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ANALYSIS OF GPS SATELLITE OBSERVABILITY OVER THE INDIAN SOUTHERN REGION

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ABSTRACT

Global Positioning System (GPS) is a satellite based navigation system that provides instantaneous 3D PVT (position, velocity and time) in the common reference system anywhere on or above the earth surface. The position of the GPS receiver is calculated from the satellite orbit positions and the distance between the satellites and the receiver. GPS is implemented on the principle of trilateration - the method of determining position by measuring distances to known coordinates i.e. satellite position and the unknown coordinate i.e. receiver position. The satellite orbit coordinates and pseudo range information of at least four satellites are necessary to compute the receiver position. The GPS receiver position estimation is dependent on the visibility of satellites and the accuracy of the information the signals provide. The accuracy of the estimated receiver position depends on the information acquired from the GPS signals. The satellites at higher elevation are known to provide signals with lesser noise. At any instant of time, four or more satellites may be visible to the user. The receiver may be able to choose satellites that give more accurate signals by knowing the elevation angle. In this paper, the elevation angle and azimuth angle of all the satellites visible during 24 hours duration are computed and visibility is analysed.

KEYWORDS: GPS, Satellite Position, Elevation, Azimuth

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INTRODUCTION

The Global Navigation Satellite System (GNSS) consists of more than 24 satellites. The minimum number of satellites for a full constellation is 24, operational 95% of the time. The orbital patterns and spacing of the satellites is such that they are distributed among six orbital planes. This design enables the visibility of at least four satellites anywhere-anytime from the Earth's surface. Global Positioning System (GPS) uses satellites and receivers to determine positions anywhere on Earth throughout the day. GPS is implemented on the principle of trilateration [1] - the method of determining position by measuring distances to known coordinates. The GPS receiver computes position from satellite orbit positions and the distance between the satellite and the receiver. This distance is called pseudo range. The information about the orbital parameters is obtained from the GPS signals. The GPS signals are driven by atomic clocks, usually Cesium which has long term stability. The fundamental frequency of the signals is 10.32 MHz. Information is encoded on two carrier signals,

L1 and L2 of frequencies 1572.42 MHz and 1227.60 MHz respectively. The carrier signal has three types of codes – Coarse Acquisition (C/A) Code, Precise (P) Code and navigation message. The GPS receiver position estimation is dependent on the visibility of satellites and the accuracy of the information the signals provide.

To provide the best navigation accuracy[2], the constellation needs to have good geometric properties, which entails a dispersion of satellites in both azimuth and elevation angle from a user.

In this paper, the satellite visibility over the Indian southern region is analysed. The elevation angle and azimuth angle of all the satellites visible in the 24 hours duration are computed. The visibility is estimated and analysed for ephemeris data collected on 23 January 2014 at IISC, Bangalore (13.0219° N, 77.5671° E).

ANALYSIS OF SATELLITE VISIBILITY

Satellite visibility is the ability of a receiver to acquire and receive a signal from a satellite. The GPS receiver position estimation is dependent on the visibility of satellites as information from at least four satellites are required to compute the receiver position[3]. If there are more than four visible satellites, the receiver may be able to select the ones that provide more accurate information or it may be able to use more than four GPS signals. The satellite visibility is lost as the satellite moves over the horizon and new satellites become visible as they come over the horizon.

The information regarding the range between the satellite and receiver can be obtained from the GPS signals and is termed pseudo range as it is not equal to the true range between the satellite and the receiver. This is due errors like clock offset, ionosphere delay, multipath error etc[4]. The ionosphere delay and the multipath error can be modelled but the clock offset has to be estimated. The satellite orbital parameters are obtained from the GPS signals. The receiver position and clock offset can be estimated from the pseudo range equation[5] given by (1).

$$P=\sqrt{(x_s-x)^2+(y_s-y)^2+(z_s-z)^2}+c\tau \qquad (1)$$

Where P = observed pseudo range (metres); x_s = X coordinate of the satellite (metres); y_s = Y coordinate of the satellite (metres); z_s = Z coordinate of the satellite (metres); x = X coordinate of the receiver (metres); y = Y coordinate of the receiver, (metres); z = Z coordinate of the receiver (metres); c = 299792458 (metres/sec); τ = clock offset (seconds). The accuracy of the receiver position estimated depends on the accuracy of the information provided by the GPS signals. The information provided by signals obtained from satellites at higher elevation are known to be more accurate with lesser noise.

