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Research Paper

MODELLING OF GPS SIGNAL LARGE SCALE PROPAGATION CHARACTERISTICS IN URBAN AREAS FOR PRECISE NAVIGATION

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Accurate prediction and modelling of GPS satellite signal propagation characteristics is necessary in all precise navigation solution applications such as aircraft navigations, missile guidance and surveying. The signal propagation characteristics severely affect the quality, availability and continuity of the system. The received signal strength of a GPS satellite at a given location on or near the earth surface can be predicted by analyzing the propagation characteristics of the channel with an appropriate propagation model. There are two types of variations that occur in a GPS signal when it is travelling from the satellite to receiver on the earth's surface. They are: large-scale variations and small scale variations. Large-scale variations in a signal are mainly due to the path loss and shadowing. These variations depend on the distance, carrier frequency and atmospheric conditions. Secondly, the variations those characterize the rapid fluctuation of the received signal strength over very short travel distance is known as small-scale variations. These are mainly due to multipath reflections and doppler shift which degrades the quality of the signal received particularly in urban environments. The large scale propagation characteristics of GPS channel were investigated in this paper. The propagation characteristics of GPS signal was analyzed by considering the factors like carrier frequency and distance between obstacle and receiver.

Keywords: GPS, Navigation, Pathloss, Large-scale variations

INTRODUCTION

Global Positioning System (GPS) is a space based navigation system that provides three dimensions position, velocity and time by measuring the distance from the user location to the precise locations of the GPS satellites (Rao, 2010). The accuracy of the computed position depends on the received signal strength, which may degrade due to several reasons such as travelling from long distances through vacuum, dense clouds, dust particles, different layers of the earth's atmosphere such

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as troposphere, ionosphere, protonosphere. In addition the random fluctuations in the received signals due to different fading phenomena also affect the signal quality and system availability and ultimately a major cause of system outages. The above mentioned GPS signal variations can be classified into two types: i) Large-scale variations and ii) short term variations. The large-scale variations in a signal are mainly due to pathloss and shadowing. The average value of the signal strength at any point depends on its distance, carrier frequency, type of antennas used, atmospheric conditions and so on, and it may also vary because of shadowing caused by terrain and clutter such as hills, buildings, and other obstacles (Branka Vucetic and Jun Du, 1992). This type of signal variation, which is observable over relatively long distances, has a log normal distribution.

The second type of variation is due to multipath reflections. In urban or dense urban areas, there may not be any direct line-of-sight path between a satellite and a receiver antenna. Instead, the signal may arrive at the GPS receiver over a number of different paths after being reflected from tall buildings, towers and so on. Because the signal received over each path has a random amplitude and phase, the instantaneous value of the composite signal is found to vary randomly about a local mean (Xie and Fang, 2000).

Whenever, a signal is transmitted from a GPS satellite it follows a 'multiple' number of propagation 'paths' on its way to receiving antenna. These multiple signal paths are due to the fact that the signal gets reflected back to the antenna off surrounding objects, including the earth's surface. The GPS receiver tracks both the direct and reflected signal components.

LARGE SCALE ANALYSIS

Large scale variations are very slow and are calculated over a large area. These variations are generally assumed to have log normal distribution. Empirical channel models have been the best for the analysis of large scale variations. In this paper, the Hata-Okumura Model is presented which will be used for large scale variation analysis. The path loss equations for urban, sub-urban and rural areas are obtained for different amounts of obstructions.

HATA-OKUMURA MODEL

Hata obtained mathematical expressions by fitting the empirical curves provided by Okumura. In order to analyze the GPS signals, i.e., the signals transmitted from satellite to GPS receiver, this model may not be applicable as the distances between the GPS receiver and satellite is around 22,000 km and hence the direct line of sight (LOS) path is not possible between satellite and GPS receiver due to the various factors in the channel like hills, buildings and other obstacles. By applying Hata-Okumura model, the propagation characteristics of GPS signals (L1 and L2) are analyzed by considering the transmitter as one of the obstacle from where the signal is reflected and the transmitter height is assumed to be the height of the obstacle.

