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Geosynchronous Satellite Uplink Budget Analysis Using The Orbital Slot And Earth Station Geo-Location Dataset

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Abstract **- In this paper, geosynchronous satellite uplink budget analysis using the orbital slot and earth station geo-location data is presented. The orbital slot and earth station geo-location data is used to determine the elevation angle, the slant range, the boundary orbital slot for visibility of the satellite at the given earth station. Four case study satellites in the geo-stationary category were considered, namely ECHOSTAR 6, ECHOSTAR 16, Astra 1A and NIGCOMSAT 1R. The earth station is at Ibom e-library with geo-coordinates of 5.015295 latitude and 7.912762 longitude. The results for the uplink budget analysis for NIGCOMSAT 1R satellite with orbital slot of 42.452 East shows that the uplink carrier to noise ratio (C/N) is 8.226227721106937 dB, the propagation loss is 206.7624032063015 dB while the satellite PDF is -106.0221465556865 BW/** m^2 **. In all, the results showed that the lowest slant range and propagation loss occurred at orbital slot of 7.912815 East which is the same as the earth station's longitude. At this point, the uplink C/N is 8.53 dB. On the other hand, the highest slant range and propagation loss occurred at orbital slot of 73.3412792 West and 89.1669092 East which are the boundary visibility longitude for an orbital slot relative to the east station longitude of 89.1669092 East. At these two points, the uplink C/N is 7.22 dB.**

Keywords: Geosynchronous, Uplink, Satellite, Link Budget Analysis, Orbital Slot, Earth Station, Geo-Location

1. INTRODUCTION

In order to ensure effective communication between the earth station and a geosynchronous satellite link budget analysis is required [1,2,3,4,5,6,7,8,9,10,11,12,13]. The link budget analysis accounts for all the gains and losses in the link and determines the received signal strength, link margin and other salient performance parameters of the link [14,15, 16,17, 18,19, 20,21, 22,23, 24,25].

In order to carry out the link budget analysis for satellite-earth station link, the path length must be determined [26,27,28,29]. The path length, in most cases, is not given. Rather, other parameters that can be used to determine the path length are given. Usually, the elevation angle and orbital altitude are given from which the path length and hence path loss can be computed. However, in some cases, the orbital altitude, the orbital longitude and latitude of the satellite along with the earth station longitude and latitude are given. In such case, first the elevation angle and must be determined from the satellite and earth station geo-coordinates. Then, the elevation angle and orbital altitude are used to determine the path length. Such is the case in this paper where there location parameters of the satellite and earth station are given and analytical computation of the elevation angle and path length are carried out before the link budget is done.

Furthermore, the paper considered only the uplink budget analysis, which is the earth station to satellite link [30,31,32,33,34,35]. The study in this paper is used to determine the uplink signal to noise ratio and other link parameters for a selected number of geosynchronous satellites. The effect of variations in the geo-location datasets for the earth station and the satellite are also considered and the results are captured in tables and graph plots.

2. METHODOLOGY

2.1 Slant range and path loss computation

The orbital slot of a geosynchronous satellite is given in terms of the longitude (denoted as φ_s) and the latitude(denoted as Ψ_s). Also, the earth or ground station geo-location is expressed in terms of the longitude (denoted as φ_e) and the latitude (denoted as Ψ_e). The earth radius (R_e), the geosynchronous satellite orbital altitude (h_s) and radius (R_s) are related as follows;

$$R_s = R_e + h_s \qquad (1)$$

Where $R_e = 6{,}378.21$ and $5{,}786$ hence $= 42{,}164.21$ km. The slant range (d_{sr}) and elevation angle (El) are computed as follows;

$$d_{sr} = R_s\left(\sqrt{\left(1+\left(\frac{R_e}{R_s}\right)^2 - 2\left(\frac{R_e}{R_s}\right)(\cos(\gamma))\right)}\right) \qquad (2)$$

$$\cos(\mathrm{El}) = \frac{\sin(\gamma)}{\left(\sqrt{\left(1+\left(\frac{R_e}{R_s}\right)^2 - 2\left(\frac{R_e}{R_s}\right)(\cos(\gamma))\right)}\right)} \qquad (3)$$

where

$$\cos(\gamma) = \cos(\Psi_e)\cos(\Psi_s)\cos(\varphi_s - \varphi_e) + \sin(\Psi_e)\sin(\Psi_s) \qquad (4)$$

