Wireless Channels

Large Scale Path loss ⇒

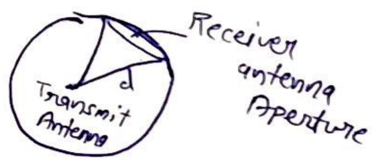
Propagation models that predict the mean signal strength for an arbitrary transmitter-receiver (T-R) separation distance are useful in estimating the radio coverage area of a transmitter & are called large-scale propagation models.

As the mobile moves away from the transmitter over much large distances, the local average received signal will gradually decrease and it is local average signal level that is predicted by large-propagation models. (measurement track of 5λ to 40λ)

FREE-Space Propagation Model :- It is used to predict the received signal strength when transmitter & receiver have clear, unobstructed LOS path b/w them.

The received power decays as a function of T-R separation distance raised to some power.

(Difference b/w effective transmitted power & received power → path loss)



Free space power received by receiver antenna from a radiating transmitter antenna by distance d, is given by Friis Free space eqn:

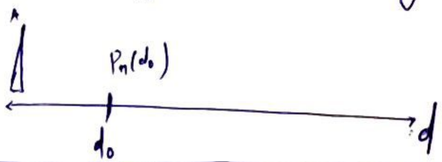
$$P_r(d) = P_t G_t G_r \lambda^2 / (4\pi)^2 d^2 L \quad , \quad G = \frac{4\pi A_e}{\lambda^2} \quad , \quad \lambda = \frac{c}{f} = \frac{2\pi}{\omega_c}$$

Effective Isotopic Radiated Power (EIRP) $= P_t G_t$

$(P_t - P_r)$ Path loss in free space $= 10 \log\left(\frac{P_t}{P_r}\right) = -10 \log\left[\lambda^2/(4\pi)^2 d^2\right]$ —— ① [when antenna gains are excluded]

$d_f = 2D^2/\lambda$

$(d_0 > d_f)$



$P_r(d_0) \propto \frac{1}{d_0^2}$ → $P_r(d) = P_r(d_0) \left(\frac{d_0}{d}\right)^2$

$$\boxed{P_r(d)\ dB_m = 10\log\left[\frac{P_r(d_0)}{0.001\,W}\right] + 20\log\left(\frac{d_0}{d}\right) \quad d \geq d_0 \geq d_f \quad \text{Received Signal Strength}}$$

Two-Ray Models :-

A Two-Ray model, which consists of two overlapping waves at the receiver, one direct path & one reflected wave from the ground.

The received signal consists of two components: the LOS component or ray, which is just the transmitted signal propagation through free space, and a reflected component or ray, which is transmitted signal reflected off the ground.

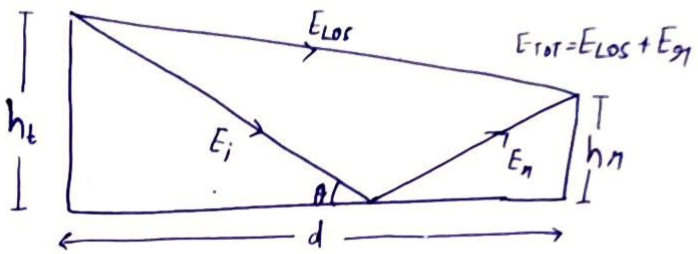


fig:- Two Ray Model

The free space propagating E-field is

$$E(d,t) = \frac{E_0 d_0}{d} \cos\left(w_c\left(t - \frac{d}{c}\right)\right) \quad (d > d_0)$$

Two propagating wave arrive at receiver, one LOS wave which travels a distance of 'd' & another ground reflected wave

$$|E(d,t)| = \frac{E_0 d_0}{d}$$

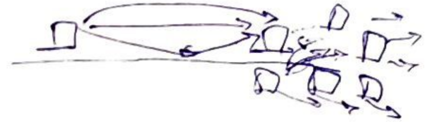
$$E_{TOT} = E_{LOS} + E_r = \frac{E_0 d_0}{d'} \cos\left(w_c\left(t - \frac{d'}{c}\right)\right) + (-1)\frac{E_0 d_0}{d''}\left(w_c\left(t - \frac{d''}{c}\right)\right)$$

$$\Delta = d'' - d' = \sqrt{(h_t+h_r)^2 + d^2} - \sqrt{(h_t-h_r)^2 + d^2} = \frac{2 h_t h_r}{d} \quad \& \quad \tau = \frac{\Delta}{c} = \frac{\theta_\Delta}{2\pi f_c}$$

$$E_{TOT}(d) = \frac{2E_0 d_0}{d} \cdot \frac{2\pi h_t h_r}{\lambda d} = \frac{k}{d^2}, \quad P_r = P_t G_t G_r \frac{h_t^2 h_r^2}{d^4}$$

$$PL(dB) = 40\log d - (10\log G_t + 10\log G_r + 20\log h_t + 20\log h_r)$$

Fading



Fading is a phenomenon in which the strength & quality of a radio signal fluctuate over time & distance. Fading is caused by a variety of factors, including multipath propagation, & movement of objects in transmission path.

