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1.5 FADING EFFECTS DUE TO MULTIPATH TIME DELAY SPREAD

Flat Fading

If the mobile radio channel has a constant gain and linear phase response over a bandwidth which is greater than the bandwidth of the transmitted signal, then the received signal will undergo flat fading.

In flat fading, the multipath structure of the channel is such that the spectral characteristics of the transmitted signal are preserved at the receiver. However the strength of the received signal changes with time, due to fluctuations in the gain of the channel caused by multipath.

The characteristics of a flat fading channel are shown in Figure 1.5.1.

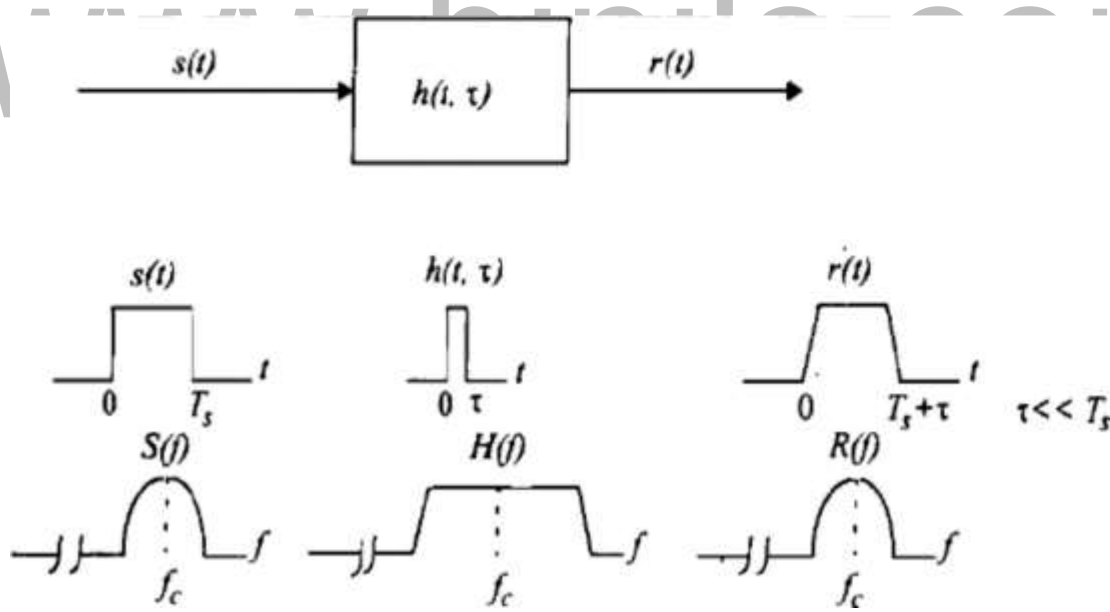

Fig 1.5.1: Characteristics of a Flat Fading Channel.
[Source: "Wireless communications "by Theodore S. Rappaport, Page-168]

It can be seen from Figure 1.5.1, that if the channel gain changes over time, a change of amplitude occurs in the received signal.

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The received signal r (t) varies in gain, but the spectrum of the transmission is preserved.

Flat fading channels are also known as amplitude varying channels and are sometimes referred to as narrowband channels, since the bandwidth of the applied signal is narrow as compared to the channel flat fading bandwidth.

\Flat fading occurs when the bandwidth of the transmitted signal is less than the coherence bandwidth of the channel. We can say that flat fading occurs when

$$B_s \ll B_c$$

Where BS is the signal bandwidth and BC is the coherence bandwidth.

$$T_s \gg a_v$$

Where TS is the symbol period and a_c is the RMS delay spread. And in this case, mobile channel has a constant gain and linear phase response over its bandwidth.

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Frequency Selective Fading

If the channel maintains a constant-gain and linear phase response over a bandwidth that is smaller than the bandwidth of transmitted signal, then the channel creates frequency selective fading on the received signal.

Under such conditions the channel impulse response has a multipath delay spread which is greater than the reciprocal bandwidth of the transmitted message waveform. When this occurs, the received signal has multiple versions of the transmitted waveform which are attenuated (faded) and delayed in time, and hence the received signal is distorted. Frequency selective fading is due to time dispersion of the transmitted symbols within the channel.

Thus the channel induces inter symbol interference (ISI). Frequency selective fading channels are much more difficult to model than flat fading channels since each

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Multi path signal must be modelled and the channel must be considered to be a linear filter. It is for this reason that wideband multipath measurements are made, and models are developed from these measurements.

