The 5th IVS General Meeting Proceedings, 2008, p. 439–444

Progress in Technology Development
and the Next Generation VLBI System

First Considerations on the Feasibility of GNSS Observations by the VLBI Technique

Vincenza Tornatore [1], *Gino Tuccari* [2], *Erhu Wei* [3]

[1] *DIIAR Politecnico di Milano, Italy*

[2] *INAF-IRA, National Astrophysical Institute — Radio Astronomy Institute, Italy*

[3] *School of Geodesy and Geomatics, The Key Laboratory of Geospace Environment and Geodesy , Ministry of Education, Wuhan University, China*

Abstract. GNSS (Global Navigation Satellite System) is a global navigation satellite system consisting of different satellite constellations that transmit ranging signals used for positioning and navigation anywhere around the globe. In this work we present first investigations on the possibility to observe GNSS signals using the VLBI technique with the main goal to obtain satellite orbits by VLBI. The achievement of this goal could represent the opportunity to obtain a direct link between VLBI and the different GNSS reference systems; moreover, it could be also useful internally to the GNSS system itself to establish an external link among the different GNSS reference systems of each constellation.

The different characteristics of the GNSS system will be presented to evaluate if it is possible to observe any of these different constellations with present VLBI antennas. Then the contribute that the new VLBI2010 antennas and data acquisition system could bring to the observation of GNSS signals will also be examined.

1. Introduction

The most important and complicated mission of modern geodesy and geodynamics is the definition, realization and interconnection of different reference systems, which include the Conventional Inertial System (CIS) fixed in space and defined by radio sources, the Conventional Terrestrial System (CTS) fixed to the earth and defined by a series of observation stations on the ground, and the dynamic reference system defined by the movement of the satellite.

Since 2003 with the establishment of the IVS working group 3, the VLBI community is devoting several efforts to designing the next generation of geodetic VLBI system called VLBI2010 that would provide enhanced performances. In the meantime a demand of higher positioning accuracy for the global earth parameter estimation is growing too. A combination/integration of different spatial geodetic techniques is the key to ensure the consistency and to improve the accuracy of the resulting geodetic products.

At present VLBI solutions, and solutions from other positioning techniques (such as GPS, SLR, LLR, etc.,) are jointly used for indirect interconnection between CIS and CTS [1]. The local geodetic ties between GPS and VLBI antennas play an essential role within the inter-technique combination. However several studies already revealed non-negligible discrepancies between the terrestrial measurements and the space-geodetic solutions. Causes of these inconsistencies can be different, among them local tie uncertainties that have a significant influence on estimated geodetic parameters [4]. An indipendent link (a sky link) could help to discriminate between different possible error sources. Then with the development/advent of different Navigation satellite systems, each one referred to its own reference system, it will become necessary for high level accuracy applications to know with precision the transformation from one reference system to another one.

In this work we make first steps to investigate on the possibility to determine GNSS orbits by the VLBI technique. The knowledge of GNSS orbits in the VLBI system would allow to obtain terrestrial GNSS coordinates in a unique reference system, the VLBI one, without the need of making local ties, besides this method could also be the key to link the different GNSS reference systems among them. After a short overview on GNSS characteristics, the possibility to receive the GNSS signals using the present VLBI antennas and also the future VLBI2010 antennas will be examined. In particular the signal frequencies and strength has been considered, since they will be on the wings of the filters and feed response.

2. GNSS Characteristics

GNSS has shown a rapid growth in the last few years: the U.S. Global Positioning System (GPS/Navstar GPS), and the Russian GLObal NAvigation Satellite System (GLONASS) have started an extensive modernization, moreover there are plans to develop a European GALILEO system and China is planning to have its own version called Compass. The main features of GNSS constellations are presented in Tabl. 1. IGS, the International GNSS Service, formerly the International GPS Service, is a voluntary federation of more than 200 worldwide agencies that pool resources and permanent GPS and GLONASS station data to generate precise GPS and GLONASS products. The conventional GPS data processing techniques are also being modified to incorporate the new satellite system of GNSS which poses major challenges of different satellite signals, different reference frames and different time scales to be incorporated for combined processing. In this paper we have not considered the two regional systems: the Japanese QZSS (Quasi –Zenith Satellite system) that will be used to enhance GPS in Japan and the IRNSS (Indian RadioNavigation