- Fading
  - Large Scale Fading
    - Path loss
    - Shadowing
  - Small Scale Fading
    - Multiple delay Spread
    - Doppler Spread

Large Scale Fading :-

- It is a phenomenon that occurs when signal strength decreases over long distances.
- Large Scale fading is a slow-varying phenomenon, meaning that it changes over time scales of seconds to minutes.

Path Loss :--→ It is the reduction in signal power as signal travels from transmitter to the receiver.

→ The path loss is generally modeled using an attenuation equation that takes into account these factors.

→ Path loss can be mitigated by increasing transmitted power, using directional antennas or reducing distance b/w transmitter & the receiver.

$$\frac{P_t}{P_r} = \frac{(4\pi f d)^2}{G_t}$$

Shadowing :→ It occurs due to presence of obstancles in path of signal.

→ Shadowing causes signal power to vary as receiver moves in environment.

→ Shadowing is a slow-varying phenomenon & affects the overall received signal power.

- Variety Strategies
- Balance Procedures
- Power Control Strategies
- Tweak Procedures

Small Scale Fading

→ Small Scale fading refers to the rapid change of the amplitude & phase of a radio signal over a short period of time on short distance.

→ It occurs due to multi-path waves. Short term fluctuation in signal amplitude caused by local multipath.

- Fading due to Multipath time delay Spread ⇒
  - → Flat Fading
  - → Frequency Selective Fading

Flat Fading

- BW of signal < BW of ~~signal~~ channel
- Delay Spread < Symbol period

Frequency Selective Fading

- BW of signal > BW of channel
- Delay Spread > Symbol period

- Fading due to Doppler Spread ⇒
  - ⟶ Fast Fading
  - ⟶ Slow Fading

Fast Fading

1. High Doppler Spread
2. Coherence time < Symbol period
3. Channel variations faster than base band signal variations

Slow Fading

1. Low Doppler Spread
2. Coherence time > Symbol period
3. Channel variations slower than baseband signal variations

Doppler Spread :- It occurs when there is relative motion b/w the transmitter & the receiver.
The doppler shift causes different frequency components of signal to arrive at receiver with different phases & amplitudes.

→ The doppler Spread is measure of rate of change of Doppler Shift & determines the time-varying characteristics of the channel.

→ Doppler techniques are used to combine multiple signal paths to mitigate effects of fading.

Parameters of Mobile Multipath Channels

Many multipath channel parameters are derived from the power delay profile (PDP).
Because PDP gives the intensity of a signal received through a multipath channel as a function of time delay.

→ Power delay profile are measured using the following techniques :-

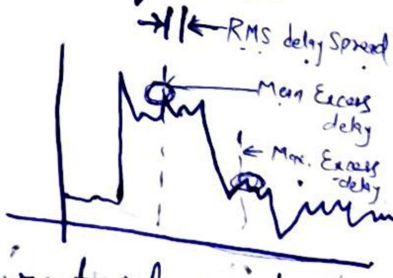
1. Time Dispersion Parameters.
2. Coherence Bandwidth
3. Doppler Spread & Coherence Time

→ PDP are generally represented as the plots of relative received power as a function of Excess delay.

1. Time Dispersion Parameters ⇒ In order to compare different multipath channels & to develop some generating design guidelines for wireless systems, parameter which grossly quantify the multipath channel are used.

Mean Excess Delay :- This is the first moment of PDP.

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



RMS Delay Spread (σ_τ) :- It is the square root of second central moment of power delay profile & is defined to be

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

$$\because \overline{\tau^2} = \frac{\sum a_k^2 \tau_k^2}{\sum a_k^2} = \frac{\sum P \tau^2}{\sum P}$$

Maximum Excess Delay (X in dB) :-

It is defined as time delay during which multipath energy falls to X dB below to maximum