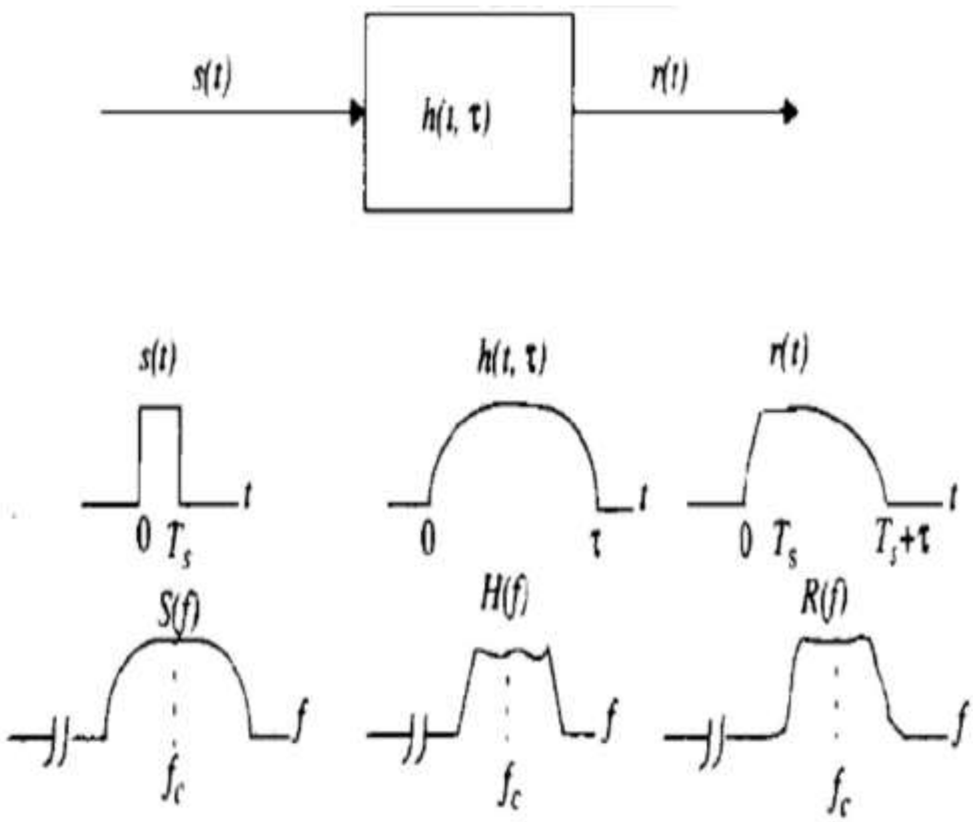

Fig 1.5.2: Characteristics of a Frequency Selective Fading Channel.

[Source:" Wireless communications "by Theodore S. Rappaport, Page-170]

For frequency selective fading as in figure 1.5.2, the spectrum S (f) of the transmitted signal has a bandwidth which is greater than the coherence bandwidth BSc of the channel. Viewed in the frequency domain, the channel becomes frequency selective, where the gain is different for different frequency components. Frequency selective fading is caused by multipath delays that exceed the symbol period of the transmitted symbol.

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Frequency selective fading occurs when the signal bandwidth is more than the coherence bandwidth of the mobile radio channel or equivalently the symbol duration of the signal is less than the RMS delay spread.

$B_S \gg B_C$ And

A channel is frequency selective if , $T_c \leq 10\, a_c$.

Fadding Effects Due to Doppler Spread

Fast fading

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In a fast fading channel, the channel impulse response changes rapidly within the symbol duration. That is, the coherence time of the channel is smaller than the symbol period of the transmitted signal. This causes frequency dispersion (also called time selective fading) due to Doppler spreading, which leads to signal distortion.

Viewed in the frequency domain, signal distortion due to fast fading increases with increasing Doppler spread relative to the bandwidth of the transmitted signal. Therefore, a signal undergoes fast fading if

$T_s \ \Sigma \ T_c$ and $B_s \ € \ B_D$

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

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Slow Fading

In a slow fading channel, the channel impulse response changes at a rate much slower than the transmitted baseband signal s (t). In this case, the channel may be assumed to be static over one or several reciprocal bandwidth intervals. In the frequency domain, the Doppler spread of the channel is much less than the bandwidth of the baseband signal. Therefore, a signal undergoes slow fading if

$$T_{so} \ll T_{ic} \quad \text{and} \quad B_{us} \gg B_D$$

The velocity of the mobile (or velocity of objects in the channel) and the baseband Signaling determines whether a signal undergoes fast fading or slow fading.

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UNIT1 WIRELESS CHANNELS

1.1 LARGE SCALE PATH LOSS

Propagation models are focused on predicting the average received signal strength at a given distance from the transmitter, as well as the variability of the signal strength in close spatial proximity to a particular location.

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 and are called large-scale propagation models.

As the mobile moves away from the transmitter over much larger distances, the local average received signal will gradually decrease, and it is this local average signal level that is predicted by large-scale propagation models. Typically, the local average received power is computed by averaging signal measurements over a measurement track of 5h to 40 h.

