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UNIT-IV

1. Explain ground incident angle, elevation angle, ground reflection and reflection point.

Answer:

The ground incident angle and the ground elevation angle over a communication link are described as follows. The ground incident angle 0 is the angle of wave arrival incidently pointing to the ground as shown in Fig. 1.1. The ground elevation angle is the angle of wave arrival at the mobile unit as shown in Fig. 1.1

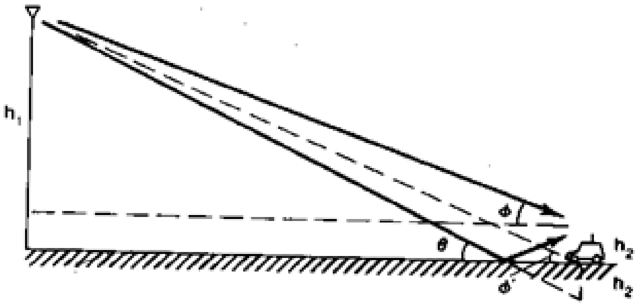

Figure 1.1 Representation of Ground Incident Angle θ and Ground Elevation Angle φ

Based on Snell's law, the reflection angle and incident angle are the same. Since in graphical display we usually exaggerate the hilly slope and the incident angle by enlarging the vertical scale, as shown in Fig. 1.2, then as long as the actual hilly slope is less than 100, the reflection point on a hilly slope can be obtained by following the same method as if the reflection point were on flat ground. Be sure that the two antennas (base and mobile) have been placed vertically, not perpendicular to the sloped ground. The reason is that the actual slope of the hill is usually very small and the vertical stands for two antennas are correct. The scale drawing in Fig. 1.2 is somewhat misleading however, it provides a clear view of the situation.

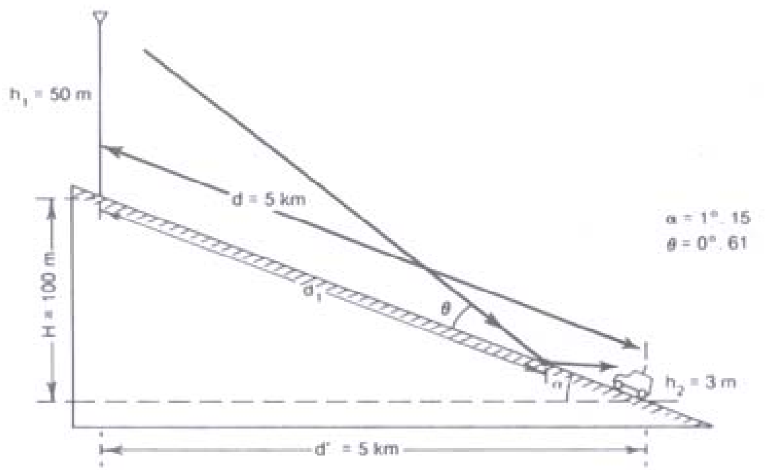

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Fig 1.2 Ground reflection angle and reflection point

2. Write about the phase difference between the direct path and the ground reflected path.

Answer:

Based on a direct path and a ground reflected path, the equation

$$P_r = P_0 \left(\frac{1}{4\pi d/\lambda}\right)^2 \left|1 + a_v e^{j\Delta\phi}\right|^2$$

where a_v = the reflection coefficient
$\Delta\phi$ = the phase difference between a direct path and a reflected path
P_0 = the transmitted power
d = the distance
λ = the wavelength

indicates a two-wave model which is used to understand the path-loss phenomenon in a mobile radio environment. It is not the model for analyzing the multipath fading phenomenon. In a mobile environment av = - 1 because of the small incident angle of the ground wave caused by a relatively low cell-site antenna height. Thus,

$$P_r = P_0 \left(\frac{1}{4\pi d/\lambda}\right)^2 \left|1 - \cos\Delta\phi - j\sin\Delta\phi\right|^2$$

$$= P_0 \frac{2}{(4\pi d/\lambda)^2}(1 - \cos\Delta\phi) = P_0 \frac{4}{(4\pi d/\lambda)^2}\sin^2\frac{\Delta\phi}{2}$$

where $\Delta\phi = \beta\,\Delta d$

and Δd is the difference, $\Delta d = d_1 - d_0$, from Fig. 4.4.

$$d_1 = \sqrt{(h_1 + h_2)^2 + d^2}$$

and $$d_2 = \sqrt{(h_1 - h_2)^2 + d^2}$$

Since Δd is much smaller than either d_1 or d_2,

$$\Delta\phi = \beta\,\Delta d \approx \frac{2\pi}{\lambda}\frac{2h_1h_2}{d}$$

Then the received power of Eq. (4.2-3) becomes

$$P_r = P_0 \frac{\lambda^2}{(4\pi)^2 d^2}\sin^2\frac{4\pi h_1 h_2}{\lambda d}$$

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If $\Delta\phi$ is less than 0.6 rad, then $\sin(\Delta\phi/2) \approx \Delta\phi/2$, $\cos(\Delta\phi/2) \approx l$, then

$$P_r = P_0 \frac{4}{16\pi^2(d/\lambda)^2}\left(\frac{2\pi h_1 h_2}{\lambda d}\right)^2 = P_0\left(\frac{h_1 h_2}{d^2}\right)^2$$

