Large - scale Path Loss:-

Introduction:-

* Line-of-sight (LOS) - In free space, radio signals propagate as light. If such a straight line exists b/w a sender & receiver it is called line-of-sight.

* The transmission path in mobile communication b/w the transmitter and receiver can vary from severely obstructed by buildings, mountains.

* Propagation models have traditionally focused on predicting the average received signal strength at a given distance from the transmitter.

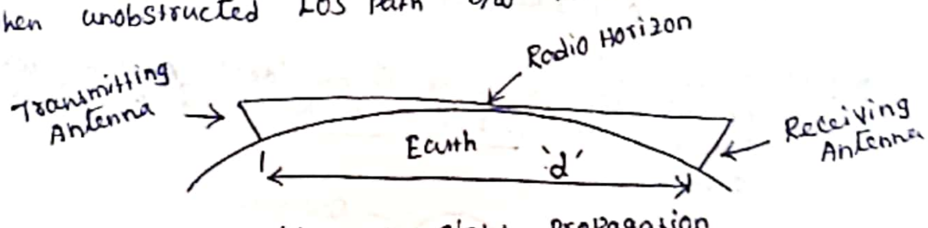
* Propagation models that predict the mean signal strength for an arbitrary transmitter - receiver (T-R) separation distance are useful in estimating the radio coverage area of a transmitter.

* Large - scale Propagation Models:-
  The propagation models that characterize the signal strength Large T-R separation distances (several hundreds (or) thousands of meters)

* Small scale (or) Fading Models:-
  The propagation models that characterize the rapid fluc-tuations of the received signal strength over very short travel distance are called small-scale (or) fading models.

Free space propagation model

* The free space propagation model is used to predict received signal strength when unobstructed LOS path b/w transmitter & receiver.



Line-of-Sight Propagation

* The free space power received by a receiver antenna which is separated from a radiating transmitter antenna by a distance 'd'

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

where

$P_r(d) \rightarrow$ Received power which is a function of the T-R separation distance 'd'

P_t - Transmitted power

G_t - Transmitter Antenna gain

G_r - Receiver Antenna gain

'd' $\rightarrow$ T-R separation distance in meters

$L \rightarrow$ Loss factor

$\lambda \rightarrow$ wavelength in meters

Note

$L \rightarrow 1$ indicates no loss in the system hardware.

* Effective Area (or) Effective Aperture

* The effective area of an antenna can be defined as

$$A_{eff} = \frac{P_r}{P_D} \rightarrow (2)$$

where

A_{eff} - Effective area of the antenna in m^2
P_r - Power delivered to the receiver in W
P_D - Power density of the wave in W/m^2

* From equation (2),

$$P_r = A_{eff} P_D \rightarrow (3)$$

* Power density P_D is given by

$$P_D = \frac{P_t G_t}{4\pi d^2} \rightarrow (4)$$

* Equation (4) in (3), we get,

$$P_r = \frac{A_{eff} P_t G_t}{4\pi d^2} \rightarrow (5)$$

* The effective area of a receiving Antenna is

$$A_{eff} = \frac{\lambda^2 G_r}{4\pi} \rightarrow (6)$$

where
G_r - Receiver antenna gain.
λ - wave length of the signal

* The gain of an antenna is related to its effective aperture (A_{eff})

$$G_r = \frac{4\pi A_{eff}}{\lambda^2} \rightarrow (7)$$

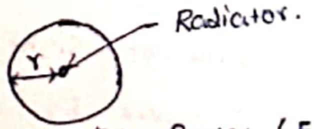
where

$$\lambda = \frac{c}{f} = \frac{2\pi c}{\omega_c} \rightarrow (8)$$

$f \rightarrow$ carrier frequency in Hertz
$\omega_c \rightarrow$ carrier frequency in radians/sec
$c \rightarrow$ speed of light in free space (3×10^8 m/s)

* Isotropic Radiator

- An isotropic radiator is an ideal Antenna which radiates power with unit gain uniformly in all directions, in wireless system.



* Effective Isotropic Radiated Power (EIRP) :-

- To produce the same power density in the given direction
- EIRP is given by

$$EIRP = P_t G_t \rightarrow (9)$$

where
Transmitting Antenna gain, $G_t = \frac{P_{DA}}{P_{DI}}$

$P_{DA} \rightarrow$ Power density in a given direction from the real Antenna.
$P_{DI} \rightarrow$ power density at the same distance from an isotropic radiator with the same P_t

* The eq - (9) represents the maximum radiated power available from a transmitter in the direction of maximum antenna gain, as compared to an isotropic radiator.

* Path Loss (or) Attenuation :-

- The Path Loss is defined as the difference (in dB) b/w the effective transmitted power and the received power, and may or may not include the effect of the antenna gains.

