Application of Geodetic Parameters as GIS inputs in Radio Propagation Studies

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Abstract

Geomatics engineering is an emerging and fast growing interdisciplinary field which has found increasing applications in telecommunications industries. This paper presents the techniques of determining the geodetic variables, the azimuth and elevation angles, which are used as GIS inputs in radio signal propagation along earth-satellite path. A case study of Geomatics application in propagation studies over Ku band in tropical Malaysia is presented. The measurement site was at Universiti Teknologi Malaysia, UTM, Malaysia (Lat.: $1.45^{o}N$ and Long.:103.75^{o}E). The geodetic variables are used for determining the optimal position of the earth station receiving antenna. The computed values of the elevation and azimuth are 75.59^{o} and 262.79^{o}, respectively. These values are considered to be accurate because they are very close to the values specified in the antenna aiming chart provided by ASTRO for the site under study. It has been demonstrated in this paper how the elevation of the receiving earth station can affect the quality and strength of the received signal. The study will provide useful information for the radio engineer in optimizing both the signal quality and strength in the earth-satellite propagation.

Keywords: Geodetic Parameters, Geomatics, Optimal Positioning, Radio Propagation

1. Introduction

Over eighty percent of all information and data handled today is either location based or associated (M.K. Gachari, 2001). The spatial component is fundamental to the usefulness and efficiency of information in its applications. Efficient management and utilisation of spatial information is central to coherent and sustainable development, efficient exploitation and management of resources and preservation of a healthy environment (Africa Environment Information Network: Implementation guidelines, 2004). Geomatic Engineering is an emerging and rapidly growing geospatial information based discipline that integrates the various modern disciplines involved in collection, storage, processing, analysis, modelling and dissemination of geospatial information (M.K. Gachari, 2005). Positional information is fundamental in efficient decision making. The rapid evolution of Geomatic Engineering in particular has been accelerated by the advent of modern technologies including Global Positioning System (GPS), Geoinformation Systems (GIS), Remote Sensing, Computing technology, instrumentation technology and Communication Technology. Recently, increasing number of advanced applications requires more functionality from such spatial system, e.g. applications in advanced urban planning, geology, oil and minerals exploration, and underground mapping including utility mapping (Alias Abdul Rahman, 2009).

The applications of Geomatics in telecommunication are broadly categorized into two (Su Hui et al., 2002): One application is that it provides spatial data service in telecommunication field and that it is an assistant measure to manage telecommunication infrastructure, to plan and design network and to decide running (Su Hui et al., 2002). This paper describes the role of Geomatics in telecommunication engineering and offers practical application of the derived parameters for positioning of an earth satellite station in satellite communication.

An earth station is a terrestrialterminal station designed for extra planetary telecommunication with spacecraft, and/or reception of radio waves from an astronomical radio source. According to Federal Standard 1037C, General Services Administration, Earth stations are located either on the surface of the Earth, or within Earth's atmosphere (retrieved 2009). Earth stations communicate with spacecraft by transmitting and receiving radio waves in the super high frequency or extremely high frequencybands. When an earth station successfully transmits radio waves to a spacecraft (or vice versa), it establishes a telecommunications link. Earth stations may occupy either a fixed or itinerant position. When a satellite is within an earth station's line of sight, the earth station is said to have a view of the satellite. Location of the earth station antenna is by far the most important consideration, in order to have the best coverage(http://www.free-press-release.com/news-how-to-survey-the-site-of-earth-station-antenna-1280914396.html). One of the most important factors to be considered for trouble-free, high-quality signal reception from desired satellites is the location of the antenna (that is, the antenna site). For optimal signal reception, it is important that the antenna selected site adheres to the following:

I. Operational clearance: The site must allow clearance for the antenna movement (both elevation and azimuth) necessary for aiming and maintenance purposes.
II. Clear line-of-site. The site must allow clearance for the ante-sky antenna to be aimed (pointed) at desired satellite(s) with no obstructions between satellite(s) and any portion of the reflector.
III. Absence of signal interference. The site must be free of strong microwave and other signal interference. The altitude must be reasonably high in order to prevent ground noise from contaminating the received signals. Usually during or after rain, the ground will evolve thermally generated noise in the form of sidelobes. So if the altitude is not reasonably high enough, then the quality and level of RSL will not be acceptable.

