GNSS Sky Visibility Planning and Dilution of Precision Analysis for EOS Ground Station Selection for Nigeria Space Programme

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Abstract

The establishment of Earth Observation Satellite (EOS) ground receiving stations in parts of Nigeria and other parts of the globe, similar to the Indian Remote Sensing (IRS) model will enhanced global tele-commands, precise EOS tracking, data transmission and distribution of NigeriaSat data, which will enhance global-scale data awareness, usage and higher financial returns for Nigeria. This study therefore attempts the application of Global Navigation Satellite System (GNSS) sky visibility planning and dilution of precision analysis technique to select optimal location for EOS ground station(s) in Nigeria. The Nigerian Geodetic Network (NigNet) GNSS Continuously Operating Reference Stations (CORS) RINEX data of February 2012 and Trimble Total Control (TTC) software were used for the determinations of the baselines and positions of the 11 available CORS. The technique of GNSS sky visibility planning and dilution of precision (DOP) was adopted because signals from satellites behave in similar pattern in the atmosphere, so poor visibility in GNSS signal in a particular observation window translates relatively to poor orbit definition signal for an EOS. Based on Jon's rating of DOP values [1= ideal; 2-3 = excellent; 4-6 =good; 7-8= moderate; 9-20=fair; 21-50= poor)], the DOP values for the stations across Nigeria can be adjudged to range between excellent and good for ground receiving stations. However, the overall results showed that, GEMB on ellipsoidal heights of 1795.7857m has the most suitable DOPs and sky visibility plan for ground receiving sites; followed by CGG Toro (916.7853m) and RAMPOLY Maiduguri (702m). The sky visibility analysis showed availability of an average of 9 GPS and 2 GLONASS constellation satellites to receivers at elevation angles of 10^o-15^o between 6:00hrs and 24:00hrs daily across Nigeria. The approach of EOS ground receiving station suitability analysis demonstrated in this study is recommended for the Nigerian Space programme in EOS ground-based antennae farm establishment. It is also relevant in the densification of GNSS reference stations by public-private organizations for geoinformation development, engineering infrastructure tracking and navigation at state and local government levels across the country.

***Key Words**: GNSS, Sky Visibility, Planning, DOP, EOS, Ground Station*

1.0 INTRODUCTION

Ground receiving station network (GRSN) is the means by which satellites in space stay in contact with the Earth. Human operators at the ground stations send commands to correct the satellites' trajectories, maneuver them into different orbits, and operate their instruments. The satellite transmits back to earth not only the scientific data that it is gathering, but also the 'housekeeping' information needed by the operators to check the satellite's performance (ESA, 2008). The types of control necessary for earth observation satellites include those of orbit, attitude, pointing of observation instrument, thermal, telemetry, communication, command, and electric power (ERSDAC, 2010). With the rapid advancement in the technologies of Earth Observation Satellites in low Earth orbit, the ability to precisely predict the position and velocity of the satellite is extremely important.

The ground station of an Earth Observation Satellites (EOS) system consists of all communicating earth stations which access the operational satellite. The ground station's job is two-fold, transmitting and receiving. When transmitting, the terrestrial data in the form of

baseband signals is passed through a baseband processor, an up-converter, a high-powered amplifier, and through a parabolic dish antenna up to an orbiting satellite. In the case of a receiving station, it works in the reverse fashion by converting signals received through the parabolic antenna to baseband signal. The mission data acquired by the ground station from a spacecraft are transferred to the data users along with any telemetry and tracking information the data users may need for general station keeping. The basic functions of GRSN include among others; *telemetry tracking and control support, satellite orbit determination and monitoring, general station keeping, satellite payload management* and *in-orbit test (IOT).* One of the strategic ways of monitoring the Orbit of an EOS is the use of (TLE) for velocity, *orbit inclination, eccentricity and coefficient of drag variation analysis* (Langer et al, 1994, 2002; Cox et al, 2000; Ojigi, 2012).

Obtaining a precise orbit with sparse tracking data and the ability to accurately propagate it so that it can be used for scheduling instruments and ground station operations are important procedures selection of the estimation algorithm and force modeling. When GNSS observables have to be incorporated in the software, those suited for batch estimators must be used. The option is to obtain the processed baseline and navigation results using double differences of ionospheric free carrier phase and double difference pseudorange. Dow et al (1994) suggested that, measurements with GPS observables should be implemented either for pairs of ground stations or for geodesy, and for orbiting receiver or ground station pairs, in order to obtain precise orbits of the satellite carrying the GPS receiver.

Most modern satellites utilize space-borne GNSS receivers as primary navigation sensors, which allow positioning accuracies to the decimeter level because of the high precision of GPS carrier-phase measurements (Hauschild, *undated*; Hauschild and Montenbruck, 2008). The determination of Two Line Element (TLE) sets are enhanced by GNSS observable and receivers on EOS, whose orbit attitudes are subsequently tracked, monitored, propagated and modeled. High accuracy in EOS telemetry tracking and control is guaranteed using the GNSS carrier phase observable, free of ionospheric errors when dual frequency data is used. The unsurpassed observability is provided by the high number of GPS satellites than can be simultaneously tracked by an orbiting receiver (http://nng.esoc.esa.de/gps/onboard_gps.html; Cox et al, 2000).

Satellite Visibility and Observation Planning

GNSS planning software have been developed (Fruet al, 1999; Sguerso and Zatelli, 1999; zatelli and D'Inca, 2004) and recently updated (Federici and Sguerso, 2009), and introduced as modules of most GNSS solution software (commercial, scientific and open source software). GNSS Planning allows the identification of optimal areas to perform a survey in a given temporal window, or the best time interval for a survey campaign in a certain area (Federici, et al, 2010), taking into account the realistic obstructions to satellite signals due to factors such as terrain morphology, building and communication structures, weather and atmospheric conditions, etc. A popular representation of satellite availability is the skyplot, which is a plot of satellite tracks on a zenithal projection centered at the ground station (fig.1.1).

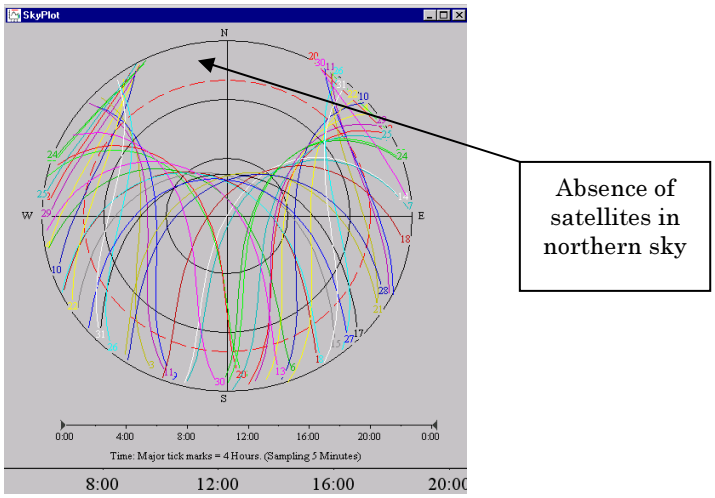


Figure1.1: Skyplot showing absence of Satellites in Northern sky (Source: Oppliger, 2007)

Dilution of Precision (DOP)

