Module V: Mobile Radio Propagation : Small Scale Fading and Multipath

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Small Scale Fading

Small-scale fading, or simply *fading*, is used to describe the rapid fluctuation of the amplitude of a radio signal over a short period of time or travel distance, so that large-scale path loss effects may be ignored. Fading is caused by interference between two or more versions of the transmitted signal which arrive at the receiver at slightly different times. These waves, called *multipath waves*, combine at the receiver antenna to give a resultant signal which can vary widely in amplitude and phase, depending on the distribution of the intensity and relative propagation time of the waves and the bandwidth of the transmitted signal.

Small-Scale fading

- **Small-Scale fading,or simply** Fading is used to describe the rapid fluctuation of the **amplitude, phase** of a radio signal over a short period of time or travel distance.

Small Scale Multipath Propagation

4.1 Small-Scale Multipath Propagation

Multipath in the radio channel 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 shifts on different multipath signals
- Time dispersion (echoes) caused by multipath propagation delays.

Multipath Waves

- Fading is caused by interference between **two or more versions** of the transmitted signal which arrive at the receiver at slightly different time. These waves, called multipath waves.

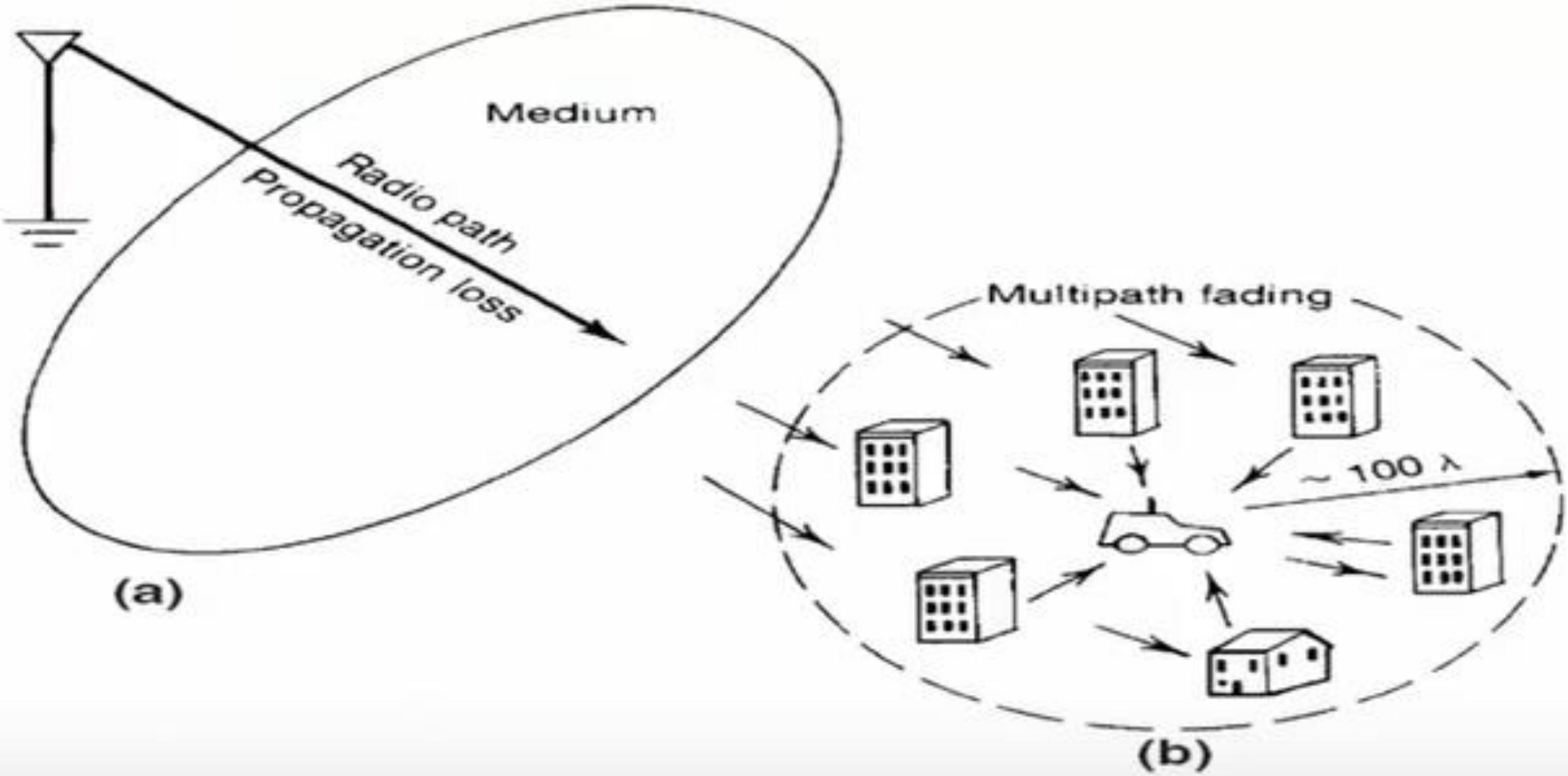
Multipath Waves

- Multipath wave Combine at the receiver antenna to give resultant signal which can very in amplitude and phase, depending on the

  intensity,

  relative **propagation time** of the waves and

  the **bandwidth** of the transmitted signal.


Medium
Radio path
Propagation loss
(a)
Multipath fading
~ 100 λ
(b)

Small-scale Multipath Propagation

- **Multipath** in the radio channel creates fading effects.
- Three most important effects are:

1. Rapid changes in **signal strength** over a small travel distance or time interval.
2. Random **frequency modulation** due to varying Doppler shifts on different multipath signals.

Small-scale Multipath Propagation

3) **Time dispersion** caused by multipath propagation delays.

- ***In urban area,***

Fading occurs because height of the mobile antennas are well below the height of surrounding structures.

Small-scale Multipath Propagation

- So, multipath occur due to reflection from the ground and surrounding structures.
- The incoming radio wave arrive from different directions with different propagation delays.
- The signal received by the mobile at any point in space may consist of large number of plane wave having randomly distributed amplitude ,phase, and angles of arrival.

Small-scale Multipath Propagation

- These multipath components combine at the receiver antenna, and can case the signal received by the mobile to distort or fade.

- Even when **receiver is stationary**, the received signal may fade due to movement of surrounding objects the radio channel.

