VGOS Wideband Reception and Emerging Competitor Occupations of the VLBI Spectrum

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Abstract The VGOS wideband receivers cover a spectrum from 2 to 14 GHz. In this range, many frequencies are allocated to other services. VGOS provides up to four 1 GHz wide sub-bands, which can be tuned to frequencies where detrimental radio frequency interference is absent. The increasing demand of commercial users of radio spectrum and related on-going telecommunication projects are threatening the VGOS observation plans. The examples of a compatibility study for 5G concerning the German Wettzell site and the global availability of Starlink/OneWeb illustrate the impact on VGOS and the need of regulation by spectrum authorities. This article contains a brief introduction how spectrum management is organized and what needs to be done on the national level to achieve protection for VGOS sites.

Keywords VGOS, wideband, spectrum management, RFI, 5G, Starlink, OneWeb, ITU, CRAF, CORF, RAF-CAP, WRC

1 Introduction

New technologies making use of large bandwidths at frequencies above 2 GHz are introduced into the mass market. For example, the mobile Internet is rapidly spreading both in developed and developing countries. It is expected that the number of mobile Internet users will outperform the users of fixed access in the coming years. Mobile phone services based on Internet technology are expanding in the demand for a more electromagnetic spectrum in terms of global coverage. Undisturbed parts in the radio spectrum are becoming fewer and fewer, and radio-quiet remote rural regions are becoming less. Satellite and airborne radio transmission services are another threat to radio astronomy observatories, since they overcome the shielding by the local terrain. Many of these services have plans to emit broadband signals in a range that overlaps in several parts of the range of the spectrum where old legacy VLBI antennas (2.20−2.35 GHz, 8.1−8.9 GHz) and new VGOS[1] radio telescopes (2−14 GHz) intend to receive signals from weak natural radio sources.

We will briefly present in this paper two of the upcoming active services: 5G mobile telephone (3.3−4.2 GHz, 4.4−4.9 GHz, 5.9−7.1 GHz) and the satellite-based communication infrastructure (10.7−12.7 GHz), which are using parts of the spectrum now for tests. These frequencies are also targeted to be used by the new VGOS broadband receivers.

There have been numerous cases in the past where a satellite system was responsible for strong emissions into radio astronomical bands, effectively blinding the radio antennas in parts of the sky or for some time [Jessner 2013].

Spectrum allocations to radio services are established by international conventions in a complex process, considering not only the technical feasibility, but also driven by economic and historical aspects. It is

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[1] VGOS: *VLBI Global Observing System* is the contribution of the International VLBI Service to the Global Geodetic Observing System (GGOS). It comprises a modernized version of geodetic and astrometric VLBI to achieve globally 1 mm accuracy in positioning. The global network will extend to more than 15 new VGOS radio telescopes.

very difficult to increase the allocations to scientific services, or to adapt their protection to modern developments in the current climate of the high commercial exploitation of the radio spectrum.

At the same time, as the emerging competitors are asking for more spectrum, the geodetic and geoscience community also reached high-level recognition and was given tasks, which are in practice related to Earth monitoring by VLBI:

- [UN-Resolution 69/266] of the General Assembly on February 26th, 2015;
- [Directive 2007/2/EC] of the European Parliament and of the Council on establishing an Infrastructure for Spatial Information in the European Community (INSPIRE), March 14, 2007;
- [ITU-R TF.460] Standard-frequency and time-signal emissions, determination of UT1 by VLBI provided by the IERS.

This legal frame demonstrates an administrative interest to get information from VLBI observations. One important requirement to conduct VLBI observations is the absence of harmful radio interference. The expansion of wireless communication is a threat to exercise the VLBI task properly.

In this paper we will give an overview of the bodies involved at national, regional and global level for spectrum management (Section 2). We will demonstrate two cases of emerging spectrum competitors to VGOS: 5G (Section 3.1) and Broadband communication satellites for global internet and mobile telephone (Section 3.2). Action strategies against the threat of losing spectrum is discussed in our conclusions.

2 Spectrum Management

The use of the electromagnetic spectrum is managed by national, regional, and global regulatory frameworks. Spectrum management aims at coordinating the frequency allocation for different telecommunication systems. The finite resource of radio spectrum is oversubscribed and does not satisfy the demand of the wireless technologies without compromising existing services.