The Dilution of Precision (DOP) is a measure of the geometrical strength of the observations model. DOP can also be a measure of the strength of the satellite-constellation geometry. The higher the number of satellites observed and used in the final solution, the better the solution. In mathematical terms, DOP is a scalar quantity used in an expression of a ratio of the positioning accuracy. It is the ratio of the standard deviation of one coordinate to the measurement accuracy. Therefore, since DOP *(Time DOP, Vertical DOP, Horizontal DOP and Geometric DOP)* can be used as a measure of geometrical strength, it can also be used to selectively choose four satellites in a particular constellation that will provide the best solution (U.S. Army Corps of Engineers, 1996; Strang et al, 1997; Gladstone, 2006). In general, DOP values below 4 indicate excellent observation conditions (Oppliger, 2007). Jon's interpretation of DOP values (http://www.developerfusion.com) include: *1= ideal; 2-3 = excellent; 4-6 =good; 7-8= moderate; 9-20=fair; 21-50= poor.*

The DOP factors used in satellite positioning are derived from the diagonal elements of the inverse of the normal matrix of the observation. The normal matrix is computed as part of standard GNSS navigation solutions during the post processing of observed data. The navigation solution is based on the measured Coarse Acquisition Code Pseudo ranges and solves for the 3-D receiver coordinates (X, Y, Z) and the receivers clock offset (dT) using the least squares algorithm. In the least squares solutions, the inverse of the normal matrix is, of course, the variance matrix of the estimated parameters and therefore takes the form of equation (1) (Langley, 1999; Misra and Enge, 2001).

$$Q_{xx} = \begin{bmatrix} \sigma_X^2 & \sigma_{YX} & \sigma_{ZX} & \sigma_{TX} \\ \sigma_{XY} & \sigma_Y^2 & \sigma_{ZY} & \sigma_{TY} \\ \sigma_{XZ} & \sigma_{YZ} & \sigma_Z^2 & \sigma_{TZ} \\ \sigma_{XT} & \sigma_{YT} & \sigma_{ZT} & \sigma_T^2 \end{bmatrix} = \begin{bmatrix} \sigma_E^2 & \sigma_{EN} & \sigma_{Eh} & \sigma_{EdT} \\ \sigma_{EN} & \sigma_N^2 & \sigma_{Nh} & \sigma_{NdT} \\ \sigma_{Eh} & \sigma_{Nh} & \sigma_h^2 & \sigma_{hdT} \\ \sigma_{EdT} & \sigma_{NdT} & \sigma_{hdT} & \sigma_{dT}^2 \end{bmatrix} \quad (1)$$

Where,

$$TDOP = \sigma_{dT} \quad (2)$$

$$VDOP = \sigma_h \quad (3)$$

$$HDOP = \left(\sigma_E^2 + \sigma_N^2\right)^{1/2} \quad (4)$$

$$PDOP = \left(\sigma_E^2 + \sigma_N^2 + \sigma_h^2\right)^{1/2} = \left(\sigma_X^2 + \sigma_Y^2 + \sigma_Z^2\right)^{1/2} \quad (5)$$

$$GDOP = \left(\sigma_E^2 + \sigma_N^2 + \sigma_h^2 + c\sigma_{dT}^2\right)^{1/2} = \left(\sigma_X^2 + \sigma_Y^2 + \sigma_Z^2 + c\sigma_{dT}^2\right)^{1/2} \quad (6)$$

c = velocity of light ($\approx 3.0*10^8$m/s-^{2})

1.1 Statement of Problem

The ground receiving station network (GRSN) allows for data access and provision of highly-accurate ephemerides earth-centered inertial (ECI) coordinates, satellite sub-point (latitude, longitude, and altitude for non-spherical earth), look angles (azimuth, elevation, range, and range rate), and right ascension and declination. One major outlet of satellite data distribution from the Indian Cartosat-1 Spacecraft is the Indian Remote Sensing (IRS) International Ground Stations operating in various parts of the World (http://www.nrsa.gov.in). The establishment of ground receiving stations elsewhere in Nigeria and other parts of the globe, similar to the IRS model will enhance global tele-commands, data transmission and distribution of NigeriaSat imageries, and lead to global-scale data awareness, usage and higher financial returns.

GNSS technology plays strong role in the selection of suitable ground station location through sky visibility and DOP analysis, precise determination and monitoring of orbital elements of Low Earth Orbit Satellites (LEOS), determination of unpredictable spacecraft trajectories, leveraging on GNSS continuous coverage and great accuracy (*when spacecrafts are performing frequent maneuvers or flying at very low altitudes their flight modes may sometimes be so unpredictable*), and computation of the relative position of two spacecrafts (e.g. N-2 and N-X) using relative or differential modes of GNSS receivers. In view of this, it is therefore imperative to use the GNSS CORS infrastructure in Nigeria and associated International GNSS Service (IGS) facilities to plan and select the optimal ground stations for Nigeria space programme.

1.2 Aim and Objectives of Study

The study aims at applying the GNSS sky visibility planning and dilution of precision analysis for EOS ground station selection for Nigerian space programme**.** The **objectives** of the study are to:

i. Carry out the sky visibility analysis at elevation cutoff angles of 10^o, 12^o and 15^o using satellite visibility planning technique;
ii. Carry out the multiple and single station dilution of precisions (DOPs) analysis of eleven (11) Nigeria Geodetic Network (NigNet) GNSS COR stations in Nigeria at elevation cutoff angles of 10^o, 12^o and 15^o respectively;
iii. Use the DOPs and satellite visibility analysis to identify and select suitable locations for ground receiving antenna in Nigeria, in addition to the existing one at the National Space Research and Development Agency (NASRDA) in Abuja;

iv. Recommend strategies to mitigate signal obstruction and interferences in GRSN locations and operations for the Nigeria space programme.

1.3 Nigeria's Ground Station Facility and Satellites in Orbit

The NigeriaSat-2 and NigeriaSat-X have two common ground stations located in Surrey, UK and NASRDA, Abuja receptively. The satellite is routinely tracked by the two ground stations, with a satellite pass in about 3-4days for N-2 and N-X in 3-5 satellites days interval. The integrated Ground Station Telemetry Tracking and Control (TTC) also consists of GPS_Receivers (*onboard N-2 and N-X*, and operated at the ground simultaneously) to create reference frame of the satellite, and the Inertial Reference Unit (IRU) to record attitude variations (*pitch, roll and yaw*) of the platform; required for satellite orbit's attitude corrections. Parameters involved in typical command links include changes and corrections in attitude control and orbital control, antenna pointing and control, transponder mode of operation and battery voltage control.

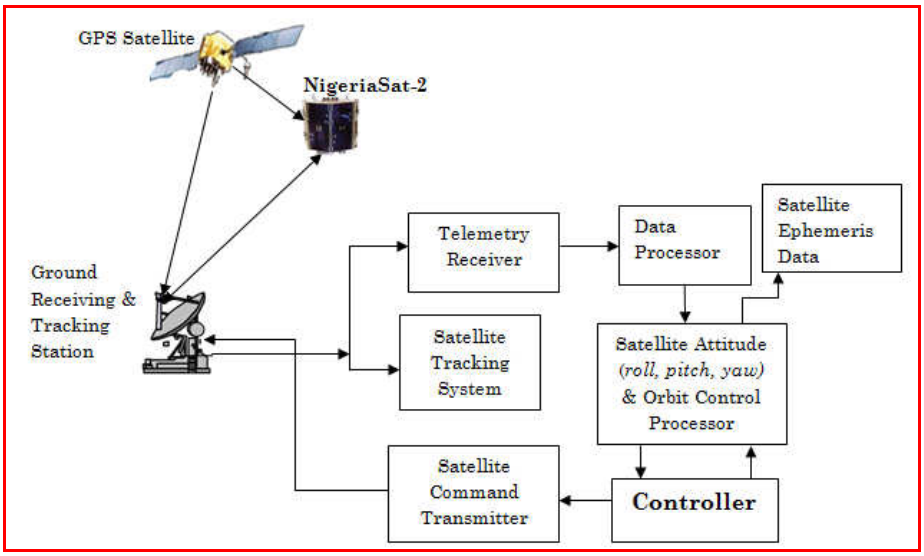


Figure 1.2: A Model of Tracking and Control Functional Elements for the NigeriaSat at NASRDA, Abuja, Nigeria (Source: Authors' Design).