- **Elevation Angle and Azimuth Angle of Satellites**

The elevation angle is the counterclockwise angle between the horizontal and the line of sight between the receiver antenna and a satellite. The azimuth angle is the clockwise angle between true North and the line of sight between the receiver antenna and a satellite. Azimuth and elevation are angles used to define the apparent position of satellite, relative to a specific observation point.

Signal-to-noise ratio (SNR) is a measure of satellite's signal strength. When SNR is low, the accuracy of computed receiver position is degraded. Signals from satellites at low elevation angle is one of the causes of low SNR. When tracking satellites low on the horizon, there is an increased chance of encountering atmospheric error and multipath effects as well. To minimize this problem, elevation mask can be used. Elevation mask restricts the receiver to use only those satellites which are above a certain elevation in the sky.

The E arth Centered Earth Fixed (ECEF) coordinate system is a 3D geocentric coordinate system i.e., its origin coincides with the center of the earth. The coordinates of a point in ECEF coordinate frame can be transformed to a local coordinate frame defined at user position, called East North Up system (ENU)[6]. The coordinates of ENU are oriented in such a way that the axis 1 points east, axis 2 points north, and the axis 3 points upward. If the user's ECEF XYZ coordinates are represented as coordinates of a vector x_0, the geodetic coordinates are (ϕ, λ, h), and the satellite position in ECEF as x_s then the user-to-satellite vector in ECEF is $(x_s - x_0)$. To represent the satellite position in the ENU coordinate system, the vector $(x_s - x_0)$ has to be represented in the ENU coordinate system and the azimuth and elevation angles of the satellite are to be determined.

In order to determine the transformation from ECEF to ENU coordinate system, the rotations of the ECEF coordinate axes that would bring them to coincidence with the axes of ENU are to be determined. The first rotation is about z-axis by an angle $(\lambda+90^o)$. The second rotation is about the x-axis (which is now parallel to the east-axis after first rotation) by an angle $(90^o - \phi)$. The corresponding transformation of the position vector, $(x_s - x_o)$ from ECEF to ENU is obtained from the elementary rotation matrices as follows:

$$R_L = \begin{bmatrix} -\sin\lambda & \cos\lambda & 0 \\ -\sin\phi\cos\lambda & -\sin\phi\sin\lambda & \cos\phi \\ \cos\phi\cos\lambda & \cos\phi\sin\lambda & \sin\phi \end{bmatrix} \tag{2}$$

Let $x_L = (x_E, x_N, x_U)$ be the representation of $(x_s - x_o)$ in ENU, then

$$x_L = R_L (x_s - x_o) \tag{3}$$

The transformation matrix R_L is orthogonal. Representing unit vectors along the east, north and up-axes as *e, n, u* respectively,

$$e = \begin{bmatrix} -\sin\lambda \\ \cos\lambda \\ 0 \end{bmatrix};\; n = \begin{bmatrix} -\sin\phi\cos\lambda \\ -\sin\phi\sin\lambda \\ \cos\phi \end{bmatrix};\; u = \begin{bmatrix} \cos\phi\cos\lambda \\ \cos\phi\sin\lambda \\ \sin\phi \end{bmatrix} \tag{4}$$

The azimuth angle (α) and zenith angle (ξ) of the satellite defined in the ENU co-ordinate frame are obtained. The azimuth is measured from the north (0^0 to 360^0), and is clockwise. The zenith angle is measured from the local vertical (0^0 to 90^0). The elevation angle from the local horizontal (positive up) is defined as $(90^0 - \xi)$.