Sub. equation (6) in (5)

$$P_r = \frac{A_{eff} P_t G_t}{4\pi d^2}$$

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

$$\boxed{P_r = \frac{\lambda^2 P_t G_t G_r}{16\pi^2 d^2}} \longrightarrow (10)$$

- The Path Loss for the free space model when antenna gains are included is given by

Note $\boxed{4\times4=16}$

$$\text{PL (dB)} = 10 \log \frac{P_t}{P_r}$$

$$= +10 \log \frac{\cancel{P_t}}{\frac{\lambda^2 \cancel{P_t} G_t G_r}{16\pi^2 d^2}}$$

$$= -10 \log \left[\frac{G_t G_r \lambda^2}{(4\pi)^2 d^2}\right] \longrightarrow (11)$$

- when antenna gains are excluded, the antenna are assumed to have unity gain $(G_t = G_r = 1)$ and Path Loss is given by

$$\text{PL (dB)} = -10 \log \left[\frac{\lambda^2}{(4\pi)^2 d^2}\right] \longrightarrow (12)$$

$\boxed{\text{where, } G_t = G_r = 1}$

* Far-Field Region

- A transmitting antenna is defined as the region beyond the far-field distance. which is related to the largest linear dimension of the transmitter antenna aperture and the carrier wavelength.

- The Far-Field distance is given by

$$d_f = \frac{2D^2}{\lambda} \longrightarrow (13)$$

where D is the largest physical linear dimension of the antenna.

- Far-Field region, d_f must satisfy,

$$d_f \gg D \longrightarrow (14a)$$

and $$d_f \gg \lambda \longrightarrow (14b)$$

- The received power $P_r(d)$, at any distance $d > d_0$, may be related to P_r at d_0. d_0 is known as received power reference point.

- The received power in free space at a distance greater than d_0 is given by

$$P_r(d) = P_r(d_0)\left(\frac{d_0}{d}\right)^2 \quad d \geq d_0 \geq d_f \rightarrow (15)$$

- Equation (15) may be expressed in units of dBm (or) dBW. If P_r is in units of dBm, the received power is given by

$$\boxed{P_r(d)\,dBm = 10\log\left[\frac{P_r(d_0)}{0.001W}\right] + 20\log\left(\frac{d_0}{d}\right) \quad d \geq d_0 \geq d_f} \rightarrow (16)$$

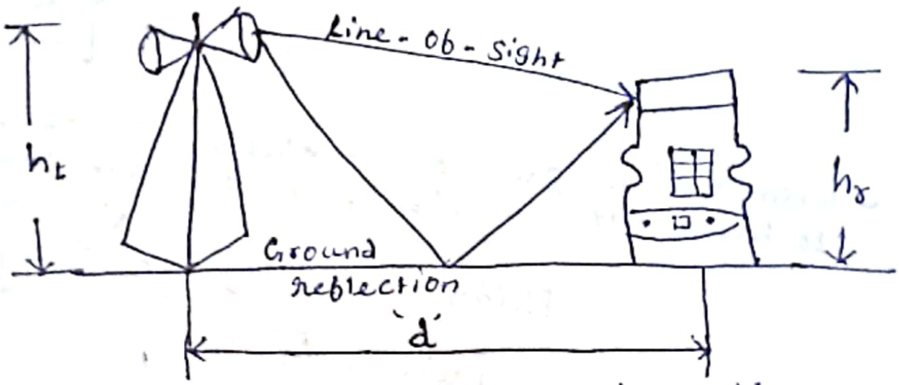
where $P_r(d_0)$ is in units of watts

Ground Reflection Model

Ground Reflection (Two-Ray) Model :-

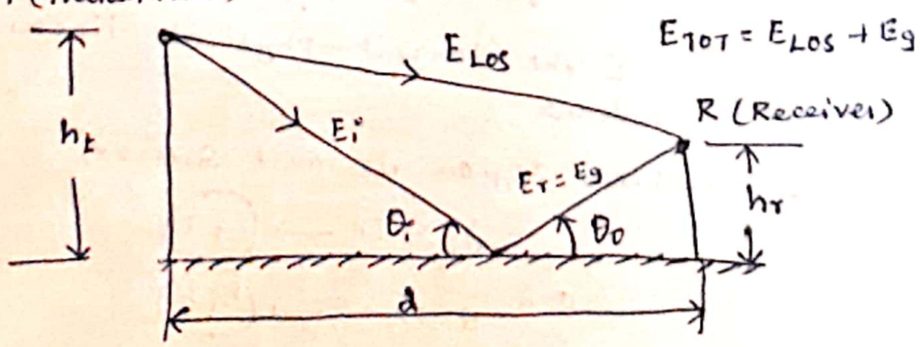
- The two-path or two-ray model that is used for modeling the land mobile radio.

