Fundamentals of MIMO Wireless Communication

Tutorial

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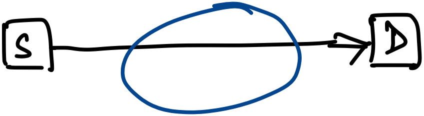
Protocol layers.



→ hosts

→ router

→ communication links

→ Application running on end users systems

→ Protocols

→ hew s/w on router devices

☑ Need for proper structure. → how data goes from source to destination.

Air travel: (Source)

→ ticket ⟷ → Tickets (complaint)

→ Baggage (check) ⟷ → Baggage (claim)

→ Gates (load) ⟷ → Gates (unloaded)

→ Takeoff ⟷ → landing

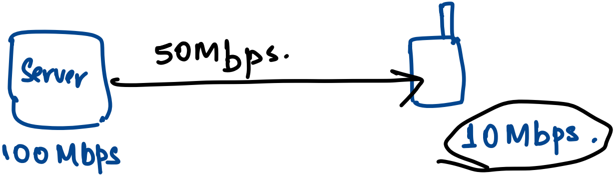
Airplane routing
(ATC) centres.

- Application → Presentation & Session layer.
- Transport
- Network layer
- Data Link layer
- Physical layer (Physical transmission of data).

Application layer : eg: Browser on client side
Webserver on server side.

→ HTTP, HTTPS, etc.

Transport layer : → Reliability of commⁿ. (QoS)



→ decrease data rate
→ ↑se data rate.

Send Automatic Repeat Request & get the data retransmitted.

→ TCP, UDP

✓ TCP : Provides feedback (slow, reliable).

✓ UDP : faster, no feedback (movie streaming).

Network layer: Determines correct path to reach destination.

→ Routing from source to destination.

→ IP protocol.

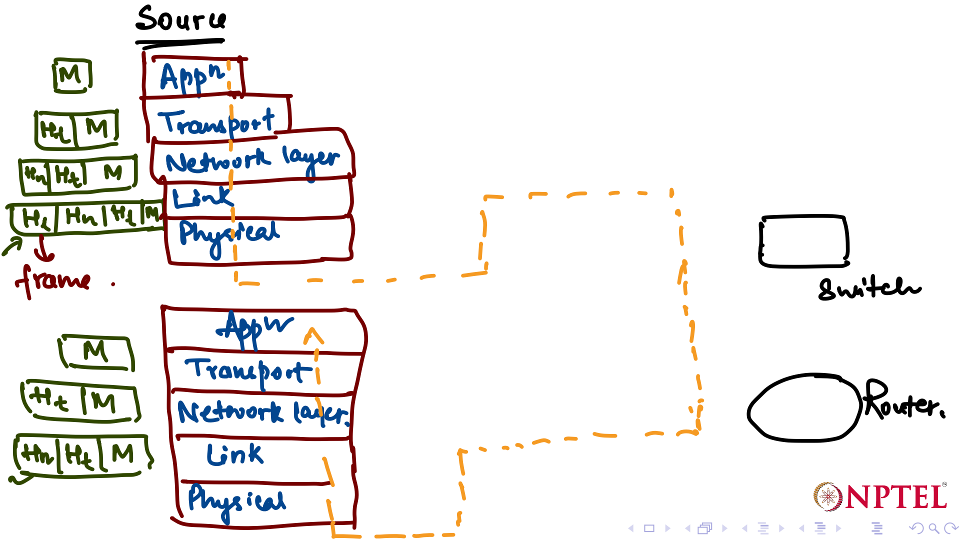
Data link layer :- transmitting between neighbouring data elements.

- Doesnt know source or destination.
- Ensures the data reaches to next hop to reach destination.

Neighbouring hop.

Physical layer: bits are actually sent through the medium.

→ wireless, wired, OF -- .

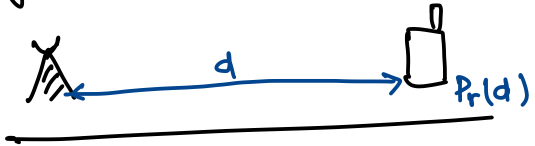


Presentation layer:
- Data is translated into bits
- Compression → lossy, lossless. (Speed).
- Encryption → data security

Session layer:
2. Authorization (User has permissions or not).
1. Authentication (User is valid or not)

Web browser:- works as application, presentation & session layer.

