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A NOVEL GPS MULTIPATH ERROR ESTIMATION TECHNIQUE FOR URBAN CIVIL SURVEYING

N Swathi[1], V B S Srilatha Indira Dutt[1] and G Sasibhushana Rao[2]
[1]Department of Electrical and Computer Engineering, Gharda Institute of Technology, GITAM (Deemed to be University), Visakhapatnam, India
[2]Department of Electrical and Computer Engineering, Andhra University College of Engineering (A), Visakhapatnam, India
E-Mail: nadipineniswathi@gmail.com

ABSTRACT

The awareness of orientation of multipath is critical for site selection or for antenna accumulation, particularly in the applications like precise monitoring of earthquake movement and tsunami detection. This paper presents the analysis of the multipath error estimated on the L1 frequency (1575.42MHz) of all the GPS satellites that are visible from the Andhra University College of Engineering, Visakhapatnam. This analysis is useful in determining the location of the obstructions in the path between satellites and receiver. From this analysis the location of the satellite which is affected more by the multipath can also be determined. The analysis is done using the TEQC toolkit and the CF2SKY toolboxes [1, 2]. The analysis made in this paper is also useful in determining which location of the receiver antenna has more multipath and at which location it is less and thereby the antenna can be mounted at less multipath location.

Keywords: CF2SKY, GPS, TEQC.

1. INTRODUCTION

Multipath disturbance is largely dependent on the receiver environment since satellite signals can arrive at the receiver via multiple paths, due to reflections from nearby objects such as trees, buildings, vehicles, etc. Although the multipath effect can be reduced by choosing sites without multipath reflectors or by using choke-ring antennas to mitigate the reflected signal, but it is difficult to eliminate all multipath effects from GPS observations. Since, the reception of multipath can create a significant distortion to the shape of the correlation function leading to an error in the receiver position estimate, Multipath is undesirable.

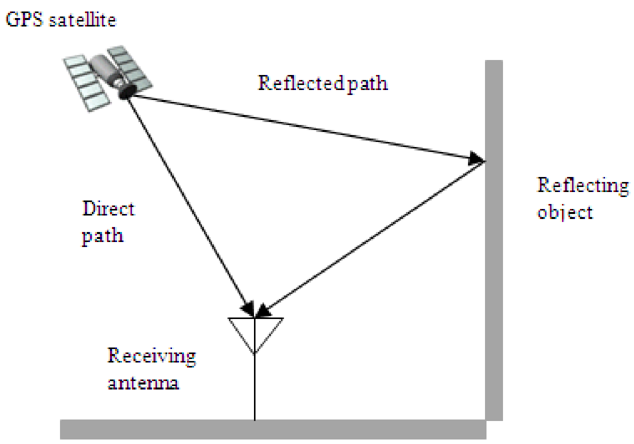

Figure-1. Multipath environment.

The GPS system provides two ranging measurements namely code range measurements and carrier phase measurements to provide the positioning information [5].

The code range observable on L1 frequency (1575.42MHz) is expressed as Equation 1.

$$\rho_1 = P + c(dt - dT) + d_{ion} + d_{tro} + MP_{\rho L1} + \varepsilon_{\rho L1} \quad (1)$$

The carrier phase observable on L1 frequency is expressed as Equation. 2

$$\phi_1 = P + c(dt - dT) - \lambda_1 N_1 - d_{ion} + d_{tro} + MP_{\phi L1} + \varepsilon_{\phi L1} \quad (2)$$

Where ρ_1 is measured pseudo range, ϕ_1 is carrier phase, P is geometric range, c is velocity of light, dt is receiver clock error, dT is satellite clock error, d_{ion} is ionospheric error, d_{tro} is tropospheric error, $MP_{\rho L1}$, $\varepsilon_{\rho L1}$ and $\lambda_1 N_1$ are multipath error(meters), measurement noise(meters) and integer ambiguity respectively on L1 frequency. Carrier phase measurements are represented with subscript ϕ, of which $MP_{\phi L1}$ and $\varepsilon_{\phi L1}$ are assumed to be small and negligible.