- The two-ray ground reflection model is a useful propagation model that is based on geometric optics, and considers both the direct path and a ground reflected propagation path b/w transmitter and receiver.



Two-way model for Mobile radio Environments

- Predicting the large-scale signal strength over distances of several km for mobile radio systems that use tall towers (height which exceed 50m), as well as for LOS



Two-ray ground reflection model

* In the figure,

h_t is the height of the transmitter
h_r is the height of the receiver
E_0 is the free space E-field (in units of V/m) at a reference distance d_0 and.
d_0 is the reference distance from transmitter.

* In most mobile communication systems, the maximum T-R separation distance is at most only a few tens of km, and the earth may be assumed to be flat. Then the total received E-field is given by

$$E_{TOT} = E_{LOS} + E_g \rightarrow (1)$$

where

$E_{LOS} \rightarrow$ Direct Line-of-Sight
$E_g \rightarrow$ Ground reflected component

* For $d > d_0$, the free space propagating E-field is given by

E_0 – Free space E-Field
d_0 – Reference Distance

$$E(d,t) = \underbrace{\frac{E_0 d_0}{d}}_{\text{Envelope of E-Field}} \cos\left(w_c\left(t - \frac{d}{c}\right)\right) \rightarrow (2)$$

where,

$|E(d,t)| = \frac{E_0 d_0}{d}$ represents the envelope of the E-field at 'd' meters from the transmitter.

* Two propagating waves arrive at the receiver
(i) The direct wave that travels a distance d'
(ii) The reflected wave that travels a distance d''

* The E-field due to the LOS component at the receiver can be expressed as

$$E_{LOS}(d',t) = \frac{E_0 d_0}{d'} \cos\left(w_c\left(t - \frac{d'}{c}\right)\right) \rightarrow (3)$$

* The E-field due to the Ground reflected wave,

$$E_g(d'',t) = \Gamma \frac{E_0 d_0}{d''} \cos\left(w_c\left(t - \frac{d''}{c}\right)\right) \rightarrow (4)$$

* According to laws of reflection in dielectric

$$\theta_i = \theta_0 \quad — (5)$$
$$E_g = \Gamma E_i \quad — (6)$$
$$E_t = (1+\Gamma) E_i \quad — (7)$$

where
- Γ is the reflection co-efficient for ground.
- Reflected wave is equal in magnitude with the incident wave
- 180° out of phase

* The resultant total E-field envelope is given by

$$|E_{TOT}| = |E_{LOS} + E_g| \rightarrow (8)$$

* The electric field $E_{TOT}(d,t)$ can expressed as

$$E_{TOT}(d,t) = E_{LOS}(d',t) + E_g(d'',t)$$

$$= \frac{E_0 d_0}{d'} \cos\left(\omega_c\left(t - \frac{d'}{c}\right)\right) + \Gamma \frac{E_0 d_0}{d''} \cos\left(\omega_c\left(t - \frac{d''}{c}\right)\right)$$

$$= \frac{E_0 d_0}{d'} \cos\left(\omega_c\left(t - \frac{d'}{c}\right)\right) + (-1) \frac{E_0 d_0}{d''} \cos\left(\omega_c\left(t - \frac{d''}{c}\right)\right) \rightarrow (9)$$

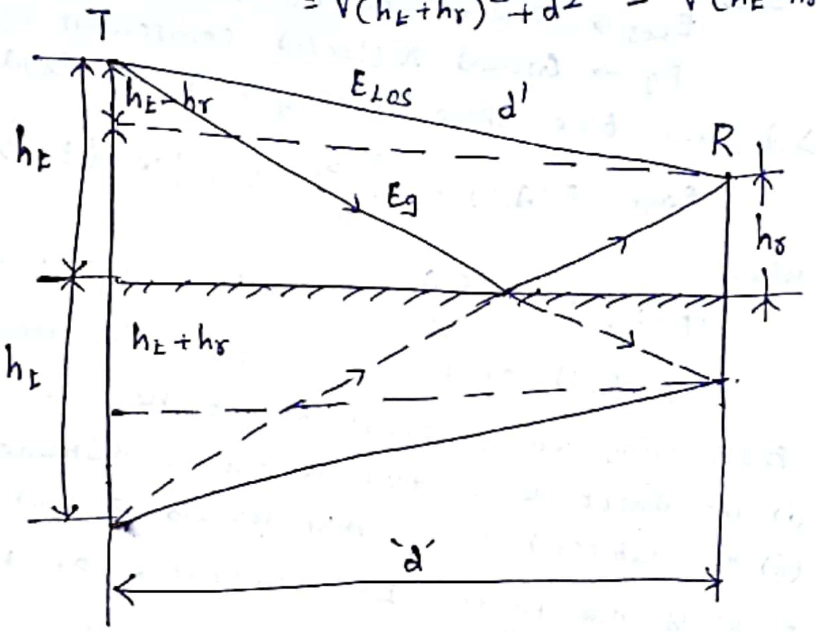
$\Gamma = -1$

METHOD OF IMAGES

* The Method of images is used to find the path difference b/w LOS & Ground reflected Paths.