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Free-Space Propagation Model

Free space propagation model is used to predict the received signal strength when transmitter And receiver have **clear, unobstructed LOS** path between them.

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

Path Loss: Signal attenuation as a positive quantity measured in dB and defined as the difference (in dB) between the effective transmitted power and received power.

Free space power received by a receiver antenna separated from a radiating transmitter antenna by a distance d, is given by **Fries free space equation**:

$$P_R(d) = P_t G_t G_r h^2 / (4\pi)^{2d2L} \qquad \text{[Equation 1]}$$

Where P_t is transmitted power

$P_r(d)$ is the received power, G_t is the transmitter antenna gain (dimensionless quantity) G_r is the receiver antenna gain (dimensionless quantity), d is T-R separation distance in meters L is

t related to propagation (L >= 1)

L = 1 indicates no loss in system hardware (for our purposes we will take L = 1, so we will ignore it in our calculations). H is wavelength in meters.

The gain of an antenna G is related to its affective aperture A_E by:

$G = 4\pi A_E / h^2$ [Equation 2]

The effective aperture of A_E is related to the physical size of the antenna,

H is related to the carrier frequency by:

$h = \frac{c}{F} = \frac{2n}{m_c}$ [Equation 3]

F is carrier frequency in Hertz

M.C. is carrier frequency in radians per second. C is speed of light in meters/sec

An isotropic radiator is an ideal antenna that radiates power with unit gain uniformly in all directions. It is as the reference antenna in wireless systems.

The effective isotropic radiated power (EIRP) is defined as:

$EIRP = P_t G_t$ [Equation 4]

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Antenna gains are given in units of dB (dB gain with respect to an isotropic antenna) or units of dBd (dB gain with respect to a half-wave dipole antenna).

Unity gain means: G is 1 or 0dBi

Path loss, which represents signal attenuation as positive quantity measured in dB, is defined as the difference (in dB) between the effective transmitted power and the received power.

Path loss for the free space model when antenna gains are included

$PL\,(dB) = 10\log\left(\frac{P_T}{P_R}\right) = -10\log\,[(G_t G_r h^2)/\,(4n)^{2d^2}$ [Equation 5]

When antenna gains are excluded, the antennas are assumed to have unity gain,

and path loss is given by

$PL\,(dB) = 10\log\,(P_T/P_r) = 10\log\,[h^2\,/\,((4n)^{2d^2}$ [Equation 6]

For Fries equation to hold, distance *d* should be in the far-field of the transmitting antenna.

The far-field, or Franco for region, of a transmitting antenna is defined as the region beyond the Far-field distance d_F Given by:

$Do = 2D^2/ß$ [Equation 7]

D is the largest physical dimension of the antenna.

Additionally, $d_F >> D$ and $d_f >> l$

It is clear that, [Equation 1] does not hold for d = 0.

For this reason, models use a close-in distance d_0 as the receiver power reference point.

D_0 should be >= d_f

D_0 should be smaller than any practical distance a mobile system uses

Received power $P_R(d)$, at a distance $d > d_0$ from a transmitter, is related to Pat d_r, which is $_0$

Expressed as $P_R(d_0)$.

The power received in free space at a distance greater than d_0 is given by:

$P_r(d) = P_r(d_0)\ (d_0/d)^2 \quad d >= d_0 >= d_f$ [Equation 8]

Expressing the received power in dB and dB

P_r (d) (dB) =10log [P_r (d_0)/0.001W] +20log (d_0/d) [Equation 9]

where $d >= d_0 >= DF$ and $P_r(d_0)$ is in units of watts.

P_r (d) dB) =10log [P_r (d_0)/1W] +20log (d_0/d) [Equation 10]

Where $d >= d_0 >= DF$ and $P_r(d_0)$ is in units of watts.

Reference distance d_0 for practical systems using low gain antennas:

For frequencies in the range 1-2 GHz

1m in indoor environments

100m-1km in outdoor environments

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1.3 LINK BUDGET DESIGN USING PATH LOSS MODELS

Radio propagation models can be derived by use of empirical methods: collect measurement, fit curves. And by use of analytical methods. Model the propagation mechanisms mathematically and derive equations for path loss.

1. Long Distance Path Loss Model

Empirical and analytical models show that received signal power decreases logarithmically with distance for both indoor and outdoor channels

The average large-scale path loss for an arbitrary T-R separation is expressed as a function of distance by using a path loss exponent n.

$$\overline{PL}(d) \propto \left(\frac{d}{d_0}\right)^n$$

or

$$\overline{PL}(\mathrm{dB}) = \overline{PL}(d_0) + 10n\log\left(\frac{d}{d_0}\right)$$

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Path loss exponent **n** indicates the rate at which the path loss increases with distance.

The value of n depends on the propagation environment: for free space it is2.

When Obstructions are present it has a larger value.

Path Loss Exponent for Different Environments is shown in table1 below.