The free space path loss (L_{fsp}) in dB is given in terms of the frequency (f) in Hz and the slant (d_{sr}) in km as follows;

$$L_{fspup} = 32.45 + 20\,\mathrm{Log}(f) + 20\mathrm{Log}(d_{sr}) \qquad (5)$$

In order for an earth station to be accessible to a satellite, the following condition must be satisfied;

$$\gamma \le \cos^{-1}\left(\frac{R_e}{R_s}\right) \qquad (6)$$

So, if the condition is not satisfied, the earth station-satellite link is not feasible.

2.2 Uplink budget computation

The earth station uplink parameters, such as the antenna diameter (D_{eu}), frequency (f_{eu}) or wavelength (λ_{eu}) and the antenna efficiency (η_{eu}) are used to compute the earth station uplink antenna gain ($G_{eu(dB)}$) as follows;

$$G_{eu(dB)} = 10Log\left(\left(\frac{\eta_{eu}}{100}\right)\left(\frac{\pi(D_{eu})}{\lambda_{eu}}\right)^2\right) = 10Log\left(\left(\frac{\eta_{eu}}{100}\right)\left(\frac{\pi(D_{eu})}{\left(\frac{3x10^8}{f_{eu}}\right)}\right)^2\right) \qquad (7)$$

Similarly, the satellite uplink antenna parameters like antenna diameter (D_{su}), and the antenna efficiency (η_{su}) are used to compute the satellite uplink antenna gain ($G_{su(dB)}$) as follows;

$$G_{su(dB)} = 10Log\left(\left(\frac{\eta_{su}}{100}\right)\left(\frac{\pi(D_{su})}{\lambda_{su}}\right)^2\right) = 10Log\left(\left(\frac{\eta_{su}}{100}\right)\left(\frac{\pi(D_{su})}{\left(\frac{3x10^8}{f_{su}}\right)}\right)^2\right) \qquad (8)$$

The received power ($P_{rsu(dB)}$) at the satellite is calculated from the earth station uplink transmitter power ($P_{teu(dB)}$), the earth station uplink antenna gain ($G_{eu(dB)}$), the receiver satellite antenna gain ($G_{su(dB)}$), the free space path loss (L_{fsp}) and atmospheric losses ($L_{eatmu(dB)}$),other losses ($L_{Oup(dB)}$) as follows;

$$P_{rsu(dB)} = EIRP_{teu(dB)} - L_{up} + G_{su(dB)} \qquad (9)$$

Where,

$$EIRP_{teu(dB)} = P_{teu(dB)} + G_{eu(dB)} \qquad (10)$$

$$L_{up} = L_{fsp} + L_{eatmu(dB)} + L_{O(dB)} \qquad (11)$$

The operating flux density (PFD) of the satellite with unit given in dB/m^2 is computed in terms of distance, d is in meters as follows;

$$PFD = EIRP - 10\,\log10(4\pi d^2) \qquad (12)$$

The receiver noise power, N_{up} is computed as;

$$N_u = 10(\mathrm{Log(K)} + 10Log(T_u) + 10(\mathrm{LOG}(B_u)) \qquad (13)$$

$$N_u = 10(Log(1.381\ x\ 10^{-23}) + 10Log(T_u) + 10(\mathrm{LOG}(B_u)) \qquad (14)$$

Where B_u is the bandwidth in Hz. Then, the uplink carrier to noise ratio, C/N is given as;

$$C/N|_{up} = P_{rsu(dB)} - N_u \qquad (15)$$

$$C/N|_{up} = EIRP_{teu(dB)} - L_{up} + G_{su(dB)} - 10Log(T_u) - 10(\mathrm{LOG}(B_u)) - 10(\mathrm{Log(K)} \qquad (16)$$

