Analysis of Multi-Frequency Multi-GNSS Real-Time Signal Observations Acquired by Septentrio PolaRx5 Receiver Station

Dr. K.C.T. Swamy, Dr. N. Ramamurthy, Pasuluri Bindu Swetha, M.Riyaz Pasha

Abstract— Global Navigation Satellite System (GNSS) constellations such as Global Positioning System (USA), GLONASS (Russia), Galileo (European Union), BeiDou (China) transmit radio signals continuously on multiple frequencies for PNT applications on or above the globe. On the other side IRNSS(India) and QZSS (Japan) are the regional navigation systems with limited service area. The combination of multiple constellations with quality signals improves robustness and stability of position,navigation and time measurements. Hence, this research work investigates signal quality to identify strong/ important signals and geometry of the satellites for the combined use of global and regional constellations over the Indian region. Real-time signal observations of multiple GNSS were collected by 'Septentrio PolaRx5' receiver stations installed at GPCET, Kurnool (15^0.47'N, 78^0.04'E). From the results, it is found that the user over this region can receive signals from a minimum of 60 satellites with Position Dilution of Precision (PDOP) value less than unity.

Index Terms— multi-GNSS, DOP, Carrier to noise ratio

I. INTRODUCTION

Satellite based navigation system is a more powerful technique or approach for precise Position, Navigation and Time (PNT) estimation. At present two systems, namely Global Positioning System (GPS) of USA and GLObal NAvigation Satellite System (GLONASS) of Russia are fully operational [1]-[2]. Galileo of European Union (EU) and BeiDou of China are under development. All these four systems are meant for PNT services at anywhere over the entire globe. In addition to these global systems, India and Japan have been developing their own satellite navigation systems, namely Indian Regional Navigation Satellite System (IRNSS) and Quasi-Zenith Satellite System (QZSS) with limited service area confined to their geographical region and surroundings [3]-[4]. Therefore, users over the Indian subcontinent get signals from GPS, GLONASS, Galileo, BeiDou, IRNSS and one or two satellite signals from QZSS at all the time. Various GNSS signals which could be available over the Indian Latitude are listed in the Table I [5]. IRNSS constellation consists of 4 Geosynchronous and 3 geostationary satellites to transmit signals on L and S bands for position, navigation and time applications over the India [6]. However, in urban areas and dense foliage environment, GNSS and regional constellation signal strength decreases and sometimes receiver gets insufficient number of satellites in view to achieve good Dilution of Precision (DOP). Moreover, continuity of the service is also being interrupted due to the insufficient number of satellites. GNSS signal strength can be measured in terms of carrier-to – noise density ratio (C/No) using the following mathematical expression given in equation (1) [7],

Table I. Signals and frequency bands of multiple GNSS constellation [12]-[17]

Constellation	Signal	Frequency Band /Frequency (MHz)	No. of Satellites in operation
GPS	L1 C/A L1 P(Y) L2 P(Y) L2C L5	L1/1575.42 L2/1227.60 L5/1176.45	31
GLONASS	L1 C/A L1 P L2 P L2 C/A L3	L1/1602+k*9/16 k=-7……+12 L2/1246+k*716 L3/1202.025	24
Galileo	L1 BC E5a E5b E5 E6BC	L1/1575.42 E5a/ 1176.45 E5b/1207.14 E5/1191.795 E6/1278.75	18
BeiDou	B1 B2 B3	B1/1561.098 B2/1207.14 B3/1268.52	17
IRNSS	L5 S	L5/1176.45 S/2492.028	07
QZSS	L1 C/A L2 C L5	L1/1575.42 L2/1227.60 L5/1176.45	04

$$C/N_0\,(dB-Hz) = C-(N-BW)$$
$$C-N_0 = SNR+BW \qquad (1)$$

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Where, C = carrier power in dBm or dBw, N = noise power in dBm or dBw, N_o= noise power density in dBm-Hz or dBw-Hz, BW = bandwidth of observation and SNR= Signal to Noise Ratio.

DOP gives quality of GNSS geometry at the given location and time. The mathematical expression expression for various DOPs and significance given in Table II [8, 9],

Table II Mathematical expressions for various DOPs

S.No	DOP	Mathematical expression	Significance
1	PDOP	$PDOP = \frac{\sqrt{\sigma_E^2+\sigma_N^2+\sigma_U^2}}{\sigma} = \sqrt{D_{11}+D_{22}+D_{33}}$ $PDOP^2 = HDOP^2 + VDOP^2$	Provides accuracy degradation in 3D position
2	HDOP	$HDOP = \frac{\sqrt{\sigma_E^2+\sigma_N^2}}{\sigma} = \sqrt{D_{11}+D_{22}}$	Provides accuracy degradation in the horizontal direction
3	VDOP	$VDOP = \frac{\sigma_U}{\sigma} = \sqrt{D_{33}}$	Provides accuracy degradation in vertical direction
4	TDOP	$TDOP = \frac{\sigma_T}{\sigma} = \sqrt{D_{44}}$	Provides accuracy degradation in time
5	GDOP	$GDOP^2 = PDOP^2 + TDOP^2$	Provides accuracy degradation in 3D position and time

$\sigma_E^2, \sigma_N^2, \sigma_U^2$ = variances of east, north and up components of receiver position, σ_T^2 = variance of receiver clock offset, σ = standard deviation of pseudo range measurement error plus residual model error.