Table1: Path Loss Exponent

Environment	Path Loss Exponent, *n*
Free space	2
Urban area cellular radio	2.7 to 3.5
Shadowed urban cellular radio	3 to 5
In building line-of-sight	1.6 to 1.8
Obstructed in building	4 to 6
Obstructed in factories	2 to 3

Selection of free space reference distance

In large coverage cellular systems 1km reference distances are commonly used.

In microcellular systems, much smaller distances are used: such as100m or 1m.

The reference distance should always be in the far-field of the antenna so that near-field effects do not alter the reference path loss.

2. Log-Normal Shadowing

This method deals with measurements that are different than the predicted values obtained using the above equation.

Measurements show that for any value d, the path loss PL (d) at a particular location is random and distributed normally. That is

$$PL(d)[dB] = \overline{PL}(d) + X_\sigma = \overline{PL}(d_0) + 10n\log\left(\frac{d}{d_0}\right) + X_\sigma$$

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And $P_r(d)[dBm] = P_t[dBm] - PL(d)[dB]$ (antenna gains included in PL(d).

Where A_x, is a zero-mean Gaussian distributed random variable (in dB) with standard deviation σ (also in dB).

The equation takes into account the shadowing affects due to cluttering on the propagation path. It is used as the propagation model for log-normal shadowing environments.

The received power in log-normal shadowing environment is given by the following formula

$$P_r(d)[dBm] = P_t[dBm] - PL(d)[dB]$$

The antenna gains are included in PL (d).

The log-normal distribution describes the random shadowing effects which occur over a large number of measurement locations which have the same T-R separation, but have different levels of clutter on the propagation path. This phenomenon is called log-normal shadowing.

SMALL SCALE FADING

• Describes the rapid fluctuations of the amplitude, phase of multipath delays of a radio signal over short period of time or travel distance

• Caused by interference between two or more versions of the transmitted signal which arrive at the receiver at slightly different times.

• These waves are called multipath waves and combine at the receiver antenna to give a resultant signal which can vary widely in amplitude and phase.

Effects of multipath

Rapid changes in the signal strength over small travel distances, or over small time intervals.

Random frequency modulation due to varying Doppler shifts on different multiple signals.

Time dispersion (echoes) caused by multipath propagation delays.

Multipath occurs because of: Reflections and Scattering.

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At a receiver point, Radio waves generated from the same transmitted signal may come

☐ From different directions

☐ with different propagation delays

☐ with (possibly) different amplitudes (random)

☐ with (possibly) different phases (random)

☐ These multipath components combine ectopically at the receiver antenna and cause the total signal to fade or distort.

Factors Influencing Small Scale Fading

☐ **Multipath propagation**

• Presence of reflecting objects and caterers cause multiple versions of the signal to arrive at the receiver

• With different amplitudes and time delays

• Causes the total signal at receiver to fade or distort

☐ **Speed of mobile**

• Cause Doppler shift at each multipath component

• Causes random frequency modulation

• Speed of surrounding objects

• Causes time-varying Doppler shift on the multipath components.

☐ **Transmission bandwidth of the channel**

The transmitted radio signal bandwidth and bandwidth of the multipath channel affect the received signal properties:

• If amplitude fluctuates or not

• If the signal is distorted or not.

Doppler Effect

• When a transmitter or receiver is moving, the frequency of the received signal changes, i.e. İt is different than the frequency of transmission. This is called Doppler Effect.

• The change in frequency is called Doppler Shift.

• It depends on the relative velocity of the receiver with respect to transmitter.

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Dpoplar Shift

Consider a mobile moving at a constant velocity v, along a path segment having length d between points X and Y, while it receives signals from a remote source S, as illustrated in Figure 1.2.

The difference in path lengths traveled by the wave from source S to the mobile at points X and Y is Δl = dcos8 = Put cos8, Where Δ t is the time required for the mobile to travel from X to Y, and $ is assumed to be the same at points X and Y since the source is assumed to be very far away.

The phase change in the received signal due to the difference in path lengths is therefore

$$\Delta\phi = \frac{2\pi\Delta l}{\lambda} = \frac{2\pi v\Delta t}{\lambda}\cos\theta$$

And hence the apparent change in frequency, or Doppler shift, is given by fd' where

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

The above equation relates the Doppler shift to the mobile velocity and the spatial angle between the direction of motion of the mobile and the direction of Arrival of the wave.

It can be seen that if the mobile is moving toward the direction of arrival of the wave, the Doppler shift is positive (i.e., the apparent received frequency is increased), and if the mobile is moving away from the direction of arrival of the wave, the Doppler shift is negative.