Now,

$$G_{su(dB)}/T_u = G_{su(dB)} - 10Log(T_u) \qquad (17)$$

Hence,

$$C/N|_{up} = EIRP_{teu(dB)} + (G_{su}/T_u) - L_{up} - 10(\mathrm{LOG}(B_u)) - 10(\mathrm{Log(K)} \qquad (18)$$

$$C/N|_{up} = P_{teu(dB)} + G_{eu(dB)} + (G_{su}/T_u) - L_{up} - 10(\mathrm{LOG}(B_u)) - 10(\mathrm{Log(K)} \qquad (19)$$

2.3 The case study data

Four case study geo-stationary satellites are selected to reflect the range of elevation angles that are feasible within the visibility range. The four case study satellites are listed in Table 1 along with their orbital slots. The earth station is at Ibom e-library with geo-coordinates of 5.015295 latitude and 7.912762 longitude, as shown in Figure 1. The results of the visibility check of the four satellites with respect to the earth station at 5.015295 latitude and 7.912762 longitude are shown in Table 2. The status column (column 7) in Table 2 shows that all the four satellites are visible with respect to the earth station. The pictorial representation of the elevation angle and slant range based on the NIGCOMSAT 1R satellite orbital slot and the case study earth station at Ibom e-library is shown in Figure 2 while Table 3 shows the results of the elevation angle and slant range computation for the four satellites. The input parameters dataset used for the uplink budget analysis of the four satellite are shown in Table 4.

The results for the uplink budget analysis for NIGCOMSAT 1R satellite based on the input parameters in Table 4 (and repeated in Table 5 on the rows with green background) are shown in Table 5 (in the rows with yellow background). The uplink C/N is 8.226227721106937 dB, the propagation loss is 206.7624032063015 dB while the satellite PDF is -106.0221465556865 BW/m^2.

Table 1 The four case study satellites with their orbital slots.

S/N	Satellite name	Orbital slot
1	**NIGCOMSAT 1R**	**42.452 East**
2	**Astra 1A**	**5.2 East**
3	**ECHOSTAR 16**	**61.5 West**
4	**ECHOSTAR 6**	**72.7 West**

