characterizes outdoor environment.

- All the channels are characterized by a parameter 'K' where -

$$K = \frac{\text{Power in dominant path}}{\text{Power in scattered paths}}$$

i) For Rayleigh channel, numerator is zero therefore K = 0

ii) For AWGN channel, denometor is zero therefore $K = \infty$

iii) For Rician channel, with reasonably strong signal K = 4 to 16

- Bit Error Rate (BER) for various fading conditions is shown in Fig. 3.12.1.

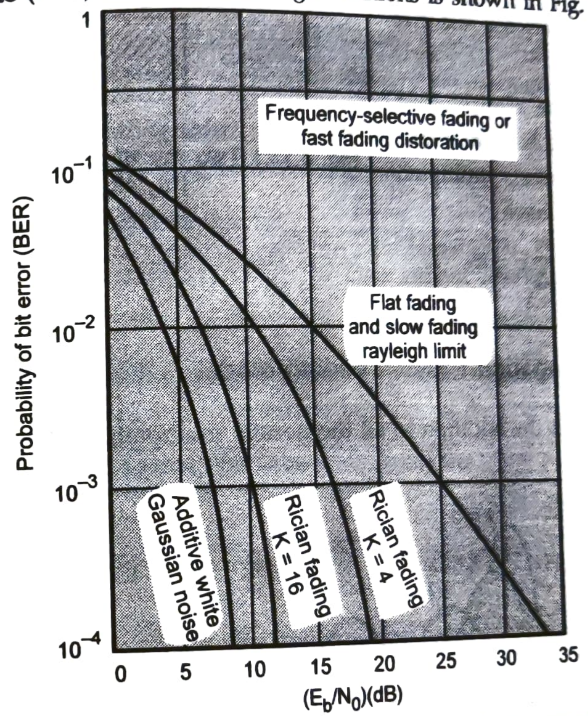

Fig. 3.12.2 Theoretical bit error rate for various fading conditions

- Fig. 3.12.2 shows the Ricean probability distribution function (pdf).

3.13 Statistical Models for Multipath Propagation

- Many multipath models have been proposed to explain the observed statistical nature of a practical mobile channel. Both the first order and second order statistics have been examined in order to find out the effective way to model and combat the channel effects.
- The most popular of these models are Rayleigh model, which describes the NLoS propagation. The Rayleigh model is used to model the statistical time varying nature of the received envelope of a flat fading envelope.

3.13.1 NLoS Propagation : Rayleigh Fading Model

- Let there be two multipath signals S1 and S2 received at two different time instant due to the presence of obstacles as shown in Fig. 3.13.1 Now there can either be constructive or destructive interference between the two signals.
- Let En be the electric field and θn be the relative phase of the various multipath signals. So we have

$$\tilde{E} = \sum_{n=1}^{N} E_n e^{j\theta_n}$$

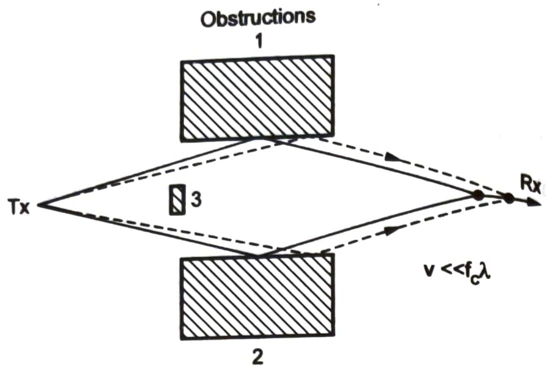

Fig. 3.13.1 Two ray NLoS multipath, resulting in Rayleigh fading

3.13.2 LoS Propagation : Rician Fading Model

- Rician fading is the addition to all the normal multipaths a direct LOS path.

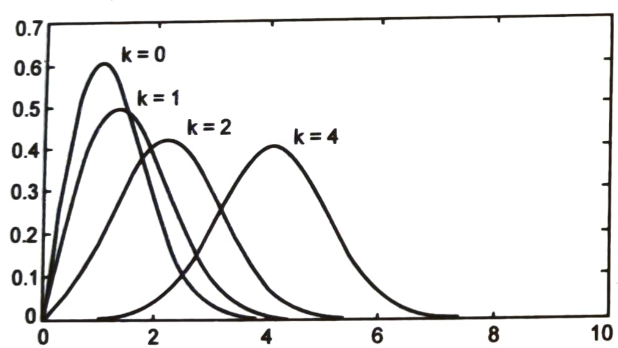

Fig. 3.13.2 Ricean probability density function

- Its probability distribution function is given by:

$$f_R(r) = \frac{r}{\sigma^2} e^{-\frac{(r^2+A^2)}{2\sigma^2}} I_0\left(\frac{A_r}{\sigma^2}\right)$$

- For all A ≥ 0 and r ≥ 0. Here A is the peak amplitude of the dominant signal and I0 is the modified Bessel function of the first kind and zeroth order.

3.14 Multiple Choice Questions

Q.1 Large scale fading refers the attenuation in ______.

a) Amplitude b) Phase c) Signal power d) None of the mentioned

[Ans. : c]

Explanation : large scale fading refers to signal power attenuation or path loss due to motion in large area.

Q.2 Small scale refers to changes in ______.

a) Amplitude b) Phase
c) Both of the mentioned d) None of the mentioned [Ans. : c]

Explanation : Small scale fading refers to changes in amplitude and phase as a result of small changes in spatial positioning between transmitter and receiver.

Q.3 Small scale fading manifests due to ______.

a) Signal dispersion b) Time variant behavior
c) Both of the mentioned d) None of the mentioned [Ans. : c]

Explanation : Small scale fading manifests itself in two mechanisms - time spreading of the signal (signal dispersion) and time variant behavior of the channel.

Q.4 The parameters used to describe large scale fading are ______.

a) Reference distance b) Path loss exponent
c) Standard deviation of random variable d) All of the mentioned

[Ans. : d]

Explanation : The parameters used to statistically describe path loss due to large scale fading are reference distance, path loss exponent and standard deviation of random variable.

Q.5 Small scale fading occurs due to ______.

a) Doppler shift b) Time delay
c) Both of the mentioned d) None of the mentioned [Ans.: c]

Explanation : Small scale fading occurs due to time delay and frequency or Doppler shift.

Q.6 What are the types of small scale fading that occurs due to Doppler shift ?

a) Slow fading b) Fast fading
c) Both of the mentioned d) None of the mentioned [Ans. :c]