Propagation models :-



→ large scale propagation model.

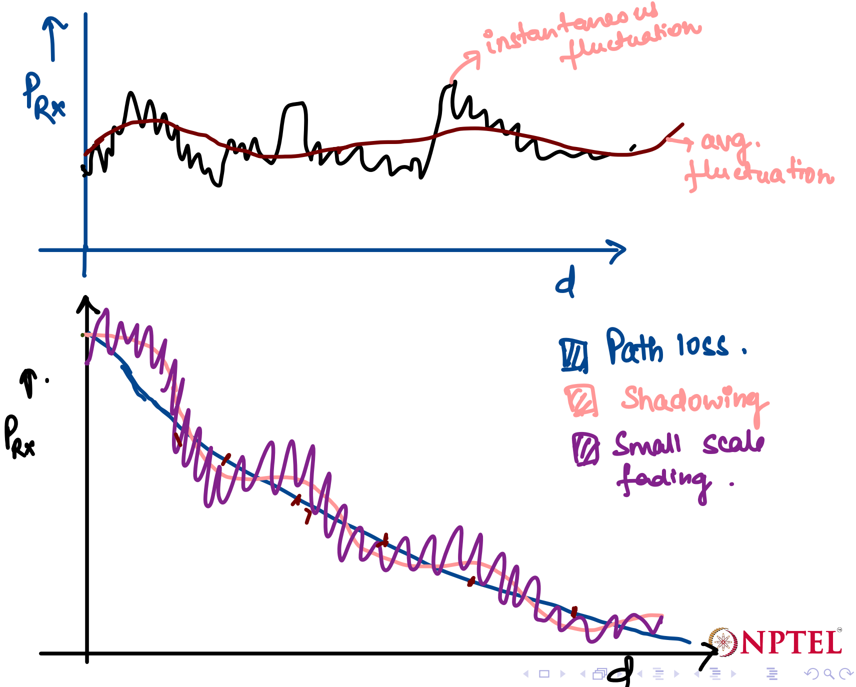
• depicts rx power at a dist. d.

d ~ 100m

→ Small scale propagation model :-

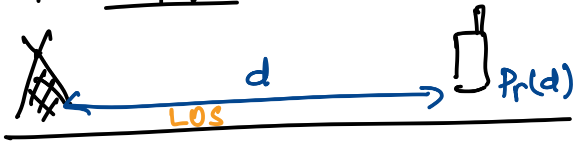
• fluctuation of signal over short dist (order of wavelength). over short duration (few seconds).

when power is below a threshold → Outage happens.



P_{Rx}
instantaneous fluctuation
avg. fluctuation
d
P_{Rx}
d
Path loss.
Shadowing
Small scale fading.

Free space Propagation :-



Friis free space propagation loss :-

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

Usually, $L = 1$.

coupling loss, filter loss, etc.

LOS :

$$\boxed{P_r(d) \propto \frac{1}{d^2}} \Rightarrow 20\,\text{dB}/\text{decade}.$$

$$G = \frac{4\pi A_e}{\lambda^2}$$

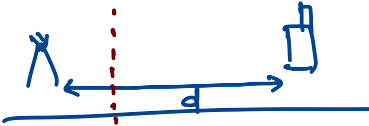
$A_e \rightarrow$ Antenna aperture.

$$\boxed{PL_{dB} = 10\log_{10}\frac{P_t}{P_r} = -10\log_{10}\left(\frac{G_t\, G_r\, \lambda^2}{(4\pi)^2 d^2}\right)}$$ *

Antenna gain $G_t = G_r = 1$.

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

$$\boxed{P_r(d) \propto \frac{1}{d^2}}$$



$d_0 \to$ min distance.

$d=0$

$P_r(d_0) \propto \frac{1}{d_0^2} \Rightarrow$ known.

$$\star \quad \boxed{P_r(d) = \frac{P_r(d_0)\cdot d_0^2}{d^2}}$$

$$\boxed{d > d_0}$$

$P_r(d_0) \to$ calculated empirically.

Fraunhaufer distance :

$$\boxed{d_f = \frac{2D^2}{\lambda}}$$, $D \rightarrow$ Largest dimension of antenna
$\lambda \rightarrow$ wavelength of radio wave.