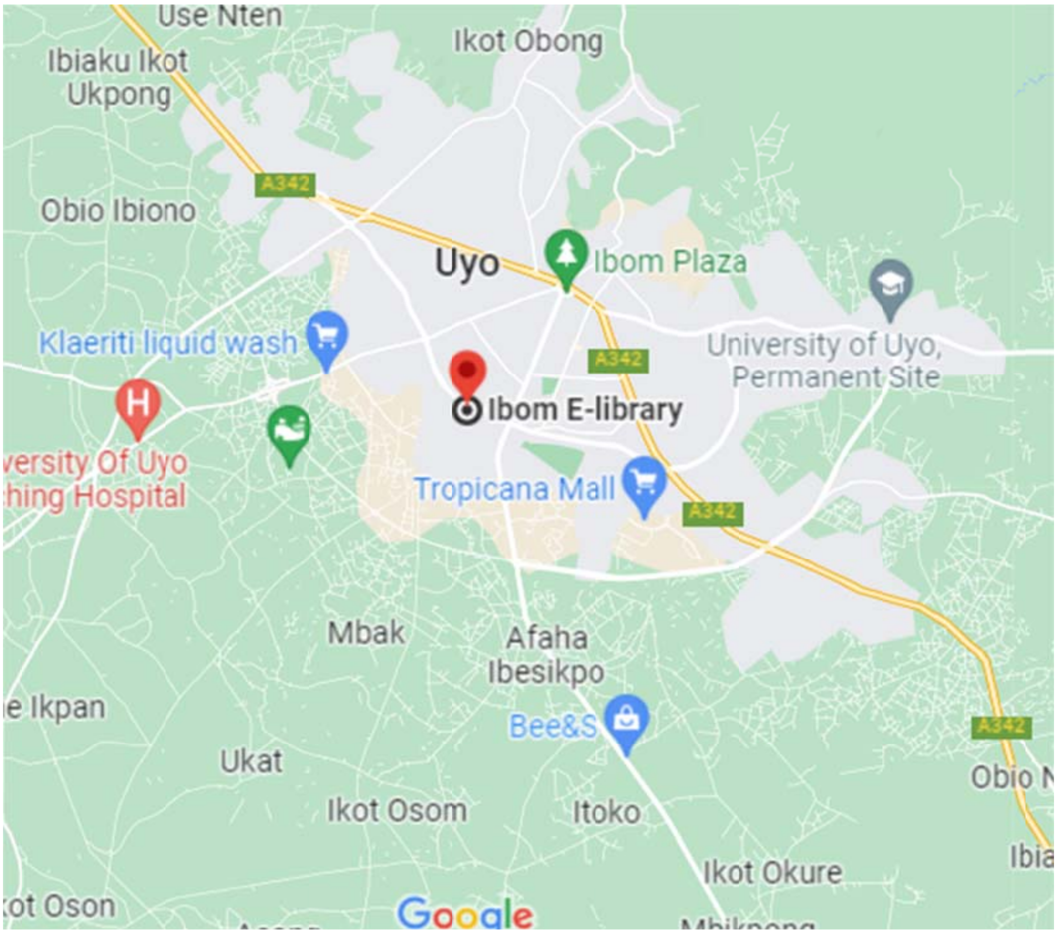

Figure 1 The earth station location at Ibom e-library with geo-coordinates of 5.015295 latitude and 7.912762 longitude

Table 2 The results of the visibility check of the four satellites with respect to the earth station at 5.015295 latitude and 7.912762 longitude

1	2	3	4	5	6	7
S/N	**Satellite name**	**Satellite Longitude (°)**	γ	$\cos^{-1}\left(\frac{R_e}{R_s}\right)$	$\gamma - \cos^{-1}\left(\frac{R_e}{R_s}\right)$	**Status**
1	NIGCOMSAT 1R	42.452	0.608441	1.418944	-0.8105	Visible
2	Astra 1A	5.2	0.099501	1.418944	-1.31944	Visible
3	ECHOSTAR 16	-61.5	1.213077	1.418944	-0.20587	Visible
4	ECHOSTAR 6	-72.7	1.407774	1.418924	-0.01115	Visible

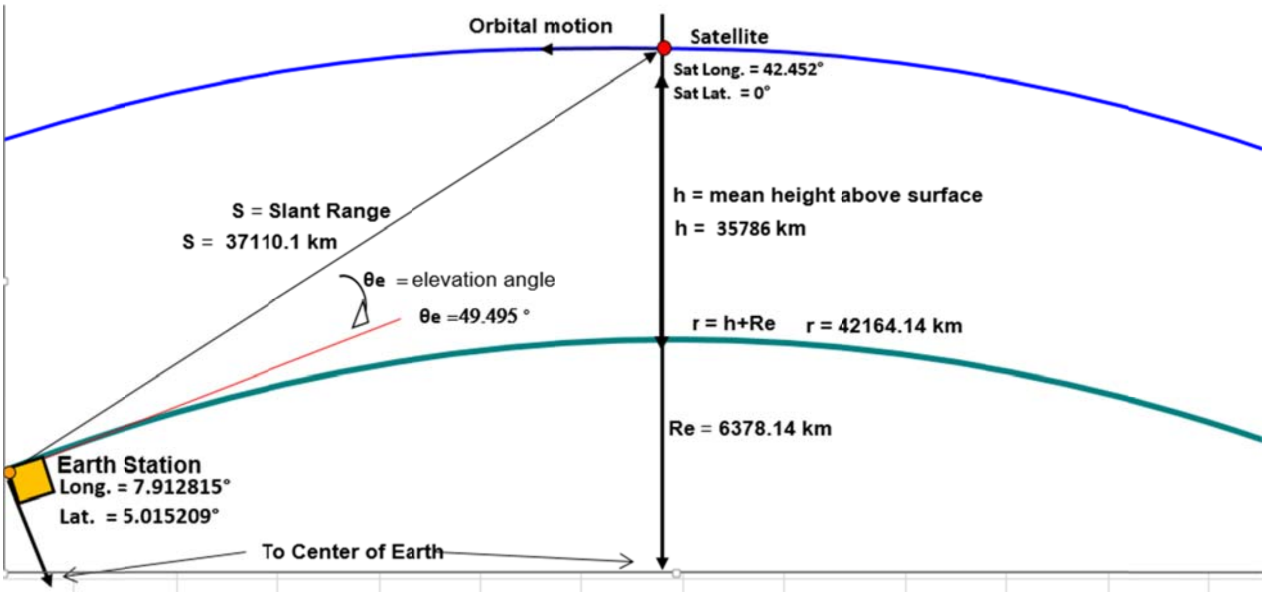

Figure 2 The pictorial representation of the look angle and slant range based on the NIGCOMSAT 1R satellite orbital slot and the case study earth station at Ibom e-library