The following expressions are used for calculating the path loss L (dB) for urban, suburban and rural environments.

For flat urban areas,

$$L(dB) = \left[69.55 + 26.16\log(f) - 13.82\log(h_t) - a(h_m)\right] + \left[44.9 - 6.55\log(h_t)\right]\log(d) \quad ...(1)$$

where

f = frequency (MHz),

h_t = height of the obstacle (meters),

h_m = height of the GPS receiver antenna (meters),

d = radio path length.

$a(h_m)$ = correction unit for GPS receiver antenna height which depends on the environment.

$$a(h_m) = \left[1.1\log(f) - 0.7\right]h_m - \left[1.56\log(f) - 0.8\right] \quad ...(2)$$

For example, if the height of one of the obstacle from where the GPS signal is reflected is 30 m and the receiver antenna height 1.8 m, the model gives the following path loss at 1575.42 MHz (L1 frequency) for a typical urban area.

$$P_L = 131.90 + 35.31\log_{10}(d)\,dB, \quad d \geq 1(Km) \quad ...(3)$$

Notice that the path loss at 1 km from the obstacle is 131.897 dB. Similarly, the path loss for the same antenna heights at f_c = 1227.60 MHz is given by

$$P_L = 129.11 + 35.31\log_{10}(d)\,dB, \quad d \geq 1(Km) \quad ...(4)$$

The pathloss in suburban and open areas is less than that in urban areas. Corrections for determining pathloss in suburban and rural areas are also determined by Hata as,

For a suburban area,

$$L_s = L - 2\left[\log\left(f/28\right)\right]^2 - 5.4 \quad ...(5)$$

For rural areas,

$$L_r = L - 4.78\left[\log(f)\right]^2 + 18.33\log(f) - 40.94 \quad ...(6)$$

According to Hata model, at 1575.42 MHz (L1), the

Pathloss in sub-urban area is given as

PL_{su} = 119.496+ 35.31 $\log_{10}d$

Pathloss in rural area is given as

PL_{rural} =119+ 35.31 $\log_{10}d$

According to Hata model, at 1227.60 MHz (L2)

Pathloss in sub-urban area is given as

PL_{su} =117.14+ 35.31 $\log_{10}d$

Pathloss in rural area is given as

PL_{rural} =115.26+ 35.31 $\log_{10}d$

The model is valid for the following range of input parameters:

$$150 \leq f(MHz) \leq 1600, \quad 30 \leq h_t(m) \leq 200, \quad 1 \leq h_r(m) \leq 10, \quad d \leq (Km) \leq 20 \quad ...(7)$$

EFFECT OF VARIOUS FACTORS ON SIGNAL PROPAGATION

In order to design a propagation model for the GPS, knowledge about factors contributing to large-scale variations is required. In the following sections, the effect of various factors on the signal power is described and appropriate signal propagation models were designed.

Effect of Distance

For the evaluation of the effect of distance on signal power, the terrain is considered to be quasi-smooth where the average height of surface undulations is 30m or less. The power received at a given distance from the obstacle varies as per the equation

$$P_R = \frac{k}{d^n} \quad \text{...(8)}$$

where, *k* is a constant whose value depends on the environment, *n* lies in the range of 1.5 to 3.5.

Effect of Frequency

The received signal level also varies as a function of the frequency, decreases as the frequency increases. The signal level vary with the frequency according to the relation,

$P_R = \frac{k}{f^n}$ ...(9) where, *k* is a constant which depends on the environment.

For example, for a height of the reflected obstacle h_t of 30.48 m, for a height of the GPS receiver antenna, h_m of 3m and when the distance between obstacle and receiver is 20Km, Using Hata model, the equation for path loss is

$$P_L\,(db) = 92.20 + 26.16 \log_{10} f_c \quad \text{...(10)}$$

where f_c is the frequency in MHz.