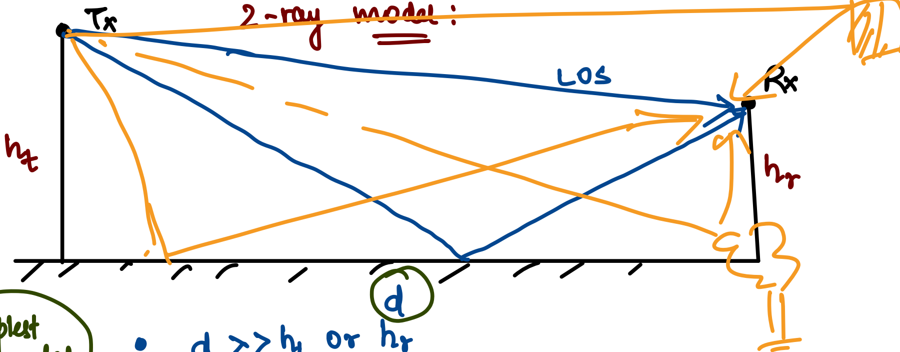
$d_0 > d_f$

$d_0 <<$ BS-MS distance

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

$$\boxed{P_r(d)_{dB} = P_r(d_0)_{dB} + 20\log\left(\frac{d_0}{d}\right)}$$

2-ray model :



Simplest model

- $d >> h_t$ or h_r

$$\boxed{P_r = P_t G_t G_r \frac{h_t^2 h_r^2}{d^4}}$$

- for LOS, $P_r \propto 1/d^2$
- for two-ray, $\boxed{P_r \propto \frac{1}{d^4}}$.

$$\boxed{P_r = P_t G_t G_r \frac{h_t^2 h_r^2}{d^4}}$$

$$PL(dB) = 10\log \frac{P_t}{P_r} = 40 \log d - \left(10\log G_t + 10\log G_r + 20\log h_t + 20\log h_r\right).$$

in real environment, $10 \times n_p$ → coeff.

n_p → Path loss exponent

$$\boxed{1.4 \le n_p \le 6}$$

Calculated empirically.

Tx band pass signal:

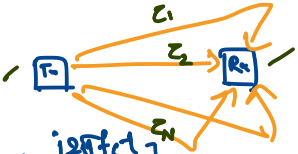
$$s(t) = \mathrm{Re}\left\{ \underbrace{\tilde{s}(t)} e^{j2\pi f_c t} \right\}$$ → txed sig

$\tilde{s}(t)$ → complex envelope of tx signal.

noiseless rxed sig:

$$r(t) = \mathrm{Re}\left[\sum_{n=1}^{N} c_n \, e^{j2\pi(f_c + f_{D,n})(t-\tau_n)} \, \tilde{s}(t-\tau_n) \right]$$

c_n → amplitude scaling



Phase diff from nth path. ← $\phi_n = 2\pi\left[f_{D,n} t - (f_c + f_{D,n})\tau_n \right]$

$$r(t) = \mathrm{Re}\left[\sum_{n=1}^{N} \underbrace{c_n \, e^{j\phi_n(t)} \, \tilde{s}(t-\tau_n)}_{\tilde{r}(t)} \, e^{j2\pi f_c t} \right]$$

$$= \mathrm{Re}\left[\tilde{r}(t) \, e^{j2\pi f_c t} \right]$$ → Rxed sig.

$$\tilde{r}(t) = \underbrace{\sum_{n=1}^{N} c_n e^{j\phi_n(t)}}\, \tilde{s}(t-\tau_n)$$

$$h(t,\tau_n) = c_n e^{j\phi_n(t)}.$$

$y = hx$

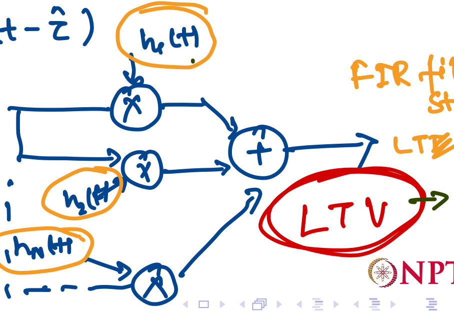
$$\tilde{r}(t) = \sum_{n=1}^{N} h_n(t)\, \tilde{s}(t-\tau_n)$$