Table 3 The results of the elevation angle and slant range computation for the four satellites

S/N	**Satellite name**	**Satellite Longitude (°)**	**Earth station latitude (°)**	**Earth station Longitude (°)**	**Elevation (°)**	**Slant Rang (km)**
1	NIGCOMSAT 1R	42.452	5.015209	7.912815	49.494675	37110.1
2	Astra 1A	5.2	5.015209	7.912815	83.274798	35823.2
3	ECHOSTAR 16	-61.5	5.01521	7.912815	11.984908	40375.4
4	ECHOSTAR 6	-72.7	5.01521	7.912815	0.639308	41608.7

Table 4 The input parameters dataset used for the uplink budget analysis

S/N	Description of Parameter	Symbol used for the Parameter	Value of the Parameter	Unit of the Parameter
1	Frequency	f_u	14	GHz
2	Transmitter antenna diameter	D_{Gtu}	1.2	m
3	Transmitter antenna efficiency	η_{Gtu}	70	%
4	Transmitter Power,	P_{tu}	20	W
5	Receiver figure of merit	G_{su}/T_u	70	%
6	(Noise) Bandwidth	B_{Nu}	25	MHz
7	Boltzmann's constant	K	1.381×10^{-23}	J/K
8	Path length or slant range	d_u	variable	km

Table 5 The results for the uplink budget analysis for NIGCOMSAT 1R satellite based on the input parameters in the rows with green background and output in the rows with yellow background

S/N	Uplink Parameter Description	Parameter Value
1	Frequency (GHz)	14
2	Antenna diameter (m)	1.2
3	Antenna aperture efficiency (in fraction)	0.7
4	Antenna transmit gain (dBi)	43.35773105748904
5	Antenna, power at the feed (W)	20
6	The EIRP (dBW)	56.368031014128846
7	Slant Range (km)	37110.1
8	Propagation loss (dB)	206.7624032063015
9	PDF at satellite (dBW/m^2)	-106.0221465556865
10	Bandwidth (Hz)	25000000
11	Satellite G/T (dB/K)	4
12	C/N (dB)	8.226227721106937

In this paper, a visibility test parameter is defined as α, where

$$\alpha = \left(\cos^{-1}\left(\frac{R_e}{R_s}\right)\right) - \gamma \qquad (20)$$

Hence, if $\alpha \geq 0$ the satellite is visible while for $\alpha < 0$ the satellite is not visible. The value of α is greatest when the satellite longitude is the same as the earth station longitude, (as shown in Figure 3). At this point, the elevation angle from the earth station to the satellite is at its peak value (as shown in Figure 4) while the slant range is the lowest, (as shown in Figure 5) .Hence, the greater the value of α the better the visibility of the satellite. The summary of the results for the four satellites along with three fictitious satellites located at the three salient orbital slots (two at the boundary visibility points and one at the highest elevation angle point) are shown in Table 6. In all, the results showed that the lowest slant range and propagation loss occurred at orbital slot of 7.912815 East which is the same as the earth station's longitude. At this point, the uplink C/N is 8.53 dB. On the other hand, the highest slant range and propagation loss occurred at orbital slot of 73.3412792 West and 89.1669092 East which are the boundary visibility longitude for an orbital slot relative to the east station longitude of 89.1669092 East. At these two points, the uplink C/N is 7.22 dB.