COMPARISON OF SIGNAL VARIATIONS IN URBAN, SUB-URBAN AND RURAL AREAS

The propagation of radio waves in built-up areas is strongly influenced by the nature of the environment, in particular the size and density of buildings (Osborne and Yongjun Xie, 1999). The signal strength received by a GPS receiver would depend not only on the satellite power, the separation distance between the GPS receiver and the obstacle and carrier frequencies but also on the terrain features. Environmental clutter such as buildings, tall structures, trees, lakes, or other bodies of water; the width of the streets traversed by the GPS receiver; the angle at which the signal is incident at the receiving antenna; and the direction in which the vehicles travel with respect to the signal propagation also affects the signal strength.

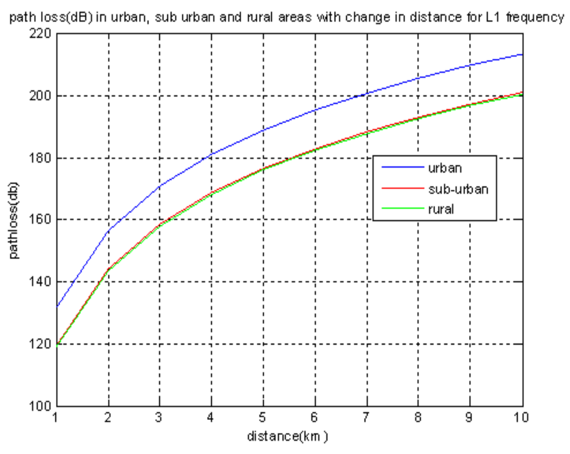
In propagation studies, a qualitative description of the environment is often employed using the terms such as rural, suburban, urban and dense urban. Dense urban areas are generally defined as being dominated by tall buildings, office blocks and other commercial buildings, whereas suburban areas comprise residential houses, gardens and parks. The term 'rural' defines open farmland with sparse buildings, woodland and forests. So far, we have only discussed signal variations in urban areas. Because the effect of the environmental clutter in suburban or rural areas is not as severe, the average signal level in these areas is comparatively better. This improvement in the signal levels increases with frequencies, but does not appear to depend on the distance between satellites and receivers (Hata, 1980).

RESULTS

Path loss is the important factor in determining the user position in GPS. The pathloss is dependent on various factors like frequency and distance between the obstacle and the receiver. The variations of pathloss in urban, rural and suburban areas are compared. The analysis has been used for calculating accurate position of GPS receiver.

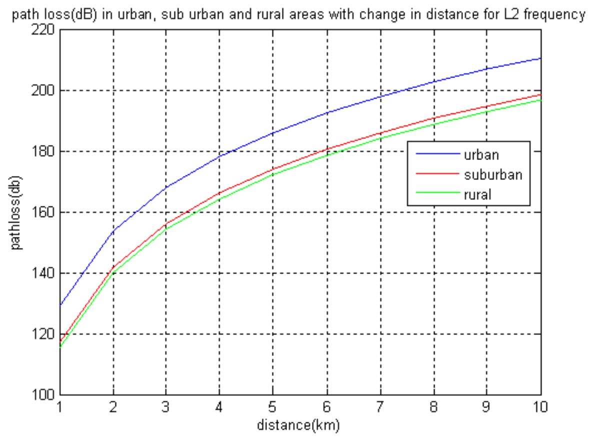
The comparison of path loss in urban, sub urban and rural areas as a function of distance for L1 and L2 frequencies are shown in Figure 1 and Figure 2. It was observed that maximum pathloss obtained in urban areas is more compared to the path loss in sub urban areas which in turn greater than in rural areas.

Figure 1: Comparison of Pathloss in Urban, Sub-Urban and Rural Areas as a Function of Distance for L1 Frequency



In each case the pathloss increases with increase in distance. This is due to the fact that in urban or dense urban areas, there may not be any direct line-of-sight path between the satellite and the GPS receiver. Instead, the signal may arrive at a GPS receiver over a number of different paths after being reflected from tall buildings, towers, and so on.