, thus

$$\Delta P = 40 \log \frac{d_1}{d_2} \qquad \text{(a 40 dB/dec path loss)}$$

$$\Delta G = 20 \log \frac{h'_1}{h_1} \qquad \text{(an antenna height gain of 6 dB/oct)}$$

Where P is the power difference in decibels between two different path lengths and G is the gain (or loss) in decibels obtained from two different antenna heights at the cell site. From these measurements, the gain from a mobile antenna height is only 3 dB/oct, which is different from the 6 dB/oct . Then

$$\Delta G'' = 10 \log \frac{h'_2}{h_2}$$

3. Why there is a constant standard deviation along a path-loss curve.

Answer:

When plotting signal strengths at any given radio-path distance, the deviation from predicted value. is approximately 8 dB.1012 This standard deviation of 8 dB is roughly true in many different areas. The explanation is as follows. When a line-of-sight path exists, both the direct wave path and reflected wave path are created and are strong. When an out-of-sight path exists, both the direct wave path and the reflected wave path are weak. In either case, according to the theoretical model, the 40-dB/dec path-loss slope applies. The difference between these two conditions is the 1-mi intercept (or 1-km intercept) point. It can be seen that in the open area, the 1-mi intercept is high. In the urban area, the 1-mi intercept is low. The standard deviation obtained from the measured data remains the same along the different path-loss curves regardless of environment.

Support for the above argument can also be found from the observation that the standard deviation obtained from the measured data along the predicted path-loss curve is approximately 8 dB. The explanation is that at a distance from the cell site, some mobile unit radio paths are line-of-sight, some are partial line-of-sight, and some are out-of-sight. Thus the received signals are strong, normal, and weak, respectively. At any distance, the above situations prevail. If the standard deviation is 8 dB at one radio-path distance, the same 8dB will be found at any distance. Therefore a standard deviation of 8 dB is always found along the radio path as shown in Fig.3. The standard deviation of 8 dB from the measured data near the cell site is due mainly to the close-in buildings around the cell site. The same standard deviation from the measured data at a distant location is due to the great variation along different radio paths.

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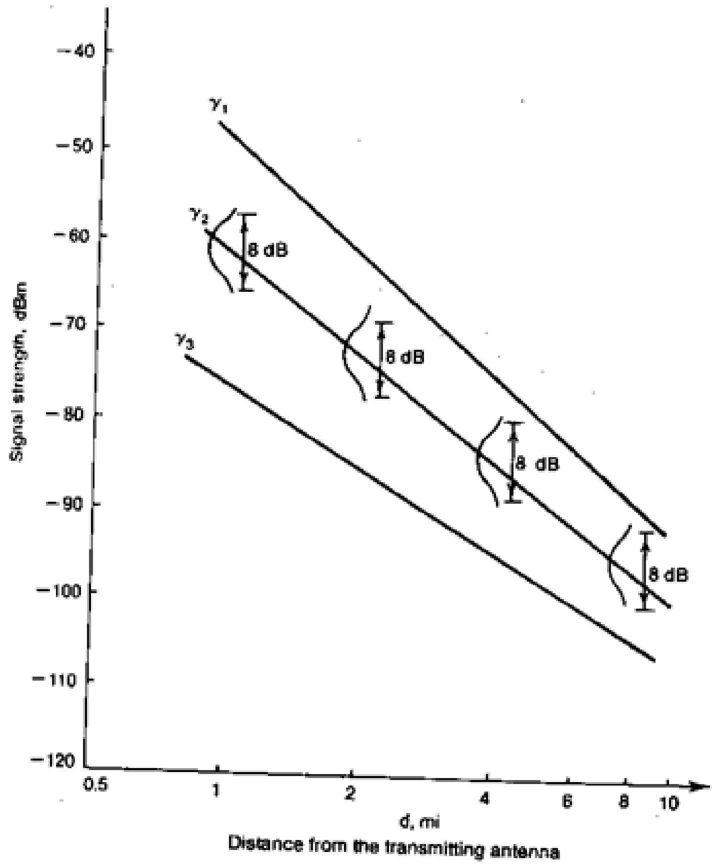

Fig 3 An 8-dB local mean spread

4. Discuss the merits of point-to-point model.

Answer:

The area-to-area model usually only provides an accuracy of prediction with a standard deviation of 8 dB, which means that 68 percent of the actual path-loss data are within the ± 8 dB of the predicted value. The uncertainty range is too large. The point-to-point model reduces the uncertainty range by including the detailed terrain contour information in the path-loss predictions.

The differences between the predicted values and the measured ones for the point-to-point model were determined in many areas. In the following discussion, we compare the differences shown in the Whippany, N.J., area and the Camden-Philadelphia area. First, we plot the points with predicted values at the x-axis and the measured values at the y-axis, shown in Fig. 4. The 450 line is the line of prediction without error. The dots are data from the Whippany area, and the crosses are data from the Camden-Philadelphia area. Most of them, except the one at 9 dB, are close to the line of prediction without error.

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The mean value of all the data is right on the line of prediction without error. The standard deviation of the predicted value of 0.8 dB from the measured one.