1.3.1 NigeriaSat Infrastructure

The NigeriaSat infrastructure is comprised of the NigeriaSat-2 (N-2) and NigeriaSat-X (N-X) spacecrafts, Mission Control Centre *[Mission Control Suite (MCS), Ground Station (GS) and the Mission Operations Centre (MOC)]*, Communication and Power Control Systems, etc. N-2 and N-X are polar orbiting, Low Earth Observation Satellites (LEOS) at an altitude of about 700km. The Payload of NigeriaSat-2 is Camera-based, comprising 2.5m ground sampling distance (GSD) panchromatic (very high resolution); 5.0m GSD (high resolution) in four (4) spectral bands and 32m GSD also in 4 spectral bands (Red, Green, Blue and NIR) (medium resolution). On the other hand, the NigeriaSat-X is a multi-spectral system with sensors in three (3) spectral bands (Red, Green and Blue) with images of 22m GSD (http://www.sstl.co.uk; Chizea et al, undated; Tamunopekerebia et al, 2009).

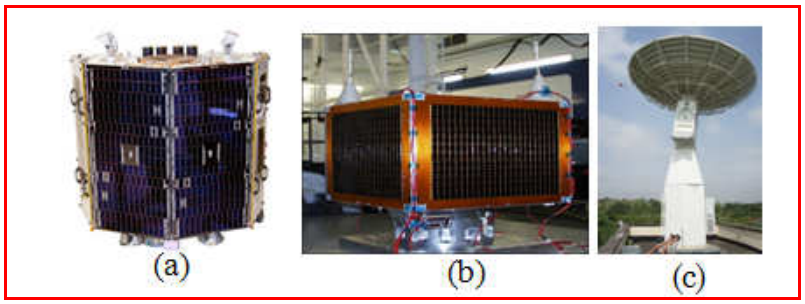


Figure 1.3(a, b and c): The NigeriaSat Spacecrafts and Ground Station Antenna [a, b: N-2, N-X (http://www.sstl.co.uk); c: GS Antenna at NASRDA, Abuja (source: Authors' field work)].

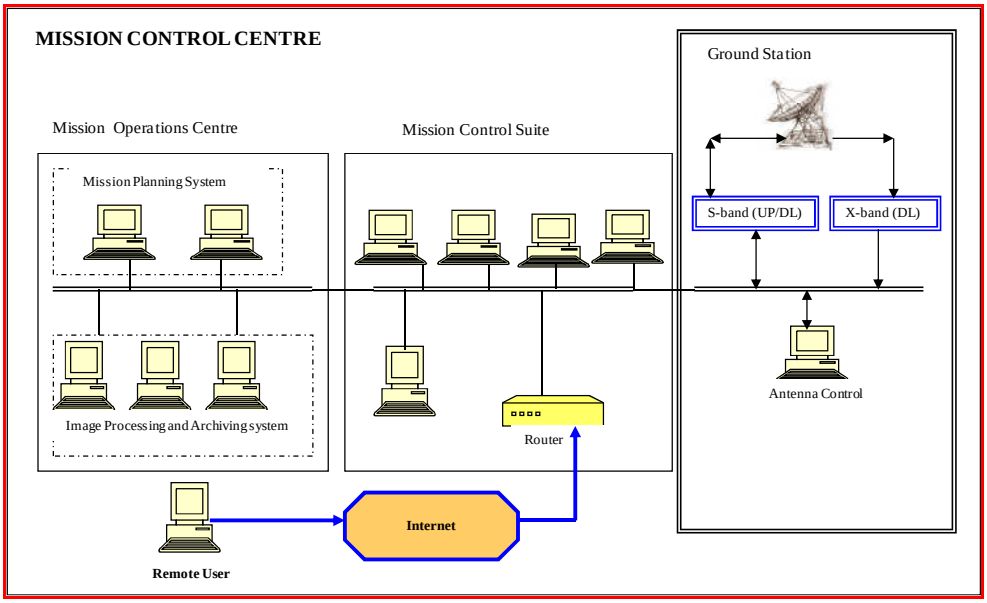


Figure1. 4. Mission Control Centre (Source: Chizea et al, *undated*)

2.0 MATERIALS AND METHODS

2.1 Data Collection and Sources

The dataset used is a collection of NigNet RINEX data for nine (9) COR Stations observed in February 2012 and obtained from the Office of the Surveyor General of the Federation (OSGoF) Nigeria, and International GNSS Service (IGS) Navigation Data (http://igs.org; http://igscb.jpl.nasa.gov/).

2.2 Description of NigNet CORS

The NigNet CORS came into existence in 2008 and since then the number of stations have increased gradually to Eleven (11) as of April 2011 (http://www.nignet.net). The CORS were established by the Office of the Surveyor General of the Federation (OSGF). The eleven (11) NigNet COR Stations already installed and operational are located in: Abuja (OSGoF), Port

Harcourt (RUST), Gembu (GEMB), Lagos (ULAG), Kebbi), Zaria (ABUZ), Yola (FUTY), Enugu (UNEC), Calabar (UCAL), Toro (CGGT) and Maiduguri (RAMPOLY).

2.3 Ground Station Site Selection Procedure with GNSS

Generally, the factors used for selecting ground receiving stations include geographic location, ground elevation, sky visibility, site's geology and structural stability, antenna diameter, power and communication facilities, security, Internet and data access, weather and climate, etc. The site selection was based on satellite sky visibility planning and dilution of precision. This is because signals from satellites behave in similar pattern in the atmosphere, so poor visibility in GNSS signal in a particular observation window translates relatively to poor orbit definition signal for the EOS. The ground elevation, geographical locations (coordinates) and local mean time (LMT) were used for generating the sky visibility and DOPs criteria for site selection procedure in this study.

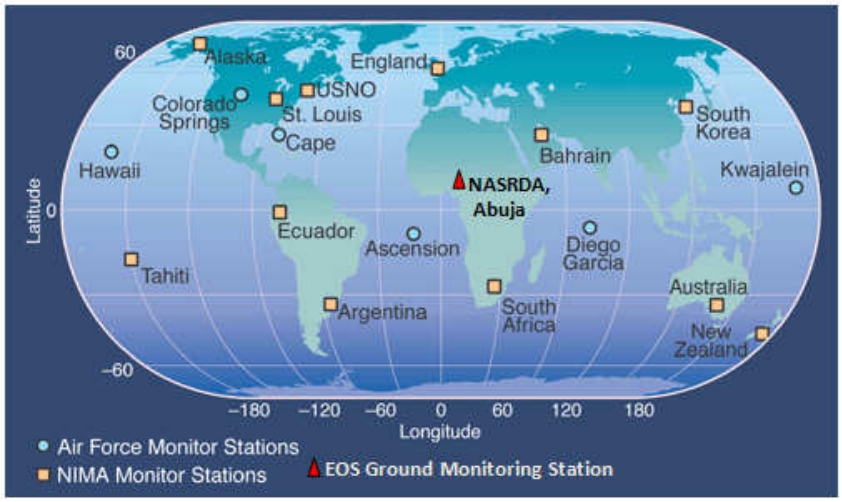


Figure 2.3: GPS Monitoring Stations, NIMA Tracking Stations across the globe and NigeriaSat Ground Monitoring Station (Modified after Langer et al, 2002)

To schedule GNSS operations for effective EOS operations and maintenance, the following factors, amongst others need to be considered:

i. From the ground stations, satellites are not normally tracked below an elevation of 10° to 20° due to large atmospheric refraction and interference errors at lower elevation angles.
ii. There is a 24 hour observation window for GNSS, but not possible for EOS
iii. There are periods when many more satellites are visible than the other due to climatic factors.
iv. The satellites' positions in the sky are predictable. They can be computed and output in a convenient graphical form, and taken out into the field during reconnaissance.

