FACTORS AFFECTING WIRELESS SIGNAL PROPAGATION AND THEIR RECOMMENDED SOLUTIONS

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Abstract

The propagation medium is an essential part of any communication system. A signal may be sent between two points along a wire, a metal coaxial cable, a fibre optic cable or through space(wireless). Transmission via wire or metallic coaxial cable is governed by the Radio Frequency (RF)

Transmission line theory, while communication over an optical fibre is governed by the Fibre optic transmission line theory, The main focus of this paper is the transmission of a communication signal through the space (wireless), considering factors like *the free space propagation effects, Terrain effects, atmospheric effects, Tropospheric effects and the ionospheric propagation effects.* For each effect, an example of solution is given so that the designed link budget calculation that will be performed by the designed engineer when siting mask and antenna, will be made simple.

Engineers can make use of such examples in projecting their future designs and the knowledge of the frequencies involved, particularly at microwave frequencies range and beyond, will be useful to their applications.

Introduction

The purpose of communication system is to transfer information between two or more points. In general a communication system requires a Transmitter, Propagating

Medium and a Receiver. The information to be transferred may be in analogue form (e.g. voice or video), or in a digital format (computer data, digitized voice and so on). The transmitter must have some means of superimposing this information onto its output using frequency generating circuits and amplifier, to amplify the signal (modulation). There are two types of modulations involved - the Low level Modulation and the High level Modulation. The Modulated transmitted signal pass through a propagation medium to a receiver. The propagation medium may be free space, an RF transmission line or a fibre optic cable. The function of the receiver is to select (filter) the desired signal, amplify it and extract the original information. A simplified block diagram of the generalized communication system is as shown in fig. 1.

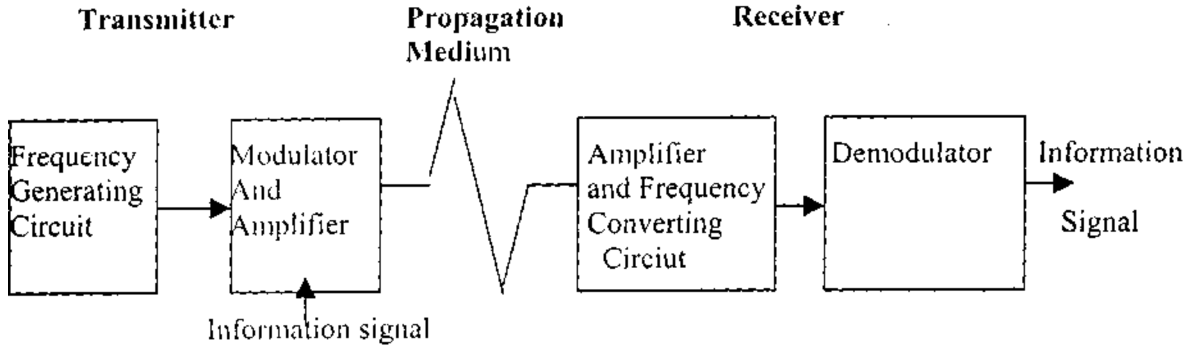

Fig. 1.0 Generalized communication system

Methodology and Principles Involved

Any communications signal transmitted through space requires a transmitting antenna and a receiving antenna. An antenna may be thought of as an impedance matching device between a transmission line and the free space. If a signal transmitted

through space does not encounter objects or mechanisms that absorbs or reflect RF Power, then the path from transmitter to receiver (or vice versa) is called *Free Space* and the process is called *free space propagation.* Reflections from the ground gives rise to terrain effects, which may cause fading and/or multipath transmission. If the signal is high enough in frequency, so that atmospheric constituents (water molecules, fog and smoke) absorbs or reflect RF power, the process is called *atmospheric propagation. Tropospheric propagation* is the name of the process whereby signals are sent from a transmitter to a receiver via a layer of the atmosphere called the troposphere. If the signal is in the

Ionosphere layer of the outer space, the process is called *ionospheric propagation.* Tropospheric and Ionospheric propagations allow communications beyond the optical line of sight, which is limited by the earths curvature.