In other areas, the differences were slightly larger. However, the standard deviation of the predicted value never exceeds the measured one by more than 3 dB. The standard deviation range is much reduced as compared with the maximum of 8 dB from area-to-area models. The point-to-point model is very useful for designing a mobile cellular system with a radius for each cell of 10 mi or less. Because the data follow the log-normal distribution, 68 percent of predicted values obtained from a point-to-point prediction model are within 2 to 3 dB. This point-to-point prediction can be used to provide overall coverage of all cell sites and to avoid cochannel interference. Moreover, the occurrence of handoff in the cellular system can be predicted more accurately.

The point-to-point prediction model is a basic tool that is used to generate a signal coverage map, an interference area map, a handoff occurrence map, or an optimum system design configuration, to name a few applications.

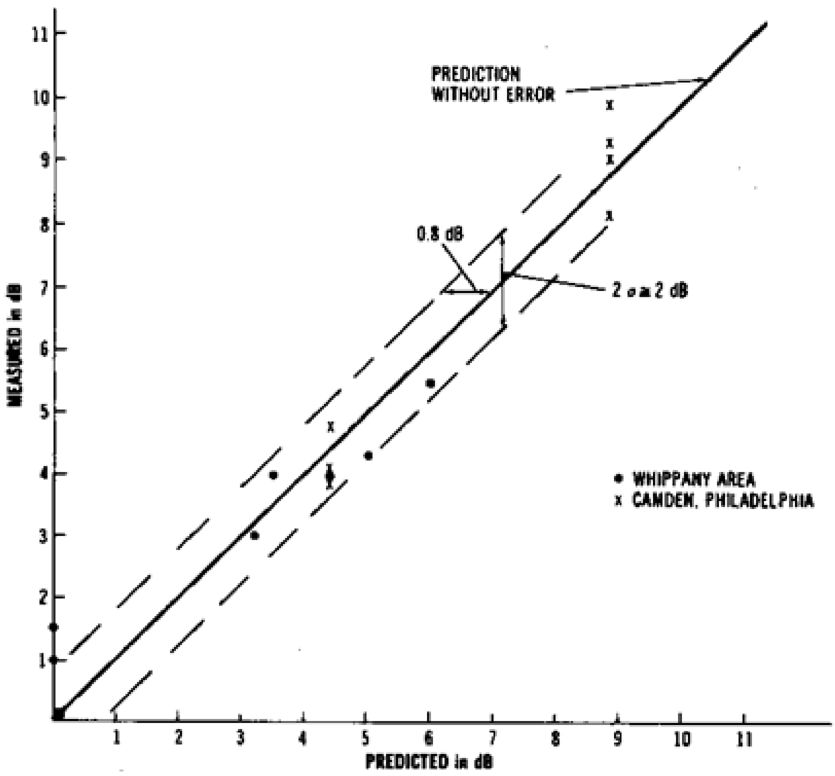

Fig .4. Indication of errors in point-to-point predictions under non obstructive conditions.

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5. Explain about foliage loss

Answer:

Foliage loss is a very complicated topic that has many parameters and variations. The sizes of leaves, branches, and trunks, the density and distribution of leaves, branches, and trunks, and the height of the trees relative to the antenna heights all be considered. An illustration of this prv1em is shown in Fig. 5.1. There are three levels: trunks, branches, and leaves. In each level, there is a distribution of sizes of trunks, branches, and leaves and also of the density and spacing between adjacent trunks, branches, and leaves. The texture and thickness of the leaves also count. This unique problem can become very complicated and is beyond the scope of this book. For a system design, the estimate of the signal reception due to foliage loss does not need any degree of accuracy.

Furthermore, some trees, such as maple or oak, lose their leaves in winter, while others, such as pine, never do. For example, in Atlanta, Georgia, there are oak, maple, and pine trees. In summer the foliage is very heavy, but in winter the leaves of the oak and maple trees fall and the pine leaves stay. In addition, when the length of pine needles reaches approximately 6 in., which is the half wavelength at 800 MHz, a great deal of energy can be absorbed by the pine trees. In these situations, it is very hard to predict the actual foliage loss.

However, a rough estimate should be sufficient for the purpose of system design. In tropic zones, the sizes of tree leaves are so large and thick that the signal can hardly penetrate. In this case, the signal will propagate from the top of the tree and deflect to the mobile receiver. We will include this calculation also.

Sometime the foliage loss can be treated as a wire-line loss, in decibels per foot or decibels per meter, when the foliage is uniformly heavy and the path lengths are short. When the path length is long and the foliage is non uniform, then decibels per octaves or decibels per decade are used. In general, foliage lose occurs with respect to the frequency to the fourth power. Also, at 800 MHz the foliage Lou along the radio path is 40 dB/dec, which is 20 dB more than the free- space loss, with the same amount of additional loss for mobile communications. Therefore, if the situation involves both foliage loss and mobile communications, the total loss would be 60 dB/dec (=20 dB/ dec of free-space loss + additional 20 dB due to foliage loss + additional 20 dB due to mobile communication).