2.4 Data Preparation and Processing

The NigNet RINEX data for February 2010 were prepared and processed at intervals of 10seconds. Fixed solution, ionospheric free computations and biased adjustment of the baselines and station coordinates were carried out using Trimble Total Control Software.

2.5 Sky Visibility and DOPs Computation

The multistation sky visibility plots for the entire 11 selected were carried out for three different elevation cutoff angles of 10^o, 12^o and 15^o respectively using Trimble Total Control software. This approach is to simulate the availability of the Global Navigation Satellites System during station and space craft tracking sessions. The input variables include the 3D spatial coordinates (latitude, longitude, and ellipsoidal height) of the stations, time and period of observation (06hr-24hrs/28 days of February 2012), and cutoff angles of 10, 12 and 15 degrees. Similarly, the mean DOPs values were computed for the same stations at elevation cutoff angles of 10^o, 12^o and 15^o respectively for the same period of observations. A popular representation of satellite availability is the skyplot, which is a plot of satellite tracks on a zenithal projection centered at the ground station. The satellite azimuth and elevation are functions of time.

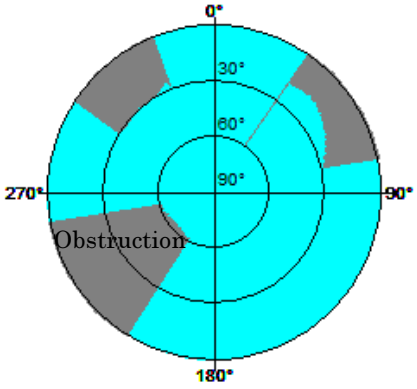


Figure 2.4: A sample of satellite signal obstructions *(shadow regions)* on a skyplot

3.0 RESULTS AND DISCUSSION

3.1 Results

Table 3.1 shows the post-processed curvilinear coordinates (ϕ, λ, h) of the nine of the eleven NigNet reference controls in Nigeria. The relevance of these points to the selection of ground station is that they provide the frame work for baseline and spatial analysis in relation to the NASRDA Satellite Ground Stations in Abuja, Nigeria.

Table 3.1: The adjusted reference points in WGS84 (geographical coordinates and std. dev.)

Point	Latitude(ϕ)	σ(mm)	Longitude(λ)	σ(mm)	Height (m)	σ(mm)
ABUZ	N 11° 09' 06.26225"	0.0	E 7° 38' 55.22929"	0.0	705.4601	0.0
BKFP	N 12° 28' 06.87297"	2.7	E 4° 13' 45.22956"	6.8	250.5099	8.5
CGGT	N 10° 07' 23.14085"	1.2	E 9° 07' 05.87589"	1.6	916.7853	5.2
FUTY	N 9° 20' 59.07440"	3.2	E 12° 29' 52.02238"	9.0	247.6116	9.9
GEMB	N 6° 55' 01.92069"	3.5	E 11° 11' 02.13748"	7.7	1795.7857	10.5
OSGF	N 9° 01' 39.59767"	1.6	E 7° 29' 10.78586"	1.7	532.9498	6.1
RUST	N 4° 48' 06.61408"	5.4	E 6° 58' 42.63372"	12.3	45.5320	17.0
ULAG	N 6° 31' 02.37835"	3.1	E 3° 23' 51.40406"	8.0	44.7918	10.6
UNEC	N 6° 25' 29.30450"	3.1	E 7° 30' 17.92300"	5.9	254.4941	10.5

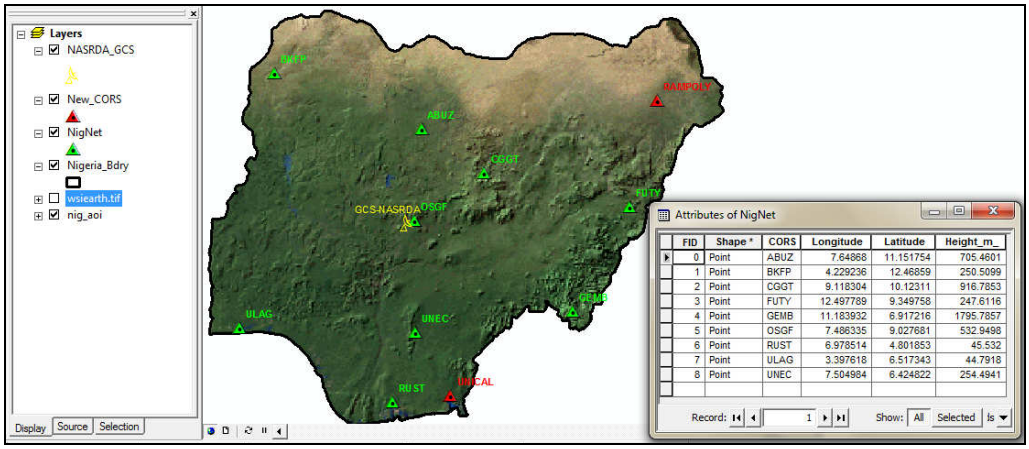


Figure 3.1: NigNet Stations and NigeriaSat Ground Station at NASRDA, Abuja

Figures 3.2a-c show the multistation sky visibility chart for the elevation cutoff angles 15^o, 12^o and 10^o respectively. On the other hand, figures 3.3a-b show the single station sky visibility plan for GEMB station at both 15^o and 10^o elevation cutoff angles.

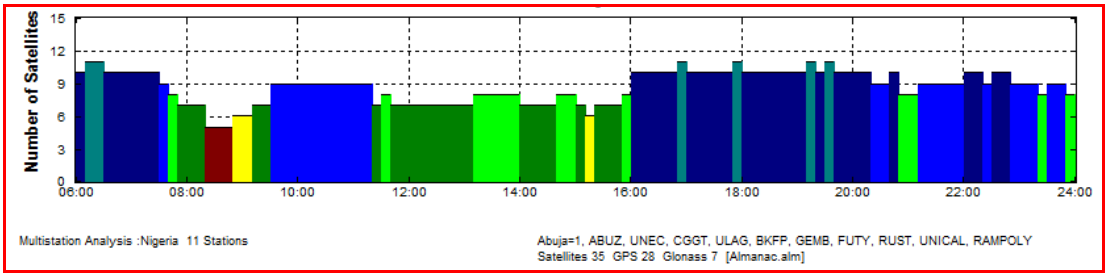


Figure 3.2a: Multistation (11 stations) Satellite Visibility Chart at Elevation Cutoff Angle of 15^o