The GDOP value is low for healthy and enough widely separated satellites. And it is most desirable for the precise applications. The integration of multiple GNSS systems or regional system integration with GNSS could enhance DOP for quality of service with better availability, accuracy and continuity [10]-[11]. But, before integrating multiple GNSS or regionals systems the difference between them must be studied. The main objective of this research work is to analyse the visibility of multi-GNSS satellites and identify the strong signals. Further, to estimate and analyze DOP values for the combination of GPS+GLONASS+ Galilleo+BeiDou+ SBAS+QZSS+IRNSS and IRNSS+GPS (combined).

This paper focuses on the analysis of multiple constellation signals with real-time data to understand the performance of multi-GNSS systems.

II. EXPERIMENTAL SETUP AND DATA PROCESSING

To investigate all available GNSS and IRNSS signal quality, a multi-frequency multi-GNSS receiver station is established at GPCET Kurnool, India. Multi-Frequency multi-GNSS receiver station is equipped with high gain RHCP multi frequency antenna (Model: PolaNt-x MF, Make: Septentrio) which is mounted on the roof of the 5 floor building and PolaRx5 receiver. Antenna was connedted to the receiver through a 25 meters, RF cable TNC-M to TNC-M as shown in the Fig. 1.

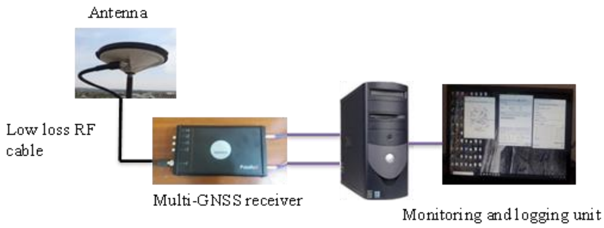

Fig.1 Multi-Frequency Multi-GNSS signal receiving system

The antenna receives signals from multiple GNSS constellation (GPS, GLONASS, Galileo, BeiDou) in addition to regional constellations namely QZSS and IRNSS systems. The real-time raw data of 12 October, 2018 was recorded with 1 Hz sampling rate for the purpose of research in multi-GNSS signal availability and quality analysis. The receiver raw data was in the form of Septentrio Binary Format (SBF). It can be converted into the RINEX format using a graphical user interface called SBF converter. In this work, SBF Analyzer was used to compute various parameters such as No. of PRNs, C/No and DOP.

III. EXPERIMENTAL RESULTS AND DISCUSSION

All the satellites of multiple constellations broadcast signals continuously towards the earth in all weather conditions. The Effective Isotropic Radiated Power (EIRP) of the satellites transmitting antenna is same for all the satellites in one constellation. However, signals from different satellites will undergo different environment when broadcasting to the receivers. Satellite to receiver path length, disturbances in the propagation medium vary from satellite to satellite. Since, the path loss is a function of path length and propagation medium characteristics the received signal strength is not same for all the satellites. The rapid changes in the received signal strength degrade the performance of receiver code and carrier phase tracking loops by introducing error in the measurements. Sometimes, receiver losses signal lock which causes degradation of availability. In this research work, the quality of received signal strength is measured in terms of C/No for multiple GNSS constellations.

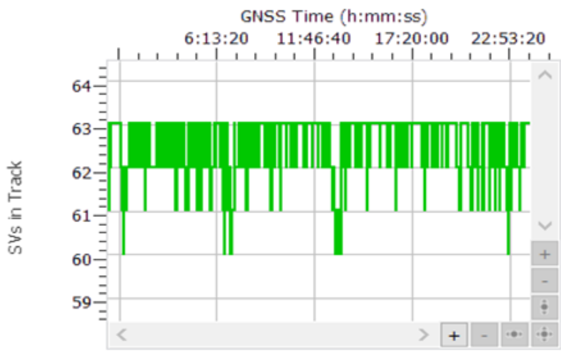

Fig.2 Number of satellites in view from multiple-constellations over the GPCET, Kurnool (150.47'N, 78.040E)