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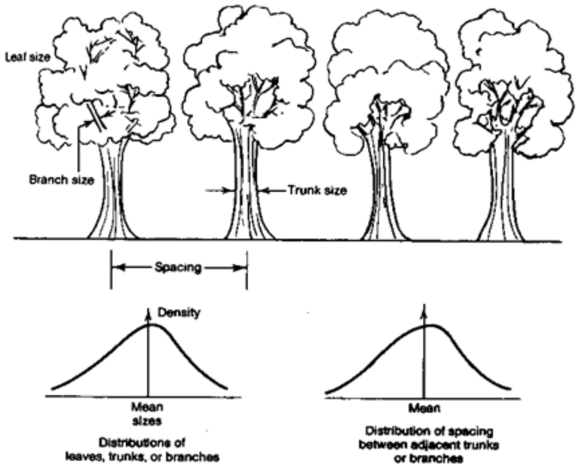

Fig.5.1. A characteristic of foliage environment

This situation would be the case if the foliage would line up along the radio path. A foliage loss in a suburban area of 58.4 dB/dec is shown in Fig.5.2. As demonstrated from the above two examples, close-in foliage at the transmitter site always heavily attenuates signal reception. Therefore, the cell site should be placed away from trees.

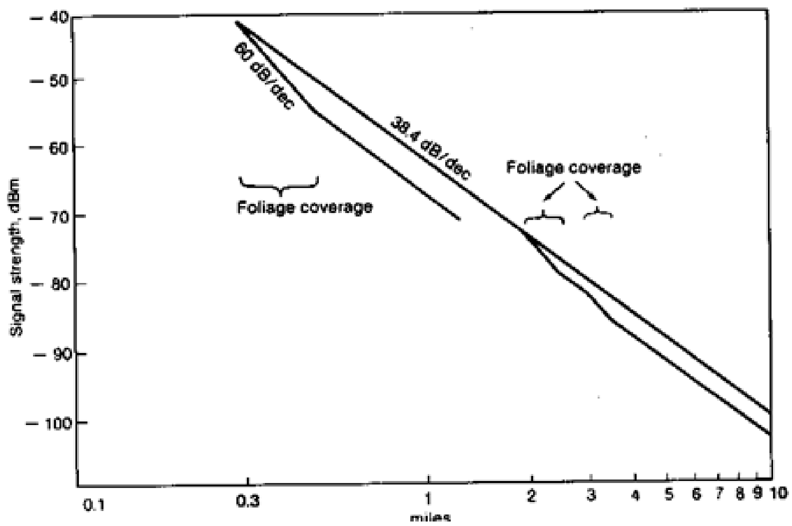

Fig.5.2. Foliage loss calculation in suburban areas

6. Discuss the "Lee model" for point to point propagation.

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Answer:

In general, the mobile point-to-point model can be obtain in three steps.

(i) Generate a standard condition.
(ii) Obtain an Area-to-Area prediction model.
(iii) Obtain a mobile Point-to-Point model using Area-to-Area prediction model.

The purpose of developing this model is try to separate two effects.

(a) Natural terrain contour.

(b) Human made structures.

(i) Standard Condition: To generate the standard condition, transmitted power and antenna height at base station and mobile unit should satisfy the following requirements.

	Standard Condition At the mobile Unit	Correction Factors
1.	Antenna height $h_2 = 10$ ft (3m)	$\alpha_1 = 10\log\left(\frac{h_2'}{h_2}\right)$
2.	Antenna gain $g_m = 0$ dB/dipole	$\alpha_2 = g_m'$
	At the Base Station	
1.	Transmitted power $p_t = 10$ w (40 dBm)	$\alpha_3 = 10 \log\left(\frac{P_t'}{10}\right)$
2.	Antenna height $h_1 = 100$ ft (30 m)	$\alpha_4 = 20 \log\left(\frac{h_1'}{h_1}\right)$
3.	Antenna gain $g_t = 6$ dB/dipole	$\alpha_3 = g_{t2}' - 6$

(ii) Obtain Area-to-Area Predication Curves for Human Made Structures: In the Area-to-Area prediction model, all the areas are considered. as flat even though the data may be received from non flat area

(iii) Effect of the Human Made Structures: The terrain configuration of each city is different, and the human made structure of the each city unique. So that, try to separate the two effects. The path loss curve obtained on virtually flat ground indicates the effects of the signal loss due to solely human made structures. The average path loss slope shown below which is a combination of measurements from high spots and low spots along different radio paths.

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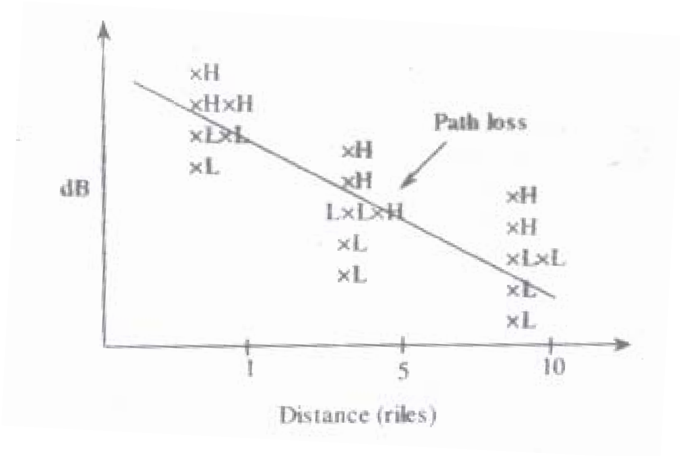

The Area-to-A prediction curve is obtained from the mean value of the measured data and used for further prediction in that area The Area-to-Area prediction model can be used as a first step towards achieving the point-to-point prediction model. The performance of d Area-to-Area prediction model can be represented by two parameters.