Doppler Shift

- ***Shift apparent*** in each multipath wave ***frequency*** Due to Relative motion between the mobile and the base station.
- Shift in received signal frequency due to motion is called the Doppler shift.

Factors influencing Small-scale fading

- Multipath propagation
- Speed of the mobile
- Speed of surrounding objects
- The transmission bandwidth of the signal

Multipath propagation:-

- Propagation in Multipath, reflecting object and scatterers in the channel that dissipated the signal energy in **amplitude, phase, and in time.**

- Due to multipath propagation **multiple versions** of the transmitted signal that arrive at the receiving antenna, **displaced** with respect to one another in time.
- At the receiving antenna random phase and amplitude of the different multipath components case fluctuations in the signal strength, thereby inducing ***small-scale fading, signal distortion*** ,or both

Speed of the mobile:-

- The relative motion between the base station and the mobile results in random frequency modulation due to different Doppler shift on each of the multipath components.
- Doppler shift will be positive or negative depending on whether the mobile receiver is moving toward or away from the base station.

Speed of the surrounding objects

- If **objects** in the radio channel are in motion, they induce a time varying **Doppler shift** on multipath components.
- Surrounding object move grater rate than the mobile, then fading at the mobile receiver.

The transmission bandwidth of the signal

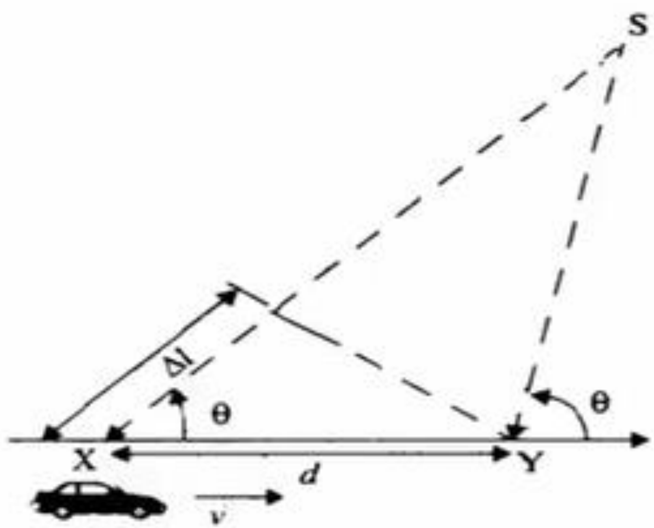
- If the transmitted radio signal bandwidth is greater than the bandwidth of the multipath channel, the received signal will be distorted.

Doppler shift

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

- Mobile moving at a constant velocity v,
- Path having length d between point X & Y,
- It receives signal from a source S,

Doppler shift



- Difference in path

$$\Delta l = d\cos\theta = v\Delta t\cos\theta.$$

- Where Δt time required for the mobile to travel from X to Y
- Doppler shift,

$$f_d = \frac{1}{2\pi}\cdot\frac{\Delta\phi}{\Delta t} = \frac{v}{\lambda}\cdot\cos\theta$$

Coherence time Tc

- Coherence time (Tc) is used to characterize the time varying nature of the **frequency depressiveness** of the channel in the **time domain.**

- Doppler spread and coherence time are inversely proportional to one another.

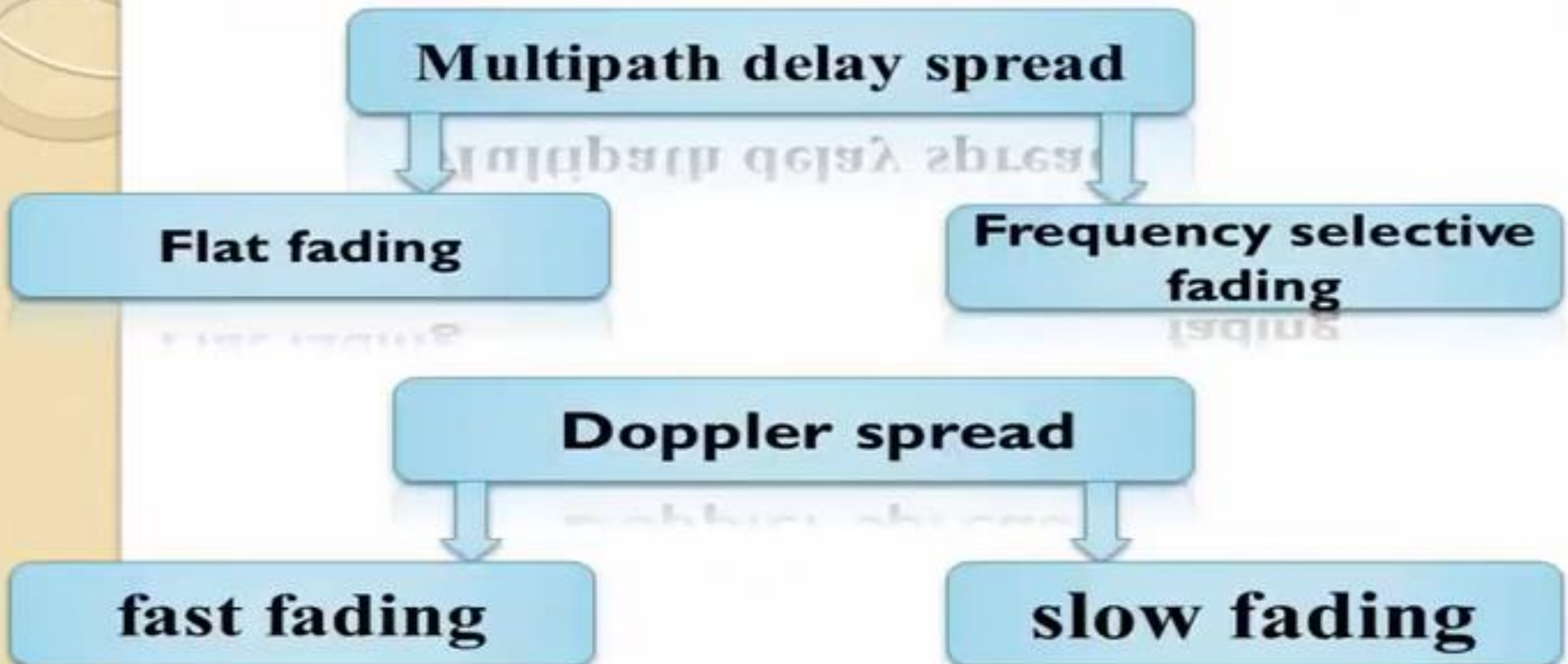
$$Tc = 1/fm$$

Types of small-scale fading

- Depending on the relation between the signal parameter and the channel parameter, different transmitted signal will undergo different types of fading.

