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~~Chapter 2~~ Unit 2

Revision :- diff b/n wired / wireless, Types of services, requirements, challenges, link budget, fading.

Activity : write points on these.

Unit 2 : Physical model : Propagation & loss models.

Properties of wireless channel

→ Time variant / static [mobility of Rx]
→ Time dispersive / non dispersive [one time one signal / diff time. one signal]
→ Linear / non linear [AWGN, Interference]
→ ~~Slow~~ Short or large scale fading
→ . Exhibit Pulse spreading effect - (LPF).

These properties makes the design of WC system a complicated task. Hence we need to model.

- modeling helps to analyse the effects of channel on Txd signal & to predict the reception of signal.
- To simulate process & check the performance.

But unique model cannot describe radio propagation b/n Tx & Rx. Hence we need multiple models.

What are factors to consider when we make model?

- (1) Noise.. / Loss

WKT, if $s(t)$ is Txd signal then

$$\underset{(\text{received})}{r(t)} = \underbrace{\alpha(t)}_{\text{attenuation}} \cdot s(t) + \underbrace{n(t)}_{\text{noise}}.$$ (An

<u>Factors that cause attenuation of Txd signal in Wireless medium</u>

① <u>Free space loss..</u>

Near field: Here radiated power from Antenna is very high & is diff. to calculate power.

$$\boxed{A_{er} = G_r \cdot \frac{\lambda^2}{4\pi}}$$

The free space attenuation is

$$L_{dB} = 20 \log\left(\frac{4\pi d}{\lambda}\right)$$

In far field, signal is affected by mpc & ↑ distance

The received signal power can be measured as

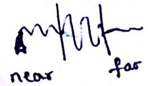
$$P_r = P_t G_t \cdot \frac{1}{4\pi d^2} \cdot A_{er} \rightarrow \text{Effective area of Antenna } \underline{Rx},$$

or $P_r = P_t \cdot G_t\, G_r \cdot \left(\frac{\lambda}{4\pi d}\right)^2$. In terms of λ, G_r

This relation is valid for <u>far field antenna</u>.

Antenna is said to be at far field if the Tx & Rx antenna are <u>at least one</u> <u>Rayleigh distance</u> apart

Rayleigh distance | Fraunhofer distance $d = \frac{2D^2}{\lambda}$.



D: ~~max~~ Largest dimension of Antenna

$(d \gg \lambda$ & $d \gg D) \rightarrow$ far field.

Beyond some area of coverage, the height of Rx also matters. Consider $\boxed{\text{2-ray model}}$.

$$P_r = P_t \cdot G_t \cdot G_r \cdot \frac{h_{\text{basestation}}^2 \cdot h_{\text{mobile}}^2}{d^4}$$ {Path loss model}

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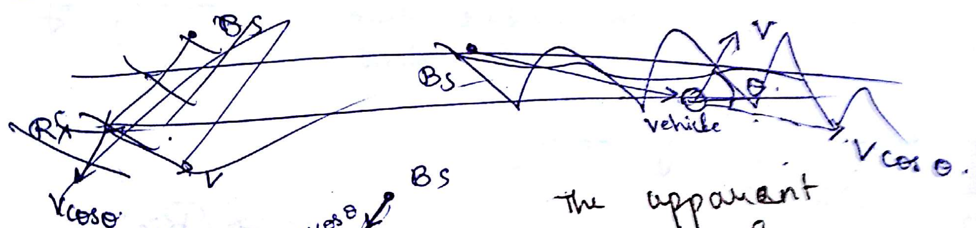
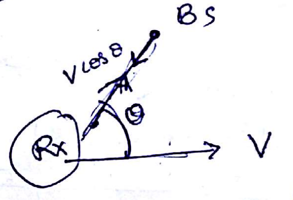
(2) Doppler Spread : [measure of spectral broadening caused by time rate of change of mobile radio channel]

When MS is moving wrt BS, then different direction of multi path components (MPCs) arriving at the MS give rise to different frequency shift. This leads to broadening of received spectrum (Amount of broadening = Doppler Spread).



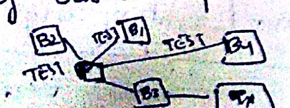


The apparent change in frequency of the wave caused by relative motion between source and observer

f_r (received frequency) $= f_c$ (carrier freq) $\pm f_{shift}$

$f_{shift} = \dfrac{v\cos\theta}{\lambda}$ → wavelength of carrier

(3) Delay Spread: ~~Time delay btw~~ Delay between time when antenna receives first copy of the signal on shortest path & time when it receives last copy of same signal on longest path.



non los→.. scatter all sides

TTTT EEEE SSS TTT

(4) **Fading**: Phenomenon caused by constructive interference of 2 or more copies of same signal that arrive at the receiver.