$$\tan\alpha = \frac{x_E}{x_N} \tag{5}$$

$$\cos\xi = \frac{x_U}{\sqrt{x_E^2 + x_N^2 + x_U^2}} \tag{6}$$

Hence, alternatively, elevation angle is given by (7),

$$\xi = \arctan\left(\frac{x_U}{\sqrt{x_E^2 + x_N^2}}\right) \tag{7}$$

RESULTS AND DISCUSSIONS

The elevation angles and azimuth angles of the visible satellites are computed for 24 hours duration and the analysis of visibility of the satellites, supported by relevant graphs and tables is presented in this paper. The elevation and azimuth angles are estimated using the data collected by the receiver from 00:00 hours to 23:59 hours with an epoch interval of 30 seconds. Though the elevation and azimuth angles were computed for all the visible satellites, data from only nine satellites (02, 05, 12, 15, 18, 21, 25, 26, 29), at 02:00 hours, is presented here. The visibility analysis of the same nine satellites for 24 hours duration is also presented in this paper. The broadcast ephemerides were collected on 23 January 2014 from the receiver located at IISC Bangalore (13.0219° N, 77.5671° E).

Table 1 details the elevation angle and azimuth angle of nine satellites (02, 05, 12, 15, 18, 21, 25, 26, 29) at 02:00 hours. When the signal was acquired by the receiver first, at 02:00 hours, nine satellites were visible, among which satellite vehicle 12 was observed at the highest elevation, 58.38692^o with azimuth angle, 210.51026^o whereas, satellite vehicle 21 was observed at the lowest elevation, 14.53675^o with azimuth angle, 285.42112^o. Figure. 1 shows the duration of visibility and elevation angle of the nine satellites. Figure. 2 – Figure 10 shows the elevation angle and duration of visibility of the nine satellites individually.

Table 1: Elevation Angle and Azimuth angle of 9 Satellites

Satellite Vehicle No.	UTC (Hh: Mm: Ss)	Elevation Angle (Degree)	Azimuth Angle (Degree)	Pseudo range (Metre)
18	02:00:00	18.933	225.636	23738343.432397
5	02:00:00	48.548	26.755	21367455.503385
29	02:00:00	30.717	336.841	22777509.471087
25	02:00:00	49.619	282.170	21424663.024107
21	02:00:00	14.536	285.421	24687080.504563
12	02:00:00	58.386	210.510	21040216.861689
15	02:00:00	34.725	160.944	22289512.992227
2	02:00:00	22.950	43.372	23464071.935953
26	02:00:00	33.166	115.433	22431522.079659

Table 2 details the elevation angle, the time of appearance and disappearance, and duration of visibility of nine satellites *(02, 05, 12, 15, 18, 21, 25, 26, 29)*, for 24 hours duration. Figure 11 shows the polar plot or visibility diagram of the nine satellites over 24 hours duration. Out of the nine satellites, satellite vehicles 18, 29, 25, 21, 12 and 15 were visible continuously for different durations whereas satellite vehicles 02, 05 and 26 disappeared and reappeared after 10 hours, 10 hours and 8 hours respectively. Satellite vehicle 18 was observed to be continuously visible for the longest duration i.e. 8 hours and 10 minutes, with elevation angle ranging from 11.99468^o to 18.93374^o, as shown in Figure 6. Satellite vehicle 12 was continuously visible but for a short duration of 2 hours and 9 minutes, with elevation angle ranging from 58.38692^o to 9.17833^o, as depicted in Figure. 4. Satellite vehicle 26 was first visible at 02:00 hours and later disappeared at 04:29 hours, then it reappeared from 20:00 hours to 22:34 hours but the signal was not available from 21:59 hours to 22:17:30 hours, which can be observed from Figure. 9. Similarly, the discontinuity in visibility of satellite vehicles 02 and 05 is shown in Figure. 2 and Figure 3. The satellite vehicles 29, 25, 21, and 15 were visible continuously, as can be observed from Figure 10 Figure 8 Figure 7 and Figure 5 respectively