In order to evaluate the antenna site selected against the above criteria, the antenna pointing position (i.e. aiming coordinates) for the desired satellites must be determined. In short, it is very important to survey the earth station antenna site before the transmitter/receiver positioning (TX/Rx) is done.

Basic geodetic theory has been applied to determine the geodetic azimuth and geodetic altitude required to point dish antennas to geostationary communication satellites (Tomás Soler, et al., 1994). Mathematical models take into consideration the ellipticity of the earth. However, this generalization contrasts with standard formulas published in technical books in satellite communication engineering where a spherical approximation is implemented. Comparisons between the spherical and more rigorous ellipsoidal methods have been discussed (Tomás Soler, et al., 1994) and it turns out the differences between the two approaches are not significant. They should only be taken into consideration when very precise pointing to geostationary communication satellites or other space objects is dictated.

2. Determination of Azimuth, Elevation and Altitude

The satellite orbiting in the geostationary orbit appears to be stationary with respect to a point on the earth's surface (Dharma Raj Cheruku, 2009). So in order to establish communication with the satellite, it is sufficient for the earth stations antennae to point in a given direction towards the satellite antennae. Such a positioning of the earth stations antenna is achieved by determination of look angles, that is, the elevation angle (E) and azimuth angle (A), as illustrated in Figure 1. Azimuth is measured eastwards from geographic north to the projection of the satellite on a horizontal plane at the earth station. Elevation is the angle measured upward from this horizontal plane to the path.

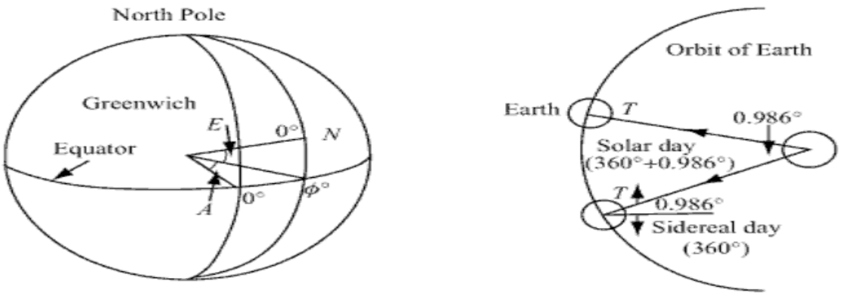

Figure 1. Look angles $\theta^0 N$ and $\phi^0 E$

Look angels can also be determined by using the geographic coordinates of the sub-satellite point. The sub-satellite point is a place where a line drawn from the centre of the earth to the satellite passes through the earth's surface. For an ideal geostationary satellite, the sub-satellite is at the equator at some fixed longitude. As shown in Figure 2, based on the earth station latitude θ_1 , longitude θ_L and the satellite longitude θ_S , the two look angles can be determined.