$$\Delta = d'' - d'$$

$$= \sqrt{(h_t + h_r)^2 + d^2} - \sqrt{(h_t - h_r)^2 + d^2} \rightarrow (10)$$



* when T-R separation is very large compared to $h_t + h_r$ the equation can be simplified by using Taylor series approximation

$$\Delta = d'' - d' \approx \frac{2 h_t h_r}{d} \rightarrow (11)$$

The Phase difference $\theta_\Delta = \frac{2\pi\Delta}{\lambda} = \frac{\Delta \omega_c}{c} \rightarrow (12)$

time delay $\tau_d = \frac{\Delta}{c}$

From equation (12) $\Delta = \frac{\theta_\Delta c}{\omega_c}$

$$\tau_d = \frac{\theta_\Delta c}{\omega_c c} = \frac{\theta_\Delta}{2\pi f_c} \rightarrow (13)$$

when d becomes larger, the difference b/w the distances d' and d'' becomes very small, and the amplitudes of E_{LOS} and E_g are virtually identical and differ only in phase.

$$\left|\frac{E_0 d_0}{d}\right| \approx \left|\frac{E_0 d_0}{d'}\right| \approx \left|\frac{E_0 d_0}{d''}\right| \rightarrow (14)$$

* The free space power received at d is related to the square of the electric field

* The received power at a distance 'd' from the transmitter for the two-ray ground bounce model can be expressed as

$$P_r = P_t G_t G_r \frac{h_t^2 h_r^2}{d^4} \rightarrow (15)$$

* Equation (15) at large distances ($d >> \sqrt{h_t h_r}$), the received power falls off with distance raised to the fourth power, or at a rate of 40dB / decade.

* At large values of d, the received power and path loss become independent of frequency.

* The path loss for the two-ray model (with antenna gains) can be expressed in dB as,

$$\boxed{PL\,(dB) = 40 \log d - (10 \log G_t + 10 \log G_r + 20 \log h_t + 20 \log h_r)} \rightarrow 16$$

Link Budget Design using PATH LOSS MODELS

* Most radio propagation models are derived using a combination of analytical and empirical method.

* The empirical approach is based on fitting curves (or) analytical expressions that recreate a set of measured data.

* To considered all propagation factors, both known and unknown through actual field measurement.

* It consists of two models,

(i) Long-distance path loss model

(ii) Log-normal shadowing model

* By using path loss models to estimate the received signal level as a function of distance, it becomes possible to predict the SNR for a mobile communication system.

Long-distance path loss model:-

* The mobile user moves away from its base station, the received signal becomes weaker because of the growing propagation attenuation with the distance.

* Let $\overline{PL}(d)$ denote the long distance path loss, which is a function of the distance 'd' seperating the Tx & Rx

$$\overline{PL}(d) \propto \left(\frac{d}{d_0}\right)^n, \; d \geq d_0 \rightarrow (1)$$

Or equivalently

$$\overline{PL}\,(dB) = \overline{PL}(d_0) + 10n \log\left(\frac{d}{d_0}\right) dB, \; d \geq d_0 \rightarrow (2)$$

where
n – Path loss exponent
d_0 – reference distance
For given d_0, the value of $\overline{PL}(d_0)$ depends on the carrier frequency, antenna heights and gains.

* The eq ① & ② denote the ensemble average of all possible path loss values for a given value of d.
* The value of 'n' depends on the specific propagation environment.
* Loss Exponents for Different Environments:-

Environment	Path Loss exponent, n
– Free space	2
– urban area cellular radio	2.7 to 3.5
– Shadowed urban cellular radio	3 to 5
– In building with LOS	1.6 to 1.8
– obstructed in building	4 to 6
– obstructed in factories	2 to 6

* Free space reference distance that is appropriate for the propagation environment
* Large coverage cellular system, 1km reference distances
* Micro cellular system much smaller distances (such as 100m (or) 1m are used.

Log - Normal Shadowing Path Model

* The long - distance path loss model equation does not consider the fact that the surrounding environmental random and distributed
* The Path loss PL(d) at a particular location is random and distributed log-normally about the mean distance - dependent value.

$$PL(d)\,[dB] = \overline{PL}(d) + X_\sigma$$
$$= \overline{PL}(d) + 10n \log\left(\frac{d}{d_0}\right) + X_\sigma \rightarrow (3a)$$
&
$$P_r(d)\,[dBm] = P_t(dBm) - PL(d)\,[dB] \rightarrow (3b)$$

where
$P_r(d)\,[dBm] \rightarrow$ Received signal power
$P_t\,[dBm] \rightarrow$ Transmitted signal power.
X_σ is a zero $\rightarrow$ mean Gaussian distributed random variable,

Log - Normal Shadowing :-

Shadowing effects
↓
measure T-R separation
↓
But has different levels of propagation path
↓
Referred to as log-normal shadowing.