$\Rightarrow \tau_1 = \tau_2 = \cdots = \tau_N = \hat{\tau}$

$$\tilde{r}(t) = h_1(t)\,\tilde{s}(t-\tau_1) + h_2(t)\,\tilde{s}(t-\tau_2) + \cdots + h_N(t)\,\tilde{s}(t-\tau_N)$$

$$\tilde{r}(t) = \left(\sum_{n=1}^{N} h_n(t)\right) \hat{s}(t-\hat{\tau})$$

$$\tilde{s}(t) \longrightarrow \tilde{s}(t-\hat{\tau})$$



FIR filter Structure

1) Among the below mentioned Open Systems Interconnection (OSI) layers, which one directly interacts with the medium

a. Data-link layer

b. Physical Layer

c. Transport Layer

d. Application Layer

→ Application
Presentation
Session
Transport
Network layer
Data link layer
Physical

Destination.

14) The quality of service (QoS) between end to end devices is maintained by the

a. Presentation Layer

b. Session Layer

c. Transport Layer

d. Application Layer

QoS → performance.

Transport layer :- Reliability of transmission.

Segmentation :-

flow Control :- Slow / speed rate.

Error Control :- ARR.

☑ TCP

☑ UDP

2) The Diversity combining helps to :

a. Increase average SNR
b. Combat large scale fading
c. Reduce Inter Symbol Interference (ISI)
d. None of these

Same information from diff. paths.

Diversity: → Combat shadowing effect.

3) In general, the wireless channels are

a. Linear Time Invariant (LTI)
b. Linear Time Varying (LTV)
c. Additive White Gaussian Noise (AWGN)
d. None of these

4) Among the listed type of fading, which is/are considered to be small scale fading?

a. Path loss. → large scale.

b. Shadow fading →

c. Rayleigh fading

d. Rician fading

→ small scale fading.

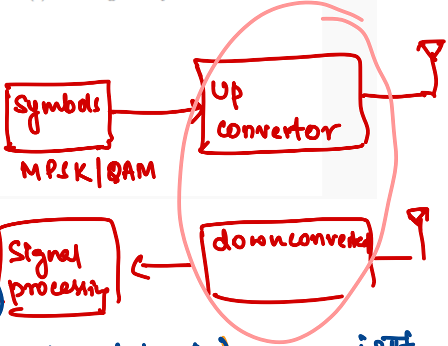
5) At the transmitter the baseband signal "x(t)" is up converted to "RF" frequency of 2.4 GHz using a local oscillator. At the receiver the local oscillator used for down converting has frequency of 2.3999999 GHz and phase difference between oscillator at TX and RX is $\frac{\pi}{6}$ radian. The down converted signal can be written as, y(t)= x(t)z(t)+ n(t), where n(t) is the noise term. z(t) can be given by:

a. 1

b. $e^{j(100\pi t+\frac{\pi}{6})}$

c. $e^{j(1000\pi t-\frac{\pi}{4})}$

d. $e^{j(200\pi t-\frac{\pi}{6})}$ ✓



tx: $x(t)\, e^{j(2\pi f_{c_t} t + \phi_t)}$

rx:

$$y(t) = r(t)\, e^{-j(2\pi f_{c_r} t + \phi_r)}$$

$$r(t) = x(t) + n(t) \Rightarrow e^{-j(2\pi f_{c_r} t + \phi_r)} \left(x(t)\, e^{j2\pi f_{c_t} + \phi_t} \right) + \tilde{n}(t)$$

$$= x(t)\, e^{j2\pi(f_{c_t} - f_{c_r})t + (\phi_t - \phi_r)} + n(t)$$

$$= x(t)\, e^{(200\pi t - \pi/6)} + n(t).$$

$f_{c_t} - f_{c_r} = 10^{-7} \times 10^{9}$ Hz

$= 100$ Hz

6) A cellular communication system is operating at the carrier frequency of 6 GHz. What should be the range of distance over which the average received signal power should be computed to model the large scale fading?

a. 0.1m - 10 m

b. 0.25m - 10m

c. Greater than 10m

d. 0.25m - 2m

$f_c = 6\,GHz.$

$$\lambda = \frac{c}{f_c} = \frac{3 \times 10^8}{6 \times 10^9} = 0.05\,m.$$

for large scale fading,

$d \to 5\lambda$ to 40λ

$\Rightarrow$ 0.25m - 2m

7) MIMO systems consisting of:

a. Multiple antennas at both the transmitter and receiver side.