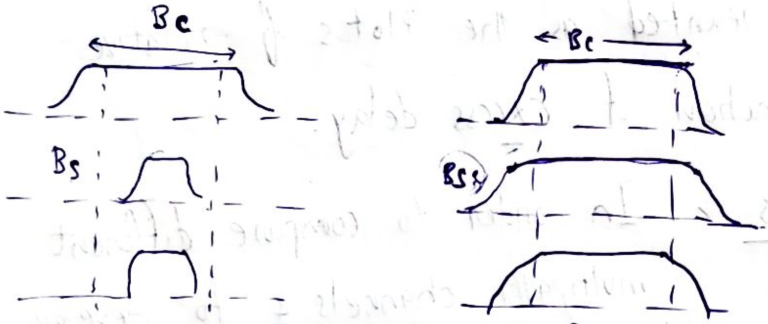
$$X = \tau_x - \tau_0$$

τ_x : max. delay

τ_0 : First Arriving signal

2. Coherence Bandwidth →

Coherence Bandwidth is the statistical measure of range of frequency over which the channel can be considered "FLAT" (a channel which passes all spectral components with approx. equal gain & linear phase.



$B_s < B_c$

[No attenuation in Signal. Called as FLAT Fading Scenario]

$B_s > B_c$

[More attenuation in Signal. Called Frequency Selective fading]

If B_c is defined as bandwidth over which frequency correlation f^n is above 0.9 & 0.5, then B_c is approx. given by

$\boxed{B_c \approx \frac{1}{50\sigma_\tau}}$ for 0.9

$\boxed{B_c \approx \frac{1}{5\sigma_\tau}}$ for 0.5

3. Doppler Spread & Coherence Time →

These describes time dispersive nature of the channel in local area.

Doppler Spread (B_d) :–

- This is the measure of spectral broadening caused by the time rate of change of mobile radio channel & it is defined as range of frequencies over which received doppler Spectrum is essentially non zero.
- The Doppler Spectrum for a sinusodial signal ~~an~~ will have the components $(F_c - F_d)$ to $(F_c + F_d)$ Where F_d is doppler Shift.

$$B_s > B_d \rightarrow \text{Slow Fading}$$

Coherence Time (T_c) :–

- T_c is used to characterise the time varying nature of frequency depressiveness in channel in time domain.
- The Doppler Spread & T_c are inversely proportional.

$$T_c \simeq \frac{1}{f_m}$$

Fast fading Scenario: $T_c \simeq \dfrac{9}{16 \pi f_m}$

When the time Correlation Function is above 0.5

$$T_c \simeq \frac{0.423}{f_m}$$

Fading Effects due to Doppler Spread :-

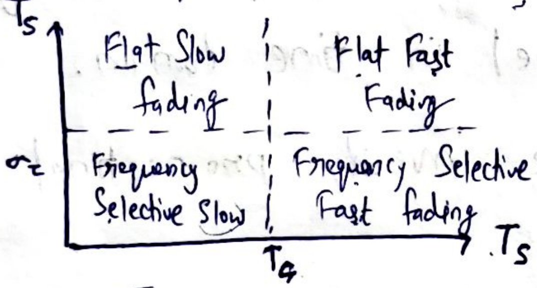
1.) Fast Fading ⇒ The channel impulse response changes rapidly within the symbol duration. That is, the coherence time of channel is smaller than the symbol period of transmitted signal. This causes frequency dispersion due to Doppler Spreading, which leads to signal distortion.

If $T_s > T_c$ & $B_s < B_d$

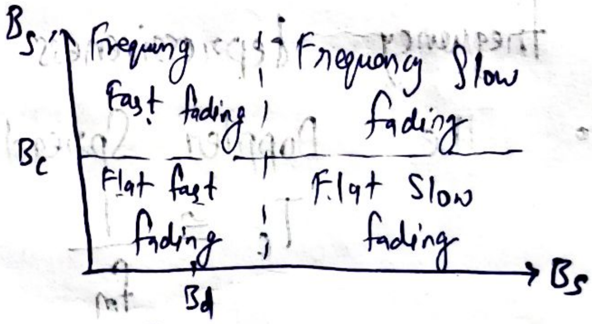
In practice, fast fading only occurs for very low data rates.

2.) Slow fading ⇒ The channel impulse response changes at a rate much slower than transmitted baseband signal.

$T_s << T_c$ & $B_s >> B_d$



(a) Transmitted Symbol Period



(b) Transmitted Baseband Signal Bandwidth

It should be emphasized that fast & slow fading deal with relationship between time rate of change in channel & the transmitted signal, & not with propagation path loss models.