* The probability that the received signal level (in dB) will exceed a certain value Y can be calculated from the cumulative density function as,

$$P_r\left[P_r(d) > Y\right] = Q\left(\frac{Y - \overline{P_r(d)}}{\sigma}\right) \rightarrow (4)$$

* Similarly the probability that the received signal will be below Y is given by

$$P_r\left[P_r(d) < Y\right] = Q\left[\frac{\overline{P_r(d)} - Y}{\sigma}\right] \rightarrow (5)$$

Small - scale Fading & MultiPath

* The term fading is used to describe rapid fluctuation of the amplitude of a radio signal over a short period of time (or) travel distance

* Fading is caused by destructive interference b/w two or more version of the transmitted signal being out of phase due to the different propagation time.

* The different components are due to reflection & scattering from trees, buildings & hill etc.

* At a receiver the radio waves generated by same transmitted signal may come,

From different direction
with different propagation delays
with different amplitudes
with different phases

each of the factor given above is random

* Multipath propagation creates small scale fading effects :-
The three most important effects are:

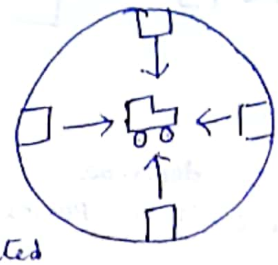
- Rapid changes in signal strength over a small travel distance (or) time interval
- Random frequency Modulation due to varying Doppler shift on different multipath signal
- Time delayed caused by multipath propagation.

Factor's of Fading:-

* Multipath propagation
* Speed of mobile receiver
* Speed of surrounding objects
* Transmission B.W

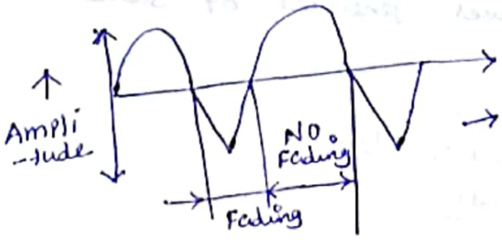
1- Multipath Propagation:-

* The presence of reflecting objects and scatterers in the space b/w Tx & Rx
* causes the signal at receiver to fade (or) distort.



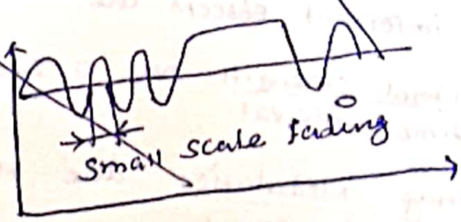
Prolems associated with Multipath

1. * If cause of amplitude, phase fluation and time delay in the received signal means to reduced signal strength
   - out of Phase
   - ↓ Amplitude level



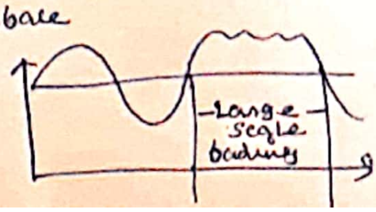
- Small scale Fading:-

Small scale fading propagation signal small amount spot in earth surface



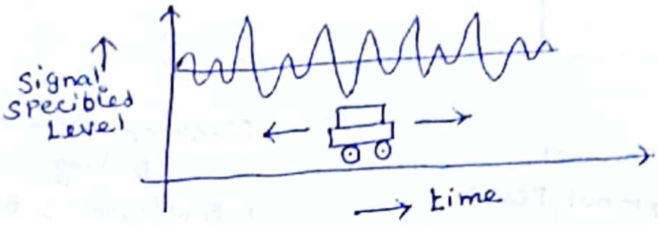
- Large Scale Fading:-

Large scale fading propagation signal large amount spot in earth surface



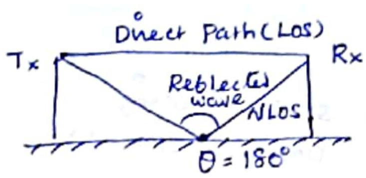
② Speed of Mobile:-

Due to relative motion b/w base station to mobile unit, there will be apperant shift in the frequency due to different Doppler shift



③ Speed of Surrounding Objects:-

If the speed of surrounding objects is greater than mobile, the fading is dominated by those object.