Discussion of Results for the Different Forms of Propagations With examples of Factors Affecting Them

Free Space Propagation : Many communication systems are designed to transfer information directly between two points. Unless tropospheric or ionospheric effects are utilized, such communications are generally limited to line- of- sight, with the earth station antenna pointed up at the satellite and the satellite antenna pointed towards the earth station for reception. Most line of sight systems approximate free space propagation characteristic if the frequencies involved are well into the microwave range.

Free space propagation is governed by the well known Friis transmission formula, (Edward, 2001) which is given by

$$\frac{P_r}{P_t} = \frac{\lambda_o G_t G_r}{(4\pi R)^2}$$

Where P_r is the received antenna power in watts, P_t is the transmitter power in watts, *Xo* is the free space wavelength in meters, G_t is the gain of the transmitter antenna and G_r is the receiver antenna gain, R is the distance between receiver and transmitter in meters. The Friis transmission formula assumes that the main beam of each is pointed ^at the opposite antenna, and also that the antenna are far enough apart so that each is in the far field of the other.

Consider a 2.2 GHz data link that will be used to provide communications between two buildings separated by 100 meters. The data link receiver and transmitter have identical monopole antennas with a gain of 15dB. The transmitter output is 1 watt,

since it is only for internal communication. It is possible to determine the received power in the second building by using the Friis transmission formula. The 2.2 GHz suggest that the equipment being used will be in the S-band (1.5 - 3.9 GHz), and knowing that

$$V = f \times \lambda o \rightarrow \quad \lambda_o = \frac{V}{f} = \frac{3\times 10^{8}}{2.2\times 10^{9}} = 1.36\times 10^{-1} = 0.136m$$

$G_t = G_r$ as they are identical monopole antenna

$$= \log^{-1}\frac{G_{dB}}{10} = \log^{-1}\frac{15}{10} = \log^{-1}1.5 = 3.16\times 10^{1} = 31.6$$

Given the distance of separation R = 100m, P_t = 1 watt, then P_r is obtained as

$$P_r = \frac{\lambda_o{}^2 P_t G_t G_r}{(4\pi R)^2} = \frac{1\times(0.136)^2(31.6)(31.6)}{4(3.142)(100)^2} = 1.17\times 10^{-5} = 11.7\mu W$$

The path loss in a free transmission system is given by

$$L_p = \frac{[4\pi R]^2}{[\lambda_O]^2} = \frac{[4\times 3.14\times 100]^2}{[1.36\times 10^{-1}]^2} = 85.29\times 10^{6} = 8.53\times 10^{7} = 10\log 8.53\times 10^{7} = 79.3dB.$$

This loss is not a loss in the ohmic sense, but merely describes the spreading of the propagating wave according to the inverse square law.

Terrain Effect : A communication signal may be subject to loss due to the effect of trees, buildings or hills. A signal may also be affected by reflections from the ground or water. A reflected signal is often different phase from the direct signal and therefore may either add to or subtract from it, resulting in fading and / multipath transmission, which can result in distortion especially in Frequency Modulation (FM) systems.

The effect of obstacles may sometimes be effectively eliminated by placing the receiver and the transmitting antennas at heights that provide adequate terrain clearance.

Adequate clearance is usually taken to be the so called FRESHNEL clearance given by

$$h = \sqrt{\frac{\lambda_o}{\frac{1}{d_1} + \frac{1}{d_2}}}$$

In this expression, /; is the necessary clearance *above the obstacle* in meters, *di* is the distance from the transmitter antenna to the obstacle in meters, *d*$_2$ is the distance from the obstacle to

experience path loss with ± 0.5dB of the value given by the Friis transmission formula. If the

the receiver antenna and *Xo* is the free space wavelength in meters, a flat terrain is assumed.