Except ionospheric refraction and multipath error all the other errors are independent of frequency and influences code and carrier phases by the same amount. By using a dual frequency GPS receiver code ranges and carrier phases are extracted and corresponding differences called Code Carrier Difference (CCD) is performed, which results in cancellation of all effects except multipath and measurement noise. Hence the CCD on L1 frequency is represented by Equation. 3.

$$CCD = \rho_1 - \phi_1 + K1 \cong 2d_{ion} + MP_{\rho L1} + \varepsilon_{\rho L1} \quad (3)$$

The multipath and measurement noise on L1 carrier frequency is given as,

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$$MP_{\rho L1} + \varepsilon_{\rho L1} \cong \rho_1 - \phi_1 - 2d_{ion} + K1 \quad (4)$$

The constant K1 is due to the integer ambiguity. The ionospheric delay on L1 frequency by using dual frequency receiver data can be estimated as

$$d_{ion} = \frac{f_{L2}^2}{f_{L1}^2 - f_{L2}^2}(\phi_{L1} - \phi_{L2}) \quad (5)$$

By substituting d_{ion} in Equation 4, code multipath error (including measurement noise) on L1, MP_{L1} is given as:

$$MP_{L1} = \rho_{L1} - \frac{f_{L1}^2 + f_{L2}^2}{f_{L1}^2 - f_{L2}^2}(\phi_{L1}) + \frac{2f_{L2}^2}{f_{L1}^2 - f_{L2}^2}(\phi_{L2}) + K1 \quad (6)$$

Similarly, the code multipath error (including measurement noise) on L2 can be given as:

$$MP_{L2} = \rho_{L2} + \frac{f_{L1}^2 + f_{L2}^2}{f_{L1}^2 - f_{L2}^2}(\phi_{L2}) - \frac{2f_{L1}^2}{f_{L1}^2 - f_{L2}^2}(\phi_{L1}) + K2 \quad (7)$$

By using above equations, for all the samples of dual frequency GPS data the multipath error on L1 (1575.42MHz) and L2 (1227.60MHz) frequencies can be estimated. K1 and K2 are functions of unknown integer ambiguities and measurement noise, which can be assumed constant if there is no cycle slip in the carrier phase data [6].

The CF2SKY is a new issue in the GPS toolbox, which is an extended version of the earlier program. This program Takes the TEQC plot files (.mp1 or .mp2) as inputs and produces a skyplot file, which consists of positive and negative values of multipath plotted with respect to the corresponding satellites azimuth and elevation angle. TEQC stands for Translation, Editing, and Quality Check. TEQC toolkit [3] is used in analyzing the multipath error on the pseudorange observed due to the code and phase on each satellite. The analysis is useful to indicate the real local direction of multipath on the ground and also gives the orientation with respect to the geometry of the satellites in the sky. This information can aid the interpretation of ground multipath geometry at the site.

2. GENERATING SKYPLOTS USING CF2SKY

The CF2SKY program execution requires four *.cpp files: skyplot.cpp, datetime.cpp, rinex.cpp, intrpsp3.cpp, five *.h files: consts.h, physcon.h, datetime.h, rinex.h, intrpsp3.h, and three input files: a RINEX OBS file, a RINEX NAV file, a pseudorange multipath plot file (.mp1 or .mp2). The RINEX files are obtained from the data collected by the GPS receiver. The plot file is obtained from the TEQC toolkit. A detailed description of the toolkit is accessible from the Web page http://www.facility.unavco.org/software/teqc/teqc.html.

The TEQC requires two input files namely RINEX OBS file and RINEX NAV file. The TEQC is executed by giving specialized commands in the command prompt. The procedure to get TEQC report files is as follows:

a) A new OBS file consists of only L1, L2, C1 and P2 parameters is obtained from the input OBS file by giving the command: teqc -O.dec 30 -O.obs L1L2C1P2 AUCE19Feb.10o >AUCE19Feb1.10o.
b) Eight TEQC report files are obtained by giving the command: teqc +qc -nav AUCE19Feb.10n AUCE19Feb1.10o.