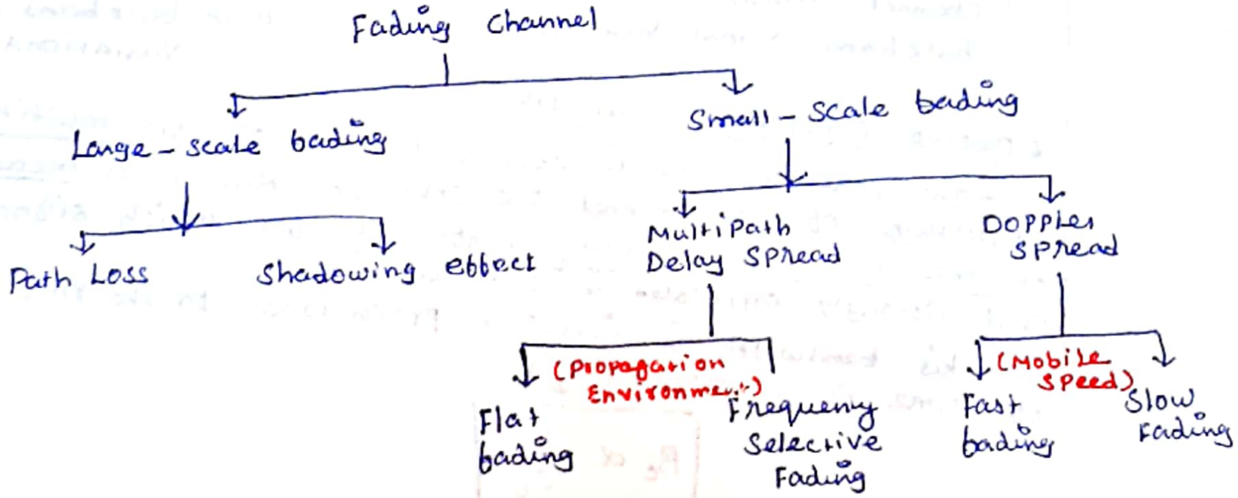


– Due to Reflected signal

④ Transmission B.W

* Depending on the relation b/w the signal B.W and the coherence B.W of the channel, the signal is either distorted or faded.

Types of Fading



Types of Small-Scale Fading

Small Scale Fading
(Based on multipath Time Delay spread)

- Flat Fading
  1) B.W signal < B.W channel
  2) Delay spread < Symbol Period
- Frequency Selective fading
  1) B.W signal > BW of Channel
  2) Delay spread > symbol Period.

Delay spread
Due to multipath tx & Rx to Received signal different time (Delay spread)
symbol period

Small scale Fading
(Based on Doppler spread)

- Fast Fading
  1) High Doppler spread
  2) coherence Time < symbol Period
  3) channel Variation faster than baseband signal variations
- Slow Fading
  1) Low Doppler spread
  2) coherence Time > symbol period
  3) channel variation smaller than baseband signal variations.

* Define Coherence Bandwidth?

- The coherence BW is related to the specific multipath structure of the channel. The coherence B.W is a measure of the maximum frequency difference for which signals are still strongly correlated in amplitude.

- This bandwidth is inversely proportional to the rms value of time delay spread (σ_τ)

$$\boxed{B_c \propto \frac{1}{\sigma_\tau}}$$

* what is coherence time (T_c)?

- coherence time (T_c) is usually defined as the required time interval to obtain an envelope correlation of 0.9 (or) less.

- It is inversely proportional to the maximum Doppler frequency

$$T_c = \frac{1}{f_m}$$, where, f_m - maximum Doppler frequency

Note :- The coherence time defines the static less of the Channel.

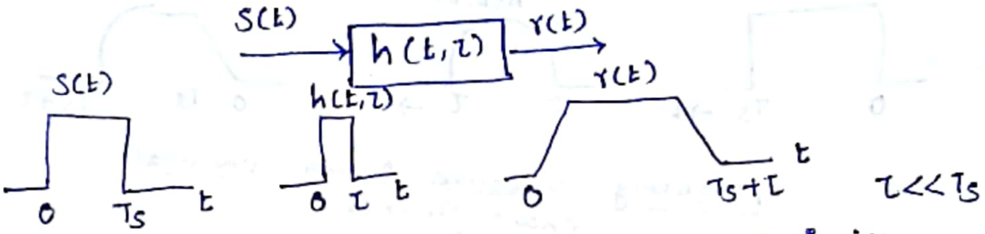
* Define Doppler shift ?
  - The shift in received signal frequency due to motion is called the Doppler shift

⇒ Fading Effects Due to MultiPath Time Delay spread

- Time dispersion due to multipath causes the transmitted signal to undergo either
  (i) Flat
  (ii) Frequency selective fading

(i) Flat Fading :-

- If the mobile radio channel has a constant gain & linear phase response over a bandwidth of the transmitted signal, then the received signal will undergo flat fading.