- The **time dispersion** and **frequency dispersion** in mobile radio channel lead to four possible distinct effects, which are depending on the nature of the **transmitted signal, the channel, and the velocity.**

Types


Multipath delay spread
Flat fading
Frequency selective fading
Doppler spread
fast fading
slow fading

Fading effects due to Multipath delay spread

- **Flat fading:-**
- If the **channel processes** a constant-gain and linear phase response over a **bandwidth** that is **grater** than the bandwidth of **transmitted Signal**, then the received signal will undergo flat fading.

BW of Channel > BW of Signal

Flat fading

- In case of Multipath, Fluctuations in gain of the channel.
- Due to this Strength of the received signal changes in time.
- Fluctuations in gain
- So, changes in amplitude of the received signal.

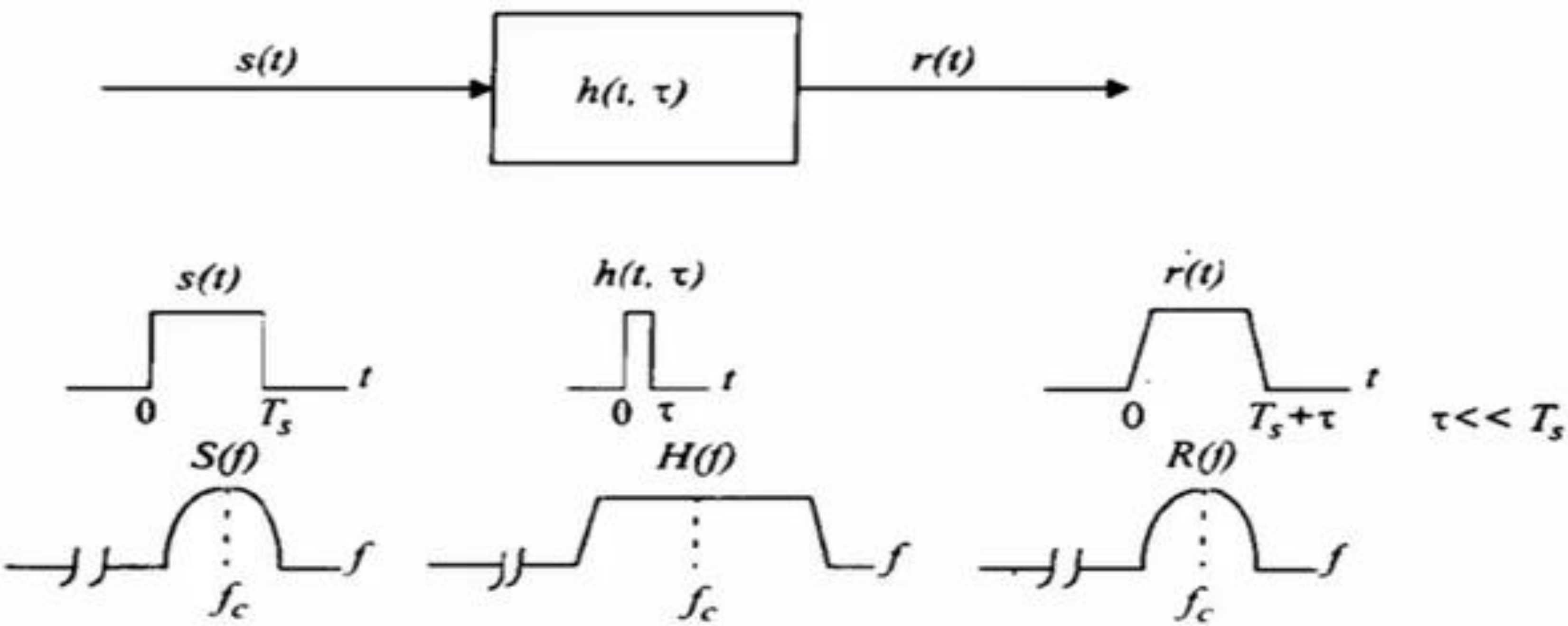
Flat fading

- Flat fading channel are also known as Narrowband channels.
- Bandwidth of applied signal is narrow as compare to the Bandwidth of the flat fading channel.

BW of Signal $<$ BW of Channel

Multipath Structure of channel such that **spectral characteristics** of the transmitted signal are preserved at the receiver

Flat fading channel characteristics



Flat fading

- Deep fades cause, it require 20 or 30db more transmitter power to achieve low bit error rates

  at receiver.