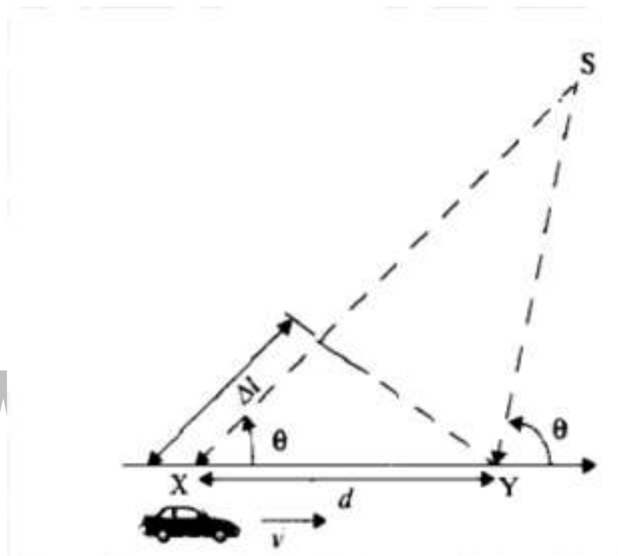

Fig 1.3.1: Doppler Shift

[Source: "Wireless communications "by Theodore S. Rappaport, Page-142]

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1.4 PARAMETERS OF MOBILE MULTIPATH CHANNELS

Power delay profiles are found by averaging instantaneous power delay profile measurements over a local area in order to determine an average

Small-scale power delay profile.

Time dispersion parameters

The time dispersive properties of wide band multipath channels are most commonly quantified by their mean excess delay and RMS delay spread.

The mean excess delay is the first moment of the power delay profile and is defined as

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

Where AK is the amplitude, wk. is the excess delay and P (To) be the power of the individual multipath signals.

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The RMS delay spread is the square root of the second central moment of the power delay profile and is defined as

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

Where

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

These delays are measured relative to the first detectable signal arriving at the

receiver at no = 0.

Typical values of RMS delay spread are on the order of microseconds in outdoor mobile radio channels and on the order of nanoseconds in indoor radio channels.

Note that the RMS delay spread and mean excess delay are defined from a single power delay profile which is the temporal or spatial average of consecutive impulse response

Measurements collected and averaged over a local area. Typically, many measurements are made at many local areas in order to determine a statistical range of multipath channel parameters for a

Mobile communication system over a large-scale area.

The maximum excess delay (X dB) of the power delay profile is defined to be the time delay during which multipath energy falls to X dB below the maximum.

Figure 1.4.1, illustrates the computation of the maximum excess delay for multipath components within 10 dB of the maximum.