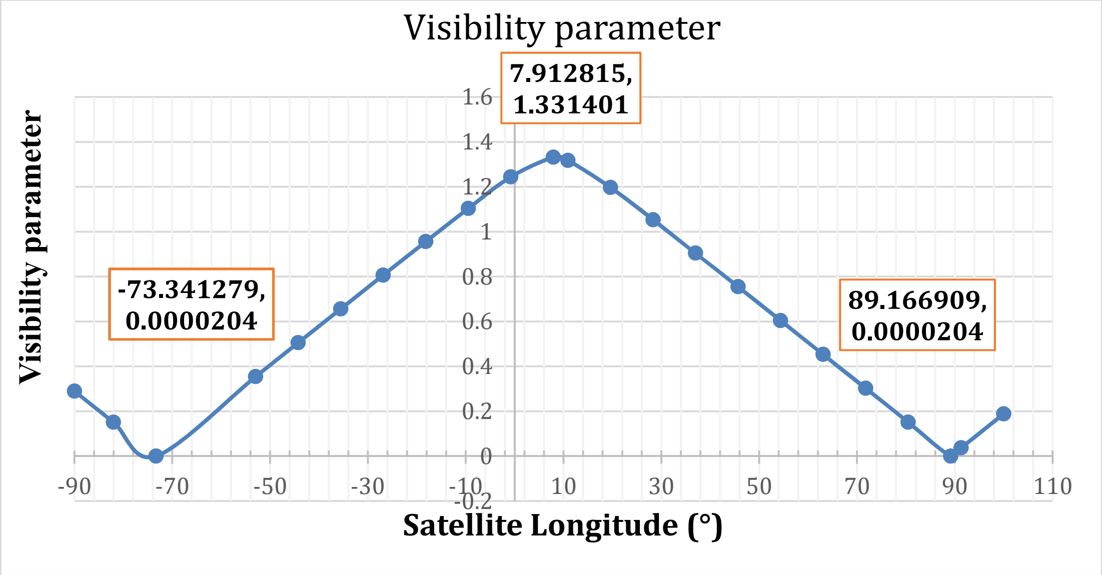

Figure 3 Visibility parameter versus satellite longitude with respect to the earth station at 5.015295 latitude and 7.912762 longitude

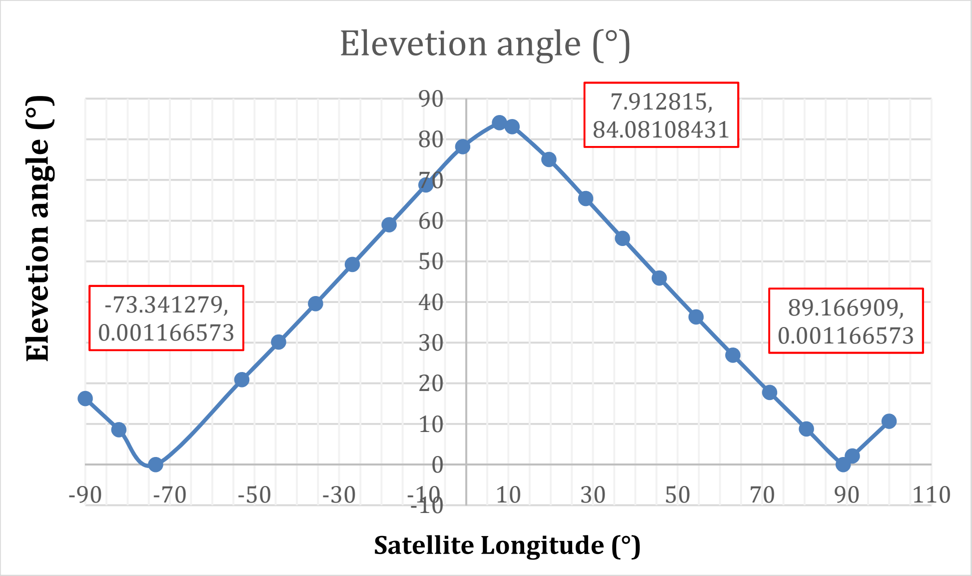

Figure 4 Elevation angle versus satellite longitude with respect to the earth station at 5.015295 latitude and 7.912762 longitude