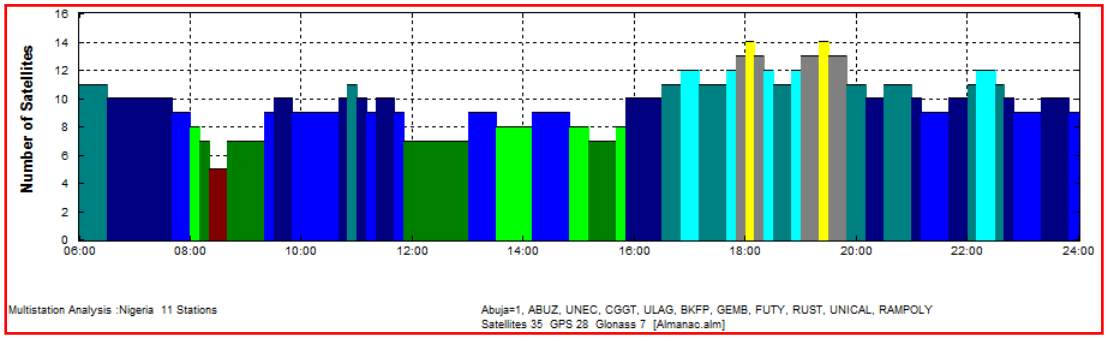


Figure 3.2b: Multistation (11 stations) Satellite Visibility Chart at Elevation Cutoff Angle of 12^o

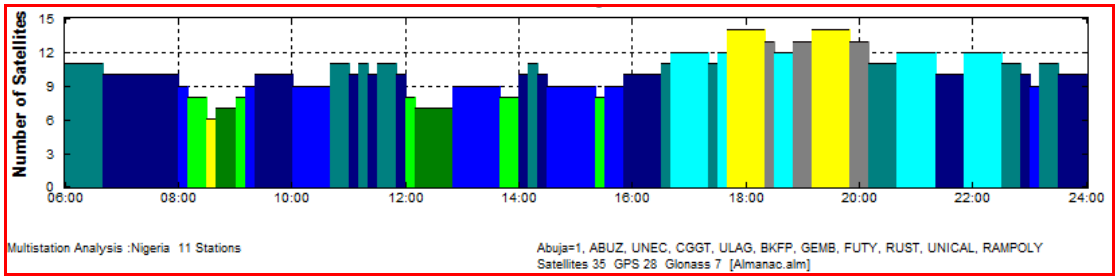
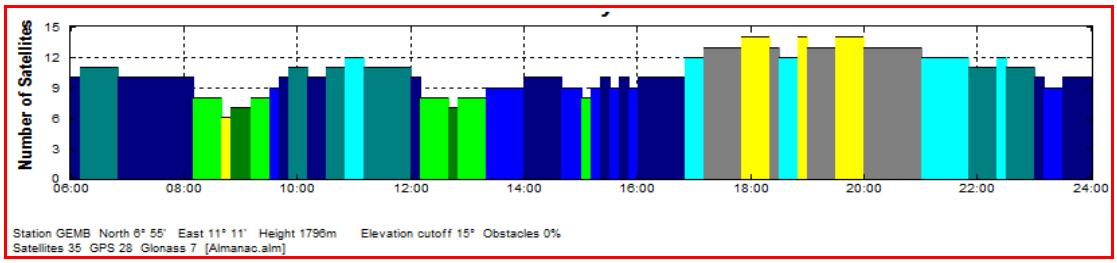


Figure 3.2c: Multistation (11 stations) Satellite Visibility Chart at Elevation Cutoff Angle of 10^o



Figiure 3.3a: GEMB (Single Station) Satellite Visibility Chart at Elevation Cutoff Angle of 15^{o}

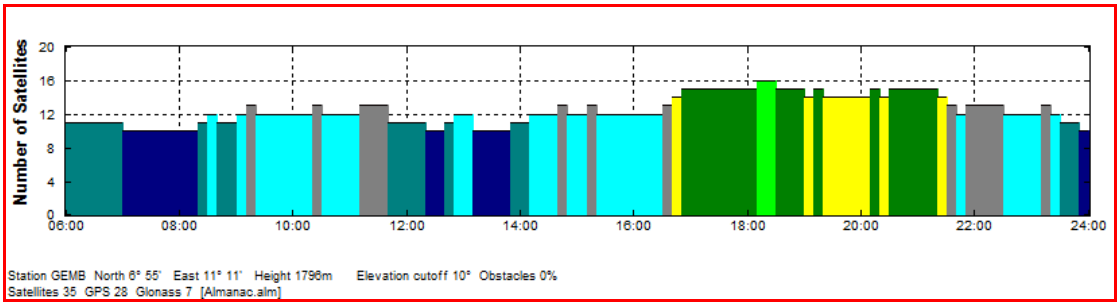


Figure 3.3b: GEMB (Single Station) Satellite Visibility Chart at Elevation Cutoff Angle of 10^{o}

Figures 3.4a-c show the multistation (11 stations) DOPs at elevation cutoff angles of 15^{o}, 12^{o} and 10^{o} respectively. The single station DOPs for each of the 11 stations in the network are shown in fiugres 3.5a-k.

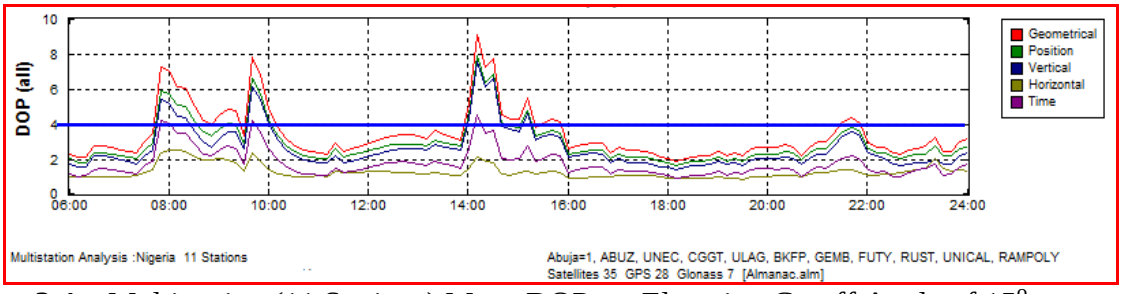


Figure 3.4a: Multistation (11 Stations) Mean DOPs at Elevation Cutoff Angle of 15^{o}

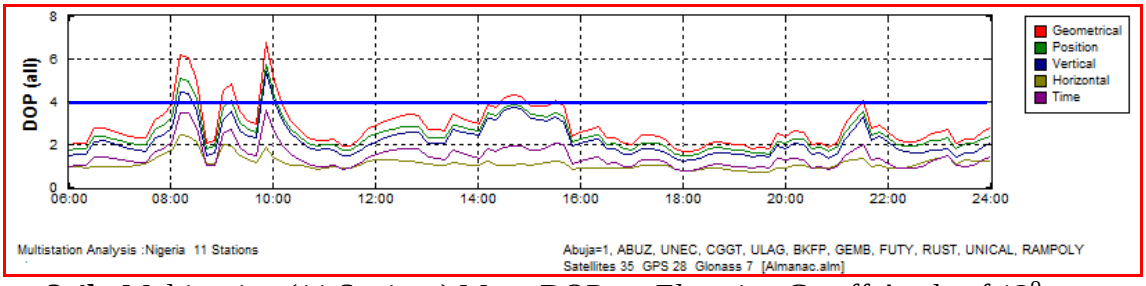


Figure 3.4b: Multistation (11 Stations) Mean DOPs at Elevation Cutoff Angle of 12^{o}