A line of sight path that provides clearance equal to or greater than the freshnel clearance will clearance is exactly zero, an additional attenuation of approximately 6dB will be experienced. If the line of sight path is below (i.e. cuts through) the obstacle, the signal will not be totally blocked, but will experience considerable attenuation. A line of sight path that is below an obstacle by the distance equal to the freshnel clearance will experience an additional attenuation of approximately 17dB, and a path that is Two freshnel clearances below an obstacle will experience about 23dB of additional attenuation.

Consider a 6 GHz data link that is to be established between two buildings separated by 5km, each 100 meters in height. A third building 120 meters in height is in the line of sight path of the communication link and is 2km from the first building. To determine the height of the data link transmitter and receiver antennas above the building for minimal effect from the third building will

be, Knowing that $\lambda_o = \frac{v}{f} = \frac{3\times10^{8}}{6\times10^{9}} = 5\times10^{-2} = 0.05m$

$d_1 = 2km = 2 \times 10^3 - 2000m$, $d2 = 3km = 3000m$, then

$$h = \sqrt{\frac{\lambda_o}{\frac{1}{d_1} + \frac{1}{d_2}}} = \sqrt{\frac{0.05}{\frac{1}{2000} + \frac{1}{3000}}} = \sqrt{\frac{0.05}{0.0005 + 0.00033}} = \sqrt{60.24} = 7.76m$$

The line of sight should be 7.76m above the obstacle, which is 20 meters above the building that houses the obstacle between the transmitter and receiver, so towers of 27.76 meters would be required on top of the previous 100 meters building. To save cost, that could be the reason you see additional mask on top of a high rise building especially in the cities, for good line of sight communications link.

Consider another case where a 1.3 GHz FM communication link is to be established between two points separated by a distance of 10km, and a hill 70 meters in height lies between the two points in the link. Identical transceivers and antenna are used at both ends with an output power of l0watts and an antenna gain of 15dB. Each of the antenna is mounted on a tower at a height of 20 meters. To estimate the total path loss for this link, by using the same principle

$$\lambda_o = \frac{v}{f} = \frac{3\times10^{8}}{1.3\times10^{9}} = 2.3\times10^{-1} = 0.23m$$

$d_1 = 5km = 5000m$; $d_2 = 5km = 5000m$; then

$$h = \sqrt{\frac{\lambda_o}{\frac{1}{d_1} + \frac{1}{d_2}}} = \sqrt{\frac{0.23}{\frac{1}{5000} + \frac{1}{5000}}} = 24m$$

The line of sight path is 50 meters below the obstacle of 70 meters or approximately two freshnel clearances. The additional attenuation over the free space path loss will be approximately 23dB. The free path loss is

$$L_p = \frac{(4\pi R)^2}{(\lambda_o)^2} = \frac{(4(3.14)(10\times10^3)^2}{(2.3\times10^{-1})^2} = 2.98\times10^{11} = 114.8dB.$$

The total path loss is the sum of the free space loss and the additional loss due to tiie obstacle or L_r = 114.8dB + 23dB = 137.8dB

The concept of freslinel clearance may also be used to set the height of antennas when no obstacle exits between transmitter and receiver. A transmission path at a distance above level ground at least equal to the freslinel clearance will minimize facing and multipath effects due to the ground. The obstacle may be assumed to be midway between the antenna in such a case. If it is allowed to calculate the antenna height necessary to minimize ground effects in a 150 MHz FM communication link at 30 km lonw

Knowing that $\lambda_o = \frac{v}{f} = \frac{3\times10^8}{150\times10^6} = 2m$

$d_1 = d_2 = 15km = 15{,}000m$

$$h = \sqrt{\frac{\lambda_o}{\frac{1}{d_1}+\frac{1}{d_2}}} = \sqrt{\frac{2}{\frac{1}{15000}+\frac{1}{15000}}} = \sqrt{15000} = 122.47m$$