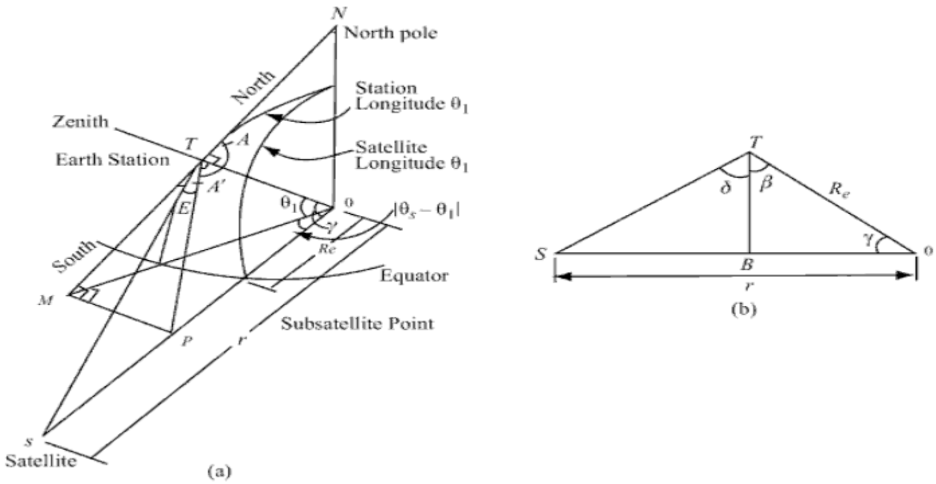

Figure 2. Solar and sidereal days- triangle to calculate elevation

The azimuth angle is defined as the angle produced by the intersection of the local horizontal plane TMP and the plane TSO with the true north. Depending on the location of the earth station, the azimuth angle A is given by:For northern hemisphere, the positioning of the earth station is given as follows:

Earth station west to satellite: $A = 180^0 - A'$;

Earth station East to satellite: $A = 180^0 + A'$;

For southern hemisphere, the positioning of the earth station is given as follows:

Earth station west to satellite: $A = A'$;

Earth station east to satellite: $A = 360^0 - A'$;

Where A is as defined in figure b, and is given as:

$$A' = \tan^{-1}\left[\frac{\tan|\theta_s - \theta_L|}{\sin\theta_1}\right] \quad (1)$$

The elevation angle can be derived from

$$E = \tan^{-1}\left(\frac{r - R_e\cos\theta_1\cos|\theta_s - \theta_L|}{R_e\sin\left[\cos^{-1}\left(\cos\theta_1\cos|\theta_s - \theta_L|\right)\right]}\right) - \cos^{-1}\left(\cos\theta_1\cos|\theta_s - \theta_L|\right) \quad (2)$$

Where A' is the azimuth angle, R_e is the radius of Earth (approximately 35,800km), r is the distance from the centre of the earth to the satellite (which ranges from 6,353 km to 6,384 km), θ_1 is the earth station latitude, θ_L and θ_S are the earth station and satellite longitudes, respectively.In this paper, the longitude and latitude of the earth station located at Wireless Communication centre (WCC), UTM were obtained by using a GPS system. Four different locations were used for the measurements, although the average of only two measurement sets were actually used for the computations, as presented in Table 1.

Table 1 Co-ordinates of the Earth station located at WCC, UTM

	1	2	Average
Latitude (N)	$1^0 33' 41.6882''$	$1^0 33' 43.6882''$	$1^0 33' 43.6882''$
Longitude (E)	$103^0 38' 50.97''$	$103^0 38' 50.95''$	$103^0 38' 50.96''$

MEASAT-1 upon which the rain attenuation computations are based is located at longitude of $91.5^0 E$. According to the data shown in Table 1, the approximated values of the latitude and longitude are $1.56^0 N$ and $103.65^0 E$, respectively. Therefore, we have substituted the values of the satellite longitude, earth station latitude and longitude, radius of the earth and the distance from the centre of the earth to the satellite in Equations (1) and (2). From these analyses, we have obtained a value of 75.59^0 and 262.79^0, for the elevation and azimuth, respectively.

3. Application in Satellite Communication: Slant- Path Calculation

Satellites in geostationary orbit are 35,800 km above the earth, and since rain only forms in the troposphere, which extends seven miles above the earth, a signal travelling through a rain cell will experience attenuation during only a small portion of its transmission path (Freeman, R. L., 2007). The important input parameters are azimuth and elevation which are computed from the absolute values of longitude and latitude.
Rain attenuation is one of the most crucial factors to be considered in the link budget estimation for microwave satellite communication systems, operating at frequencies above 10 GHz (A. Y. Abdulrahman, et al., 2010).The elevation angle, altitude and latitude are used for calculating the slant path. Slant path means the total propagation length that radio signals would travel in the rainy medium. The slant path is in turn used for calculating the rain attenuation for a particular region or location. All these GIS inputs (the Azimuth and Elevation) are indispensable in the accurate predictions of the overall attenuation when propagating signals through earth-satellite links. However, the accuracy of the attenuation highly depends on the careful measurements of the GIS inputs mentioned above. The inherent errors associated with the GPS navigation can degrade the accuracies of the GIS inputs, which would in turn be reflected in the estimation of slant path attenuation (Carlo Kopp).