	GPS	GLONASS	GALILEO	COMPASS
Planned satellites Number	21+3 active spares MEO	24 MEO	27+3 non active spare MEO	30 non GEO, 5 GEO
Orbital height	20200 km	19100 km	23200 km	21500 km
Orbital planes inclination	55°	64.8°	56°	
Orbital planes	6, spaced by 60°	3, spaced by 120°	3, non uniformly spaced	
Satellites per orbital plane	6, unequally spaced	8, unequally spaced	10, unequally spaced	
Revolution period and ground track repeatability	11h 58min; every sidereal day	11h 16min; every eight sidereal day	14 h	
Reference frame	WGS84	PZ 90	GTRF	
UTC correction	UTC (USNO)	UTC(SU)	UTC(GST)	
Satellite separation technique	CDMA (Code Division Multiple Access)	FDMA (Frequency division Multiple Access)	CDMA	
Carrier Frequencies MHz	Constant L1(E1): 1575.42 L2 : 1227.60 L5 : 1176.45	Variable L1: 1602…1615.5 L2: 1246…1256.5 L3: 1201.5 for channel number 0-24	Constant L1(E1) E6 (L5) E5a E5b	Constant B1-2 B1 B3 B2
Code Number	One for service (and satellite)	One for service and frequency (band)	One for service (and satellite)	One for service (and satellite)
Commercial Services	No	No	Yes	Yes
Integrity	No (yes with GPS III)	No (Yes con GL-K)	Yes	

Figure 1. GPS, GLONASS, GALILEO, Compass Constellation Characteristics

Satellite System). IRNSS will seek to maintain compatibility with other GNSS systems of the region and to provide services for critical national application.

The panorama of existing and planned navigation systems is very wide and diversified. In the GNSS community there are efforts to harmonize all the GNSS system.

3. GNSS Signals Compatibility with Present VLBI Antennas and Data Acquisition System

Several experiments have been performed in the last years using VLBI for spacecraft tracking [5]. VLBI is the technique with highest angular resolution and e-VLBI showed rapid progress in recent years: with the improvement of these characteristics the VLBI technique can be more and more used for spacecraft tracking.

Emission from GNSS satellites are in a range between 1100 and 1600 MHz, well below the 2 GHz limit that the VLBI2010 receiver would have to cover