Figure 2: Comparison of Pathloss in Urban, Sub Urban and Rural Areas as a Function of Distance for L2 Frequency



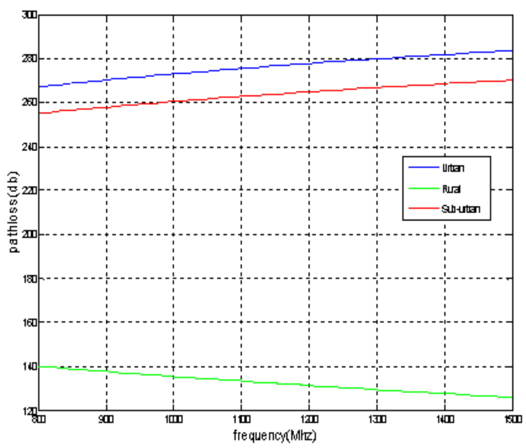
Path loss in urban, sub urban and rural areas as a function of distance between obstacle and the GPS receiver for carrier frequencies L1 and L2 are shown in Table 1. From Table 1 it was observed that the path loss increases with the increase in distance between obstacle and the GPS receiver.

The comparison of path loss in urban, sub urban and rural areas as a function of carrier frequencies is shown in Figure 3. It was observed that in urban and sub urban areas, the path loss is increasing with frequency while in rural areas, the path loss is decreasing gradually with frequency.

Table 1: Path loss in urban, sub urban and rural areas as a function of distance between obstacle and receiver for L1 and L2 frequencies

Distance (Km)	Pathloss (dB)					
	Urban Areas		for Sub-Urban Areas		Rural Areas	
	For Carrier Frequency (Mhz)					
	f_c = 1575.42Mhz (L1)	f_c = 1227.60Mhz (L2)	f_c = 1575.42Mhz (L1)	f_c = 1227.60Mhz (L2)	f_c = 1575.42Mhz (L1)	f_c = 1227.60Mhz (L2)
1	131.89	129.11	119.50	117.14	118.99	115.26
2	142.53	139.74	130.13	127.77	129.63	125.89
3	148.75	145.96	136.34	133.99	135.85	132.11
4	153.16	150.37	140.76	138.40	140.26	136.52
5	156.58	153.79	144.18	141.82	143.68	139.94
6	159.38	156.59	146.97	144.62	146.48	142.74
7	161.74	158.95	149.34	146.98	148.84	145.11
8	163.79	160.99	151.39	149.03	150.89	147.15
9	165.59	162.81	153.19	150.84	152.69	148.96
10	167.21	164.42	154.81	152.45	154.31	150.57

Figure 3: Comparison of Pathloss in Urban, Sub Urban and Rural Areas as a Function of Carrier Frequencies



CONCLUSION

In this paper modelling of large scale variations for calculating the path loss was discussed. In the large scale analysis, the dependency of path loss on carrier frequency and distance between obstacle and receiver was presented in this paper. Path loss increases with the increase in distance between obstacle and receiver and with increase in the carrier frequency. Maximum path loss was obtained in urban areas which were much more compared to the path loss in sub urban areas and rural areas. This is due to the fact that the urban areas are generally dominated by tall buildings and hence there may not be any direct line-of-sight path between the satellite and the GPS receiver. Instead, the signal may arrive at the GPS receiver over a number of different paths after being reflected from tall buildings, towers, and so on.

REFERENCES

1. Branka Vucetic and Jun Du (1992), "Channel Modeling and Simulation in Satellite Mobile Communication Systems", *IEEE Journal on Selected Areas in Communications*, Vol 10. No. 8.
2. Hata M (1980), "Empirical Formulae for Propagation Loss in Land Mobile Radio Services," *IEEE Trans. Vehic. Tech.*, Vol. VT-29, No. 3.
3. Osborne P and Yongjun Xie (1999), "Propagation Characterization of LEO / MEO Satellite Systems at 900-2100 MHz", William University of Texas at Dallas, 21.1-21.8.
4. Rao G S (2010), *Global Navigation Satellite Systems*, 1st Edition, Tata McGraw Hill, India.
5. Xie Y and Fang Y(2000), "A General Statistical Channel Model for Mobile Satellite Systems", *IEEE Trans. Veh. Technol.*, Vol. 49, pp. 744-752.