The International Telecommunication Union-Radio (ITU-R P. 618-9, 2007)has provided a step-by-step approach for calculating slant-path attenuation at any geographical location. Interestingly, the first four steps involve determination of geodetic parameters, briefly described as follows:

Step 1: Freezing height during rain $H_R(km)$ is calculated from the absolute values of latitude and longitude of Earth station, as follows (ITU-R P. 618-9, 2007):

$$H_R = 0.36 + h_0 \tag{3}$$

where $h_0(km)$ is the 0^0C isotherm height above mean sea level and its value can be obtained from the isotherm chart of (ITU-R P. 618-9, 2007).

Step 2: Slant-path length $L_s(km)$ below the rain height is given by:

$$L_s = \frac{H_R - H_S}{\sin\theta} \tag{4}$$

Where $H_S(km)$ is the altitude of the Earth is station above sea-level, and θ is the elevation angle in degrees.

Step 3: The horizontal projection of slant-path length, $L_G(km)$ is calculated as:

$$L_G = L_s \cos\theta \tag{5}$$

4. Results and Discussions

Figure 3 shows the dependence of slant path on the elevation angle according to Equation (4). The figure shows four locations used for inspecting the behavior of slant path with different look angles. The locations have different values of altitude, though only one value of altitude was used at a time while observing the variation of slant path with respect to elevation angles. It can be observed from the figure that the higher the elevation angle, the smaller the slant path through which the radio signal will propagate in the troposphere. It is interesting to note that at elevation angles below 15 degrees, the values of slant path are in the range of 22.4590 to 49.3368 km, depending on the altitude. The slant path values are within tolerable range when elevation angle is from 15 to 90 degrees. This range of elevation angles is logical because in practical deployment of Earth station antenna, look angles are seldom low. The reason being that apart from the rain attenuation, the ground noise entering the side lobes is another important issue which must be considered.

The dependence of slant path on the height above the mean sea level is presented in Figure 4. As shown in the figure, different values of elevation angles were employed for studying the variation pattern of the slant path with respect to the altitude. Unlike the one whose results are presented in the preceding figure, in this experiment, one value of elevation angle was used at time, while varying the slant path with respect to altitude. It has been demonstrated in the figure how the selected values of the mean height above the sea level can significantly affect the value of the slant path; and the overall signal attenuation. For very high altitude, the value of slant path can be as small as 5.1753 km, while for low altitudes, the value can be as high as 9.3146 km.

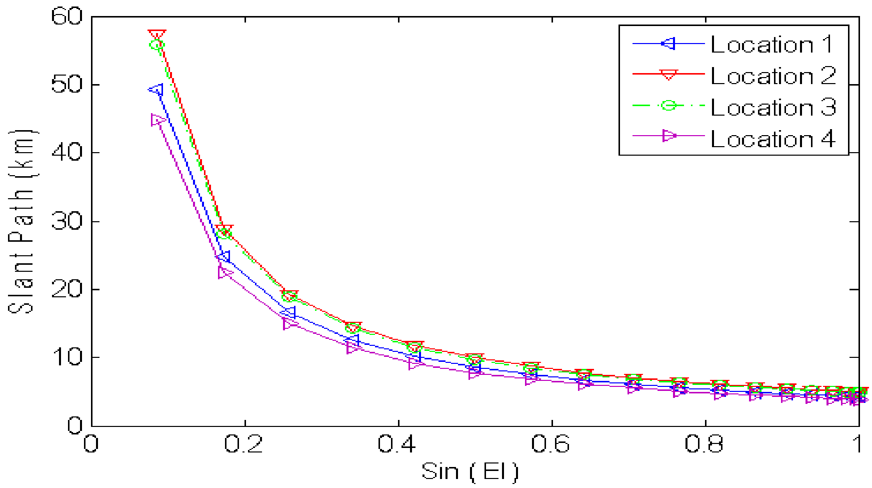

Figure 3. Dependence of Slant path on elevation angle, and (b) height above the mean sea level