1. 1 mi intercept point.
2. The path loss slope.

The 1 ml intercept point is the power received at a distance of 1 mi from the transmitter. The 1 mi intercept point is depends upon the effective antenna height gain.

ΔG = Effective antenna – height gain = 20 log(he/h1)

Where, he= Effective antenna height

h1= Actual height

7. Derive the relation for the maximum coverage distance in mobile environment.

Answer:

The structure of a mobile environment is shown in below figure

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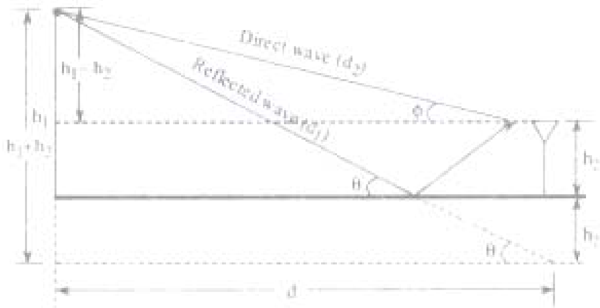

Figure: Mobile Unit Environment

Consider a cell site antenna of height 'h1' and a mobile antenna of height 'h2' is moving away from cell site. The maximum distance up to which, the mobile antenna receives the signal is the maximum coverage distance.

Let the maximum coverage distance is 'd'. So when mobile antenna moving away from the cell site we can observe two waves of propagation, i.e., direct wave and reflected wave.

Direct wave is the direct propagation from cell site to mobile antenna, without any deviation and the distance travelled by this wave is considered to be (d2), a range 'φ' with surface angle φ is known as elevation angle.

Reflected wave is the wave propagated from cell site to surface and then surface to mobile antenna, let the distance travelled by it is 'd1' angle done by it with surface is 'θ'.

Based on direct path and ground reflected path the received power 'Pr' is given by

$$\boxed{P_r = P_0\left(\frac{1}{4\pi d/\lambda}\right)^2 \left|1 + a_v . e^{j\Delta\phi}\right|^2}$$

P0 = Transmitted Power,
d = Maximum coverage distance,
av = Reflection coefficient.

Δφ = The phase difference between direct path and reflected path
λ=Wave length.

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We know that,

$$e^{j\theta} = \cos\theta + j\sin\theta,\ a_a = -1$$

$\therefore$ Equation (1) can be rewritten as,

$$P_r = P_0\left(\frac{1}{4\pi d/\lambda}\right)^2 |1 - \cos\Delta\phi - j\sin\Delta\phi|^2$$

$$P_r = P_0 \boxed{P_r = P_0\frac{1}{(4\pi d/\pi)^2}\left|\begin{matrix}(1-\cos\Delta\phi)\\ -(j\sin\Delta\phi)\end{matrix}\right|^2}$$

We know that from algebra

$$|a - jb| = |a + jb| = \sqrt{a^2 + b^2}$$

$$\therefore \quad |(1-\cos\Delta\phi) - (\sin\Delta\phi)|^2$$

$$= \left(\sqrt{(1-\cos\Delta\phi)^2 + (\sin\Delta\phi)^2}\right)^2$$

$$= \left(\sqrt{1 - 2\cos\Delta\phi + (\cos^2\Delta\phi + \sin^2\Delta\phi)}\right)^2$$

$$= \left(\sqrt{1 - 2\cos\Delta\phi + 1}\right)^2$$

$$= \left(\sqrt{2 - 2\cos\Delta\phi}\right)^2$$

$$= (2 - 2\cos\Delta\phi)$$

$$= 2(1 - \cos\Delta\phi).$$

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∴ By substituting this value in equation (2), we get,

$$\therefore \quad P_r = P_0 \cdot \frac{2}{\left(\frac{4\pi d}{\lambda}\right)^2}(1 - \cos \Delta\phi)$$

$$= P_0 \frac{2}{(4\pi d/\lambda^2)}\left[1 - \left(1 - 2\sin^2\frac{\Delta\phi}{2}\right)\right]$$

$$\Rightarrow \boxed{P_r = P_0 \frac{4}{(4\pi d/\lambda)^2}\sin^2\frac{\Delta\phi}{2}} \qquad \ldots (3)$$

Where,

$\Delta\phi = \beta\Delta d$ and Δd is the path difference,

i.e., $\boxed{\Delta d = d_1 - d_2}$

But from figure, $d_1 = \sqrt{(h_1 + h_2)^2 + d^2}$

$$d_2 = \sqrt{(h_1 - h_2)^2 + d^2}$$

and also Δd is much smaller than d_1 and d_2.

$$\therefore \quad \text{As } \Delta\phi = \beta\,\Delta d \simeq \frac{2\pi}{\lambda} \cdot \frac{2h_1h_2}{d}$$