- Most common amplitude distribution is the RAYLEIGH DISTRIBUTION

Frequency selective fading

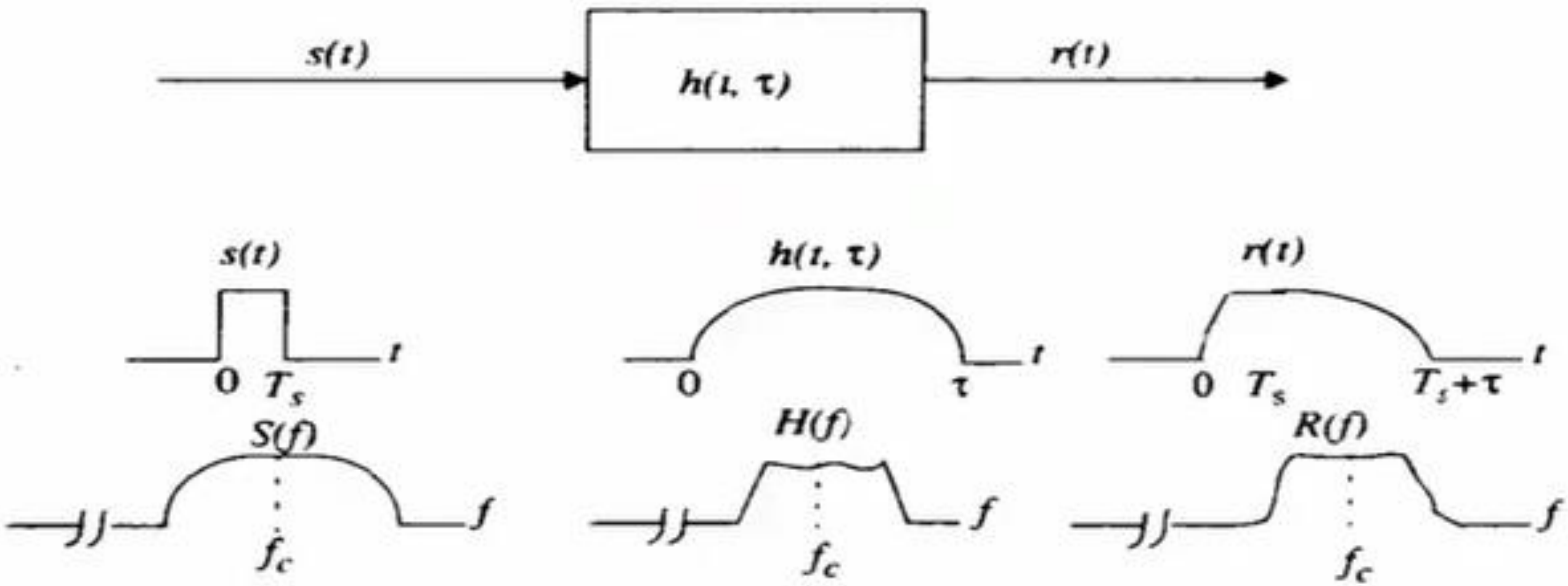
- If the **channel processes** a constant-gain and linear phase response over a **bandwidth** that is **smaller** than the bandwidth of **transmitted Signal**, then the channel create frequency selective fading on the receive signal.

BW of Channel < BW of Signal

Frequency selective fading

- The received signal includes multiple versions as compare to the transmitted waveform which attenuated(faded) and delayed in time, So the received signal is distorted.
- Frequency selective fading is due to time dispersion of the transmitted symbols within the channel.
- So, channel induces **ISI**

Frequency selective fading



fading effects due to Doppler spread

- Channel may be classified as,
  1. fast fading channel.
  2. slow fading channel.

fast fading channel

- Channel **impulse response changes** rapidly within the symbol duration.
- Channel **impulse response changes** rapidly(so, frequency high) then Coherence time(**Tc**) of the channel is **small.**
- Doppler spread due to Channel **impulse response changes** rapidly.
- So, fm high

$$Tc = 1/fm$$

fast fading channel

Doppler spread and coherence time are inversely proportional to one another

$$Tc = 1/fm$$

So, fm increase then Tc(**Coherence time**) decrease then the transmitted signal

slow fading :-

- Channel **impulse response changes** at a rate much **slower** then **transmitted baseband signal.**
- **So, fm decrease and Tc increase.**
- Symbol period of the transmitted signal is much **slower** then the Coherence time(**Tc**)(frequency depressiveness of the channel in the time domain)

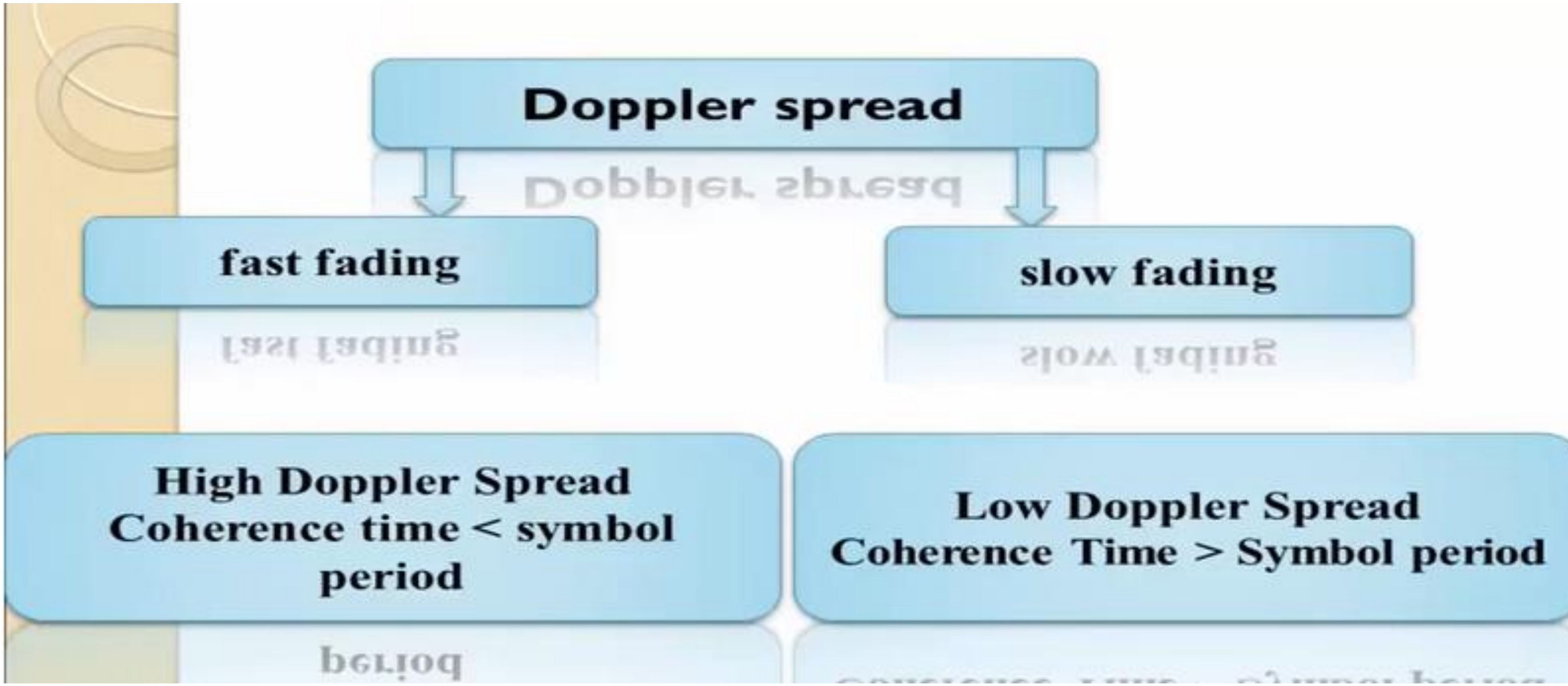
$$T_c > T_s$$

slow fading

- Fm decrease,
- So, low Doppler spread.