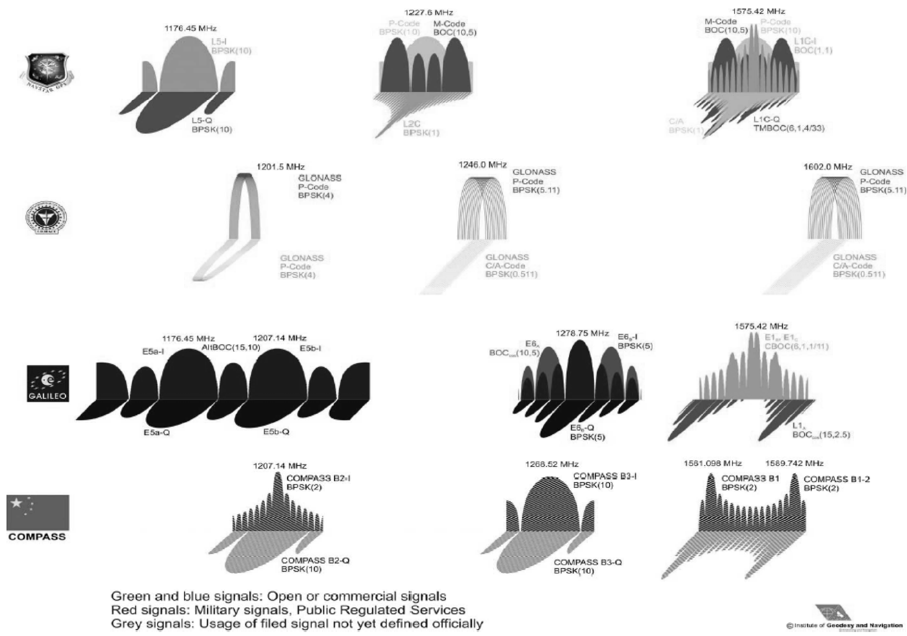

Figure 2. GPS, GLONASS, GALILEO, and Planned Compass Signals

to reduce interference contribution in the L band. On the other hand, the transmission range adopted by the GNSS is due to different reasons: 1) frequencies have to be chosen below 2 GHz, as frequencies above 2 GHz would require beam antennas for the signal reception; 2) the PRN-codes (modulation schemes) require a wide bandwidth for the code modulation on the carrier frequency; therefore it is necessary to adopt frequencies larger than 1 GHz, with the possibility that a larger bandwidth has to be chosen; 3) the chosen frequency should be in a range where the signal propagation is not too influenced by weather phenomena. GPS receivers use the L1 frequency with 1575.42 MHz (GLONASS 1602.0). L1 frequency carries the navigation data as well as the SPS code (standard positioning code). L2 frequency (1227.60 MHz) only carries the P code and is only used by receivers which are designed for PPS timing determination. The L1 component represents a possible signal source to determine accurate satellite positions provided that the overall system gain is able to detect such emission with the standard S/X receiver. The L2 detection could anyway be essential for the determination of the complete parameter set. Most of the today used S/X receivers filter the S band with a minimum usable limit placed at around 2200 MHz, so even considering the large antenna surface of a medium size IVS radio-telescope, signal components of the GNSS emission are probably under the detection threshold. Moreover very few systems having coaxial L/S/X feeds are adopted. A new approach could be considered in case a new generation of receivers plans to adopt a lower limit closer to the L1 (or L2) signal components, even with a controlled attenuated response.

4. New Opportunities from VLBI2010 Antennas

With VLBI2010, it is expected that phase delays are used, and that delay precision for the radio sources have a target of 1 ps, although systematic effects will make this worse. On the other hand, the GPS signal could be treated quite differently since only the L-band frequency are usable. The new VLBI2010 systems will be able to receive very wide band signals with a lower limit of 2 GHz. This in principle avoids to receive GNSS L1 emission even if it could be considered how the signals will appear in the overall system response, since they will be on the wings of the filters and feed pass-band.

A generic GPS/GLONASS receiver antenna receives the signals coming from the satellites from potentially any direction, so they have a standard gain close to 4-5 dB. The new typical 12 m VLBI2010 antenna dish will have a 47 dB gain at L1 frequency, considering a 50% efficiency. So if the overall gain loss between the antenna and the first amplification stage, including feed and sky frequency filters response, will present an attenuation at 1600 MHz of about 43 dB with respect to the in-band level, the expected SNR obtained pointing on a satellite will be similar to what is achieved in a standard GPS receiver. The related slope, considering a −3 dB level at 2000 MHz would be 10 dB/100 MHz. An additional loss to be taken into account is the circular polarization adopted in the satellite transmitters that produce a further 3 dB attenuation due to the linear polarization scheme adopted in the new receiver system. A more stepped performance could affect the possibility to safely receive the emission coming from the L1 modulated carriers, while it could be required to moderate the effects due to cellular phones and related repeaters operating in the range 1800–1900 MHz.

The condition to have a system able to detect GNSS signals would then come by considering a feed frequency attenuation shape in the lower side of the band that would not exceed the described slope, and the introduction of an additional filter to be included or not in the lower side in order to get better attenuation performance in the L-band, still maintaining the possibility to have it excluded by the chain getting a quite convenient attenuation factor for the detection of the very strong signals coming from the satellite transmitter.

5. Conclusions and Future Developments

In this work we have performed preliminary investigations on the observability of GNSS signals by the VLBI technique, with the main goal to determine GNSS orbits in the same reference system of the VLBI technique. Some characteristics of the GNSS constellations and of the emitted signals have been presented with the objective to evaluate if GNSS signals are detectable by the VLBI technique. Also improvements that the next VLBI2010 antennas could bring for the observations of the GNSS signals have been considered and it was found that to achieve a full information available a full bandpass starting from around 1.150 GHz should be considered in order to be able to detect the entire GNSS range. Such extension from 2.0 GHz is strongly affected by several potential RFI signals, due to the large number of services operating in such portion of the spectrum. Nevertheless it could be worthwhile to consider such lower range in the feed horn bandwidth and low noise amplifiers, while still keeping a choice to cut it in a further more advanced stage in the receiver. This solution could bring the opportunity to observe GNSS signals with a standard VLBI2010 terminal. Then since the final configurations of the new VLBI2010 antennas are still not established, some observation campaigns could be planned to perform some analysis to estimate different signal strengths, and to establish targets for the system design.

Further investigations are required on the processing of GNSS signal by the VLBI data acquisition system and on the data correlation. The obtainable accuracy of GNSS orbit determinations by the VLBI technique need also to be evaluated. A good accuracy in the GNSS orbit determination by VLBI is very important because the knowledge of the orbits of the different constellations in the same reference system could represent a good link among the different GNSS reference systems and also a good link between GNSS and VLBI.

Acknowledgements

We gratefully acknowledge G.W. Hein, J.A.A. Rodriguez, T. Pany, P. Hartl, authors of the paper 'Envisioning a Future GNSS System of System', Inside GNSS Jan/Feb 2007, for giving permission to publish Fig. 2 of this paper.

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