CELLULAR Architecture

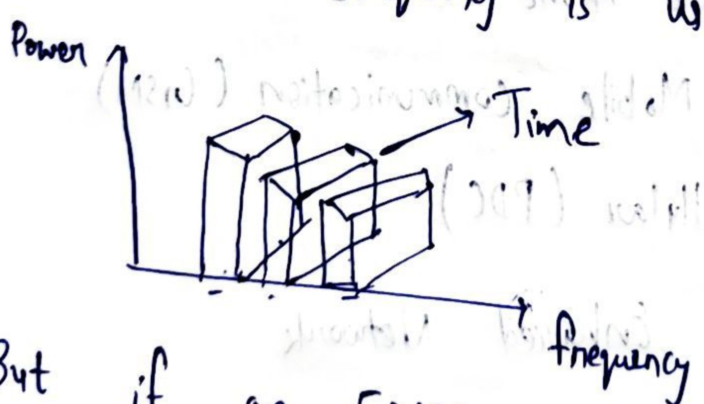
Multiple Access ⇒ It is a signal transmission situation in which two or more users wish to simultaneously communicate with each other using same propagation channel.

Multiple Access Techniques :-

(i) Frequency Division multiple access (FDMA)
(ii) Time Division multiple access (TDMA)
(iii) Code Division multiple access (CDMA)
(iv) Space Division multiple access (SDMA)

(i) Frequency Division Multiple Access (FDMA) ⇒

FDMA is the oldest & multi access method.
FDMA assigns individual channels to individual users.
The users are assigned a channel as a pair of frequencies; One frequency is used for upward channel, while other frequency is used for downward channel.



- But if an FDMA channel is not in use, then it sits idle & cannot be used by other users to increase or share capacity.

→ In FDMA, there is a central controller that allocates the frequency band to users, solely based on their needs.

→ FDMA allows the users to transmit simultaneously; but over disjoint frequency bands, a user exploits a fixed portion of band all the time.

2. Time Division Multiple Access (TDMA) ⇒

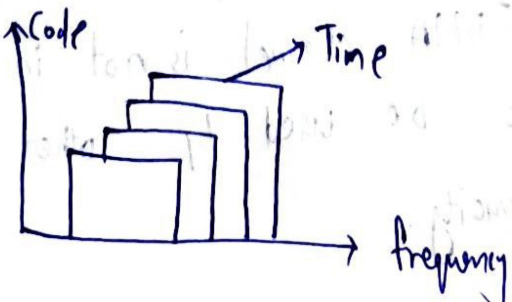
It is a digital modulation technique used in digital cellular telephone & mobile radio commⁿ.

TDMA is one of two ways to divide the limited spectrum available over a radio frequency cellular channel.

→ TDMA enables multiple users to share the same frequency by dividing each cellular channel into different time slots. In effect, a single frequency supports multiple & simultaneous data channels.

⇒ Almost all 2G cellular systems use TDMA, including following:-

- Digital Advanced Mobile Phone Service
- Global System for Mobile Communication (GSM)
- Personal Digital Cellular (PDC)
- Integrated Digital Enhanced Network

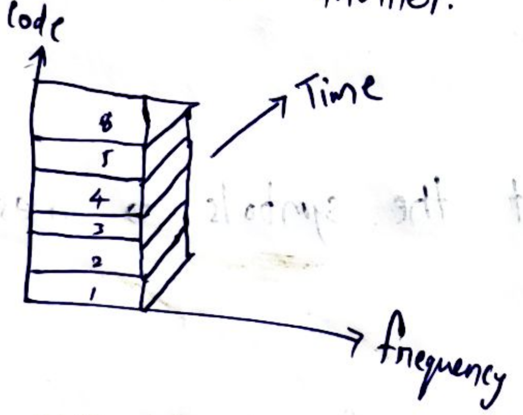


3.] **CDMA** :- It is a method of encoding several sources of data so they may all be transmitted over a single RF carrier by one transmitter, or by using a single RF carrier frequency with multiple transmitters.

→ CDMA refers to any of several protocols used in 2G & 3G wireless communications.

As the term implies, CDMA is a form of multiplexing which allows numerous signals to occupy a single transmission channel, optimizing the use of available band width.

→ CDMA networks use a scheme called soft handoff, which minimizes signal breakup as a handset passes from one cell to another.