Doppler spread of the channel is much less then the bandwidth of the **signal.**

Bs > Bd


Doppler spread
fast fading
slow fading
High Doppler Spread
Coherence time < symbol period
Low Doppler Spread
Coherence Time > Symbol period

Small Scale Multipath Propagation

In built-up urban areas, fading occurs because the height of the mobile antennas are well below the height of surrounding structures, so there is no single line-of-sight path to the base station. Even when a line-of-sight exists, multipath still occurs due to reflections from the ground and surrounding structures. The incoming radio waves arrive from different directions with different propagation delays. The signal received by the mobile at any point in space may consist of a large number of plane waves having randomly distributed amplitudes,

phases, and angles of arrival. These multipath components combine vectorially at the receiver antenna, and can cause the signal received by the mobile to distort or fade. Even when a mobile receiver is stationary, the received signal may fade due to movement of surrounding objects in the radio channel.

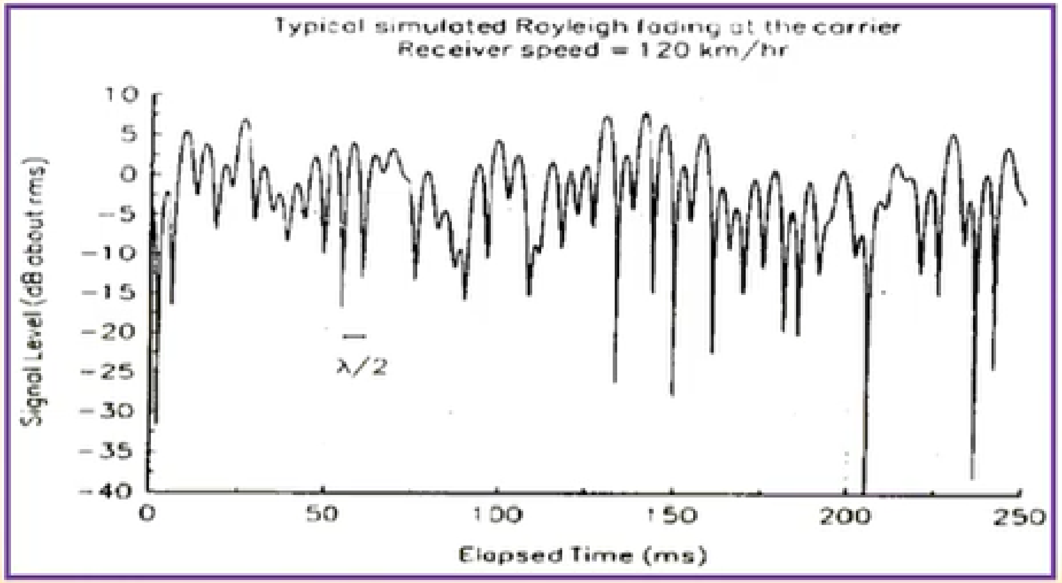
Doppler Shift

Due to the relative motion between the mobile and the base station, each multipath wave experiences an apparent shift in frequency. The shift in received signal frequency due to motion is called the Doppler shift, and is directly proportional to the velocity and direction of motion of the mobile with respect to the direction of arrival of the received multipath wave.

Rayleigh fading channel

Rayleigh Fading

- If all the multipath components have approximately the same amplitude (when MS is far from BS), the envelope of the received signal is ***Rayleigh distributed***.
- ***No dominant peak*** (such as LOS).
- It describes the statistical time varying nature of received envelope of a flat fading signal or the envelope of an individual multipath component. .



$$P(R) = Pr(r \le R) = \int_0^R p(r)\,dr = 1 - \exp\left(-\frac{R^2}{2\sigma^2}\right)$$

$$p(r) = \begin{cases} \dfrac{r}{\sigma^2}\exp\left(-\dfrac{r^2}{2\sigma^2}\right) & (0 \le r \le \infty) \\ 0 & (r < 0) \end{cases}$$