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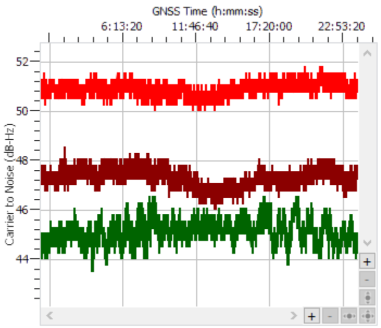
A. Number Of SVs Tracked

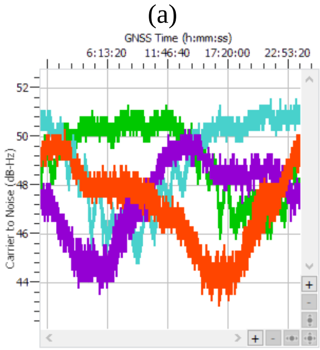
Fig. 2 shows the number of satellites in view over 24-hours to the multi-GNSS antenna mounted at GPCET, Kurnool, India. From the Fig.2, users in this region can get a minimum of 60 satellite signals from all the constellations, including GPS, GLONASS, Galileo, BeiDou, IRNSS, QZSS and SBAS. Most of the time receiver is able to track signals from 62 or 63 satellites. Out of the total available satellites (62), 60% of the satellites are having an elevation angle greater than 30^0. However, the receiver is able to get the signals from 7 IRNSS satellites with the elevation above 25^0. IRNSS include 3 geostationary, and 4 geosynchronous satellites. From GPS constellation, 8 to 12 satellites are in view for all the time. Also, the investigation is done in indoor environments by placing the antenna inside the building. It is found that a very few number of satellites are in view which are not sufficient for PNT calculations. Results show that the integration of multiple constellations could enhance the availability of the service with increased number of satellites. So that the users will get uninterrupted services in any adverse space weather and urban environment. The integration of GPS with IRNSS will provide a minimum of 15 satellites signals. Further, advantage of multiple constellations in DoP is discussed in the succeed sections.

B. Carrier-to- Noise Density Ratio

Fig.3 shows IRNSS constellation signal strength variation in terms of C/No with GNSS time during a day (24 hours). IST is equal to the GNSS time + 5:30 Hrs. The mathematical expressions used to calculate C/No are given in eqn (1).



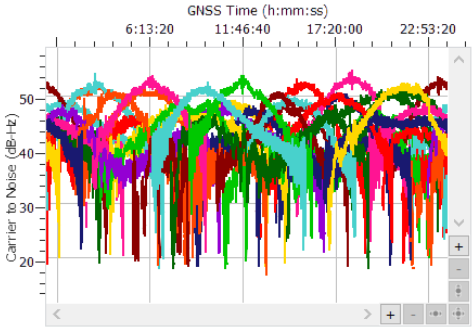
(a)



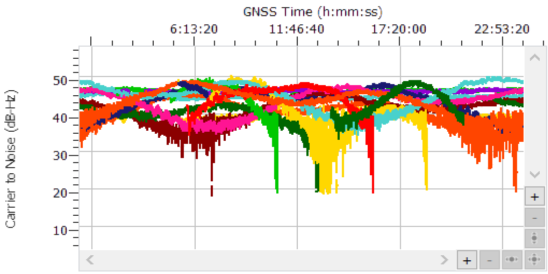
(b)

Fig.3 IRNSS C/No with respect to the local time: (a) IRNSS GEO satellites C/No; (b) IRNSS GSO satellites C/No

In figure (3) and (4) different colors indicate different satellites. Figure (3) shows IRNSS signal strength variation with GNSS time. From the results (3a), it can be observed that the C/No of any GEO satellite is almost constant for all the time because the orbital period of the satellites and earth is same. However, the received signal strength is not same for all GEO satellites because they are placed in three different locations in the orbit. Further, for GSO satellites C/No varies with elevation angle of the satellite. C/No is maximum at high elevation angles and it is minimum at low elevation angles. This is because of longer path length at lower elevation angles and reduced path length at high elevation angles. Users over this region can get a maximum C/No from IRNSS GEO satellites is greater than 51 dB-Hz and the minimum is 44 dB-Hz. From GSO satellites users can get signal power in between 44 dB-Hz and 51 dB-Hz.



(a)



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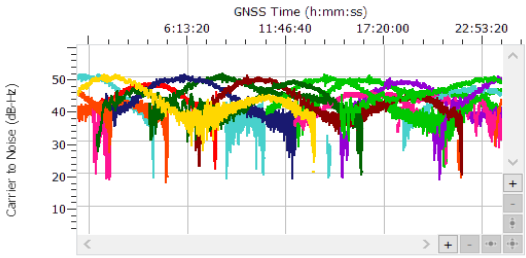
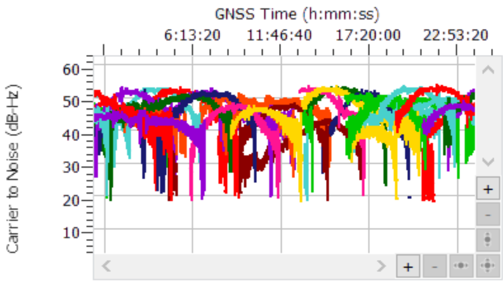