Flat fading channel characteristics

- In flat fading, the strength of the received signal changes with time, due to fluctuations in the gain of the channel caused by Multipath.
- Flat fading Channels are also known as amplitude varying channels
- If the channel gain changes overtime, a change of amplitude occurs in the received signal. over time, the received signal r(t), varies in gain, but the spectrum of the transmission preserved.
- The condition for flat fading is

Bw of signal << Bw of channel

$$B_S << B_C$$

and

Symbol Period >> Delay spread

$$T_S >> \sigma_\tau$$

where

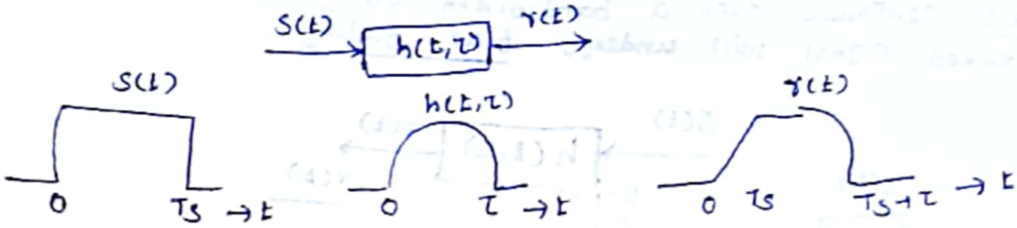
T_S → Reciprocal B.W
B_S → Signal B.W
σ_τ → rms delay spread and
B_C → Coherence B.W

Frequency selective fading (Time delay spread)

- It 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 on the received signal.

- Frequency selective fading variable propagation distance of reflected signals causes time variations in the reflected signal.

- Frequency selective fading channels are also known as wide band channel because the bandwidth of the signal is wider than the B.W of the channel impulse response.



Frequency selective fading channel characteristics

- A signal undergoes frequency selective fading if

BW of signal > B.W of channel

$$B_S > B_C$$

and

Symbol Period < Delay Period

$$T_S < \sigma_\tau$$

Fading Effects Due to Doppler Spread:-

Based on Doppler spread, a channel may be classified into two types

(i) Fast fading
(ii) Slow fading

→ **Fast Fading channel:-**

- The channel impulse response changes rapidly within the symbol duration. This type of channel is called fast fading channel.

- The coherence time of the channel is smaller than the symbol period of the transmitted signal.

- Signal distortion due to fast fading increases with increasing Doppler spread relative to the B.W of the transmitted signal.

- A signal undergoes fast fading if

Symbol Period > Coherence time

$$T_S > T_C$$

and

BW of signal < BW of Doppler Spread

$$B_S < B_D$$

Scanned with CamScanner

- Fast fading only deals with the rate of change of the channel due to motion

- In practice, fast fading only occurs for very low data rate

Slow Fading

- The channel impulse response changes at a rate much slower than the transmitted baseband signal. This type of channel is called slow fading channel.

- The channel may be assumed to be static over one or several reciprocal B.W intervals.

- A signal undergoes slow fading if

Symbol period << coherence time

$$T_S << T_C$$

and

B.W of signal >> BW of Doppler spread

$$B_S >> B_D$$

Register No ....
Class & Sec ....
Subject ....
Date ....
Staff sign....

UNIT-4

Reduce (or) eliminate Long-term risk to people

Multipath Mitigation Technique

Multipath Mitigation - Multipath Mitigation is a term typically used in code Division Multiple Access (CDMA) communications and in GNSS navigation to describe the methods that try to compensate for (or) cancel the effects of the Non Line of sight (NLOS) propagation.

- There are many types of wireless channel impairments such as Noise, Path Loss, Shadowing and fading and impairment mitigation techniques should be adopted according to system requirement and channel enviroments.

- There are many techniques to mitigate wireless channel impairments. For example :- For the purpose of mitigating delay spreads Global system for Mobile communication (GSM) system uses adaptive channel equalization techniques and Code Division Multiple Access (CDMA) system uses a rake receiver.

What a Mean by Equalization?

* Equalization : is the process of remove ISI and noise effects from the channel.
* It's located at receiver end of the channel.

The goal of equalization - is to mitigate the effects of ISI However, this goal must be balanced so that in the process of removing ISI, the noise power in the received signal is not enhanced.

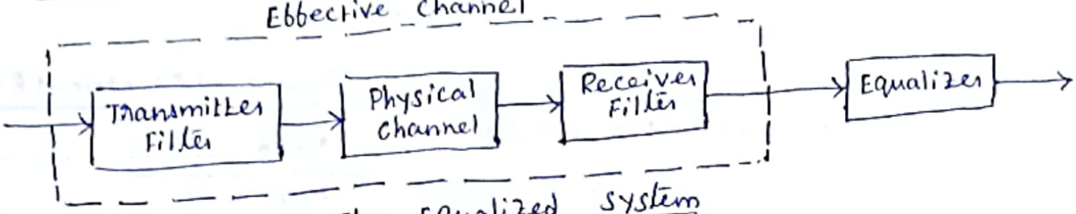
Diversity techniques:-

- Diversity techniques mitigate multipath fading effects and improve the reliability of a signal by utilizing multipath received signals with different chs.