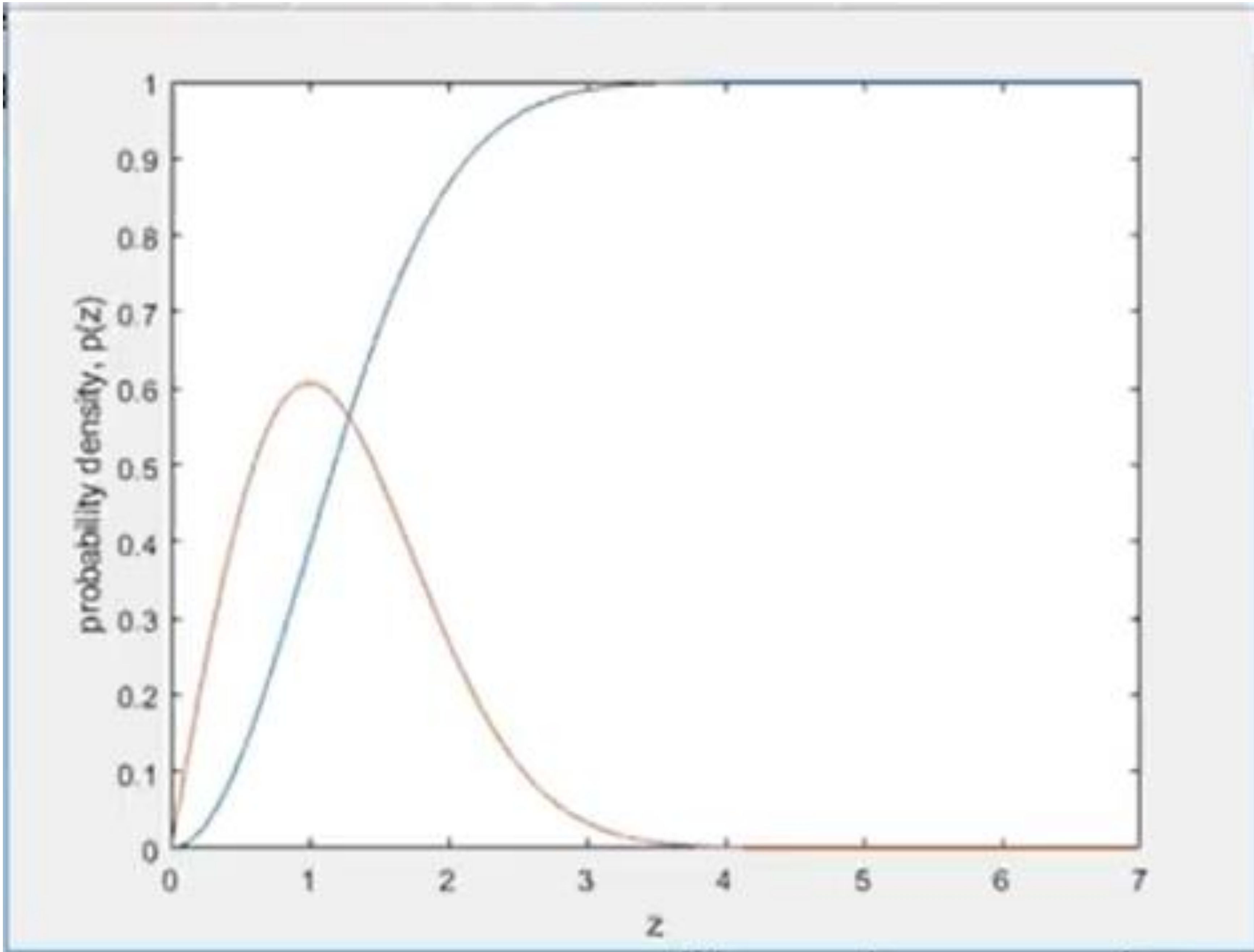
where σ is the rms value of the received voltage signal before *envelope detection*, and σ^2 is the time-average power of the received signal *before* envelope detection. The probability that the envelope of the received signal does not exceed a specified value R is given by the corresponding cumulative distribution function (CDF)

$$P(R) = Pr(r \le R) = \int_0^R p(r)\,dr = 1 - \exp\left(-\frac{R^2}{2\sigma^2}\right) \tag{4.50}$$

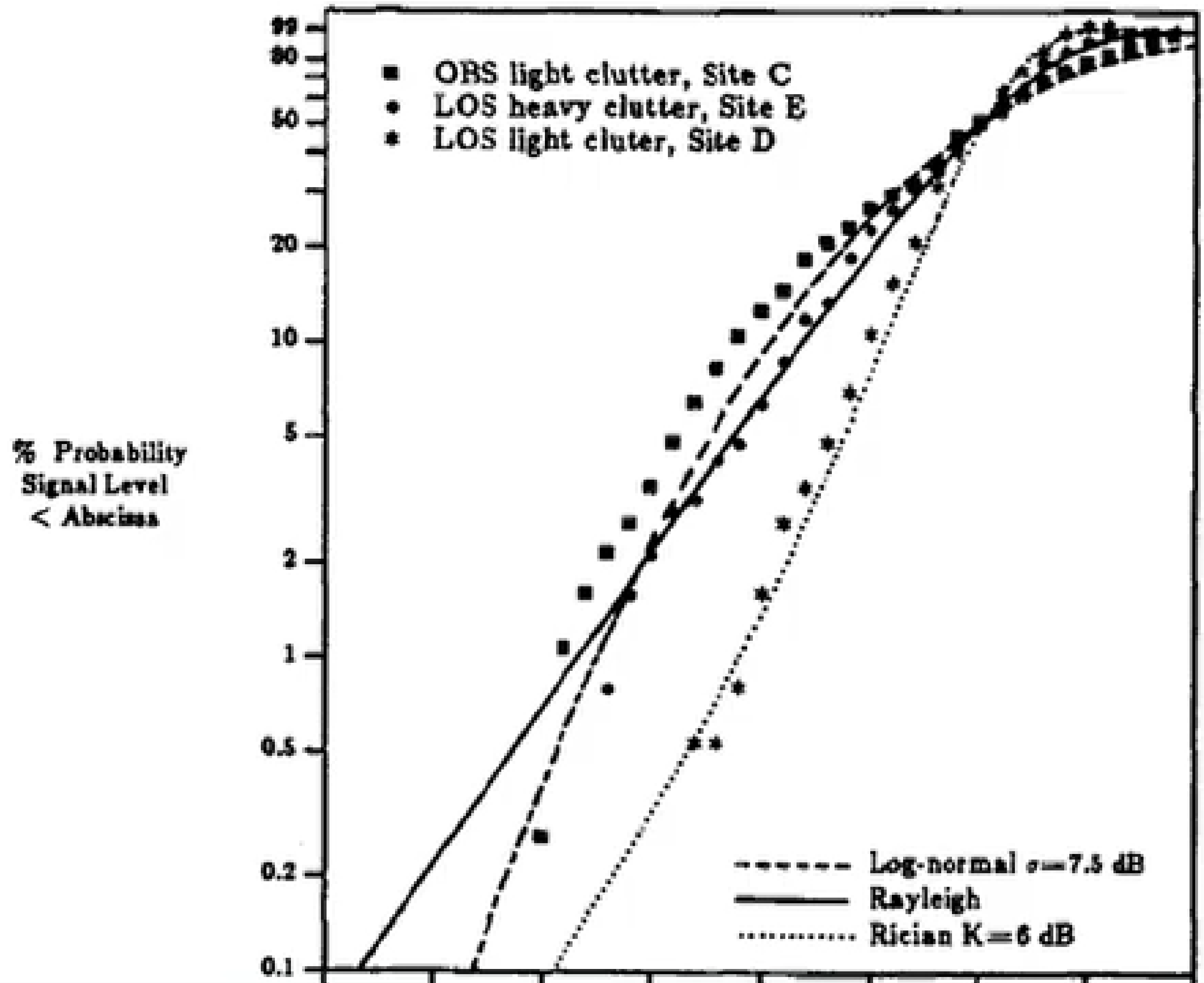
The mean value r_{mean} of the Rayleigh distribution is given by

$$r_{mean} = E[r] = \int_0^\infty rp(r)\,dr = \sigma\sqrt{\frac{\pi}{2}} = 1.2533\sigma \tag{4.51}$$

```
close all
clear all
N = 10^8;
x = randn(1,N); % gaussian random variable, mean 0, variance 1
y = randn(1,N); % gaussian random variable, mean 0, variance 1
z = (x + j*y);  % complex random variable
% probability density function of abs(z)
zBin = [0:0.01:7];
sigma2 = 1;
pzTheory = (zBin/sigma2).*exp(-(zBin.^2)/(2*sigma2));
ccdfTheory = 1- exp(-(zBin.^2)/(2*sigma2));
plot(zBin,ccdfTheory);
hold on
plot(zBin, pzTheory);
xlabel('z');
ylabel('probability density, p(z)');
```