The International Telecommunication Union (ITU) is the authority responsible to regulate globally information and communication technologies. The treaty organization that deals with radio waves is the Radiocommunication Sector of the ITU (ITU-R). It divides the world into three administrative regions. The interests of the European radio astronomers in ITU-R1, are represented by the Committee on Radio Astronomy Frequencies (CRAF), an Expert Committee of the European Science Foundation. Similar organizations to protect radio astronomy interests exist both for the Americas (CORF) in ITU-R2 and for the Asian-Pacific areas in ITU-R3 (RAFCAP).

ITU activity is organized in about four-year cycles, which culminate in the World Radio Conference (WRC), a major event assembling all national spectrum agencies and sector members with an interest in the radio frequency spectrum.

Common interests of a particular region are discussed within regional international groups. Member states within a region may, and often do, have bilateral or multilateral agreements. It is worth noting that each national administration has the sovereign right to administer spectrum use within its borders, as long as they do not violate ITU-R radio regulations.

At the European level, the European Conference of Postal and Telecommunications Administrations (CEPT) is the official body dealing with spectrum management issues. Some of the other regional administration bodies in the world are the Inter-American Telecommunications Commission (CITEL), the African Telecommunications Union (ATU), the Asia-Pacific Telecommunity (APT), and the Arab Spectrum Management Group (ASMG). Structures of spectrum management differ among the nations. Some nations have internal structures to provide input both to national regulation and to the WRC.

Regulations established at international levels are implemented in each country through the national frequency allocation tables. In addition to the regulatory work, there is a great deal of technical and policy expertise and consultative infrastructure around the ITU-R, primarily centered on the so-called Study Groups. The Study Groups are broken down into Working Parties and ad-hoc Task Groups, where the adopted questions and assigned WRC agenda items are studied and considered. Study Group 7 addresses issues for the scientific services, WP7D is concerned with radio astronomy.

The Radio Astronomy Service (RAS) was recognized as a service at the 1959 World Administrative Radio Conference. Radio astronomy is very sensitive to the protection of its bands being a passive service (only reception) and receiving extremely faint signals. For radio astronomy, threshold levels of detrimental interference for both single-dish and VLBI mode are provided in the recommendation [ITU-R RA.769-2].

3 Examples of Potential Interferers

3.1 5G Earth Base and Mobile Stations

Broadband mobile radio systems are based on the ITU International Mobile Telecommunications (IMT) standard, for example IMT-2000 for the 3G system and IMT-Advanced for 4G. [ITU IMT-2020] is the standard platform on which to build the next generation (5G) of broadband connection. 5G performance targets include high data rate, reduced latency, energy saving, cost reduction, higher system capacity, and massive device connectivity.

WRC-15 has harmonized the existing spectrum and identified new bands for IMT. The focus is now on feasibility studies for the identification and allocation of frequency bands for IMT-2020 (5G) operations (WRC-19 agenda item 1.13). The cooperation of all nations within the regional groups is of vital importance in order to achieve the optimal use of the spectrum resources. Different countries have proposed and are working on different frequency bands that range from 600 MHz to 71 GHz. There is a lower band and a higher band in each country and region. In Europe, for example, there is a focus on mid-band (3.4−3.8 GHz) and 26 GHz (24.25−27.50 GHz).

5G will likely be available in pre-standard form by late 2018 and early 2019. However, the technology is not to be prevalent until the 2020s. 5G networks will enable more Internet-of-things (IoT) capabilities as well as connected cars and smart city applications. 5G networks consist of base stations (BS) and user equipment (UE), although alternatives such as mesh-network based topologies seem also viable. The targeted densities and antenna heights are not fully defined yet [Draft ECC Report 281].

The 5G operations represent a potential detriment to observations at radio telescopes. Compatibility studies have to be performed to determine the expected level of radio frequency interference at an RAS-site due to an active service. For this, the Python package `pycraf` was used [Winkel, Jessner 2018][2]. It implements algorithms recommended by ITU-R, e.g., [ITU-Rec. P.452-16], that can be used to calculate the path attenuation between a transmitter and the radio telescope, accounting for various effects such as diffraction at elevated terrain features.