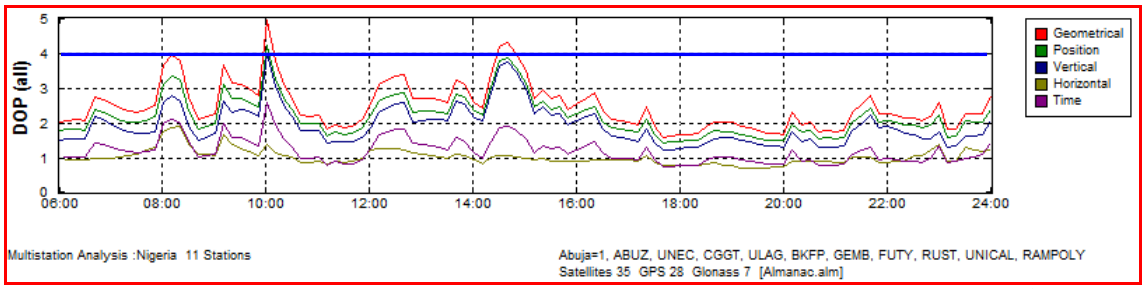


Figure 3.4c: Multistation (11 Stations) Mean DOPs at Elevation Cutoff Angle of 10^{o}

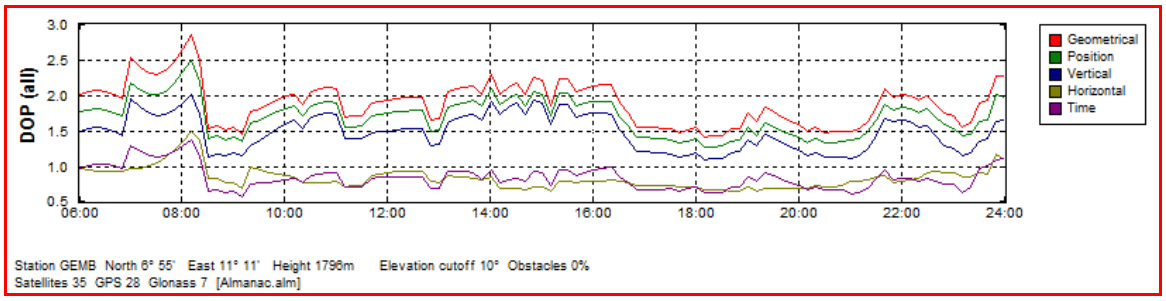


Figure 3.5a: GEMB (Single Station) DOP at Elevation Cutoff Angle of 10^{o} [all round GDOP ≤2.8 (Overall Best DOPs)]

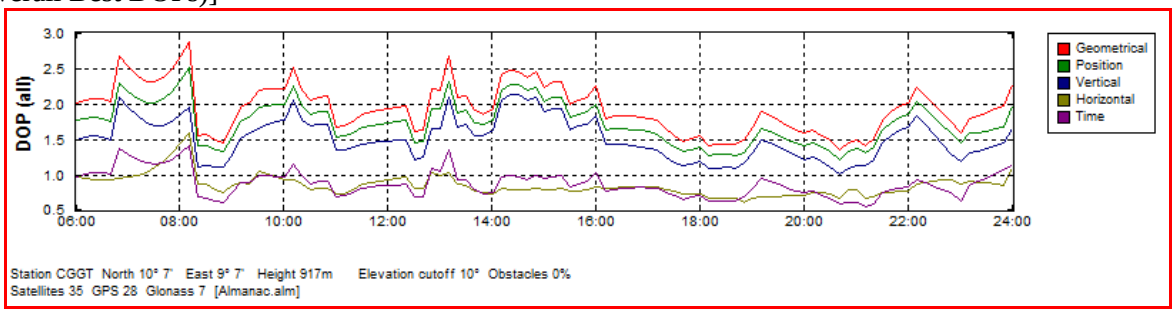


Figure 3.5b: CGGT (Single Station) DOP at Elevation Cutoff Angle of 10^{o} [all round GDOP ≤2.9]

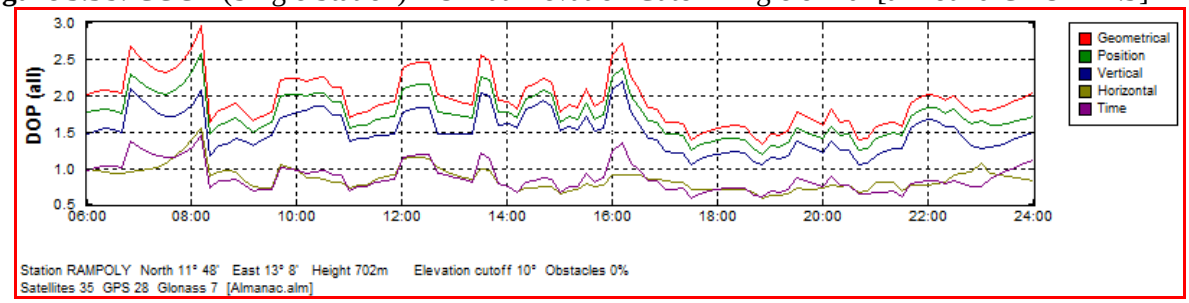


Figure 3.5c: RAMPOLY (Single Station) DOP at Elevation Cutoff Angle of 10^{o} [all round GDOP ≤2.9]

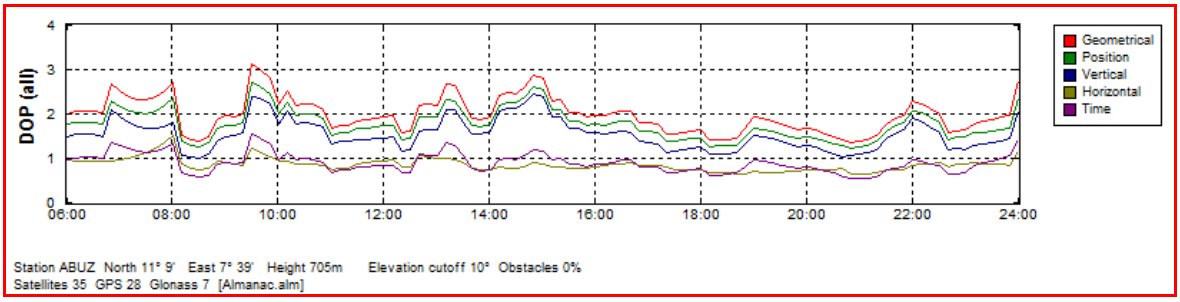


Figure 3.5d: ABUZ (Single Station) DOP at Elevation Cutoff Angle of 10^{o} **[**all round GDOP ≤3.0]

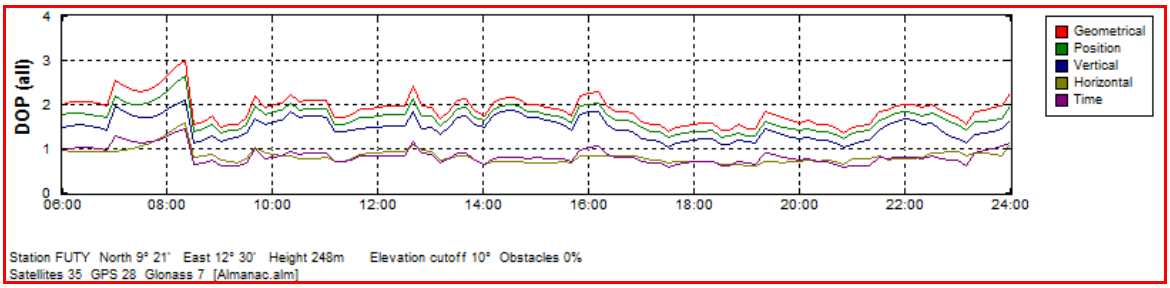


Figure 3.5e: FUTY (Single Station) DOP at Elevation Cutoff Angle of 10^{o} [all round GDOP ≤3.0]

