

Subject :

Date :

**A5**

NPTEL Lecture

Wireless Communication:-

By :- Prof. Aditya K. Jagannatham

2G

Wireless System

family for 2G | 2.5 | 2.7 G.

Wireless Standard

2G

GSM (Global system for mobile communication)

Basic voice data rate  
10 kbps (kilo bits/sec)

2G

CDMA (Code Division multiple Access)

10 kbps

2.5G

GPRS (General packet Radio service) has  
Access of data rate.

~50 kbps

2.5G (G)

EDGE (Enhanced Data for GSM Evolution)

~200 kbps

2.7G

3 Generation Wireless standards:-

Data Rate

3G

WCDMA (wide band CDMA) / UMTS (universal mobile  
Telecom standard)

WCDMA (384 kbps)  
voice/video.

3G.

CDMA 2000

384 kbps

3.5G

HSDPA / HSUPA (High speed downlink packet Access)  
High " uplink " "

5-30 Mbps

3.5G

1xEVDO ; ~~Rev~~ A,B,C (Revision A,B,C version)  
(Evolution Data optimized)

5-30 Mbps

## 4G Wireless System Standards:-

4G	LTE (Long Term Evolution)	100 - 200 Mbps.
4G	WiMax (Worldwide Interoperability for 802.11a/b/g/n wave Access)	100 - 200 Mbps.

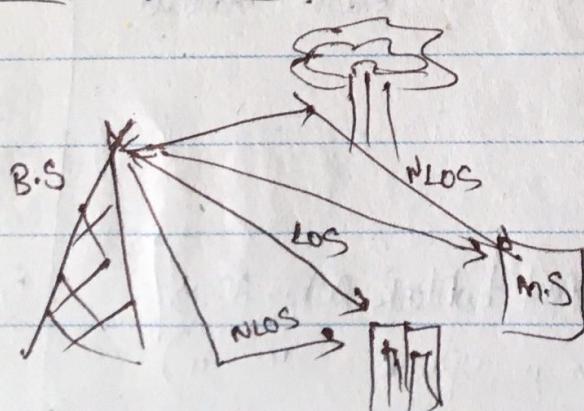
## Prerequisites :-

1. Probability & Random Process
2. Digital Communication Systems
3. Introductory Course Wireless Systems
4. Linear Algebra

## Relevant Nptel Courses

1. Communication Engineering
2. Digital Comm.
3. Wireless Communication

## Wireless Communication:-



Scatters occurred b/w Base station to mobile station  
Eg:- Trees ; Cells ; Buildings

→ Multipath Propagation Environ

- Direct path is known as LOS (Line of Sight) components.
- Scatter paths is " " NLOS (Non-line of sight) Components.

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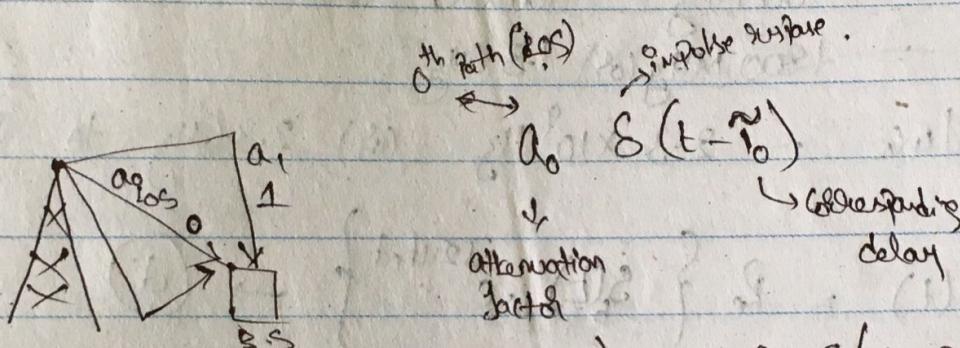
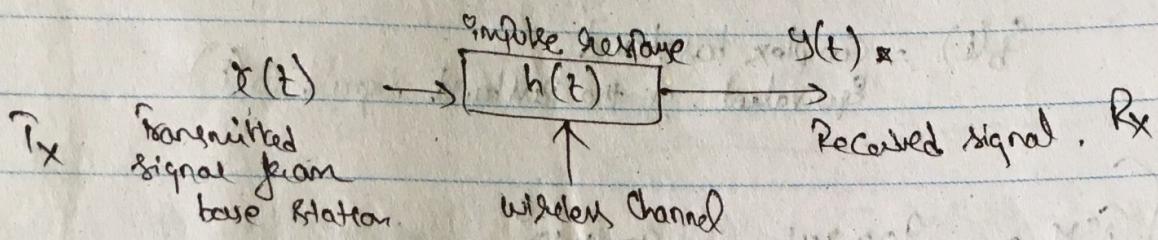
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→ Multipath Components add with different components with different phases  
 factors resulting as Constructive (g) Destructive Interference