Then the received power from equation (3) becomes,

$$P_r = P_0 \frac{\lambda^2}{(4\pi)^2 d^2} \sin^2 \frac{4\pi\, h_1 h_2}{\lambda d}$$

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If $\Delta\phi$ is very small then $\sin\left(\frac{\Delta\phi}{2}\right) = \left(\frac{\Delta\phi}{2}\right)$

$$\Rightarrow P_r = P_0 \frac{4}{16\pi^2 (d/\lambda)^2} \left(\frac{2\pi h_1 h_2}{\lambda d}\right)^2$$

$$= P_0 \left(\frac{h_1 h_2}{d^2}\right)^2$$

$$\therefore \quad P_r = P_0 \left(\frac{h_1 h_2}{d^2}\right)^2$$

Where, 'd' is maximum coverage distance and is given by,

$$\boxed{d = \sqrt{\frac{h_1 h_2}{\left(P_r / P_0\right)^{1/2}}}} \quad \ldots (4)$$

From equation (4), we can deduce two relationships,

First

$$\boxed{\Delta p = 40 \log \frac{d_1}{d_2}} \quad \text{(a 40 dB/dec path loss)}$$

When ΔP is the power difference in decibels between two different path lengths.

Second

$\Delta G = 20 \log (he/h1)$ …………(5)

Where, h1= Height of the cell antenna

he = Effective antenna height

= (h1 + h2) and

ΔG is the gain in decibels obtained from two different antenna heights at the cell site.

Hence, equation (5) represents, equation for the system gain.

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8. What are the factors that effect accuracy of prediction

Answer:

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Factors effecting the Accuracy of Prediction

The standard deviation is constant along a path loss curve. The path-loss slope is 40dB/dec in case of both line-of-sight path and out-of-sight path. However, the direct path and reflected path in case of line-of-sight path are strong and in out-of-sight path is weak. By media ting these two conditions, 1-mi intercept is obtained, which is strong in open area but weak in urban areas.

The standard deviation obtained from the predicted path-loss curve is almost equal to S dB and is constant throughout the radio path. But the received signals vary based on the type of path. i.e. for line-of-sight path the received signal is strong for partial line-of-sight path it is norm al and for out-of-sight path the received signal is weak. These are few factors, which affect the accuracy of the prediction.

9. Discuss in detail about small scale multipath propagation.

Answer:

Small Scale Multipath Propagation: The multipath propagation of radio signals over a short period of time or to travel a distance is considered to be the small scale multipath propagation. As every type of multipath propagation results in generating a faded signal at receiver, the small scale multipath propagation also results in small scale fading. Hence, the signal at the receiver is obtained by combining the various multipath waves. These waves will vary widely in amplitude and phase depending on the distribution of the intensity and relative propagation time of the waves and bandwidth of the transmitted signal.

The three fading effects that are generally observed due to the small scale multipath propagation are,

1. Fast variations in signal strength of the transmitted signal for a lesser distance or time interval.
2. The variations in Doppler shift on various multipath signals are responsible for random frequency modulation
3 The time dispersed signals are resulted due to multipath propagation delays.

In order to determine the small scale fading effects, we employ certain techniques. They are,

1. Direct RF pulse measurement
2. Spread spectrum sliding correlator measurement.
3. Swept frequency measurement.

The first technique provides a local average power delay profile.

The second technique detects the transmitted signal with the help of a narrow band receiver preceded by a wide band mixer though the probing (or received) signal is wide band.

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The third technique is helpful in finding the impulse response of the channel in frequency domain. By knowing the impulse response we can easily predict the signal obtained at the receiver from the transmitter.

10. Explain the effect of propagation of mobile signals over water.

Answer:

Propagation over Water or Flat Open Area: Propagation over water or fiat open area is becoming a big concern because it is very easy to interfere with other cells if we do not make the correct arrangements. Interference resulting from propagation over the water can be controlled if we know the cause. In general, the permittivities Er of seawater and fresh water are the same, but the conductivities of seawater and fresh water are different. We may calculate the dielectric constants Ec where Ec = Er - j60σλ. The wavelength at 850MHz is 0.35m. Then Eo (sea water) = 80 - j84 and Ec (fresh water)=80-jO.021.

However, based upon the reflection coefficients formula with a small incident angle both the reflection coefficients for horizontal polarized waves and vertically polarized waves approach 1. Since the 180* phase change occurs at the ground reflection point, the reflection coefficient is -1. Now we can establish a scenario, as shown in Fig 10.1 Since the two antennas, one at the cell site and the other at the mobile unit, are well above sea level, two reflection points are generated. The one reflected from the ground is close to the mobile unit; the other reflected from the water is away from the mobile unit. We recall that the only reflected wave we considered in the land mobile propagation is the one reflection point which is always very close to the mobile unit. We are now using the formula to find the field strength under the circumstances of a fixed point-to-point transmission and a land-mobile transmission over a water or flat open land condition.

