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A network of global monitoring of positions of geostationary satellites by their payload radio signals

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Continuous high-precision non-invasive tracking of active geostationary satellites is an urgent need. The solution to this problem may be the creation of simple VLBI networks.

The main method of functioning of such networks is the passive correlation ranging (PaCoRa). The ESA project PaCoRa was executed by Fraunhofer Institute for Integrated Circuits (IIC) and SES during the years 2010–2013. The simple VLBI network consisting of 5 stations has been in operation in Ukraine and Latvia since 2015. The Chinese network consisting of 4 stations started observations in June 2019. The networks have identical hardware and software. The synchronizing error is 20 ns, which causes the accuracy of satellite coordinates determination at a level of 200 m.

The simple VLBI network proposed for the global monitoring of active geostationary satellites may consist of clusters. The list of works on upgrading existing networks is presented to reduce the measurement error and ensure complete automation of the network's operation.

Keywords: Geostationary satellite, VLBI, passive correlation ranging

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1 Introduction

A simple or micro VLBI network uses correlation analysis of digital satellite television signals with DVB-S modulation, 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.

The described network is a prototype of passive correlation ranging (PaCoRa) system developed by Fraunhofer IIC and SES in 2010–2013 (ESA-2 (2020)). The first system implementation consisted of 4 main and 1 back-up stations (ESA-1 (2020)). The system is described as "an accurate and great low-cost alternative to conventional ranging systems" which has been developed "for a wide international market, including small operators with single satellites and also large organizations looking to track multiple satellites". 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 (2020)). But this information is not confirmed by other sources.

2 Ukrainian–Latvian and Chinese networks

The Ukrainian-Latvian network has been in operation 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 1372 and 180 days, respectively. The catalogs are presented on the RI "MAO" site `http://www.nao.nikolaev.ua/index.php?catalog_id=459`.

Works on the modernization of the network continues. Today, three additional stations, located in Mykolayiv, Rivne, and Ventspils, are continually operating. Upon commissioning the ninth station in Ventspils, an opportunity appeared to track simultaneously all three satellites located in the geostationary cell 13° E by three triplets of stations. Unfortunately, the Eutelsat-13E satellite has only DVB-S2 transponders. This information has been confirmed by orbit determination of satellites using signals of some DVB-S transponders which maybe belong to Eutelsat-13E according to site satbeam.com. All of these transponders actually belong to Eutelsat-13B or Eutelsat-13C as orbit determination has shown.

The Chinese network consists of three stations located in Shanghai, Duyun, Urumqi and began tracking the Apstar-6C satellite (134° E) in June 2019. The fourth network station located in Changchun has operated now since the end of 2019. Only

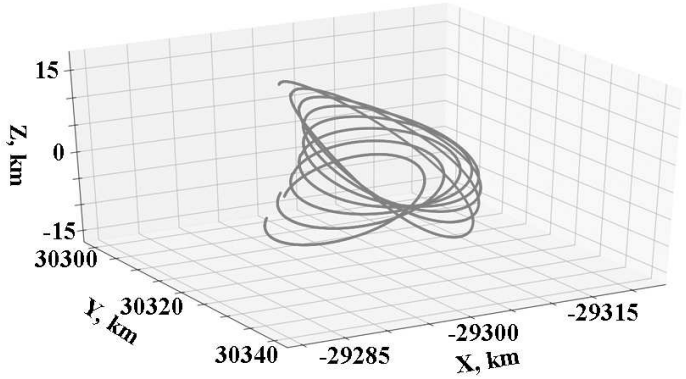


Figure 1 The 3D positions of Apstar-6C in ITRF2008 obtained during the eight days from 18 to 25 June 2019.

one satellite is located in the geostationary cell 134° E. The network observations have been used 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 standard deviation of the residuals of measured and model values of the TDOA is 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 Figure 1.

3 Global monitoring geostationary satellites by their payload radio signals

A detailed 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-2 (2020)). 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. The 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 TDOA error depends on the spectrum width of the satellite TV signal, which causes the physical limit of the error, and on the error of the synchronization of stations and the stability of the ADC reference oscillator. The physical limit of the TDOA error is inversely proportional to the width of the signal spectrum and is about 0.1 ns for digital satellite television signals with the spectrum width of about 100 MHz (Harles et al. (2001)). It is proposed to reach the limit by using a quantum reference