Constructive interference is good, signal level goes up.

Destructive level is bad " " " down (ie no reception in signal)



$$1^{\text{st}} \text{ path} \rightarrow a_1 \delta(t - \tau_1); a_2 \delta(t - \tau_2)$$

$$\vdots$$

$$a_{L-1} \delta(t - \tau_{L-1})$$

wireless channel impulse response  $\underbrace{h(t)}$  multipath component

$$h(t) = a_0 \delta(t - \tau_0) + a_1 \delta(t - \tau_1) + a_2 \delta(t - \tau_2) + \dots + a_L \delta(t - \tau_{L-1})$$

wireless channel

$$h(t) = \sum_{i=0}^{L-1} a_i \delta(t - \tau_i)$$

→ time domain  
 → (b)



(4) (a)

Widely Spaced Signal  $S(t)$  :-

$$S(t) = \operatorname{Re} \left\{ S_b(t) \cdot e^{j2\pi f_c t} \right\} \rightarrow (c)$$

↓ Read Part

Polar Baseband - Passband Representation.

 $f_c$  = Carrier Frequency $S_b(t)$  = Complex baseband equivalent of the passband signal  $S(t)$ 

$$f_c = \begin{cases} \text{GSM} = 900 \text{ MHz} & 900 \times 10^6 \\ = 1800 \text{ MHz (or)} & 1.8 \text{ GHz} \\ 3G/4G = 2.3 \times 10^9 \text{ Hz (or)} & 2.3 \text{ GHz to } 2.6 \times 10^9 \text{ Hz (or)} 2.44 \text{ GHz} \end{cases}$$

$$S(t) = \operatorname{Re} \left\{ S_b(t) \cdot e^{j2\pi f_c t} \right\} \rightarrow (d)$$

$$h(t) = \sum_{i=1}^{L-1} a_i \delta(t - \tau_i) \rightarrow (e)$$

$$\therefore y(t) = S(t) * h(t) \rightarrow (f)$$

 $\alpha^{\text{th}}$  Component

$$y(t) = \operatorname{Re} \left\{ a_0 S_b(t - \tau_0) \cdot e^{j2\pi f_c (t - \tau_0)} \right\} \rightarrow (f)$$

$$y_1(t) = \operatorname{Re} \left\{ a_1 S_b(t - \tau_1) \cdot e^{j2\pi f_c (t - \tau_1)} \right\}$$

$$y_{L-1}(t) = \operatorname{Re} \left\{ a_{L-1} S_b(t - \tau_{L-1}) \cdot e^{j2\pi f_c (t - \tau_{L-1})} \right\} \rightarrow (g)$$

(5)

Net Signal  $y(t) =$ 

$$y(t) = \operatorname{Re} \left\{ \sum_{i=0}^{L-1} a_i s_b(t - \tau_i) e^{j2\pi f_c(t - \tau_i)} \right\} \rightarrow \text{Received signal (Rx)}$$

$$= \operatorname{Re} \left\{ \left\{ \sum_{i=0}^{L-1} a_i s_b(t - \tau_i) e^{-j2\pi f_c \tau_i} \right\} \cdot e^{j2\pi f_c t} \right\} \rightarrow h$$

Complex signal.