Fundamentals of Equalization:-

Equalizer:-

The device which equalizes the dispersive effect of a channel is referred to as an Equalizer.



The Equalized system

step:-1 → For channel equalization at baseband place it b/w the Demodula-tor

step:-2 → To design an equalizer and

step:-3 → Decision device such that the O/P of the equalizer is ISI free.

∴ ISI is the major obstacle to high speed data transmission over wireless channels, equalization is a technique used to compensate Inter symbol Interference.

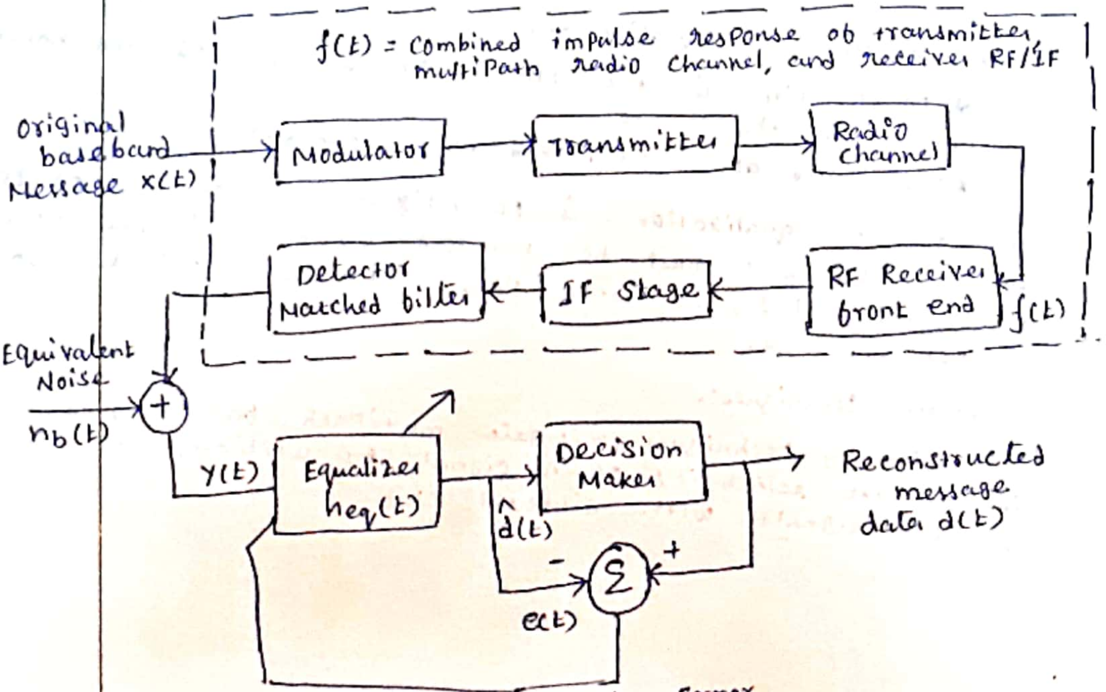
Adaptive Equalizer:-

In Mobile cellular environment, wireless dispersive fading channel

- The characteristics of the change randomly with time.

- In order for an equalizer to effectively combat ISI, the equalizer co-efficients should change according to the channel status so as to track the channel variations.

- Adaptive equalizer since it adapts to the channel variations.



Adaptive Equalizer at the receiver

* If $x(t)$ is the original information signal, and $f(t)$ is the combined complex, base band impulse response of the transmitter, channel, and the RF / IF sections of the receiver.

* The signal received by the equalizer may be expressed as,

where

$$y(t) = x(t) \otimes f^*(t) + n_b(t) \longrightarrow (1)$$

$f^*(t) \rightarrow$ complex conjugate of $f(t)$

$n_b(t) \rightarrow$ Base band noise at the input of the equalizer.

$\otimes \rightarrow$ convolution operation.

* Impulse response of the equalizer is $h_{eq}(t)$, then the o/p of the equalizer is

$$\hat{d}(t) = x(t) \otimes f^*(t) \otimes h_{eq}(t) + n_b(t) \otimes h_{eq}(t) \longrightarrow (2)$$

* Data sequence to compute the initial optimum tap co-efficients of the adaptive equivalizer.

* The training sequence normally is a deterministic sequence is like noise. so it is called as pseudorandom sequence.

* The sequence is known to the receiver, and is used to adjust its tap coefficients to the optimum values.

Operating modes of an Adaptive equalizer.

The general operating modes of adaptive equalizers are training and tracking.

* Training :-

~~First~~ First, a known fixed-length training sequence is sent by the transmitter