Caused by Reflection, Diffraction, Scattering & presence of MPCs.

Reflection: Snell's law: $\frac{\sin\theta_1}{\sin\theta_2} = \frac{\lambda_1}{\lambda_2} = \frac{n_2}{n_1}$

Diffraction: bending along edges of MPC. This may result in shadowing.

Scattering: Rough-surface leads to spreading of signal

Two types of fading

(nLOS) Rayleigh ← Large Scale (large distance)

→ Small scale (LOS) ⇒ Rician. (within small area)

To measure such kind of attenuation, we need probability distribution (density) function.

Hence 2 types of distribution is used.

(1) Rayleigh : $\alpha(t) \rightarrow$ attenuation factor wrt time

$$pdf(\alpha) = \frac{\alpha}{\sigma^2} \cdot e^{-\frac{\alpha^2}{2\sigma^2}} \quad 0 < \alpha < \infty.$$

σ : rms value of received signal. (std. dvn) (root mean square)

$\left(\frac{\alpha}{\sigma^2}\right) \rightarrow$ instantaneous power.

This is valid for $\boxed{\text{non-Light of Sight}}$ propagation

(3)

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2) Rician Distribution :

$$\text{pdf}(\alpha) = \frac{\alpha}{\sigma^2} \cdot e^{-\frac{(\alpha^2 + A^2)}{2\sigma^2}} I_0\left(\frac{\alpha A}{\sigma^2}\right).$$

$0 < \alpha < \infty$.

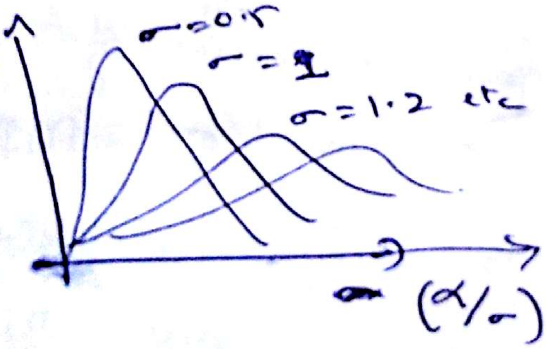
$I_0(x)$: modified Bessel function. describes behaviour of waves in cylindrical medium

$\frac{\alpha}{\sigma^2}$: instantaneous power

A : peak amplitude of dominant signal. which is LOS

Significance of PDf

Plot graph of



⇒ we get the window in which attenuation is maximum.

This adds on to find the maximum coverage area where received signal strength is good. (for designing the WC system) ratio of signal carrying useful info. to unwanted interference

Effect of fading on a device
attenuation

(less signal more ↑ noise.)

→ Reduced signal to Noise Ratio

→ Intersymbol Interference

→ Accounts for total link budget analysis

Measures : 3 band equilizer (high, mid range and low) allows you to ↑/↓ strength of signal within certain frequency band

- Avoid it by using Equalizers.
- Use orthogonal frequency division multiplexing (OFDM) → study this later

orthogonal frequency division multiplexing

Thus we have seen major factors that affect transmitted signal because of the properties of channel or presence of MPCs. This helps us to design a better Receiver system with high Receiver sensitivity.

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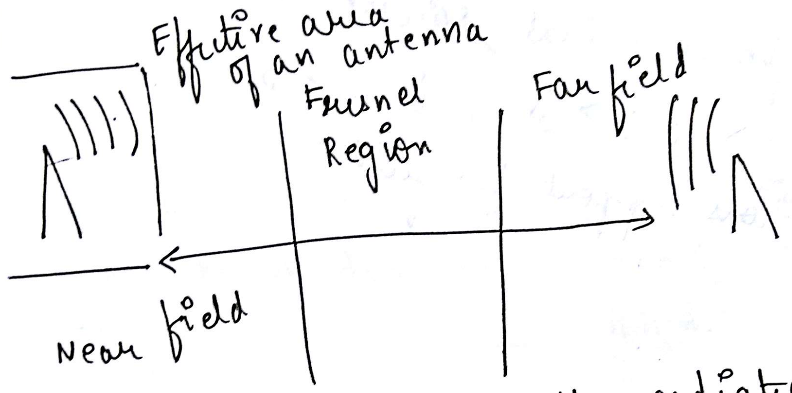
Freespace propogation → Assumes transmitter and reciever antennae are in an obstruction free environment



Near field → Here as the radiated power from the antenna is very high it is very difficult to calculate power.