Table 2: Satellite Visibility Time and Duration

Satellite Vehicle No.	Appearance		Disappearance		Duration Of Visibility (Hh:Mm:Ss)
	Elevation Angle (Degree)	*UTC Time (Hh:Mm:Ss)*	*Elevation Angle (Degree)*	*UTC Time (Hh:Mm:Ss)*	
18	11.994	02:00:00	18.933	10:10:00	08:10:00
29	30.717	02:00:00	8.1835	07:01:30	05:01:30
25	49.619	02:00:00	10.810	05:09:00	03:09:00
21	14.536	02:00:00	12.482	09:05:30	07:05:30
12	58.386	02:00:00	9.178	04:09:00	02:09:00
15	34.725	02:00:00	12.006	06:06:30	04:06:30
2	22.950	02:00:00	16.018	02:51:30	00:51:30
2	60.611	22:00:00	48.618	23:59:30	01:59:30
26	33.166	02:00:00	14.328	04:29:00	02:29:00
26	30.664	20:00:00	11.798	21:59:00	01:59:00
26	9.690	22:17:30	8.355	22:34:00	00:17:30
5	48.548	02:00:00	14.988	03:24:00	01:24:00

Table 2: Contd.,					
5	15.091	22:00:00	66.251	23:59:30	01:59:30

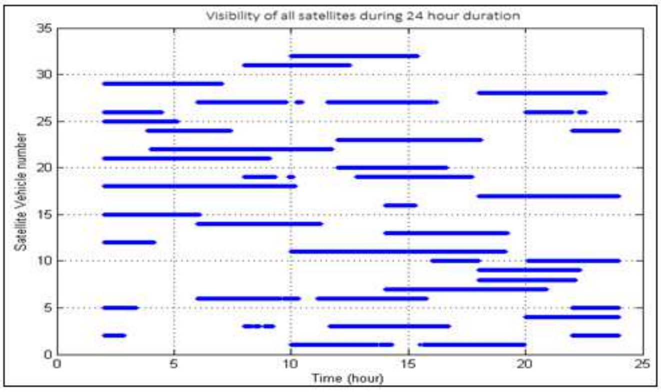

Figure 1: Visibility of all Satellites for 24 Hours Duration