The eight report files consists of information about site multipath, receiver signal to noise ratios on L1 and L2, satellite azimuth and elevation angles, ionospheric delay and rate of change of ionospheric delay with .mp1, .mp2, .sn1, .sn2, .ele, .azi, .ion and .iod extensions respectively. The CF2SKY requires either .mp1 or .mp2 file as input file. In addition to these files an input file is to be created which consists of begin and end times for the plot, satellite ephemeris file name (RINEX navigation file), title of the plot, elevation angle cut-off, name of the RINEX observation file and name of the TEQC plot file respectively.

Execution of CF2SKY.exe generates some output files i.e., one ASCII file for every satellite in the plot file (Ex: 1.sat.xy, 2.sat.xy.... etc), a DOS batch file called skyplot.bat and a summary file called cf2sky.log. Each sat.xy file contains the x and y-coordinates data from the centre of the polar plot. A new file called skyplot.ps file is obtained with the execution of the skyplot.bat file. This .ps file consists of the skyplot in which both positive and negative values of the pseudorange multipath error are plotted90^0 to their matching satellite track with positive values plotted up and negative values plotted down.

The CF2SKY first creates the elevation angle rings at 0, 30 and 60^0 and also an elevation cut-off ring as a dashed line at 5^0 with shaded portion between 0 and 5^0 rings. It next creates the three line title at the top centre of the plot. Next pseudorange multipath values are plotted using bars. Next, satellite tracks are plotted in dark color. Next, a centre cross is created at approximate position of the GPS receiver with labels N, S, E and W at four ends above the elevation rings. Next, the azimuth angle labels are created at 45, 135, 225 and 315^0. Next, the scale of the bar for pseudorange multipath is created at the lower right end for 1, 5 and 10m. Next, the arrows and corresponding satellite numbers are created at the end of every satellite track. Lastly the elevation angle boxed labels are created. The height of the satellite tracks are also indicated in the skyplot.

To begin with CF2SKY to create sky plots, first windows versions of GMT, TEQC and Ghost script/GS view software's must be properly installed in the computer in the C: Program files directory.

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3. MATLAB IMPLEMENTATION

In this section MATLAB programs are implemented (TEQCPLOT, TEQCSPEC), which extracts the TEQC report files and produces corresponding plots in MATLAB [4]. The control variables in these programs are time span, frequency band and maximum plot frequency. The TEQCPLOT program extracts only one of the report files at a time in the defined time span and produces time series plot at the frequency band of interest. Whereas TEQCSPEC program takes either .mp1 or .mp2 file as input file and it automatically extracts elevation and azimuth files and produces azimuth, elevation, satellite multipath patterns, polar maps of both unfiltered and filtered multipath plots.

These plots are explained with an example data taken from the GPS receiver located at Andhra University College of Engineering, Visakhapatnam. The data is in RINEX format. Execution of TEQC with the two input files AUCE19Feb.10n, AUCE19Feb.10o generates 8 report files (Ex: AUCE19Feb1.mp1, AUCE19Feb1.sn1...etc). These files are extracted using MATLAB programs and the corresponding output plots are produced.

4. RESULTS AND DISCUSSIONS

The RINEX Format consisting of 2 files (Navigation Message and Observation data) corresponding to a typical day 19th Feb, 2010. The receiver is located at Department of ECE, Andhra University College of Engineering, Visakhapatnam with the surveyed coordinates latitude/Longitude: 17.730231^{o}N/ 83.31956^{o} E, 91.6 m. Using the standard MATLAB programs all visible satellite positions, and their azimuths and elevation angles are computed.