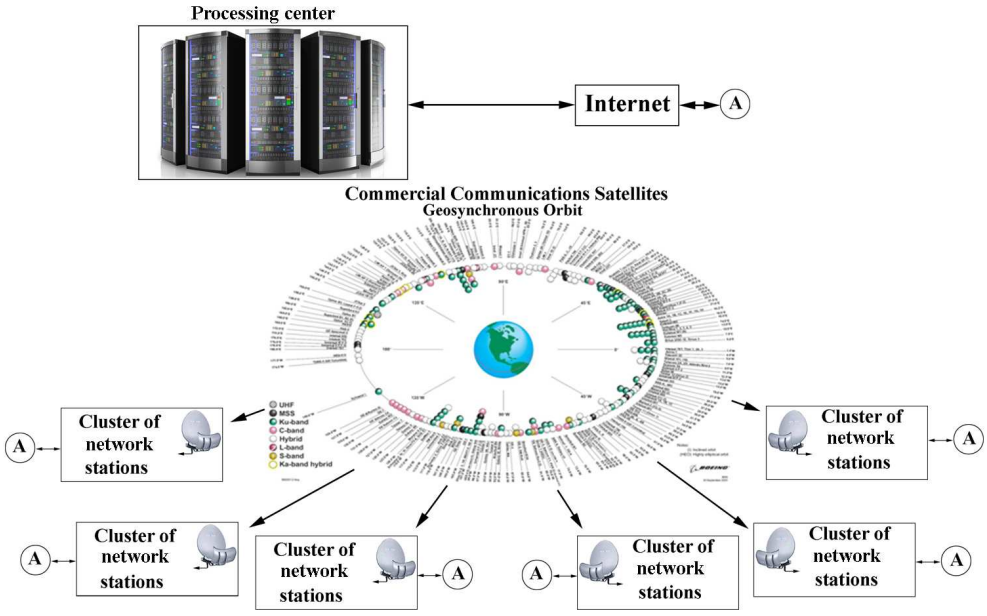


Figure 2 A simple VLBI network for global tracking geostationary communications satellites.

oscillator for synchronizing and as an ADC reference oscillator. Then the error of coordinate determination will be at the level of about 1 m (Huang et al. (2011)). 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 automated targeting and operation. 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 communication satellites, which will consist of separate regional networks or clusters. The structure of the network is shown in Figure 2. The central part of the figure is taken from Boeing (2017).

Pan-European cooperation should be organized to create the network. The following organizations may be involved in the modernization of the Ukrainian–Latvian and Chinese networks to reduce measurement error and provide complete automation of targeting and network operation:

- The Fraunhofer IIC – development of a special DVB-S (S2) receiver including ADC with the external reference oscillator. Their DARTS (Digital Advanced Ranging using Transport stream Signals) receiver may be considered as a prototype, see Harles et al. (2001).
- HILTRON Communications – manufacturing of high-precision targeting antennas. It was reported in 2015 that the company made antennas for the USA PaCoRa (HILTRON, 2020).

- European companies – software development for a) control of station equipment, b) automatic registration by the stations of samples of DVB-S (S2) signals, and transfer them in the processing center.
- Ukrainian, Latvian and Chinese companies – software development for automatic coordinate determination of tracked satellites, and the solution of scientific (geodetic) issues.

4 Conclusion

Two simple VLBI networks operate separately 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 modernization 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.

References

Boeing. Commercial Communications Satellites Geosynchronous Orbit [online]. Available at: http://www.boeing.com/assets/pdf/defense-space/space/bss/launch/980031_002k.pdf. Accessed 27 June 2017.

Bushuev F., Kaliuzhnyi M., Sybiryakova Ye. et al. (2016) Latvian Journal of Physics and Technical Sciences, 53, No. 5, 5.

Bushuev F. Kaliuzhnyi V., Shulga O. et al. (2017) in Proceedings of the 9th IAASS Conference Session 11: Space Traffic Control - I, Toulouse (France), 18–20 October 2017, 213.

Harles G., Siebert P., Eberlein E. et al. Proc. Seventh International Workshop on Digital Signal Processing Techniques for Space Communications (DSP 2001). Sesimbra (Portugal). 2001. Available at: http://esamultimedia.esa.int/conferences/01C14/papers/P2.2.pdf.

HILTRON Communications. Delivery of HMAM antennas for PaCoRa project in USA at the final stage. September 2015. Newsletter [online]. Available at: http://www.hiltron.de/media/hiltron/HiltronNewsSeptember2015.pdf. Accessed 05 April 2020.

Huang Yong, Hu XiaoGong, Zhang XiuZhong, et al. (2011) Chinese Science Bulletin, 56, No. 26, 2765.

ESA-1. TELECOM ARTES.PROGRAM. A new way to track geostationary orbiting satellites [online]. Available at: https://artes.esa.int/news/new-way-track-geostationary-orbiting-satellites. Accessed 05 April 2020.

ESA-2. TELECOM ARTES.PROGRAM. Passive Correlation Ranging (PaCoRa) [online]. Available at: https://artes.esa.int/projects/passive- correlation-ranging-pacora. Accessed 05 April 2020.

Kaliuzhnyi M., Bushuev F., Shulga O. et al. (2016) Odessa astronomical publications, 29, 203.

Kaliuzhnyi M., Bushuev F., Sibiriakova Y. et al. (2017) Science & Innovation, 13(1), 41.

SatMagazine. Year in Review 2016: Part VII [online]. Available at: http://satmagazine.com/story.php?%20number=2062213544. Accessed 05 April 2020.