

ONGOING OPERATION AND PERSPECTIVES OF SIMPLE VLBI NETWORKS OF GEOSTATIONARY SATELLITES MONITORING

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ABSTRACT. The report is dedicated to introducing the operation and prospects of further development of simple VLBI networks which were created in Ukraine, Latvia, and China for monitoring the orbital information of geostationary satellites. The Ukrainian-Latvian network consists of five stations located in Mykolaiv, Kharkiv, Mukacheve, Ventspils, and Rivne, and it operates since 2015. The Chinese network consists of three stations located in Shanghai, Duyun, and Urumqi, and it formally carried out a network observation from June 2019.

The networks have identical hardware and software. The main principle of the operation of the networks learned from the VLBI is correlation analysis of broadband noise-like signals of satellite television DVB-S, which are emitted by satellites and synchronously received by the stations of the networks. Single-frequency GPS receivers are used for the synchronizing of network stations. Time difference of arrival (TDOA) between the signals paths from the identical TV satellite to different stations is obtained via using correlation analysis. These values of TDOA are used to determine orbital elements of the tracked satellites which are given in the report. Notably, the cost of one set of station equipment does not exceed \$2000, and the current operating costs are about \$50 per day.

The prospects of further development of the simple VLBI networks include a) the possibility of continuous independent non-invasive high-precision determination of the position of arbitrary active satellites (especially important in the case of their co-location), b) the possibility to fully automate targeting and operation, c) the possibility of using accumulated observational data to solve scientific geophysical and astronomical tasks, d) relatively few funds necessary for the modernization and operation of the networks.

АНОТАЦІЯ. Доповідь присвячена ознайомленню з роботою та перспективам подальшого розвитку мереж простих РНДБ, створених в Україні, Латвії і в Китаї для моніторингу орбітального положення геостационарних супутників. До складу українсько-латвійської мережі, яка функціонує з 2015 року, входять п’ять станцій, розташованих в містах Миколаїв, Харків, Мукачеве, Вентспілс і Рівне. Китайська мережа складається із 3-х станцій, розташованих в Shanghai, Duyan і в Urumqi і офіційно проводить спостереження з червня 2019.

Мережі мають ідентичне апаратне і програмне забезпечення. Основним принципом функціонування мереж, запозиченим з РНДБ, є кореляційний аналіз широкосмугових шумоподібних сигналів супутникового телебачення DVB-S, які випромінюються супутниками і синхронно приймаються станціями мережі. Для синхронізації станцій мережі використовуються одночастотні GPS-приймачі. В результаті кореляційного аналізу визначаються значення TDOA (Time Difference Of Arrival) сигналів супутникового телебачення. Виміряні значення TDOA використовуються для визначення елементів орбіти контрольованих супутників та створення каталогів, фрагменти яких наводяться в доповіді. Зазначимо, також, що вартість одного комплексу обладнання станції не перевищує \$2000, а поточні експлуатаційні витрати – \$50/доба.

Перспективність подальшого розвитку мереж простих РНДБ обумовлена а) можливістю безперервного незалежного неінвазивного високоточного визначення положення довільних активних супутників (особливо важливо у випадку co-location), б) можливістю повної автоматизації націлювання та функціонування, в) можливістю використання накопичених даних спостережень для вирішення наукових геофізичних та астро-

номічних задач, г) порівняно незначні кошти, необхідні для модернізації і експлуатації мереж.

Keywords: geostationary satellite, TDOA, orbital elements, DVB-S.

1. Introduction

Simple VLBI network uses correlation analysis of digital satellite television signals, synchronously received by geographically spaced network stations, to calculate the time difference of arrival (TDOA) of these signals to the network stations (Bushuev et al., 2016). The obtained values of the TDOA and the known station coordinates are used to determine the orbital elements of a tracked satellite. It is shown in (Bushuev et al., 2017) that the error of calculating satellite coordinates by a network of three or more stations is 223 m. The error of calculating coordinates by a network of two stations exceeds 7000 m.

Herewith the network is a prototype of passive correlation ranging (PaCoRa) system developed by Fraunhofer IIS and SES in 2010-2013 (ESA, 2019). It is reported that PaCoRa systems are created in the US and Europe and that the systems enable SES to track 80% of its geostationary satellites (SatMagazine, 2019).