For the upcoming use of the 3.4−3.8 GHz band, technical parameters are still under discussion. One major uncertainty is the final deployment density of 5G equipment. Therefore, only the so-called single-interferer case, where the compatibility of VGOS observations vs. a single base station is analyzed, is discussed here. It is likely, that in this frequency band, 5G BS will utilize antenna arrays to improve the effective gain of the links (to the cell phones) with the help of beam forming. Since the beams will point quasi-randomly to any direction in the forward sector, the single-element antenna pattern can be used on average to sufficiently predict the typical effective gain towards the RAS station. The acceptable emitted power levels (EIRP) are still under debate, which is why the calculations have been done for 30, 40, 50, and 60 dBm/MHz. Terrain height profiles have been queried from SRTM Space Shuttle Mission data [Farr et al. 2007]. For VGOS operations, the VLBI thresholds in [ITU-R RA.769-2] were interpolated, giving a value of -203 dB W/m^2/Hz that must not be exceeded. It is foreseeable that 5G base stations will usually be installed in locations where substantial clutter attenuation provides additional shielding. However, the worst-case of zero clutter loss here is assumed to obtain the size of a coordination zone, within which one should carefully assess potential installation locations.

Given path attenuation and considering the transmitted power and the power level acceptable for the radio telescope, coordination zones were calculated. Figure 1 shows the results of simulations for the German VGOS station Wettzell. The blue lines mark the coordination zone for base stations with 30 dBm/MHz at 3.4 GHz. If the base stations had more power, the coordination zones would need to be larger. With 40 dBm/MHz even the city of Munich falls into the coordination zone, as well as parts of the Czech Republic. The results presented here are only valid under the assumptions made. Especially the true

[2] The open source software `pycraf` can be retrieved from https://pypi.org/project/pycraf/

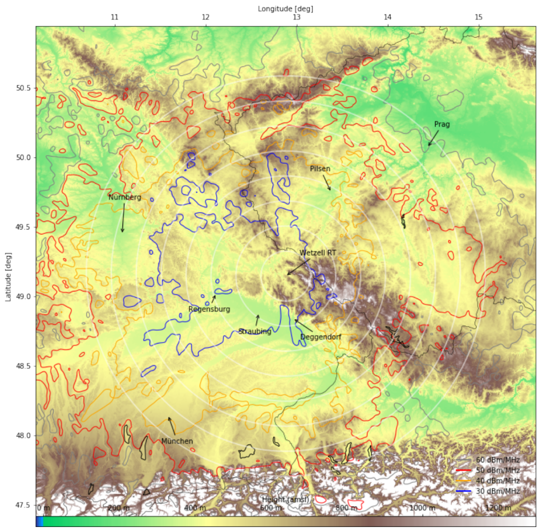

Fig. 1 Compatibility study for Wettzell site: coordination zone for 5G at 3.4 GHz (blue 30dBm/MHz, red 50dBm/MHz). White circles mark distances to the RAS station in steps of 20 km.

effective antenna gain and possible clutter attenuation can make a big difference. Also, a 5G operator could choose to provide additional mitigation measures (i.e., lower output power, decreased effective gain to RAS station by antenna pointing/beam forming, and utilizing clutter attenuation), which would allow to use equipment within the coordination zone without doing any harm.

These results are important for the national authorities as they have to implement the coordination zone. In the case of Germany, the Wettzell observatory is protected by national law [BGeoRG], which entrusts BKG to contribute to the global reference frame activities.

3.2 Satellite Missions at Ku Band

Several companies are working on projects to supply global Internet access via satellites. More advanced are SpaceX and OneWeb. The non-geostationary orbit (NGSO) satellite systems are operating in 10.70−12.75 GHz (space-to-Earth), in 12.75−13.25 GHz, and 14.0−14.5 GHz (Earth-to-space) bands in Fixed Satellite Service (FSS) allocations (for fixed and moving platforms). The new services will contain hundreds or even thousands of small satellites that can provide high-capacity and low-latency multimedia services and may generate harmful interference, especially for a passive service as VGOS. Figure 2 shows the future number of visible active satellites vs. latitude.