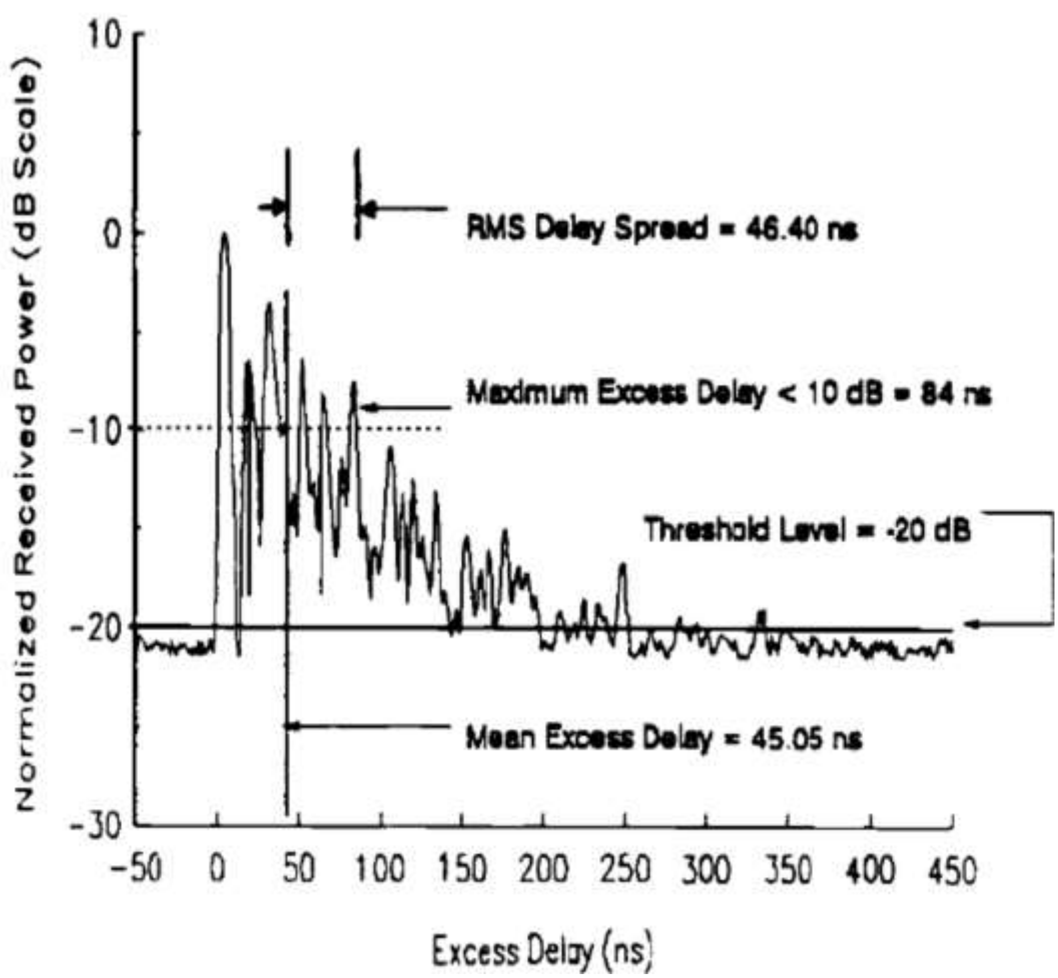

Fig 1.4.1: Power Delay Profile

[Source:" Wireless communications "by Theodore S. Rappaport, Page-163]

The values of time dispersion parameters also depend on the noise threshold

(the level of power below which the signal is considered as noise).

In practice, values of $\bar{v}$, $\overline{v^2}$, a_c depend on the choice of noise threshold used to process P (t).

The noise threshold is used to differentiate between received multipath components and thermal noise. If the noise threshold is set too low, then noise will be processed as multipath, thus giving rise to values of t, P. and that are artificially high.

Coherence Bandwidth (BC)

It is a measure of the range of frequencies over which the channel can be considered flat (i.e. channel passes all spectral components with equal gain and linear phase). It is a definition that depends on RMS Delay Spread. Two sinusoids with frequency separation greater than Bc are affected quite differently by the channel. If we define Coherence Bandwidth (BC) as the range of frequencies over which the frequency correlation is above 0.9, then

$$B_C = \frac{1}{50\sigma}$$ σ is rms delay spread.

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If we define Coherence Bandwidth as the range of frequencies over which the frequency correlation is above 0.5, then, this is called 50% coherence bandwidth.

$$B_c \approx \frac{1}{5\sigma_\tau}$$

Doppler Spread and Coherence time

Doppler Spread and Coherence time are parameters which describe the time varying nature of the channel in a small-scale region.

Measure of spectral broadening caused by Motion Doppler spread, BD, is defined as the maximum Doppler shift: FM= v/λ If the baseband signal bandwidth is much greater than BD, then effect of Doppler spread is negligible at the receiver.

Coherence time is the time duration over which the channel impulse response is essentially invariant. If the symbol period of the baseband signal (reciprocal of the baseband signal bandwidth) is greater the coherence time, then the signal will distort, since channel will change during the transmission of the signal.

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The Doppler spread and coherence time are inversely proportional to one another. That is,

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

In other words, coherence time is the time duration over which two received signals have a strong potential for amplitude correlation. If the reciprocal bandwidth of the baseband signal is greater than the coherence time of the channel, then the channel will change during the transmission of the baseband message, thus causing distortion at the receiver.

If the coherence time is defined as the time over which the time correlation function is above 0.5, then the coherence time is approximately given by.

$$T_C = \sqrt{\frac{9}{16\pi f_m^2}} = \frac{0.423}{f_m}$$

The definition of coherence time implies that two signals arriving with a time separation greater than T_c are affected differently by the channel.

For example, for a vehicle traveling 60 mph using a 900 MHz carrier, a conservative value of T_c can be shown to be 2.22 Ms.

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1.2 TWO RAY GROUND REFLECTION MODEL

Two ray model considers both the direct path and a ground reflected propagated path between transmitter and receiver.