As the signal propogate further then power of the signal gets affected due to
→ attenuation
→ multipath propogation elements

The minimum distance beyond which the power transmitted by the transmitter varies

dB is a logarithmic ratio of powers

is called as Rayleigh distance

$$d = \frac{2D^2}{\lambda}$$

light speed

where λ is the frequency [wavelength]

and D is the dimension of the antenna

which can be spherical, square etc.

far field $\rightarrow$ $d >> \lambda$, $d >> D$

These conditions support far field.

is called as Rayleigh distance

$$d = \frac{2 \times D^2}{\lambda}$$

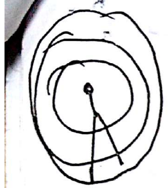
where λ is the $\frac{\text{light speed}}{\text{frequency}}$ [wavelength]

and D is the dimension of the antenna which can be spherical, square etc.

far field $\rightarrow$ $d >> \lambda$, $d >> D$

These conditions support far field.

Friis transmission equation



→ radiation is isotrophic ie in all direction.

$$\text{Power Density} = \frac{\text{Transmitted Power}}{\text{Surface Area.}}$$

(radiated power per unit area) reduces with distance

since the area is spherical

$$\text{Power density} = \frac{\text{Transmitted Power}}{4\pi d^2}$$

Tranmitting antenna also involves gain

$$St \rightarrow \text{Power density} = \frac{P_T}{4\pi d^2} \times G_T$$

$$\text{Recieving power} = St \times \underbrace{A_r}_{\text{Effective area of the reciever}}$$

$$= \frac{P_T}{4\pi d^2} \times G_T \times A_r$$

where effective area is the area of the antenna which actually captures the signal

$$A_r = \frac{G_r \lambda^2}{4\pi}$$

dB is a logarithmic ratio of powers

On substituting

$$P_r = P_T \times G_T \times G_R \left(\frac{\lambda}{4\pi d}\right)^2$$

Doppler effect–

when a wave source and reciever are moving frequency of recieved signal will not be the same as the source

→ when moving towards each other frequency is higher than source

→ when moving away from each other frequency is lesser.

The frequency of recieved signal

$$f_R = \underbrace{f_c}_{\text{source}} \pm \underbrace{f_D}_{\text{Doppler frequency}}$$

$$f_D = \frac{v}{\underbrace{\lambda}_{\text{wavelength of carrier}}} \cos\theta .$$

Delay spread → when signal propogates from transmitter to reciever signal suffers 1/more reflections. This forces the signal to follow different paths of varied path length. The time of arrival for each path is different causing spreading of signal (intersymbol interference)

Why modelling is important?

→ Channels have various effects on them, some of which is adverse. One must be able to analyze the effects of the channel on the transmitted signal and to predict the reception of the signal.

→ Rather than directly making the channel (which is costly) we simulate the channel conditions to analyze the its performance in various selected conditions.

Introduction to channel modelling

Channel modelling is necessary to study & analyze a wireless system. So listing out channel properties is essential as these contribute to performance of the system:

→ Time varying or static → Multipath effect makes the channel time varying and depending on constructive/destructive interference quality of signal deteriorates. Effect of mobility which results in rapid fluctuations of received power slower movement, lesser variation

→ Time dispersion / non dispersive → causes inter symbol interference by pulse spreading

→ linear / nonlinear (o/p not proportional to i/p) caused by distortion (variation in shape of signal)

→ low pass filter (allows signal with a frequency lower than certain threshold) and attenuates the signal higher than cut off

→ channels may be fading or shadowing

Time dispersion → display of multiple pathways that spread signal in time so that length of time of signal is recieved is greater than that signal was sent out.

reflection → occurs when a radio wave hits a surface with much greater length than the wavelength and bounces off

diffraction → occurs when the path btw the transmitter and reciever is blocked by a dense object (with much greater wavelength) forming secondary wave behind obstruction. which bend around the obstacle.

scattering → when wave hits a rough surface smaller than the wavelength / surface with dimensions causing reflected energy to scatter (tx signal reach reciever using many directions) (particles in air)

Principle of fading & deep fade.
→ used to combat fading

Traditionally

If this single link is in deep fade disrupt communication

[Tx] —— single link —— [Rx]
Transmitter link Reciever

No attenuation to transmit the signal.