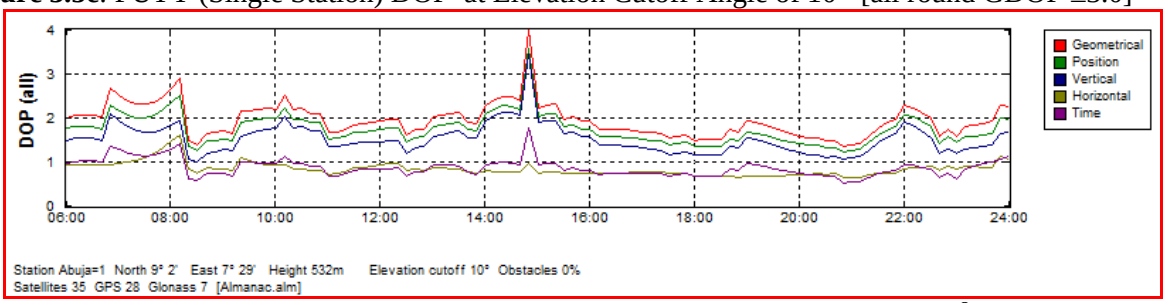


Figure 3.5f: ABUJA-1 (Single Station) DOP at Elevation Cutoff Angle of 10^{o} [all round GDOP ≤3.0, but GDOP ≤4.0 at 14:40-14:50hrs]

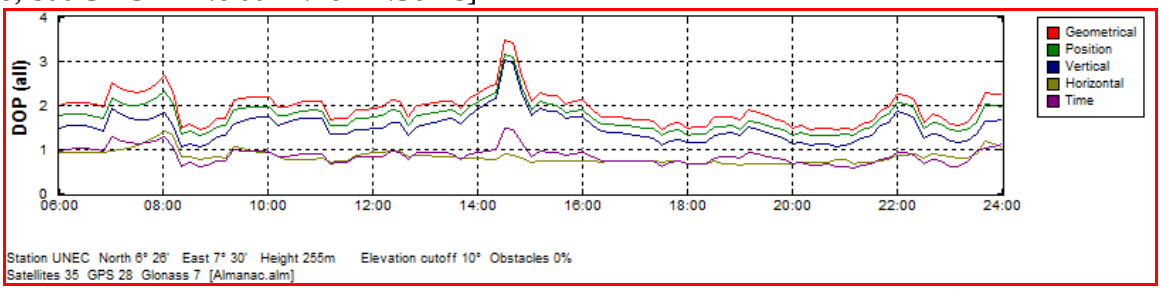


Figure 3.5g: UNEC (Single Station) DOP at Elevation Cutoff Angle of 10^{o} **[**all round GDOP ≤3.0, but GDOP ≤3.4 at 14:30-14:50hrs]

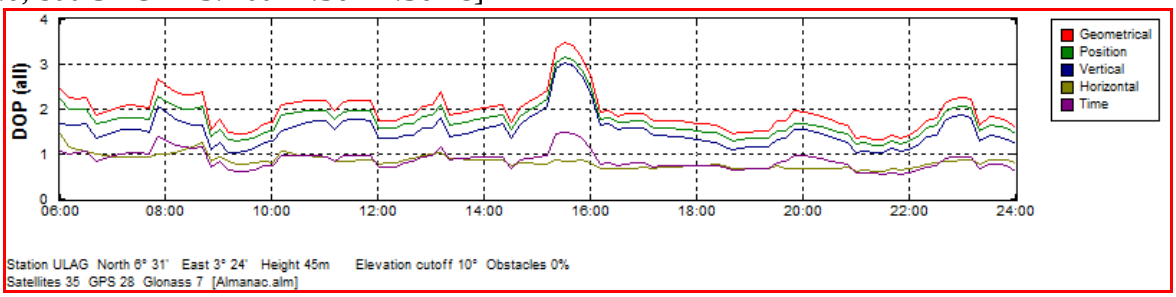


Figure 3.5h: ULAG (Single Station) DOP at Elevation Cutoff Angle of 10^{o}[all round GDOP ≤3.0, but GDOP ≤3.3 at 15:30-16:00hrs]

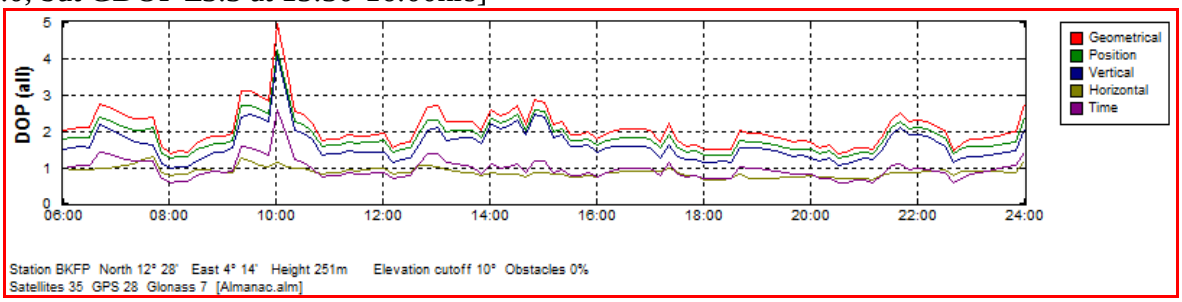


Figure 3.5i: BKFP(Single Station) DOP at Elevation Cutoff Angle of 10^{o} [all round GDOP ≤3.0, but GDOP ≤5.0 at 10:00hrs]

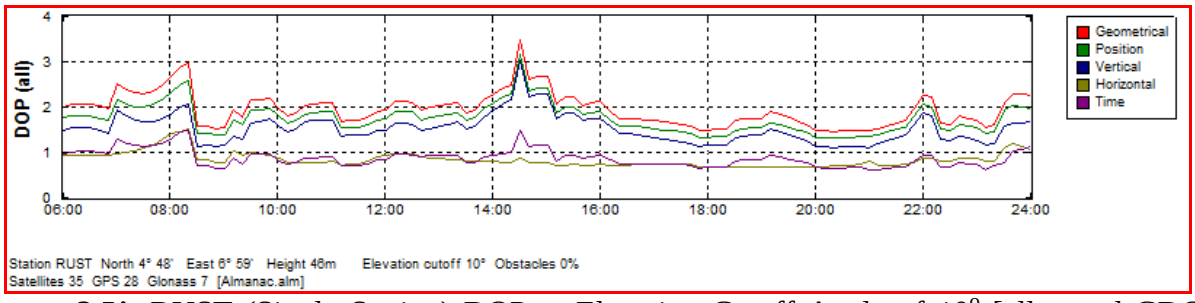


Figure 3.5j: RUST (Single Station) DOP at Elevation Cutoff Angle of 10^{o} [all round GDOP ≤3.0, but GDOP ≤3.2 at 14:40hrs]

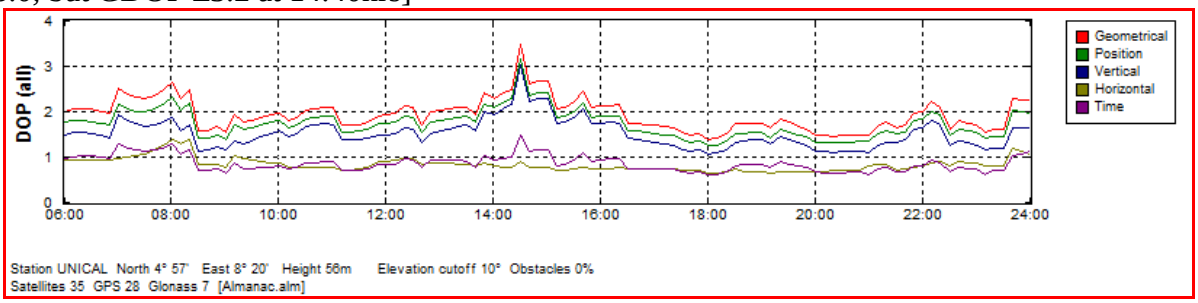


Figure 3.5k: UCAL (Single Station) DOP at Elevation Cutoff Angle of 10^{o} [all round GDOP ≤3.0, but GDOP ≤3.2 at 14:40hrs]

3.2 Discussion of Results

Table 3.1 shows the ionospheric-free, processed and adjusted WGS84 geographical coordinates with their corresponding standard deviations, while Figure 3.1 shows the geospatial locations of the 9 out of the 11 NigNet CORS on the ITRF-based global earth model (subset for Nigeria). These points provided the frame work for baseline and spatial analysis in relation to the NASRDA Satellite ground stations in Abuja, Nigeria.