Complex Baseband Rx signal =

$$s_b(t) = \sum_{i=0}^{L-1} a_i s_b(t - \tau_i) e^{-j2\pi f_c \tau_i}$$

Complex phase factor

 $a_i$  - amplitude $\tau_i$  - delay factor.

$$s_b(t) = \sum_{i=0}^{L-1} a_i s_b(t - \tau_i) e^{-j2\pi f_c \tau_i}$$

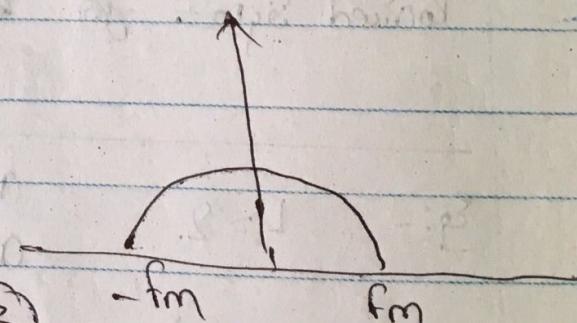
let narrow band signal assumptionlet  $f_m$  be maximum frequency component of  $s_b(t)$ Eg:- GSM  $f_m = 100 \text{ KHz}$ 

Narrow band condition

$$\text{if } f_m \ll \frac{1}{\tau_i} \rightarrow ①$$

$$\tau_i = 1 \mu\text{sec} \rightarrow ②$$

$$\frac{1}{\tau_i} = 1/\mu\text{sec} = 1 \text{ MHz} \rightarrow ③$$



GSM is a narrowband signal.



for a narrowband signal:-

$$S_b(t - \tau_p) = S_b(t) \rightarrow J$$

$$\therefore y_b(t) = S_b(t) \cdot \sum_{i=0}^{L-1} e^{-j2\pi f_c \tau_i} \rightarrow K$$

↓                            ↓  
 × base band    × Complex Received / complex factor  
 signal            signal.

Complex Co-efficient

Example:-

$$L=2 \quad \left\{ \begin{array}{l} a_0 = 1 \quad ; \quad \tau_0 = 0 \\ 2\text{-Path} \quad a_1 = 1 \quad ; \quad \tau_1 = \frac{1}{2}f_c \end{array} \right.$$

Complex Co-efficient

$$h = \sum_{i=0}^{L-1} a_i e^{-j2\pi f_c \tau_i}$$

Path 1

$$= \sum_{i=0}^{L-1} a_i e^{-j2\pi f_c \tau_i}$$

$$h = 1 + 1 \underbrace{\left( e^{-j\pi} \right)}_{2\text{-nd Path}} = 1 + (-1) = 0$$

Received Signal. ~~at~~ ~~for~~  $y = S_b(t) \times 0$

$$= 0$$

Eq:-  $L=2$        $a_0 = 1 \quad \tau_0 = 0$   
 $a_1 = 1 \quad \tau_1 = \frac{1}{2}f_c$

$$\Rightarrow h = 1 + 1 = 2$$

$$\therefore y_b(t) = S_b(t) \times 2 = 2 S_b(t)$$

here signal is twice in amplitude and in power.

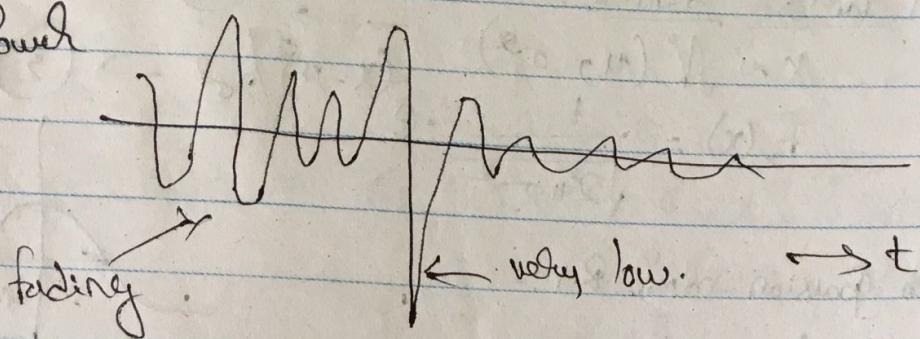
where signal is received in direct & indirect path both are combined at  $2 S_b(t)$