Example → stopping at traffic light and hearing FM broadcast degenerate into static, signal is reacquired if the vehicle moves fraction of a meter. (momentary fade experienced due to severe distructive interference)

If single link is in a deep fade performance of communication systems

Deep Fade → Reciever sees superimposition of multiple copies of transmitted signal each traversing a different path. Each single copy experiences attenuation, delay and phase shift causing constructive or distructive interference (amplifying or attenuating) the signal.

strong distructive interference is called as deep fade which may result in temporary failure of communication due to severe drop in SNR ratio

To avoid deep fade

- Consider a system with multiple links

2 links in deep fade

alternative paths are present for signal to propagate from transmitter to reciever.

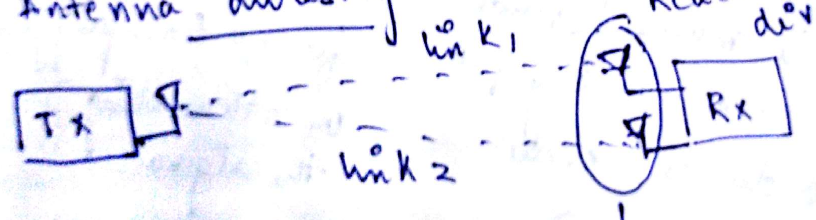
Thus, communication is not disrupted.

Diversity term means many alternative.

Example

Antenna diversity

Recieve diversity



multiple recieve antennas.

Reciever gets redundant copy of the same signal and it selects signal with greater power.

Multiple transmit antennas → Transmit diversity

Then choose the signal with greater strength → combining

Diversity → Multiple versions of the same signal are transmitted using different paths

→ Main difference between behavior of wireless and wired media is the extensive fluctuations of multipath and shadow fading.

→ In order to compensate the effects of fading when operating ~~when operating~~ with a fixed power transmitter, the power must be increased by several orders of magnitude relative to non fading operation

Principle of diversity → Ensure that the same information reaches the reciever on statistically independent channels

Consider the simple case of reciever with 2 antennas. The antennas are assumed to be far enough from each other and the small scale fading is independent at the 2 antennas. The reciever choses the antenna that has larger recieve power.

Types → Macro diversity → 4 large scale. select 4m BS that is not shadowed
→ Micro diversity → 4 small scale. separated by a fraction of m. Choose the signal with greater strength

Schemes → ① space diversity → wired → uses multiple paths btwn transrecievers
wireless → transmit (multiple transmitter antennas)
↘ recieve diversity (multiple reciever antennas)
seperated by a distance of $\frac{1}{2}\lambda$

Eg site based diversity where reciever antennas are located at different sites.

② Polarization → single polarized antenna → waves that are transmitted / recieved are either horizontal / vertical polarized
dual polarized → 2 seperate set of transrecievers each 4 horizontal and vertical polarization

③ Angle diversity → antennas with different radiation patterns eg horn antenna and vertical antenna are used.

④ Frequency diversity → use more than 1 carrier frequency (transmitter operating at different frequencies) used in microwave communication that employs frequency band 2 - 60 GHz in FDM mode.

⑤ Time Diversity → multiple versions of the same signal are transmitted in various time instants

Time difference = $\frac{1}{\text{fading bandwidth}}$ where fading bandwidth = 2 × speed of MS / λ

Scanned by CamScanner

separate with multiple

G_{dBi} for reciever $= 10^{0/10} = 10^0 = \underline{\underline{1}}$

On substituting

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

$$= 6.3 \times 1 \times \left(\frac{1.116}{4 \times \pi \times 5000}\right)^2$$

$$= 6.3 \times (1.776 \times 10^{-5})^2$$

$$= 1.98 \times 10^{-9} \text{ dBi}$$

$$G\,dB = 10 \log_{10} G_{dBi}$$

$$G\,dB = 10 \log_{10} 1.98 \times 10^{-9}$$

$$= \underline{\underline{-87\,dB}}$$

$$\frac{P_t}{P_r} = \left(\frac{4\pi d}{\lambda}\right)^2 \times \frac{1}{G_t \times G_r}$$

$$= \left(\frac{4 \times \pi \times 5000}{1.116}\right)^2 \times \frac{1}{6.3 \times 1}$$

$$= 503142262.2 \text{ dBi}$$

$$G_{dB} = 10 \log_{10} G_{dBi}$$

$$= 87\,dB$$

dB is a logarithmic ratio of powe...