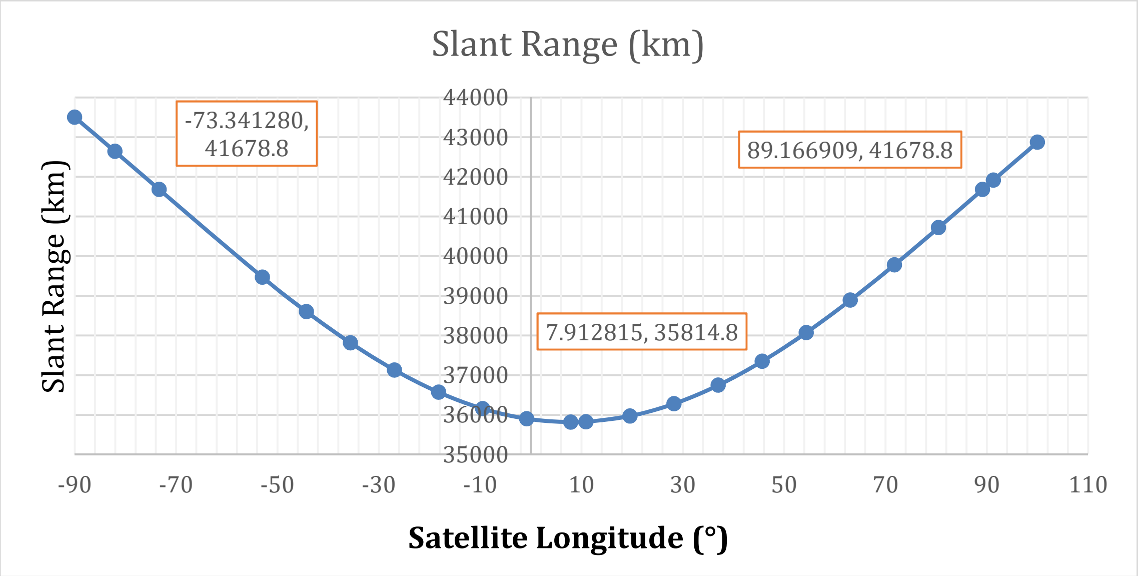

Figure 5 Slant range versus satellite longitude with respect to the earth station at 5.015295 latitude and 7.912762 longitude

Table 6 The summary of the results for the four satellites along with three fictitious satellites located at the three salient orbital slots (two at the boundary visibility points and one at the highest elevation angle point)

	Orbital slot	Satellite Longitude (°)	Elevation angle (°)	Slant Range (km)	Propagation loss (dB)	PDF at satellite (dBW/m^2)	C/N (dB)
Boundary Visibility point West	**73.3412792 West**	**-73.34128**	**0.00120**	**41678.8**	**207.8**	**107**	**7.22**
ECHOSTAR 6	**72.7 West**	**-72.70000**	**0.63931**	**41609**	**207.8**	**-107**	**7.23**
ECHOSTAR 16	**61.5 West**	**-61.50000**	**11.98491**	**40375**	**207.5**	**-106.8**	**7.49**

Astra 1A	**5.2 East**	**5.20000**	**83.27480**	**35823**	**206.5**	**-105.7**	**8.53**
Highest Elevation Angle, Lowest Slant Range	**7.912815 East**	**7.91282**	**84.08110**	**35814.8**	**206.5**	**-105.7**	**8.53**
NIGCOMSAT 1R	**42.452 East**	**42.45200**	**49.49468**	**37110**	**206.8**	**-106**	**8.23**
Boundary Visibility point East	**89.1669092 East**	**89.16691**	**0.00120**	**41678.8**	**207.8**	**-107**	**7.22**

3 Conclusion

The computation of look angle and the uplink budget analysis for geo-stationary satellites are presented. The link budget determined the carrier to noise ratio (C/N) at the satellite end. The computation considered the visibility range for the case study satellite with respect to the earth station. The link budget analysis also considered four satellite in the geo-stationary category, namely ECHOSTAR 6, ECHOSTAR 16, Astra 1A and NIGCOMSAT 1R. The analysis also considered three salient points, the case where the elevation angle is at its peak value and the cases where the orbital slot is at the visibility boundary points. In all, the results show that the point of peak elevation gave the lowest slant range and propagation loss as well as the highest C/N value whereas the highest slant range and propagation loss and lowest C/N occurred with orbital slot at the visibility boundary points.

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