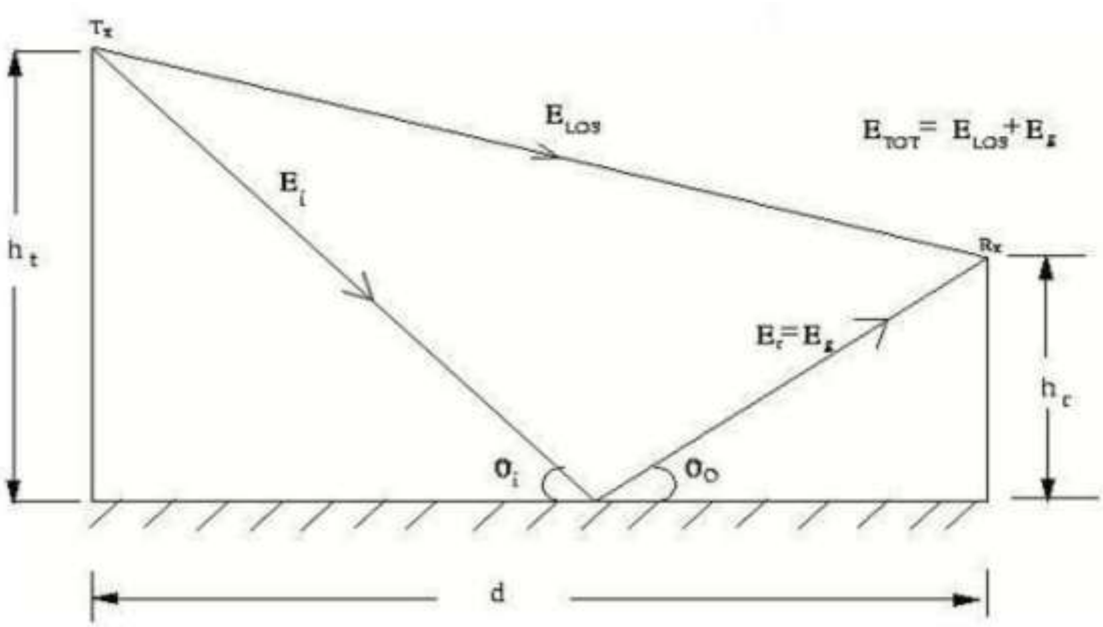

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Fig1.2.1: Two Ray Model

[Source: "Wireless communications "by Theodore S. Rappaport, Page- 86]

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

The total received E-field E_{TOT} is the result of the direct line of sight component E**LOS** and the ground reflected component E.g.

Referring to Figure 1.2.1, h**it** is the height of the transmitter and hr is the height of the receiver.

If E**0**is the free space electric field (in V/m) at a reference distance d**0** from the transmitter then ford>d0,

The free space propagating E-field is

$$E(d,t) = \frac{E_O d_O}{d} \; cost(m_c (t - \frac{d}{c})) \quad (dB \; d_o)$$

The envelop of the electric field at d meters from the transmitter at any time t is therefore

$$|E(d, t)| = \frac{E_O d_O}{D}$$

Two propagating waves arrive at the receiver, **one LOS wave** which travels a distance of d’ and another **ground reflected wave** that travels $d^{||}$.

The E-field due to the line-of-sight component at the receiver can be expressed as

$$E_{LOS}(d^{|}, t) = \frac{E_O d_O}{d^{|}} \text{ Cost } (m_c \left(t - \frac{d^{|}}{c}\right)$$

The E-fleld for the ground reflected wave, which has a propagation distance of d", can be expressed as

$$E_g (d^{||}, t) = T \frac{E_O d_O}{d^{|}} \text{ cost } (m (t \frac{d^{||}}{c}))$$

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According to the law of reflection in a dielectric,

If = 8_O and E.g. = Γ Eli

$$E_t = (1 + T)E_{li}$$

Where Γ is the reflection coefficient for ground.

For small values of if (i.e., grazing incidence), the reflected wave is equal in magnitude and 180° out of phase with the incident wave.

The resultant total E-field envelope is given by

$$|E_{TOT}| = |E_{LOS} + E_g|$$

The electric field T_{ot} (d, t) can be expressed as

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

Using the method of images, which is shown in Figure 1.2.2, the path difference, Δ between the line-of-sight and the ground reflected paths can be expressed as