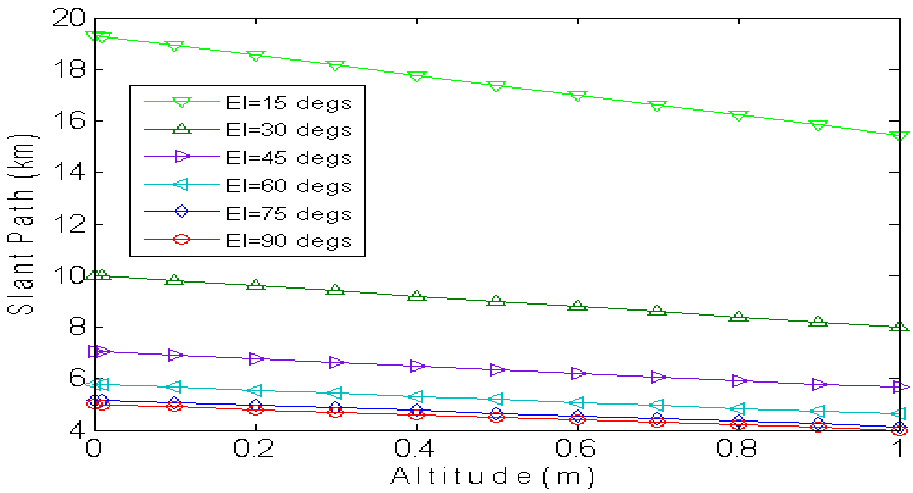

Figure 4. Dependence of Slant path on mean height above sea level.

5. Conclusion

It has been demonstrated in this paper how the elevation of the receiving earth station can affect the quality and strength of the received signal. Therefore, it has been clearly shown that accurate determination of elevation angle in the positioning of the Earth station antenna could help the radio engineer in optimizing both the signal quality and strength in the earth-satellite propagation. This is because most of the propagation impairments, like tropospheric scintillation, cloud and rain attenuation, are directly proportional to the slant path. Therefore, the higher the elevation angle, the smaller the slant path, and the better the satellite signal quality and strength.
In this study,interestingly,the estimatedvalues of both the elevation and azimuth are very close to the ones specifiedin the antenna aiming chart provided by ASTROfor Johor Bahru city. For instance, the computed values of elevation and azimuth are approximately $75.59^o$and 262.79^o, respectively, while the corresponding values specified in the antenna aiming chat are76^oand264^o. Therefore, these results have shown that the measurements and analyses were accurate and very reliable for the siteunder study. The study will therefore provide useful information for the radio engineer in optimizing both the signal quality and strength in the earth-satellite propagation.

The most notable limitation of the proposed application is the inherent errors associated with the use of GPS navigation. The error sources include electrical noise in the receiver, ionospheric signal delay and the phase noise in the PRN code modulation which can degrade accuracy by about 2 meters. Others include multipath and signal propagation delays in the troposphere due changes in humidity, temperature and pressure changing the refractive index. The former can degrade accuracy by about 0.5 meter, while the latter can degrade it by 1 meter. All these radio issues associated with the use of GPS will inherently affect the proposed applications.

In the future works, the use of differential GPS (DGPS) is proposed to defeat some of the systematic errors associated with the conventional GPS. The central idea behind DGPS scheme is to broadcasting an error signal which informs a GPS receiver of the difference between the receiver's calculated position and actual position. The GPS error signal can be generated by siting a GPS receiver at a known surveyed location, and then comparing the received GPS position with the known actual position. The difference in positions will be very close to the actual error seen by a receiver in the geographical vicinity of the beacon broadcasting the error signal.

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