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Power



\* Analytical models :-

Wired Systems

$$y_b(t) = h s_b(t) \rightarrow l$$

Complex fading Co-efficient

both cases have noise

wired (or) wireless Systems

$$\boxed{y_b(t) = s_b(t)} \quad \text{ie only a single path} \rightarrow m$$

\* Statistics of the fading Co-efficient :-

$$h = \sum_{i=0}^{L-1} a_i e^{-j2\pi f_c t_i} = x + jy = a \cdot e^{j\phi} \rightarrow n$$

magnitude

$$= \sum_{i=0}^{L-1} a_i \cos(2\pi f_c t_i) - j \sum_{i=0}^{L-1} a_i \sin(2\pi f_c t_i) \rightarrow o$$

$$x = \sum_{i=0}^{L-1} a_i \cos 2\pi f_c t_i \rightarrow p$$

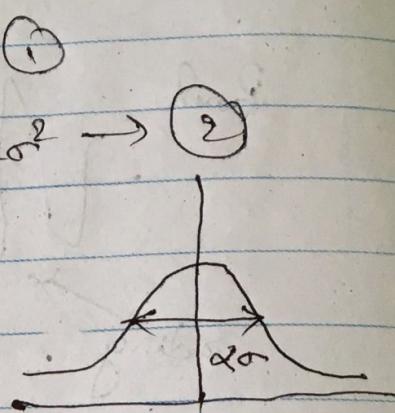
$$y = \sum_{i=0}^{L-1} a_i \sin 2\pi f_c t_i \rightarrow q$$



(6)

\* Gaussian Random Variable :-

$$X \sim N(\mu, \sigma^2) \xrightarrow{1} f_X(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \xrightarrow{2}$$



a) Standard Gaussian random R.V. :-

$$N(0, 1) \xrightarrow{1} f(x) = \frac{1}{\sqrt{2\pi}} e^{-\frac{x^2}{2}} \xrightarrow{2} \text{PDF of Standard Gaussian R.V.} \xrightarrow{3} \text{Probability Distribution Function.}$$

(b) Complex fading Co-eff.

$$h = x + iy \xrightarrow{a}$$

sum of a large no. of random components

$x, y$  to be Gaussian in nature.

Central Limit Theorem

$$h = x + iy$$

$$f_x(x) = \frac{1}{\sqrt{2\pi}} e^{-\frac{x^2}{2}}$$

$$= \frac{1}{\sqrt{\pi}} e^{-\frac{x^2}{2}}$$

$$f_y(y) = \frac{1}{\sqrt{\pi}} e^{-\frac{y^2}{2}}$$

$$f_{x,y}(x, y) = \frac{1}{\pi} e^{-(x^2+y^2)}$$

$$x \sim N(0, 1/2)$$

$$y \sim N(0, 1/2)$$

$x, y$  are independent R.V.s

Joint distribution of components  $x$  &  $y$   $\xrightarrow{c}$



(7)

$$\Rightarrow h = x + iy = a \cdot e^{j\phi} \xrightarrow{\text{Phase}} \rightarrow \textcircled{4}$$

magnitude  $(a, 0)$

$$x = a \cos \phi ; y = a \sin \phi$$

$$f_{x,y}(x,y) \approx x^2 + y^2 = a^2 \cos^2 \phi + a^2 \sin^2 \phi \\ = a^2 (\cos^2 \phi + \sin^2 \phi) \\ = a^2.$$

$$\text{Jacobian } f_{x,y}(x,y) = \frac{1}{\pi} \cdot e^{-(x^2+y^2)} \rightarrow \textcircled{5}$$

$$\therefore f_{A,\phi} = \frac{1}{\pi} e^{-a^2} \det(J_{xy}) \xrightarrow{\text{Jacobian matrix}} \textcircled{6}$$

$$\text{where } J_{xy} = \begin{bmatrix} \frac{\partial x}{\partial a} & \frac{\partial y}{\partial a} \\ \frac{\partial x}{\partial \phi} & \frac{\partial y}{\partial \phi} \end{bmatrix} \rightarrow \textcircled{7}$$

$$J_{xy} = \begin{bmatrix} \cos \phi & \sin \phi \\ -a \sin \phi & a \cos \phi \end{bmatrix} \rightarrow \textcircled{8}$$

$$\text{Determinant } \det(J_{xy}) = (a \cos \phi \cdot \cos \phi - (-a \sin \phi) \cdot \sin \phi) \\ = a \cos^2 \phi + a \sin^2 \phi \\ = a (\cos^2 \phi + \sin^2 \phi) \rightarrow \textcircled{9}$$

$$\det(J_{xy}) = a$$

$$f_{A,\phi} = \frac{1}{\pi} \cdot e^{-a^2} \cdot a$$

$$\boxed{f_{A,\phi} = \frac{1}{\pi} \cdot a \cdot e^{-a^2}} \rightarrow \textcircled{10}$$