Problems → Attenuation Example 3.1 Vijay Garg

Free space attenuation →

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

Given frequency = 881.52 MHz

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8 \text{ m/s}}{881.52 \text{ M}} = 0.34032 \text{ m}$$

To convert m to ft

m × 3.281 = ft

0.34032 × 3.281 = 1.116 ft.

As distance is given in ft conversion is required

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

Gain should be expressed in GdBi

$G_{dB} = 10 \log_{10} G_{dBi}$ ⟹ $P_{dB} = 10 \log_{10} P_{unitless}$

$G_{dBi} = 10^{G_{dB}/10}$

$8\,dB = 10 \log_{10} G_{dBi}$

$G_{dBi} = 10^{8/10} = 10^{0.8} = 6.3$ [transmitter]

$\times 3$

1.144

o ft conversion

$\times 3.281 = ft$

$1.144\ ft$

$f_m = \dfrac{v \cos\theta}{\lambda}$ → as the vehicle is moving towards source.

$= \dfrac{88}{1.144} = 77\ Hz$

$$\frac{P_t}{P_r} = \left[\frac{d^2}{h_b h_m}\right]^2 \times \frac{1}{G_b G_m} = \left[\frac{5000^2}{100 \times 5}\right]^2 \times \frac{1}{6.3 \times 1}$$

$$= 396825396.8 \text{ dBi}$$

To find $G_{dB} = 10 \log_{10} G$ dBi

86 dB

$$P_{dBm} = 10 \cdot \log_{10}\left(\frac{P_{mW}}{1 mW}\right)$$

$$P_{mW} = 1 mW \times 10^{P_{dBm}/10}$$

$$P_W = 1W \times \frac{10^{(P_{dBm}/10)}}{1000}$$

Problem → Doppler's spread

60 miles/hr to feet/sec

1 m = 5280 ft

1 hr = 60 min

1 min = 60 sec

$$\frac{60 \text{ miles}}{1 \text{ hr}} \cdot \frac{5280 \text{ ft}}{1 \text{ miles}} \cdot \frac{1 \text{ hr}}{60 \text{ min}} \cdot \frac{1 \text{ min}}{60 \text{ sec}}$$

$$= \frac{5280}{60} = \frac{88 \text{ ft}}{1 \text{ sec}}$$

Doppler's shift $= f_m = \frac{v \cos\theta}{\lambda}$

$$\lambda = \frac{c}{f_c} = \frac{3 \times 10^8}{860 \text{ MHz}} = 0.3488 \text{ m}$$

Problems on LCR and AFD

$LCR = \sqrt{2\pi} \cdot f_m \cdot \rho \cdot e^{-(\rho^2)}$

Given $\rho = 1$

$f_m = 20\,Hz$

On substituting, $LCR = 18.44$ fades/s.

$f_m = \frac{v}{\lambda} \cos\theta$ where $\lambda = \frac{c}{f}$

$= \frac{v}{c/f} \cos\theta$ considering $\angle\theta = 0$

$f_m = v \times \frac{f}{c}$

$v = f_m \times \frac{c}{f} = 20 \times \frac{3 \times 10^8}{900 \times 10^6} = 6.66\ m/s.$

Average fade duration $= \frac{e^{-\rho^2}}{\rho \cdot f_m} \times \frac{1}{\sqrt{2\pi}}$

$\frac{e^{-(1^2)}}{1 \times 20} \times \frac{1}{\sqrt{2\pi}} = 0.00738$

Taking $f_m = 77\,Hz$

$LCR = \sqrt{2\pi} \times 77 \times \rho \times e^{-1}$

$= 71.004$ fades/second

$$ADF = \frac{e^{-1}}{1 \times 77} \times \frac{1}{\sqrt{2\pi}}$$

$$= 1.906 \times 10^{-3} s$$

We infer that more the doppler shift more fades

Calculate ADF and LCR for $f_m = 88\,Hz$

$LCR = 81$ fades/s

$ADF = 1.66 \times 10^{-3}\,s$.

client

dBm → transmitter
-2 dB → cable.

+10 dBi → Transmitter antenna

+ 14 dBi → reciever antennae
- 2 dB → cable

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40 dB
- 114 dB → free space loss

- 74 dBm → dBm because it is at the reciever and must be compared with the reciever sensitivity
- - 82 dBm

8

client to AP

+ 15
- 2
+ 14
+ 10
- 2

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35 dB
- 114 dB

- 79 dBm

- 79 dBm
- - 89 dBm

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10 dB

link margin