(c)



(d)

Fig. 4 GNSS C/No with respect to the local time, (a) GPS; (b) GLONASS; (c) Galileo; (d) BeiDou

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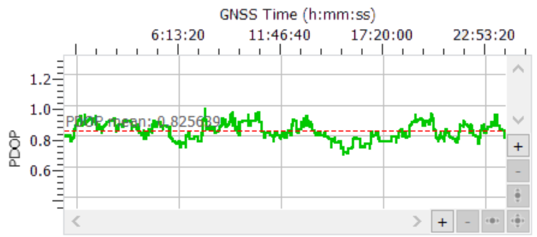
Fig. 4 shows C/No of received signals from (a) GPS, (b) GLONASS, (c) Galileo and (d) BeiDou satellites. Here also, in each figure different colours indicate different satellites. The maximum received signal strength from GPS satellites which were located in MEO is 51 dB-Hz and the minimum is 20 dB-Hz. The results show that the IRNSS satellite signals are stronger than the GPS satellites, though the GPS satellites were located at shorter distance (20200 Kms) compared to the IRNSS satellites (~36000 Kms). For other constellations (GLONASS & Galileo) also the maximum C/No is 50 dB-Hz minimum is 20 dB-Hz. This variation is due to the change in elevation angle of satellites.

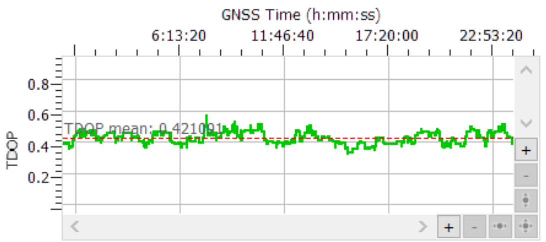
Therefore, the C/No for IRNSS satellites is high compared to other constellations over the selected GNSS station with continuity greater than 99.9%.

C. Dilution Of Precision (DOP)

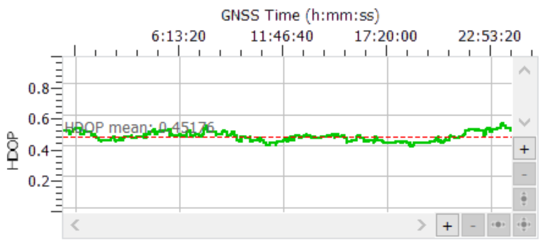
At present most of the real-time applications are demanding for uninterrupted services with good DOP value. Because DOP is one among the important parameters which can affect the accuracy of the GNSS. It gives geometric strength of the satellites selected for PVT calculation. Fig. 5 shows the variation of multi constellation geometry (PDOP, TDOP, HDOP and VDOP) with GNSS time.



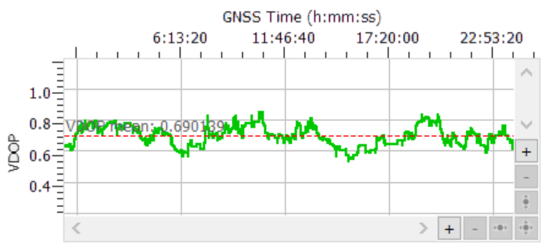
(a)



(b)



(c)



(d)

Fig. 5 Geometry of multi-Constellations (a) PDOP; (b) TDOP; (c) HDOP and (d) VDOP

Results show that PDOP value lies in-between the 0.8 and 1, means that the geometry of considered satellites is ideal and the accuracy of estimated position is high. The statistics of various DOPs are presented in the Table III.

Table III Statistics of multi- constellation DOP values

	Dilution of Precision		
	Minimum	Maximum	Mean
PDOP	0.69	0.97	0.82
TDOP	0.32	0.56	0.42
HDOP	0.4	0.54	0.45
VDOP	0.53	0.84	0.69

Also, the PDOP value becomes greater than 2, if only greater than 30^0 elevation angle satellites are considered. Since, the GNSS users over the Indian region get signals from IRNSS, investigation of GDOP variation is done for GPS+IRNSS constellation (combined). It is noted that the geometry is excellent (greater than 2) rather than ideal to compute PNT.

IV. CONCLUSION

Out of the research work done in this paper, conclusions are drawn in the aspect of satellite visibility, signal strength and DOP. GNSS users over the Kurnool region can view at least 60 satellites from multiple constellations. Out of that 15 are from the combined IRNSS+GPS constellation. IRNSS constellation provides strong signals with C/No range from 44dB-Hz to 51 dB-Hz. Further, PDOP of IRNSS+GPS (combined) constellation was lower than that of each individual constellation.

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