The antenna would need to be mounted on rather tall towers or buildings of suitable height. At this frequency, it might be cost effective to accept some ground effects and increased power to compensate rather than to mount the antenna at a height of 122 meters Terrain effects that results in fading often may be minimized by a technique known as *Diversity* . A communication system may utilize *space diversity, frequency diversity, polarization diversity* or some combination of these techniques. Space diversity utilizes two or more transmitting and/or receiving antennas with sufficient physical separation, so that if one link experiences a significant fade, the system can automatically switch to the other link. This technique is one of the excellent factors when considering a roaming case. Frequency diversity accomplishes the same task by utilizing two transmitters and receivers at different frequencies. Polarization diversity takes advantage of the fact that a fade may be deeper for one antenna polarization than for another, and automatically, switching is arranged to maximize the signal. Diversity systems are more complex and expensive than non diversity systems, but their installation may often be justified in critical applications.

Atmospheric Propagation : The concept of free space propagation depends on the assumption that the atmosphere is uniform and does not absorb the signal. The concept also disregards terrain effects, but examines the effect of atmospheric absorption.

The gases in the atmosphere absorb energy from electromagnetic waves. The only gaseous absorption of importance to communication system at microwave and lower frequencies is that caused by oxygen and water vapour. Oxygen exhibits its maximum absorption at a wavelength of approximately 0.5cm or a frequency of 60GHz. Water vapour exhibits its maximum absorption at a wavelength of approximately 1.3cm or a frequency of 23GHz.

Since the vast majority of communication systems operate at frequencies less than 18GHz, these absoqrtion maxima is of little concern. Of more interest to communication system designer is the attenuation due to atmospheric absorption at frequencies below 18GHz. For typical conditions(20°C, 70% relative humidity), the total atmospheric absorption due to oxygen and water vapour is approximately 0.02dB/km over a frequency range of 12GHz to 18GHz, approximately 0.015dB/km from 4GHz to 12GHz, and less than 0.0l0dB/km below 4GHz.

Consider an 8-GHz data link that will be used to provide digital voice communication between two government facilities located at 40km apart. To determine the loss due atmospheric absorption over this link is Loss(Lp) = 0.015dB/km x 40 = 0.6dB

Thus, atmospheric absorption introduces an additional 0.6dB loss over and above the free space path loss. Atmospheric attenuation caused by rain or fog are normally much more important than gaseous absorption at frequencies above 4GHz. Atmospheric attenuation due to rain or fog is not primarily due to absorption, but is the result of scattering by the water droplets. *Heavy rain (16mm/Hr) results in approximately 0.3dB/km* attenuation at 10GHz, while a *light rain (2mm/Hr) or light fog (visibly 100m) results in approximately 0.015dB/km* attenuation at 10GHz. Below 4GHz, the effect of rain and fog are less than 0.0ldB/km and are usually neglected.

Consider a 10GHz FM communication link that operates over a free path length of 30km. To determine the loss over and above the free space path loss when the system is operating during a heavy rainstorm occupying the entire path length, knowing that the atmospheric absorption loss is 0.015dB/km, the attenuation due to heavy rain is 0.3dB/km. The total attenuation is (0.015 + 0.3)dB/km = 0.3 15dB/km or *Loss = 0.315dB/km x 30 = 9.5 dB for the entire length.*

It should be noted that areas of heavy rainfall are normally localized and would not extend over the entire 30km path length, thus the attenuation could be considerably less than 9.5 dB.

In telecommunication systems where repeaters are used, the spacing specified would depend strongly upon the rainfall statistic for the area and the allowable down time for the system. At higher frequencies (~ 18Gllz) repeater spacing may be limited to few kilometers. Diversity, especially space diversity is often used to combat the effect of heavy rainfall.

Tropospheric Propagation : The earths atmosphere is usually divided into four regions. The *troposphere,* which extends from the ground to a height of 10 - 15 km; the *tropopause* a transition zone ranging from approximately 5km at the two poles to approximately 20km at the equator; *Stratosphere,* which extends to approximately 50km above the surface; and finally the *ionosphere.* In the troposphere, the temperature generally decreases with altitude, while in the stratosphere, it is relatively constant. The trosphere cotains most of the clouds responsible for active weather. In the troposphere, the index of refraction (a measure of the ability of a medium to bend electromagnetic waves) decreases with height.