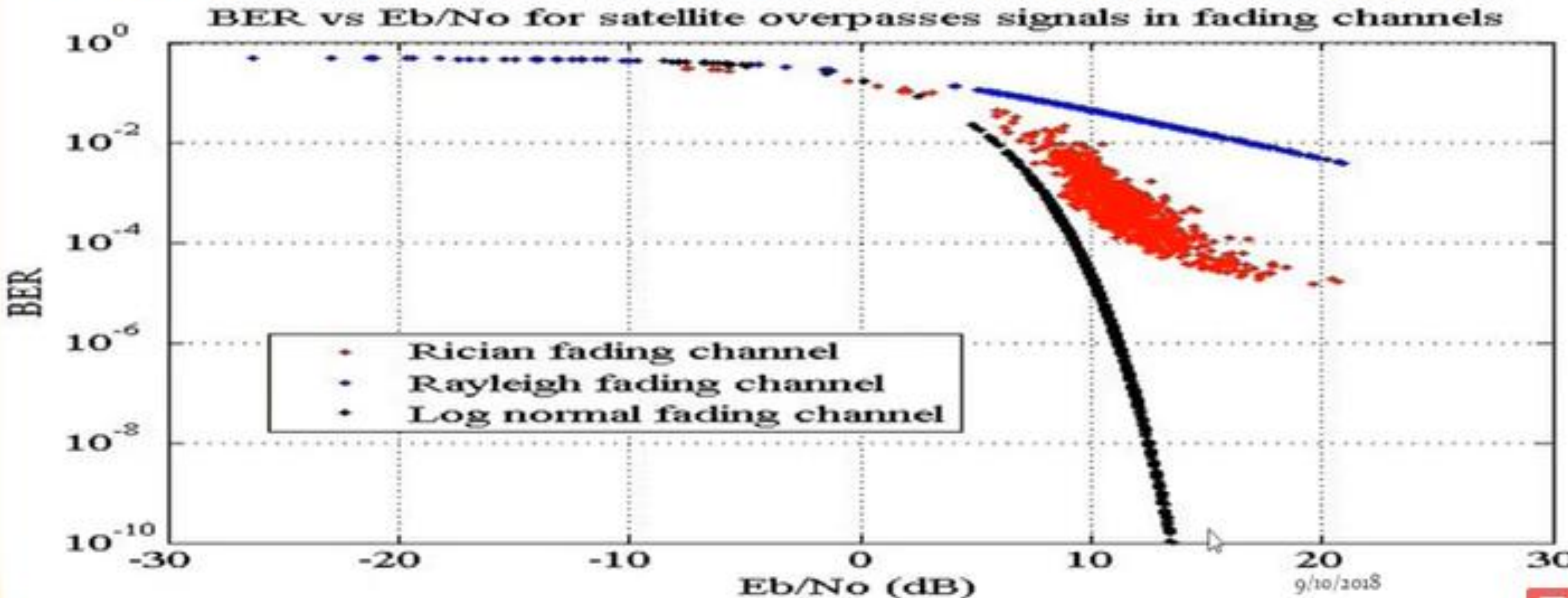
probability density, p(z)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1
2
3
4
5
6
7
z



% Probability
Signal Level
< Abscissa
99
90
50
20
10
5
2
1
0.5
0.2
0.1
ORS light clutter, Site C
LOS heavy clutter, Site E
LOS light cluter, Site D
Log-normal σ=7.5 dB
Rayleigh
Rician K=6 dB

Ricean Fading

- When there is a dominant, stationary (non-fading) signal component present (such as LOS, when MS and BS are close to each other) → ***Ricean Distribution***.
- ***It degenerates to Rayleigh when the dominant component fades away***



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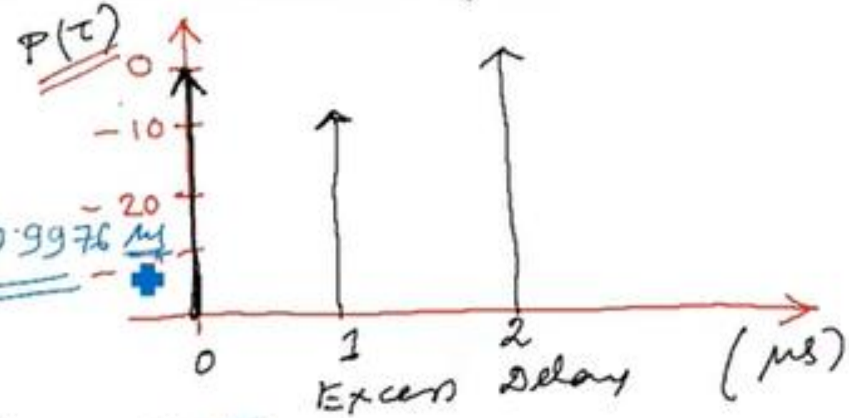
A Local spatial average of power delay profile is given below:

(a) Calculate the RMS delay spread and Mean Excess Delay ??

(b) Maximum Excess Delay (20 dB)??