C1 Pseudorange multipath
Lat: 17.7303E Lon: 83.3202E Ell Ht: 1.6(m)
GPS time: Start 2010/02/19 00:00:00
Stop 2010/02/19 02:00:00

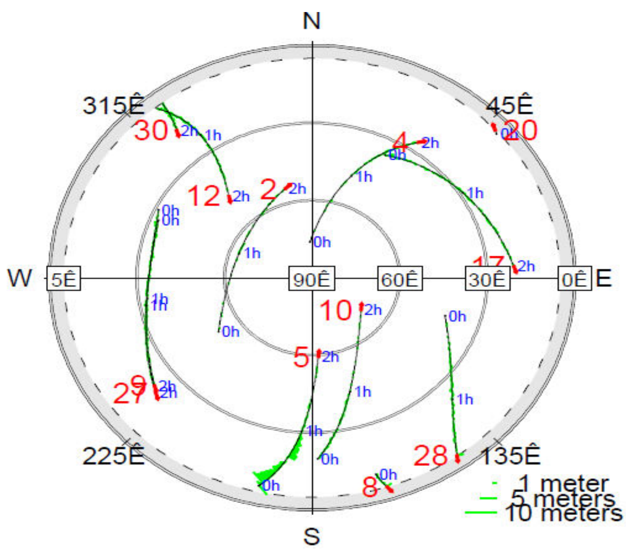

Figure-2. Skyplot.ps file created by program CF2SKY.

All satellite tracks are analyzed with the various azimuth and elevation angles. The GPS satellites that are visible during the 2hour period are Satellite Vehicle Pseudorandom Numbers (SV PRNs) 2, 4, 5, 8, 9, 10, 12, 17, 20, 27, 28 and 30.

Figure-2 shows the skyplot of these 12 SVPRNs. From Figure-2, the size of the multipath values indicates at which azimuths and elevation angles the corresponding satellites are affected by pseudorange multipath. For example SV PRN 5 is affected by multipath (up to 5m) at an elevation of about 60^{0} and azimuth of 200^{0} within the time span of 00:00:00-02:00:00.

Figures 3, 4 and 5 are obtained from the TEQCSPEC program with .mp1 file as input in MATLAB with time span of 00:00:00-02:00:00, frequency band of 0.01-0.02Hz, maximum plot frequency of 0.017Hz and Figures 6 and 7 are obtained from the TEQCPLOT program with the same control variables.

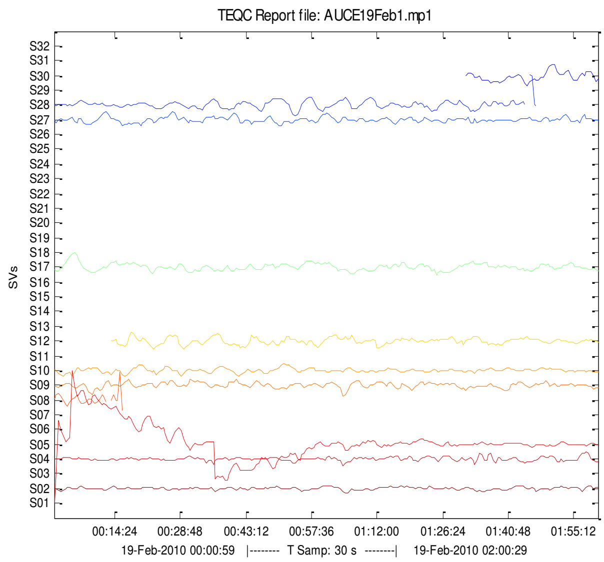

Figure-3. L1 Multipath satellite specific patterns.