2. Operation of the Ukrainian-Latvian and Chinese networks

The Ukrainian-Latvian network operates since December 2015 (Kaliuzhnyi et al., 2017) and initially tracked the single satellite Eutelsat-13B located in the geostationary cell 13°E together with two other satellites Eutelsat-13C and Eutelsat-13E. An additional sixth station was put into operation in Mykolaiv in September 2018. This allowed two triplets of stations to track two satellites Eutelsat-13B and 13C. The results of these observations are used to determine the orbit elements of the satellites using two models of motion: the analytical model SGP4 / SDP4 and the numerical model of integrating the equations of motion of the satellites (Kaliuzhnyi et al., 2016). Today, the Eutelsat-13B and Eutelsat-13C catalogs contain orbit elements obtained for 1175 and 106 days, respectively.

Works on modernization the network continues. Today, two additional stations, located in Mykolayiv and Rivne, are constantly operating and the ninth station in Ventspils is being set up. Upon commissioning the ninth station, three triplets of stations will be able to simultaneously tracking all three satellites located in the geostationary cell 13°E. This would track the relative position of the satellites in the geostationary cell and determine the moments of the approach of the satellites to each other.

The Chinese network of three stations located in Shanghai, Deyun, and Urumqi has begun tracking the Apstar-6C satellite (134°E) in June 2019. Only one satellite is located in the geostationary cell 134°E. The network observations have been used as to determine the error of the TDOA measurement, and the orbit elements of the satellite. The standard deviation of the TDOA at an averaging interval of 60 s for all pairs of stations is ± 8.6 ns and coincides with the TDOA error obtained by the Ukrainian-Latvian network (Bushuev et al., 2016). The fact that the SGP4/SDP4 model is significantly less accurate than the numerical model was also confirmed. So the stan-

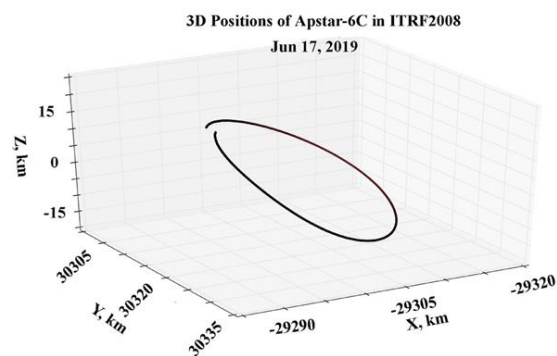


Figure 1: The 3D position of Apstar-6C in ITRF2008 on June 17, 2019.

dard deviation of the residuals of measured and model values of the TDOA about 20 times less for the numerical model than for the SGP4/SDP4 model.

The obtained daily orbit elements (numerical model) are used to calculate the 3D position of Apstar-6C in ITRF2008 that is shown in Fig. 1.

3. Prospects: a network of global monitoring of geostationary satellites

A detail list of the benefits of a simple VLBI network or passive correlation ranging system over traditional satellite positioning systems is given on the website (ESA, 2019). The prospects of using such systems, first of all, in our opinion, depend on their cost and the value of the error of determining the orbital position of the satellite. The price of one station of the simple VLBI networks is about \$2000. This is three orders of magnitude less than the cost of a single VGOS (VLBI Global Observing System) station. Herewith operating costs are at a level of about \$50 per day for the existing network stations.

The error of satellite orbit determination is proportional to the TDOA error. The physical limit of the TDOA error is inversely proportional to the width of the signal spectrum and is estimated at 0.1 ns for digital satellite television signals. It is proposed to reach the limit by using a quantum reference oscillator for synchronizing and as an ADC reference oscillator. Then the error of coordinate determination will be at the level of about 1 m. Despite the significant increase in the cost of the upgraded station, the cost of a simple VLBI network of five such stations is estimated at the cost of one VGOS station. The operating costs of the upgraded simple VLBI network would remain low because of the fully automate targeting and operation. Herewith the network of such stations could track almost all geostationary satellites that radiate TV signals, for example, on Europe. Therefore, it is possible to create a simple VLBI network for global monitoring of geostationary satellites, which will consist of separate regional networks or clusters.

4. Conclusion

Two simple VLBI networks separately operate now in Europe and China. They could be considered as two clusters of the network of global monitoring of geostationary satellites. Relatively few funds are necessary for the mod-

ernization and operation of the networks to provide coordinate accuracy of about 1 m. The modernized networks could be used also for accumulated observational data to solve scientific geophysical and astronomical tasks.

In the short term, it is proposed to carry out joint observations of satellites that have DVB-S transponders with a footprint as in Europe and China.

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