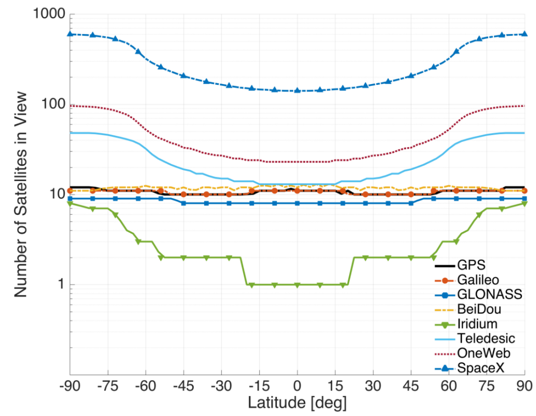

Fig. 2 Number of satellites in view vs. latitude (graphic from: https://pdfs.semanticscholar.org/487e/24483f22b43d57da78772dac9d20a948ec23.pdf.)

The SpaceX company wants to create a giant constellation named Starlink of nearly 12,000 satellites by mid-2020. One set of 4,425 satellites will be placed at an altitude of approximately 1,100 km, while 7,518 satellites will sit about 300 km up. Such a massive satellite fleet will be constantly in motion around the planet and will supposedly be able to provide coverage to basically any spot on Earth at all times. The first two prototype satellites, called Tintin A and Tintin B, were already launched on 22 February 2018.

The OneWeb satellite constellation is supposed to be made up of approximately 882 satellites to become operational in 2019−2020. The 882 communication satellites will operate in circular low Earth orbit, at approximately 1,200 km altitude, transmitting and receiving in the Ku band. Most of the capacity of the initial 648 satellites has been sold, and OneWeb is considering nearly quadrupling the size of the satellite constellation by adding 1,972 additional satellites.

4 Conclusions

The modernization of the global VLBI observation infrastructure, called VGOS, demands for wider observation spectra in the range of 2−14 GHz in order to achieve the goals of the establishment of a Global Geodetic Observing System (GGOS). The societal need for precise global reference frames calls for extended VGOS observation programs.

This effort is contrasted by projects to improve the global communication abilities. Projects like 5G and satellite-based Internet may have a strong impact on the conduction of VGOS observations. We showed by the examples of the compatibility study to 5G for the VGOS site Wettzell and the scenario of Starlink/OneWeb that a severe impact on the VGOS operation must be expected. The upcoming WRC-19 will be an important forum at which VGOS will need many voices from the national and regional authorities.

Considering the increasing demand for spectrum in the radio window of the atmosphere targeted by VGOS observations, a strategic plan needs to be addressed by the IVS community. We propose to the VLBI sites:

1. Strengthen the link to the authorities responsible for the radio spectrum.
   a. Sharpen the awareness of national authorities about VLBI requirements. Today VGOS sites can plead the UN resolution, the EC directive and the ITU document cited in Section 1.
   b. Request compatibility studies from national spectrum authorities considering VGOS sites.
   c. Register your VGOS site through your national authority at ITU-R [Hase et al. 2016].
2. Perform compatibility studies to compare to the results of the national authority or other services.
3. Cooperate with RAS groups CRAF, CORF, and RAFCAP. Share information and documents on actions and achievements at your national or regional level with CRAF, CORF, or RAFCAP members.

Besides the regulation on spectral use, the IVS community should also address technical radio frequency interference (RFI) mitigation strategies at their radio telescope sites:

1. Investigate mitigation of RFI in the signal chain: providing a high-dynamic range with switchable filter banks and using 14-bit analog-digital converter to channelize 32 MHz without clipping.
2. Introduce notch filters at the front end.
3. Consider mitigation of RFI by passive microwave barriers around the RAS site against terrestrial based transmitters to conserve the elevation mask.
4. Define specific 1-GHz sub-bands in the 2−14 GHz range as the future VGOS observation bands. This would enable the design of new four-band receivers which would be insensitive to other occupied parts in the range of 2−14 GHz.
5. Develop software for RFI detection and excision.

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