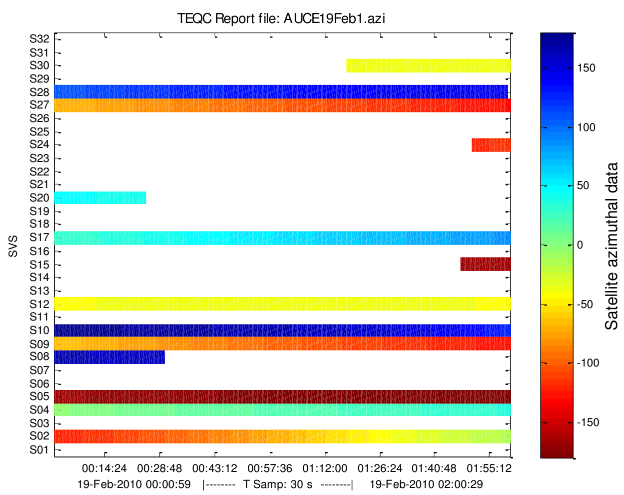

Figure-4(a). Satellite azimuth angle plot. The unit of color bar scale is degrees.

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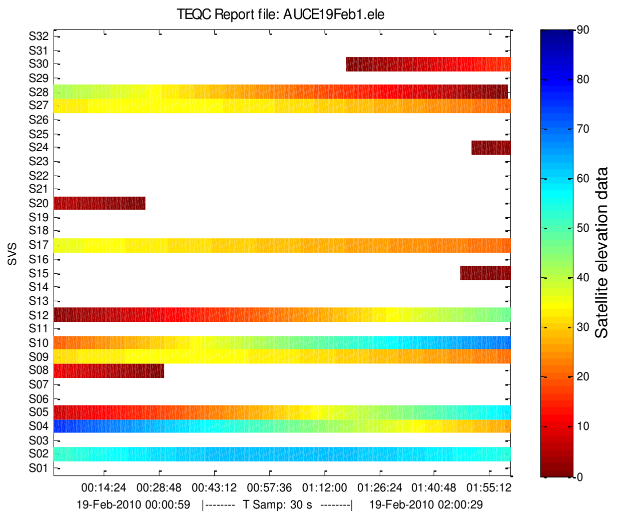

Figure-4(b). Satellite elevation angle plot. The unit of color bar scale is degrees.

Figure-3 is the L1 multipath traces showing the satellite-specific patterns. Figures 4(a) and 4(b) are the color-coded plots of the satellite azimuth and elevation angles that correspond to the multipath traces in Fig. 3. From Fig.4 it can be observed that the satellites have more multipath signals at low elevation angles compared to high elevation angles. Also, satellites S25, S20, and S15 seem in Figure-4, they are absent in Figure-3 because the RINEX observation file "AUCE19Feb.10o" was recorded at an elevation masking angle setting of 5°.

Polar plots of multipath time series before and after filtering is shown in Figure-5(a) and Figure-5(b) for the time span 00:00:59-02:00:29. Figure-5(b) shows that the high-frequency multipath is more when the satellite (satellite number S05) is located at an azimuth of about 200° and low elevation. We can also observe the data gap occurred in the satellite track of S05.

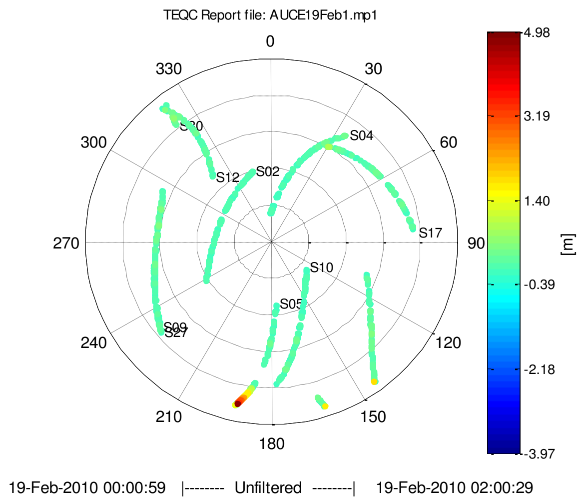

Figure-5(a). Polar map of multipath before filtering in the time span 00:00:59–02:00:29.