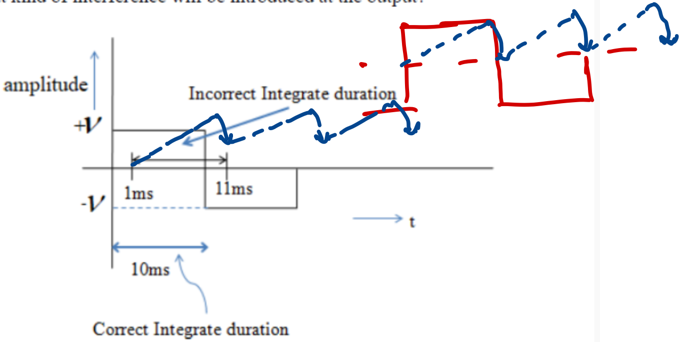
b. Single antenna at the transmitter side and multiple antennas at the receiver side.

c. Multiple antennas at the transmitter and single antenna at the receiver side

d. Single antenna at both the transmitter and the receiver side.

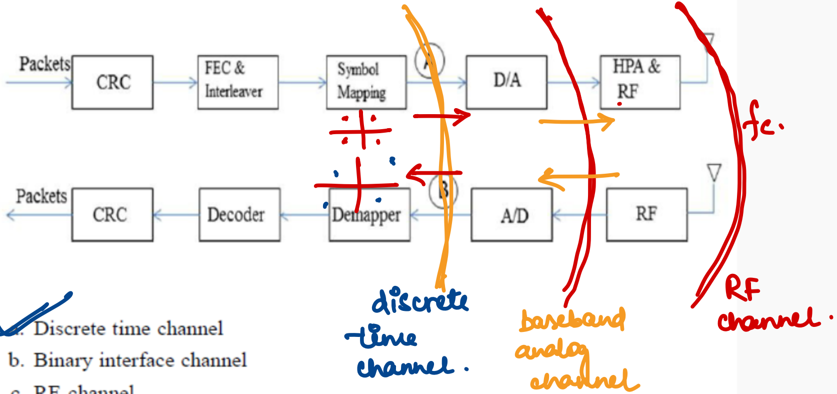
	$\boxed{Tx}$	$\boxed{Rx}$
SISO	1	1
SIMO	1	multiple
MISO	multiple	1.
MIMO	multiple	multiple.

8) In the figure below, the received baseband pulse as shown. Symbol duration, T=10ms.The pulse is given at the input of integrate and dump circuit.
Due to an error in time synchronization, if the integration starts at 1 ms instead of origin, what kind of interference will be introduced at the output?



a. Adjacent Channel Inerference
b. Inter Carrier Interference
c. Co-channel Interference
d. Inter Symbol Interference

9) The interface channel between point A and B in the communication system shown in figure is:



a. Discrete time channel

b. Binary interface channel

c. RF channel

d. Binary symmetric channel

The power of a certain transmitted signal is 10 mW, the power in dBm is

a. 10 dBm

b. 20 dBm

c. 30 dBm

d. 40 dBm

$P_t = 10\ mW.$

$$P_{t_{dBm}} = 10\log_{10}\left(\frac{P_t}{10^{-3}}\right)$$

$$= 10\log_{10}\left(\frac{10\times 10^{-3}}{10^{-3}}\right) = 10\log_{10}10$$

$$= 10\ dBm.$$

Path Loss Exponent of indoor line of sight communication is

a. 1

b. 3

c. < 2

d. > 4

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

path loss exponent

$$1.4 \leq n_p \leq 6$$

Given received power at a distance of 30 m as -20 dBm. Find the received power at 100 m by assuming free space propagation.