The sky visibility planning with the multistation analysis showed that, more satellites are available at the elevation cutoff angle of 10^{o} than those of 12^{o} and 15^{o} respectively. Similarly, the single station sky visibility planning for GEMB station as a test case also showed that, wider view of the sky is possible at elevation cutoff angle of 10^{o} at the station than for higher elevation cutoff angle of 15^{o}. Therefore, if a ground receiving antenna is to be established at Gembu, in Taraba State, it therefore implies that, longer session of satellite signal and telemetry tracking would be possible and enhanced at elevation cutoff angle of 10^{o}, and with 0% obstruction, compared to elevation cutoff angle of 15^{o}. The only potential drawback with low elevation cutoff angle may be the atmospheric refraction effect. From the sky visibility analysis, average of 9 GPS and 2 GLONASS satellites are visible daily to receivers at 10^{o}-15^{o} elevation angles between 6:00hrs and 24:00hrs across Nigeria. The advantage of the skyplots and visibility chart is that, in the actual satellite data tracking, information on possible percentage obstructions becomes useful. If the data quality is poor (usually indicated by the signal-to-noise ratio during operations), the possible source(s) of interference can be identified and appropriate actions taken to assist subsequent data processing.

From figures 3.4a-c, the multistation DOPs analysis for elevation cutoff angle of 10^{o}, recorded excellent results ranging from 0-4, while those of 12^{o} recorded similar results, but with slight decline between the hours of 8:00am and 10:00 am. For elevation cutoff angle of 15^{o}, the DOP

values declined to between 4-9 for the time period of 8:00am to 10:00am, and 14:00hrs to16:00hrs, while other hours of the days recorded DOP values ≤.3.0. On a general note, the interpretations of the multistation of the DOP values indicated ideal to fair values. DOP is a measure of satellite fix geometry quality, which is a product of signal travel time, overhead satellite geometry and the ranged positions (horizontal and vertical).

The individual station DOP analysis showed that, GEMB in Gembu, Taraba State on ellipsoidal height of 1795.7857m has the best DOP values of ≤2.8, followed by both CGGT in Toro, Bauchi State on ellipsoidal height of 916.7853, and RAMPOLY, Maiduguri, Borno State on ellipsoidal height of about 702m with DOP values ≤2.9 respectively. ABUZ in Zaria, Kaduna state and FUTY in Yola, Adamawa State, located on ellipsoidal heights of 705.4601m and 247.6116m respectively recorded DOP values of ≤3.0. ABUJA-1 in Abuja, RUST in PortHarcourt, ULAG in Lagos, UNEC in Enugu, UCAL in Calabar and BKFP in Birnin Kebbi showed DOP values of ≤3.0 at all times, excluding hours of 10:00am and 14:00-16:00hrs with values ranging between 3.2 and 5.0.

For Earth observation satellite system, the quality of satellite signal or telemetry at a the ground receiving station may be significantly compromised by *permanent scene cloud cover, interferences from spectrum and signal propagation* activities near or around the site, which sometimes results in broken images and creation of artifacts. Therefore, the establishment of ground station based on excellent sky visibility and DOP will favour high telemetry signal reception and quality data access in Nigeria. In the case of ground stations in other countries of the world, bilateral agreements or scientific collaborations between the affected countries and Nigeria are necessary conditions, in addition to the geospatial and infrastructural criteria.

3.3 Summary of Findings

The key findings from the study include:

1. Based on Jon's rating of DOP values [1= ideal; 2-3 = excellent; 4-6 =good; 7-8= moderate; 9-20=fair; 21-50= poor (http://www.developerfusion.com)], the DOP values for the stations across Nigeria can be adjudged to range between excellent and good for satellite ground receiving stations;
2. The DOP and sky visibility for satellite observations at elevation cutoff angles of 10^o are better than those of 12^o and 15^o respectively;
3. GEMB on ellipsoidal heights of 1795.7857m has the most suitable DOPs and sky visibility chart for ground receiving sites; followed by CGG Toro (916.7853m) and RAMPOLY Maiduguri (702m). This is a strong indication that, ellipsoidal heights and geographical locations are key factors in achieving excellent DOP and sky visibility for very good satellite observations
4. From the sky visibility analysis, average of 9 GPS and 2 GLONASS satellites are visible daily to receivers at 10^o-15^o elevation angles between 6:00hrs and 24:00hrs across Nigeria;

4.0 CONCLUSION

In this study, satellite observation planning technique was used to generate multiple and single stations sky visibility and dilution of precison analysis as vital criteria and preliminary decision support for satellite ground station site selection in Nigeria. The key datasets and materials used

include the geographical coordiates, ground elevation, local mean time, elevation cutoff angles, GPS and GLONASS constellations for a period of one month. The technique therefore, produced excellent results, which were used to rank and select most suitable locations for ground receiving antenna in Nigeria, in addition to the existing one at the National Space Research and Development Agency (NASRDA) in Abuja.

However, it should be noted that, this approach of sky visibility and DOP analysis does not provide the final criteria for ground receiving antenna selection; hence other key factors such as the site's geology and structural stability, antenna diameter, power and communication facilities, security, Internet and data access, weather and climate varaiablilty, etc, must be considered in an integrated manner. In case of international ground stations, bilateral agreements and scientific collaborations between the affected countries and Nigeria are additional requirements.

4.1 Recommendations

The following are hereby recommended:

i. In order to avoid signal obstruction and interferences at GRS in Nigeria, the stations should be located on elevated ground outside city centres and regions free of telecommunication masts and tall building structures and towers;
ii. Elevation cutoff angle of 10^{o} from the horizon should be implemented in ground receiving station selection in Nigeria.
iii. This approach should be adopted for the Nigerian space programme in EOS ground-based antennae farm establishment, and for the densification of GNSS reference stations by public-private organizations involved in geoinformation development, geodetic and atmospheric research, engineering infrastructure tracking and navigation at state and local government levels across the country.
iv. Before selecting an acceptable site and to be fixed with certainty for satellite tracking or ground station, several stations of interest should be sampled, as there may be many candidate locations with similar geospatial characteristics suitable for the desired station.
v. Other key factors such as the ground stability, security, power and communication infrastructure in the phases of ground station site analysis and selection must not be compromised.

Acknowledgements

We appreciate the Office of the Surveyor General of the Federation (OSGoF) for the implementation of the CORS infrastructure for Nigeria, and freely providing the RINEX data of the existing CORS on the NigNet website (http://www.nignet.net). Thanks to the International GNSS Service (IGS) for providing the orbit/navigation data used for the post processing of the CORS data. The authors wish to acknowledge NASRDA, Abuja for the Ground Station Infrastructure for NigeriaSat-2/X.

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