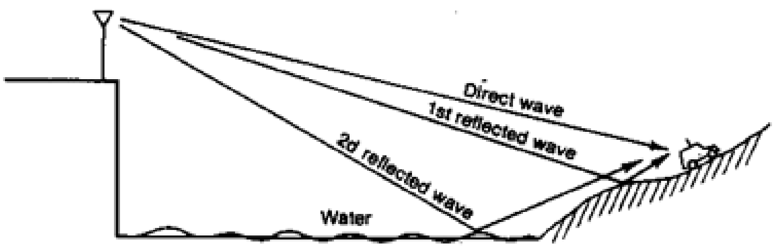

Fig 10.1.A model for propagation over water

Between fixed stations: The point-to-point transmission between the fixed stations over the water or flat open land can be estimated as follows. The received power *P,* can be expressed as (see Fig.10.2)

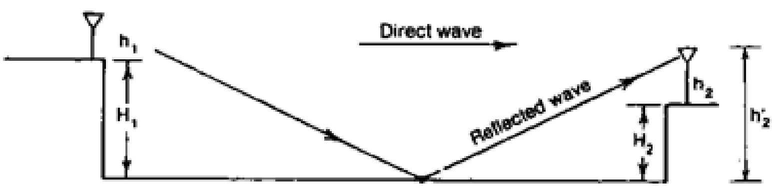

Fig 10.2.Propagation between two fixed stations over water or flat open land.

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$$P_r = P_t\left(\frac{1}{4\pi d/\lambda}\right)^2 \left|1 + a_v e^{-j\phi_v} \exp(j\,\Delta\phi)\right|^2$$

where P_t = transmitted power
d = distance between two stations
λ = wavelength
a_v, ϕ_v = amplitude and phase of a complex reflection coefficient, respectively

$\Delta\varphi$ is the phase difference caused by the path difference M between the direct wave and the reflected wave, or

$$\Delta\phi = \beta\,\Delta d = \frac{2\pi}{\lambda}\Delta d$$

The first part of i.e. the free-space loss formula which shows the 20 dB/dec slope; that is, a 20-dB loss will be seen when propagating from 1 to 10 km.

$$P_0 = \frac{P_t}{(4\pi d/\lambda)^2}$$

The complex reflection co-efficients and can be found from the formula

$$a_v e^{-j\phi_v} = \frac{\epsilon_c \sin\theta_1 - (\epsilon_c - \cos^2\theta_1)^{1/2}}{\epsilon_c \sin\theta_1 + (\epsilon_c - \cos^2\theta_1)^{1/2}}$$

When the vertical incidence is small, θ is very small and

$$a_v \approx -1 \qquad \text{and} \qquad \phi_v = 0$$

can be found from equation. Ec is a dielectric constant that is different for different media. The reflection coefficient remains -1 regardless of whether the wave le propagated over water dry land, wet land, Ice, and so forth. The wave propagating between fixed stations is illustrated in Fig. 10.2.

$$P_r = \frac{P_t}{(4\pi d/\lambda)^2}\left|1 - \cos\Delta\phi - j\sin\Delta\phi\right|^2$$
$$= P_0(2 - 2\cos\Delta\phi)$$

since $\Delta\varphi$ is a function of d and d can be obtained from the following calculation. The effective antenna height at antenna 1 is the height above the sea level.

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$$h_1' = h_1 + H_1$$

The effective antenna height at antenna 2 is the height above the sea level.

$$h_2' = h_2 + H_2$$

As shown in Fig.10.2 where h1 and h2 are actual heights and H1and H2 are the heights of hills. In general, both antennas at fixed stations are high, so the resection point of the wave will be found toward the middle of the radio path. The path difference d can be obtained from Fig. 10.2 as

$$\Delta d = \sqrt{(h_1' + h_2')^2 + d^2} - \sqrt{(h_1' - h_2')^2 + d^2}$$

Since $d \gg h_1'$ and h_2', then

$$\Delta d \approx d\left[1 + \frac{(h_1' + h_2')^2}{2d^2} - 1 - \frac{(h_1' - h_2')^2}{2d^2}\right] = \frac{2h_1'h_2'}{d}$$

Then

$$\Delta\phi = \frac{2\pi}{\lambda}\frac{2h_1'h_2'}{d} = \frac{4\pi h_1'h_2'}{\lambda d}$$

We can setup five conditions:

1. ***P, <P0.*** The received power is less than the power received in free space; that is,

$$2 - 2\cos\Delta\phi < 1 \quad \text{or} \quad \Delta\phi < \frac{\pi}{3}$$

2. $P_r = 0$; that is,

$$2 - 2\cos\Delta\phi = 0 \quad \text{or} \quad \Delta\phi = \frac{\pi}{2}$$

3. $P_r = P_0$; that is,

$$2 - 2\cos\Delta\phi = 1 \quad \text{or} \quad \Delta\phi = \pm 60^\circ = \pm\frac{\pi}{3}$$

4. $P_r > P_0$; that is,

$$2 - 2\cos\Delta\phi > 1 \quad \text{or} \quad \frac{\pi}{3} < \Delta\phi < \frac{5\pi}{3}$$

5. $P_r = 4P_0$; that is,

$$2 - 2\cos\Delta\phi = \max \quad \text{or} \quad \Delta\phi = \pi$$

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11. Write short notes on mobile-to-mobile propagation.