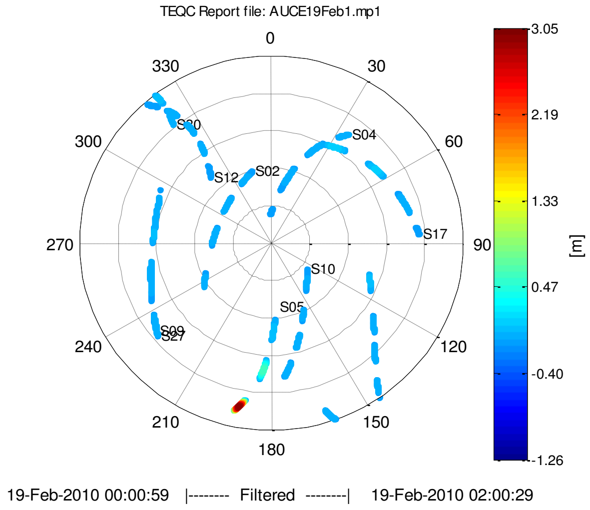

Figure-5(b). Polar map of band pass-filtered multipath in the time span 00:00:59–02:00:29.

From figures 6(a) and 6(b) it should be noted that the multipath values are high (up to 1m) for satellite S05 in the time span of 00:00:00-00:28:48 and are low (up to -1m) for the same satellite S05 in the time span of 00:38:00-00:56:00.

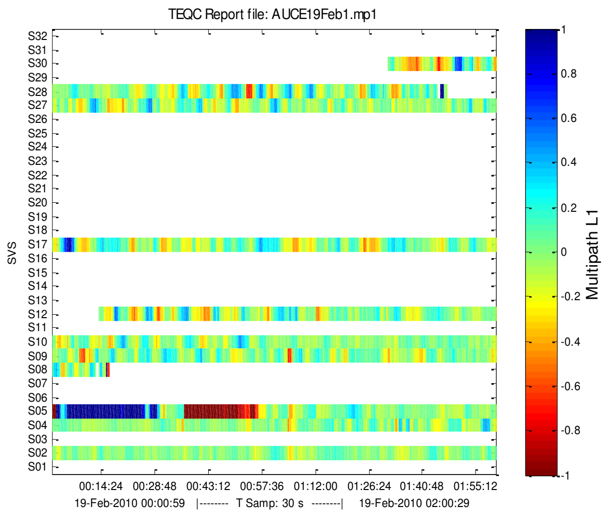

Figure-6(a). L1 pseudorange multipath error in the time span 00:00:59–02:00:29.

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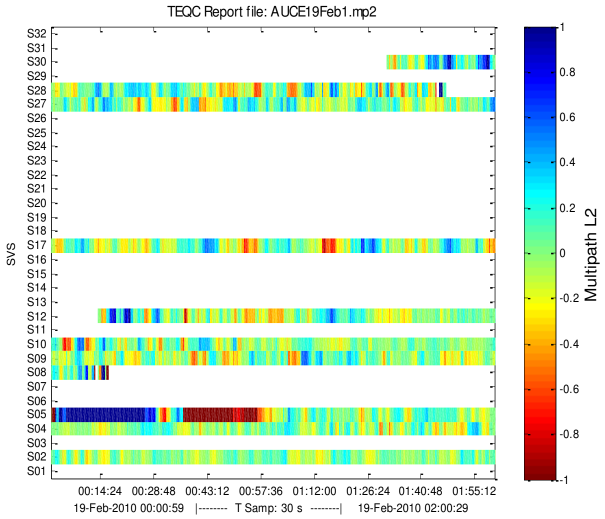

Figure-6(b). L2 pseudorange multipath error in the time span 00:00:59-02:00:29.