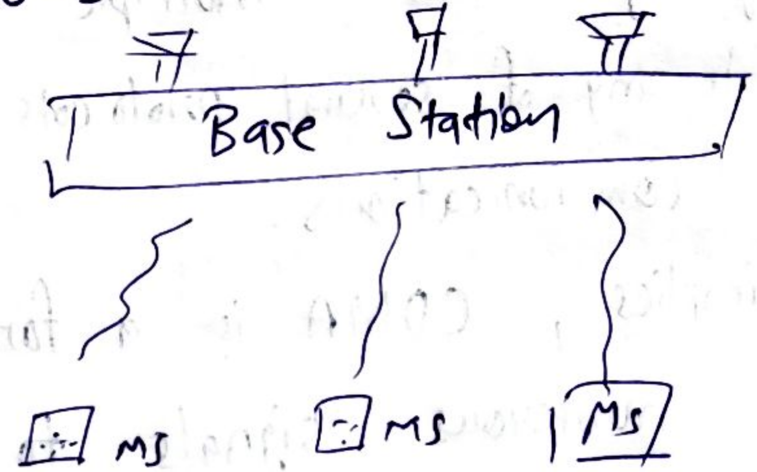
4. **SDMA** :- Space division multiple Access or spatial division MA is a technique which is MIMO (multiple input multiple output) architecture & used mostly in wireless & satellite commn.

→ All users can commn at same time using same channel

→ A single satellite can commn with more satellites receivers of same frequency.

→ The main advantage of SDMA is frequency Reuse.

→ It provides collision free access to comm^n medium for the users.



System Capacity :- Wireless Commn deal with atleast two main concerns: coverage & capacity.

1. **Channel Capacity ⇒** One fundamental concept of information theory is one of channel capacity or how much information can be transmitted in a commn channel.

The shannon capacity equation gives an upper bound for the capacity in a non-faded channel with added white Gaussian noise:

$$C = W \log_2 \left(1 + \frac{S}{N} \right)$$

where
C = capacity (bits/s)
W = Bandwidth (Hz)
S/N = Signal to noise ratio

That capacity eqn assumes one transmitter & one receiver, through multiple antenna can be used in diversity scheme on the receiver side.

2. **Cellular Capacity ⇒** Practical capacity of many wireless systems are far from the Shanon's limit & practical capacity is heavily dependent on implementation & standard choices.

CDMA systems are interference limited and have tradeoffs b/w capacity, coverage and other performance metrics.

Cellular Analog Capacity :- Fairly straight forward, every voice channel uses a 30KHz frequency channel, these frequencies may be reused according to reuse pattern.

TDMA/FDMA Capacity:- In digital FDMA systems, capacity improvements mainly come from the voice coding & elaborate Schemes to decrease reuse factor. The frequency reuse factor hides a lot of complexity.

CDMA Capacity:→

(total noise & interference) $N = 1 + \frac{W}{R} \cdot \frac{1}{E_b/N_t} \cdot \frac{1}{\alpha} \cdot \frac{1}{1+\beta}$

where W is channel bandwidth

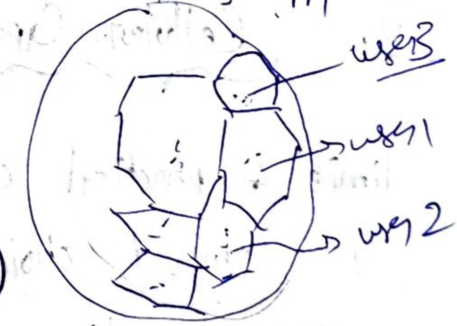
R is user data bit rate

E_b/N_t is ratio of energy per bit by total noise

α is voice activity factor

β interference reuse factor

Channel AssignMent:— It is the process of assigning separate orthogonal channel or partially over lapped orthogonal channels to all nodes in comm^n range.



Channel assignment Strategies ⇒

- Fixed Channel Assignment (FCA)
- Dynamic Channel Assignment (DCA)
- Hybrid Channel Assignment (HCA)

1. Fixed Channel Assignment (FCA) :-

→ It is a strategy in which fixed number of channels are allocated to cells.

→ Cells in this Strategy are allowed to borrow channels ~~fully~~ from adjacent cells if their channels are fully occupied while adjacent cells have free channels. No interference occurs by moving the channel from one cell to another.

→ If all channels are occupied, the call is blocked & subscriber does not receive service.

2. Dynamic Channel Assignment (DCA) :-

It is a strategy in which channels are not permanently allocated to cells.

→ When a User makes a call request then Base Station send that request to MSC (Mobile Station Center) for allocation of channels.

→ MSC allocates frequency channels on dynamic basis if that frequency channel is not presently in use in cell or any other cell which falls within minimum restricted distance of frequency reuse to avoid co-channel interference.

→ It reduces chances of blocking which increases trunking capacity of system as all available channels are accessible to all cells.

3. Hybrid Channel Assignment (HCA) :-

It is combination of both FCA & DCA.

In this total number of channels are divided into fixed & dynamic sets.

The main purpose of HCA is to work efficiently under heavy traffic.