Answer:

Mobile-to-Mobile Propagation: In mobile-to-mobile land communication, both the transmitter and the receiver are in motion. The propagation path in this case is usually obstructed by buildings and obstacles between the transmitter and receiver. The propagation channel acts like a filter with a time-varying transfer function H (f, t) which can be found in this section.

The two mobile units M1 and M2 with velocities V1 and V2 respectively are shown in Fig.11.1. Assume that the transmitted signal from M1 is

$$s(t) = u(t)e^{j\omega t}$$

The receiver signal at the mobile unit M_2 from an ith path is

$$s_i = r_i u(t - \tau_i)e^{j[(\omega_0 + \omega_{1i} + \omega_{2i})(t - \tau_i) + \phi_i]}$$

where $u(t)$ = signal
ω_0 = RF carrier
r_i = Rayleigh-distributed random variable
ϕ_i = uniformly distributed random phase
τ_i = time delay on ith path

and

ω_{1i} = Doppler shift of transmitting mobile unit on ith path

$$= \frac{2\pi}{\lambda} V_1 \cos \alpha_{1i}$$

ω_{2i} = Doppler shift of receiving mobile unit on ith path

$$= \frac{2\pi}{\lambda} V_2 \cos \alpha_{2i}$$

where a1i and a2i are random angles as shown in Fig.11.1. Now assume that the received signal is the summation of n paths uniformly distributed around the azimuth.

$$s_r = \sum_{i=1}^{n} s_i(t) = \sum_{i=1}^{n} r_i u(t - \tau_i) \times \exp\{j[(\omega_0 + \omega_{1i} + \omega_{2i})(t - \tau_i) + \phi_i]\}$$

$$= \sum_{i=1}^{n} Q(\alpha_{i,t}) u(t - \tau_i)e^{j\omega_0(t - \tau_i)}$$

where $Q(\alpha_i, t) = r_i \exp\{j[(\omega_{1i} + \omega_{2i})t + \phi_i']\}$

$$\phi_i' = \phi - (\omega_{1i} + \omega_{2i})\tau_i$$

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The above equation can be represented as a statistical model of the channel, as shown in Fig 11.2.

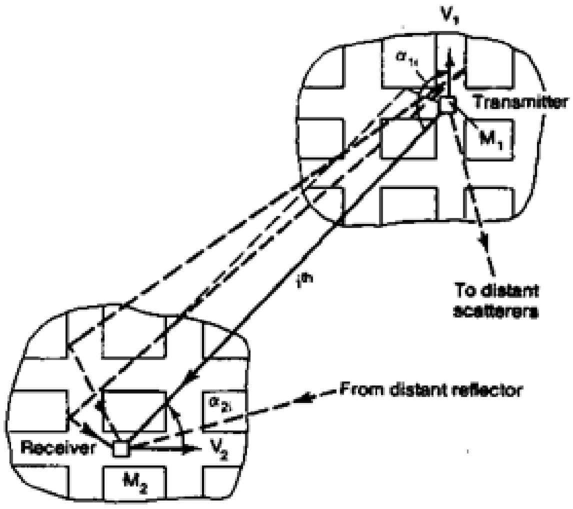

Fig.11.1. Vehicle-to-vehicle transmission

Let $u(t) = e^{j\omega t}$, then the above equation becomes

$$e_r(t) = \left[\sum_{i=1}^{n} Q(\alpha_i, t)e^{-j(\omega_0+\omega)\tau_i}\right]e^{j(\omega_0+\omega)t} = H(f, t)e^{j(\omega_0+\omega)t}$$

Therefore $$H(f, t) = \sum_{i=1}^{n} Q(\alpha_i, t)e^{-j(\omega_0+\omega)\tau_i}$$

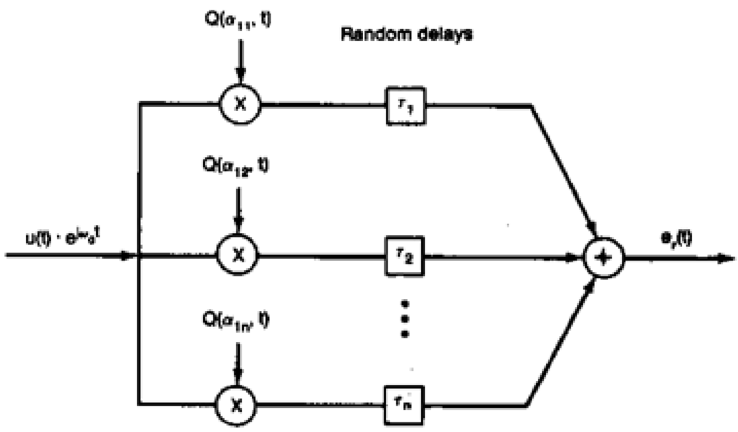

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Fig.11.2. Statistical model for mobile-to-mobile channel

where the signal frequency is w = 2Πf. Equation is expressed in Fig.11.2. Let f=*0;* that is only a sinusoidal carrier frequency is transmitted. The amplitude of the received signal envelope from the equation is

$$r = |H(0, t)|$$

where r is also a Rayleigh-distributed random variable with its average power of $2\sigma^2$ shown in the probability density function as

$$P(r) = \frac{r}{\sigma^2} e^{-r^2/2\sigma^2}$$

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