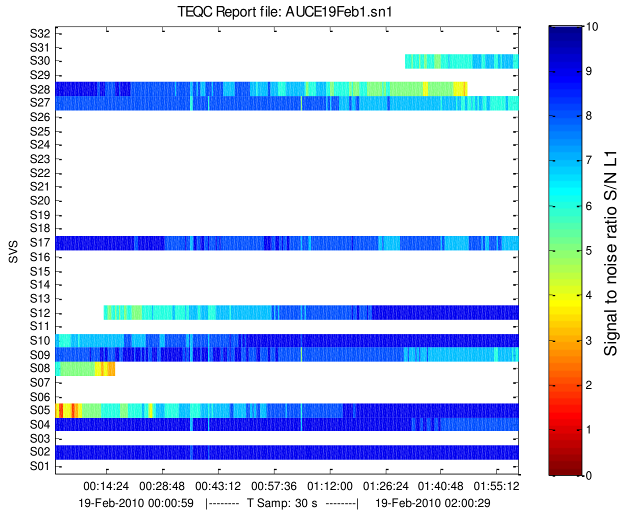

Figure-7(a). L1 Signal to noise ratio in the time span 00:00:59-02:00:29.

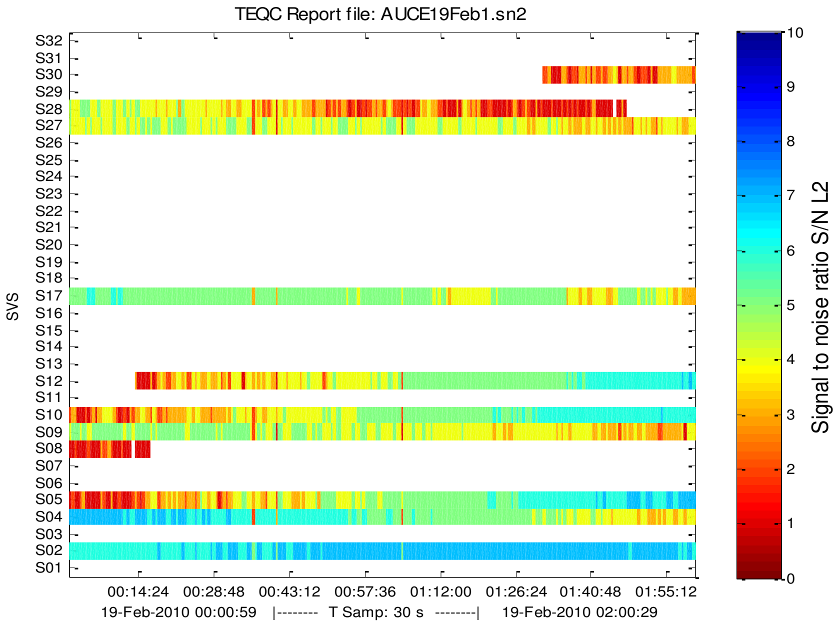

Figure-7(b). L2 Signal to noise ratio in the time span 00:00:59-02:00:29.

From Figure-7(a) it should be noted that the signal to noise ratio values are high for satellite S02 in the time span of 00:00:00-02:00:00 and are low for satellite S05 in the time span of 00:00:00-00:07:00. From Figure-7(b) it should be noted that the signal to noise ratio values are high for satellite S02 in the time span of 00:00:00-02:00:00 and are low for satellite S08 in the time span of 00:00:00-00:15:00.

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Table-1. Observations for SVPRN 05 in the time span of 00:00:00-00:07:00.