a. -30.45 dBm
b. -60.45 dBm
c. -90.45 dBm
d. -120.54 dBm

$$P_r(d_0) = -20\,\text{dBm}, \quad d_0 = 30\,\text{m}.$$

$$= -50\,\text{dB} = 10^{-5}\,\text{W}$$

$$d = 100\,\text{m}.$$

$$n = 2.$$

$$P_r(d) = P_r(d_0)\cdot\left(\frac{d_0}{d}\right)^n = 10^{-5}\left(\frac{30}{100}\right)^2$$

$$P_r(d)\Big|_{\text{dBm}} = -30.45\,\text{dBm}.$$

The distribution followed by the received power in linear scale for a shadow fading channel is

a. Gaussian
b. log-normal
c. exponential
d. Rayleigh

Match the channel path loss models given in column A with the corresponding n_p given in Column B

	Column A		Column B
1	$PL(d) = 42 + 25log_{10}(d) + 14log_{10}(f)$	1	6.5
2	$PL(d) = 27 + 35log_{10}(d) + 17log_{10}(f)$	2	3.5
3	$PL(d) = 36 + 48log_{10}(d) + 13log_{10}(f)$	3	2.5
4	$PL(d) = 52 + 65log_{10}(d) + 24log_{10}(f)$	4	4.8

a. A1-B1; A2-B2; A3-B3; A4-B4

b. A1-B2; A2-B1; A3-B4; A4-B3

c. A1-B3; A2-B2; A3-B4; A4-B1

d. A1-B4; A2-B3; A3-B2; A4-B1

$10 n_p \log(d)$.

A1: $10 n_p = 25 \Rightarrow n_p = 2.5$ B3.

A2: $10 n_p = 35 \Rightarrow n_p = 3.5$ B2

A3: $10 n_p = 48 \Rightarrow n_p = 4.8$ B4

A4: $10 n_p = 65 \Rightarrow n_p = 6.5 \Rightarrow$ B1

Find the doppler shift when the mobile user is moving away from base station with a speed of 90 kmph with angle of arrival of 30^0. Consider carrier $f_c = 2$ GHz.

a. 150 Hz ✗

b. 144 Hz ✗

c. -150 Hz

d. -144 Hz ✓

When MS is moving away from BS → doppler shift is −ve.

$$v = 90\,\text{kmph} = 90 \times \frac{5}{18} = 25\,\text{m/s}.$$

$$f_D = \frac{v\cos\theta}{\lambda} = \frac{v\cos\theta}{c}\cdot f_c.$$

$$25 \times \frac{\sqrt{3}}{2} \times \frac{2\times 10^9}{3\times 10^8} = 144\,\text{Hz}.$$

∵ MS is moving away ⇒ $f_D = -144$ Hz.

Local average fluctuations of received signal power with transmitter-receiver separation distance is observed due to,

a. small scale fading

b. path loss

c. shadowing

d. none of the above

Given the transmit power is 0 dBm and received power at a distance d is -90 dBm ($d \gg$ Antenna dimensions). Find the corresponding path loss in dB

a. -120 dBm

b. 90 dB

c. 60 dBm

d. -60 dB

$$PL|_{dB} = 10\log_{10}\frac{P_T}{P_R}$$

$$= 10\log_{10}P_T - 10\log_{10}P_R$$

$$= P_T|_{dB} - P_R|_{dB}.$$

$P_T = 0\,dBm = 30\,dB$

$P_R = -90\,dBm = -90+30 = -60\,dB$

$$PL|_{dB} = P_T|_{dB} - P_R|_{dB} = 30-(-60)\,dB$$

$$= 90\,dB.$$

Match the pairs from column A and column B. (K = Rician K-factor)

	Column A		Column B
1	NLOS channel	1	$K = 0$
2	Rayleigh fading	2	$K > 0$
3	Almost no fading	3	$K = \infty$

a. A1-B1; A2-B2; A3-B3

b. A1-B2; A2-B1; A3-B3 ✓

c. A1-B1; A2-B3; A3-B1

d. A1-B3; A2-B1; A3-B2

A1 : B2

A2 : B1

A3 : B3.

Rician fading channel: One path is dominant.

$$P_\alpha(x) = \frac{x}{b_0} \exp\left\{-\frac{x^2+s^2}{2b_0}\right\} I_0\left(\frac{xs}{b_0}\right), \quad x \geq 0$$

$$K = \frac{s^2}{2b_0}$$

$K \to \infty \Rightarrow$ No fading $\Rightarrow$ LOS channel

$K = 0 \Rightarrow$ Rayleigh

$K > 0 \Rightarrow$ NLOS.

NPTEL