σ_τ = RMS Delay Spread

$$= \sqrt{\overline{\tau^2} - (\bar{\tau})^2} \quad \text{—(i)} \simeq 0.9976\ \mu s$$

$$\overline{\tau^2} = \frac{\sum P(\tau_k)\,\tau_k^2}{\sum P(\tau_k)} \quad \text{—(ii)} \rightarrow = 1.995\ \mu s$$

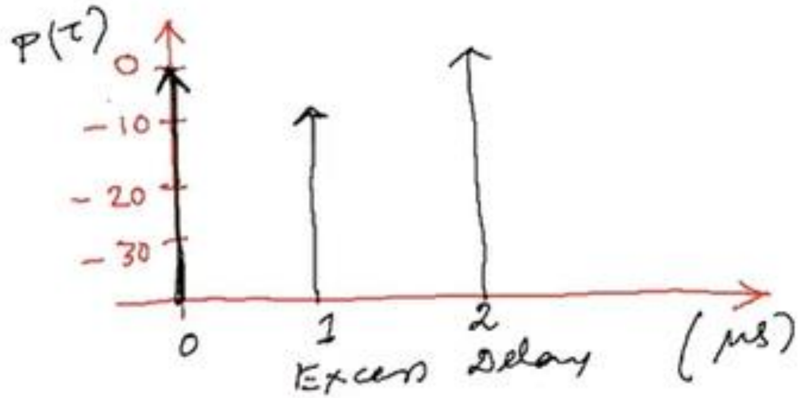
$$\bar{\tau} = \frac{\sum P(\tau_k)\,\tau_k}{\sum P(\tau_k)} \quad \text{—(iii)}$$

$$\rightarrow = \frac{(1 \times 0) + (1 \times 0.1) + (1 \times 2)}{1 + 0.1 + 2} = 1\ \mu s$$

b) $T_x - T_0$

$= 2 - 0 = 2\,\mu s$

If the channel is to be used with a modulation that requires an equalizer whenever the symbol duration T is less than equal to$10\sigma_T$, determine the maximum RF symbol rate that can be supported.



Flat Fading / Frequency Selective Fading

❑ *Common rule of thumb is*

- *FLAT FADING*
  - $T_s => 10\,\sigma_\tau$ *or* ***Bs < Bc***
- *FREQUENCY SELECTIVE FADING*
  - $T_s <= 10\,\sigma_\tau$ *or* ***Bs > Bc***

PDP (Rx vs T) $\rightarrow \sigma_\tau$

$\downarrow$

$10\sigma_\tau$

$\downarrow$

Symbol duration

Max data rate

Tx

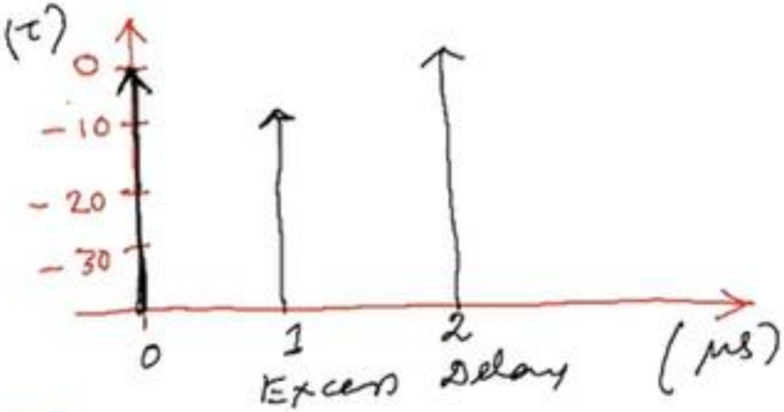
If the channel is to be used with a modulation that requires an equalizer whenever the symbol duration T is less than equal to $10\sigma_\tau$, determine the maximum RF symbol rate that can be supported.

Freq. Selective channel

$$T_{min} = 10\,\sigma_\tau$$

$$= 10 \times 0.9976$$

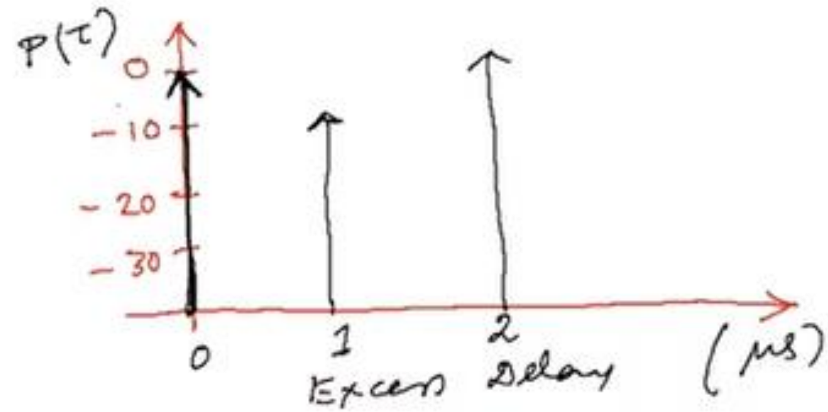
$$= 9.976\ \mu s$$



$$\text{symbol rate} = \frac{1}{T_{min}}$$

$$= \frac{1}{9.976 \times 10^{-6}} \simeq 100\ \text{Kbps}$$

If a mobile travelling at 30 km/hr receives a signal through this channel, determine the time over which the channel appears stationary (at least highly correlated)



If a mobile travelling at 30 km/hr receives a signal through this channel, determine the time over which the channel appears stationary (at least highly correlated)

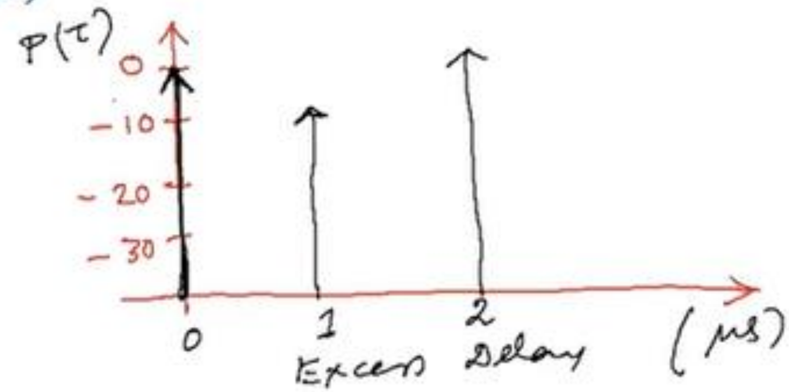
Coh-BW

coh-Time

$$C_T = \frac{0.423}{f_m} \approx 1.7 \text{ ms}$$

$$f_m = \frac{v}{\lambda} = \frac{v}{c/f}$$

$f = 900$ MHz



$$\boxed{B_C = \frac{1}{5\sigma_\tau}}$$