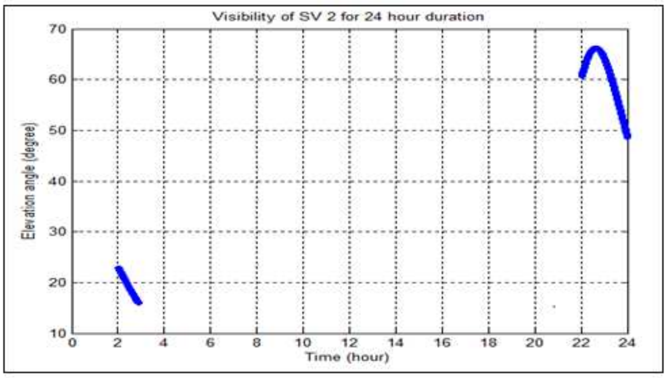

Figure 2: Visibility of Satellite Vehicle 02 for 24 Hours Duration

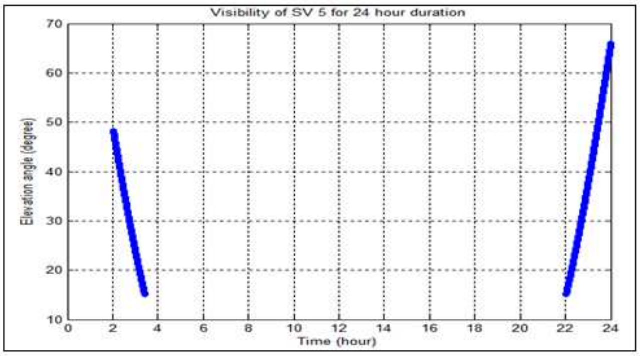

Figure 3: Visibility of Satellite Vehicle 05 for 24 Hours Duration

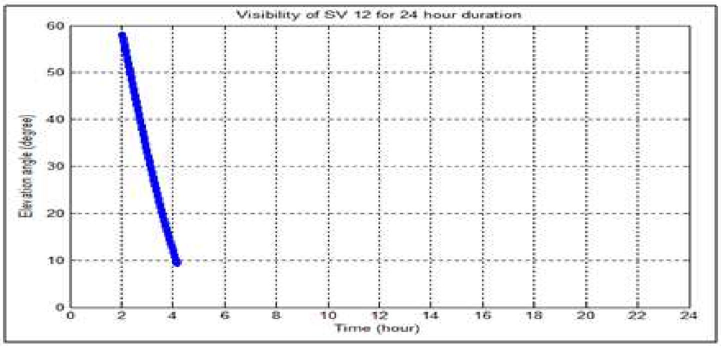

Figure 4: Visibility of Satellite Vehicle 12 for 24 Hours Duration

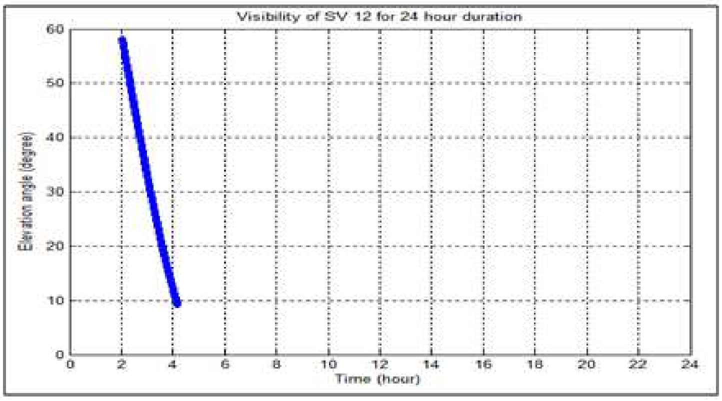

Figure 5: Visibility of Satellite Vehicle 15 for 24 Hours Duration

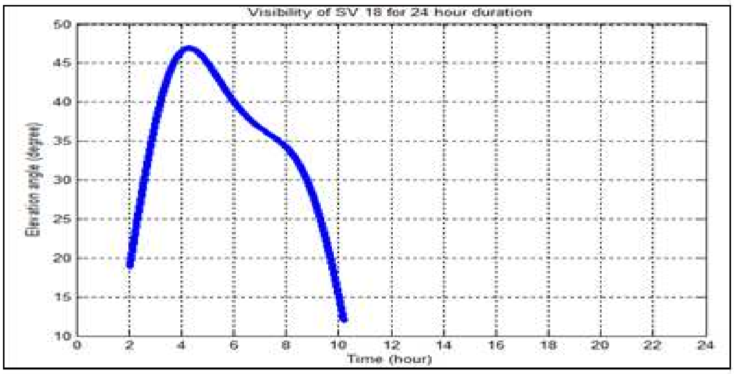

Figure 6: Visibility of Satellite Vehicle 18 for 24 Hours Duration

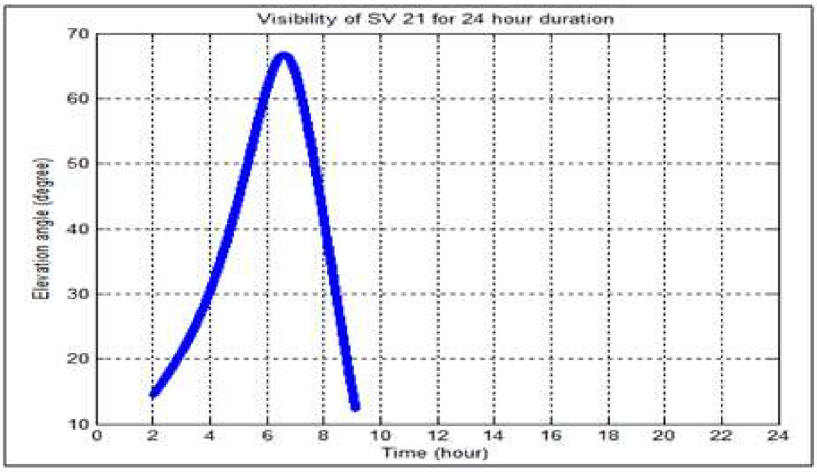

Figure 7: Visibility of Satellite Vehicle 21 for 24 Hours Duration

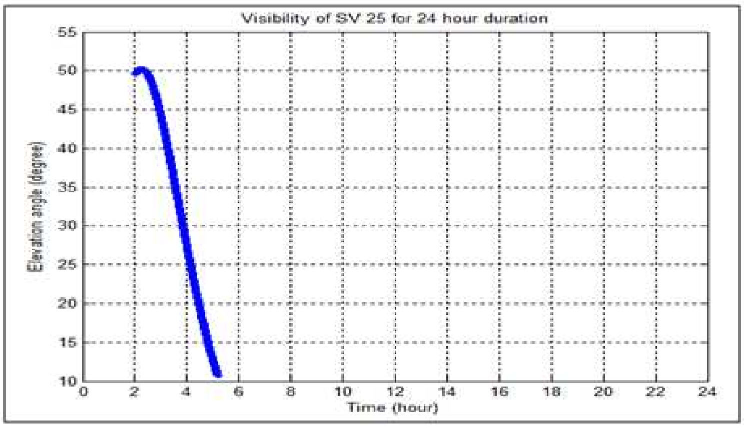

Figure 8: Visibility of Satellite Vehicle 25 for 24 Hours Duration

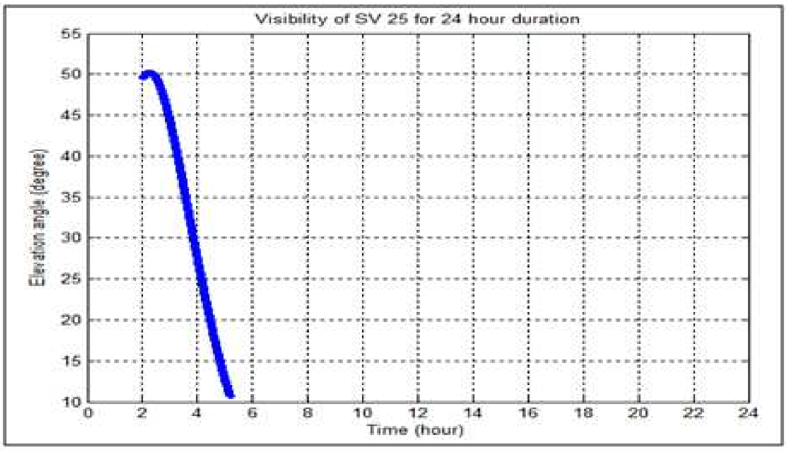

Figure 9: Visibility of Satellite Vehicle 26 for 24 Hours Duration

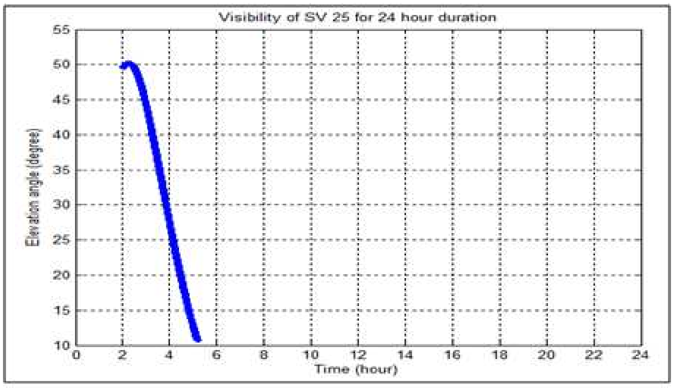

Figure 10: Visibility of Satellite Vehicle 29 for 24 Hours Duration

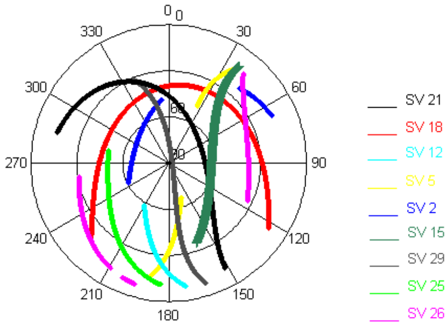

Figure 11: Polar Plot of Azimuth Angle Vs Elevation Angle of Nine Satellites

CONCLUSIONS

From the results, it is observed that at any given epoch, more than four satellites are visible and it is found that few of the satellites are tracked continuously for the entire observation period whereas other satellites' visibility is discontinuous. It is also observed that some of the satellites are visible at high elevation angle. Since the signal transmitted from the satellites at high elevation angle propagate through the shortest path, they undergo the least delay, providing better accuracy in the estimation of receiver position. Hence the visibility analysis presented in this paper will be useful in selecting the satellites with higher elevation and least propagation path delay.

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