SV PRN	Azimuth (degrees)	Elevation (degrees)	S/N on L1	S/N on L2	Multipath on L1(m)	Multipath on L2(m)	Ionospheric delay(m)	Derivative of Ionospheric delay(m/s)
5	-167.190	7.316	3.000	1.000	0.000	0.000	0.000	0.000
5	-167.290	7.479	3.000	1.000	-3.968	-3.925	0.000	0.000
5	-167.389	7.642	4.000	2.000	-2.266	-2.871	0.065	0.130
5	-167.488	7.806	2.000	1.000	1.574	1.247	0.065	0.130
5	-167.587	7.970	2.000	1.000	0.982	0.391	-0.068	-0.266
5	-167.685	8.136	4.000	2.000	0.586	1.331	-0.007	0.121
5	-167.782	8.301	4.000	3.000	0.206	1.654	-0.009	-0.004
5	-167.879	8.467	4.000	1.000	0.262	0.687	0.049	0.117
5	-167.975	8.634	4.000	1.000	0.449	0.577	-0.033	-0.164
5	-168.071	8.802	3.000	1.000	4.984	7.691	-0.033	-0.164
5	-168.167	8.970	2.000	1.000	3.933	6.564	0.006	0.078
5	-168.261	9.138	3.000	1.000	3.294	6.228	0.005	-0.001
5	-168.356	9.307	3.000	1.000	3.356	5.832	0.020	0.029
5	-168.450	9.477	4.000	3.000	3.633	5.176	0.114	0.189
5	-168.543	9.647	4.000	2.000	3.595	4.790	0.116	0.003

Table-2. Observations for SVPRN 17 in the time span of 00:00:00-00:07:00.

SV PRN	Azimuth (degrees)	Elevation (degrees)	S/N on L1	S/N on L2	Multipath on L1(m)	Multipath on L2(m)	Ionospheric delay(m)	Derivative of Ionospheric delay(m/s)
17	27.730	36.318	9.000	5.000	0.000	0.000	0.000	0.000
17	27.980	36.246	9.000	5.000	-0.120	-0.058	-0.006	-0.012
17	28.230	36.175	9.000	5.000	-0.276	-0.123	-0.017	-0.021
17	28.480	36.105	9.000	5.000	-0.301	-0.253	-0.023	-0.013
17	28.729	36.034	9.000	5.000	-0.078	-0.359	-0.026	-0.006
17	28.979	35.964	9.000	5.000	0.127	-0.367	-0.023	0.006
17	29.229	35.895	9.000	5.000	0.288	-0.325	-0.030	-0.014
17	29.479	35.825	9.000	5.000	0.515	-0.251	-0.039	-0.018
17	29.729	35.756	9.000	6.000	0.673	0.061	-0.045	-0.011
17	29.979	35.687	9.000	6.000	0.884	0.216	-0.054	-0.019
17	30.229	35.619	9.000	6.000	0.965	0.154	-0.049	0.011
17	30.479	35.551	9.000	5.000	0.818	0.127	-0.047	0.004
17	30.729	35.483	9.000	5.000	0.538	0.079	-0.050	-0.007
17	30.979	35.415	9.000	5.000	0.260	0.045	-0.044	0.011
17	31.229	35.347	9.000	5.000	-0.067	0.306	-0.053	-0.018

From Table-1, it should be noted that SV5 has maximum multipath value i.e.4.984m on L1, 7.691m on L2 at an elevation of 8.802^0 and azimuth of -168.071^0 and minimum multipath value i.e.0m on both L1 and L2 at an elevation of 7.316^0 and azimuth of -167.190^0 in the time span of 00:00:00-00:07:00.

From Table-2, it should be noted that SV17 has maximum multipath value i.e. 0.965m on L1 at an elevation of 35.619^0 and azimuth of 30.229^0, 0.306m on L2 at an elevation of 35.347^0 and azimuth of 31.229^0 and minimum multipath value i.e.0m on both L1 and L2 at an elevation of 36.318^0 and azimuth of 27.730^0 in the time span of 00:00:00-00:07:00.

5. CONCLUSIONS

In this paper, the multipath errors on each satellite that are visible from the Andhra University College of Engineering are estimated. The maximum multipath error observed on Satellite Pseudo Random Number (SV PRN) 05 on L1 frequency and L2 frequency are 4.984m, 7.691m respectively. These errors are observed during the period 00:00:00Hrs-00:07:00Hrsat an elevation angle of 8.802^0 and azimuth of -168.071^0. The results presented in this paper corresponding to 2Hrs duration only. To find out the exact location and direction of the multipath source, the analysis is to be further carried out on all SV PRNs for a period of 24Hrs duration.

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