(B)

Marginal distribution :-

$$\underbrace{f_A(a)}_{\text{marginal distribution}} = \int_{-\pi}^{\pi} f_{A,\phi}(a, \phi) d\phi$$

$$= \int_{-\pi}^{\pi} \frac{a}{\pi} \cdot e^{-a^2} d\phi$$

$$= \frac{a}{\pi} e^{-a^2} \int_{-\pi}^{\pi} d\phi$$

$$F_A(a) = 2 \pi \frac{a}{\pi} e^{-a^2} = 2a \cdot e^{-a^2}$$

$$a = \sqrt{x^2 + y^2}$$

Envelope

Fading channel

$$0 \leq a \leq \infty$$

$$f_A(a) = 2a \cdot e^{-a^2}$$

Rayleigh fading distribution  
density function.

$$f_\phi(\phi) = \int_0^\infty \frac{a}{\pi} \cdot e^{-a^2} da$$

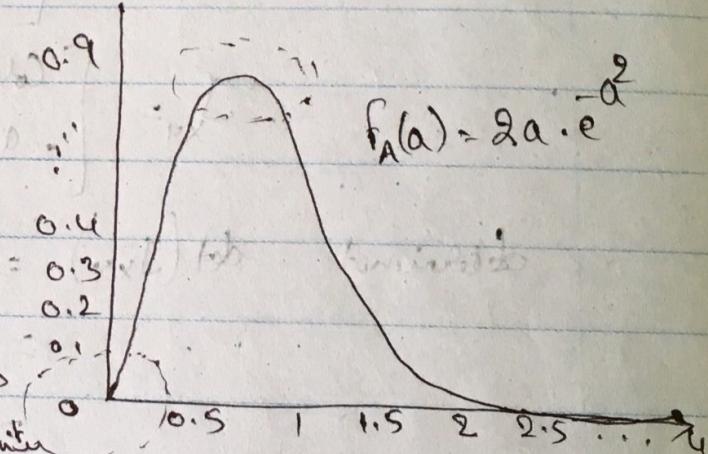
$$= \int_0^\infty \frac{1}{2\pi} \cdot (2ae^{-a^2}) da$$

$$= \left[ \frac{a^2}{2} \right]$$

$$= \frac{1}{2\pi} \left( -e^{-a^2} \Big|_0^\infty \right)$$

$$= \left( \frac{1}{2\pi} \right)$$

$$\Rightarrow f_\phi(\phi) = \frac{1}{2\pi}$$



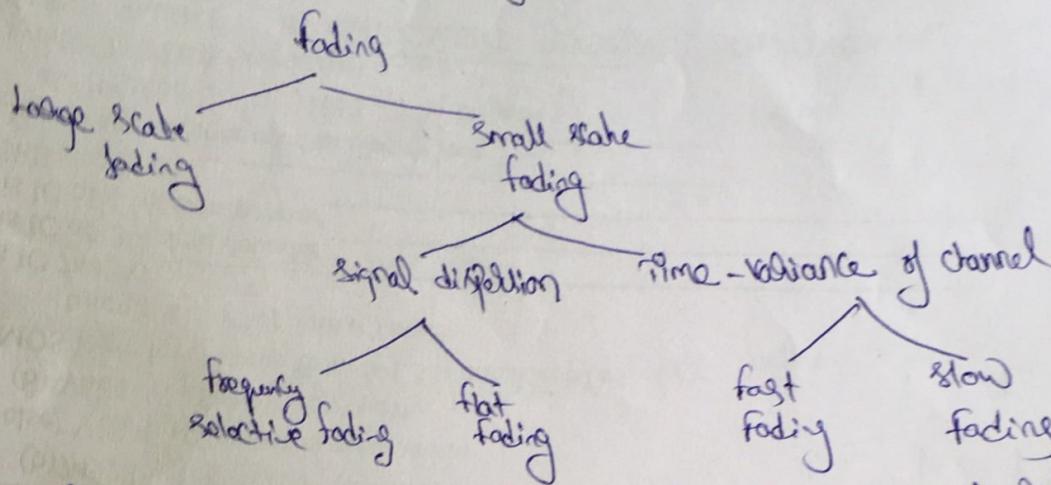
deep fade  
when channel magnitude  
Amplitude is low