$$\Delta = d'' - d' = \sqrt{(h_t + h_r)^2 + d^2} - \sqrt{(h_t - h_r)^2 + d^2}$$

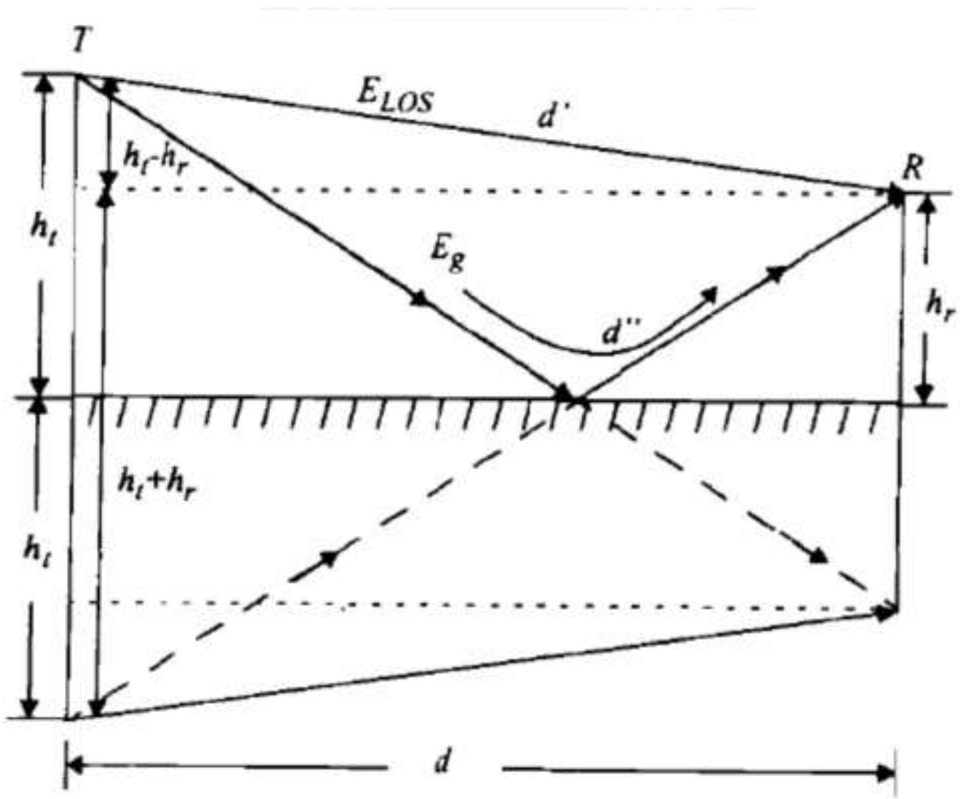

Fig 1.2.2: The Method of Images- Two Ray Model.

[Source: "Wireless communications "by Theodore S. Rappaport, Page- 87]

When the T-R separation distance d is very large compared to $h_{it} + h_{r.}$, the above equation can be simplified using a Taylor series approximation

$$\Delta = d'' - d' \approx \frac{2h_t h_r}{d}$$

Once the path difference is known, the phase difference 8_O between the two Electric field

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Components and the time delay a_d between the arrivals of the two components can be easily computed using the following relations.

$$\theta_\Delta = \frac{2\pi\Delta}{\lambda} = \frac{\Delta\omega_c}{c}$$

And

$$\tau_d = \frac{\Delta}{c} = \frac{\theta_\Delta}{2\pi f_c}$$

It should be noted that as d becomes large, the difference between the distances d' and d'' becomes very small, and the amplitudes of E_{LOS} and E.g. are virtually identical and differ only in phase.

$$\left|\frac{E_0 d_0}{d}\right| \approx \left|\frac{E_0 d_0}{d'}\right| \approx \left|\frac{E_0 d_0}{d''}\right|.$$

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If the received electric field is evaluated at $t = \frac{d''}{c}$, it can be expressed as

$$E_{TOT}\left(d, t = \frac{d''}{c}\right) = \frac{E_0 d_0}{d'}\cos\left(\omega_c\left(\frac{d'' - d'}{c}\right)\right) - \frac{E_0 d_0}{d''}\cos 0^\circ$$
$$= \frac{E_0 d_0}{d'}\cos\theta_\Delta - \frac{E_0 d_0}{d''}$$
$$\approx \frac{E_0 d_0}{d}[\cos\theta_\Delta - 1]$$

Referring to the pharos diagram of Figure 1.3, which shows how the direct and ground reflected rays combine, the electric field (at the receiver) at a distance d from the transmitter can be written as

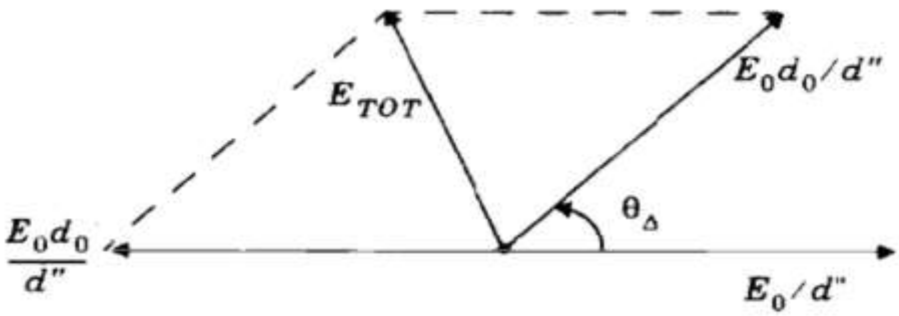

Fig 1.2.3: Pharos diagram

[Source: "Wireless communications "by Theodore S. Rappaport, Page- 89]

Using trigonometric identities, the above equation can be expressed as

$$|E_{TOT}(d)| = 2\frac{E_0 d_0}{d}\sin\left(\frac{\theta_\Delta}{2}\right)$$

Where d Implies that

$$d > \frac{20\pi h_t h_r}{3\lambda} \approx \frac{20 h_t h_r}{\lambda}$$

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The received E-field can be approximated as

$$E_{TOT}(d) \approx \frac{2E_0 d_0}{d}\frac{2\pi h_t h_r}{\lambda d} \approx \frac{k}{d^2}\ \text{V/m}$$

Where k is a constant related to E0, the antenna heights, and the wavelength.

The received power at a distance d from the transmitter can be expressed as

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

At large distances ($d \gg \sqrt{h_t h_r}$) the received power falls off with distance raised to the fourth power, or at a rate of 40 dB/ decade. This is a much more rapid path loss than is experienced in free space.

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

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