If the index of refraction decreases with height in a linear fashion, electromagnetic waves are bend downwards, so that they can be received beyond the optical line of sight. This effect is equivalent to assuming that the earth radius increased or that the earth is effectively flattened. Under normal atmospheric conditions, the earths effective radius is increased by a factor of approximately 1.3. Under special conditions that caused the index of refraction to decrease rapidly, the effective radius of the earth can become infinite, which implies a flat earth for electromagnetic propagation. Variations of index of refraction with heights are a strong function of meteorological conditions such as temperature and humidity. So that successful communication via tropospheric bending is difficult to predict.

A second tropospheric propagation mode called tropospheric scatter, or troposcatter, is more predictable and widely used. In troposcatter, electromagnetic energy is scattered in a forward direction by a volume in the troposphere, where the transmitter and receiver antenna beam intersect. The scattering is the result of irregular variations in the index of refraction of the atmosphere. Troposcatter communication may extend to distances over 100 km. This mode has been utilized in systems operating from 50MHz to 10GHz. Successful systems are often high power(50kw) and utilized high gain(40dB) transmitting and receiving antenna at low angles (3°). A troposcatter signal is subject to fading and therefore, space, frequency and/or polarization diversity are often useful in improving the signal levels existing on the link. A polarization mechanism in some ways similar to troposcatter is meteor burst propagation in which signals propagate as a result of scattering from meteorities.

Ionospheric Propagation : Above the stratosphere is the ionosphere, ranging from approximately 50km to 300km in height. The ionosphere consists of several layers of charged particles or ions, which can reflect (sharply bend) electromagnetic energy (generally below 30MHz) back down to the earth surface to greatly increase the communication range over that attainable by the line of sight system. The characteristic of the ionosphere are primarily influenced by ultraviolet light and by the charged particles emitted by the sun. The lowest useful layer of the ionosphere is called the E - Layer, whose average height of maximum ionization is about 110km. A layer below the E layer, called the D - Layer absorbs electromagnetic energy below approximately 5MHz and thus prevents extended communication range when it is present. The D and E layers only exists when sunlight is present. The ionospheric layer most useful for long distance communication is the F - Layer, which splits into F, and F_2 layers during the day and merges into a single layer at sunset. The F| layer has its maximum ionization at a height of approximately 225km and the F_2 layer has its maximum at a height of about 320km. In the evening, the F layer is about 280km above the earth surface. Because the atmosphere is so thin at the height of the F layer, the ionization which occurs during the day due to sunlight, decay very slowly during the dark hours. As the ionization decreases, the Maximum Useable Frequency (MUF) for a given path decreases throughout the night. The maximum distance for a single - hop E layer communication link is approximately 2000km. The maximum F layer single - hop link is approximately 4000km. Multi - hops in which the signals is reflected from the ionosphere to the earths surface and back to the ionosphere before reaching the receiving antenna, may extend the maximum range even further, although the received signal level will be very low.

Ionospheric propagation is characterized by a limited predictability of maximum useable frequency range and total path loss. In addition, communications via the ionosphere is often subject to deep fade. During periods when the solar flux levels are low, the MUF may be less than 15MFlz. Ionospheric propagation is generally most useful for broadcast, armateur, and other non - optical communication system. In critical systems (such as those used in military applications or data communications) satellite link or troposcatter are used for long distances.

Conclusion

Having seen the different forms of propagations and their respective designed problems, the solutions being provided in the worked examples are practically applicable in the current GSM expansion especially when considering the Freshnel clearances in heights, and for the provision of either Space, Frequency and Polarization diversities. In practice, they act as practical solutions to many of the unpredictable weather conditions and act by readjusting automatically within microseconds without the subscriber noticing it. Since this is a design implementation problem, engineers and technicians should make a choice of the best option at a high price of equipment rather than considering poor implementation at a low price of the equipment. It will pay more and is more profitable especially in critical conditions of the nowadays satellite communications to have an optimized design.

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