$\Rightarrow$  uniform distribution in  $(-\pi \text{ to } \pi)$

## FADING

①

- Fading:- In cellular Comm - channels the time variant feature leads to a particular phenomenon - called fading.
- (\*) Fading is deviation of attenuation which affects a signal during propagation.
  - (\*\*) " " Caused by interference b/w 2 or more versions of transmitted signals which arrive at the receiver at slightly different times.



- In wireless Comm the signal can travels tx to Rx over multiple reflective paths, is called (multipath propagation)
- Constructive and destructive interference and phase shifting of signals results from multipath propagation.
- Destructive interference cause fading
- When the magnitude of signals arriving by the various paths have a distribution resembling the Rayleigh distribution it is known as Rayleigh fading.
- Where one component dominates, a Rician distribution is a better suited model, known as Rician fading.

### Techniques for avoiding:-

- OFDM :- Orthogonal Frequency Division Multiplexing) is a method where digital data is encoded on multiple parallel frequencies. (wire & wireless digital communication).
- MIMO :- In radio Comm - Multiple Input Multiple Output is a method of using multiple antennas at both tx and rx to improve Comm Performance. It is a part of Smart Antenna technology.

→ RAKE Receiver:- Is a radio receiver designed to overcome the effects of multipath fading. Several sub receivers, each assigned to a different multipath are used.

→ Each independently decodes a single multipath component and the contribution of all combined to provide a high signal to noise ratio or  $(E_b/N_0)$  in multipath environment.

→ Rayleigh fading:-

The Rayleigh distribution has a Probability density function given by,

$$P(x) = \begin{cases} \frac{x}{\sigma^2} \exp\left(-\frac{x^2}{2\sigma^2}\right) & (0 \leq x \leq \infty) \\ 0 & (x \leq 0) \end{cases} \quad (\sigma = \text{rms})$$

$\sigma$  = rms value of received signal.

$x^2$  = instantaneous Power

$\sigma^2$  = low average power of received signal before detection.

→ Rayleigh fading channel:-

In mobile radio channels the Rayleigh distribution is commonly used to describe the statistical time varying nature of received envelope of a flat fading signal, (or) the envelop of an individual multipath component.

→ It is well known that envelop of the sum of two independent Gaussian noise signals obeys a Rayleigh distribution

→ AWGN:- (Additive White Gaussian Noise)

is a basic noise model used to replicate the effect of several random process that occur in nature.

→ 'Additive' bcz it is added to any noise that might be intrinsic to information system

→ 'White' bcz the fact that it has uniform power across the freq band for the information system. It is analogy to the color white has uniform emission at all frequencies in visible spectrum.

→ "Gaussian" :- bcz it has normal distribution in the time domain with an average time domain value of zero.

→ AWGN model does not account for fading, frequency selectivity, interference, non-linearity (or) dispersion.

→ Bit Error Rate (BER) / Bit Error Ratio (BER):-

is the no. of bit errors divided by total no. of transferred bits during a studied time interval.

$$BER = \frac{\text{no. of errors bits}}{\text{total no. of bits sent}}$$

→ In a noisy channel the BER is often expressed as a function of the normalized carrier to noise ratio measure denoted ( $E_b/N_0$ ) (Energy per bit to noise power spectral density ratio).

BER Condition:- In AWGN channel the BER as

In the case of QPSK modulation and AWGN channel the BER as function of the  $E_b/N_0$  given by

$$BER = \frac{1}{2} \operatorname{erfc} \left( \sqrt{\frac{E_b}{N_0}} \right)$$

→ Nakagami fading:-